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PAPER 1

MEASUREMENT TECHNIQUES FOR VENTILATION AND AIR LEAKAGE

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SYNOPSIS

Ventilation has a considerable influence on both the indoor air quality and energy consumption of buildings. Three parameters can be identified which are of key importance in the assessment of ventilation behaviour:

- air change rate
- interzonal air flows
- air leakage characteristics

This paper describes measurement techniques which enable these parameters to be evaluated. The list of techniques presented is not exhaustive and the descriptions given are not particularly detailed. The main aim of this report is to illustrate the spectrum of techniques which are currently available for the quantification of ventilation and air leakage.

1. INTRODUCTION

It is necessary to understand the process of ventilation since it affects both the energy consumption and internal environment of a building. While recognising the need to supply a certain amount of fresh air to enclosed spaces, it must be realised that excessive ventilation may place an undue burden on a building's heating system. Insufficient ventilation will have an adverse effect on internal environments, making them uncomfortable or, in extreme cases, harmful to building occupants. Therefore the principle task, with regard to ventilation, is to minimise energy consumption while still maintaining indoor air quality. In order to assist the assessment of the ventilation characteristics of buildings, three key parameters may be identified.

1.1 Air Change Rate

This is a measure of the bulk movement of air into and out of a building and is defined as the volumetric rate at which air enters or leaves an enclosed space divided by the volume of the space. The air change rate, N, is a variable parameter which is dependent upon climatic forces, building construction, mechanical ventilation systems and occupant effects. Its main importance lies in heat load calculations and the stipulation of ventilation requirements. For example, an approximate expression for the heat loss in a building due to the ingress of cold air can be given by

$$H_v = 0.33\ NV\ (T_i - T_e) \qquad W \qquad [1]$$

where H_v = heat loss due to ventilation, W
N = air changes per hour, h^{-1}
V = volume of the building, m^3
T_i = internal temperature, K
T_e = external temperature, K

1.2 Interzonal Air Flows

The bulk movement of air into and out of a building causes air to flow between the various internal spaces of the structure. Interzonal air flows are of particular importance in relation to the movement of airborne contaminants from one part of the building to another. An illustration of this would be the effect of air flow between occupied spaces in a dwelling and the cold, unheated roof space above. Here warm, moist air could be carried from the living areas and cause condensation problems on the cold internal surfaces of the roof structure. Thus these air flows cannot be ignored when considering the ventilation process.

1.3 Air Leakage Characteristics

Air enters and leaves a building through openings in the thermal envelope. These openings may be adventitious or purpose provided and the actual flow through them will be dependent on the air leakage characteristics of the openings and the prevailing climatic conditions. A knowledge of air leakage characteristics enables buildings to be evaluated and compared without interference from variable weather parameters. In addition, the evaluation of building leakage characteristics is the first step towards the mathematical modelling of the ventilation process.

Several measurement techniques have been developed which enable air change rate, interzonal air flows and air leakage characteristics to be evaluated. This paper identifies some of these techniques, examines their theoretical background and practical realisation, and discusses their application and limitations.

2. MEASUREMENT OF AIR CHANGE RATE

The direct measurement of air change rate involves the release and monitoring of a suitable non-toxic tracer gas (see Appendix 1) within the building. If the building is treated as a single enclosure in which tracer and ventilating air are perfectly mixed, then the generalised tracer mass balance equation (also known as the continuity equation) can be presented as

$$V \frac{dC}{dt} = Q[C_e - C_{(t)}] + F \qquad [2]$$

where V = effective volume of enclosure, m^3
Q = air flow through enclosure, m^3s^{-1}
C_e = external concentration of tracer gas
$C_{(t)}$ = average internal concentration of tracer gas at time, t
F = production rate of tracer from all sources within enclosure

The assumption of perfect mixing is not usually achieved in practice, especially in larger buildings. Three major mixing problems can be identified:

Mixing of ventilation air into the enclosure

When fresh air enters an enclosure through a variety of openings, it may not disperse evenly throughout the space. In extreme cases the outdoor air can bypass the indoor air without mixing (short circuit) or it can propel the "old" air before it as it moves through the building (piston flow). The poor mixing of outdoor air can cause spatial variations of tracer gas concentration to occur. This problem may be overcome by monitoring the tracer gas at several locations within the building, but in some cases a multi-zone approach (see Section 3) may have to be taken.

Mixing of tracer gas into the enclosure

When gas is injected into a building it may take some time to mix with the internal air. If injection and sample points are located some distance apart, there will be a delay between the time gas is injected and the time the additional volume is reflected in the sampled concentration.

If, however, injection and sample points are close together, the tracer may not be allowed to disperse evenly in the air before being sampled. Injection problems are often reduced by artificially mixing the tracer gas with the air at the injection point. Care must be taken, however, to ensure that this process does not induce artificial flow conditions within the test space.

Mixing of air and tracer within the enclosure

It can be seen from Equation [2] that the volume used in the continuity equation is the effective volume. This is defined as the volume in which mixing occurs and it is not necessarily equivalent to the physical volume of the enclosure. The presence of cupboards and furniture can lead to the effective volume being smaller than the physical volume. These areas can often be readily identified and allowed for. Alternatively, their effect can be nullified, in the case of cupboards for example, by opening them to the main space. However, there may be other "dead" volumes, such as areas near the ceiling, isolated by stratification, which are more difficult to evaluate.

If there are attached spaces which can communicate with the measured enclosure, then the effective volume may be larger than the obvious physical volume. An example of this would be a suspended ceiling above a living space. While it is often usual to assume that the effective volume will be approximately the same size as the physical volume, a careful examination of the building will lead to a more accurate evaluation of this parameter.

If due care and attention is given to the mixing problems outlined above, it is possible to experimentally evaluate air change rate from tracer gas concentration data. There are three distinct approaches to the solution of the continuity equation. These are considered in turn below.

2.1 Concentration Decay Method

The most straightforward method of solving the continuity equation is to make a one-time injection of tracer gas into the enclosure. Following the cessation of gas injection, assuming that the outdoor concentration of tracer gas is negligible, $C_e = 0$, and that there are no incidental sources of tracer within the building, F = 0, the continuity equation reduces to

$$V \frac{dC}{dt} = -QC_{(t)} \qquad [3]$$

Assuming that Q remains constant, Equation [3] can be solved for the tracer gas concentration, i.e.

$$C(t) = C_{(o)} e^{-\frac{Q}{V}t} \qquad [4]$$

where $C_{(o)}$ = concentration of tracer gas at time, t=0
$\frac{Q}{V}$ = N = air change rate, h^{-1}

Hence, under ideal conditions, the tracer gas concentration will exhibit an exponential decay with time. Therefore, if the time variation of the tracer concentration can be obtained, the air change rate, N, can be evaluated. The simplest method of performing this is to plot the concentration against elapsed time in hours on linear/logarithmic paper. The negative slope of the line is then equal to the air change rate expressed in units of h^{-1}.

There are essentially two methods of obtaining concentration data from test sites. Firstly there are techniques which require the equipment used to analyse the tracer concentration to be placed in the measurement building (site analysis). Secondly there are techniques, known as grab sampling, which involve obtaining samples of air in the building and removing them to another site for analysis.

2.1.1 Site Analysis

In its basic form, the site analysis technique for concentration decay measurements requires the following equipment:

a. A tracer gas and some means of injecting it into the test space.

b. A means of mixing the gas into the test space in order to obtain a uniform concentration.

c. An analyser which can detect the tracer (see Appendix 1).

d. A sampling system whereby a quantity of air can be introduced into the analyser.

e. Some means of recording time.

The tracer gas is introduced to the test space and allowed to mix with the air. This mixing may be promoted by the use of paddles, electric fans or the ventilation system. After the mixing is complete, the tracer gas concentration is monitored over a period of time. Data can be taken by hand or by connecting the analyser to an x-t chart recorder. The data can then be analysed and a value for the air change rate obtained.

Even with associated measurements of wind speed and temperature, a single value of the air change rate provides little information regarding the ventilation behaviour of a building. Ideally a series of measurements should be made, preferably under a range of climatic conditions. In order to ease this process, several refinements can be made to the basic system. The gas injection process can be automated so that once the concentration has reached a certain minimum level, a further amount of tracer is injected into the test space (Grot et al [1981]). This allows many individual decays to be obtained . If more than one sample point is being used, then automatic switching between locations can be performed with solenoid valves.

For analysis purposes, the output of the analyser can be fed into a computer or data logger and this, together with the associated software, can calculate and output the air change rate directly. This computer could also be used for the storage of wind and temperature data. Hence the dependence of N upon climatic parameters can be examined. The main advantage of this type of technique is the basic simplicity of the instrumentation and analysis, an important point being that only relative and not absolute tracer concentrations need be measured.

2.1.2 Grab Sampling

This technique requires no expensive analysis equipment to be used on site. The tracer gas is initially injected into the space and allowed to mix with the air. Because this whole process is designed to be as simple as possible, rudimentary injection techniques are usually employed. Slowly releasing the tracer from a syringe or plastic bottle has shown itself to be adequate for the purpose, (e.g. Harrje et al [1982]).

After an initial time lapse to enable a uniform concentration of tracer gas to be reached, the air in the space is sampled. This can be performed with a syringe, bottle or bag. A sample taken in this manner is intended to give an instantaneous value of the tracer concentration at that time, hence the actual time taken to fill the container should be as short as possible. After further periods of time, more samples can be taken. A minimum of two samples are required to evaluate the decay but often more are taken to ensure accuracy. The time interval between samples or the absolute time they were taken must also be recorded. Air samples are then shipped to the laboratory for analysis. Concentrations are determined, the decay plotted and the air change rate evaluated.

The main advantage of this technique is its simplicity. Because of the minimum amount of site equipment required, many buildings can be examined from a central analysis point. Also, as it is kept at one location, delicate analysis equipment is less likely to be damaged or go out of calibration. Disadvantages include not being able to obtain results until some time after the site data is taken, and the likelihood of unintentional errors caused by non-technical site operators.

2.2 Continuous Emission

A second approach to the solution of the continuity equation is to set the source term, not at zero but at some fixed value. Assuming that $C_e = 0$, the mass balance equation is given by

$$V \frac{dC}{dt} = -QC_{(t)} + F \qquad [5]$$

For a constant ventilation rate, N, and constant gas discharge rate, F, Equation [5] can be solved in terms of tracer gas concentration to give

$$C_{(t)} = \frac{F}{NV} [1 - e^{-Nt}] \qquad [6]$$

If N remains constant, a finite time is required for the concentration to reach equilibrium. This time is determined by the bracketed function in Equation [6]. Once the concentration has reached equilibrium, the air change rate is given by

$$N = \frac{F}{VC_{(t)}} \qquad [7]$$

Hence, if measurements of tracer gas flow rate and tracer gas concentration can be made, N may be evaluated. There are two distinct types of constant emission technique.

2.2.1 Site Analysis

The essentials of the experiment are similar to the decay method except that the gas is injected continuously over the measurement period. In order to aid mixing, the gas may be discharged into the air stream of a small fan. It is necessary to have some instrumentation which enables the mass flow rate of tracer to be kept at a known constant value. Prior to monitoring, it may be necessary to spend some time injecting gas into the test space in order that approximate equilibrium conditions may be reached.

Once the transient effect has become minimal, the air change rate becomes inversely proportional to the tracer gas concentration in the test space and N can be calculated from Equation [7]. If the air change rate alters, then the gas concentration should again be allowed to reach equilibrium before the value of N is evaluated. This type of measurement is usually performed with automated equipment. The tracer gas concentration is measured continuously or at short intervals. Thus with care, continuous measurement of the air change rate may be made.

The main disadvantage of this technique is that large amounts of tracer gas are required and a certain amount of time must be allowed to enable equilibrium conditions to be achieved.

2.2.2 Averaging Techniques

An alternative to having all the analysis equipment on site is to have only the gas injection and sampling systems in the building. These are called averaging techniques because their main function is to determine the longterm average air change rate of a building.

Gas is released at a constant rate into the test space. Several methods have been used for this ranging from gas cylinders with a needle valve, through airtight bags fitted with a peristaltic pump (Sherman et al [1981]), to totally passive sources which emit tracer through a porous plug (Dietz et al [1986]). Once approximate equilibrium conditions have been achieved, the air in the building can be sampled.

Slowly drawing air through a pump into an uncontaminated gas bag and collecting tracer using a solid adsorbent have both been used as sampling methods. After the required averaging time, the air or tracer samples are returned to a laboratory and the tracer gas concentration evaluated. The average air change rate can be evaluated from

$$\bar{N} \simeq \frac{F}{V\bar{C}} \qquad [8]$$

where $\bar{N}$ = average air change rate over a given time period
$\bar{C}$ = average concentration over given time period

The approximation is given in Equation [8] because it can be shown that the reciprocal of an average concentration is close but not identical to the average of reciprocal concentrations. Similar to the grab sampling method for decay measurements, site equipment is simple and may be used by non-technical personnel. The obvious disadvantage to this is that no detailed information about the variation of air change rate is obtained.

2.3 Constant Concentration

The third technique reduces the continuity equation to its simplest form. If the concentration of tracer gas is held at a constant level, then there is no rate change in tracer. Hence

$$F - QC_{(t)} = 0 \qquad [9]$$

which can be solved to give

$$N = \frac{F}{VC_{(t)}} \qquad [10]$$

This is the same expression as for the constant emission method. However, the only variable quantity here is the tracer gas production rate. The air change rate is then directly proportional to the gas injection rate required to maintain the concentration.

A constant concentration of tracer gas can be maintained only by using sophisticated equipment (Bohac [1986]). The constant concentration system varies the rate of tracer injection to regulate the concentration in the enclosure. This is known as a closed loop operation. The system feeds back information about the measured concentration in the enclosure in order to adjust the injection rate which maintains the concentration at the required level The known injection rate is then used to evaluate the air change rate. Fully automated instrument packages incorporating a micro-computer have been designed for this purpose. Using these packages, the concentration can be kept constant in several zones of the test building thus enabling the air change rate of individual rooms to be evaluated.

Being automated, the systems are ideal for measuring air change rates over extended periods. The main drawback with these systems is cost and such sophisticated instrumentation may only be suitable for long-term research projects.

3. MEASUREMENT OF INTERZONAL AIR FLOWS

The continuity equation given in Section 2 assumes that the test space is a single, well mixed enclosure. Recently, attention has been turned to the way in which air flows between internal spaces of a building. Measurement of these interzonal air flows also uses tracer gas techniques. The structure under consideration is assumed to consist of a number of physical cells, in each of which air and tracer are perfectly mixed. There are n cells and the volume of the i'th cell is V_i. A tracer mass balance equation can be developed for each cell. In this case, as well as the exchange with the environment, the tracer lost to, and gained from, each of the other cells must be taken into account. Assuming $C_e = 0$, the continuity equation for the i'th cell is given by

$$V_i \frac{dC_i}{dt} = F_i + \left[\sum_{j=1}^{n} Q_{ji}\, C_j\, (1 - \delta_{ij})\right] - \left[Q_{i0}\, C_i + \sum_{j=1}^{n} Q_{ij}\, C_i (1 - \delta_{ij})\right] \qquad [11]$$

where V_i = effective volume of cell, i.
C_i = tracer gas concentration in cell, i, at time, t.
F_i = production rate of tracer in cell, i.
Q_{ij}/Q_{ji} = volume flow rate of air between cells i and j. Q_{ij} indicates flow from cell i to cell j, Q_{ij} and Q_{ji} are not necessarily equal.
Q_{i0} = air flow from cell, i, to the environment.

The delta function is given as

$$\delta_{ij} = 0, \text{ when } i \neq j$$
$$\delta_{ij} = 1, \text{ when } i = j$$

Since there is no net buildup of air in the building, the total air flow into a cell must equal the total flow out. From the conservation of mass of air, a second set of n equations can be developed, i.e.

$$\text{Flow in} = \text{Flow out}$$

$$Q_{0i} + \sum_{j=1}^{n} Q_{ji}\,(1 - \delta_{ij}) = Q_{i0} + \sum_{j=1}^{n} Q_{ij}\,(1 - \delta_{ij}) \qquad [12]$$

The principle task here is to determine the interzonal air flows, Q_{ij}'s. There are $(n^2 - n)$ unknown Q_{ij}'s plus 2n unknown values of Q_{i0} and Q_{0i}, given a total of $(n^2 + n)$ unknown values of air flow. If the n equations of Equation [12] are used, then there are still n^2 unknown air flows with only the n equations of Equation [11] left to solve them. Therefore (n-1) independent sets of equations similar to Equation [11] must be generated. This is usually performed by using n different tracer gases. Two multiple tracer gas systems are described below, each of which is based on a measurement technique already described in Section 2.

3.1 Multi-zone Decay Measurements

This technique is an extension of the single zone decay method described in Section 2.1. A total of n tracers are required to examine a building with n zones. The method has been tested in buildings with up to three zones and tracer gases are released, one to each zone (Irwin [1985]). Injection of the tracer gas can be performed using an airtight syringe. Alternatively it may be released directly from the cylinder by briefly opening the gas valve. After injection, the tracer gases are mixed using oscillating desk fans and sampling of the air tracer gas mixture is achieved by drawing air through polythene tubes. The analysis system must be able to evaluate the concentration of all tracer gases in all zones. Freons have been used as the tracer gases and the concentrations evaluated using an electron capture detector (see Appendix 1).

The instantaneous interzonal air flows can be calculated from a knowledge of the time variation of tracer gas concentrations. While providing highly detailed information about the ventilation behaviour of buildings, this method requires the use of complex equipment and sophisticated analysis techniques.

3.2 Multi-zone Constant Injection Measurements

This technique utilizes the tracer gas emitters and passive samplers mentioned in Section 2.2. A different tracer source is placed in each distinct zone. Tracer gas is injected at a constant rate and the time average concentration is measured by the samplers (Dietz [1986]). From these concentrations and the known emission rates of tracer, the average interzone air flows can be calculated.

4. MEASUREMENT OF AIR LEAKAGE

The measurement of air leakage requires the production of an artificial pressure difference across a building envelope or component. The volume flow rate through the test object is then determined as a function of the pressure differential. A primary role of this approach is to negate the influence of climatic parameters and characterise the building structure itself. Therefore the imposed pressures are generally much greater than those created by natural forces.

The functional relationship between the air flow through and pressure difference across a leakage path is frequently described by a Power Law of the form

$$Q = k(\Delta P)^n \qquad m^3s^{-1} \qquad [13]$$

where Q = flow rate, m^3s^{-1}
ΔP = pressure difference, Pa
k,n = flow coefficients

The flow coefficient, k, is related to the size of the opening and the exponent, n, characterises the type of flow. For laminar flow $n = 1.0$. For turbulent flow $n = 0.5$. Experimentally derived values of k and n uniquely define the air leakage characteristics of the test piece. Substitution into Equation [13] will enable the air flow at any given pressure difference to be evaluated. This type of information is invaluable with regard to the numerical modelling of the ventilation process. Pressure tests can be used to evaluate whole buildings or individual building components.

4.1 Whole Building Air Leakage

4.1.1 Small Buildings

The majority of measurements in this category have been performed in small residential buildings. By replacing an external door with a panel containing a variable flow rate fan, a pressure difference can be created across the building envelope. Initially a research tool, several "blower doors" are now available from commercial manufacturers. Air flow through the fan creates a uniform static pressure within the building. Internal and external pressure taps are made and a manometer is used to measure the pressure difference across the envelope. The volumetric flow rate through the fan must also be evaluated. The higher the flow required to produce a given pressure difference, the less airtight the building.

The air flow required to produce a given pressure difference under pressurization will not necessarily be identical to the flow required to produce the same pressure difference under depressurization. This difference is due, in the main, to the fact that certain building elements can act as flap valves . In addition to this effect, the asymmetric geometry of some cracks with respect to the flow direction may explain significant changes in leakage characteristics with no associated change in leakage area. Hence, ideally, the fan and flow measuring mechanism must be reversible (Swedish Standard [1987]).

Wind round the building together with internal/external temperature differences produce natural pressure differences across the building envelope. These pressures superimpose themselves on the pressure difference generated by the fan. The stack effect will have little influence except in high rise buildings. Wind velocity produces a significant effect even in low rise buildings. The maximum error will occur at combinations of high wind velocity and low induced pressure difference.

These measurements can be performed in a relatively short time. Practical uses for these techniques include the 'before' and 'after' testing of retrofit measures and assessing whether buildings meet airtightness regulations.

4.1.2 A.C. Pressurization

A technique is available which enables building airtightness at small pressure differences to be measured directly and without interference from climatic forces. Called AC pressurization (Modera and Sherman [1985]), it differs from normal fan pressurization in that a piston is used to create a sinusoidal change in the internal volume of the building at a known amplitude and frequency. The airtightness of the building affects the pressure change including amplitude and phase in that building, due to the periodic volume change.

If the building envelope was a rigid and completely airtight structure, the change in pressure could be precisely determined from the building volume and the piston displacement. Therefore, any deviation from predicted pressure can be attributed to leakage through the envelope. If the volume change and pressure response is measured, then the air flow through the envelope can be calculated. The main advantage of this technique is that it operates at the pressures which actually drive infiltration, i.e. -5 Pa $< \Delta P <$ 5 Pa 5 Pa. Its main disadvantage is that it does not permit the measurement of large, long leaks such as undampered chimneys or open windows.

4.1.3 Large Buildings

Theoretically there is no limit to the size of building which can be examined with normal fan pressurization. However, the maximum volume of enclosure which may be pressurized is governed by the overall airtightness of the structure and the size of the available fan. Trailer mounted fans, with flow capacities in the range of 25 m^3/s^{-1} have been used to examine volumes in the region of 50,000 m^3 (e.g. Shaw [1981]. Because of the cost of such equipment and the inherent difficulties of transportation and required manpower, other techniques have been developed for the examination of large buildings. One method is to create the required pressure differential using the building's existing air handling system (Persily and Grot [1986]). This technique relies on the building possessing a suitable mechanical ventilation system which can be adjusted to meet the needs of the experiment. Essentially the supply fans are operated while all return and exhaust fans are turned off. All return dampers must be closed so that the air supplied to the building can only leave through the doors, windows and other leakage sites.

4.2 Component Air Leakage

The air leakage characteristics of individual building components can be evaluated either directly or indirectly. By selectively sealing different potential leakage paths during a whole building pressurization test, it is possible to determine the fraction of the total air leakage through different components of the building envelope. As the components will be generally sealed from the inside, it is preferable that an overpressure rather than an underpressure be created within the building. Pressurization will tend to force the seal onto the component while a negative pressure would tend to act against the seal making it less airtight.

Direct measurement of component leakage entails using an airtight chamber to cover the interior face of a window or door, supplying air to or exhausting air from the chamber at a rate required to maintain a specified pressure difference across the specimen, and measuring the resultant airflow through the specimen. The test can be made more accurate if the pressure in the rest of the room is balanced to that in the chamber, thus minimising unwanted air leakage through the chamber walls. Measurements of individual components enables an air leakage profile of a large building to be created.

A further method of component testing consists of using a laboratory test rig into which the specimens can be fitted. A pressure is created across the component and the flow rate through it is measured. This has the advantage that a large number of tests can be performed under similar conditions and the effects of climatic forces are nullified.

5. CONCLUSIONS

This account of measurement techniques is neither detailed nor exhaustive. Instead emphasis has been placed on giving an introductory overview of the spectrum of methods by which the air change rate, interzonal air flows and air leakage characteristics of buildings can be measured.

Tracer techniques range from one-off measurements of the air change rate using the decay method, through passive evaluation of average air change rate, to continuous measurements of air change rate involving sophisticated control and analysis methods. Interzonal air flows can be evaluated using multiple tracer techniques and relatively simple fan pressurization methods can be used to evaluate the air leakage characteristics of whole buildings and building components. The Air Infiltration and Ventilation Centre is currently preparing a full analysis of ventilation measurement techniques which will be published in the near future.

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APPENDIX 1

Tracer Gases and Analysers

The fundamental requirement of a gas used as a tracer is that its concentration must be measurable to a good order of accuracy, even when highly diluted. The tracer should be cheap and readily available as should the gas analysis equipment. For site measurements the instrumentation must be compact, robust and portable. The gases present in ordinary air should not affect the tracer gas analysis. The tracer gas should not normally be present in outdoor air thus allowing the external concentration to be assumed to be zero. There should be no natural source of tracer within the enclosure, hence the source terms in the continuity equation will consist solely of the tracer deliberately produced for the test.

The tracer, which should have a similar density to air, must not be absorbed by walls or furnishings, or decompose, or react with building surfaces or constituents of air. This ensures that all the tracer leaving the enclosure does so by the process of ventilation. For safety considerations the gas should be neither flammable nor explosive and, as experiments are often performed in occupied buildings, it should have no adverse health effects in the concentrations required for the tests.

No gas fulfils all the requirements given above. However, several gases are currently being widely used as tracers. These include sulphur hexafluoride, nitrous oxide, freons, perfluorocarbons and carbon dioxide.

The concentration of nitrous oxide or carbon dioxide is usually evaluated using an infra-red absorption analyser. Infra-red analysis makes use of the fact that many gases exhibit energy absorption characteristics in the infra-red portion of the electro-magnetic spectrum. The amount of infra-red energy absorbed varies from gas to gas and is dependent on the concentration of absorbing gas in a sample. Elemental gases which are composed of multiple similar atoms such as oxygen and nitrogen (which are the main constituents of air) do not absorb in the infra-red and, therefore, do not interfere with the detection of the tracer.

One method of performing this analysis is to pass two beams of infra-red radiation of equal intensity through an analysis cell and parallel reference cell respectively. The analysis cell contains a sample of air in which the tracer gas is present while the reference cell contains a non-absorbing reference gas. The difference in intensity between these two streams after passing through the cells is monitored and this provides a measure of the tracer gas concentration.

Some gases, for example sulphur hexafluoride, perfluorocarbons and freons, capture electrons. This property can be utilized to detect the concentration of some tracers. Electron capture detectors use a small radioactive source to generate a cloud of electrons in an ionisation chamber. When a pulsed voltage is applied across the chamber, a current flows. A sample of gas is injected into the cell. If the sample contains a tracer which is electron capturing, then the number of electrons in the chamber is reduced. This in turn causes the current across the chamber to decrease. The reduction in current is proportionate to the tracer gas concentration. Atmospheric oxygen has electron capturing properties, so this type of detector is invariably used with a gas chromatograph upstream of the detector to separate the oxygen from the tracer gas.