

## Review of Airflow Measurement Techniques

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### Abstract

Airflow measurement techniques are necessary to determine the most basic of indoor air quality questions: "Is there enough fresh air to provide a healthy environment for the occupants of the building?" This paper outlines airflow measurement techniques, but it does not make recommendations for techniques that should be used. The airflows that will be discussed are those within a room or zone, those between rooms or zones, such as through doorways (open or closed) or passive vents, those between the building and outdoors, and those through mechanical air distribution systems. Techniques that are highlighted include particle streak velocimetry, hot wire anemometry, fan pressurization (measuring flow at a given pressure), tracer gas, acoustic methods for leak size determination, the Delta Q test to determine duct leakage flows, and flow hood measurements. Because tracer gas techniques are widely used to measure airflow, this topic is broken down into sections as follows: decay, pulse injection, constant injection, constant concentration, passive sampling, and single and multiple gas measurements for multiple zones. Selected papers are annotated, and a bibliography is included for each topic with full abstracts.

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## 1.0 Introduction

Ventilation rates and air movements in buildings need to be quantified and documented to answer the most basic indoor air quality (IAQ) question: “Is the proper amount of outdoor air reaching the occupants of the building to maintain acceptable indoor air quality?” This issue is of increasing concern as buildings become tighter and we rely more on mechanical ventilation systems to maintain acceptable indoor air quality. Another reason to quantify and document building airflows is that too much ventilation constitutes a needless heating and cooling energy load and insufficient distribution system flows can reduce equipment capacity and efficiency. For example, it is estimated that one eighth of all energy used in Organization for Economic Cooperation and Development (OECD) countries is consumed in residential and service sector buildings, to meet the ventilation and air infiltration load (Orme, 1997).

The threat of global warming, and the developing world's dependence on fossil fuel make energy conservation opportunities increasingly important. To take the best advantage of these opportunities, we must be able to make accurate measurements of airflows within a room or zone, those between rooms or zones, those between the building and outdoors, and those through mechanical air distribution systems. Many techniques have been developed to measure these different types of airflow in buildings. This paper has divided these techniques into five categories generally organized as follows: air velocity, envelope air leakage, tracer gas (single zone and multiple zone) and air distribution system measurements.

Most of the papers in this report are listed in the AIVC database, and the AIVC database number is used to reference each paper. The papers that are not in the AIVC database are listed without a number. The full abstract is listed with each reference when available. The reference section is organized by topic contained in the text, and papers are listed in order of the AIVC database number. This corresponds roughly to the chronological order by date of publishing. Papers without an AIVC database number were inserted by date of publishing. Papers were chosen to be included in the annotation section by relevance, and also by availability. Papers that are relevant to more than one section were included in the section of most relevance. Those that are equally relevant to more than one section were repeated.

## 2.0 Air Velocity Measurements

The most basic airflow measurement is the velocity and direction of the air flowing past a given point in space at a given time. Although it sounds simple, this has not been an easy thing to measure, particularly for small flows, because a measuring device placed in the airstream changes the airflow slightly. This effect is magnified when multiple points are measured close to each other. This leads to the second difficulty, which has been measuring enough points to define the airflow patterns within a room. Traditional techniques such as thermal anemometers have difficulties measuring low air velocities, and the direction of airflow. Laser Doppler velocimetry (LDV) accurately measures low velocity and direction, but it is expensive and difficult to set up on a full size room. Also,

it can only measure one point at a time, which causes problems when there are transient flows or turbulence.

## **2.1 Particle Streak-Velocimetry**

Particle streak velocimetry is a relatively new technique to measure airflow patterns in buildings. It is still in the developmental stages, but it has the potential to be more useful than traditional techniques since it is able to measure low velocities between 0 and 0.4 m/s, and give the direction of flow. Zhao et al. (#12688, 1999) describe the history of this measurement technique in their literature review section, and also describe their measurement technique in a climate-controlled laboratory facility. Their application of this technique uses halogen lamps to create a light sheet that is 65mm thick, and seed the room with neutrally buoyant helium filled bubbles. They then use a photographic camera to capture images, which are subsequently scanned and processed by a computer. The shutter speed of the camera is adjusted so that the particles create streaks on the film as they move through the light sheet. This information alone is insufficient to determine the direction of the velocity vector and needs to be supplemented by transversely moving the film a known amount during the exposure. With this movement, a known stationary particle can then be used to calibrate the movement of the other particles. The overall error of this method is estimated at about 15%, due mostly to the mechanical shutter speed of the camera, which can have an uncertainty of up to 10% from the setting value. If the shutter were electronically controlled, the error is estimated to be about 5% since the exposure time is exactly the same as the setting value.

## **2.2 Hot Wire Anemometer**

Hot wire anemometry has been widely used to measure air velocities in buildings. Muller and Vogel (#7960, 1994) describe the advantages and disadvantages of this technique. The advantages are that the equipment is much lower priced than laser-optical equipment, it provides high resolution in time and space, and is able to measure velocity, and turbulence intensity in time and space. On the other hand, its disadvantages are that the probes disturb the flow field unless they are very small, they have a cut off frequency of about 10 kHz, and they have a spatial resolution limitation due to the wire dimension. The last two disadvantages are generally not a problem in airflow measurements. These probes become even more useful with the addition of an analog to digital converter and computer control, which allow fluctuations in time to be recorded from one sensor and simultaneous readings to be taken from multiple sensors.

Karimipناه and Sandberg (#9854, 1994) performed both experimental and numerical analysis of the flow field in a room to determine if ventilation of the room would cause discomfort to the occupants. (They accepted as a premise that velocities higher than 0.15 m/s are uncomfortable to occupants.) The authors used a hot wire probe to measure velocities for ten minutes consecutively at each measurement location, allowing them to compute average velocity and turbulent fluctuation in a full scale test room. They state that their measured turbulence intensities varied from 15% to 85%, however, this does not represent the actual turbulence intensity because hot wires are not able to measure large fluctuations at low velocities. In a previous study, the authors found that the maximum measurable turbulent intensity is about 20%. The authors conclude that the

high turbulent intensity is an artifact of the low mean velocities, indicating that a better measuring technique is needed.

### **3.0 Envelope Air Leakage**

Another airflow measurement of interest is how much air flows across a given boundary or envelope such as a building shell. The boundary could also be a portion of a building such as a room or a collection of rooms called a zone. During normal building operation wind and stack effects create pressure differences across the building envelope which cause air to flow through the cracks and holes in the building construction. Tracer gas techniques have been developed to measure these flows. As tracer gas detection equipment is expensive, other techniques have been developed to measure airflow across a boundary such as fan pressurization, AC pressurization, infrasonic impedance, acoustic techniques, and quantified thermography. Fan pressurization is the most widely used technique, thus papers have been selected describing this technique.

#### **3.1 Whole Building Techniques**

Fan pressurization is the primary method used to measure envelope leakage. The fan pressurization method involves setting up a large fan in an opening (usually a door) in the building shell. A pressure (usually between 20 Pa and 70 Pa) is maintained across the building shell, and the flow through the fan is measured. Sometimes a single point test is performed, generally at 50 Pa, or a multiple point test is performed over a range of induced pressures. If a multiple point test is performed, a curve of the form  $Q = C(\Delta P)^n$  can be fit where  $Q$  is the flow through the fan and  $\Delta P$  is the pressure difference across the building shell. The parameters  $C$  and  $n$  are characteristic of the particular building being measured and are determined from the curve fit.

Often the leakage between various buildings is compared using  $CFM_{50}$ , the leakage through the building shell at 50 Pascals. The information that would be more interesting is the flow across the building shell due to the actual pressure across the shell. This flow is constantly changing since the pressure across the shell varies with wind and weather conditions. To take this into account, a parameter called Effective Leakage Area (ELA) was developed, which is the area of an orifice that provides the same flow as the building shell when subjected to a given pressure differential. The pressure differential that is commonly used in the U.S. is 4 Pa because it is on the order of the pressure that buildings experience due to wind and weather conditions.

ASTM method E779 (#2889, 1995) outlines how to determine building envelope ELA using fan pressurization. Although fan pressurization does not give a measurement of actual ventilation during normal building operation, it is a useful test in order to compare the leakage area of two different buildings, to assist in identifying leakage sources, and to determine the leakage reduction from an individual retrofit. This standard discusses the equipment, procedures and data analysis.

Sherman and Palmiter (#10107, 1993) discuss the uncertainties associated with fan pressurization testing and with determining the Effective Leakage Area referenced to an envelope pressure differential of 4 Pa from fan pressurization data. The cases of a one-

point test, a two-point test, and a multi-point test are discussed. Their discussion includes an analysis of precision errors, bias errors, and modeling errors. They conclude that the multi-point test can be improved by taking more data at each pressure differential, limiting the wind effects, and carefully choosing which envelope pressure differentials are used for the measurements.

### **3.2 Techniques for Multizone and Large Buildings**

Bahnfleth et al. (#12566, 1999) discuss two methods used to determine leakage area in large buildings: the floor-by-floor blower door method and the air-handler pressurization method. The floor-by-floor method involves isolating each floor of a building in order to do a fan pressurization test on each floor in succession. The adjacent floors are also pressurized so that there is no air leakage between floors. The sum of the leakages measured on each floor equals the total leakage for the building. They found that the floor-by-floor method does not work in buildings with large, inaccessible inter-floor leakage that cannot be sealed (such as elevator shafts and mechanical chases).

The air handler pressurization method uses the air handlers (with outdoor air intakes) to create a pressure difference across the building envelope. The building leakage can be calculated when the outdoor airflow is measured with tracer gas or orifice flow plates. The air handler method could be used in both buildings that were tested. The authors discuss the non-uniformity of indoor-outdoor pressure difference that is found across the building shell. There is both vertical and horizontal variation due to wind and stack effects. In order to minimize these effects, they suggest that testing not be done if the wind speed is greater than 9 miles per hour, or if the outdoor temperature is greater than 95°F or lower than 41°F. They also suggest that, in order to improve the regression analysis, a range of envelope pressure differentials be used between 12.5 Pa and 75 Pa.

### **3.3 Component Leakage Techniques**

In diagnostic applications, component leakage techniques are used to determine how the leaks are distributed throughout the building. The building can be divided into sections by floor or by a wall, and the leakage is measured separately in each section (or component). Reardon et al. (#2628, 1987) describe a balanced fan approach for measuring component leakage area. They give a detailed description of the technique used to determine the leakage area between different floors of detached residential buildings and across the party walls of linearly attached row houses. This method is based on using multiple blower doors to simultaneously depressurize the test space and adjacent spaces relative to outdoors, such that there is always a zero pressure difference between the test space and the adjacent spaces. This ensures that there is no leakage between the test space and adjacent spaces. The method also makes use of Blower Door subtraction to measure leakage of test areas that cannot be isolated and tested directly. For instance, a house has two floors. Because of the layout the second floor cannot be tested independently. So a test is performed on the two floors together, and a second test is performed on the first floor only. The second test result is subtracted from the first test result to obtain the leakage of the second floor.

### **3.4 Leak Detection Methods**

Pickering et al. (#2630, 1987) conducted an experiment in a plutonium facility using bubbles, smoke, and helium-filled balloons to visually determine the airflow patterns. They videotaped the experiment so they could view it later. Small pieces of tape were added to the balloons in order to make them neutrally buoyant. They found that the neutrally buoyant balloons were the most effective method, because they were large enough to be easily seen and could be released without any initial momentum from any point in the room. Releasing the balloons at different points allowed them to determine the airflow patterns throughout the space. The problems with bubbles were that they were too small and too numerous to be easily seen. Also, they were released with initial momentum, which affected their trajectory. Smoke had a similar initial momentum problem, as well as being irritating to the lungs of the users and clogging the exhaust filters.

Oldham et al. (#5324, 1991) conducted experiments to see if an acoustic technique would work for determining the size of cracks in buildings. Their experiments were done exclusively in the laboratory using a wall made of steel beams. They found that the technique would work under these conditions, but they did not test the technique in the field or with a conventional wall segment. Judging by the literature after this study was performed, this type of technique does not seem to be pursued in the field of building science, however it has been extensively used in automotive applications.

## **4.0 Air Exchange and Ventilation Effectiveness**

### **Measurements for Simple Systems:**

#### **Single-Zone Tracer Gas Measurements**

Tracer gas methods are used to determine the air movement across a boundary during normal operating conditions. The boundary could be the building shell, a zone within the building, or a room. Single-zone measurements determine the air exchange across the boundary regardless of whether the air on the outside of the boundary is outdoor air, or air in another part of the building. Ventilation effectiveness implies exchange between the room air and outdoor air. Certain tracer gas tests can be used to determine both temporal and spatial ventilation effectiveness, although some, such as the decay test, can only be used to determine spatial ventilation effectiveness due to the time averaging nature of the test.

ASTM standard E741 (2000) outlines tracer-gas test methods based on decay, constant injection, and constant-concentration measurements. It also describes the tracer gases that can be used, along with their toxicology, chemical reactivity, and ability to be detected. It gives details about calibrating gas analyzers and how to conduct analyses to determine the propagation of errors for the tracer gas tests. This paper relates to Sections 4.1, 4.3, 4.4 and 4.7. It is listed only once in the reference section under section 4.0.

Tracer gas theory assumes that the tracer gas concentration is constant throughout the measured zone. Therefore, complete mixing of the air within the testing zone is very important. Mixing fans have been used by some researchers to improve the uniformity of



tracer gas concentrations. Multiple sampling points can also be used to verify that the concentration is constant across the zone. The expected error of tracer gas results is in the range of 5-10%.

#### **4.1 Tracer Decay**

The tracer decay test involves seeding the zone with tracer gas and mixing the zone so that there is a uniform concentration of tracer gas within the zone, and (ideally) no tracer gas outside the zone. Tracer gas is not added to the zone after the start of the test. The flow across the boundary is determined by looking at the initial and final concentrations, and the time period between the initial and final concentration measurements. This test method is appropriate for medium to low air exchange rates (less than 6 air changes per hour) because if the air exchange rate is too high then the tracer concentrations have to be measured very quickly before all the tracer gas has left the zone. The optimal measuring time period is the inverse of the volumetric air change rate. If the air change rate is 6 air changes per hour, the ideal measuring time is 10 minutes. (Heidt and Werner, #2536, 1986.)

It is important to note that the decay technique cannot be used for continuous measurements of varying ventilation rates. The decay test provides an average ventilation rate over the time period of the test because the concentrations are only measured at the beginning and end of the test. Several decay tests can be performed in series to see if the ventilation rate changes, but the resolution cannot be better than the time period. Errors related to flow rate oscillations can generally be neglected compared to other errors (mixing errors are estimated at 12-18%), as long as the measuring time is at least one third the oscillation time period. If, however, temporally unsteady ventilation is to be investigated, then either the constant injection or constant concentration technique must be used.

Tamura and Evans (#1272, 1983) show that evacuated glass tubes can be used in decay tests to sample SF<sub>6</sub> tracer gas so that expensive gas analysis equipment does not need to be moved to each testing location. They note that other researchers have used methods such as flexible plastic bottles which are filled by squeezing multiple times or plastic sample bags which are filled with a pump to collect gas samples. The ability to collect samples and bring them back to the lab for analysis significantly facilitates these tracer gas tests.

#### **4.2 Pulse Injection**

Stymne and Boman (#11930, 1998) discuss the pulse injection technique, which has the advantage over the other techniques in that it can be used to make an instantaneous measurement. The technique involves injecting a volume-weighted pulse of tracer gas into the supply air for the zone, and then making a measurement at a point some distance away from the injection point. The local mean age of air is calculated by dividing the first moment of the concentration (the integral of the concentration multiplied by the time) by the zeroth moment (the integral of the concentration.) This technique is also useful for making measurements in a multiple zone system.

### **4.3 Constant Injection**

Heidt and Werner (#2536, 1986) describe a measurement system for decay and constant-injection tracer gas tests. They talk in detail about the measurement apparatus, which has been designed for ease of use (e.g., automated error analyses for each measurement are carried out using a computer). The authors show that the decay method is more appropriate for measuring air exchanges of relatively tight spaces. Constant injection is more appropriate for leaky spaces where the gas would be quickly ventilated from the space and the measuring time would have to be very short with the decay method. Neither one of these procedures is appropriate when the ventilation rate is unsteady. This requires the constant concentration technique.

### **4.4 Constant Concentration**

The constant concentration technique uses a feedback control loop to regulate the flow of tracer gas to the zone in order to maintain a constant concentration of tracer gas in the space. The tracer gas flow into the zone is directly related to the ventilation rate of the room at a given time. Varying ventilation rates can be measured with this method. The disadvantage of the constant concentration method is that the equipment is more complicated and more expensive than the equipment required for the other tracer gas test methods.

Kvisgaard and Collet (#3572, 1989) give a detailed description of the tracer gas measurement equipment used for the constant concentration tracer gas test. Although this equipment was developed in the early 1980s, it is still in use today. The authors also describe equipment measurement errors. In particular, they list all error sources, with the corresponding value of the error, and provide some examples where the total error is computed for various situations. They conclude that the existing equipment is sufficiently accurate for making tracer gas measurements, because the uncertainties associated with the equipment (30 per mil or 3 % on the measured value) are on the order of those associated with insufficient mixing of tracer gas (20 per mil) and the purity of calibration gases (10 per mil). They state that tracer gas measuring methods, when used with the constant concentration tracer gas method, are normally better than 5%.

Axley (#5301, 1991) explains that differential mass balance equations were used originally for the decay, constant injection and constant concentration techniques, but that these equations were mathematically ill-conditioned in the sense that they required very accurate measurements of the tracer gas concentration, and were sensitive to error such as incomplete air mixing and unsteady flow. Integral formulations of the equations have been used successfully to improve the tracer decay and constant injection techniques, integrated measurements are much easier to make. The integral formulation of the mass balance equations has not yet been applied to the constant concentration technique because this technique does not have the same sensitivity to measurement accuracy as the other techniques. This paper outlines the integral formulation of the constant concentration equations as an alternative to the current methodology. Interestingly, when the zone concentration is well controlled, the integral of the concentration becomes negligibly small, and the integral formulation of the mass balance equations becomes the same as the conventional mass balance equations. This begs the question, how much

variation is acceptable? Axley compared two tolerance limits: 1% and 2% variation between the integral of the zone concentration and the integral of the target concentration. The new method was applied to eight sets of existing data where the actual flow was known, and various control algorithms were investigated to see if they would yield accurate results when the ventilation flow experienced a sudden step change. The new mass balance equations were applied, and were found to yield more accurate results than the previous equations. This was partly due to the correction factor, and partly due to the tolerance criteria, which screened the data for time periods where the zone concentration was not able to be accurately controlled, and therefore predicting that it was not possible to produce accurate results during that time period.

#### **4.5 Passive Sampling Techniques**

Tracer gas concentrations are often analyzed using infrared spectroscopy equipment, which is expensive and cumbersome to transport to the test site. Tracer decay and constant injection tracer gas tests can benefit from passive capillary adsorption tube samplers (CATS), which absorb gas at the testing site, and then can be analyzed in a laboratory. According to Leaderer et al. (#2278, 1985), these samplers use about 50 mg of Amborsorb as the collection media. The tracer gas adheres to the surface of the media during sampling, and then the tubes can be brought to a lab where the gas is de-sorbed and channeled through a gas chromatograph to determine the concentration during sampling. These passive sampling tubes are generally paired with perfluorocarbon tracer (PFT) release tubes. PFT tubes contain a substance, which emits one of four perfluorocarbon gasses at a constant rate. The emission rate can be maintained for 2-7 years, although it does vary with temperature.

Vercammen et al. (#2825, 1987) examine the effect of high air velocity (0.8 to 6.4 m/s) and orientation at constant temperature on PFT sampling. They found that these air velocities do in fact cause measurement errors, over 100% relative error for air velocity of 6.38 m/s and a sampling tube oriented at 90 degrees to the flow. However, the errors can be minimized by using enclosures (two sizes were investigated) around the sampling tubes or orienting the tube at 180 degrees with respect to the bulk airflow velocity vector. They state that more work needs to be done to optimize the size and shape of the enclosures.

#### **4.6 Comparison of Tracer Gases**

Grimsrud et al. (#200, 1980) compare the results of tracer gas decay tests using three different tracers to see if the choice of tracer gas affects the test result. They chose sulfur hexafluoride ( $\text{SF}_6$ ), methane ( $\text{CH}_4$ ), and nitrous oxide ( $\text{N}_2\text{O}$ ) as tracer gases. They found that the infiltration rate determined using  $\text{SF}_6$  results was slightly higher than the rates determined using either of the other two gases, but the difference was within the expected error of tracer gas results (5 to 10%).

The ASTM standard E741 (2000) also describes the tracer gases that can be used including hydrogen, helium, carbon monoxide, carbon dioxide, sulfur hexafluoride, nitrous oxide, ethane, methane, and halocarbons (C-318, 13B1, 12 and 116). The standard

gives their toxicology, chemical reactivity, and ability to be detected. It does not evaluate the gases in terms of how they perform in tracer gas testing.

#### **4.7 Comparison of Tracer Gas Methods**

Kumar et al. (#284, 1979) compare the constant concentration and decay methods at two fixed constant flow conditions driven by a pressurization fan. They find that the two tracer gas methods produce results that agree within 1.5%, and when compared to pressurization results the error is less than 5%.

Sandberg (#2367, 1986) compares the constant concentration method with the decay method, both theoretically and experimentally. His theoretical analysis seeks to determine how flow rate oscillations affect measurement error. He finds that errors related to flow rate oscillations can generally be neglected compared to other errors (mixing errors are estimated at 12-18%) as long as the measuring time is at least one third the oscillation time period. In the experiment, he determined that the oscillations in flow rate were high frequency and therefore did not significantly affect the accuracy. He found good correlation between the constant concentration method and the decay method.

Bohac et al. (#2738, 1987) compare infiltration rates determined using PFT samplers (constant injection method) with rates determined using constant-concentration tracer gas measurements. Tests were performed in one unoccupied house, and in one occupied house. They found that PFT measurements under-predicted infiltration results significantly. The under-prediction ranged between 5% and 29% during cold weather when the infiltration fluctuated due to weather changes and there was little occupant airing of the house. Simulations were performed to identify and estimate the sources of this error. The variation in flow rate accounted for the winter time error, however occupant airing accounted for the largest discrepancies. It was found that springtime occupant airing led to under-predictions of 32 to 78%.

Sutcliffe and Waters (#4866, 1990) compare the decay, step up, and pulse techniques, as used to determine local and room mean air age. They used real and generated data to evaluate the errors associated with each technique. The generated data assumed that the air was fully mixed, and used a random error generator to add error within a standard deviation set at 1%, 2%, 5% and 10 %. They determined that the decay technique was marginally better than the pulse and step up techniques for determining local room air age. The decay test was found to be much easier to perform from a practical standpoint.

### **5.0 Tracer Gas Air Exchange Measurements for Multi-zone Systems**

The constant concentration method can be used to study outdoor infiltration into multiple zones by injecting enough tracer gas in each zone to keep the concentration constant. If the inter-zonal flows are needed then it is necessary to use more than one tracer gas.

## **5.1 Single-Gas Techniques**

Harrje et al. (#1862, 1985) discuss the decay, and constant concentration tracer gas methods for use in multi-zone buildings. They briefly mention the PFT constant injection technique, and its applicability to multi-gas multi-zone measurements. Single gas decay and constant concentration tests can be used to determine inter-zonal flow. The authors state that two zones are the maximum number of zones that can be studied by the decay method, but multiple zones can be studied by the constant concentration method. They describe gas detector calibration details which are still relevant today.

Roulet and Scartezzini (#2882, 1987) discuss the measurement of outside air infiltration into various zones using a constant-concentration tracer gas technique. This method does not allow determination of inter-zonal flows. They have a very detailed description of the equipment and methods that they use for these measurements. They do not estimate errors or validate their method by comparison to any other method. They say that more detailed data are needed in order to compare their measurements to a theoretical model such as the LBL Infiltration Model developed by Sherman and Modera.

Bohac and Harrje (#2745, 1987) describe a method for estimating inter-zonal airflows using only one tracer gas. This technique is a modified version of a constant-concentration technique where the concentration in a single zone is varied. The resulting change in concentration gives information about how that room is connected with the other rooms, which are maintained at constant concentration. These measurements were compared to multiple tracer gas PFT measurements, and it was found that the infiltration flows and the downstairs to upstairs flow had good agreement (within 30%), but the exfiltration flows and the upstairs to downstairs flow disagreed by more than 50%. The discrepancy may be due to the fact that the injection technique measured flows for discrete two hour periods whereas the PFT technique measured the average over the entire period of testing. Further testing is needed to determine if the difference in these two methods are real.

Stymne et al. (#13079, 2000) compare five different techniques for using a single tracer gas to determine the mean age of air for steady flow conditions: decay, step-up, constant injection, inlet pulse (injected into the supply air) and homogeneous pulse (injected directly into the zones). They find that the homogeneous pulse technique produces results that agree very well with the established tracer decay technique, and it is much easier to perform because the evaluation of mean age of air uses a total time integration, allowing the use of adsorption tubes for sampling.

## **5.2 Active Multigas Techniques**

Active tracer gas techniques are those, such as constant concentration, which require a control feedback loop in order to run the test. The tracer concentration in a zone is monitored, and then the appropriate amount of tracer is added to the zone in order to keep the concentration constant. The equipment set up becomes more complicated as more zones are included in the analysis.

Kvisgaard and Collet (#3123, 1988) describe general constant concentration methods using two tracer gases to determine air exchange between rooms and from outdoors. They discuss where the tracer gases should be seeded and collected, and what information can be gained from the various configurations. They do not discuss details of theory or measurement equipment.

Compagnon et al. (#3132, 1988) discuss their work on a new control strategy for maintaining constant tracer gas concentration. Their method is based on a PI control method with some improvements. They account for the limitations of the tracer gas injection system and anticipate the next control loop step in order to minimize the over and under shooting that happens when a change in concentration is called for. The control algorithm was only tested for the single zone case. It was found that this control algorithm works well for the single zone case, and could be extended to a multivariable control algorithm for use in multiple zones.

### **5.3 Passive Multigas Techniques**

Perera et al. (#1258, 1983) describe their experimental procedure for measuring inter-zonal airflows in an office building in detail. They used three zones, and seeded each with a different tracer gas. After mixing, they measured the gases, and used a numerical gradient method to solve for the inter-zonal flows. They compared predicted concentrations with those measured and found good agreement. They suggest further validation of the technique in a test chamber where flows are known.

Irwin and Edwards (#3576, 1989) compare three calculation methods for multi-zone decay tests. They analyze a particular set of data using a numerical concentration gradient method, a numerical integration technique, and an analytical solution. They find that the two numerical methods have problems when the data have fluctuations due to wind effects.

## **6.0 Air Distribution System Measurements**

### **6.1 Duct Leakage Flows**

Francisco (#13604, 2000) compares five test methods: the duct pressurization test, the house pressure test, supply blocked house pressure test, the hybrid test (duct pressurization and house pressure tests), and the nulling pressure test. He compared results from all the other tests to duct leakage that was determined by measuring the flows out of all the registers using a propeller flow hood and subtracting this from the measured HVAC fan flow. I will call it the register flow method. Fan flow is measured by drawing all of the return flow through a duct blaster.

Some of these tests measure duct leakage flows directly while the air handler fan is operating normally. Other tests, such as the pressurization test, measure the leakage at a fixed pressure induced by an external fan, then the operating pressure is estimated, and the leakage flow is corrected to the actual operating conditions. There is inherent error in

estimating the operating pressure of the system since the operating pressure is not constant throughout the system.

He found that the house pressure test and the hybrid test measured higher leakage than the register flow method whereas the pressurization test and supply blocked pressure test measured lower leakage. The nulling pressure test agreed with the register flow method. There was quite a bit of scatter in the data - especially for the house pressure tests. The house pressurization test had the least scatter. All the methods, on average, produced results within 5% of the register flow method. However, only two tests, house pressurization and nulling pressure test, had standard deviation of about 5% of air handler flow. The other tests had standard deviation of 9%-11%.

Walker et al. (2001) describe the Delta Q test in detail. This is a newly developed test, which determines duct leakage flows by measuring the difference in flow through the house envelope when the house is maintained at a constant envelope pressure differential and the HVAC fan is turned off and on. The flows are measured at a number of different envelope pressure differentials, and then used to calculate duct leakage in the supply and return duct systems during operating conditions. Two major advantages of this test are that: 1) it determines the leakage at operating conditions whereas tests such as duct pressurization determine the leakage at a given pressure difference which may be quite different from the actual pressure difference which varies throughout the system, and 2) it does not require the sometimes difficult task of covering registers. In this paper, Walker et al. describe how to do the test; results from several field evaluations, including a repeatability study; and provide an uncertainty analysis.

Andrews (2000) also provides an uncertainty analysis of the Delta Q test. He provides a parametric analysis, using a Monte Carlo technique to examine the error. He also performed field tests to evaluate the theoretical analysis. He found that the Delta Q test results were not strongly affected by the inputs for the pressure of the leaks in the supply and return plenum. He concluded that the Delta Q test is able to give useful results even with an uncertainty of 3% for blower door measurements. He finds that the Delta Q test is limited when the envelope leakage is large, or when the duct leakage is low.

## **6.2 Airflow through Ducts and Duct Networks**

Tracer gas methods have several advantages over pitot tube, vane anemometer, and hot wire anemometer measurements for flow in duct networks. Tracer gas does not require a long duct to develop laminar flow and does not require determination of the cross sectional area or knowledge of the flow profile across the duct. It is important to have good tracer gas mixing in the duct, therefore the injection site should be carefully chosen. The sampling site must be sufficiently downstream and carefully placed in the air stream to ensure that the sample is representative of the total concentration. Sometimes this requires long duct runs or mechanical mixing such as fans placed inside the duct.

Riffat and Holmes (#4835, 1990) compare three types of tracer gas measurements of flows in ducts (constant injection, pulse injection, and concentration decay) to pitot tube flow measurements. (Note that the accuracy of a pitot-tube traverse strongly depends on

duct geometry and its effects on flow patterns at the traverse plane. A more accurate method such as an orifice would have been a better benchmark.) They find that the constant-injection technique correlates most closely, and they postulate that the other tracer gas techniques could be improved by more frequent sampling and better mixing of the tracer gas.

Sateri (#5266, 1991) describes his procedure for making PFT measurements in ducts. He places the sources in various orientations and measures the uptake (the amount of tracer gas absorbed by the tube) of each orientation over a range of flow speeds. He finds that the uptake does not vary significantly with source orientation, but that it does vary with flow velocity. There was a 10% to 16% increase in uptake for each 1 m/s increase in velocity. He therefore recommends that PFT measurements always include a velocity correction when used in ducts, and that more measurements are needed to determine this correction. He concludes that active (pumped) techniques would work better in ducts than passive techniques because it would eliminate the effects due to velocity and turbulence.

Cheong and Riffat (#6005, 1992) use tracer gas measurements to determine the k-factors (the multiplier which quantifies the change in velocity pressure across a particular duct fitting) for various duct fittings and several filters. These values were compared to k-factors in CIBSE and ASHRAE data as well as to k-factors calculated from pitot tube measurements by the authors. They found that the k-factors estimated from tracer gas measurements were similar to those given in the CIBSE guide, and these were lower than those estimated from pitot tube measurements.

Cheong and Riffat (#7051, 1993) describe in detail their tracer gas sampling system for measuring airflow in ducts. They use an active system as suggested by Sateri (#5266, 1991). Their results were very good (5% to 10% difference), agreeing with measurements from a static pitot tube traverse, however earlier papers indicate that this may not be the best benchmark.

### **6.3 Airflow through Air Terminal Devices**

Walker et al. (2001) tested four different flow hoods in a laboratory and 13 flow hoods in a field study to determine if the flow hoods measure flows accurately for residential applications. In the laboratory, they compared the flows measured by the hoods to the flow measured by a flow nozzle with an accuracy of  $\pm 0.5\%$ . Laboratory tests of several residential flow hoods showed that many of the hoods can be inadequate to measure flows in residential systems. Potential errors are about 20% to 30% of measured flow, due to poor calibrations, sensitivity to grille flow non-uniformities, and flow changes from added flow resistance of the hood. A new type of hood was tested called an active flow hood, which consists of a conventional flow capture hood attached to a duct and a fan. The fan is adjusted until there is no pressure difference between the inside and outside of the hood indicating that the fan has compensated for the increased flow resistance of the hood. Active flow hoods are insensitive to grille airflow patterns, have an order of magnitude less error, and are more reliable and consistent, in most cases, than conventional flow hoods. In the field study, the hoods were compared to the active flow hood since this hood had the best accuracy in the laboratory tests. The field evaluation



showed that it is possible to obtain reasonable results using some flow hoods if the field tests are carefully done, the grilles are appropriate size, and grille location does not restrict flow hood placement.

#### ***6.4 Airflow through Fans, Heat Exchangers, and Fresh Air Inlets***

Sauer and Howell (#4799, 1990) describe a procedure for measuring the volume flow rate of air through a heating or cooling coil using a vane anemometer. They show that this procedure, which can be used for flows between 100 and 1100 ft/min (0.508 to 5.588 m/s), has an accuracy of  $\pm 7\%$ , when measured results are compared to the predicted results. This is in the same accuracy range as pitot tube traverses (5% to 10%). If accuracy is not required, the authors describe a simplified procedure (#4070, 1990) where they omit the density correction and correlate the k-factor only to face velocity. This procedure has an accuracy better than  $\pm 20\%$ . A similar procedure is often applied to flow measurements across register grills, however, it is difficult to align the anemometer with the direction of flow out of the grill.

Palmiter and Francisco (2000) discuss a new technology for measuring airflow through a residential air handler system. The system consists of removing the HVAC filter and installing in its place a perforated plastic plate, where the flow through the plate can be determined by measuring the pressure difference between the velocity pressure and the static pressure at the plate. This technology has been commercialized by The Energy Conservatory. Field tests have been performed where the flow plate method is compared to the temperature rise method, which is the industry standard at this time, although not very accurate, and the Duct Blaster method, which is better than the temperature split method but can still be inaccurate in certain flow geometries. These tests showed that the flow plate method has a standard deviation of 7% from the Duct Blaster method and a 29% standard deviation for the temperature rise method. Both the flow plate method and the temperature rise method take about 15 minutes to perform, which is much less time than the Duct Blaster method which takes 30 minutes to 1 hour to perform.

## References

### 1.0 Introduction

The papers in this section are organized by topic. These topic headings are the same as those in the front section of this paper. The papers are listed in roughly chronological order within each section. Those papers that were listed in the AIVC database are listed with the AIVC reference number first. Those papers that were not listed come at the end of each section, and have no reference number.

#### **#NO 12340 Energy Impact of Ventilation: Estimates for the Service and Residential Sectors.**

AUTHOR Orme, M.

BIBINF UK, Air Infiltration and Ventilation Centre (AIVC), 1998, Technical Note 49, 43 pp, 15 figs, 5 tabs, refs.

ABSTRACT Considers air change energy use in thirteen major industrialised countries, and the effect that air change energy use has on carbon dioxide emissions due to the use of fossil fuels, both directly in combustion appliances, and indirectly as electricity. In order to quantify the energy impact of air change on total energy use, the AIVC has been undertaking a study of current estimates for non-industrial buildings. The potential for reduced energy use by improved ventilation control is also briefly reviewed. It is found that air infiltration and ventilation together account for a significant proportion of energy use in buildings. This report outlines the findings from a study into estimating the full impact of air change on building energy use. Considering the non-industrial building stock of the 13 countries collectively, the total annual loss of heating energy due to air change

is estimated to amount to 48% of delivered space conditioning energy (including heating equipment losses). Stated in terms of delivered space heating energy alone (i.e., excluding space cooling), this rises to 53%. If the outdoor air supply rate per occupant were to be universally reduced to a minimum level, taking into account metabolic needs and pollutant loads, then it is conceivable that the heating air change energy loss could be reduced to approximately a third of the current level. The consequent reduction in the total carbon dioxide emissions from the service and residential sectors (for all end uses) would be in the region of 20% per year. The results emphasise that air change related energy losses are as important as conduction and equipment losses (including "flue" losses) in dissipating delivered space conditioning energy from buildings. In fact, as national standards, regulations or codes of practice improve the thermal integrity of building and increase equipment efficiency, it is expected that ventilation and air movement will become the dominant loss mechanism. KEYWORDS energy use, air change rate, calculation techniques

### 1.1 Airflow Measurement Techniques

#### **#NO 66 A review of experimental techniques for the investigation of natural ventilation in buildings.**

AUTHOR Hitchen E.R. Wilson C.B. BIBINF Bldg. Sci. March 1967, 2, 1, 59-82, 1 graph, 10 tabs, 91 refs. in English ABSTRACT After discussing briefly the principles of natural ventilation, goes on to describe tracer gas techniques, air movement measurements, and various model techniques including analogues.

Advantages and disadvantages of each method are indicated, and their suitability for particular applications. KEYWORDS air change rate, natural ventilation, tracer gas, modelling, instrumentation

**#NO 418 Airtightness - measurement and measurement methods  
Matningar och matmetoder for lufttathet**

AUTHOR Kronvall J.

BIBINF Swedish Council for Building Research, Stockholm 64p. 10 refs.

D8:1980 ISBN 91-540-3201-6 in English T6: ISBN 91-540-2967-8 in Swedish

ABSTRACT Describes methods of measuring the air tightness of whole buildings. Outlines three tracer gas methods, constant concentration, decreasing concentration and constant emission. Describes pressurisation method. Describes measuring equipment and test procedure and discusses calculation of ventilation rate and error magnitudes. Gives brief summary of measured results and an appendix contains a print-out of data on the airtightness of houses.

KEYWORDS air infiltration, tracer gas, pressurization, instrumentation

**#NO 1536 Measurement techniques for air change and air penetration of residential buildings  
Messmethoden zur Erfassung des Luftwechsels und der**

**Luftdurchlassigkeit von Wohnbauten.**

AUTHOR Muhlebach H.

BIBINF Heizung und

Luftung/Chauffage et ventilation, No 5, 1984. p20-22, 6 diags, 1 tab, 10 refs. in German

ABSTRACT Defines air change and air penetration. Describes the differential

pressure method, the infrasound method, qualitative judgement methods, and acoustic measurement devices for determining air penetration. Explains procedures to determine air change - the rate of decay method, the constant concentration method, and the constant emission method.

KEYWORDS air change, air leakage, pressurization, tracer gas, thermography

**#NO 1862 Documenting air movements and infiltration in multicell buildings using various tracer-gas techniques.**

AUTHOR Harrie D T, Dutt G S, Bohac D L, et al.

BIBINF Preprint. ASHRAE

Transactions 1985, Vol 91, Pt 2. HI-85-40 No 3. 15p. 11 figs, 18 refs. in English

ABSTRACT Tracer gas techniques for measuring airflows in buildings fall into three categories - dilution, constant injection, and constant concentration.

Dilution of a single tracer works well in buildings with a single zone and also in some two-zone buildings. Multiple tracer gas measurements, necessary to characterize flows among more zones, are best conducted using the constant injection approach. The constant concentration method uses a single tracer gas to determine the airflow rates from the outside into each of as many as ten building zones. The paper outlines the different tracer techniques for making airflow measurements in multicell buildings and describes the operation of a constant concentration system. This system measures tracer gas concentration in different zones and injects accordingly to maintain a constant concentration in each zone. The system was tested in a single zone structure and successfully applied to a small three-zone house. Sensitivity

analyses and calibration procedures described in this paper define the capabilities and limitations of this technique. Although this method does not fully characterize all interzone airflows in the building, it can be useful in analyzing the energy balance of multizone buildings. Additionally, these measurements can be used to evaluate the dilution of indoor air pollutants and the ventilation efficiency of buildings.

**KEYWORDS** multi-chamber, tracer gas, measurement technique, decay rate, constant concentration, constant emission, air movement, air infiltration

**#NO 2216 Tracer gases as a ventilation tool: methods and instrumentation.**

**AUTHOR** Farant J P, McKinnon D L, McKenna T A

**BIBINF** Ventilation '85. (Chemical Engineering Monographs 24). Edited by H D Goodfellow. Amsterdam, Elsevier, 1986. p263-274. 4 figs, 5 tabs, 3 refs. in English AIVC bk

**ABSTRACT** Tracer gas techniques, used for routine ventilation checks or trouble shooting are outlined with emphasis on their applicability in a variety of situations. These include methods of determining volumetric flow rates in closed conduits and finding ventilation rates at work stations. Other uses of tracer gases are also dealt with. Investigations have been performed on the use of occupant generated carbon dioxide (CO<sub>2</sub>) as an indicator of ventilation rates. Results comparing the simultaneous decay of CO<sub>2</sub> and sulphur hexafluoride (SF<sub>6</sub>) are presented showing the former to be a potentially useful ventilation tool. Presently, tracer gas studies are limited by available sampling and analytical equipment. Recent developments in the technology

used for tracer gas testing and the research being performed on sampling and analytical techniques are outlined. Several different sampling methods are considered ranging from passive to pump operated bag sampling. SF<sub>6</sub> has received wide acceptance as a tracer gas. However, investigations have shown that while it has most of the desirable tracer gas characteristics, it also has some shortcomings. The physical, chemical, and toxicological properties of alternative gases were reviewed for this reason and their relative usefulness as tracer gases is presented.

**KEYWORDS** tracer gas, carbon dioxide, sulphur hexafluoride

**#NO 2277 A review of tracer gas techniques for measuring airflows in buildings.**

**AUTHOR** Lagus P, Persily A K

**BIBINF** ASHRAE Trans, 1985, Vol 91 Part 2B, H1-85-22 No 1, p1075-1087. 8 figs, 2 tabs, 38 refs. in English

**ABSTRACT** This paper describes tracer gas measuring techniques that have been used to characterize ventilation and air infiltration in buildings, with an emphasis on recent developments and applications in large industrial and commercial structures. Fundamentals and applications are presented for both single and multiple tracer gas methods. In addition to techniques suitable for detailed characterization of building airflows, procedures and equipment appropriate to surveying large numbers of buildings are also discussed. Illustrative examples of the various measuring techniques as well as discussion of their advantages and disadvantages are provided. A detailed bibliography is also included to facilitate a more thorough examination of the topics discussed.

KEYWORDS tracer gas, measurement technique, airflow, industrial building, office building, pressurisation

**#NO 2682 Measurement techniques for ventilation and air leakage.**

AUTHOR Charlesworth P S

BIBINF 8th AIVC conference

'Ventilation Technology - Research and Application', 21-24 September 1987, Ueberlingen, West Germany, Proceedings, AIVC 1987, p1.1-1.15, 10 refs. in English

ABSTRACT 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 airflows, 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.

KEYWORDS measurement technique, air leakage

**#NO 3094 What is ventilation efficiency?**

**Was ist Luftungseffektivitat?**

AUTHOR Raatschen W

BIBINF Klima Kalte Heizung, May-August 1988, 18pp. in German

ABSTRACT The first of this three-part series gives a bibliography and review about methods for measuring air exchange rates of rooms, in between rooms and of whole buildings. Included are diverse tracer-gas methods as well as

pressurization methods. Whenever possible, the methods are illustrated by examples. The insufficiency of the nominal air exchange rate to predict exposure to contaminants is discussed. The second part deals with the efficiency of the air exchange in rooms. The "age concept" and the "air exchange efficiency" are explained for the application with the tracer-gas decay method. A practical example of a tracer-gas measurement is given to deepen the theory. The third part explains the constant-concentration and the pulse method and definitions to characterize the removal of contaminants.

KEYWORDS ventilation efficiency, air change rate, tracer gas, pressurization, constant concentration

**#NO 3296 Instrumentation for the measurement of air infiltration - an annotated bibliography.**

AUTHOR Manning S

BIBINF UK, AIC, Technical Note 4, 1981. in English

ABSTRACT An annotated bibliography containing 89 references to papers selected from the AIC's library and intended to be selective rather than comprehensive. Includes references only to papers entirely or substantially concerned with instrumentation of containing information about a particular measurement technique. References are divided into three sections according to subject: tracer gas methods, pressure tests, and other associated techniques such as thermography and acoustic detection of leakage paths.(Out of Print)  
KEYWORDS measurement technique

**#NO 3550 Air Infiltration Measurement Techniques.**

AUTHOR Sherman M

BIBINF in: UK, 10th AIVC Conference Proceedings Volume 1, held Espoo, Finland, 25-28 September 1989, published February 1990, pp63-88, 38 refs. in English

**ABSTRACT** Tracer gas techniques have become widely used to measure the ventilation rates in buildings. The basic principle involved is that of conservation of mass (of tracer gas) as expressed in the continuity equation, by monitoring the injection and concentration of the tracer, one can infer the exchange of air. Although there is only one continuity equation, there are many different experimental injection strategies and analytical approaches. These different techniques may result in different estimates of infiltration due to uncertainties and biases of the procedures. This report will summarize the techniques and the relevant error analyses. As more detailed information is required for both energy and indoor air quality purposes, researchers are turning to complex, multizone tracer strategies. Both single gas and multiple gas techniques are being utilized, but only multigas are capable of uniquely determining the entire matrix of airflows. This report will also review the current effort in multizone infiltration measurement techniques.

**KEYWORDS** measurement technique, ventilation rate

## 1.2 Energy Measurements

**#NO 3383 Energy efficiency in buildings: progress and promise.**

**AUTHOR** Hirst E, Clinton J, Geller H, Kroner W

**BIBINF** USA, American Council for an Energy Efficient Economy, 1986, 328pp. in English

**ABSTRACT** The purpose of this book is twofold: to review current knowledge on energy use and efficiency in residential and commercial buildings and to suggest important research and program topics for future study. First reviewed are overall patterns of energy use in residential and commercial buildings and the dramatic changes in energy trends after 1973. Next are discussed the reasons for continuing research and programs to improve energy efficiency in buildings and note the complexity and diversity among buildings in their design, construction, operation, maintenance, and use. Finally, suggestions are offered that merit attention in both the short and long runs.

**KEYWORDS** energy efficiency

**#NO 6579 Air tightening new houses for improved energy efficiency what is the potential?**

**AUTHOR** Swinton M C, Reardon J T  
**BIBINF** Canada, Solplan Review, December-January 1993, pp 10-11, 1 fig. in English

**ABSTRACT** In the last ten years, construction practice has evolved in response to the need for reducing air leakage through the building envelope of houses. As a result, new houses are being built more airtight. Recognizing this fact, the 1990 National Building Code (NBC) requires a mechanical ventilation system capable of producing 0.3 air changes per hour, thus providing a mechanical means of achieving minimum ventilation levels when needed. With only a few regional exceptions, builders have been meeting the intent of the mechanical ventilation provisions of the NBC with exhaust-only fans-typically kitchen and bathroom fan combinations. Given these developments in NBC requirements, recent trends in

house design, and the need to achieve energy efficient construction, the following questions arise: How energy efficient is current house construction with respect to overall air change and Can we achieve additional energy efficiency, without compromising minimum ventilation requirements? KEYWORDS air tightness, energy efficiency, building envelope

**1999 ASHRAE Handbook- Applications, chapter 42. Building Operations and Management: Building Envelopes**

AUTHOR ASHRAE

BIBINF American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., 1999

SUMMARY This chapter covers residential foundations, walls, roof and ceiling assemblies, fenestration, wall/window interface, wall/roof interface, thermal bridges in buildings, and thermal mass.

**2001 ASHRAE Handbook - Fundamentals, chapter 26. Load and Energy Calculations: Ventilation and Infiltration.**

AUTHOR ASHRAE

BIBINF American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., 2001

SUMMARY This chapter covers basic concepts and terminology, driving mechanisms for ventilation and infiltration, ASHRAE standard 62, indoor air quality, thermal loads, natural ventilation, residential air leakage, residential ventilation, residential ventilation requirements, simplified models of residential ventilation and infiltration, non residential air leakage, nonresidential ventilation, and tracer gas measurements.

### 1.3 IAQ Measurements

**#NO 726 Energy conservation and indoor air quality.**

AUTHOR Hadley J.

BIBINF ASHRAE jnl. March 1981 p.35-37 7 refs. in English #AIC 363 ABSTRACT Reviews the topic of indoor air quality as it relates to energy efficient homes. Discusses air pollution from combustion, airborne particles, formaldehyde and radon. Concludes that indoor air quality in existing homes and those currently being constructed, can be managed so as to avoid adverse effects on the occupants.

KEYWORDS air quality, formaldehyde, radon, review

**#NO 6246 ASHRAE STANDARD 62-89 Ventilation for acceptable IAQ.**

AUTHOR Tucker G

BIBINF Indoor air quality, ventilation and energy conservation, 5th International Jacques Cartier Conference, Montreal, Canada, October 7-9, 1992, publisher: Center for Building Studies, Concordia University, Montreal, Canada, pp 211-220. in English/French ABSTRACT ASHRAE Standard 62 contains design procedures and guidelines for ventilation rates in all indoor or enclosed spaces that people may occupy, except where other applicable standards and requirements dictate larger amounts of ventilation than this standard. Standard 62 is the basis for ventilation requirements in many codes for commercial, institutional, and residential buildings in North America. The Standard is reviewed every 5 years or less, and updated as needed to incorporate new information or improve its usefulness to building designers and code officials. This paper highlights some of the key features of the design

procedures in Standard 62 and summarizes the status of the review process.

KEYWORDS standard, indoor air quality, ventilation rate, ventilation requirements

## **2.0 Air Velocity Measurements**

### **2.1 Particle streak-velocimetry**

#### **#NO 8007 Particle-streak-velocimetry for room airflows.**

AUTHOR Scholzen F, Moser A, Suter P -Bibinf

BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 2, pp573-584. ABSTRACT This paper presents a measurement technique to perform quantitative visualization of room airflows. The visualization is done by discrete particles, namely helium-filled soap bubbles, illuminated in a plane light sheet generated by a point light source in combination with a special lens.

The recording is done stereoscopically with 3 standard cameras by streak photography. The scanned negatives are analysed digitally. The method is able to give the three-dimensional instantaneous velocity field of room air movements, also in real-scale.

KEYWORDS (airflow, measurement technique)

#### **#NO 8119 Measurement of room air currents by means of particle image velocimetry (PIV). Messung von Raumluftstroemungen mit der Particle-Image-Velocimetry (PIV).**

AUTHOR Ewert M

BIBINF Germany, HLH, Vol 45, No 9, 1994, pp 470-472, 4 figs, 2 refs in German.

ABSTRACT Describes the measurement of room air currents using particle image velocimetry.

KEYWORDS measurement technique, airflow

#### **#NO 9088 High resolution particle-imaging velocimetry for full scale indoor airflows.**

AUTHOR Cui M M, Topp C, Pedersen S, Christianson L L, Adrian R J, Leovic K W

BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 537-550.

ABSTRACT A high resolution particle-imaging velocimetry has been developed and applied to study full-scale room airflows. The system is designed to study local field quantities in occupied zones (microclimate), ventilation effectiveness, and airborne pollutant transport in the indoor environment. The system can be applied to evaluate indoor environment in typical commercial and residential settings. The technique and instrumentation have been applied successfully to study localized airflow patterns and particle concentration distribution in the indoor environment. The results of this research can be used to assess the ventilation effectiveness and energy efficiency in rooms and buildings.

KEYWORDS airflow, ventilation effectiveness, particulate

#### **#NO 9743 The introduction of the desk displacement ventilation concept:**



**measurement of indoor airflows  
applying the PTV technique.**

AUTHOR Loomans M G L C, van  
Mook J R, Rutten P G S

BIBINF Japan, proceedings of the 5th  
International Conference on Air  
Distribution in Rooms, Roomvent '96,  
held Yokohama, Japan, 17-19 July  
1996, Volume 1, pp 99-106.

ABSTRACT This paper introduces the  
research at a new type of task  
conditioning concept, the desk  
displacement ventilation concept. The  
total research comprises several phases,  
in which the measurement and  
calculation of indoor airflows play a  
major role: 1. Literature research on  
velocity measurement techniques. 2.  
Experimental tests of different velocity  
measurement techniques, in particular  
the Particle Tracking Velocimetry (PTV)  
technique. 3. Measurements at a full-  
scale experimental set-up of an office-  
model, equipped to operate according to  
the desk displacement ventilation  
concept. 4. Comparison with  
Computational Fluid  
Dynamics-simulations. After the  
introduction of the new desk  
displacement ventilation concept, this  
paper reports on phases one and two of  
this research project. A theoretical  
analysis of the PTV-technique shows its  
suitability for indoor airflows. Two  
PTV-experiments underline the  
quantitative and qualitative possibilities.  
The generation of sufficient and  
consistently neutrally buoyant soap  
bubbles, which are used as tracer  
particles, still requires a technical  
solution.

KEYWORDS displacement ventilation,  
measurement technique

**#NO 11512 An Experimental Study on  
Chair Air Supplying**

AUTHOR Li Q, Meng G

BIBINF Sweden, Stockholm, KTH  
Building Services Engineering, 1998,  
proceedings of Roomvent 98: 6th  
International Conference on Air  
Distribution in Rooms, held  
June 14-17 1998 in Stockholm, Sweden,  
edited by Elisabeth Mundt and Tor-  
Goran Malmstrom, Volume 1, pp 265-  
270.

ABSTRACT Displacement ventilation is  
acknowledged to be an efficient system  
for the removal of contaminants and  
excess heat from occupied zones of  
rooms, this system is aiming at  
supplying clean undiluted supply-air  
directly to the zone of occupation.

Airflow rate, temperature and the design  
of the supply device strongly influence  
the parameters that determine thermal  
comfort. In the paper, one kind of  
displacement ventilation system - a chair  
air supplying system - is investigated. A  
full-scale experimental model is  
established, temperature field and  
velocity field are measured at different  
airflow rate, supply air temperature with  
four different chair air outlets. PIV  
(particle Image Velocimetry) technology  
is applied in measuring velocity field.  
The PD (percentage of Dissatisfied) in  
occupied zone is evaluated. The results  
show that this system has a stable  
temperature gradient, the vertical  
temperature difference between 0.1m  
(above floor level) and 1.1m is lower  
than 3 °C in most cases. So a  
comfortable thermal environment is  
given by this displacement ventilation  
system.

KEYWORDS displacement ventilation,  
airflow rate, thermal comfort, full-scale  
experiments, air velocity, temperature  
gradient, thermal comfort

**#NO 12124 Indoor low speed air jet flow: 3-dimensional particle streak velocimetry.**

AUTHOR Linden E, Todde V, Sandberg M

BIBINF Sweden, Stockholm, KTH Building Services Engineering, 1998, proceedings of Roomvent 98: 6th International Conference on Air Distribution in Rooms, held June 14-17 1998 in Stockholm, Sweden, edited by Elisabeth Mundt and Tor-Goran Malmstrom, Volume 2, pp 569-576, 11 figs, refs.

**ABSTRACT** This paper presents results from a larger project on the use of Particle Steak Velocimetry (PSV) to determine the air movements in ventilated rooms. With this method it is possible to record the instantaneous three-dimensional velocities over a large area. The method has been optimised for large field of views ( 10m<sup>2</sup> which is required for ventilation applications. With the use of small light particles in the air, we can present images of their tracks. Then, with the help computerised image processing and with Stereo-Photogrammetry analysis, we can obtain three-dimensional velocity. This particular application deals with the evaluation of the instantaneous velocities of a low speed jet. The isothermal jet flow was issued from a small nozzle (diameter, d=5.0cm), in a room of the size 3.6x3.6x2.5m (LxWxH). The test was conducted for the supply velocity of 30cm/s, corresponding to Reynolds number,  $Re = 1075$ . This paper treats the results obtained with the PSV method and presents an analysis of the instantaneous three-dimensional velocities in the jet flow. Smoke has also been used to visualise the jet flow. The results show that our whole-field method can be a

good tool for measuring three-dimensional velocities in rooms and to visualise the indoor-climate.

The method should be improved by finding homogeneous and light particles. It is also important to increase the resolution of photographs.

**KEYWORDS** air velocity, full scale experiments, measurement technique

**#NO 12126 Indoor low speed air jet flow: fibre film probe measurements.**

AUTHOR Todde V, Linden E, Sandberg M

BIBINF Sweden, Stockholm, KTH Building Services Engineering, 1998, proceedings of Roomvent 98: 6th International Conference on Air Distribution in Rooms, held June 14-17 1998 in Stockholm, Sweden, edited by Elisabeth Mundt and Tor-Goran Malmstrom, Volume 2, pp 585-592, 10 figs, 3 tabs, 5 refs.

**ABSTRACT** This paper presents results belonging to a larger investigation on low velocity indoor air jets. The experiment is undertaken in a climate room where an isothermal air jet is issued from the centre of one lateral wall. Measurements are performed with a single fiber film probe, and with Particle Steak Velocimetry system. With Particle, Steak Velocimetry has been developed a three dimensional analysis of the instantaneous velocity field. With the use of fiber film probe, the fluid-dynamics of the jet flow is explored in terms of longitudinal velocity, and relative turbulence intensity. This paper treats exclusively the results obtained with the fiber film probe from the measurements along the centre-line of the jet flow. The investigation deals with a number of test cases of practical value for designing supply to provide air

at low speed directly to the occupied zone.

KEYWORDS air velocity, full scale experiments, jet, measurement technique

**#NO 12688 Development of PIV techniques to measure airflow patterns in ventilated airspaces.**

AUTHOR Zhao L, Zhang Y, Wang X, Riskowski G L, Christianson L L  
BIBINF USA, ASHRAE Transactions, Annual Meeting 1999, Seattle, 9 pp, 11 figs, refs.

ABSTRACT A measurement technique based on particle image velocimetry (PIV) to measure quantitatively airflow patterns and distribution in ventilated airspaces is presented. Air laden with helium filled bubbles was illuminated by a two dimensional light sheet in a full scale ventilated room. Images of bubbles visualized in the light sheet were recorded using a photographic camera. Relatively long camera exposure time makes it possible to record the bubble path in the designed time period. Image shift techniques remove the directional ambiguity. The photographic images were scanned into a computer, and the digitised images were processed automatically using an image processing program to extract flow field velocity information. The configuration, working principles, sample results, accuracy, capability, and limitations of the technique are discussed in this paper. This measurement method is part of a larger study of aerosol spatial distribution, ventilation effectiveness, and aerial contaminant control strategies.  
KEYWORDS airflow measurement technique

## **2.2 Hot Wire Anemometer**

**#NO 329 A review of the literature on the structure of wind turbulence, with special regard to its effect on buildings.**

AUTHOR Jones M.E.

BIBINF Build. Sci vol3 p41-50 bibliog. in English.

ABSTRACT Gives short state-of-the-art review of knowledge of wind turbulence. Mentions results from field investigations. Summarizes available knowledge. An appendix discusses hot-wire anemometry. Gives bibliography of subject.

KEYWORDS wind, turbulence

**#NO 488 Shelter behind two-dimensional solid and porous fences**

AUTHOR Perera M.D.A.E.S.

BIBINF 4th Colloquium on Industrial Aerodynamics, Aachen 18-20 June 1980 9p. 8 figs 10 refs. in English

ABSTRACT Reports measurements of the wake flows behind solid and porous fences, made with a pulsed wire anemometer (PWA) and a hot-wire anemometer (HWA). Discusses results which show the superiority of PWA in correctly measuring the highly turbulent and sometimes re-circulating wake flows. Gives empirical formula for profile of the velocity defect and shear stress perturbations. Concludes that porosity, and not the form of construction of the fence, determines the structure of the wake flow. States that in general it is difficult to say which value of porosity provides the best shelter. A solid fence is best for protecting the near wake zone, while a fence with porosity of 0.1 provides good shelter characteristics in the far wake.

KEYWORDS shelter belt, airflow

**#NO 662 The measurement of rapidly fluctuating airflows.**

AUTHOR Robertson P. Cockroft J.P.

BIBINF A.I.C. Conference  
 "Instrumentation and measuring techniques". Windsor 6-8 October 1980.  
 5p. 5 figs. 2 refs. in English AIC  
 ABSTRACT Describes the development of an anemometer for the measurement of rapidly fluctuating airflows. Describes the B.R.E. shielded hot wire anemometer. Discusses modifications made to this anemometer to improve its response by using different shields and moving sensor wires closer together. Outlines system for processing signals from the anemometer using a micro-computer. Gives results of performance tests. Gives simple applications of the instrument.  
 KEYWORDS instrumentation, anemometer, airflow

**#NO 943 Three sensor hot wire/film technique for three dimensional mean and turbulence flow field measurement.**

AUTHOR Lakshminarayana B.  
 BIBINF TSI quarterly vol.8 no.1  
 January-March 1982 p.3-30 in English  
 ABSTRACT Describes methods of measuring the three-dimensional flow field using a three-sensor hot-wire probe, with emphasis on the techniques developed by the author's group at the Pennsylvania State University. The hot-wire equations, data processing procedure, calibration techniques, and a discussion of various errors in the measurement are included. Some typical data acquired by this probe is also included.  
 KEYWORDS probe, airflow, measurement

**#NO 2014 Calibration and Use of a Hot-Wire Probe for Highly Turbulent and Reversing Flows, LOCATION Europe,**

AUTHOR Cook, N. J., Redfearn, D.,  
 BIBINF Building Research Establishment, Great Britain, , , Journal of Industrial Aerodynamics, Vol.1, pp 221-231, CP 18/76, Elsevier Scientific Publishing Company, Amsterdam in English

ABSTRACT The calibration and use of a shielded dual sensor hot-wire probe, originally developed at McGill University for velocity measurement in highly turbulent and reversing flows, is described. The new probe permits measurements to be made in flow conditions which are not amenable to conventional hot-wire techniques. Two conventional hot-wire anemometers are used to drive the probe and a simple electronic circuit is required to decode the signals and produce a continuous voltage analogue of the velocity component in one dimension.,  
 KEYWORDS ,instrumentation, airflow, probe, turbulence,

**#NO 3583 Buoyancy-driven airflow in a closed half scale stairwell model: velocity and temperature measurements.**

AUTHOR Zohrabian A S,  
 Mokhtarzadeh-Dehghan M R, Reynolds A J  
 BIBINF in:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28 September 1989, Volume 2, February 1990, pp167-187, 7 figs, 6 tabs, 18 refs. in English  
 ABSTRACT This paper describes an experimental study of the buoyancy-driven flow and the associated energy transfer within a closed, half-scale stairwell model. It provides new data on the velocity, temperature, volume and mass flow rates of the air circulating between the upper and lower storeys. The results are presented for various heat

input rates from the heater, located in the lower floor. For most of the data presented, heat transfer to the surrounding atmosphere takes place through the side walls. However, the case of insulated side walls is also included and the effects on the parameters of interest are discussed. The velocities were measured using hot-wire anemometers of a temperature compensated type, and the temperatures were measured using platinum resistance thermometers. These measurements were supported by flow visualisation using smoke. The paper also provides data on the rate of leakage through the stairwell joints, measured using a concentration decay method.

KEYWORDS air movement

**#NO 4079 Comparatory tests of omnidirectional and hot wire anemometers.**

AUTHOR Knobloch B, Mierzwinski S  
BIBINF Norway, Oslo, Norsk VVS, proceedings Roomvent 90, paper 29, 16 pp, 7 figs, 5 refs. in English  
ABSTRACT Airflows in a two-dimensional supply stream and in the zone of secondary flows were tested by means of a hot sphere anemometer, type HST 1, and a hot wire anemometer, type DISA 55P81. The following parameters were measured: the mean velocity, standard deviation and turbulence scales. The discrepancies of the results were checked for the cases when: \* hot wire anemometer was applied for both the anemometer types \* a hot sphere anemometer was applied for both the anemometer types \* techniques proper for each of the anemometer types were used. It was found that a hot sphere anemometer should preferably be used to measure velocity as an element of thermal conditions of a room whereas in

those cases a hot wire anemometer is not suitable. A hot sphere anemometer may also be used to measure velocities of low turbulence flows.

KEYWORDS anemometer, instrumentation

**#NO 4080 Pulsed hot wire anemometry: an accurate method to measure highly turbulent flows at low speeds.**

AUTHOR Krogstad P A  
BIBINF Norway, Oslo, Norsk VVS, proceedings Roomvent 90, paper 30, 14 pp, 11 figs, 7 refs. in English  
ABSTRACT The operating principle of Pulsed-Hot-Wire-Anemometry has been described. This type of anemometer has proven a reliable and accurate measuring device for highly turbulent and recirculating flows. Since the measurement principle consists of measuring a time of flight of a temperature tracer, the accuracy of the device increases as the velocity decreases, in contrast to most other measurement systems. Its ability to measure velocities in flows where the general flow direction is not known a priori and the insensitivity of the device to changes in flow temperature and gas composition makes it a very versatile device. It has been demonstrated that for measurement devices that cannot detect changes in flow direction severe measurement errors may occur. Being sensitive only to the part of the velocity vector in a predefined direction makes it possible to map the total flow velocity vector at a point with a limited number of measurements.

KEYWORDS anemometer, turbulence, airflow

**#NO 5322 Hotwire/film anemometry for room air motion studies.**

AUTHOR Zhang J, Christianson L, Wu G

BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 3, pp 277-288. in English

ABSTRACT Application of hot wire/film anemometry in room airflows presents difficulties because: (1) the effect of natural convection due to the heated wire becomes significant for low air velocity measurements, (2) the angle sensitivity of a hotwire becomes small at low air velocities, which makes it difficult to resolve the direction of each velocity component. This study aimed at quantifying the uncertainty of the hot wire anemometry and examining the angle sensitivity of a hot wire in low air velocity measurements. Based on the experiments, it was concluded that: (1) the uncertainties due to natural convection in the velocity measurements with a single component hot wire probe operating at 200 Deg C wire temperature are within + or -15%, + or - 5%, + or - 1% and 0.5% for velocities of 0.05~0.1 m/s, 0.1~0.15 m/s, 0.15~0.25 m/s and 0.25~0.5 m/s, respectively, and correction can be made based on the visualization of the room airflow pattern to achieve higher accuracy, (2) air velocity components can not be measured simultaneously with multi-component hot wire probes if the air velocity is below 0.2m/s since the angle sensitivity of the probe will be heavily contaminated by the noise signal due to the natural convection.

KEYWORDS anemometer, air movement

**#NO 6006 Experimental and numerical investigations within a post-Annex 20 model.**

AUTHOR Hanel B, Richter E, Vogel P  
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. in English

ABSTRACT A small test room has been built which is five times smaller than the so called Annex-20-room. Different kinds of tracers have been used for visualizing of flow patterns. Velocities, concentrations and mass transfer coefficients have been measured. The measuring instrumentation is based on thermal anemometry (hot wire probes) and a special ammonia-mass transfer method, respectively, in order to estimate the heat flux coefficient at the walls. The values measured and the flow patterns have been applied in order to compare and to evaluate a computer code developed in Dresden to simulate three dimensional flows. This code is based on a finite-volume-discretization for the transport equations (Navier-Stokes- with k-e-model) solved with a new iteration technique including a multi grid solver.

KEYWORDS numerical modelling, airflow, tracer gas, anemometer

**#NO 6331 Near floor air movement in an enclosure with mixing type ventilation.**

AUTHOR Jin Y, Ogilvie R  
BIBINF Roomvent '92, Third International Conference, Aalborg, Denmark, September 2-4 1992, Publisher: DANVAK, Lyngby, Denmark, Volume 3, pp 245-262. in English

ABSTRACT The mean air velocity, and the RMS value, of the reverse flow in

the zone up to 0.62 m above the floor of a 4.8 m (long) x 3.8 m (wide) x 3 m (high) building were measured with a hot-wire anemometer. The isothermal experiment was conducted for 35 inlet conditions in a full-scale slot-ventilated room. The vertical distributions of average time-mean velocity, RMS value, and turbulence intensity are shown at five horizontal positions along the flow direction at the floor. The mean velocity distributions at the mid floor region showed a similar form and approximated a jet profile. At the corners, the main rotary flow was deflected and the small recirculation flows were formed, causing high flow turbulence. Analysis of variance indicated that the same ventilation rates, arising from different combinations of inlet opening height and incoming air velocity, resulted in significantly different velocities in the measurement zone. The reverse flow velocities were not a function of ventilation flow rate alone.

KEYWORDS floor, air movement, mixing ventilation, anemometer

**#NO 7018 The effect of Various Inlet Conditions on the Flow Pattern in Ventilated Rooms - Measurements and Computations.**

AUTHOR Vogel P, Richter E, Rosler M  
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp99-108. in English

ABSTRACT A test room which was built at a scale 1:5 to the original one has been used to investigate air-conditioned rooms. The original room was specified by the international project IEA ANNEX 20. A lot of experiments were made on

different inlet geometries and air change rates. Velocities and turbulent quantities were measured not only in the inlet plan but also in the room itself by means of hot wire anemometry. The ammonia absorption method according to Kruckels has been applied to determine the heat transfer coefficients at the walls. Qualitative results were obtained by laser light sheets. The experimental results serving as boundary conditions and relative values for numerical studies are used to progress the computer code ResCUE developed in Dresden. Further on, the experimental data provide statements on conditions in the occupied zone.

KEYWORDS air inlets, air change rate

**#NO 7960 Methods for investigating indoor air conditions of ventilated rooms.**

AUTHOR Mueller H, Vogel P  
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 1, pp101-108.  
ABSTRACT The acquisition of temperatures and velocities is a permanent recurrent task for the investigation of airflow in ventilated rooms. On the one hand it is important to measure the temperature and velocity field with a high spatial resolution. On the other hand, in general, varying outdoor conditions prevent from reaching a steady state and a additional demand consists in short measuring times. Sometimes, the obtained measuring results are used both to supply appropriate boundary conditions for numerical computations and to verify the CFD-codes used. Therefore, the processing of received data has further importance. In this paper the advantages

and limitations of thermography, the usage of thermocouples and hot wire anemometry for temperature and velocity measurement is discussed. It is shown how the application of modern system components and data post processing in connection with these methods can satisfy better the already mentioned requirement.

KEYWORDS temperature, measurement technique, thermography

**#NO 9854 Maximum velocity of return flow close to the floor in a ventilated room - experimental and numerical results.**

AUTHOR Karimpanah M T, Sandberg M

BIBINF UK, Air Infiltration and Ventilation Centre (AIVC), 1996, proceedings of 17th AIVC Conference, "Optimum Ventilation and Airflow Control in Buildings", Volume 1, held 17-20 September 1996, Gothenburg, Sweden, pp 263-271.

ABSTRACT The problem of sensation of draught in ventilated spaces is connected to inappropriate velocities in the occupied zone. In Scandinavia, velocities higher than 0.15 m/s are said to be an indicator of that occupants are likely to feel discomfort. Therefore knowledge of the flow field (both mean velocities and fluctuations) is necessary. Both experimental and numerical analysis of the flow field in a full scale room ventilated by a slot inlet, with two inlet Reynolds numbers 2440 and 7110, have been carried out. Results from both approaches show that the location of the maximum velocity near the floor is nearly independent of the Reynolds number. For a two-dimensional room, the maximum velocity at the floor level occurred at about 2/3 room length from the supply. The distance from the floor

level is dependent on the inlet Reynolds number. The velocity profiles far away from the wall opposite to the inlet device have the same character as a wall jet profile. However, close to the corners they are transformed. The relative turbulence intensities measured in the return flow region are questionable, because of a hot wire's inability to record large fluctuations at low mean velocities. These turbulence intensities close to floor level vary from 15 to 80% and as the authors have pointed out previously hot wires do not indicate the real value of the turbulence intensities beyond 20%. Difficulties appear in numerical predictions of return flow properties. Comparison between predicted values and experimentally obtained values show a reasonable agreement. This is promising for future CFD-predictions. However, there is a need for an appropriate measurement technique that can cope with reversing flow. KEYWORDS airflow, draughts, human comfort, measurement technique

### ***3.0 Envelope Air Tightness***

#### **3.1 Whole Building Techniques**

**#NO 185 Testing of houses for air-leakage using a pressure method.**

AUTHOR Kronvall J.

BIBINF ASHRAE trans. vol 84 no 1 p 72-79 5 figs, 13 refs. in English

ABSTRACT Describes pressure method for testing whole houses for air leakage. States main advantages compared to tracer gas technique are that equipment is inexpensive, easy to handle and so well adapted to routine tests. The house is pressurized using a powerful fan and the flow through the fan is equivalent to the leakage through the building



envelope at given pressure. Summarizes measurements made on test houses and shows use of thermography to detect leaks. Suggests use of pressure test to estimate the natural ventilation of a house. Gives brief extract from new directions for air-tightness of houses according to the Swedish building code (SBN 1975).

KEYWORDS fan, pressurization, air infiltration, air leakage, thermography, instrumentation, house, building code

**#NO 260 Infiltration - pressurization correlations: detailed measurements on a California house.**

AUTHOR Grimsrud D.T. Sherman M.H. Diamond R.C. et.al.

BIBINF ASHRAE trans. vol.85 no.1 p.851-865, 7 figs, 1 tab, 5 refs, in English

ABSTRACT Describes detailed study of infiltration rates measured with a tracer gas and air leakage rates obtained from fan pressurization in small, 3 - bedroom California house as part of a larger study. Finds surface pressure measurements are an essential step in process of finding a correlation between natural air infiltration and air leakage by pressurization. Measurements also show significant duct leakage and airflow between attic, living space and crawl space. Concludes by listing additional work to be done before it is possible to model adequately infiltration processes in house under investigation.

KEYWORDS fan, tracer gas, air change rate, air infiltration, pressure distribution, nitrous oxide, house, pressurization correlation

**#NO 463 Air leakage measurement of buildings by an infrasonic method**

AUTHOR Card W.H. Sallman A. Graham R.W. Drucker E.E.

BIBINF Dept of Electrical and Computer Engineering, Syracuse University technical report TR-78-1 110p. 28 refs. in English

ABSTRACT Describes an infrasonic method as an alternative to blower method for measuring the composite effective size of all the air-leakage passages of a building. Sinusoidally-varying volumetric flows between 0.05 and 5Hz are generated by a motor-driven bellows-like source located inside the building under test. Resulting pressure variations are measured using a microphone-like sensor having an electronic signal processor. Reports system design and test results obtained to date. One house, five apartment and three interior rooms have been tested. Finds results of infrasonic tests usually agree with results of blower tests within a factor of three.

KEYWORDS alternating pressure, pressurization, air leakage.

**#NO 479 Air leakage in a building at low pressures using an alternating pressure source.**

AUTHOR Grimsrud D.T., Sherman M.H., Sonderegger R.C.

BIBINF Proceedings XXI International Congress for Building Services Engineering 17-18 April 1980 in English

ABSTRACT Reports low-pressure measurements of the leakage function of a building using an alternating (AC) pressure source with variable frequency and displacement. Synchronous detection of the indoor pressure signal created by the source eliminates the noise due to fluctuations caused by the wind. Finds good agreement between AC and DC leakage results in pressure regions where the results can be compared. The low-pressure values made with the AC source suggest that

the airflow is dominated by orifice flow effects down to pressures less than one Pascal.

KEYWORDS pressurization, alternating pressure, air infiltration

**#NO 501 Infrasonic impedance measurement of buildings for air leakage determination.**

AUTHOR Graham R.W.

BIBINF Dept. of Electrical and Computer Engineering, Syracuse University. Technical report TR-77-15 54p 9 refs. in English AICR US8

ABSTRACT Reports preliminary research directed towards developing a new method for measuring the air leakage property of an enclosure. The low-frequency acoustic impedance of the enclosure is measured by an infrasonic method. Describes and analyses a diaphragm-type motor-driven source and a pressure sensor with electronic filters used to measure infrasonic impedance. < Reports tests run in enclosures of different volumes and degrees of leakiness. Compares results with blower tests and finds disagreement of less than 10% for small enclosures, but for larger enclosures results differed by more than a factor of three.

KEYWORDS air leakage, alternating pressure.

NOTES See Card et. al. "Air leakage measurement of buildings by an infrasonic method" abstract no 463 for a final report on this project

**#NO 659 Development of an acoustic method for the determination of the air leakage of building elements installed in a building.**

Entwicklung einer akustischen Messmethode zur Ermittlung der Luftdurchlässigkeit von

**Bauelementen in eingebauten Zustand.**

AUTHOR Esdorn D.E.

BIBINF Kurzber. Bauforsch. vol.19 no.7 1978 p.521-527 3 figs. 1 tab. in German #AIC 314=AIC Translation No.11

ABSTRACT The conduction of sound through the gap between window and wall depends on the width of the gap. This width also determines the air leakage, suggesting that air leakage might be measured by an acoustic method. Notes method requires that cracks are relatively large and have fewer than three kinks. Reports measurements in a wind tunnel of airflow through crack models made from aluminum and compares results with theory. Finds empirical expression relating pressure difference to airflow and gives graphs of results.

KEYWORDS window, joint, air leakage, sound

**#NO 831 Standard practice for measuring air leakage by the fan pressurization method.**

AUTHOR ASTM

BIBINF In:Annual Book of ASTM Standards, part 18, July 1981, p.1-10. in English

ABSTRACT This practice represents a standardized technique for measuring air leakage rates through a building envelope under controlled pressurization or evacuation, and is applicable to small temperature differentials and low-wind pressure conditions. It is primarily intended for use in one- story buildings.

KEYWORDS fan, air leakage, pressurization, low rise building

**#NO 1016 A review of possible techniques to measure ventilation in occupied spaces.**

AUTHOR Sinclair V.J. Croome D.J. O Cathain C.S.

BIBINF School of Architecture and Building Engineering Report, University of Bath April 1982 57pp. 3 tabs. in English

ABSTRACT Reviews current methods of ventilation measurement in occupied buildings including tracer methods, pressurisation, and thermography. Gives criteria for good ventilation rate measurement techniques. Also explores new methods of measuring ventilation rates in occupied buildings. These include:< 1. Use of non-toxic tracers, including negative ions, CO<sub>2</sub> and odour levels< 2. AC pressurisation< 3. The quantification of thermography< 4. Small-scale detection of local air velocities using hot-wire anemometry. KEYWORDS measurement technique, tracer gas, pressurization, anemometer, thermography

**#NO 1340 Calculating infiltration - implications for a construction quality standard.**

AUTHOR Grimsrud D.T. Sherman M.H. Sonderegger R.C.

BIBINF Proc. ASHRAE/DOE Conference "Thermal performance of the exterior envelope of the building II" Dec 6-9 1982 USA p.422-450 9 tabs. 5 figs. 30 refs. in English

ABSTRACT Describes a simple method to calculate the leakage area of a house regardless of design or weather conditions. The leakage area is used in the LBL infiltration model to calculate infiltration for any weather condition. This method, which uses fan pressurization to measure leakage area has been used in a survey of over 300 houses located through out North America. Presents the results of that survey and suggests that the present

capability in air infiltration modelling offers an excellent framework for an air leakage standard for residential buildings. Examples of the interpretation of such a standard are described, based on the ventilation rates adopted in ASHRAE Standard 62-1981. The results of the interpretations illustrate differences in structural requirements that will occur when such a standard is applied to several ventilation system designs.

KEYWORDS air infiltration, modelling, pressurization correlation, air leakage

**#NO 1355 Airflow calibration of building pressurization devices.**

AUTHOR Persily A.K.

BIBINF Preprint ASTM Symposium on measured air leakage performance of buildings Philadelphia USA April 2-3 1984 = NBSIR 84-2849 30pp. 7 figs. 4 tabs. 23 refs. and 5th AIC Conference 'The implementation and effectiveness of air infiltration standards in buildings' Reno, Nevada, 1-4October 1984, pp21.1-21.18 in English

ABSTRACT Describes a calibration technique to relate the airflow rate through a blower door to the fan speed and pressure difference across the door. To obtain an accurate and well-documented calibration of pressurization devices, a facility was designed and constructed at the US National Bureau of Standards. This accurately determines the flow rate through the fan as a function of fan speed, air density and pressure difference across the fan. Describes the calibration facility, presents the results of the calibration of one blower door, and discusses the effect of the form of the calibration equation on the accuracy of the airflow rate determination.

KEYWORDS fan, blower door, pressurization, airflow

**#NO 1398 Natural and mechanical ventilation in tight Swedish homes - measurements and modeling.**

AUTHOR Blomsterberg A. Lundin L.  
BIBINF Preprint ASTM Symposium on measured air leakage performance of buildings Philadelphia USA April 2-3 1984 22pp. in English

ABSTRACT Evaluates results from constant concentration tracer gas measurements and fan pressurization measurements in three houses and predicts ventilation rates for longer time periods using the LBL model. Test results show that the best way of both supplying adequate ventilation and conserving energy is to make sure that the building envelope is sufficiently tight and then install a mechanical ventilation system. Shows that it is possible to correlate fan pressurization measurements and infiltration rates.

KEYWORDS pressurization correlation, tracer gas, constant concentration, house, modeling, air infiltration

**#NO 1853 Accuracy in pressurization data analysis.**

AUTHOR Persily A K, Grot R A  
BIBINF Preprint. ASHRAE Transactions, 1985, Vol 91, Pt 2. 14p. 5 tabs, 18 refs. in English

ABSTRACT Several different ratings of building airtightness are used to report the results of fan pressurization tests. These are generally based on airflow rates at specific reference pressures, predicted by curve fits to the test data. The statistical analysis used to obtain these curves allows estimates of the uncertainties associated with these calculated airtightness ratings. The accuracy of the various ratings of

building airtightness are important issues in airtightness standards enforcement and the evaluation of retrofit effectiveness. The various airtightness ratings being used are presented and the uncertainties associated with these ratings due to measurement errors, fan calibration and test conditions are discussed. Standard statistical techniques are applied to calculate confidence limits for the predicted airflow rates used in the airtightness ratings. Using data from many pressurization tests, several common airtightness ratings are calculated and the predictive uncertainties associated with each are determined. This discussion is based on a data set of pressurization test results in about seventy houses of different sizes, construction, and airtightness, along with detailed measurements made on a single house. The results of this analysis have implications for the reporting of pressurization test results, for their use in models to predict natural infiltration rates, and in the enforcement of airtightness standards.

KEYWORDS pressurization, air tightness, measurement technique

**#NO 1872 AC pressurization: a technique for measuring leakage area in residential buildings.**

AUTHOR Modera M P, Sherman M H  
BIBINF Preprint. ASHRAE Transactions 1985, Vol 91 Pt 2. HI-85-03 No 3. 12p. 4 figs, 2 tabs, 20 refs. in English

ABSTRACT This report presents a new technique for measuring the leakage area of residential buildings. This technique, called AC pressurization, is designed to overcome most of the shortcomings of fan pressurization, the conventional technique for measuring leakage area. The fan pressurization technique (often

performed using a blower door) has several known deficiencies: 1, the pressures it exerts on the building envelope are significantly higher than those experienced under natural conditions, thereby requiring extrapolation outside of the measurement range to calculate the leakage area, 2, it cannot make real-time leakage area measurements, and 3, the large volumes of air displaced by the fan can cause inconveniences such as large indoor temperature changes. AC pressurization, which induces sinusoidal pressure differences across the building envelope, can make real-time leakage measurements at low pressures without inducing large flows through the building envelope. The AC pressurization apparatus and analytical technique, as well as the laboratory measurements that determined the specifications for the field device are described herein. Field measurements of leakage area obtained with the prototype AC pressurization device are compared with those obtained by fan pressurization tests of six single family residences. KEYWORDS alternating pressure, measurement technique

**#NO 1873 Fan pressurization of buildings: standards, calibration, and field experience.**

AUTHOR Gadsby K J, Harrje D T  
BIBINF Preprint. ASHRAE Transactions 1985, Vol 91 Pt 2. HI-85-03 No 1. 10p. 6 figs, 1 tab, 24 refs. in English

ABSTRACT The fan pressurization method has been widely used by groups working with building retrofits and with new construction to evaluate the air tightness of building envelopes. To ensure uniformity in the testing method ASTM Standard E779-81 was

developed. This standard is reviewed with commentary on practical aspects of its application. Calibration of the fan pressurization systems, often referred to as blower doors, is also discussed, pointing out where calibration difficulties have arisen and the implications on field inspections. Use of fan pressurization together with infrared scanning is one of the best methods to pin-point air leakage sites in building envelopes. The applications of such methods in a variety of buildings are discussed in order to demonstrate the utility of the methods in the evaluation of building tightness, including seasonal variations, effectiveness of envelope sealing, and the location of problem areas in the building envelope. KEYWORDS pressurization, measurement technique, standard

**#NO 1952 The prediction of air infiltration.**

AUTHOR Sherman M, Dickinson B  
BIBINF Proceedings of the CLIMA 2000 World Congress on Heating, Ventilating and Air-Conditioning, Copenhagen, 25-30 August 1985. Edited by P Fanger. Vol 2. Building Design and Performance. p1-6. 2 tabs, 3 refs. in English

ABSTRACT Describes a reasonably accurate method for estimating air infiltration for engineers or energy auditors who are not specially trained in infiltration research. The method requires two steps: field measurement of the building properties, and calculation of the infiltration from weather data and the measured properties. Fan pressurization techniques are described and how to use them to measure the air tightness of the building envelope, and the procedures required to make infiltration predictions with the

Lawrence Berkeley Laboratory infiltration model.

KEYWORDS measurement technique, mathematical modeling, prediction, air infiltration

**#NO 2409 Measuring air leakage.**

AUTHOR Uglow C

BIBINF Building Services, Vol 8, No 2, February 1986, p59, 2 figs, 6 refs. in English

ABSTRACT Describes a simple fan pressurisation technique being used at BRE to study the air leakage characteristics of dwellings.

KEYWORDS pressurization technique, air leakage, residential building

**#NO 2640 Low frequency measurement of leakage in enclosures.**

AUTHOR Sherman M, Modera M

BIBINF LBL, Applied Science Div, University of California, March 1986, 10p, 2 figs, 10 refs. in English

ABSTRACT A wide variety of enclosed structures either require or cannot entirely prevent leakage from their interior space to the outside. Existing methods for measuring such leakage have important disadvantages. We have developed a device and technique that permits leakage areas to be measured from within or without the enclosure without causing unacceptable disturbance. The apparatus uses low-frequency (1 Hz) acoustic monopoles to generate an internal pressure signal which is then analyzed synchronously to provide a measurement of leakage area. We have successfully applied this technique to measuring air tightness in residential houses, and believe it can be easily adapted for use in field, laboratory, or classroom applications. We are currently evaluating why the values we obtained were, on average,

14% lower than those obtained through conventional methods and we are investigating the apparent inability of the device, as presently designed, to measure large leaks.

KEYWORDS air leakage, measurement technique, sound, leakage area

**#NO 2889 Standard test method for determining air leakage rate by fan pressurization.**

AUTHOR ASTM

BIBINF ASTM Designation E779-99, 6p, 3 figs. in English

ABSTRACT This test method describes a standardised technique for measuring air leakage rates through a building envelope under controlled pressurization and de-pressurization. It is applicable to small temperature differentials and low wind pressure conditions. The test method consists of mechanical pressurization or de-pressurization of a building and measurements of the resulting airflow rates at given indoor-outdoor static pressure differences. From the relationship between the airflow rates and pressure differences, the air leakage characteristics of a building envelope can be evaluated.

KEYWORDS standard, air leakage, fan depressurization

**#NO 3124 Analysis of errors for a fan-pressurization technique for measuring interzonal air leakage.**

AUTHOR Herrlin M K, Modera M P

BIBINF in: " Effective Ventilation", 9th AIVC Conference, Gent, Belgium, 12-15 September 1988. in English

ABSTRACT The problem of predicting airflows in a multi-zone building has received considerable attention in the past ten years. An important issue identified by this work was the lack of reliable measurements of the flow

resistances between the zones of such buildings. This report analyzes the uncertainties associated with a fan-pressurization technique for measuring the inter-zonal leakage (inverse flow resistance) in a multi-zone building. The technique involves two blower doors, one in each of the two zones between which the leakage is being measured. The evaluation of the technique is based upon simulations using MOVECOMP, a multizone infiltration and ventilation simulation program, which is used to determine what data would be recorded when using the procedure in a multi-family building under typical wind conditions using typical fan pressurization equipment. These simulations indicate that wind-induced uncertainties in the determined leakage parameters do not exceed 10% for wind speeds lower than 5 m/s, but that pressure and flow measurement uncertainties raise leakage parameter uncertainties above 40% at any wind speed. By performing additional simulations, the sensitivity of our results to the subtleties of the measurement protocol and the assumed test conditions are examined. These examinations highlight the importance of using an appropriate reference for the pressure difference across the primary-zone envelope, as well as the importance of improving the precision of this measurement.

**KEYWORDS** fan pressurization, air leakage, blower door

**#NO 3361 Signal attenuation due to cavity leakage.**

**AUTHOR** Sherman M H, Modera M P  
**BIBINF** Journal of the Acoustic Society of America, Vol 84, No 6, December 1988, pp2163-2169, 3 figs, 1 tab, 19 refs. in English

**ABSTRACT** The propagation of sound waves in fluids requires information about three properties of the system: capacitance (compressibility), resistance (friction), and inductance (inertia). Acoustical design techniques to date have tended to ignore the frictional effects associated with airflow across the envelope of the acoustic cavity (e.g., resistive vents). Since such leakage through the cavity envelope is best expressed with a power law dependence on the pressure, standard Fourier techniques that rely on linearity cannot be used. In this article, the theory relevant to nonlinear leakage is developed and equations presented. Potential applications of the theory to techniques for quantifying the leakage of buildings are presented. Experimental results from pressure decays in a full-scale test structure are presented and the leakage so measured is compared with independent measurements to demonstrate the technique.

**KEYWORDS** cavity, air leakage, sound

**#NO 4787 Airtightness in buildings.**

**Permeabilite a l'air des batiments.**

**AUTHOR** Riberon J, Bienfait D, Chandellier J  
**BIBINF** "Ventilation et Renouvellement d'Air dans les Batiments", AIVC/AFME Workshop, held 18-22 March 1991, Lyon, France, 10pp, 5 figs, refs. in French

**ABSTRACT** Air leakage through a building envelope can disrupt the intended operation of heating and ventilating. In view of the high stakes, research work was conducted at the CSTB into air infiltration in buildings. They involved improvement in heat loss calculation due to cross ventilation and development of air leakage measurement methods. Using computer code which

includes climatic data, a new way of calculating cross ventilation flow rate was derived. Cross ventilation heat losses do not only depend on flow rate through the building envelope (air leakage and air inlets) but also on flow rate due to ventilation system operation. They are decreasing when the negative pressure inside the building, caused by the operation of the ventilation system, is increasing. A guideline which describes how to determine the airtightness of a building by using the fan pressurisation method has been carried out. The test method is suitable for research work or field investigations. In order to extend its field of application to building inspection, a simplified method has been added. Studies have also been undertaken in order to get a better understanding of the technical basis which are aimed at reducing air leakage in dwellings, specifying airtightness levels and assessing the technical implementations with regard to these levels.

**KEYWORDS** air tightness, air leakage, cross ventilation, measurement technique

**#NO 4915 Determination of leakages in the building envelope using pressurization test measurements.**

**AUTHOR** Jensen L

**BIBINF** Air Infiltration Review, Vol 7, No 4, August 1986, pp 6-8, 3 figs, 2 tabs, 1 ref. in English

**ABSTRACT** There are several methods by which the airtightness of a building can be measured. One method involves the use of a fan to pressurize or depressurize the building. This creates a known pressure difference across the building envelope. The corresponding airflow through the fan is measured and this is an indication of the airtightness of

the building. This airflow rate can be expressed as the number of building air changes per hour, a useful unit when comparing buildings of different volumes. So far only simple methods have been employed to analyze this condition. However, it is possible to use a more strict scientific approach based on mathematical models and known parameter identification methods. These techniques are described in this article.  
**KEYWORDS** air leakage, building envelope, pressurization

**#NO 4926 AC pressurisation model tests.**

**AUTHOR** Sutcliffe H, Waters J R  
**BIBINF** Air Infiltration Review, Vol 9, No 4, August 1988, pp 12-15, 6 figs, 1 tab, 2 refs. in English

**ABSTRACT** Leakage area measurement by fan pressurization becomes more difficult as the volume of a building is increased. The equipment becomes bulky, and measurements of airflow through the fan and the resulting pressure differential require more care. AC pressurization offers an attractive alternative. However, in the case of large industrial buildings, the exterior envelope is often constructed of thin flexible sheet material, and also industrial leakage paths may have a much larger area than is found in, say, typical domestic construction. Thus the inertance effect described by Card et al (1) and the flexing constant described by Sherman (2) may be particularly important. In order to explore these problems, tests are being carried out on a laboratory model. This note reports the results of the first sets of measurements.  
**KEYWORDS** pressurization, testing chamber



**#NO 10107 Uncertainties in fan pressurization measurements.**

AUTHOR Sherman M, Palmiter L  
BIBINF in: Airflow performance of building envelopes, components and systems, USA, ASTM 1995, papers presented at a symposium held in Dallas, Texas, 10-11 October 1993, pp 266-283.  
ABSTRACT The ASTM Method for Determining Air Leakage Rates by Fan Pressurization Test (E 799-87) measures the airtightness of building envelopes using fan pressurization. Uncertainty is introduced in the process from the uncertainty of the airflow and pressure measurements as well as from nonlinearities in the system to be measured. This paper analyses the precision and bias associated with making a measurement using E 779 in typical field situations. Model specification (or modelization) errors may also contribute significantly to the overall uncertainty in the estimates of the 4 Pa leakage, the sources and sizes of these modelization errors interact with the instrumentation errors in making a fan pressurization test. Insufficient field data exist to fully include the effects of modelization and other low-pressure phenomena, but the current standard can nevertheless be improved by tightening the instrumentations and procedural specifications and by judicious choice of pressure measurement stations.  
KEYWORDS building envelope, air leakage, airflow

**#NO 11734 Thermal insulation - determination of building airtightness - fan pressurization method. ISO 9972.**

AUTHOR Anon  
BIBINF ISO, 1996, 10 pp.  
ABSTRACT The fan pressurization method produces a result that

characterizes the airtightness of the building envelope or parts thereof. It can be used: to compare the relative airtightness of several similar buildings or building components, to identify the leakage sources and rates of leakage from different components of the same building envelope, to determine the air leakage reduction for individual retrofit measures applied incrementally to an existing building or building component. This method does not measure the air infiltration rate of a building. The results of the fan pressurization test can be used to estimate the air infiltration by means of calculation. If a direct measurement of the air infiltration is desired, other methods must be used. It is better to use the fan pressurization method for diagnostic purposes and measure the absolute infiltration rate with the tracer dilution method.

KEYWORDS standard

**Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method, CAN/CGSB-149.10-M86**

AUTHOR CGSB  
BIBINF Canadian General Standards Board, 1986  
ABSTRACT This is a method for the determination of the airtightness of building envelopes. It is not a method for determining the actual air leakage which occurs through a building envelope under the influence of wind and buoyancy pressured or the operation of heating and ventilation systems. The method is applicable to small detached buildings (especially houses) but with appropriate modifications, it can also be used for other buildings or parts of buildings.

**Determination of the Overall Envelope Airtightness of Buildings by the Fan Pressurization Method using the Building's Air Handling System, CAN/CGSB-149.15**

AUTHOR CGSB

BIBINF Canadian General Standards Board, 1996

ABSTRACT This is a method for the determination of the air tightness of building envelopes. It is not a method for determining the actual air leakage which occurs through a building envelope under the influence of wind and buoyancy pressures or the operation of heating and ventilation systems. The method is applicable to small detached buildings (especially houses) but with appropriate modifications, it can also be used for other buildings or parts of buildings.

**ASHRAE Standard 62, Air Leakage Performance for Detached Single-Family Residential Buildings**

AUTHOR ASHRAE

BIBINF ASHRAE, 1989

The purpose of this standard is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to minimize the potential for adverse health effects.

**ASHRAE Standard 119, Air Leakage Performance for Detached Single-Family Residential Buildings**

AUTHOR ASHRAE

BIBINF ASHRAE, 1988

The purpose of this standard is to establish performance requirements for air leakage of residential buildings to reduce the air infiltration load.

**ASHRAE Standard 136, A Method of Determining Air Change Rates in Detached Dwellings**

AUTHOR ASHRAE

BIBINF ASHRAE, 1993

ABSTRACT The purpose of this standard is to provide a procedure for determining effective outdoor air change rates in detached dwellings. This procedure is intended for use in evaluating the impact of these air change rates on indoor air quality.

**3.2 Techniques for Multizone and Large Buildings**

**#NO 653 Automated air infiltration measurements in large buildings.**

AUTHOR Grot R.A. Hunt C.M. Harrie D.T.

BIBINF A.I.C. Conference

"Instrumentation and measuring techniques." Windsor 6-8 October 1980, 22p. 9 figs. in English AIC

ABSTRACT Describes an automated air infiltration measurement system for large buildings. The system consists of a micro-computer, electron capture gas chromatograph, a ten port sampling manifold, and five tracer gas injection units. The system controls the injection and sampling of tracer gas in a multi-zone building, calculates the air infiltration rates of each zone, and measures the duration of events such as HVAC fan operation, exhaust fan operation and door/window openings. The measurements also include such analog variables as interior and exterior temperatures, wind speed, wind direction and pressure differentials across the building envelope. The data collected by the system will allow the determination of the relative importance of air leakage and forced ventilation to the energy requirements of the building as well as evaluating the influence of meteorological conditions, HVAC fan

operation, exhaust fan operation and exterior building pressure on the air leakage.

KEYWORDS tracer gas, automatic equipment, sulphur hexafluoride, constant concentration, instrumentation

**#NO 1062 Occupant-generated CO<sub>2</sub> as an indicator of ventilation rate.**

AUTHOR Turiel I. Rudy J.V.

BIBINF Preprint ASHRAE Transactions vol.88 no.1 1982 12pp. 4 figs. 1 tab. 11 refs. in English

ABSTRACT Reports on 2 methods of measuring ventilation rates in the 8-storey San Francisco Social Services Building, using occupant-generated CO<sub>2</sub> as a tracer gas. Measures CO<sub>2</sub> concentration at regular intervals on the first floor using an infra-red gas detector. Uses the tracer gas decay method and the constant concentration (integral) method to determine ventilation rates. Finds that the CO<sub>2</sub> decay method compares favourably with both SF<sub>6</sub> tracer gas measurements and with air-flow measurements in the ducts. The integral method of determining ventilation rate is satisfactory when the system is circulating outside air, but it overestimates the ventilation rate when air is recirculated, because of the presence of CO<sub>2</sub> gradients. When outside air ventilation rates are low, CO<sub>2</sub> concentration rises and the CO<sub>2</sub> decay method is more easily applied.

KEYWORDS tracer gas, carbon dioxide, decay rate, constant concentration, high rise building

**#NO 1253 Ventilation measurements in large buildings.**

AUTHOR Freeman J. Gale R. Lilly J.P.

BIBINF 4th AIC Conference "Air infiltration reduction in existing buildings" Switzerland, 26-28

September 1983 p.5.1-5.14 6 figs. 2 refs. in English

ABSTRACT Compares and contrasts different methods of ventilation measurement in large buildings. Conventional methods of using tracer gas to measure ventilation rates in large volumes are cumbersome and expensive. These constant concentration and decay measurements require artificial mixing, complex monitoring equipment and large installation costs. By using discrete injection and sampling units, long term samples of tracer gas be collected with the minimum of capital and installation costs. Samples collected represent the mean local equilibrium tracer gas concentrations. Finds the method to be a useful measure of ventilation rate but increasing problems are found with increase of measured volume requiring greater attention to thorough mixing of the atmosphere and injection sample bag positioning.

KEYWORDS tracer gas, measurement technique, constant emission

**#NO 1276 Air leakage in industrial buildings - preliminary results.**

AUTHOR Lundin L.

BIBINF 4th AIC Conference "Air infiltration reduction in existing buildings" Switzerland, 26-28 September 1983 p.6.1-6.8 5 figs. 1 ref. in English

ABSTRACT Describes pressurization tests conducted by the National Testing Institute on 3 large industrial buildings. Sets out equipment and methods used including a tracer gas method to calculate airflow through the fan rather than the usual measuring duct. Gives construction and volume details of buildings measured.

KEYWORDS industrial building, air leakage, pressurization, fan, tracer gas, instrumentation, measurement technique

**#NO 1386 The measurement of air infiltration in large single cell industrial buildings.**

AUTHOR Waters J.R. Simons M.W.  
BIBINF Preprint ASTM Symposium on measured air leakage performance of buildings Philadelphia USA April 2-3 1984 23pp. 7 figs. 4 tabs. in English  
ABSTRACT Carries out measurements of the air infiltration rate of 3 large single cell buildings using the tracer dilution method. The purpose is to determine whether or not there are any special difficulties in using the tracer dilution method in this type of building, prior to embarking on a more substantial measurement program. Uses nitrous oxide and sulphur hexafluoride as tracers. Finds both to be satisfactory, but concludes that SF6 in conjunction with a portable gas chromatograph performs more reliably when used for on-site measurements.

KEYWORDS tracer gas, decay rate, sulphur hexafluoride, nitrous oxide, air infiltration

**#NO 1513 Application of the constant concentration technique for ventilation measurement to large buildings.**

AUTHOR Etheridge D W.  
BIBINF SERC Workshop on Ventilation, Coventry Polytechnic, 25-26 October 1984, 16pp, 6 figs. in English Rev. version BSERT, Vol 6, No 3, 1985. p129-133

ABSTRACT The British Gas 'Autovent' system utilises the constant concentration technique and was developed for measuring ventilation rates in dwellings. It has recently been

used in two large open-plan buildings, a school nursery and a factory unit, and the opportunity was taken to carry out special tests to assess its validity in such buildings. The reason why these tests were needed, the nature of the tests and the results obtained form the main content of the paper. The evidence from the tests strongly indicates that the system is suitable. This evidence is supported by the ventilation measurements themselves, examples of which are presented.

KEYWORDS school, factory, ventilation, constant concentration, measurement technique

**#NO 1809 The reduction of air infiltration in an industrial laboratory.**

AUTHOR Lilly J P, Gale R  
BIBINF 6th AIC Conference "Ventilation Strategies and Measurement Techniques", Het Meerdal Park, Netherlands, 16-19 September 1985. Bracknell, UK: Air Infiltration Centre, 1985. p10.1-10.11. 4 figs, 1 tab, 8 refs. in English AIVC bk

ABSTRACT As part of a programme to develop measurement methods for determining the ventilation rates of large buildings, two series of tests were performed in a single-celled laboratory with a volume of 600 m3. The first series utilised constant concentration, constant emission and decay rate tracer gas techniques to determine the characteristics of the infiltration pattern in varying winds and external temperatures. Both discrete and continuous injection and sampling methods were used. Pressurisation techniques were employed to determine the overall leakage of the building and the spatial distribution of the leaks with flow visualisation methods. The building

was then draught proofed with commonly available materials and techniques before further pressurisation tests and thorough ventilation measurements were undertaken. The experiment thus provided detailed comparisons of ventilation measurement methods and detailed performance characteristics of the building envelope in two states of leakiness. The interaction between the changed leakage characteristics and the measurement methods is discussed together with a critical evaluation of the measurement methods themselves.

KEYWORDS measurement technique, tracer gas, constant concentration, constant emission, decay rate, pressurization

**#NO 1816 Continuous air renewal measurements in an occupied solar office building.**

AUTHOR Scartezzini J-L, Roecker C, Quevit D

BIBINF Paper presented at CLIMA 2000, Copenhagen, August 1985.

Rapport No. 85-01-03. Ecole Polytechnique Federale de Lausanne. 5p. 4 figs, 12 refs. in English

ABSTRACT A Compact Equipment for Air Renewal Survey (CESAR) has been developed by the Ecole Polytechnique Federale de Lausanne. The device has been designed for simultaneous analysis of up to 10 different inhabited rooms over extended periods of time (days or weeks). The constant concentration tracer gas technique was used for the first survey done in the South rooms of the LESO building. Mean outdoor to room flow rates of between 1 and 40 m<sup>3</sup>/h were found. The mean building to room airflow was found to be 5 m<sup>3</sup>/h for rooms with only one communicating door with the rest of the building. A

second survey, performed a year later in 1984/85, showed an increase in building to room airflows within the range of 11 to 45%, due to occupancy effects.

KEYWORDS air change rate, measurement technique, tracer gas, multi-chamber, constant concentration, air movement, office

**#NO 1819 Continuous air infiltration measurements in the LESO.**

AUTHOR Quevit D, Roecker C

BIBINF Paper presented at INTERSOL 85, Montreal. Rapport No 85-01-10.

Ecole Polytechnique Federale de Lausanne, June 1985. 5p. 4 figs, 3 refs. in English

ABSTRACT The total air infiltration rates can be determined by the tracer gas decay method, but to measure the influence of inhabitants or convective exchanges between rooms, the constant concentration method is more suitable. In order to measure these effects, the Compact Equipment for Survey of Air Renewal (CESAR), developed at the LESO, was used to perform an air exchange analysis on data recorded at regular intervals in up to 10 locations simultaneously. Three tracer gas methods were implemented: decay, constant concentration and continuous flow. Successful continuous measurements were worked out in 10 locations and the exchange flow rates and occupancy effects were measured by the constant concentration method.

KEYWORDS air change rate, measurement technique, tracer gas, constant concentration, multi-chamber, office, decay rate, constant emission, occupancy effects

**#NO 1820 Air change rate measurements in the Roulet villa at Apples.**

**Mesure du taux de renouvellement d'air dans la villa Roulet a Apples.**

AUTHOR Roulet C-A, Scartezzini J-L  
BIBINF Rapport No 84-01-10. Ecole Polytechnique Federale de Lausanne, Groupe de Recherches en Energie Solaire, 16 November 1984. 65p. figs, tabs, 3 refs. in French

ABSTRACT The air change rate and the volume of heated air of the villa were measured by the constant concentration tracer gas method during a period of 11 days. The total volume of the villa is 1000 m<sup>3</sup> and the heated volume 530 m<sup>3</sup>. It is built on six half-levels. The occupants continued their normal lifestyle during the measurements. The Compact Equipment for Survey of Air Renewal (CESAR) was used with nitrous oxide as tracer gas at a concentration of 100 ppm. The mean global air change rate was 0.50/h. The rate rose to 0.56 if a bedroom window at the top of the building was open, and fell to 0.37 when all the windows were shut. KEYWORDS air change rate, constant concentration, tracer gas, nitrous oxide, terraced house, measurement technique

**#NO 2683 Measurements of infiltration and air movement in five large single-cell buildings.**

AUTHOR Lawrence G V, Waters J R  
BIBINF 8th AIVC conference 'Ventilation Technology - Research and Application', 21-24 September 1987, Ueberlingen, West Germany, Proceedings, AIVC 1987, p2.1-2.18, 4 figs, 5 tabs, 6 refs. in English  
ABSTRACT A six channel, computer controlled, tracer gas detection system for the measurement of infiltration rates and air movement in large single-cell industrial buildings has been designed, constructed and calibrated. This has been used for over 50 sets of tracer decay

measurements in five single-cell buildings ranging in size from 4000 to 31000 m<sup>3</sup>. The buildings included a sports hall, a vehicle maintenance depot, two factory workshops and an aircraft hangar. Infiltration rates and interzonal flows were derived from the tracer curves using methods based on multizone theory. The analysis method includes a specially developed, constrained least squares technique which gives both infiltration rate and internal flow rates. The equipment and method of analysis are briefly described, and results for each data set presented. A comparison of infiltration rates, derived from interzonal flows and from averaged tracer decay data is also given. In addition examples are given of comparisons between measured decay curves and theoretical decay curves reconstructed from measured flow rates. Finally inconsistencies in the data and the model are discussed, together with suggestions for improvements to the experimental technique and the method of analysis.

KEYWORDS measurement technique, industrial building, large building, sports building, hangar, factory

**#NO 2718 The measurement of ventilation and air movement in factory buildings.**

AUTHOR Simons M W, Waters J R  
BIBINF in: Third International Congress on Building Energy Management, III Ventilation, air movement and air quality: field measurement and energy auditing, held in Lausanne, Switzerland, September 28- October 2, 1987, p154-161, 3 figs, 10 refs. in English  
ABSTRACT The majority of factory buildings may be considered as large single-cell structures. In order to measure the air infiltration

characteristics of such buildings, it has been found necessary to consider air movement patterns within them. The simultaneous consideration of both air infiltration and internal air movement has the added advantage that the dispersal of air-borne contaminants within the factory can also be studied. Using multi-zone air movement theory, in which one zone represents the outside air, air exchange between the inside and the outside and between internal zones may be measured and evaluated. The equations governing flows in the multi-zone model are well known. Application of these equations to multi-zone tracer decay measurements has shown how it is possible to: 1. determine the best initial distribution of the tracer gas, i.e. the most advantageous seeding strategy, 2. avoid inaccurate results due to ill conditioning or linear dependence, 3. maximise the information that can be obtained from a set of measured data. An automated tracer gas monitoring system has been designed and built. The system is being used to measure air infiltration and air movement in a range of large single cell buildings, most of which are factories. The objective is to gain experience of the operation of the equipment, to refine data analysis techniques, and to provide a data bank as a basis for further developments of the theory.

**KEYWORDS** factory, air movement, pollutant, tracer gas measurements, large building

**#NO 2642 A multiple tracer gas technique for the measurement of air movements in industrial buildings.**

**AUTHOR** Niemela R, Toppila E, Tossavainen A

BIBINF Roomvent 87, proceedings, Stockholm 10-12 June 1987, 19p, 4 figs, 2 tabs, 5 refs. in English

**ABSTRACT** This paper deals with a multiple tracer gas measurement system suitable for characterization of airflow patterns and ventilation effectiveness in large industrial premises and commercial structures. The highly automated system consists of a multipoint sampling unit, an IR-analyser and a microcomputer. Up to now, nitrous oxide, dichlorodifluoromethane and carbon dioxide have been used as tracers. The method was applied to study the distribution of the supplied air and the cleaned recirculated air in a finishing department of a steel foundry.

**KEYWORDS** tracer gas, carbon dioxide, nitrous oxide, industrial building, commercial building

**#NO 2880 Approaches to estimating airflows in large multi-family buildings.**

**AUTHOR** Bohac D L

BIBINF Ashrae Trans, Vol 93, Part 1 1987, p1335-1358, 8 figs, 6 tabs, 19 refs. in English

**ABSTRACT** Air infiltration can account for a significant part of the heat loss in multifamily buildings. Its magnitude, however, is difficult to determine. In the absence of a central ventilation system, pressurization tests of the whole building are virtually impossible and one-chamber tracer gas measurements become inapplicable. Heating-season-average air infiltration rates can be estimated indirectly by comparing energy consumption data with engineering models of heat loss. However, a large uncertainty is associated with this estimate. We describe various pressurization and tracer gas techniques for characterizing

airflows in large multifamily buildings. We applied a number of these techniques to a six-story apartment building. Single and multizone fan pressurization methods enable the measurement of leakage areas of apartments to the outside and to other interior spaces. Single-zone fan pressurization at the apartment building showed that the apartments were relatively tight, with leakage areas dominated by the building's many open windows. Constant-injection tracer gas techniques allow measurement of airflows in the building's vertical shafts, which are likely to be stack dominated. Constant-injection measurements were used to estimate areas in the stairwell. Three variations of the constant-concentration tracer gas technique can be used to measure outside airflows into individual apartments and allow certain interzone airflows to be estimated. These techniques applied to the apartment building showed that apartments exchange air primarily with the outside at rates depending heavily on window openings.

**KEYWORDS** multifamily building, heat loss, energy consumption, pressurization testing, tracer gas measurements, apartment building, fan, constant concentration, window opening

**#NO 3423 Tracer gas measurement systems compared in a multifamily building.**

**AUTHOR** Harrje D T, Dietz R N, Sherman M, Bohac D L, D'Ottavio T W, Dickerhoff D J

**BIBINF** USA, Princeton University, 21p, 8 tabs, 7 figs, 9 refs. in English

**ABSTRACT** The more complex building poses additional challenges to air infiltration measurement, especially the case of multiple zones and rooms.

Today's technology has provided us with a number of measurement choices which include: the constant concentration single tracer gas system, multi-tracer gas systems using the mass spectrometer, and perfluorocarbon multi-tracer systems both passive and active. This paper will compare simultaneous field measurements in a Princeton area multifamily building using each of these tracer-gas based air infiltration systems. Personnel from Princeton University, Lawrence Berkeley Laboratory, and Brookhaven National Laboratory were involved in the air infiltration measurement studies. Air infiltration rates in the various zones in each building are compared as well as the ease of implementation of the various approaches in these comprehensive measurements. Sources of errors using the various techniques also will be discussed.

**KEYWORDS** airflow, infiltration, tracer gas, measurement technique

**#NO 3581 Comparison of air infiltration rate and air leakage tests under reductive sealing for an industrial building.**

**AUTHOR** Jones P J, Powell G

**BIBINF** in:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28 September 1989, Volume 2, February 1990, pp131-152, 14 figs, 5 tabs, 2 refs. in English

**ABSTRACT** The paper compares air infiltration rate measurements with air leakage measurements in a modern industrial building. In each case the tests have been performed firstly with the building "as-built", and then with the major leakage components sealed. The building investigated was of a cladding wall construction with U-values of 0.6 W.m<sup>-2</sup>.K<sup>-1</sup> for both the walls and roof.



It had a floor area of 466 m<sup>2</sup>. The volume was 3050 m<sup>3</sup>. Tracer decay tests and constant concentration methods (both using N<sub>2</sub>O) were performed in the building to establish the air infiltration rates. The air leakage of the building was determined by the fan pressurisation method. The paper presents the results of the measurements and the discussion focuses on the variations of the air infiltration rate due to changes in internal and external conditions. The results from the three different techniques used are compared. The results show that there was good agreement between the tracer decay and constant concentration methods when determining the air infiltration rate. There was also good agreement under reductive sealing between the reductions in measured air infiltration rate and measured air leakages. The paper is a result from research work funded by the Building Research Establishment to investigate air infiltration rates and air leakage rates in industrial buildings. KEYWORDS industrial building, infiltration rate, air leakage, retrofitting, fan pressurisation

**#NO 3648 Use of BREFAN to measure the airtightness of non-domestic buildings.**

AUTHOR Perera M D A E S, Stephen R K, Tull R G  
BIBINF UK, Watford, BRE Information Paper, 6/89, April 1989, 3pp, 5 figs, 1 tab, 9 refs. in English  
ABSTRACT BREFAN is a fan "pressurization" rig designed to carry out air leakage test on the whole building envelope of most non-domestic buildings, like office and hangars. This paper describes field measurements with BREFAN in two office buildings and shows how a "leakage" index can be

evaluated and then used as a diagnostic measure of the constructional quality of the external fabric of the building. BREFAN provides a BREFAN measurement service to other organizations, and this paper will be of interest to architects, builders, building services engineers, surveyors and others concerned with the provision and control of ventilation in buildings.

KEYWORDS measurement technique, air tightness, office building, hangar

**#NO 4164 BREFAN - a diagnostic tool to assess the envelope air leakiness of large buildings.**

AUTHOR Perera M D A E S, Tull R G  
BIBINF Netherlands, International CIB W67 Symposium, "Energy, Moisture and Climate in Buildings", 3-6 September 1990, Rotterdam, p II 12, 3 figs, 8 refs. in English  
ABSTRACT A major factor in the ventilation of buildings and their energy performance is the leakiness of the building envelope. In some circumstances, the adventitious leakage through the building fabric is a source of excessive ventilation which can lead to energy waste and, in some cases, to discomfort. The air leakiness of the building envelope can be determined by carrying out whole-building leakage tests. BREFAN is a fan "pressurisation" rig designed for such tests in most non-domestic buildings. The measurements so obtained can be used to quantify the variation of air leakage through the fabric as a function of the applied pressure differential across the envelope. A "leakage" index can also be evaluated and used as a diagnostic measure of the constructional quality of the external fabric. This paper gives results from field measurements in five large buildings in the UK. Measurements in

two office buildings show that the external envelope of one specifically designed and constructed as a low-energy office (LEO), is twice as tight as the other built in a more conventional manner. Comparison with buildings tested in North America shows that the LEO is as tight as those. Measurements in two old, industrial "hangar" buildings are compared with one built within the last decade under current UK Building Regulations. Although the leakage index shows the new building to be only half as leaky as the old, comparison with tight Swedish industrial buildings shows that a further fivefold reduction is possible. Finally, tests in a large Law Court building are briefly described to show how BREFAN can be used as a diagnostic tool in a more qualitative manner. By depressurising the building, a possible cause for complaints of insufficient internal heating during cold weather was traced to excessive air leakage through the roof.

KEYWORDS air leakage, large building, building envelope, fan

**#NO 5267 The reliability of infiltration and air movement data obtained from single tracer gas measurements in large spaces.**

AUTHOR Sutcliffe H, Waters J  
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 1, pp 387-410. in English

ABSTRACT The methods available for the measurement of air infiltration and air movement in large industrial halls are restricted by the size of the building and the nature of the operations which take place within it. Single tracer decay measurements are the easiest to perform

and this paper examines the possibility of extracting useful information from them. Using a multi-zone representation of the building volume, the properties of tracer decay curves are considered, and the ease of extraction infiltration and airflow data examined by means of simulations. The results show how the error in the derived infiltration rates grow with error in the tracer gas concentration measurements for various methods of treating the results. The simulations are compared to the results of measurements made in a typical industrial hall. Despite the shortcomings of the multi-zone model and the single tracer decay method, it appears possible to obtain reasonable results for the overall air infiltration rates.

KEYWORDS tracer gas measurements, large building, multizone

**#NO 5700 Use of BREFAN to measure the airtightness of non-domestic buildings.**

AUTHOR Perera M D A E S, Stephen R K, Tull R G

BIBINF UK, Building Research Establishment, 1P 6/89, April 1989, 4pp, 5 figs, 1 tab, 9 refs. in English

ABSTRACT BREFAN is a fan 'pressurisation' rig designed to carry out air leakage tests on the whole building envelope of most non-domestic buildings, like offices and hangars. This paper describes field measurements with BREFAN in two office buildings and shows how a 'leakage' index can be evaluated and then used as a diagnostic measure of the constructional quality of the external fabric of the building. BRE provides a BREFAN measurement service to other organizations, and this paper will be of interest to architects, builders, building service engineers, surveyors and others concerned with the

provision and control of ventilation in buildings.

KEYWORDS fan pressurization, air tightness, air leakage, building envelope, office building, hangar

**#NO 11930 The principles of a homogeneous tracer pulse technique for measurement of ventilation and air distribution in buildings.**

AUTHOR Stymne H, Boman C A  
BIBINF in: UK, Air Infiltration and Ventilation Centre, proceedings of "Ventilation Technologies in Urban Areas", 19th Annual Conference - Supplement, held Oslo, Norway, 28-30 September 1998.

ABSTRACT The principles of a new tracer gas technique is described in the paper. The new technique involves pulse injection of tracer gas and has the same advantages as the previously known homogeneous emission technique. It can for example advantageously be used in large buildings and buildings with many rooms and yields information on the distribution of ventilation air within the building. However, contrary to the homogeneous emission technique, yielding the average ventilation performance during an extended time, the new technique allows measurement during short term periods. The new technique is based on homogeneous pulse injection, which means that pulses of tracer gas are injected in each zone in a zone-divided building, with amounts which are proportional to the zone volumes and integrating sampling of tracer gas concentration. Theoretical and practical aspects of the technique are described.

KEYWORDS tracer gas, air distribution

**#NO 12566 Protocol for field testing of tall buildings to determine envelope air leakage rate.**

AUTHOR Bahnfleth W P, Yuill G K, Lee B W  
BIBINF USA, ASHRAE Transactions, Annual Meeting 1999, Seattle, 12 pp, 6 figs, 6 tabs, refs.

ABSTRACT The objective of this project was to develop a relatively simple, accurate method for testing the overall envelope leakage rate of tall buildings. Two fan pressurisation test techniques, the floor-by-floor blower door method and the air handler methods, were developed and tested on two buildings. Criteria for conducting accurate tests were developed, including limitations on outdoor air temperature and wind speed. The floor-by-floor blower door method permits isolation and is difficult and time-consuming to apply. The air-handler method uses building air distribution fans for pressurization. It is most easily applied on a system-by-system level rather than floor-by-floor. Fan airflow techniques including orifice plate, pitot traverse, and tracer gas dilution were considered. The tracer gas method was found to be relatively easy to apply and highly accurate. Fan airflow rate measurement uncertainty by tracer gas was estimated to be 5.4% to 8.8% for the cases considered, assuming a 5% uncertainty in interzonal leakage.

KEYWORDS air leakage rate, building envelope, tall building

### **3.3 Component Leakage Techniques**

**#NO 41 Air infiltration measurements in a four-bedroom townhouse using sulphur hexafluoride as a tracer gas.**

AUTHOR Hunt C.M. Burch D.  
 BIBINF ASHRAE transactions 1975,  
 81, part 1. 186-201, 5 figs, 4 tabs, 18  
 refs. in English  
 ABSTRACT Reports measurements in  
 title. House was contained in  
 environmental chamber with control  
 over inside and outside temperature with  
 essentially no wind velocity. Observes  
 familiar correlation between inside-  
 outside temperature difference and  
 infiltration rate, and effect of sealing  
 doors and ducts under conditions of  
 negligible wind velocity. Compares  
 different methods of collecting air  
 samples for analysis and compares SF<sub>6</sub>  
 measurements with air exchange rates  
 imposed on the house by means of a  
 centrifugal blower.  
 KEYWORDS air infiltration, tracer gas,  
 sulphur hexafluoride, house, component  
 leakage

**#NO 175 The testing of whole houses  
 for air leakage.**

AUTHOR McIntyre I.S. Newman C.J.  
 BIBINF Building Research  
 Establishment note. 21/75. 5 figs. 1 ref.  
 in English.  
 ABSTRACT Describes portable air  
 leakage apparatus capable of measuring  
 the air infiltration of whole dwellings  
 directly on site by the pressure method.  
 Main assembly consists of a flow  
 measurement duct and electric fan.  
 Describes test procedure and gives air  
 leakage curves for an ordinary semi-  
 detached house and an experimental  
 house. Finds that doors and windows  
 account for a surprisingly small  
 proportion of total leakage.  
 KEYWORDS air infiltration, fan,  
 component leakage, pressurization,  
 house.

**#NO 1100 Simple method of  
 measuring airtightness of windows.  
 Nu finns en enkel metod att prova  
 fönsters tathet.**

AUTHOR Wetterstad L.  
 BIBINF VVS no.4 1982 p.83-84 1 fig.  
 in Swedish  
 ABSTRACT Describes method and  
 equipment for measuring air leakage  
 from windows.  
 KEYWORDS window, component  
 leakage, instrumentation, measurement  
 technique

**#NO 1103 Testing times.**

AUTHOR Turnbull N.  
 BIBINF Energy Manager vol.6 no.1  
 1983 p41 3 figs in English 674  
 ABSTRACT Describes Schlegel's test  
 chamber for measuring air and water  
 infiltration around doors and windows.  
 This can record infiltration at any point  
 around the frame to high light the exact  
 source of a leak. This is used to test the  
 company's own draught proofing and  
 weather sealing products and is available  
 to door and window manufacturers for  
 development work.  
 KEYWORDS door, window, component  
 leakage, instrumentation, measurement  
 technique

**#NO 1105 Measurement of local  
 airtightness in buildings.**

AUTHOR Siilonen V.  
 BIBINF Technical Research Centre of  
 Finland Research Note 125 July 1982 12  
 pp. 4 figs. 1 tab. in English  
 ABSTRACT Describes the "collector  
 chamber" method, where a room or  
 whole building is pressurised and the air  
 leaking through the target areas is  
 collected with a pressure compensated  
 chamber to a measurement device.  
 KEYWORDS component leakage,  
 instrumentation, measurement technique

**#NO 1423 Ventilation in small functional buildings - measurements of air leakage of interior walls**  
**Ventilatie in kleine utilitaire gebouwen metingen aan luchtlekken van binnewanden**

AUTHOR Phaff J C., de Gids W F.  
BIBINF IMG-TNO Report C522,  
September 1983, 81pp, 55 figs, 23 tabs. ,  
in Dutch

ABSTRACT This is the second part of a study on natural ventilation in functional buildings. Reports the results of 23 measurements on a number of partitions, internal walls and one brick built internal wall. Measurements were made in 4 buildings. For the largest leakages measured in these 4 buildings, a strong influence was observed on the ventilation of neighbouring rooms. The opening of a window in a room has notable consequences on the ventilation and airflow in the other rooms. The measured air leakages ranged from 0.038 to 0.068 m<sup>2</sup> for a wall and .0131 -.0529 m<sup>2</sup> for a room.

KEYWORDS component leakage, brick wall, airflow, open window

**#NO 1531 In situ measurement of air and water tightness.**

**Mesures in situ de l'etancheite a l'air et a l'eau.**

AUTHOR Guillaume M., Meert E.  
BIBINF Congress, Luxembourg, 10-13 September 1978, Union Nationale des Entrepreneurs Menuisiers et Charpentiers and Centre Scientifique et Technique de la Construction, Belgium. 16pp, 4 figs, 4 graphs, 2 tabs. in French  
ABSTRACT Describes three research programmes measuring tightness of components, of specific areas of a building and of complete buildings. Defines the Belgian standards currently

applicable. For air tightness, the area or building is depressurized by 5 to 100 Pa and the flow of air that enters is measured. Then the components are made air tight one by one, and each time the new flow rate is measured to give values for the different components. The specific area alone can be depressurized, the specific area plus the whole building or just the whole building. For water tightness, the building is maintained at various pressures and sprayed with water for 5-10 minutes. Tracer gas methods were also used on two houses, and on external woodwork.

KEYWORDS measurement technique, pressurization, air leakage, component leakage, tracer gas, buildings

**#NO 1534 The prediction of air infiltration through building components. The assembly of a device to measure air infiltration through components with a suggested method of producing data which could be used to form the basis of a prediction model.**

AUTHOR McGrath P T.  
BIBINF Dissertation for MSc,  
University of Manchester Institute of Science and Technology, 1982. 161pp, 10 figs, 27 graphs, 54 tabs, 20 refs. in English AIC bk

ABSTRACT Reviews air infiltration measurement methods, prediction models, and flow through components of buildings. Attempts to construct a device capable of measuring airflow through a building component under a given pressure difference and to investigate the existence of a coefficient which, when multiplied by the pressure difference, raised to an exponent, will yield the airflow through that component. Components were tested under differing pressure differences and the testing

device was calibrated by a tracer gas technique. Concludes that it is possible to perform pressure/airflow tests quickly and efficiently, and cites an acceptable equation in respect to the coefficient. KEYWORDS component leakage, pressure difference, measurement technique, empirical models, prediction

**#NO 1543 Theme 1 - Energy optimization of outer window and door frames.**

AUTHOR Brosio E., Esposti W., Matteoli L., et al.

BIBINF Istituto Centrale per l'Industrializzazione e la Tecnologia Edilizia. 23pp, 9 diag, 2 tab, 5 ref. in English

ABSTRACT The main objectives are 1) the collection, processing and evaluation of leakage data for opening doors and windows, obtained from certifications or tests, 2) evaluation of the influence of building technologies and component materials on leakage, 3) experimental evaluation of the reasons for the choice of wall/frame combination and of the relative components and 4) experimental evaluation of the correlation between air leakage and sound insulation in order to define new methods of acoustic measurement of air leakage for components after installation.

KEYWORDS component leakage, door, window, measurement technique, sound

**#NO 1662 The value of pressure testing to establish the viability of retrofit procedures for a high rise building.**

AUTHOR Ward I C.

BIBINF Energy and Buildings, January 1984, Vol 6, No 1, 93-94, 2 figs, 1 tab, 1 ref. in English

ABSTRACT Presents the results of air leakage tests on the windows of the Arts

Tower at Sheffield University. The results quoted show the ranges into which infiltration coefficients fall. Relates pay-back periods for weather-stripping to height above ground level. Tabulates mean values of leakage coefficient and flow exponent for defective and non-defective sealant and compares with values suggested in CIBS Guide.

KEYWORDS window, high rise building, component leakage, sealant, weather-stripping

**#NO 1739 Air leakage tests on polyethylene membrane installed in a wood frame wall.**

AUTHOR Shaw C Y.

BIBINF Ottawa: National Research Council Canada, 1985. Building Research Note No 225. 26p. 19 figs, 1 tab. in English

ABSTRACT This report presents the results of air leakage tests on polyethylene membranes installed in a frame wall. The results would be useful in evaluating the methods commonly used for installing such a component. They can be summarized as follows: 1, a 6 mil polyethylene membrane was stiffer than a 4 mil membrane and had a greater air leakage rate through the joint, 2, the best method for installing a wall joint was to have the two sheets of polyethylene overlapped by about 400 mm, with the edges stapled to two vertical studs, 3, the spline system was too difficult to apply, especially at the corners, 4, taping and caulking the joint did not produce an air-tight joint, and 5, a new technique is needed to fasten the edges of the polyethylene sheet to the window frame and hold the edges in place.

KEYWORDS wood frame, vapour barrier, component leakage, joint, pressurization

**#NO 1898 Air leakage of residential buildings.**

**La permeabilite a l'air des batiments d'habitation.**

AUTHOR Moye C

BIBINF Cahiers du Centre Scientifique et Technique du Batiment, livr 262, cahier 2019, September 1985. 20p. 23 figs, 10 tabs. in French

ABSTRACT The development and construction of portable test equipment to determine air leakage has made it possible to carry out measurements on a large number of dwellings built using different construction technologies. The recording and analysis of the data collected is presented in this paper. This makes it possible to propose a method for taking sealing defects into account in the calculation of air infiltration of dwellings.

KEYWORDS air leakage, residential building, component leakage, pressurization, measurement technique

**#NO 2143 Air leakage of residential buildings.**

**La permeabilite a l'air des batiments d'habitation.**

AUTHOR Moye C.

BIBINF CSTB Magazine No 43, Jan-Feb 1986. p12-15. 2 figs. in French

ABSTRACT Describes the instrumentation and measurement technique used by the CSTB to measure the leakiness of residential buildings. Results of the experiments are also presented.

KEYWORDS air leakage, component leakage, measurement technique, instrumentation.

**#NO 2628 Balanced fan depressurization method for measuring component and overall air leakage in single and multi family dwellings.**

AUTHOR Reardon J T, Kim A K, Shaw C Y

BIBINF Preprint, Ashrae Trans, Vol 93, Part 2, No 3062, 1987, 15p, 8 figs, 3 tabs, 6 refs. in English

ABSTRACT The balanced fan depressurization technique has been applied to measure air leakage characteristics of row houses and individual house stories. Controlled field tests on two detached, two-storey houses with full basements were carried out to verify the consistency of the method.

The technique was then used to measure the air leakage rates of three row house units and the storeys of two other houses. The results were presented and discussed.

KEYWORDS fan depressurization, component leakage, air leakage, multi family building, house, terraced house

**#NO 2708 Air leakage measurements on full-scale construction.**

AUTHOR Baker P, Valentine G

BIBINF Bldg Serv Eng Res Tech, 8(1987), p69-71, 5 figs, 5 refs. in English

ABSTRACT A technique for identifying and measuring air leakage through the fabric of buildings is presented. The leakage characteristics of a few selected full-scale building details are illustrated. The data derive from both laboratory and real-world buildings, and indicate the importance of design detailing and construction of junctions to control air leakage.

KEYWORDS air leakage, thermography, measurement technique

**#NO 2722 The validation and application of a portable pressurisation test facility for the measurement of the flow characteristics of background leakage areas.**

AUTHOR Baker P H, Sharples S, Ward I C

BIBINF in: Third International Congress on Building Energy Management, III Ventilation, air movement and air quality: field measurement and energy auditing, held in Lausanne, Switzerland, September 28- October 2, 1987, p277-284, 7 figs, 9 refs. in English

ABSTRACT The use of the pressurization system, which is capable of direct localised measurement can greatly aid the identification and quantification of individual background leakage areas. The test uses the guarded pressure box principle to measure the airflow through a specified target under pressurization. The whole room or house is pressurized using a blower door and a measurement box, pressurized by an auxillary fan, is placed over the target. The latter fan, if adjusted to maintain a zero pressure difference, between the measurement box and the room, compensates for any disturbance of the leakage flow due to the presence of the measurement box and the connected volume flow meter. The resultant flow, is the leakage due only to the target area at the pressure difference, maintained across the building envelope.

KEYWORDS validation, pressurization testing, leakage area, airflow, blower door

### **3.4 Leak Detection Methods**

**#NO 208 The use of sound to locate infiltration openings in buildings.**

AUTHOR Keast D.N. Pei H-S.  
BIBINF Proceedings ASHRAE/DOE Conference "Thermal performance of the exterior envelopes of buildings" Florida, December 3-5, 1979 in English  
ABSTRACT Suggests the use of sound waves to locate openings in buildings that allow air infiltration. Reports results of an experimental program, including laboratory tests of a specially constructed partition and field tests on eight buildings. Finds that on average openings that can be located acoustically transmit sound that is about twice as loud as that through adjacent, sealed locations. Laboratory studies indicate that the sound level increase through a leakage opening is roughly correlated with the logarithm of the local airflow rate when a steady differential pressure is established across the partition. Concludes that acoustic leak location is most useful in buildings that are draughty but works less well in tight well insulated buildings. It is a simple and inexpensive method for finding hidden openings, needing no pressure or temperature differentials across the building envelope.

KEYWORDS air leakage, air infiltration, instrumentation, sound

**#NO 375 Thermography. Testing of the thermal insulation and airtightness of buildings.**

AUTHOR Petterson B. Axen B.  
BIBINF Swedish Council for Building Research D5. 227p. 20tabs 128 figs 21 refs. in English  
ABSTRACT Discusses in general terms energy consumption and energy requirements and the testing and checking of buildings. Gives principles of thermography and discusses the influence of various parameters on the thermography of buildings. Gives rules



for interpretation of thermograms and use of comparative thermograms. Gives examples of comparative thermograms for common defects in insulation and airtightness, and actual cases where certain constructions and components were examined. Shows effectiveness of improvements made to remedy certain types of defects in insulation and air tightness. Reports results of a general survey to find systematic defects in insulation and airtightness. Recommends preparations to be made before measurement and indicates a suitable procedure for the thermography of buildings. Gives a brief history of the application of thermography to buildings.

KEYWORDS thermography, air leakage, insulation

**#NO 683 Listening for air leaks - How to spot infiltration with your ears.**

AUTHOR Bolon P.

BIBINF Popular Science February 1981 p38,40 in English #AIC 332

ABSTRACT Describes use of an acoustic method developed by Keast to detect air leaks. A loud source of sound is placed inside the building and a microphone, stethoscope, rubber hose or sound meter is used to detect places where an increase in sound indicates air leakage. Finds method is effective in detecting simple leaks but will not spot complex paths through walls.

KEYWORDS sound, air leakage, house

**#NO 1090 Some practical aspects on the infra-red thermography of buildings.**

AUTHOR Siviour J.B.

BIBINF ECRC Rep.No.1483 October 1981 6pp. in English

ABSTRACT Illustrates some practical aspects of the use of one IR camera and

associated equipment discusses some of the problems in interpretation of some pictures representing temperatures of the inside and outside surfaces of buildings particularly problems due to residual effects of the sun on external surfaces, reflection of sunlight into the IR camera, storage of heat from the sun in walls, and cold spots inside a building caused by heat loss by thermal bridges or cold-air infiltration.

KEYWORDS thermography, instrumentation

**#NO 1573 Infrared detection of leaks. Infrarood detectie van lekken.**

AUTHOR Schurer K.

BIBINF Koeltechniek, May 1983, Vol 76, No 5, p96-98, 1 fig, 5 refs. in Dutch

ABSTRACT Distinguishes two categories of leaks in buildings for cold storage. Thermal leaks through parts of the construction with poor thermal insulation and air leaks through openings in the walls allowing a more or less free flow of air. Outlines principles of infrared radiation and thermography. Discusses applications for both types of leaks. Under the conditions of high emissivity of the surface to be studied, and absence of local heating or cooling (sun, wind, rain), thermography is an effective method for the detection of thermal leaks and a powerful tool for localizing air leaks.

KEYWORDS thermography, air leakage, wall, commercial building

**#NO 2038 Acoustic Location Of Infiltration Openings In Buildings,**

AUTHOR Keast, D. N.,

BIBINF Cambridge, MA, ,, Brookhaven National Laboratory Report 50952, pp 1-144, BNL 50952, National Technical Information Service U.S. Department of

Commerce, Springfield, VA 22161, in English

**ABSTRACT** Unnecessary air infiltration, draftiness, in buildings can be a major cause for excessive energy consumption. A method for using sound to locate, for subsequent sealing, the openings of air infiltration leakage paths in buildings has been investigated. The results of pertinent analytical studies, laboratory experiments, and field applications of this acoustic location method are reported, and a plan is provided to encourage national implementation of the method. Low-cost, readily available equipment and procedures are described whereby the average building contractor or homeowner can use acoustic leak location to pinpoint many of the air infiltration openings in a building., **KEYWORDS** air infiltration, sonic techniques, sound, air leakage, instrumentation

**#NO 2630 Test ventilation with smoke, bubbles and balloons.**

**AUTHOR** Pickering P L, Cucchiara A L, et al  
**BIBINF** Preprint. Ashrae Trans, Vol 93, Part 2, NT-87-01-3, 1987, 9p, 6 figs, 6 refs. in English  
**ABSTRACT** The behaviour of smoke, bubbles, and helium-filled balloons was videotaped to demonstrate the mixing of air in the plutonium chemistry laboratories of a plutonium facility. The air distribution patterns, as indicated by each method, were compared. Helium filled balloons proved more useful than bubbles or smoke in the visualization of airflow patterns. The replay of various segments of the videotape proved useful in evaluating the different techniques and in identifying airflow trends responsible for air mixing.

**KEYWORDS** airflow, measurement technique, smoke

**#NO 5119 The use of acoustic intensimetry to size air leakage cracks.**

**AUTHOR** Oldham D J, Zhao A  
**BIBINF** Air Infiltration Review, Vol 20, No 3, June 1991, pp 7-9, 3 figs, 3 refs. in English

**ABSTRACT** The sound intensity technique and reverberant sound excitation have been used for the measurement of sound transmission loss through narrow slits in rigid walls. As predicted by theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracks using the technique described in this paper.

**KEYWORDS** measurement technique, air leakage, crack

**#NO 5324 The use of acoustic intensimetry to size air leakage cracks.**

**AUTHOR** Oldham D, Zhao X, Sharples S, Kula H-G  
**BIBINF** UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 3, pp 307-318. in English

**ABSTRACT** Reverberant sound excitation and the sound intensity technique have been used for the measurement of the sound transmission loss of narrow slits in rigid walls. A series of experiments was conducted to determine the transmission loss of slit shaped apertures. The measured transmission loss was in good agreement with existing approximate theories over their accepted ranges of validity. However, the effect of viscosity in small

apertures was found to be significant and to vary systematically with the dimensions of the apertures. As predicted by theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracks using the technique described in this paper.

KEYWORDS air leakage, crack, measurement technique

**#NO 5384 House tightening manual for homeowners and weatherization contractors.**

AUTHOR Anon

BIBINF USA, Bonneville Power Administration, 31 October 1985, 51pp, 12 refs. in English

ABSTRACT Aimed at weatherization contractors, homeowners and others, this is a guide to location and repair of major residential air infiltration sources, based on the experience of professional "house doctors", using trained visual inspection techniques. The manual is a result of the Residential Air Infiltration Leakage Repair Project conducted for BPA during 1983 and 1984. A major purpose of this study was to determine the cost effectiveness of air leakage repairs done without test equipment or highly specialized labor. The study was carried out by repairing leaks and testing the reductions in leakage on 40 electric heated site-built single family homes representative of Pacific Northwest housing. The homes tested were in Bend, Ashland, and Portland, Oregon. On each test home, a sequence of repairs was performed, with a leakage test before and after each repair. The material costs and repair time for each repair were recorded. In this fashion, both the cost and effect of a variety of leak repairs

were determined. During the repair sequence, the initial group of leaks on each home was located and repaired without test equipment. After the repair crew had done their best without test equipment, they then used test equipment (a blower door and smoke stick) to see what significant leaks they had missed, and whether the repairs had been done properly.

KEYWORDS air tightness, retrofitting, residential building

**4.0 Air Exchange and Ventilation Effectiveness Measurements for Simple Systems: Single-Zone Tracer Gas Measurements**

**Standard test method for determining air change in a single zone by means of a tracer gas dilution.**

AUTHOR ASTM

BIBINF USA, American Society for Testing and Materials, E 741-00, 16pp.

ABSTRACT Test method describes techniques using tracer gas dilution for determining a single zone's air change with the outdoors, as induced by weather conditions and by mechanical ventilation. The techniques are 1) concentration decay, 2) constant injection, and 3) constant concentration.

KEYWORDS standard, tracer gas

**4.1 Tracer Decay**

**#NO 1272 Evaluation of evacuated glass tubes for sampling of SF<sub>6</sub>/Air mixture for air exchange measurements.**

AUTHOR Tamura G.T. Evans R.G.

BIBINF ASHRAE Jnl. vol.25 no.10 p.40-43 3 figs. 2 tabs. 4 refs. in English  
ABSTRACT Grab sampling of a tracer gas/air mixture in conjunction with the

tracer gas decay technique is a convenient method for conducting a survey of air infiltration rates in homes. Examines such a method, using SF<sub>6</sub> as the tracer gas and storing the concentration in evacuated glass tubes. KEYWORDS tracer gas, decay rate, measurement technique, sulphur hexafluoride

**#NO 1944 Rapid thermal calibration of houses.**

AUTHOR Everett R

BIBINF Milton Keynes, UK:Energy Research Group, Open University,1985. ERG 055. 200p. figs, tabs, 6 refs. in English AIVC bk

ABSTRACT Presents a detailed description of the measurement technique and apparatus used to measure the air change rate in the Spencer St and Linford low-energy houses in Milton Keynes, UK. An automatic air infiltration rig using nitrous oxide tracer gas constant decay was used. Air leakage was also measured by pressurization for the Linford houses and some from the neighbouring Pennyland project.

KEYWORDS air change rate, air leakage, measurement technique, automatic equipment, nitrous oxide, tracer gas, decay rate, pressurization

**#NO 2536 Microcomputer-aided measurement of air change rates.**

AUTHOR Heidt F D, Werner H

BIBINF Energy Bldgs, Vol 9, 1986, p313-320, 8 figs, 10 refs. in English

ABSTRACT Air change rates are measured by a non-dispersive one-beam IR gas analyser using the decay and constant-emission methods with nitrous oxide as tracer gas. Disturbing influences due to H<sub>2</sub>O and CO<sub>2</sub> are low. The analyzer is coupled via a RS-232-C

interface to a microcomputer, which is programmed to service the following functions: (1) calibration, (2) preparation and control of measurements, (3) recording, displaying and storing of data, (4) evaluation of results, and (5) error analysis. The implemented programs provide an instant access to results. The whole equipment is installed in compact form on a mobile rack. Measurements have been taken in a university laboratory to examine air change rates with (1) closed door and window, (2) open door only, and (3) tilted window only. Typical results are given and show where the decay method or the constant-emission method is more appropriate. KEYWORDS computer, measurement, air change rate, decay rate, constant emission, tracer gas, nitrous oxide, door, window, instruments

**#NO 4072 Improving an IR tracer gas analyser by digital filtering.**

AUTHOR Skotte J, Breum N O, Schneider T

BIBINF UK, Building and Environment, Vol 25, No 2, 1990, pp151-154, 4 figs, 1 tab, 12 refs. in English

ABSTRACT An algorithm is described by which the time between samples can be greatly reduced in a multipoint measuring system with an infrared gas analyser. Normally such a system is rather slow due to the large cuvette volume of the analyser. By using a simple correctional algorithm the sample period can be reduced from approximately 30-45 s to 10-15 s without substantial loss of precision. It is required that the airflow through the analyser is maintained constant. The algorithm is derived using a digital filter designing technique.

KEYWORDS instruments, measurement technique, tracer gas

**#NO 4117 Mapping indoor air movements with a tracer gas technique.**

AUTHOR Afonso C F A, Maldonado E A B

BIBINF Netherlands, Kluwer Academic Publishers, 1990, proceedings "Second European conference on architecture. Science and technology at the service of architecture", held Paris, France, 4-8 December 1989, pp134-137, 5 figs, 11 refs. in English

ABSTRACT This paper describes how the tracer decay method was used to map all indoor airflows in a passive solar residence in Porto. A specific analysis of the influence of the fireplace chimney was made, showing that it accounted for a 50% increase in air exchange rate, and that indoor air movements were strongly affected in both magnitudes and directions.

KEYWORDS air movement, tracer gas

**#NO 4211 Determining delivered quantities of outside air: CO<sub>2</sub>, tracer gas or both?**

AUTHOR Turner W A, Bearg D W  
BIBINF in: The human equation: health and comfort proceedings IAQ 89, pp117-121, 2 figs, 2 tabs, 7 refs. in English

ABSTRACT As part of an indoor air quality investigation protocol, a major focus is frequently a determination of the quantities of outside air (OA) actually being delivered to the occupants of a building. This quantity is a function of both the quantity of OA taken in at the OA dampers and the effectiveness of the HVAC system in delivering this air to the people. In this paper, the ratio of the air quantity entering the OA dampers and the outside air quantity delivered to the occupants is referred to as the

ventilation efficiency (others have suggested this be called ventilation performance). Often, it is desirable to know this ventilation efficiency in order to determine if improvements in the delivery efficiency are warranted. Measurement of both the delivered quantities of outside air and the efficiency of the ventilation system is especially important in light of various protocols for design options, which are contained in proposed ASHRAE Standard 62-1981R, "Ventilation for Acceptable Indoor Air Quality". The two principal tools currently utilized for evaluating the quantity of outdoor air (OA) delivered to the occupants of a building are the measurement of carbon dioxide (CO<sub>2</sub>) concentrations and the measurement of tracer decay rates using sulfur hexafluoride. These two methods have also been utilized by the authors and other researchers to assess the efficiency of outside air delivery. Each of these techniques has its own set of advantages and disadvantages, but the performance of the two together tends to cancel out some of the weaknesses of each. Therefore, whenever possible, the authors have performed both procedures side by side to maximize the precision and the accuracy of the results. This paper discusses some of the issues raised by the results that have been obtained and presents suggestions for minimizing errors in the interpretation of the test results.

KEYWORDS outdoor air, carbon dioxide, tracer gas

**#NO 4486 The feasibility of achieving necessary initial mixing when using tracer gas decays for ventilation measurements.**

AUTHOR Alevantis L E, Hayward S B

BIBINF Canada, Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, 29 July -3 August 1990, Volume 4 "Building and System Assessments and Solutions", pp 349-354. in English

**ABSTRACT** The degree of initial mixing of tracer gas with building air was examined in four office buildings by using the tracer decay method both at low and at high ventilation rates. The results indicate that the tracer gas mixed well with building air at low ventilation rates (0.5 air changes per hour), but that at high ventilation rates (1.0 air changes per hour or above) good initial tracer gas mixing conditions were not achieved on a consistent basis.

**KEYWORDS** tracer gas, decay rate, ventilation rate

**#NO 4786 Practical determination of air change. Automated acquisition of measured data from the exchange of room air under different flow conditions in the room. (Part 2)**  
**Praktische Luftwechselermittlung. Automatisierte Messwerterfassung des Raumlufwechsels unter verschiedenen Strömungsbedingungen im Raum - 2. Teil.**

**AUTHOR** Lobeck W, Masuhr F  
BIBINF Germany, HLH, Vol 41, No 12, 1990, pp 1051-1056, 4 figs, 8 refs. in German

**ABSTRACT** The 1st part of this article, in HLH 11/90, gave a description of the tracer measuring method to determine the exchange of air in rooms. In part 2, the automated acquisition of the exchange of room air under different flow conditions in the room are specified. Comparative assessments are made under different flow conditions

between the results based on the tracer decay method and blower induced air exchange, and statements are also made on the number of outlet points required. The most suitable trial variant is determined and its advantages specified. The measured concentrations (CO<sub>2</sub> tracer) are determined with an infra-red gas analyzer, which is coupled with a small computer. The prepared software permits control of the measuring sequence, data acquisition, its protection and evaluation.

**KEYWORDS** air change rate, tracer gas

**#NO 5688 Estimation of zone effective volume using tracer-gas techniques.**

**AUTHOR** Riffat S B, Cheong K W  
BIBINF UK, Loughborough University of Technology, Dept of Civil Engineering, [1992], 12pp. in English  
**ABSTRACT** The concentration-decay and pulse-injection tracer-gas techniques were used to evaluate the effective volume of a zone. Measurement of airflow rates were carried out in an environmental chamber using SF<sub>6</sub> as the tracer gas. Results showed the flow rate estimated from the concentration-decay technique is about 4.5 to 14.3% higher than actual flow rate if the effective volume of the chamber is assumed equal to the physical volume. The effective volume estimated from tracer-gas measurements was found to be about 1.5 to 2.7% higher than the physical volume of the chamber.

**KEYWORDS** tracer gas measurements, sulphur hexafluoride, airflow

**#NO 5866 Errors in the calculation of ventilation flow rates.**

**AUTHOR** Brouns C  
BIBINF UK, Coventry Polytechnic, Dept of Civil Engineering and Building, Dissertation, May 1989, 69pp. in English

**ABSTRACT** This project investigates the effect of rounding errors in the calculation of ventilation flow rates. The flow rates are determined from the concentrations of contaminant which are measured in a tracer decay experiment. As shown in the present dissertation, the introduction of rounding errors leads to substantial changes in the final flows. Experimental errors are expected to be larger than rounding errors and therefore, they would produce greater errors in the computed flows. The aim of this research is to find a way of measuring these errors, and as shown later, the condition number used in this report is not a satisfactory measure of these errors.

**KEYWORDS** ventilation rate, airflow, pollutant

**#NO 6771 Tracer gas mixing with air.**

**AUTHOR** Shao L, Sharples S, Ward I C  
**BIBINF UK**, Building Serv. Eng. Res. Technol., Vol 14, No 2, 1993, pp 43-50, 3 figs, 5 tabs, 12 refs. in English

**ABSTRACT** The tracer gas method is one of the most widely used methods for measuring flow rates for building air infiltration and ventilation. The accuracy of this method depends vitally on the spatial uniformity of the tracer/air mixing. However, information on this critical problem has been scarce, largely due to the practical difficulty in experimentally obtaining data. In the last decade a new tool for building research has emerged, namely computational fluid dynamics or CFD. A study of tracer/air mixing has been carried out using a time dependent CFD method, supported by conceptual/dimensional analysis. In this study, 12 cases of tracer/air mixing in simulated tracer decay tests were computed. Each case had a different zonal volume or other

boundary or initial conditions. By comparing these results, it was found that there were many factors affecting tracer/air mixing and, contrary to a previous report, there does not exist a universal critical value of air change rate below which satisfactory mixing is guaranteed, although lower air change rates are generally beneficial to mixing. In addition, it has been demonstrated that smaller building zones and higher inlet airflow velocities have positive effects on tracer/air mixing while the initial tracer concentration level has no effect. Finally a statistical parameter of concentration spread coefficient for assessing tracer mixing has been introduced.

**KEYWORDS** tracer gas, mixing, air change rate, computational fluid dynamics

**#NO 7746 Tracer gas mixing with air: effect of tracer.**

**AUTHOR** L Shao & S B Riffat  
**BIBINF UK**, University of Nottingham, Building Technology Group, 1994, 21pp, 7figs, 10 refs in English

**ABSTRACT** The accuracy of tracer gas method depends vitally on the spatial uniformity of tracer/air mixing, which in many cases is unsatisfactory. However, information on this critical problem has been scarce, largely due to the practical difficulty in experimentally obtaining data. This paper presents a study of the effect of tracer species on tracer mixing, using a time dependent CFD method. It was found that for single-zone tracer decay tests, three tracer-gases, sulphur hexafluoride, nitrous oxide and carbon dioxide have virtually identical mixing patterns and thus there is no difference between them in terms of airflow measurement results. However, for multi-gas tests where there is interzonal

tracer movement, the tracer-gases with different binary diffusivities exhibit significantly different mixing behaviour. In these situations, the choice of tracer will impact the accuracy of airflow measurement. These results support recent experimental findings concerning the significant effect of tracer species on airflow measurement.

**KEYWORDS** Tracer gas, mixing, computational fluid dynamics

**#NO 8013 Investigation of effect of tracer species on tracer mixing using CFD.**

**AUTHOR** Riffat S B, Shao L  
**BIBINF** UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 2, pp645-654.  
**ABSTRACT** Tracer-gas techniques are widely used for measurement of airflow in buildings and their accuracy depends critically on the uniformity of tracer/air mixing. However, tracer mixing is still an unsolved problem and the effect of many factors remains unclear. This paper presents a study of the effect on mixing of tracer species. The investigation concentrated on tracer mixing involved in the decay technique, which is the most widely used version of the tracer gas method. The distribution and history of tracer concentration during airflow measurements were examined using Computational Fluid Dynamics (CFD). It was found that for single-zone tracer decay tests, three tracer gases, sulphur hexafluoride, nitrous oxide and carbon dioxide have virtually identical mixing patterns and thus there is no difference between them in terms of flow rate measurement results. However, for multi-tracer gas tests where there is interzonal tracer

movement, the three tracer gases with different binary diffusivities exhibit significantly different mixing behaviour. In these situations, the choice of tracer will impact the accuracy of airflow measurement.

**KEYWORDS** tracer gas, computational fluid dynamics, airflow, measurement technique

**#NO 8443 Determination of outdoor air quantities delivered.**

**AUTHOR** Bearg D W, Turner W A  
**BIBINF** Building systems - room air contaminant distribution 5-8 December 1988, University of Illinois, Ashrae 1989, Ed Christianson L L, pp 106-108, 2 refs.

**ABSTRACT** As part of an indoor air quality investigation protocol, the quantities of outside air being delivered to the occupants of a building frequently need assessment. Methods often used for this task include tracer decay assessments and the measurement of indoor CO<sub>2</sub> levels, assumed to be generated by the occupants. This paper presents data from buildings in which both CO<sub>2</sub> measurement and tracer gas decay were performed separately or simultaneously to assess the amounts of outside air reaching the occupants. The methods are explained, and discrepancies in the results of the two methods are discussed. "Ventilation efficiency" (the delivery of outside air to the occupied space vs. the quantity of outside air brought in at the air intake) protocols are suggested that are expected to minimize errors in the correct interpretation of the results, and further research needs are discussed.

**KEYWORDS** outdoor air, ventilation system



**#NO 12111 Effect of data logging frequency on tracer gas measurement.**

AUTHOR Lee H, Awbi H B  
BIBINF Sweden, Stockholm, KTH  
Building Services Engineering, 1998,  
proceedings of Roomvent 98: 6th  
International Conference on Air  
Distribution in Rooms, held June 14-17  
1998 in Stockholm, Sweden, edited by  
Elisabeth Mundt and Tor-Goran  
Malmstrom, Volume 2, pp 477-482, 8  
figs, refs.

ABSTRACT A data acquisition system which uses a computer provides a more useful analysis system. Since the processing speed of a computer is continuously increasing, the measurements can produce much more information than it is possible using conventional data acquisition systems. However, the raw measurements also include the signal noise which many lead to difficulty when the signal is analysed. This work assesses an algorithm for removing possible signal noise, usually with high-frequency, from the measurement of tracer gas concentration. The code, written by the authors, contains three main parts: fast-Fourier transformation (FFT), inverse fast-Fourier transformation (IFFT) and a digital filter. In this method, the raw data is transformed using FFT from time-domain into frequency-domain. The digital filter, so-called Notch filter, then selects the required signal without the high frequency noise. Finally IFFT conducts inverse transformation from frequency-domain to time-domain with the frequency data selected by the filter and yields a smoothed time-domain signal back.

Using this technique, the digital filtering algorithm provides the measurement data without the high frequency noise. It has been found that 1 Hz of sampling

rate is fast enough to monitor the variation of tracer gas concentration in model experiments.

KEYWORDS tracer gas, measurement technique, modelling

**#NO 13303 Pre-Processor for Ventilation Measurement Analysis**

AUTHOR Heekwan Lee and Hazim B. Awbi

BIBINF Proceeding of Seventh  
International conference on Air  
Distribution in Rooms (ROOMVENT  
2000), Reading, UK, Vol. 1, pp.355-360,  
(Ed. H.B. Awbi), Elsevier.

ABSTRACT It is well known that the introduction of tracer gas techniques to ventilation studies has provided much useful information that used to be unattainable from conventional measuring techniques. Data acquisition systems (DASs) containing analog-to-digital (A/D) converters are usually used to perform the key role which is reading and saving signals to storage in digital format. In the measuring process, there are a number of components in the measuring equipment which may produce system-based noise fluctuations to the final result. These unwanted fluctuations may cause discrepancy in computations, especially when non-linear algorithms are involved.

In this study, a pre-processor is developed and used to separate the unwanted fluctuations (noise or interference) in raw measurements and to reduce the uncertainty in the measurement. Moving average Notch filter, FIR (Finite Impulse Response) filters, and IIR (Infinite Impulse Response) filters are designed and applied to collect the desired information from the raw measurements. Tracer gas concentrations are measured during leakage and ventilation tests in a

model test room. The signal analysis functions embedded in Matlab are used to carry out the digital signal processing (DSP) work.

**KEYWORDS** Tracer Gas Measurement, Digital Signal Processing, Correlation Analysis, Signal Noise, Air Leakage

## 4.2 Pulse Injection

### **#NO 3121 Integral mass balances and pulse injection tracer technique.**

**AUTHOR** Axley J, Persily A

**BIBINF** in: "Effective Ventilation", 9th AIVC Conference, Gent, Belgium, 12-15 September, 1988. in English

**ABSTRACT** Tracer gas techniques for measuring airflow rates in building systems are considered. These techniques are classified in terms of tracer gas injection strategy employed and mass balance relationships used to analyze measured tracer concentration data. The discussion focuses on one class of tracer techniques - the pulse injection techniques - based upon pulse injection strategies and integral mass balance relationships. These pulse injection techniques have not been commonly used in the past yet they provide practically useful means for the determination of airflow rates in building systems. Pulse injection techniques are presented for measuring airflows in ducts, and for studying single-zone and multi-zone building airflow systems. Experimental procedures for these three cases are discussed, and preliminary results from field applications of these techniques are presented. The possibility of flow variation is accounted for in all cases, and the sensitivity of the single-zone pulse injection technique to these flow

variations is compared to that of the single-zone constant injection technique. This comparison leads to integral formulations of the constant injection technique for duct, single-zone, and multi-zone situations that may provide means to improve the accuracy of the commonly used constant injection tracer technique.

**KEYWORDS** tracer gas, airflow, measurement technique

### **#NO 3433 Integral mass balances and pulse injection tracer techniques.**

**AUTHOR** Axley J, Persily A

**BIBINF** US Dept of Commerce, NISTIR 88-3855, October 1988, 31pp, 1 tab, 16 figs, 30 refs. in English

**ABSTRACT** Tracer gas techniques for measuring airflow rates in buildings are considered. These techniques are classified in terms of tracer gas injection strategy employed and mass balance relationships used to analyze measured tracer concentration data. The discussion focuses on one class of tracer techniques- the pulse injection techniques - based upon pulse injection strategies and integral mass balance relationships. These pulse injection techniques have not been commonly used in the past yet they provide practically useful means for the determination of airflow rates in building systems. Pulse injection techniques are presented for measuring airflows in ducts, and for studying single-zone and multi-zone building airflow systems. Experimental procedures for these three cases are discussed, and preliminary results from field applications of these techniques are presented. The possibility of flow variation is accounted for in all cases, and the sensitivity of the single-zone pulse injection technique to these flow

variations is compared to that of the single-zone constant injection technique. This comparison leads to integral formulations of the constant injection technique for duct, single-zone, and multi-zone situations that may provide means to improve the accuracy of the commonly used constant injection tracer technique.

**KEYWORDS** airflow, infiltration, tracer gas, ventilation

**#NO 3573 A comparison between the step-up, step down and pulse injection techniques for the measurements of the mean age of air.**

**AUTHOR** Niemela R, Saamanen A, Koshela H

**BIBINF** in:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28 September 1989, Volume 2, February 1990, pp17-30, 16 figs, 20 refs. in English

**ABSTRACT** A comparison of three injection manners, step-up, step-down and pulse, for determination of the mean age of air was made by using nitrous oxide and sulphur hexafluoride as tracer gases. The concentrations of nitrous oxide and sulfur hexafluoride were simultaneously measured with a dual-channel IR-analyzer. Tests were carried out in a test chamber with air change rates of 3 h<sup>-1</sup> and 5 h<sup>-1</sup>. The tracer gases were injected under three conditions: into the inlet air and directly into the room with and without extra mixing fans. The results suggest that the pulse procedure is as reliable as the two other methods used.

**KEYWORDS** tracer gas, model, measurement techniques

**#NO 3694 The air exchange efficiency of a lecture hall.**

**AUTHOR** Breum N O

**BIBINF** Reprinted from: Ventilation '88, Proceedings of the Second International Symposium on Ventilation for Contaminant Control, 20-23 September 1988, London, UK, pp373-380, 3 figs, 1 tabs, 15 refs. in English

**ABSTRACT** The airflow pattern in a lecture hall (V=690m<sup>3</sup>) designed for displacement ventilation was characterised by age analysis in the case of a non-occupied hall as well as an occupied hall. The ventilation system was slightly (17%) unbalanced. For comparison the following three experimental signal-response tracer gas techniques were applied: "step-up", "decay" and pulse injection. The mean ages of air estimated by the "decay" technique were elevated (1-23%) compared to the results of the "step-up" method. Generally the pulse technique estimated the lowest mean ages. The estimated air exchange efficiency of the non-occupied hall was 50%, and for the occupied hall the efficiency was estimated to be 60%.

**KEYWORDS** air change rate, large building

**#NO 5688 Estimation of zone effective volume using tracer-gas techniques.**

**AUTHOR** Riffat S B, Cheong K W  
**BIBINF** UK, Loughborough University of Technology, Dept of Civil Engineering, [1992], 12pp. in English

**ABSTRACT** The concentration-decay and pulse-injection tracer-gas techniques were used to evaluate the effective volume of a zone. Measurement of airflow rates were carried out in an environmental chamber using SF<sub>6</sub> as the tracer gas. Results showed the flow rate estimated from the concentration-decay technique is about 4.5 to 14.3% higher than actual flow rate if the effective volume of the chamber is assumed equal

to the physical volume. The effective volume estimated from tracer-gas measurements was found to be about 1.5 to 2.7% higher than the physical volume of the chamber.

**KEYWORDS** tracer gas measurements, sulphur hexafluoride, airflow

**#NO 5845 9th AIVC Conference: Effective ventilation: Proceedings Volume 1.**

**AUTHOR** Air Infiltration and Ventilation Centre

**BIBINF** UK, Air Infiltration and Ventilation Centre, 9th AIVC

Conference proceedings Vol.1, held Novotel Hotel, Gent, Belgium, 12-15 September, 1988, 439pp. in English

**ABSTRACT** Twenty three papers form the ninth AIVC Conference, titles as follows: Keynote speech: Air Infiltration and Ventilation, Natural airflows between roof, subfloor and living spaces, Experimental analysis of air diffusion in large space, Determination of ventilation efficiency based upon short term tests, Ventilation strategies in the case of polluted outdoor air situations, Ventilation generated by a fluctuating pressure differential, Air motion in the vicinity of air-supply devices for displacement ventilation, Integral mass balances and pulse injection tracer-techniques, Commercial building ventilation measurements using multiple tracer gases, Constant concentration measurement with 2 tracers, Extended testing of a multifamily building using constant concentration and PFT methods, Analysis of errors for a fan-pressurization technique for measuring inter-zonal air leakage, The use of a guarded zone pressurization technique to measure airflow permeabilities of a multi-zone building, Air leakage between apartments, Air infiltration

induced by heating appliances, Indoor formaldehyde levels in energy-efficient homes with mechanical ventilation systems, Recirculation of air in dwellings, Effective ventilation in offices - the occupant's perspective, A ventilation concept for future dwelling-houses, Natural ventilation for a Crown court: developing statistical assessment techniques at the design stage, Market analysis of sensors for the use in demand controlled ventilating systems, Ventilation design for a bus station, Ventilation and air quality in Belgian buildings: a state of the art.  
**KEYWORDS** ventilation effectiveness, ventilation system

**#NO 9649 Outdoor air delivery rates to occupants and age of air.**

**AUTHOR** Li Z, Zhang J S, Christianson L L, Kulp R N, Sparks L E

**BIBINF** USA, Ashrae Transactions, Vol 102, Pt 2, 1996 [preprint], 4 figs, 2 tabs, refs.

**ABSTRACT** A simple and accurate technique to directly measure the outdoor air delivery rates to building occupants is presented. A few (two to three) measurements of tracer concentrations are sufficient for calculation. Experimental results show that the calculated outdoor air change rates from the tracer gas experiments agreed well with the outdoor airflow rates measured independently by nozzles. A relationship between the local outdoor air exchange rate and the mean age of air was derived. The proposed technique provides a way of simplifying the measurement of mean age of air and correcting experimental errors.

Experimental results show that almost all the errors in the mean age of air (a maximum of 20% in our tests) caused by inaccurate timing of the start of a tracer

gas step-up process (tracer buildup) can be corrected by the proposed method. The underestimated ages of air in the step-down processes (tracer decay) were also successfully corrected.

KEYWORDS outdoor air, occupant reaction, tracer gas, air change rate

**#NO 11930 The principles of a homogeneous tracer pulse technique for measurement of ventilation and air distribution in buildings.**

AUTHOR Stymne H, Boman C A  
BIBINF in: UK, Air Infiltration and Ventilation Centre, proceedings of "Ventilation Technologies in Urban Areas", 19th Annual Conference - Supplement, held Oslo, Norway, 28-30 September 1998.

ABSTRACT The principles of a new tracer gas technique is described in the paper. The new technique involves pulse injection of tracer gas and has the same advantages as the previously known homogeneous emission technique. It can for example advantageously be used in large buildings and buildings with many rooms and yields information on the distribution of ventilation air within the building. However, contrary to the homogeneous emission technique, yielding the average ventilation performance during an extended time, the new technique allows measurement during short term periods. The new technique is based on homogeneous pulse injection, which means that pulses of tracer gas are injected in each zone in a zone-divided building, with amounts which are proportional to the zone volumes and integrating sampling of tracer gas concentration. Theoretical and practical aspects of the technique are described.

KEYWORDS tracer gas, air distribution

### 4.3 Constant Injection

**#NO 1653 A modified tracer gas infiltration method for use in a residential indoor air quality/weatherization study.**

AUTHOR Totzke D. et al.  
BIBINF Indoor Air. Vol 5. Buildings, Ventilation and Thermal Climate. Edited by B Berglund, T Lindvall, J Sundell. Swedish Council for Building Research, 1984. 459-464, 8 refs. in English AIVC bk

ABSTRACT As part of a study to evaluate the effects of home weatherization on indoor air quality, a tracer gas method to determine infiltration rates was developed by modifying existing methods to meet several project constraints. A method was needed that did not involve occupant participation, required only a small amount of time from the field investigators, and had to be fabricated from rugged, low cost materials that could be easily transported. The method developed is based on the continuous release of pure sulfur hexafluoride (SF6) from a cylinder and the transfer of indoor air to a storage bag. The collection bags were analyzed for SF6 concentration by gas chromatography using an electron capture detector. The concentration of SF6 along with tracer release rates and house volume measurements were used to calculate an air exchange rate for each home studied. Fifty homes were evaluated several times each using this method under varying weather conditions before and after energy conservation improvements were performed.

KEYWORDS tracer gas, sulphur hexafluoride, retrofit, constant emission, sample bag, chromatograph, measurement technique

**#NO 1657 Indoor air pollution evaluation by tracer gas technique.**

AUTHOR Hampl V.

BIBINF Indoor Air. Vol 5. Buildings, Ventilation and Thermal Climate. Edited by B Berglund, T Lindvall, J Sundell. Swedish Council for Building Research, 1984. 505-510, 2 figs, 1 tab, 5 refs. in English AIVC bk

ABSTRACT A tracer gas technique has been used for evaluation and characterization of airflow pattern of contaminants penetrating into buildings. As a tracer, sulfur hexafluoride (SF<sub>6</sub>) was used and detected by a gas chromatograph equipped with an electron capture detector. SF<sub>6</sub> was released at suspected points of contaminant origin at a constant flow rate and was detected quantitatively in the room or laboratory of concern. A dilution factor concept was established which can be used to estimate room contaminant levels and to calculate the level of contaminant in a laboratory hood exhaust system which will result in any given level in the make-up air system or room supply system. In all cases, the tracer gas method was successful and proved to be an effective method for the characterization and the investigation of the contaminant flow pattern. The sensitivity of the SF<sub>6</sub> gas detection, the low toxicity, and the specificity of the tracer make this procedure a very useful tool for this type of study.

KEYWORDS tracer gas, sulphur hexafluoride, constant emission, measurement technique

**#NO 4640 Measurement of airflow through a porous medium.**

AUTHOR Riffat S B, Cheong K W

BIBINF UK, Loughborough University of Technology, Department of Civil Engineering, [1990], 11pp, 4 figs, 7 refs. in English

ABSTRACT This work examines the application of the constant-injection tracer-gas technique for measurement of airflow in a duct filled with a porous medium. The duct used for this investigation had an aspect ratio of 6.25 and measurements of tracer-gas concentration and pressure distribution along the duct were performed for Reynolds numbers between 1140 and 1790. The work indicated that the concentration of tracer-gas in the porous medium became constant at a distance of approximately 52 hydraulic diameters from the tracer-gas injection point.

KEYWORDS airflow, porosity, tracer gas

**#NO 5312 Numerical prediction of airflow patterns and ventilation effectiveness in an open office environment.**

AUTHOR Fang J, Persily A

BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 3, pp 181-182. in English

ABSTRACT Numerical modelling is performed to predict air movement, thermal comfort level and contamination distribution within an open office space. The office located in the building interior has a concentrated thermal load at its center and is conditioned by cool air delivered from a ceiling-mounted linear diffuser. The air velocity and temperature distributions and contaminant dispersion in the office are calculated for three different cooling loads and air exchange rates with a

three-dimensional turbulent finite difference model. Calculations of ventilation effectiveness based on the time variations of contaminant or tracer gas concentrations in the supply, exhaust and occupied space are performed for the condition of constant injection of tracer gas into the supply air stream. The calculated values of the Air Diffusion Performance Index (ADPI) and ventilation effectiveness in the occupied zone for different supply airflow rates are presented.

KEYWORDS prediction, airflow, ventilation effectiveness, office building, large building

**#NO 12072 Airflow patterns in Schonbrunn Palace.**

AUTHOR Holmberg J G, Kippes W  
BIBINF Sweden, Stockholm, KTH Building Services Engineering, 1998, proceedings of Roomvent 98: 6th International Conference on Air Distribution in Rooms, held June 14-17 1998 in Stockholm, Sweden, edited by Elisabeth Mundt and Tor-Goran Malmstrom, Volume 2, pp 189-196, figs, refs.

ABSTRACT The purpose of this study is to find more information of the complicated airflow pattern in the Schöenbrunn Palace. The aim is to improve the control of the air infiltration. We have used a passive tracer gas technique, a special case of the constant injection technique, called the homogeneous emission technique. The results give Air Change Rates (ACH) of 0,7 to 1,7 in different rooms and parts of the palace. Wind driven ventilation dominates stack driven ventilation. We found a considerable airflow between floors. Simple one zone calculations of air leakage over windows partly confirms the ACH measured. The palace

management will use the results of the investigation in the ongoing planning process to improve the indoor climate and abating the indoor deterioration.  
KEYWORDS airflow patterns, air exchange efficiency, air tightness, tracer gas, large building

#### **4.4 Constant Concentration**

**#NO 474 Theoretical and experimental studies of heat loss due to ventilation.**

AUTHOR Alexander D.K. Etheridge  
D.W. Gale R.  
BIBINF Proceedings XXI International Congress for Building Services Engineering, Berlin 17/18 April 1980 in English

ABSTRACT Outlines two techniques for estimating ventilation heat losses in houses. The first is a tracer gas technique using a constant concentration of gas and the second a theoretical prediction method. The theoretical technique treats the building as a multi-cell model with specified wind pressure, leakage openings and background leakage area. Reports use of the method for simulating the natural ventilation of a house in London and the effectiveness of sealing the windows and floor.

KEYWORDS heat loss, ventilation, theoretical modelling

**#NO 586 An investigation using the tracer gas method for the measurement of ventilation rate in rooms and airflow rate in ducts.**

AUTHOR Weatherall P.J.  
BIBINF MSc. dissertation. University of Manchester Institute of Science and Technology. October 1977 116p. 29 refs. in english

ABSTRACT Reviews tracer gas methods for measuring ventilation rate and discusses the diffusion of gases. Describes four tracer gas methods, rate of decay, equilibrium concentration, transfer index and constant concentration. Discusses the analysis of results. Describes an experimental room and series of measurements of air change rate using two methods a) rate of decay, where a balloon filled with gas was burst as a point source and b) equilibrium concentration where tracer gas was released continuously at a constant rate. Discusses results.< Describes further tests in different rooms using decay rate method. Treats use of tracer gas technique to measure airflow rates in ducts.< Concludes decay method has error of 15% in field conditions. KEYWORDS tracer gas, nitrous oxide, instrumentation, NOTES A discussion of this paper by T.Stathopoulos is given in vol.7 1981 p.367-368

**#NO 614 Experimental techniques for ventilation research.**

AUTHOR Alexander D.K. Etheridge D.W. Gale R. BIBINF A.I.C. Conference "Instrumentation and Measuring Techniques" Windsor 6-8 October 1980 in english AIC = in 'Ventilation of Domestic Buildings' #AIC 492 ABSTRACT Reviews experimental techniques for determining the infiltration characteristics of buildings. Discusses the use of wind tunnel models to determine surface pressure distributions and ventilation rates. Reviews the measurement of open areas and leakages. Discusses correlation of measured leakage and ventilation. Describes the British Gas method of measuring ventilation rates using tracer

gas. The system, known as "Autovent" provides a constant concentration of tracer gas and can be used for the continuous monitoring of ventilation rates.

KEYWORDS tracer gas, constant concentration

**#NO 763 Methods of measuring ventilation rates and leakage of houses.**

AUTHOR Dickson D.J. BIBINF Electricity Council Research Centre report ECRC/M1419 April 1981 13p. 12 figs. in English #AIC 410 ABSTRACT Describes methods used at ECRC for measuring the ventilation rate in houses. Two tracer gas methods are used, the decay method and the constant concentration method. Measurements have been made using both nitrous oxide and carbon dioxide as tracer gases. Also describes test of air leakage made by pressurizing the entire house. Gives for each method a detailed description of the measurement technique. KEYWORDS tracer gas, pressurization, measurement technique, decay rate, constant concentration, nitrous oxide, carbon dioxide

**#NO 916 Tracer gas measurements in low leakage houses.**

AUTHOR Blomsterberg A. BIBINF 2nd AIC Conference 'Building Design for Minimum Air Infiltration' Stockholm 21-23 September 1981 1 fig. 1 tab. 4 refs. in English ABSTRACT Measures the air infiltration in individual rooms of a one-storey airtight house, using a special tracer gas measurement technique. Concludes that the overall ventilation rate was very low for the test house, although it had mechanical ventilation (exhaust fan). States that the best way of



getting adequate ventilation is to install a ventilation system with built-in routes where fresh air can enter the building. This should either be balanced ventilation system or an exhaust fan system with special vents to the outside for supplying fresh air.  
KEYWORDS house, tracer gas, decay rate, constant concentration, air change rate, mechanical ventilation, ventilation efficiency, air infiltration

**#NO 975 Air infiltration site measurement techniques**

AUTHOR Harrie D. Grot R. Grimsrud P.  
BIBINF 2nd AIC Conference 'Building design for minimum air infiltration' Sweden 21-23 September 1981 p.113-134 9 figs. 13 refs. in English  
ABSTRACT Gives a summary of the existing types of air infiltration measurement techniques and instrumentation using tracer gases. Describes automated air infiltration instrumentation used by researchers in the US, Canada, the UK, Denmark, Sweden and Switzerland. The equipment can operate in the decay mode, constant flow mode and the constant concentration mode. Most of these instruments are microcomputer or microprocessor based and capable of performing real time determination of the air infiltration rate in multizone buildings and monitor parameters such as temperature, wind speed and energy consumption. Summarizes two simple techniques - the air bag or container method and the average infiltration monitor, developed by researchers in the US.  
KEYWORDS measurement technique, instrumentation, air infiltration, tracer gas, decay rate, constant concentration, constant emission

**#NO 977 Continuous measurements of air infiltration in occupied dwellings.**

AUTHOR Collet P.F.  
BIBINF 2nd AIC Conference 'Building design for minimum air infiltration' Sweden 21-23 September 1981 p.147-160 7 figs. 1 tab. #DATE 21:09:1981 in English  
ABSTRACT Reports on a measurement system developed by the Institute of Technology at Tastrup Denmark, involving a microcomputer- controlled system for registering air change rates using tracer gas (nitrous oxide) according to the constant concentration method. The system is designed for measuring and metering tracer gas in up to 10 separate rooms (using an infrared gas absorption detector). It operates through automatic data logging on a floppy disc and can run without supervision for extended periods (up to six days). This means that the building's true air change rate over a long period can be measured, taking into account factors such as occupancy effects. Gives the results of one day's measurements in a house, and describes the difficulties encountered in maintaining a constant concentration of tracer gas.  
KEYWORDS computer, tracer gas, nitrous oxide, constant concentration, automatic equipment

**#NO 1068 The efficiency of ventilation in a detached house.**

AUTHOR Freeman J. Gale R. Sandberg M.  
BIBINF 3rd AIC Conference "Energy efficient domestic ventilation systems for achieving acceptable indoor air quality" September 20-23 1982 UK p.15.1-15.22 9 figs. 2 tabs. 3 refs. #DATE 20:09:1982 in English

**ABSTRACT** Uses the SEGAS "Autovent" constant concentration apparatus to measure the fresh air entering and the local ventilation rate in each cell of a multi-celled dwelling with both natural and mechanical extract ventilation. Measures fresh air entry into each cell using tracer gas constant concentration and decay techniques. Conducts decay tests without artificial mixing, and interprets them by computing the area under the decay curve to obtain local ventilation rates. Compares the two measurements, giving the ventilation efficiency of each cell and an idea of air quality in each room of the house. Traces the pathways of air movement around the house by injecting an amount of tracer gas into one room and following the transfer to all other rooms of the house.

**KEYWORDS** tracer gas, decay rate, constant concentration, ventilation efficiency, natural ventilation, mechanical ventilation

**#NO 1195 Automated method for measuring ventilation rates. Automatiserad metod for luftvaxlingsmatning.**

**AUTHOR** Lundin L. Blomsterberg A.

**BIBINF** VVS and Energi no.4 1983 p.51-52,62 3 figs. in Swedish

**ABSTRACT** Describes method which permits long term tracer gas measurements in several separate rooms simultaneously. The method employs a fully automated constant concentration system developed at the laboratory for building physics at the Swedish Institute for Materials Testing. Describes measurement principles and practice.

**KEYWORDS** tracer gas, measurement technique, constant concentration

**#NO 1249 Theoretical and experimental techniques for ventilation research in buildings.**

**AUTHOR** Etheridge D. Gale R.

**BIBINF** Preprint 1983 International Gas Research Conference London June 1983 14pp. 8 figs. 12 refs. in English

**ABSTRACT** Describes some new theoretical and experimental techniques developed by British Gas to investigate the ventilation of buildings. These include:< 1. The multi-cell model "vent" for predicting ventilation rates< 2. "Autovent", the multi-cell constant concentration tracer gas technique used for measuring ventilation patterns in buildings.< 3. Pressurization techniques for measuring air leakage in buildings.< Gives a selection of results from applications of these techniques to show their scope.

**KEYWORDS** modelling, multi-chamber, measurement technique, pressurization, natural ventilation, tracer gas, constant concentration

**#NO 1316 Measurements of air change rate and ventilation efficiency in buildings. Misure di portata d'aria di ricambio e di efficienza della ventilazione negli edifici**

**AUTHOR** Sandberg M. Fracastoro G.V.

**BIBINF** Condiz.Riscald.Refrig. Feb.1984 vol.28 no.2 p.141-148 in Italian

**ABSTRACT** Describes the general methodology for ventilation measurements by tracer gas, using decay, constant concentration and constant emission methods. Defines ventilation efficiency and the ways in which it can be experimentally determined. Gives the results of a series of lab measurements to determine the accuracy of the decay method under

different conditions, and the efficiency of some mechanical ventilation systems.  
KEYWORDS measurement technique, tracer gas, decay rate, constant concentration, constant emission, ventilation efficiency

**#NO 1398 Natural and mechanical ventilation in tight Swedish homes - measurements and modelling.**

AUTHOR Blomsterberg A. Lundin L.  
BIBINF Preprint ASTM Symposium on measured air leakage performance of buildings Philadelphia USA April 2-3 1984 22pp. in English

ABSTRACT Evaluates results from constant concentration tracer gas measurements and fan pressurization measurements in three houses and predicts ventilation rates for longer time periods using the LBL model. Test results show that the best way of both supplying adequate ventilation and conserving energy is to make sure that the building envelope is sufficiently tight and then install a mechanical ventilation system. Shows that it is possible to correlate fan pressurization measurements and infiltration rates.  
KEYWORDS pressurization correlation, tracer gas, constant concentration, house, modelling, air infiltration

**#NO 1425 Continuous measurement of air change rate in occupied buildings**

**Boligers luftskifte i brugstilstand**

AUTHOR Kvisgaard B., Collet P F., Kure J.

BIBINF Byggeteknik Teknologisk Institut. Report, 1984, 95pp, 65 figs, 13 tabs, 11 refs. , in Danish

ABSTRACT The Department of Building Technology, the Technological Institute of Copenhagen, have for several years been developing equipment for

continuous measurement of air infiltration. It enables continuous measurement of air change rate in up to ten rooms, the constant concentration method with tracer gas is used, and the results are recorded on a computer diskette during measurement. Analysis of possible measuring errors show that the method is accurate and to within plus or minus 5%. Shows the results of measurement of air infiltration in 10 relatively airtight dwellings. The air change rate of an occupied dwelling can be more than 5 times the air change rate of an unoccupied dwelling.

KEYWORDS constant concentration, tracer gas, air infiltration, instrumentation, measurement technique, tight house, occupancy effects

**#NO 1536 Measurement techniques for air change and air penetration of residential buildings**

**Messmethoden zur Erfassung des Luftwechsels und der Luftdurchlässigkeit von Wohnbauten.**

AUTHOR Muhlebach H.

BIBINF Heizung und Luftung/Chauffage et ventilation, No 5, 1984. p20-22, 6 diags, 1 tab, 10 refs. in German

ABSTRACT Defines air change and air penetration. Describes the differential pressure method, the infrasound method, qualitative judgement methods, and acoustic measurement devices for determining air penetration. Explains procedures to determine air change - the rate of decay method, the constant concentration method, and the constant emission method.

KEYWORDS air change, air leakage, pressurization, tracer gas, thermography

**#NO 1570 Multi-chamber air renewal survey using constant concentration tracer-gas technique.**

**Mesures du taux de renouvellement d'air a l'aide d'un dispositif compact a concentration constante.**

AUTHOR Scartezzini J-L., Roecker C., Quevit D.

BIBINF Groupe de Recherche en Energie Solaire, Ecole Polytechnique Federale de Lausanne, 1984. 13pp, 7 figs, 11 refs. in French

ABSTRACT An accurate determination of air renewal rate and connective exchanges between units was needed for study of the solar units of the experimental building LESO, in both an occupied and empty state. The CESAR compact equipment for tracer gas (nitrous oxide) measurement was developed. This unit uses a microcomputer to perform a simultaneous and periodical gas analysis in 10 locations. Three tracer gas methods can be used: decay, constant concentration, and continuous flow. The device and regulating program work well with low rates of concentration (100ppm of nitrous oxide). The measurements by decay and constant concentration give similar results and with the simultaneous survey of the 10 rooms, a comparison between air movement and infiltration is possible. Occupancy effects can also be evaluated. KEYWORDS air infiltration, tracer gas, nitrous oxide, decay rate, constant concentration, constant emission, air movement, occupancy effects, measurement technique, automatic equipment

**#NO 1714 An automated air infiltration measurement system - its design and capabilities -: preliminary experimental results.**

AUTHOR Lundin L, Blomsterberg A. BIBINF Air Infiltration Review, November 1982, Vol 4, No 1, p8-10. 7 figs. in English

ABSTRACT Describes a completely automated constant concentration tracer gas technique for measurement of air infiltration. The equipment consists of five components: 1 a controller, 2 a tracer gas analyzer, 3 an injection and sampling unit, 4 special mixing fans and 5 apparatus for the calibration of the tracer gas flow. The system is controlled by a microcomputer.

KEYWORDS tracer gas, constant concentration, measurement technique, automatic equipment, microprocessor

**#NO 1752 Research on fresh-air change rate: 1. occupants' influence on air-change.**

AUTHOR Kvisgaard B, Collet P F, Kure J.

BIBINF 2nd. ed. Copenhagen, Denmark: Building Technology, Technological Institute of Copenhagen, 1985. 233p. 168 figs, 41 tabs, 14 refs. in English AIVC bk

ABSTRACT Knowledge of the air change in dwellings under conditions of use is a prerequisite for the calculation of energy consumption and for evaluation of a dwelling's indoor climate. Air change was measured in a total of 25 occupied dwellings over an aggregate period of 205 days, using the constant concentration tracer gas method. Results showed that the occupants exert a very considerable influence on the total air change in the dwelling. The air change rate for occupied dwellings is, on average, 3-4 times greater than the air change rate in sealed buildings (with air-escape valves, doors, windows and ventilation systems closed). The average air change rate for

the sealed dwellings is 0.19 ach. Although the average air change rate for occupied dwellings is higher than the recommended rate, some 20% of dwellings have an extremely low air change rate. Mechanically ventilated dwellings tend to have a higher air change rate than naturally ventilated dwellings. Air-escape valves with apertures of 30 cm<sup>2</sup> per room were not found to provide the requisite air change rate for sealed dwellings.

KEYWORDS air change rate, occupancy effects, measurement technique, tracer gas, constant concentration

**#NO 1784 Continuous air renewal measurements in different inhabited buildings.**

AUTHOR Scartezzini J-L, Roulet C-A, Jolliet O

BIBINF 6th AIC Conference

"Ventilation Strategies and Measurement Techniques", Het Meerdal Park, Netherlands, 16-19 September 1985.

Bracknell, UK: Air Infiltration Centre, 1985. p9.1-9.19. 16 figs, 6 refs.

inEnglish AIVC bk

ABSTRACT A Compact Equipment for Survey of Air Renewal (CESAR) was developed at the Ecole Polytechnique Federale de Lausanne in Switzerland. Controlled by a microcomputer and using tracer gas methods, this apparatus can monitor up to ten different locations in inhabited rooms simultaneously over extended periods of time. Decay, continuous flow or constant concentration methods can be used, but the constant concentration technique is mainly used. Several air renewal surveys were carried out on different inhabited buildings. During the 1983/84 and 1984/85 heating seasons the following three buildings were investigated: an

inhabited passive solar office building (LESO building), a three storey one family Swiss dwelling, and a low energy test greenhouse at the European Nuclear Research Centre (CERN). The following significant results were obtained: air renewal measurements surveys were carried out in different inhabited buildings over several weeks, determination of actual outdoor-to-room and building-to-room flow rates were obtained in multi-chamber house configurations, and the influence of inhabitants on the various airflow rates was determined. A short description of the apparatus is also reported.

KEYWORDS house, greenhouse, office, air change rate, air movement, air infiltration, occupancy effects, measurement technique, tracer gas, decay rate, constant concentration, constant emission, nitrous oxide

**#NO 1796 Improving the accuracy of a constant concentration tracer gas system.**

AUTHOR Bohac D L, Harrije D T

BIBINF 6th AIC Conference

"Ventilation Strategies and Measurement Techniques", Het Meerdal Park, Netherlands, 16-19 September 1985.

Bracknell, UK: Air Infiltration Centre, 1985. p25.1-25.23. 10 figs, 20 refs.

inEnglish AIVC bk

ABSTRACT Air infiltration flows into different zones of a building can be measured with the constant concentration technique by injecting a metered amount of tracer gas to hold the concentration of the gas constant. The control and estimation algorithm used to calculate the injection rate is designed using classical transform and optimal estimation methods. The ability of the control algorithm to keep the concentration constant and to accurately

measure time varying infiltration flows is demonstrated using digital computer simulations and laboratory experiments. Field demonstrations then complete the confirmation that all components of the total system are performing as designed, and that the desired accuracy targets have been achieved. The details of how constant concentration system accuracy targets were attained in the Princeton constant concentration tracer gas measurement system are outlined in this paper. Before the total system accuracy goals could be achieved it was necessary to focus attention on the commercial SF<sub>6</sub> detection unit based upon the principles of gas chromatography and electron capture. Gas flow paths, sequencing and critical times in a given sample analysis all directly impinge on the total system function and ultimate accuracy. Some of the points discussed are: internal air leakage, valve switching, and calibration of various subsystems.

**KEYWORDS** tracer gas, measurement technique, constant concentration, sulphur hexafluoride

**#NO 1905 Final report on the Alberta home heating research facility: results of the 1981-82 heating season and part of the 1982-83 heating season to January 1983.**

**AUTHOR** Ackerman M Y, Dale J D, Forest T W, et al.

**BIBINF** Departmental Report Number 34. Edmonton, Canada: University of Alberta, Dept of Mechanical Engineering, 1983. 138p. 53 figs, 14 tabs, 9 refs. in English

**ABSTRACT** This study used a constant concentration tracer gas measurement system to measure the air infiltration rate of three modules simulating residential buildings in Canada. The results

obtained were compared with computer predictions.

**KEYWORDS** measurement technique, sulphur hexafluoride, constant concentration, mathematical modelling

**#NO 1947 A quantitative estimate of the accuracy of tracer gas methods for the determination of the ventilation flow rate in buildings.**

**AUTHOR** Sandberg M, Blomqvist C  
**BIBINF** Building and Environment, 1985, Vol 20, No 3, p139-150. 8 figs, 5 tabs, 5 refs. in English

**ABSTRACT** This paper presents a quantitative estimate of the error of the decay and constant concentration method. A number of tests were carried out in an indoor test house located in the laboratory hall at the National Swedish Institute for Building Research. The relevant meaning of the concept of air-exchange rate is discussed and an appropriate terminology is suggested. The theoretical background, based on a multi-cell model, of the two tracer gas methods is given. Results of the studies of the accuracy of the tracer gas methods are presented, with some results of the studies of the effect on the infiltration rate due to different operation modes of mechanical ventilation systems.

**KEYWORDS** tracer gas, measurement technique, decay rate, constant concentration, multi-chamber

**#NO 2050 Interim Report on the Continuous Injection Air Infiltration Measuring Device,**

**AUTHOR** Mencher, P.,  
**BIBINF** National Bureau of Standards, Princeton University's Center for Environmental Studies, , in English  
**ABSTRACT** This report contains a brief description of an air infiltration measuring device jointly developed by

the National Bureau of Standards and Princeton University's Center for Environmental Studies. The device maintains a constant concentration of a tracer gas (SF<sub>6</sub>) in each room of a structure by injection, and relates the infiltration rate for each room to the rate of gas injected. Specifics of construction and use are included.,

KEYWORDS air infiltration, tracer gas instrumentation multi chamber

**#NO 2920 Simple adaptive control for constant tracer gas concentration.**

AUTHOR Jensen L

BIBINF Sweden, Lund Institute of Technology, Department of Building Science, Report BKL 1988:9(E), 1988, 13pp, 4 figs, 4 tabs. in English  
ABSTRACT This report describes two simple adaptive controllers for constant tracer gas concentration. The first controller determines the diluting flow from a simple mass balance equation and actual measurements. The volume is assumed to be known. The second controller determines both the diluting flow and the volume indirectly from a discrete time model determined by the least squares method and actual measurements. The first and simpler controller with fixed volume turns out to be the safest. The second controller gets out of control after too accurate control which makes the equation system in the least squares method badly conditioned. Full-scale test runs are made with both controllers for a small office room.

KEYWORDS constant concentration, tracer gas

**#NO 3572 Accuracy and development of tracer-gas measurement equipment.**

AUTHOR Kvisgaard B, Collet P F

BIBINF in:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-

28 September 1989, Volume 2, February 1990, pp1-16, 5 figs, in English

ABSTRACT In 1979 a project was launched at the Technological Institute, Copenhagen with the purpose of developing a method for continuous measurement of air change rates in occupied dwellings. Today - 10 years later - we can introduce the first generation of mass-produced measuring equipment performing measurements of air change rates employing the method of constant concentration of tracer gas. The principles used in the first model, which was introduced 1981, are largely identical to those used in the latest model. However, components and programmes have been changed several times. Furthermore, through the years new programmes that expand the capability of the measuring equipment have been developed. The paper will discuss the development that has taken place over the 10 years, which problems have caused the biggest trouble and how they were solved. Also, the types of measurement performed with the equipment will be touched upon, and we shall take a closer look at a couple of special measurements. Finally, the accuracy of the equipment as well as the cost of reaching today's level of development will be discussed.

KEYWORDS tracer gas, measurement technique, instrumentation, constant concentration

**#NO 4637 Tracer gas measurements in apartment buildings.**

AUTHOR Levin P

BIBINF Sweden, Swedish Council for Building Research, "Building Physics in the Nordic Countries", D13:1988, 6pp, 2 figs, refs. in English

ABSTRACT The development of a tracer gas method for measurements of

air change rates including passive sampling is briefly described. This method has the potential to be used in a large scale at a reasonable cost. It is also suitable for use of many tracer gases to be analysed in the same sample. The results from recent calibration measurements show that improvements of the analytical system is necessary before final evaluation of e.g. systematical measurement errors can take place. Results from continuous tracer gas measurements with the constant concentration method for one unoccupied apartment with mechanical exhaust ventilation show very small differences in air change rate due to fluctuations in wind speed and wind direction.

**KEYWORDS** tracer gas, apartment building, passive sampling

**#NO 4922 Ten years of constant concentration tracer gas measurements.**

**AUTHOR** Collet P F, Egedorf M  
**BIBINF** Air Infiltration Review, Vol 9, No 2, February 1988, pp 2-3, 5 figs, 1 ref. in English

**ABSTRACT** Ten years ago the automated constant concentration tracer gas (CCTG) method was conceived at the Technological Institute, Tastrup, Denmark. This technique is now used by researchers to examine a wide variety of air infiltration and ventilation related problems. At this juncture it would seem appropriate to summarise the development of the CCTG system and examine its use in present day research.  
**KEYWORDS** constant concentration, tracer gas measurements

**#NO 5301 An integral mass balance formulation of the constant concentration tracer technique.**

**AUTHOR** Axley J  
**BIBINF** UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 3, pp 39-50. in English

**ABSTRACT** This paper extends the integral mass balance approach to the remaining constant concentration technique. An integral formulation of the constant concentration problem is presented that accounts for the possibility of variation of tracer concentration. This approach leads, in principle, to data reduction strategies that may be expected to improve the accuracy of the constant concentration technique and that may be used to isolate those portions of a given constant concentration data set that are likely to be most reliable. The method is applied to the reduction of constant concentration data sets measured at the National Swedish Institute for Building Research and the results of this application are reviewed.

**KEYWORDS** constant concentration, tracer gas

**#NO 5842 6th AIC Conference: Ventilation strategies and measurement techniques: Proceedings.**

**AUTHOR** Air Infiltration and Ventilation Centre  
**BIBINF** UK, Air Infiltration and Ventilation Centre, 6th AIC Conference Proceedings, held at Het Meerdal Park, Southern Netherlands, 16-19 September, 1985. in English

**ABSTRACT** Contains twenty seven papers from the sixth AIC Conference as follows: Ventilation, the balance between energy and well-being, The infiltration component of ventilation in



New Zealand houses, Ventilation research and characterization in three types of residences, A passive ventilation system under trial in UK homes, Indoor air quality and air exchange in bedrooms, Effect of unvented combustion appliances on air exchange among indoor spaces, Air exchange rates based upon individual room and single cell measurements, Multiple cell air movement measurements, Continuous air renewal measurements in different inhabited buildings, The reduction of air infiltration in an industrial laboratory, Ventilation of factories, Advanced energy-efficient ventilation, Design for ventilation, Air quality and energy conservation by different ventilation strategies, Exploration of ventilation strategies in domestic housing. Theory and experimental results, Mechanical ventilation system requirements and measured results for homes constructed under the R-2000 super energy-efficient home program, Indoor formaldehyde levels in houses with different ventilation strategies, Development of a simplified multizone infiltration model, Multizone modeling and air leakage analysis, Inhabitants behaviour with regard to ventilation, the use of windows. First heating season, Basic material for the instruction of occupants of homes. How, when and where to use your windows, Monitoring of ventilation and humidity in crawl spaces of dwellings, Ventilation strategies for crawl-spaces, attics, etc, Use of a single tracer gas for measurement of ventilation rates in a large enclosure, Improving the accuracy of a constant concentration tracer gas system, Ventilation system performance evaluation using tracer gas techniques, Ventilation efficiency

measurements in occupied mechanically ventilated buildings.

KEYWORDS ventilation strategy, measurement technique

## 4.5 Passive Sampling Techniques

### **#NO 1129 Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique.**

AUTHOR Dietz R.N. Cote E.A.  
BIBINF Proceedings of the International Symposium on indoor air pollution, health and energy conservation Amherst Mass. USA 13-16 October 1981

Environmental International Special Issue "Indoor Air Pollution" vol.8 no.1 1982 p.419-433 9 tabs. 11 figs. 22 refs. in English

ABSTRACT Using miniature perfluorocarbon tracer (PFT) sources and miniature passive samplers, tests conducted in the lab and in a typical home successfully demonstrate the utility of the PFT kit as a means for implementing wide-scale infiltration measurements in homes. Shows that the PFT diffusion plug source provides steady-state concentrations in a home of about 1-10 pL/L when one source is deployed for each 28-46 m<sup>2</sup> of living space. Together with a programmable tracer sampler, deploys miniature diffusion sources and samplers in a typical home, uses 6 PFT sources, 3 on each level of a two-storey house. Shows that even in a house without forced-air circulation, a well-mixed modelling approach is justified. Analyses tracer samples using a gas chromatograph. Comparison with SF<sub>6</sub> tracer decay approach shows the results of the 2 methods to be similar. With the PFT kit,

infiltration rates in the range 0.2-0.5 ac/hr can be measured over time-averaged periods of as little as one day up to several years.

KEYWORDS air infiltration, tracer gas, decay rate, perfluorocarbon, instrumentation, measurement technique

**#NO 1732 Detailed description and performance of a passive perfluorocarbon tracer system for building ventilation and air exchange measurements.**

AUTHOR Dietz R N, Goodrich R W, Cote E A, et al.

BIBINF Paper presented at the Symposium on Measured Air Leakage Performance of Buildings, American Society for Testing and Materials, Philadelphia, Pennsylvania, April 2-3, 1984. Upton, New York, USA:Brookhaven National Laboratory, Dept of Applied Science, February 1985. 104p. 15 figs, 23 tabs, 26 refs. in English  
ABSTRACT The manufacturing procedures and performance of a building air infiltration kit consisting of miniature passive perfluorocarbon tracer permeation sources and passive adsorption tube samplers are described. Having four PFT-types available, homes and buildings with up to four separate zones can be fully evaluated under steady state conditions for the air infiltration and exfiltration rates from each zone as well as the air exchange rates between zones using this inexpensive and non-obtrusive field kit. Complete details on deployment in homes and on gas chromatographic analysis of the passive samplers are presented. Examples of total air changes per hour results in several studies showed average values between 0.25 to 0.64 h<sup>-1</sup>. A generalized correlation was used to characterize the leakiness of

eleven homes in the US and Canada, showing ACH dependency only on inside-outside temperature difference, wind speed to the 1.5 power, and a subjective terrain factor: the approach has application in evaluating weatherization performance. Details of multizone measurements in four homes provided insight into the role of attics, crawl-spaces, and basements on the indoor air quality and weatherization needs for the living zone.

KEYWORDS air infiltration, tracer gas, perfluorocarbon, passive sampling, multi-chamber, measurement technique, air change rate, air quality, attic, basement

**#NO 1737 Brookhaven Air Infiltration Measurement System (BNL/AIMS). Description and Application.**

AUTHOR Dietz R N, Goodrich R W, Cote E A, et al.

BIBINF Upton, New York, USA: Brookhaven National Laboratory, 1983. BNL 33846. 17p. 4 figs, 5 tabs, 3 refs. in English

ABSTRACT A capability to measure part-per-quadrillion concentrations of a family of perfluorocarbon tracers (PFTs) has been developed. Together with the PFT source and passive sampler, measurement of average air exchange and infiltration rate can be determined for periods as short as 12 hours. A more expensive programmable sampler can provide information on a frequency of as little as once per minute for each of its 23 sampling tubes. The principal of AIMS is based on the applicable steady-state assumption that the average concentration of a tracer gas in a chamber is equal to the emission rate of the tracer source divided by the air leakage or infiltration rate. Knowing the source rate and measuring the average

concentration then provides a means to calculate the air leakage rate. Extending this technique to a multichamber concept, in which a different type of PFT source is deployed in each chamber of a building, allows the calculation of not only the infiltration rates in each chamber but also the air exchange rates between chambers as well. Since both the PFT source and the passive sampler, a miniature Capillary Adsorption Tube Sampler (CATS), are about the size of a cigarette, inexpensive and reusable, the BNL/AIMS is a very cost-effective means for determining these air exchange rates.

KEYWORDS perfluorocarbon, tracer gas, measurement technique, passive sampling, multi-chamber

**#NO 1834 Evaluation of the perfluorocarbon tracer technique for determining infiltration rates in residences.**

AUTHOR Leaderer B P, Schaap L, Dietz R N

BIBINF BNL 36334. February 1985. 33p. 4 figs, 7 tabs, 18 refs. in English

ABSTRACT A simple means for determining air infiltration rates into homes and buildings for assessment of indoor air quality and energy conservation measures, based on a passive perfluorocarbon tracer (PFT) technique, was evaluated in a well-defined environmental chamber under experimental conditions of 1) constant temperature and ventilation rate, 2) constant temperature, variable ventilation rate, and 3) variable temperature, constant ventilation rate. Two PFT sources of known emission rate and temperature dependence produced chamber concentrations of 100 to 300 nL/m<sup>3</sup> (parts per trillion). The average relative standard deviation of 16

paired samplers deployed for 44 h during experiment 1 indicated good reproducibility of the passive sampling rate and analysis and there was little consequence of sampler orientation with respect to the low air velocities (<0.2 m/s) present in houses. Even with the nearly 3-fold variation in ventilation rates during experiment 2, the passive samplers accurately measured the average chamber tracer concentration as calculated from the known source strength and the measured ventilation rates based on CO<sub>2</sub> concentration decay: such large ventilation rate variations caused a 10% negative bias in the PFT-determined ventilation rate. Temperature cycling differences of as much as 8 degrees C were accommodated to provide essentially no bias in the PFT-determined ventilation rate. The PFT technique is applicable to the expected range of conditions in homes and buildings.

KEYWORDS tracer gas, perfluorocarbon, measurement technique, passive sampling, air change rate, environmental chamber

**#NO 2278 Evaluation of the perfluorocarbon tracer technique for determining infiltration rates in residences.**

AUTHOR Leaderer B P, Schaap L, Dietz R N

BIBINF Environ Sci Technol, Vol 19, No 12, 1985. p1225-1232. 4 figs, 7 tabs, 18 refs. in English

ABSTRACT Describes the evaluation of a new simple passive perfluorocarbon tracer technique for determining air infiltration rates into houses and buildings. The authors explain the methods used and present and discuss their results.

KEYWORDS tracer gas, house, residential building

**#NO 2594 The use of detector tubes with carbon dioxide as a tracer gas.**

AUTHOR Sandberg M, Sundberg J  
BIBINF AIR, Vol 8, No 3, May 1987, p6-7, 2 figs, 1 tab, 2 refs. in English

ABSTRACT Tracer gas concentrations are often analysed by using infrared spectroscopy. Infrared gas analysers have a fast response time and are accurate. However, this type of instrumentation is relatively expensive and can only be used for this type of measurement. A cheaper alternative is therefore preferred. Normally there is a trade-off between cost and accuracy. Detector tubes are inexpensive and are available for many gases, among them CO<sub>2</sub>. They are packed with a selective solid absorbent which gives a colour reaction with the gas in question. The higher the concentration of gas which enters the tube the further the coloured region extends down the packing. The tubes have approximate calibration markings which show the concentration of the gas. This article reports a method of measuring the ventilation airflow rate using a tracer decay technique in occupied houses with CO<sub>2</sub> as a tracer gas. The metabolic CO<sub>2</sub> from people is taken into account. The accuracy of the method has been explored through various tests.

KEYWORDS tracer gas, carbon dioxide, instrumentation, ventilation rate, decay rate, residential building, measurement technique

**#NO 2825 Influence of airflow on the performance of perfluorocarbon tracer techniques for measuring ventilation rates.**

AUTHOR Vercammen M, Leaderer B P, Dietz R N

BIBINF in: Indoor Air '87, Proceedings of 4th International Conference on Indoor Air Quality and Climate, Berlin (West), 17-21 August 1987. Vol 3  
Institute of Water, Soil and Air Hygiene, 1987, p 388-392, 3 figs. 3 refs. in English

ABSTRACT The perfluorocarbon tracer technique (PFT) is being extensively used for determining air infiltration rates in residences and office buildings. The method has been evaluated in chamber studies for effects of temperature, variable ventilation rates and orientation of the passive capillary collectors in low air velocities (<2m/s) typical of residences. This paper presents the results of chamber studies designed to evaluate the PFT method under conditions of constant temperature and high air velocities (0.8 to 6.4 m/s). The efficiency of the passive capillary collectors was evaluated as a function of air velocity and orientation in the flow. Two different enclosures for the collectors, designed to minimize the air velocity effects, were also evaluated. The results indicate that air velocities above 0.8 m/s and collector orientation affect the efficiency of the collectors. Enclosing the collector and orienting it 180° to the flow minimizes effect.

KEYWORDS airflow, perfluorocarbon, tracer gas, ventilation rate

**#NO 3095 The AIMS Monitor: Measuring Infiltration not Tightness.**

AUTHOR Dupont P  
BIBINF Energy Auditor and Retrofitter, Vol.4, No.1 Jan/Feb 1987, pp6-11. in English

ABSTRACT A monitor to measure the effective ventilation rate in houses, over extended periods of time, is described.

The infiltration measurement system was developed by Russell Dietz at Brookhaven Laboratory in New York to provide a reliable low-cost method for determining the infiltration rate in buildings. A comparison of the uses of the AIMS Infiltration Monitor and blower doors is made. It is concluded that AIMS is a useful tool for builders, housing authorities, building inspectors, and utility program managers who need to accurately assess and quantify the impact of weatherization and shell tightening measures on building performance.

KEYWORDS tracer gas, passive sampling, constant emission

#### **4.6 Comparison of Tracer Gases**

##### **#NO 200 An intercomparison of tracer gases used for air infiltration measurements.**

AUTHOR Grimsrud D.T. Sherman M.H. Janssen J.E. Pearman A.N. Harrje D.T. BIBINF Lawrence Berkeley Laboratory. University of California paper LBL-8394 2 figs =ASHRAE trans. 1980. vol 86 no 1. in English

ABSTRACT Reviews ideal characteristics of a tracer gas and gives literature review of the subject. Reports tests made on a house in California giving a direct intercomparison between common tracer gases used to measure air infiltration rates in buildings. Results indicate that air exchange rates measured using sulphur hexafluoride are slightly larger than those measured using methane or nitrous oxide. The ratio of air change rates measured using sulphur hexafluoride to air change rates measured concurrently using a lighter tracer gas was found to be  $1.10 \pm 0.10$

KEYWORDS tracer gas, air change rate, sulphur hexafluoride, methane nitrous oxide

##### **#NO 1005 The effect of tracer gas on the accuracy of air change measurements in buildings.**

AUTHOR Shaw C.Y.

BIBINF Preprint for ASHRAE Atlantic Meeting January 23-27 1983 30pp. 10 figs. 5 tabs. 6 refs. in English

ABSTRACT Compares the air change rates measured using the decay method with several different tracer gases.

Tracer gas measurements were conducted in a tightly sealed room where constant air leakage rates were maintained using an exhaust fan. Tracer gases investigated were CH<sub>4</sub>, CO, CO<sub>2</sub>, N<sub>2</sub>O and SF<sub>6</sub>. Agreement between tracer gas measurements and measured flow rates of the exhaust fan was very good for CH<sub>4</sub>, CO and N<sub>2</sub>O. The agreement was also satisfactory for CO<sub>2</sub> and SF<sub>6</sub>, but the scatter in tracer gas data was much greater than it was for the other three gases.

KEYWORDS tracer gas, decay rate, methane, carbon monoxide, carbon dioxide, nitrous oxide, sulphur hexafluoride

#### **4.7 Comparison of Tracer Gas Methods**

##### **#NO 284 An automated air infiltration measuring system using SF<sub>6</sub> tracer gas in constant concentration and decay methods**

AUTHOR Kumar R. Ireson A.D. Orr H.W.

BIBINF ASHRAE trans. vol 85 part2 p385-395 9 figs, 5 refs. in English

ABSTRACT Describes a system which measures the rate of air infiltration in

buildings using sulphur hexafluoride as a tracer gas. Discusses two methods for evaluating the infiltration rate, the decay method and the constant concentration method. The system automatically operates a portable electron capture detector /chromatograph and samples air on a one-minute cycle. In the decay method the slope of concentration vs. time on a semi-logarithmic plot can be used to compute infiltration rate. In the second method the infiltration rate is proportional to the rate at which tracer gas must be injected to maintain a constant concentration.

KEYWORDS tracer gas, sulphur hexafluoride, instrumentation, air infiltration, automatic equipment

**#NO 1954 A comparison of the perfluorocarbon and tracer gas decay methods for assessing infiltration.**

AUTHOR Schaap L, Leaderer B P, Renes S, et al.

BIBINF Proceedings of the CLIMA 2000 World Congress on Heating, Ventilating and Air-Conditioning, Copenhagen, 25-30 August 1985. Edited by P Fanger. Vol 2 Building Design and Performance. p19-24. 1 fig, 1 tab, 3 refs. in English

ABSTRACT The passive perfluorocarbon tracer (PFT) technique for determining air infiltration rates into homes and buildings was evaluated in an environmental chamber. The impact of sampler orientation at a constant ventilation rate and a constant temperature, of variable ventilation rate at a constant temperature, and of variable temperature at a constant ventilation rate were evaluated in three experiments. The average relative standard deviation of 16 paired samplers deployed in experiment 1 was plus or minus 1.9% plus or minus 1.0%

indicating good reproducibility of the passive sampling rate and sample analysis. No impact of sampler orientation with respect to low air velocities (less than 0.2 m/s) present in houses is expected. The passive samplers accurately measured the average tracer concentration as compared with calculations based on the known source strength (CO<sub>2</sub> decays) and the measured ventilation rate under conditions of a 3-fold variation in ventilation rates (experiment 2). Temperature cycling differences of 8 deg. C (experiment 3) did not produce a bias in the PFT determined ventilation rate. The PFT technique is applicable to the expected range of conditions in homes and buildings.

KEYWORDS perfluorocarbon, environmental chamber, decay rate, passive sampling

**#NO 2367 Predicting a time-varying flow rate using the constant concentration and decay technique.**

AUTHOR Sandberg M

BIBINF Ashrae Trans, Vol 93 Part 1, 4 figs, 1 tab, 3 refs. in English

ABSTRACT This study deals with the accuracy of different tracer gas techniques for predicting the mean flow rate of a time-varying airflow rate, as occurs in naturally ventilated houses. A theoretical analysis of the accuracy is first presented. Experiments were conducted in a test house ventilated by natural ventilation. The methods explored were the constant concentration method and the decay method. The airflow rate in the duct connected to the house was continuously recorded by the constant tracer gas flow technique. The oscillations in flow rates that occurred were of a high frequency nature, which

should not affect the accuracy.  
Incomplete mixing of both tracer gas and air seems to be the greatest source of error, even in cases with a time-varying ventilation airflow rate.  
KEYWORDS tracer gas, airflow, natural ventilation

**#NO 2738 Field study comparisons of constant concentration and PFT infiltration measurements.**

AUTHOR Bohac D L, Harje D T, Horner G S

BIBINF 8th AIVC Conference, 'Ventilation Technology - Research and Application', Ueberlingen, Federal Republic of Germany, 21-24 September, 1987, Supplement to Proceedings, p47-62, 9 figs, 10 refs. in English

ABSTRACT The accuracy of tracer gas measurements of building air infiltration rates has been a widely discussed topic. One question that has often come up at past AIVC conferences is the ability of passive methods, such as the Perfluorocarbon Tracer (PFT) method, to accurately measure fluctuation airflow rates. A series of field studies is being conducted to compare the air infiltration measurements of the constant concentration tracer gas (CCTG) and PFT methods and provide recommendation for their proper implementation in the field. The field studies include side-by-side measurements of multi-zone air infiltration rates using the CCTG and PFT methods. The results are reported from two tests in an unoccupied single-family house and eight tests in an occupied house. Test periods varied from one to three weeks. The measurements from the unoccupied house showed that there were no major discrepancies between the two methods. The PFT measurements in the occupied

house were consistently lower than those by the CCTG method. Warm weather periods with substantial, periodic airing resulted in the PFT method producing under-prediction errors greater than 30%. During the cold weather periods when the fluctuation in the infiltration rate was due to weather changes and a small amount of airing, the under-prediction error ranged from 5 to 29%.  
KEYWORDS constant concentration, perfluorocarbon, tracer gas measurements

**#NO 4642 A quantitative estimate of the accuracy of tracer gas methods for the determination of the ventilation flow rates in buildings.**

AUTHOR Sandberg M, Blomqvist C  
BIBINF Building and Environment, No 5, 1985, pp 139-150, 8 figs, 3 tabs, 5 refs. in English

ABSTRACT The paper presents a quantitative estimate of the error of the decay and constant concentration method. A number of tests were carried out in an indoor test house located in the laboratory hall at the National Swedish Institute for Building Research. At the beginning of the paper the relevant meaning of the concept 'air-exchange rate' is discussed and an appropriate terminology is suggested. Then follows a presentation of the theoretical background, based on a multi-cell model, of the two tracer gas methods studied experimentally. Finally, the results obtained are given. Apart from the accuracy of the tracer gas methods, some results of studies of the effect on the infiltration rate due to different operation modes of mechanical ventilation systems are also presented.  
KEYWORDS tracer gas measurements, ventilation rate

**#NO 4866 Errors in the measurement of local and room mean age using tracer gas methods.**

AUTHOR Sutcliffe H C, Waters J R  
BIBINF UK, AIVC 11th Conference, "Ventilation System Performance", held 18-21 September 1990, Belgirate, Italy, Proceedings published March 1990, Volume 2, pp 279-292, 7 figs, 9 tabs, 1 ref. in English

ABSTRACT Local and room mean ages of the air in a room may be measured by three versions of the tracer gas technique, which are the pulse method, the tracer step-up method and the tracer decay method. The values of mean age obtained are of course subject to errors in the measurement of the tracer gas concentrations. The sensitivity of the three methods to errors in the tracer gas concentrations is not the same, and in some cases can be very large. In order to examine this problem, test measurements have been carried out in a model room using the three different methods. The results obtained from these tests were then compared with each other, and with theoretical data, which was generated with differing levels of error. It has been found that the step-up method was the least reliable and local and room mean ages generated using this method varied substantially from mean ages measured using the other two tracer gas techniques.

KEYWORDS ageing, tracer gas measurements

**#NO 6377 A study of ventilation measurement in an office building.**

AUTHOR Dols W S, Persily A K  
BIBINF USA, National Inst of Standards and Technology, NISTIR 4905, October 1992, 42pp, 11 figs, 10 tabs, refs. in English

ABSTRACT The National Institute of Standards and Technology has conducted a study of ventilation and ventilation measurement techniques in the Bonneville Power Administration (BPA) Building in Portland, Oregon. The project involved the comparison of outdoor air ventilation measurement techniques for relative accuracies and an examination of changes in building ventilation rates over time. The following measurement techniques were compared: tracer gas decay measurements of whole building air change rates, the determination of air change rates based on peak carbon dioxide (CO<sub>2</sub>) concentrations, the determination of percent outdoor air intake using tracer gas (sulfur hexafluoride and occupant-generated CO<sub>2</sub>), and direct airflow rate measurements within the air handling system. In addition, air change rate measurements made with an automated tracer gas decay system approximately three years apart were compared. The major findings of the study are as follows. Airflow rates were measured in the air handling system ductwork using pitot tube, hot-wire anemometer, and vane anemometer traverses, and good agreement was obtained between the different techniques. While accurate determinations of percent outdoor air intake were achieved using tracer gas techniques, the use of CO<sub>2</sub> detector tubes yielded unreliable results. Reliable determinations of ventilation rates per person were made based on SF<sub>6</sub> decay and direct airflow rate measurements but the use of peak CO<sub>2</sub> concentrations led to inaccuracies, i.e., the over prediction of ventilation rates by as much as 100%. The measured values of the whole building air change rates, and their dependence on outdoor air temperature,



did not change significantly over a three year period. The minimum air change rates were above the building design value and ASHRAE Standard 62-1981, the standard on which the design was based, but the minimum rates were below the minimum recommendation given in Standard 62-1989. The whole building air change rate under minimum outdoor intake conditions was determined to be twice the outdoor air intake rate provided by the minimum outdoor air intake fans. The additional air change under minimum outdoor air intake conditions was due primarily to leakage through the main outdoor air intake dampers.

KEYWORDS ventilation rate, measurement technique, office building, outdoor air

## **5.0 Air Exchange Measurements for Multizone Systems**

### **5.1 Single Gas Techniques**

**#NO 1862 Documenting air movements and infiltration in multicell buildings using various tracer-gas techniques.**

AUTHOR Harje D T, Dutt G S, Bohac D L, et al.

BIBINF Preprint. ASHRAE

Transactions 1985, Vol 91, Pt 2. HI-85-40 No 3. 15p. 11 figs, 18 refs. in English

ABSTRACT Tracer gas techniques for measuring airflows in buildings fall into three categories - dilution, constant injection, and constant concentration. Dilution of a single tracer works well in buildings with a single zone and also in some two-zone buildings. Multiple tracer gas measurements, necessary to characterize flows among more zones,

are best conducted using the constant injection approach. The constant concentration method uses a single tracer gas to determine the airflow rates from the outside into each of as many as ten building zones. The paper outlines the different tracer techniques for making airflow measurements in multicell buildings and describes the operation of a constant concentration system. This system measures tracer gas concentration in different zones and injects accordingly to maintain a constant concentration in each zone. The system was tested in a single zone structure and successfully applied to a small three-zone house. Sensitivity analyses and calibration procedures described in this paper define the capabilities and limitations of this technique. Although this method does not fully characterize all interzone airflows in the building, it can be useful in analyzing the energy balance of multizone buildings. Additionally, these measurements can be used to evaluate the dilution of indoor air pollutants and the ventilation efficiency of buildings.

KEYWORDS multi-chamber, tracer gas, measurement technique, decay rate, constant concentration, constant emission, air movement, air infiltration

**#NO 1895 Strategy for measuring infiltration rates in large, multicelled and naturally ventilated buildings using a single tracer gas.**

AUTHOR Perera M D A E S, Walker R R

BIBINF Building Services Engineering Research & Technology, 1985, Vol 6, No 2, p82-88. 5 figs, 5 tabs, 7 refs. in English

ABSTRACT Large, multi-celled and naturally ventilated buildings pose many inherent problems for the measurement

of overall infiltration rates using tracer gases. Considering a single tracer gas decay technique, the most obvious problems are: (a) local variations in infiltration, (b) imperfect internal mixing of the air, and (c) practical difficulties in distributing (i.e., seeding) the tracer gas and subsequently obtaining air samples. This paper proposes a relatively simple technique which avoids these problems and which, if successful, makes a breakthrough in the measurement of infiltration rates in large and complex buildings. By considering a multi-cell model, it is shown that it can be sufficient to seed part of a building with a single tracer gas in order to measure the overall infiltration rate to a good approximation.

KEYWORDS measurement technique, multi-chamber, tracer gas, decay rate, mathematical modelling

**#NO 2076 The use of a constant concentration tracer gas system to measure ventilation in buildings.**

AUTHOR Bohac D L

BIBINF PU/CEES Report No 205, February 1986. 292p. 81 figs, 17 tabs, 45 refs in English

ABSTRACT A constant concentration tracer gas system was designed and constructed to continuously measure the air infiltration rate in as many as ten zones of a building. The portable, microcomputer controlled system injects a metered amount of tracer gas into each zone so that the concentration of the gas is held at the same target level in all the zones. With the concentration kept at the target level, the air infiltration rate of a zone is approximately equal to the tracer injection rate into the zone divided by the target concentration. The system was field tested for 11 days in an unoccupied single family house. Analysis of the data

indicate that the system is generally reliable. The startup time and control of the system was as good as, or superior to, that achieved by other constant concentration tracer gas systems. The measured air infiltration rates were reasonable and appear to respond to both wind and stack effects. In addition, large differences in the infiltration in separate zones of the house were able to be measured even when there was a high degree of interzone mixing.

KEYWORDS house, tracer gas, constant concentration, measurement technique, multi-chamber, sulphur hexafluoride

**#NO 2666 Time lags in a two-zone air movement model.**

AUTHOR Waters J R

BIBINF Bldg Serv Res Tech, Vol 18, 1987, 43-46, 7 figs, 5 refs. in English

ABSTRACT Multi zone models of air movement in buildings usually assume that there is no time lag in the flows between zones. Nevertheless, such time lags could have a significant effect on the pattern of contaminant distribution throughout a building. This note shows how such effects can be evaluated by examining theoretically a two zone model with time lags. The results have implications for the interpretation of tracer decay measurements.

KEYWORDS model, air movement, theoretical model, tracer gas

**#NO 2745 The use of modified constant concentration techniques to measure infiltration and interzone airflow rates.**

AUTHOR Bohac D L, Harrje D T

BIBINF 8th AIVC Conference, 'Ventilation Technology - Research and Application', Ueberlingen, Federal Republic of Germany, 21-24 September,

1987, Supplement to Proceedings, p129-152, 9 figs, 5 tabs, 12 refs. in English  
ABSTRACT The constant concentration tracer gas (CCTG) technique is typically used to measure air infiltration rates in multizone buildings. The measurements are performed by injecting metered amounts of a tracer gas into each zone so as to keep all the zones at a target concentration. One drawback to this method is that no information is gained about the level of interzone flow rates in the building. Modified constant concentration techniques are described which allow selected infiltration and interzone airflow rates to be estimated. These techniques differ from the typical operation in that there are certain zones where no tracer gas is injected. One approach, described as discontinued injection, is useful for measuring interzone flow rates between two sections of a building when the airflow rates are relatively constant. The tracer gas injection in one of the sections is stopped at a certain point in time, but the concentration measurements are continued. The increase of tracer gas injection in the other section and the drop in concentration in the "starved" section are used to estimate the airflow rates between the sections. Field measurements using the modified CCTG methods are presented for experiments in single family and multifamily buildings. The results are compared to those obtained by passive, multiple tracer gas tests.

KEYWORDS constant concentration, infiltration rate, airflow, tracer gas, measurement

**#NO 2882 Measurement of air change rate in an inhabited building with a constant tracer gas concentration technique.**

AUTHOR Roulet C, Scartezzini JL  
BIBINF Ashrae Trans, Vol 93, Part 1 1987, p1371-1380, 7 figs, 11 refs. in English

ABSTRACT An apparatus measuring air change rate by the tracer gas method was built at the Solar Energy Research Group of the Ecole Polytechnique Federale, Lausanne. Up to 10 locations can be measured simultaneously either by the decay method or the constant flow or the constant concentration method. This equipment was used to measure the air infiltration in various buildings. One of them was a three storey one-family house, which was inhabited during the 12 day survey. The measurements show that in such buildings, the air infiltration varies strongly from time to time, even when all the windows and doors are closed. Moreover, strong exchanges between rooms are observed. It is shown that, in multi room inhabited buildings, the constant concentration method used during a lengthy survey allows one to obtain the total air infiltration flow rate. With only one tracer gas, the infiltration rates into each room are measured, but the exchanges between rooms can only be estimated qualitatively. Some effects of the inhabitants' behaviour are quantified.

KEYWORDS air change rate, tracer gas, constant concentration, air leakage

**#NO 3113 New developments in two methods of measuring airflow in buildings.**

**Nouveaux developpements de deux methodes de mesures aeramiques dans les batiments.**

AUTHOR Compagnon R, Furbringer J M, Roecker C, Roulet C A  
BIBINF Switzerland, LESO, July 1988, 8pp, 5 figs, 12 refs. in French

ABSTRACT Techniques of measuring airflow by pressurization such as the constant concentration tracer gas technique have been initially developed to measure whole building ventilation. Here are presented two developments of these techniques which enable more detailed measurements to be made of multizone buildings. These two developments have led to the realization of two new measurement installations: MAGE and CESAR 3.

KEYWORDS measurement technique, airflow, pressurization, constant concentration, tracer gas

**#NO 4645 New developments of two airflow measurement methods in buildings.**

**Nouveaux developpements de deux methodes de mesures aeramiques dans les batiments.**

AUTHOR Compagnon R, Furbringer J M, Roecker C, Roulet C-A  
BIBINF Switzerland, ETH Zurich, "Energieforschung im Hochbau", 5th Statusseminar, 8-9 September, 1988. in French

ABSTRACT The techniques of airflow measurement by pressurisation like the constant concentration tracer gas method have been initially developed to measure whole buildings. Here are presented two developments of these techniques which enable more detailed measurements on multizone buildings to be made. These two developments have led to the realisation of two new measurement installations: MAGE and CESAR 3.

KEYWORDS airflow, pressurisation, tracer gas, constant concentration

**#NO 5691 Measurements of the rates of air change in multivolumes: constant concentration method,**

**presentation of a mobile system designed by LNE.**

**Mesures du taux de renouvellement d'air dans les multivolumes: methode a concentration constante, presentation d'un systeme mobile realise par le LNE.**

AUTHOR Rabourdin Y

BIBINF Intervention au Seminaire Gerva, 19-20 September 1989, Sophia-Antipolis, 10p. in French

ABSTRACT Presentation of the experimental device "EMMARA" (mobile automatic air change measuring equipment) aimed at determining air change rates in a multi room premises by tracer gas (N<sub>2</sub>O) at constant concentration: principle of function, measurement method, first test results. KEYWORDS air change rate, constant concentration, measurement technique

**#NO 9740 Measurement of multizone airflow in experimental house.**

AUTHOR Doi S

BIBINF Japan, proceedings of the 5th International Conference on Air Distribution in Rooms, Roomvent '96, held Yokohama, Japan, 17-19 July, 1996, Volume 1, pp 55-60.

ABSTRACT Prediction and measurement of interzonal airflow in a building is important in evaluating and planning IAQ, thermal comfort, etc. In our experimental house, we planed the distribution of fresh air, passive ventilative cooling in summer. In this context the measurement of multi-zone airflow in this house, considered as 17 rooms, was needed. In application of the measurement method using a single tracer gas, based on the system identification theory proposed by Okuyama, some improvements were made to secure accuracy. The additional measurement for the fresh airflow from

outside to each room was also carried out by another method of constant-concentration. In this paper, these measurements and results are described. KEYWORDS multizone airflow, residential building, thermal comfort

**#NO 12112 Evaluation of ventilation characteristics of residential buildings based on multi room tracer gas decay experimental techniques.**

AUTHOR Kurabuchi T, Yoshihara K, Usui M

BIBINF Sweden, Stockholm, KTH Building Services Engineering, 1998, proceedings of Roomvent 98: 6th International Conference on Air Distribution in Rooms, held June 14-17 1998 in Stockholm, Sweden, edited by Elisabeth Mundt and Tor-Goran Malmstrom, Volume 2, pp 483-490, 19 figs, 1 tab, refs.

ABSTRACT Under the conditions that the air in each room is in the state of perfect mixing and ventilation is in steady state, a method to estimate steady state concentration distribution to match an arbitrary contaminant generation distribution is proposed, using concentration data obtained from short-time tracer gas experiment. Also, a method is proposed, which is used to estimate ventilation rate by adding other available equations. The proposed method was tested on full-scale house models installed in the environmental test room, and it was confirmed that the steady state concentration by the proposed method corresponds well to the steady state concentration obtained by tracer gas continuous generating method. The proposed method was applied on one each of a single house and a collective house with high air tightness performance, for which elaborate equipment for ventilation has been

adopted, and ventilation characteristics was evaluated from multilateral viewpoints.

KEYWORDS air tightness, contaminant sources, full scale experiments, measurement technique, residential building

**#NO 12214 Comparison of modelled and measured tracer gas concentrations in a multizone building.**

AUTHOR Sextro R G, Daisey J M, Feustel H E, Dickerhoff D J, Jump C BIBINF UK, Garston, BRE, 1999, proceedings of Indoor Air 99, the 8th International Conference on Indoor Air Quality and Climate, and the Air Infiltration and Ventilation Centre (AIVC) 20th Annual Conference, held Edinburgh, Scotland, 8-13 August 1999, Volume 1, pp 696-701.

ABSTRACT Few detailed comparisons of modelled and measured pollutant concentrations in multizone buildings have been published. The COMIS airflow and contaminant transport model permits simulation of the effects of building and HVAC operation, as well as the influence of the local meteorology, on airflows within the building. We have recently used this model to simulate the release of a gas-phase tracer in a three-story, multi-room building located at Dugway Proving Ground, Utah, USA. Following detailed leakage and flow-path characterisation measurements of the building, experiments were conducted in which tracer gas concentrations were measured as a function of time in each room of the building. Comparison of the simulations with these detailed measurements showed reasonable-and in some cases, quite good - agreement. The paper describes some details of the

experiments and modelling and discusses the differences between the observed and the predicted concentrations.

KEYWORDS tracer gas, modelling, measurement technique, multizone building

**#NO 13079 Experimental testing of a homogeneous tracer pulse technique for measurement of ventilation and air distribution in buildings.**

AUTHOR Stymne H, Hansson P, Boman C A

BIBINF UK, Air Infiltration and Ventilation Centre, proceedings of "Innovations in Ventilation Technology", 21st AIVC Annual Conference, held The Hague, Netherlands, 26-29 September 2000, paper 30.

ABSTRACT A number of single tracer gas techniques (decay, step-up, homogeneous constant emission, inlet pulse and homogeneous pulse) suitable for measuring the local mean ages of air in multi-zone buildings exist, each having their advantages and drawbacks. The characteristics of the different available techniques are compared from theoretical and practical points of view. The homogeneous pulse technique has not been experimentally validated before. This technique relies on pulses of tracer gas being injected into the different zones in amounts, which are proportional to the zone volumes. Some advantages with the "homogeneous pulse" technique, compared with the "inlet pulse" technique, are that the pulses can be injected at any time path, that they must not necessarily be short and that the evaluation of local mean ages of air involves a simple total time integration of concentration, making it

possible to utilise integrating air samplers (e. g. adsorption tubes).

The homogeneous pulse technique is tested against the decay technique in a five-room indoor test house, using both automatic and manual injection of tracer gas. It is shown that this technique yields results as accurate as the decay technique. Using manual injection (with syringe), however, requires special caution in order to achieve a uniform distribution of the injection in a room and to avoid redistribution while walking between rooms.

KEYWORDS tracer gas techniques, measurement techniques, multizone building

## **5.2 Active Multigas Techniques**

**#NO 3123 Constant concentration measurement with two tracers.**

AUTHOR Kvisgaard B, Collet P F  
BIBINF in: "Effective Ventilation" 9th AIVC Conference, Gent, Belgium, 12-15 September, 1988. in English

ABSTRACT The technique of tracer gas measurement has during recent years tended towards increasingly complicated measuring methods. The new measuring techniques are essential in order to procure more information about the circulation of air through buildings, or in order to perform more accurate measurements in large and complex buildings. The measuring method by means of "constant concentration of tracer-gas", which has been applied at the Technological Institute for about 7 years, has proved to be a very accurate measuring method for both small and very large buildings. The method has the advantage of being able to continuously register the air change in a measuring

area divided in numerous zones. The limitation of this method is that only information about the infiltration from outside into the measuring area is obtained whereas no details are given about the air-flow between the individual zones of the measuring area. The limitation of the measuring method can be overcome by using 2 tracer-gases. The article describes the different philosophies on which measurements with "constant concentration of 2 tracer-gases" might be based, measurement result to be obtained, and discusses whether there is any advantage of using more than 2 tracer-gases. In addition a specific measurement is described, where the method with "constant concentration of 2 tracer-gases" is used. KEYWORDS constant concentration, tracer gas, measurement technique

**#NO 3132 Development of an efficient control algorithm for a multizone constant concentration tracer gas air infiltration measurement system.**

AUTHOR Compagnon R, Kohler A, et al

BIBINF in: "Effective Ventilation", 9th AIVC Conference, Gent, Belgium, 12-15 September, 1988. in English

ABSTRACT A constant concentration tracer gas (CCTG) measuring system needs a control algorithm to calculate, at each sampling time, the required tracer gas injection rate to keep the gas concentration at a target level. A new control algorithm is presented here in full detail. Practical considerations concerning modifications to take into account the physical limitations of the CCTG system and the computing of the optimal control parameters are also presented.

KEYWORDS computer, constant concentration, tracer gas, measurement technique

**#NO 4980 Air change measurements between zones and the outside.**

**Mesures d'echanges d'air entre les locaux et avec l'exterieur.**

AUTHOR Compagnon R, Furbringer J-M, Jakob M

BIBINF Switzerland, LESO-EPFL, March 1991, 126pp. in French

ABSTRACT 1 The multizone infiltration theory applied to multi-tracer measurement techniques. This theory presents some improvements, mainly using a correct mass balance and taking account of density variations. A zone-by-zone resolution technique is proposed, which can be applied also when there are less tracers than zones to be measured. The error analysis is also presented in details, including various solution techniques (matrix inversion, least square fit and Bayesian technique). An example is also presented. 2 The three tracers constant concentration CESAR 3 apparatus is described, as well as the related software used for monitoring and interpreting the measurements. 3 Measurements performed with that instrument are presented. There are results on the mixing time in a test chamber, multizone airflow rates measurements on the LESO building, a map of the age of air in a room, efficiency of a ventilation system, etc. 4 A bibliographic survey and the recent publications related to that research project annexed. This part is in English.

KEYWORDS air change rate, outdoor air, measurement technique

**A Multigas Tracer System for Multizone Air Flow Measurements**

AUTHOR Sherman, M.H., and Dickerhoff, D.J.  
 BIBINF Proceedings of BTECC IV: Thermal Performance of Exterior Envelope. 1989 Atlanta: ASHRAE  
 ABSTRACT Tracer gas techniques are becoming widely used to measure the ventilation rates in buildings. As more detailed information is required for both energy and indoor air quality purposes, researchers are turning to complex, multi-zone tracer strategies. Both single-gas and multiple-gas techniques are being utilized, but only multigas techniques are capable of uniquely determining the entire matrix of airflows simultaneously. A national laboratory has developed a multi-tracer measurement system (MTMS) based on a mass spectrometer to provide real time measurement capability of time varying interzonal flows. MTMS has been used in both single-family and multi-family buildings to determine the flow rates both between zones and between each zone and outdoors. This report will describe the development, theory, and operation of MTMS and provide examples of data from its first year of operation in an occupied and unoccupied house.

### **5.3 Passive Multigas Techniques**

#### **#NO 1258 Ventilation rates and inter cell airflow rates in a naturally ventilated office building.**

AUTHOR Perera M.D.A.E.S. Walker R.R. Oglesby O.D.  
 BIBINF 4th AIVC Conference "Air infiltration reduction in existing buildings" Switzerland, 26-28 September 1983 p.12.1-12.13 5 figs. 5 refs. in English

ABSTRACT Determines ventilation rates and intercell flow rates in naturally ventilated office building using multiple tracer gases. Subdivides the building into 3 zones and seeds each zone individually with a different tracer gas. Monitors the time histories of the concentrations of all gases in each zone using non-dispersive infra red gas analysers. Calculates airflow rates from experimental data. Uses an in-house computer program which predicts the dispersion of a tracer gas in a multi-zoned environment, to compare the predicted time histories of concentrations with those obtained experimentally.

KEYWORDS airflow, multi chamber, modelling, tracer gas, office building

#### **#NO 1731 Application of perfluorocarbon tracers to multizone airflow measurements in mechanically and naturally ventilated buildings.**

AUTHOR Dietz R N, Goodrich R W, Cote E A, et al.  
 BIBINF Upton, New York, USA: Brookhaven National Laboratory, Dept of Applied Science, August 1984. BNL 35249. 23p. 7 figs, 7 tabs, 10 refs. in English

ABSTRACT The Brookhaven air infiltration measurement system (BNL/AIMS) uses a family of four passive perfluorocarbon tracer sources and miniature passive adsorbent samplers to inexpensively but very effectively tag individual zones within multizone buildings with uniquely discernible tracer vapours. The concentrations measured with the passive samplers allow the air infiltration and exfiltration rates from each zone to be computed as well as the air exchange rates between zones. Two naturally ventilated buildings, a 2-zone (3056 m<sup>3</sup>) jailhouse and a 4-zone (1028



m<sup>3</sup>) apartment building were tested: the former showed a 2.5 to 1 ratio in the fresh air rates into the zones. Two mechanically ventilated buildings, each of 3-zones, were also tested. The 3-storey (each floor was a zone) library (5840 m<sup>3</sup>) was shown to have 10 times more fresh air entering the first floor than the second (1.33 h<sup>-1</sup> compared to 0.15 h<sup>-1</sup>). The 16-storey office building (142,500 m<sup>3</sup>) had 4 times as much fresh air in one zone compared to a side-by-side identical zone (1.07 h<sup>-1</sup> versus 0.25 h<sup>-1</sup>). The performance of BNL/AIMS in certifying HVAC systems is demonstrated.

KEYWORDS tracer gas, perfluorocarbon, measurement technique, multi-chamber, airflow, natural ventilation, mechanical ventilation

**#NO 1843 Automation, extension and use of the PCL multi-tracer gas technique for measuring interzonal airflows in buildings.**

AUTHOR Littler J, Martin C, Prior J  
BIBINF Final Report on SERC Grant GR/C/63427. RIB/1985/718. January 1985. 26p. 14 figs, 8 refs. in English  
ABSTRACT Describes the development of an automated air sampling equipment to measure air infiltration and interzonal airflows. A new matrix analysis method has been developed to calculate single zone infiltration and interzonal airflow rates from measured data. A number of multi-zone experiments have been carried out in the PCL solar heated house at Peterborough, and several single zone infiltration rate measurement experiments have been carried out in a wide variety of buildings. A grab-tube method has been developed for assessing air change rates.

KEYWORDS tracer gas, multi-chamber, passive sampling, passive solar house, measurement technique, automatic equipment

**#NO 1992 The measurement of airflows using a rapid response tracer gas technique.**

AUTHOR Irwin C, Edwards R E, Howarth A T  
BIBINF Building Services Engineering Research and Technology, 1985, Vol 6 No 4, p146-152. 7 figs, 1 tab, 7 refs. in English

ABSTRACT The multiple tracer gas technique of I'Anson et al. has been improved, in order to increase the rate at which samples can be taken. Using parallel gas chromatographic separation columns and an electron capture detector, it is now possible to take an air/tracer gas sample every thirty seconds in the case of a two-zone ventilation and air movement test. Rapid sampling enables a new, simplified analysis of the air movement between two connected zones to be employed. This analysis derives ventilation rates and intercell airflows simultaneously. A specimen set of results for two cell ventilation/air movement is given.

KEYWORDS tracer gas, measurement technique, decay rate, air change rate, air movement, multi-chamber

**#NO 2645 The measurement of air movements between four interconnected cells by a multiple tracer gas decay technique.**

AUTHOR Edwards R E, Irwin C  
BIBINF Roomvent 87, proceedings, Stockholm 10-12 June 1987, 16p, 9 figs, 2 tabs, 10 refs. in English  
ABSTRACT This paper describes the development and application of a multiple tracer gas decay technique for

the measurement of the ventilation rates in, and the air movements between, four interconnected cells. The measurement equipment used is a refinement of the existing UMIST parallel separation column portable gas chromatograph. By the use of the parallel electron capture detectors, it is possible to measure the concentrations of four tracer gases in four cells, within sufficiently short a time interval for an air movement calculation procedure, based on the previous procedures used for two and three cells, to be used successfully: this procedure is summarised in this paper. A typical set of results is presented, in order to demonstrate a situation in which the technique could be applied to complex air movements within the building envelope. The possible extension of the technique to five or more cells is also briefly discussed.

**KEYWORDS** measurement technique, air movement, tracer gas, decay rate

**#NO 3576 A comparison of different methods of calculating interzonal airflows by multiple tracer gas decay tests.**

**AUTHOR** Irwin C, Edwards R E  
**BIBINF in:** UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28 September 1989, Volume 2, February 1990, pp57-70, 3 figs, 2 tabs, 11 ref in English

**ABSTRACT** Measurement methods based upon multiple tracer gas techniques have become an established branch of the study of air infiltration and interzonal air movements. Three general groups of techniques have emerged, namely constant concentration, constant emission, and decay. Of the decay type group of techniques, several methods of deriving airflows from measured concentration/time curves have been

suggested. Broadly speaking, these techniques can be classified into three types: numerical methods involving the use of concentration gradients, numerical methods involving use of integration of concentration/time data, and thirdly, techniques based upon analytical solutions for the fundamental tracer gas equations. The favoured method of analysis at UMIST has been that of a simplified analytical solution in which the effects of tracer gas re-circulation are only taken into account if the degree of connection between zones is high. This method of analysis has been successfully validated for the cases of two and three interconnected cells under controlled conditions in environmental chambers. However, up until now, no direct comparison with the results generated by other methods using the same raw concentration/time data has been made. This paper describes an exercise in which site data for two and three zone regimes is analyzed by several different methods, and the results obtained by each method compared. It is demonstrated that, in particular, concentration gradient methods appear to be particularly ill-suited to dealing with site data which exhibits irregularities in concentration-time profiles caused by fluctuations in wind speed and direction. Integration techniques only appear to be marginally better.

**KEYWORDS** calculation techniques, tracer gas

**#NO 6978 Ventilation rate and airflow measurements using a modified PFT Technique**

**AUTHOR** Bloemen H J TH, Verhoeff A P, Blavers T T M, Torn P van der, Wijnen J H van

BIBINF Finland, Helsinki, Proceedings of 'Indoor Air '93', The 6th International Conference on Indoor Air Quality and Climate, July 4-8, 1993, Volume 5, "Ventilation", pp 91-96. in English  
**ABSTRACT** The ventilation rate and the airflows in buildings are important both for the management of (health) complaints related to indoor air quality, and for the assessment of the penetration of outdoor air pollutants into indoor air. A relatively simple method that provides reliable information on the ventilation rate and airflows over longer periods is needed. The BNL/AIMS PFT technique, initially developed by Dietz et al. (1), was modified using commercially available components. Three different perfluorocarbons, perfluordimethylcyclobutane, methylcyclopentane and methylcyclohexane, were used as tracers. Source strengths were constant within 3% for periods of six weeks at temperatures ranging from 20 to 27 degrees C. Passive sampling was feasible using Carbotrap as adsorbent. The adsorption and desorption efficiencies were approximately 98%. Samples were analyzed using capillary gas chromatography, a porous-layer open tubular column (Al2 O3) and electron capture detection. The accuracy of the tracer analysis at concentrations usually obtained for ventilation measurements was within 5 to 10%. In a pilot study the mean coefficient of variation was approximately 5%. The location of the sampling tube and of the source in the room had no significant influence. The mean ventilation rate in the living rooms and bedrooms was 1 and 1.7, respectively. The variation in time was small. The ventilation rate of the living room was higher in older dwellings and/or if occupants were

smokers. The ventilation rate of the bedroom was higher in flats than in single-family dwellings and in older dwellings, the rate was also higher if the occupants were smokers and rose with an increasing number of occupants.  
**KEYWORDS** ventilation rate, airflow, measurement technique, perfluorocarbon, tracer gas

## **6.0 Air Distribution System Measurements**

### **6.1 Duct Leakage Flows**

**#NO 7472 Field comparison of alternative techniques for measuring air distribution system leakage.**

**AUTHOR** Modera M P

BIBINF Paper submitted for ASTM Symposium on Airflow Performance of Building Envelopes, Components and Systems, October 10-11, 1993, Ft Worth, TX, USA, 16pp, 7 figs, 4 tabs, refs.in English

**ABSTRACT** ASTM has recently standardized a methodology for measuring the leakage of residential air distribution systems to unconditioned zones. The standard includes two alternative leakage measurement techniques, one of which requires only a blower door, whereas the second technique requires a flow-capture hood as well as a blower door. This paper reports on the results of field measurements in 30 houses using both measurement techniques, and analyzes the relative strengths and weaknesses of the two techniques. The repeatability of each of the techniques, as well as the comparability of the results from the two techniques, are examined. A key issue that is addressed in this paper is the importance of duct pressure

measurements in each of the two techniques. Analyses show that the leakage measured with the blower-door-only technique would be negatively biased by 30-50% if the duct pressure was not incorporated into the measurements and analyses as is specified in the standard. Similarly, it is shown that supply leakage measurements with the flow-capture-hood technique would be negatively biased by 33% if the envelope pressure differential was used instead of the duct pressure differential.

**KEYWORDS** Duct, air leakage, fan pressurization, measurement technique, air infiltration.

**#NO 10265 Field comparison of design and diagnostic pathways for duct efficiency evaluation.**

**AUTHOR** Andrews J W  
BIBINF USA, Washington DC,  
American Council for an Energy  
Efficient Economy (ACEEE),  
Proceedings of the 1996 Summer Study  
on Energy Efficiency in Buildings,  
"Profiting from Energy Efficiency".

**ABSTRACT** A new method of test for residential thermal distribution efficiency is currently being developed under the auspices of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). This test method will have three main approaches, or "pathways," designated Design, Diagnostic, and Research. The Design Pathway uses builder's information to predict thermal distribution efficiency in new construction. The Diagnostic Pathway uses air-flow, temperature, and pressure-difference tests intended to take one to four hours to evaluate thermal distribution efficiency in a completed house. For forced-air systems, three

distinct techniques are being considered, one based on thermal inputs and outputs in the duct system, the second based on pressure and leakage-area measurements, and the third based on pressure differentials induced in the house by partial blockage of the return duct. This paper presents and discusses the results of Design Pathway calculations based on measured duct-system and floor-plan layouts and surface areas (in lieu of building plans) for fifteen residential duct systems in Long Island, New York. These are compared with measured Diagnostic Pathway efficiencies in eight of these homes.

**KEYWORDS** duct, energy efficiency, standard

**#NO 11612 HVAC ductwork: constant-injection tracer-gas assessment of airtightness.**

**AUTHOR** Cheong K W  
BIBINF UK, Building Serv. Eng. Res.  
Technol., Vol 19, No 3, 1998, pp 171-174, 6 figs, 2 tabs, 13 refs.

**ABSTRACT** Constant injection of tracer gas was used to determine the airtightness of a straight length of 300 x 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.

KEYWORDS duct, component leakage, calculation techniques

**#NO 13604 The current state of duct leakage measurement: field evaluation of five methods.**

AUTHOR Francisco P W

BIBINF Home Energy, March/April 2001, pp 32-35, 2 figs.

ABSTRACT Describes a study of test methods for duct leakage which revealed that there is room for improvement in this evolving field. Five different methods of measuring duct leakage were evaluated. The first two were from proposed ASHRAE standard 152P: the Duct Blaster test (duct pressurization test), and the house pressure test. The other three were the supply-blocked house pressure test, which is a modification of the house pressure test, the hybrid test, which is a combination of the two tests in Standard 152P, and the nulling test, which the authors developed near the beginning of the project. Ten one-storey homes in the Pacific Northwest US were tested, including eight single family and two manufactured homes. A table is presented showing summary statistics of the five tests methods. To predict the effect of duct leakage on energy loss, it is necessary to look at the ratio of the leakage to the air handler flow rate. On average, all of the methods are within 5% of the best-estimate ratio of duct leakage to air handler flow rate. However the scatter was quite large for the two house pressure tests and the hybrid test. States that the project's

findings indicate that the measurement of duct leakage is still far from an exact science. The level of discrepancy can have a large impact on the prediction of duct losses and will sometimes provide the wrong answer as to whether it is worth performing a leakage retrofit on the ducts. The Duct Blaster and nulling test were found to be much more accurate than the other tests.

KEYWORDS duct leakage, field monitoring, pressurization testing, energy losses

**HVAC Air Duct Leakage Test Manual**

AUTHOR SMACNA

BIBINF SMACNA, 1985.

**Two New Duct Leakage Tests**

AUTHOR Andrews, J.W.

BIBINF Brookhaven National Laboratory. Report 66148, 1998.

ABSTRACT Two variations on the tests for duct leakage currently embodied in ASHRAE Standard 152P (Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems) are presented. Procedures are derived for calculating supply and return duct leakage to/from outside using these new variations. Results of these tests are compared with the original ones in Standard 152P on the basis of data collected in three New York State homes.

**Measurement Uncertainties in the DeltaQ test for Duct Leakage.**

AUTHOR Andrews, J.W

BIBINF Brookhaven National Laboratory report BNL-67894, 2000.

ABSTRACT Theoretical and field-test results are reported on a new method for measuring air leakage in residential duct

systems. This test, called the Delta Q test by its developers, involves a set of 10 or 11 pairs of measurements using a calibrated fan (blower door). Each pair of measurements is performed with the house pressurized or depressurized to a different pressure with respect to outside. One test in each pair is conducted with the system fan on, the other with it off. Each pair of measurements gives a linear equation in two unknowns, where the unknowns are the air leakage rates (under normal operating conditions) from the supply ducts to outside and into the return ducts from outside. The straight lines represented by these equations rarely intersect at a single point, so a least-squares fit is used to find the best compromise value for the supply and return leakage rates. This report describes a theoretical analysis of errors resulting from mismatches between the assumed and actual operating conditions in the ducts and Corn uncertainties in the blower-door airflow measurements. It develops a way to estimate the probable errors on a house-specific basis? using the data from a single application of the Delta Q test. Finally, it applies this analysis to field-test results from two houses.

**Analysis of Measurement  
Uncertainties in the Nulling Test for  
Air Leakage from Residential Ducts**

AUTHOR Andrews, J.W.

BIBINF Brookhaven National  
Laboratory Report BNL-68430, 2001.

ABSTRACT An analysis of measurement uncertainties in a recently proposed method of measuring air leakage in residential duct systems has been carried out. The uncertainties in supply and return leakage rates are expressed in terms of the value of the envelope leakage flow coefficient and

the uncertainties in measured pressures and airflow rates. Results of the analysis are compared with data published by two research groups.

**Development of a New Duct Leakage  
Test: Delta Q**

AUTHOR Walker, I.S., Sherman, M.H., Wempen, J., Wang, D., McWilliams, J.A., and Dickerhoff, D.J.

BIBINF Lawrence Berkeley National Laboratory publication #47308, 2001  
ABSTRACT In this study we developed the analytical calculation methods and the test procedures used in the DeltaQ test. As part of the development process, we have estimated uncertainties in the test method (both analytically and based on field data) and designed automated test procedures to increase accuracy and reduce the contributions of operator errors in performing field tests. In addition, the test has been evaluated in over 100 houses by several research teams to show that it can be used in a wide range of houses and to aid in finding limits or problems in field applications. The test procedure is currently being considered by ASTM as an update of an existing duct leakage standard.

**ASHRAE Standard 126P : Method of  
Testing HVAC Air Ducts**

AUTHOR ASHRAE

BIBINF American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., 1999.

ABSTRACT This standard provides laboratory test procedures for the evaluation of HVAC air ducts. This standard may be used to determine HVAC air duct structural strength, dimensional stability, durability and leakage characteristics.

**ASTM 1554-94 - Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization**

AUTHOR ASTM

BIBINF Annual Book of ASTM Standards Vol. 04.11. American Society for Testing and Materials, 1994

ABSTRACT These test methods cover two techniques for measuring the air leakage of the sections of air distribution systems that pass outside the conditioned space in low-rise residential and small low-rise commercial buildings. Both techniques use air flow and pressure measurements to determine the leakage characteristics, and include separate measurements of the supply-side and the return-side distribution system leakage.

**EUROVENT Guidelines 2/2 Air Leakage Rate in Sheet Metal Distribution Systems**

AUTHOR EUROVENT / CECOMAF  
BIBINF European Committee of Air Handling and Air Conditioning Equipment Manufacturers / Committee of Refrigeration Equipment Industries, 1996.

SUMMARY This document describes a leakage class system for duct leakage. It also describes testing procedures for determining leakage in a duct section.

**Improving Ductwork: A Time for Tighter Air Distribution Systems, A status report on ductwork airtightness in various countries with recommendations for future designs and regulations.**

AUTHOR F. R. Carrie, J. Andersson, P. Wouters

BIBINF AIVC and SAVE-DUCT Project Partners, 1999

SUMMARY This guide is divided into 10 chapters. Chapter 2 gives an

overview of quality requirements of ductwork. Chapter 3 summarises ductwork airtightness related standards in Europe and some other non European countries. Chapter 4 looks at today's ductwork technology. It includes a review of ductwork construction, installation and rehabilitation techniques that may be used to limit duct leakage. Chapter 5 is concerned with traditions in the design and installation of duct systems. Chapter 6 deals with duct leakage field measurements in European countries. Little information is available on this subject, however, field data from the SAVE-DUCT project suggests that the ductwork airtightness is in general very poor. Chapter 7 discusses the energy, indoor air quality and cost issues associated with duct leakage. Sample calculations are performed based on realistic data. Chapter 8 is dedicated to a macroscopic approach to the energy implications of a tight air duct policy at the European level. Chapter 9 consists of a synthesis of issues brought to light by practitioners, manufacturers, and policy makers in the international seminar on ductwork airtightness held in Brussels June 10-11, 1998. Chapter 10 is more particularly geared towards the implementation of a tight air duct policy with recommendations for technical and governmental measures.

**California Title 24, Residential & Nonresidential Energy Efficiency Building Standards**

AUTHOR CEC

BIBINF California Energy Commission, 2001

SUMMARY This document lays out the regulations and standards relating to the energy efficiency of buildings in California.

**ASHRAE Standard 152P : Method of test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems.**

AUTHOR ASHRAE

BIBINF American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., 1999.

ABSTRACT The objective of this method of test is to provide estimates of the efficiency of thermal distribution systems. This efficiency may be used in energy consumption or system capacity estimates. This method of test provides thermal distribution system efficiencies for both heating and cooling systems. In addition, thermal distribution system efficiency is calculated for seasonal conditions (for energy consumption) or design conditions (for system sizing). This results in a total of four outputs from the method of test.

**6.2 Airflow through Ducts and Duct Networks**

**#NO 3360 Measurement of turbulent flow in a duct using a tracer gas technique.**

AUTHOR Riffat S B, Lee S F

BIBINF UK, Loughborough University of Technology, Dept of Civil Engineering, 1989, 25 pp, 10 figs, 9 refs. in English

ABSTRACT We describe the use of the constant injection tracer gas technique to study turbulent flow in a rectangular duct. A comparison between tracer gas measurements and measurements made using a hot-wire anemometer and a pitot tube is presented. Measurement of tracer gas concentration, air velocity and pressure distribution at various distances from the duct wall and inlet were carried out. The Reynolds number based on the hydraulic diameter and the bulk velocity

was varied between  $7.5 \times 10^{-4}$  and  $18.6 \times 10^{-4}$ . A theoretical expression for the entrance length required for fully developed turbulent flow was obtained and this was compared with experimental results.

KEYWORDS turbulent flow, duct, tracer gas measurements

**#NO 3889 Turbulent flow in a duct: measurement by a tracer gas technique.**

AUTHOR Riffat S B

BIBINF UK, Building Serv Eng Res Technol, Vol 11, No 1, 1990, pp21-26, 10 figs, 10 refs. in English

ABSTRACT Article describes the use of the constant injection tracer gas technique to study turbulent flow in a rectangular duct. A comparison between tracer gas measurements and measurements made using a hot-wire anemometer and a pitot tube is presented. Tracer gas concentration, air velocity and pressure distribution were measured at various distances from the duct wall and inlet. The Reynolds number based on the hydraulic diameter and the bulk velocity was varied between  $7.5 \times 10$  to the power of 3 and  $18.6 \times 10$  to the power of 3. An empirical equation for the entrance length required for fully developed turbulent flow was obtained and this was compared with experimental results.

KEYWORDS turbulent flow, duct, tracer gas measurements

**#NO 4070 Field measurements of air velocity: pitot traverse or vane anemometer?**

AUTHOR Howell R H, Sauer H J

BIBINF USA, Ashrae J, March 1990, pp46-52, 4 figs, refs. in English

ABSTRACT A rotating vane anemometer at a downstream coil face



can provide the same accuracy as an in-duct pitot tube traverse.

KEYWORDS air velocity, anemometer, measurement technique

**#NO 4466 The application of tracer-gas techniques for measuring airflow in a duct.**

AUTHOR Riffat S B

BIBINF Canada, Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, 29 July -3 August 1990, Volume 4 "Building and System Assessments and Solutions", pp 21-26. in English

ABSTRACT A description of the use of tracer-gas techniques for measurement of airflow in ducts is presented.

Experimental procedures for the use of the constant-injection, pulse-injection and concentration-decay techniques are discussed. This paper also describes a new tracer-gas system with variable sampling speed which was used to measure the decay of tracer-gas concentration. Measurements of airflow made using each of the three tracer-gas techniques are compared with measurements made with a pitot tube. The closest agreement is observed for measurements made with the constant-injection technique.

KEYWORDS tracer gas, duct, airflow

**#NO 4643 A comparison of tracer-gas techniques for measuring airflow in a duct.**

AUTHOR Riffat S B

BIBINF Journal of the Institute of Energy, March 1990, pp 18-21, 5 figs, 6 refs. in English

ABSTRACT A description of the use of tracer-gas techniques for measuring airflow in ducts is presented.

Experimental procedures for the use of

the constant-injection, pulse-injection and concentration-decay techniques are discussed. This paper also describes a new tracer-gas system with variable sampling speed, which was used to measure the decay of tracer-gas concentration. Measurements of airflow made with each of the three tracer-gas techniques are compared with measurements made with a pitot tube. The closest agreement is observed for measurements made with the constant-injection technique.

KEYWORDS tracer gas, airflow, duct

**#NO 4799 Airflow measurements at coil faces with vane anemometers: statistical correlation and recommended field measurement procedure.**

AUTHOR Sauer H J, Howell R H  
BIBINF USA, ASHRAE Transactions, Vol 96, Part 1, 1990, pp 502-511, 15 figs, refs. in English

ABSTRACT A procedure for measuring the volume flow rate of air through a heating or cooling coil is presented.

When a pitot tube traverse is impossible or impractical, the rotating vane anemometer procedure described and verified here will provide volume flow rates with similar uncertainty in the results. The rotating vane anemometer procedure was shown to produce estimates of volume flow rate at coil faces with plus or minus 7%. The procedure is valid in a velocity range of 100 to 1100 fpm, and upstream disturbances such as elbows, partially blocked coils, dampers, and fan blasts had virtually no effect on the accuracy of using the K-factor procedure as long as the measured velocities were positive and relatively uniform.

KEYWORDS airflow, measurement technique, anemometer

**#NO 4835 Measurement of airflow in HVAC systems using tracer-gas techniques.**

AUTHOR Riffat S B, Holmes M  
BIBINF UK, AIVC 11th Conference, "Ventilation System Performance", held 18-21 September 1990, Belgirate, Italy, Proceedings published March 1990, Volume 1, pp 195-214, 10 figs, 3 refs. in English

ABSTRACT This paper describes the use of tracer-gas techniques to measure airflow in a rectangular duct and a HVAC system. Experimental procedures are discussed for the application of the constant injection, pulse injection and decay techniques using N<sub>2</sub>O and SF<sub>6</sub> as tracer gases. This paper also describes a new tracer-gas system with variable sampling speed which was used to measure the decay of tracer-gas concentration. A comparison is presented between tracer-gas measurements and those made with a pitot tube and a hot wire anemometer. KEYWORDS airflow, air conditioning, tracer gas

**#NO 5146 Performance testing of HVAC systems using tracer gas techniques.**

AUTHOR Cheong K W, Riffat S B  
BIBINF UK, Loughborough University of Technology, Civil Engineering, 1991. in English

ABSTRACT The constant-injection and pulse-injection techniques were used to measure airflow in a duct and small-scale HVAC system. Tracer-gas measurements were compared with measurements made using a pitot-tube. The concentration of SF<sub>6</sub> tracer gas, velocity and static pressure distributions were measured in the duct and HVAC system for various Reynolds numbers.

Results indicated that the flow rate obtained using the pulse-injection technique is in closer agreement with values obtained using the pitot-tube than results obtained using the constant-injection technique. This paper also describes the development of a tracer-gas system which has high-sampling frequency and could be used for measurement of airflow in HVAC systems.

KEYWORDS performance testing, tracer gas, air conditioning

**#NO 5266 PFT measurements in ventilation ducts.**

AUTHOR Sateri J  
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 1, pp 375-386. in English

ABSTRACT The passive perfluorocarbon method (PFT-method) has been successfully applied in ventilation measurements in rooms. The method is, in principle, also applicable to airflow measurements in ventilation ducts. There are, however, several problems in applying a passive sampling technique in a duct. First, the concentration of the tracer may not be uniform through the cross-section of a duct. Second, the velocities in a duct are normally an order of magnitude higher than in a room. Third, the orientation of the sampler in respect to the flow may affect the uptake rate. This study concentrated on the solution of these three problems. The velocity of the air in a duct had significant effect on the uptake rate of the sampler. The magnitude of the effect was in order of an 11-16% increase for each 1 m/s increase in nominal velocity. This

indicated that the passive PFT-technique should not be used without correction for uptake rate in duct measurements. More studies are needed in order to establish this correction. The deviations between samplers were found to be higher in a duct than in a test room. This means that the location of the samplers should be chosen carefully. A good first estimate would be the locations proposed by several standards for air velocity measurements. The orientation of the sampler had only a small effect on the uptake rate. It was found that the samplers should not be placed with their open end against the flow.

KEYWORDS perfluorocarbon, tracer gas measurements, duct

**#NO 5296 Measurement of the entrance length and friction factor of ducts using tracer gas techniques.**

AUTHOR Riffat S, Cheong K, Holmes M

BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 2, pp 321-334. in English

ABSTRACT We describe the use of constant injection and pulse injection techniques for measurement of airflow in a duct. Tracer-gas measurements were compared with measurements made using a pitot tube and a hot-wire anemometer. Tracer-gas concentration, air velocity and pressure distribution were measured at various distances from the duct wall and inlet. An empirical equation was obtained for the entrance length required to achieve fully-developed turbulent flow and this was compared with measurements made using a pitot tube and hot-wire anemometer. We present a relationship

for the friction-factor and Reynolds number derived from tracer-gas measurements.

KEYWORDS duct, tracer gas, measurement technique

**#NO 5689 Performance heating of HVAC systems using tracer gas techniques.**

AUTHOR Cheong K W, Riffat S B  
BIBINF UK, Loughborough University of Technology, Dept of Civil Engineering, [1992], 16pp. in English

ABSTRACT The constant-injection and pulse-injection techniques were used to measure airflow in a duct and small-scale HVAC system. Tracer-gas measurements were compared with measurements made using a pitot-tube. The concentration of SF<sub>6</sub> tracer gas, velocity and static pressure distributions were measured in the duct and HVAC system for various Reynolds numbers. Results indicated that the flow rate obtained using the pulse-injection technique is in closer agreement with values obtained using the pitot-tube than results obtained using the constant-injection technique. This paper also describes the development of a tracer-gas system which has high-sampling frequency and could be used for measurement of airflow in HVAC systems.

KEYWORDS air-conditioning, tracer gas measurements, duct, sulphur hexafluoride

**#NO 5690 Balancing airflow in HVAC systems using tracer gas techniques.**

AUTHOR Riffat S B

BIBINF UK, University of Nottingham, Dept of Architecture and Planning, April 1992, 14pp, 9 figs, 5 tabs, 1 ref. in English

**ABSTRACT** The present study describes new equipment which could be used to balance HVAC systems. The equipment allows the constant-injection tracer gas technique to be employed and has the following advantages over existing balancing methods: i) It is simple to use and allows HVAC systems to be balanced in a short period, ii) It can be used to measure airflow rates in HVAC systems directly and does not require determination of the cross-sectional areas of ducts or velocity profiles, iii) It can be used to provide accurate measurement of airflow over a wide range of air velocities, iv) It can be used to measure airflow in ducts of different sizes, shapes and lengths and does not require a long measuring duct for the establishment of fully-developed flow.

**KEYWORDS** air conditioning, tracer gas measurements, instrumentation

**#NO 5698 Tracer gas techniques for determination of velocity pressure loss factors for duct fittings.**

**AUTHOR** Riffat S B, Cheong K W  
BIBINF UK, Loughborough University of Technology, Dept of Civil Engineering, [1992], 16pp. in English

**ABSTRACT** This investigation is concerned with the determination of velocity pressure loss-factors (k-factors) for duct fittings. The constant-injection tracer-gas technique was used to measure airflow through the components of a small-scale HVAC system. Tracer-gas measurements were compared with measurements made using a pitot tube. The concentration of SF<sub>6</sub> tracer gas, velocity and static pressures in duct fittings were measured for various Reynolds numbers. Results indicated that the k-factors estimated using the pitot static traverse method were

generally higher than those obtained using the tracer-gas technique. The estimated k-factors were compared with data published in the CIBSE Guide and ASHRAE Handbook.

**KEYWORDS** tracer gas measurements, duct

**#NO 5846 Assessment of ventilation and air quality in a library building.**

**AUTHOR** Cheong K W, Riffat S B  
BIBINF UK, University of Nottingham, School of Architecture, 9 figs, 9 refs. in English

**ABSTRACT** Measurements of airflow were carried out in a library building. The constant-injection and pulse-injection tracer-gas techniques were used to measure airflow in air handling units and estimates flow rates supplied to each floor. Tracer-gas measurements were compared with measurements made using a pitot-tube. Air exchange rate, ventilation efficiency and age of air were examined. The concentrations of carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), formaldehyde (HCHO) and dust particles were monitored. In addition, a questionnaire was completed by library staff and users in order to provide a subjective assessment of indoor air quality.

**KEYWORDS** indoor air quality, library, tracer gas, airflow, occupant reaction

**#NO 6005 A new method for determination of velocity pressure loss-factors for HVAC system components**

**AUTHOR** Cheong K W, Riffat S B  
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. in English

**ABSTRACT** This investigation is concerned with the determination of velocity pressure loss-factors for HVAC system components using tracer-gas techniques. Experimental work was carried out using an HVAC system and k-factors for various components such as bends, branches, contractions, expansions and orifice were determined. Results were compared with measurements made using a pitot tube and values given in the CIBSE Guide and ASHRAE Handbook. The performance of different types of filters used in HVAC systems was also examined. The constant-injection tracer gas technique was used to develop correlations between the pressure drop and face velocity of a synthetic-fibre filter, bag filter and glass-fibre filter. Results were compared with data obtained using traditional instrumentation.

**KEYWORDS** air conditioning, tracer gas, instrumentation

**#NO 6377 A study of ventilation measurement in an office building.**

**AUTHOR** Dols W S, Persily A K  
**BIBINF** USA, National Inst of Standards and Technology, NISTIR 4905, October 1992, 42pp, 11 figs, 10 tabs, refs. in English

**ABSTRACT** The National Institute of Standards and Technology has conducted a study of ventilation and ventilation measurement techniques in the Bonneville Power Administration (BPA) Building in Portland, Oregon. The project involved the comparison of outdoor air ventilation measurement techniques for relative accuracies and an examination of changes in building ventilation rates over time. The following measurement techniques were compared: tracer gas decay

measurements of whole building air change rates, the determination of air change rates based on peak carbon dioxide (CO<sub>2</sub>) concentrations, the determination of percent outdoor air intake using tracer gas (sulfur hexafluoride and occupant-generated CO<sub>2</sub>), and direct airflow rate measurements within the air handling system. In addition, air change rate measurements made with an automated tracer gas decay system approximately three years apart were compared. The major findings of the study are as follows. Airflow rates were measured in the air handling system ductwork using pitot tube, hot-wire anemometer, and vane anemometer traverses, and good agreement was obtained between the different techniques. While accurate determinations of percent outdoor air intake were achieved using tracer gas techniques, the use of CO<sub>2</sub> detector tubes yielded unreliable results. Reliable determinations of ventilation rates per person were made based on SF<sub>6</sub> decay and direct airflow rate measurements but the use of peak CO<sub>2</sub> concentrations led to inaccuracies, i.e., the over prediction of ventilation rates by as much as 100%. The measured values of the whole building air change rates, and their dependence on outdoor air temperature, did not change significantly over a three-year period. The minimum air change rates were above the building design value and ASHRAE Standard 62-1981, the standard on which the design was based, but the minimum rates were below the minimum recommendation given in Standard 62-1989. The whole building air change rate under minimum outdoor intake conditions was determined to be twice the outdoor air intake rate provided by the minimum outdoor air intake fans. The additional

air change under minimum outdoor air intake conditions was due primarily to leakage through the main outdoor air intake dampers.

**KEYWORDS** ventilation rate, measurement technique, office building, outdoor air

**#NO 7051 Development of a New Tracer-Gas Sampling System For Measuring Airflow in Ducts.**

**AUTHOR** Cheong K.W., Riffat S.B.  
**BIBINF** UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp407-420., in English

**ABSTRACT** This paper is concerned with the measurement of airflow in ducts using an active (pumped) sampling system. The system is capable of sampling tracer gases using either tubes packed with adsorbent or sample bags. A perfluorocarbon tracer (PFT) was injected into the ducts using thermostatically-controlled heating blocks. The samples were collected and analysed using a thermal desorber/gas analyzer system. Laboratory and field testing of airflow in ducts was carried out. A large office building was studied for measurements of ventilation rate, ventilation efficiency and air quality. A questionnaire was also completed by office staff in order to assess air quality and thermal comfort.

**#NO 7468 A measurement technique guide on the application of tracer gas techniques for measuring airflow in HVAC systems.**

**AUTHOR** Cheong K W, Riffat S B.  
**BIBINF** UK, University of Nottingham, School of Architecture, Building

Technology group, (pre print) 1994, 137pp, 73 figs, 21 tabs, 42 refs. in English

**ABSTRACT** This handbook describes the use of tracer-gas techniques for measurement of airflow in ducts. Initial measurements were carried out in the laboratory to examine the accuracy of these techniques. The mixing of tracer gases (eg, sulphur hexafluoride, SF<sub>6</sub>) in ducts of various shapes and sizes was examined using different types of tracer injector. Airflow estimated using tracer-gas techniques (e.g. constant-injection, pulse-injection) was compared with measurements made with traditional instrumentation such as pitot-tubes and hot-wire anemometers. Work also involved the development of tracer-gas equipment for balancing airflow in HVAC systems. This equipment was used to balance airflow in a small-scale HVAC system. Research also involved the development of a perfluorocarbon (PFT) tracer-gas sampling system. The PFT was injected using a thermostatically-controlled injection unit and a fast-response sampling system, using stainless steel tubes packed with adsorbent, was employed to collect tracer gas samples. The samples were analysed in the laboratory using a thermal desorber and gas monitor. The PFT system was tested successfully in the laboratory. Airflow measurements were carried out in the HVAC system of an office building using tracer-gas techniques and the new PFT technique. Tracer-gas techniques were used in other applications including measurement of airflow through a porous medium in a rectangular duct and determination of the air-tightness of ductwork.  
**KEYWORDS** Measurement technique, tracer gas, airflow, air conditioning.

**#NO 7891 Application of tracer gas techniques for measurement of friction-factors of rectangular ducts.**

AUTHOR Cheong K W, Riffat S B  
BIBINF UK, Air Infiltration Review, Vol 13, No 4, September 1992, pp 10-11, 1 fig, 1 tab, 1 ref. in English  
ABSTRACT This work examines the application of the constant-injection and pulse-injection tracer gas techniques for measurement of airflow in rectangular ducts. Experiments were carried out in ducts with aspect ratios of 1,2, and 4. Tracer gas measurements were generally similar to measurements made using a pitot tube. Relationships for the friction-factor and hydrodynamic entrance length are presented for Reynolds number between 73,300 and 395,000.  
KEYWORDS tracer gas, duct

**#NO 8678 Computational and experimental study of pressure losses in duct transitions.**

AUTHOR Gan G, Riffat S B.  
BIBINF UK, University of Nottingham, Institute of Building Technology, 1995, 21 pp, 9 figs, refs.  
ABSTRACT This paper is concerned with numerical prediction and experimental measurement of airflow and pressure distribution in rectangular ducts with transitions. The constant-injection tracer-gas technique was used to measure mean air velocity in the ducts. Pressure distribution along the ducts was measured using static pressure taps. The pressure loss coefficient was calculated from the measured pressure loss and air velocity. Computational fluid dynamics was used to predict airflow and pressure distribution in the ducts. The predicted pressure loss coefficient was in good agreement with experimental results for a duct with a contraction.

KEYWORDS computational fluid dynamics, duct, pressure coefficient, tracer gas.

**#NO 12975 Error analysis of measurement and control techniques of outside air intake rates in VAV systems.**

AUTHOR Krarti M, Brandemuehl M J, Schroeder C C  
BIBINF in: ASHRAE Annual Meeting 2000, proceedings of a conference held Minneapolis, USA, June 24-28, 2000.  
ABSTRACT The results of the error analysis indicated that control strategies using direct airflow measurement from either an averaging Pitot-tube array or an electronic thermal anemometry provided the best ventilation control. The results show that the use of the temperature balance technique to calculate the outside air intake is not adequate under common building operating conditions. The use of a fixed minimum outside air damper position or a volumetric fan-tracking control strategy both proved to be inadequate control techniques for maintaining minimum ventilation rates in variable air volume.  
KEYWORDS measurement technique, temperature, airflow

**#NO 12976 Experimental analysis of measurement and control techniques of outside air intake rates in VAV systems.**

AUTHOR Krarti M, Schroeder C C, Jeanette E, Brandemuehl M J  
BIBINF in: ASHRAE Annual Meeting 2000, proceedings of a conference held Minneapolis, USA, June 24-28, 2000.  
ABSTRACT This paper presents the results of an experimental evaluation of four airflow measurement techniques and six control techniques used for maintaining minimum outside air intake

rates in variable air volume (VAV) systems. The experimental testing was conducted in a controllable environment using a laboratory equipped with a full-size HVAC system. The experimental study indicated that control strategies using the direct measurement of the outside airflow from an averaging Pitot-tube array or an electronic thermal anemometer provided the best ventilation control.

**KEYWORDS** measurement technique, air conditioning

**ASHRAE Standard 120P, Methods of Testing to Determine Flow Resistance of HVAC Ducts and Fittings**

**AUTHORS** ASHRAE

**BIBINF** ASHRAE, December 1995

**ABSTRACT** This standard establishes uniform methods of laboratory testing of HVAC ducts and fittings to determine their resistance to airflow

**6.3 Airflow through Air Terminal Devices**

**Evaluation of flow hood measurements for residential register flows**

**AUTHOR** Walker, I.S., Wray, C.P., Dickerhoff, D.J., and Sherman, M.H.  
**BIBINF** Lawrence Berkeley National Laboratory publication: LBNL-47382 2001.

**ABSTRACT** Flow measurement at residential registers using flow hoods is becoming more common. These measurements are used to determine if the HVAC system is providing adequate comfort, appropriate flow over heat exchangers and in estimates of system energy losses. These HVAC system performance metrics are determined by using register measurements to find out if individual rooms are getting the

correct airflow, and in estimates of total air handler flow and duct air leakage. The work discussed in this paper shows that commercially available flow hoods are poor at measuring flows in residential systems. There is also evidence in this and other studies that flow hoods can have significant errors even when used on the non-residential systems they were originally developed for. The measurement uncertainties arise from poor calibrations and the sensitivity of exiting flow hoods to non-uniformity of flows entering the device. The errors are usually large – on the order of 20% of measured flow, which is unacceptably high for most applications. Active flow hoods that have flow measurement devices that are insensitive to the entering airflow pattern were found to be clearly superior to commercially available flow hoods. In addition, it is clear that current calibration procedures for flow hoods may not take into account any field application problems and a new flow hood measurement standard should be developed to address this issue.

**#NO 2751 The contaminant distribution in a ventilated room with different air terminal devices.**

**AUTHOR** Heiselberg P, Nielsen P V  
**BIBINF** Institute of Building

Technology and Structural Engineering, Aalborg University, Denmark, August 1987, 14p, 9 figs, 8 refs. in English

**ABSTRACT** The room ventilation is investigated for three different air terminal devices under isothermal conditions. Velocity distribution in the occupied zone is measured for each air terminal device at different air exchange rates. The maximum air exchange rate is determined on the basis of both the throw of the jets and the comfort requirements applied to measured air



velocities in the occupied zone. Normalised concentration distribution in the test room is determined along a vertical line through the middle of the room as a function of the air exchange rate and the density of the tracer gas. The relative ventilation efficiency, based on the room average concentration is also determined as a function of the air exchange rate and the density of the tracer gas. The influence from the position of the return opening on the relative ventilation efficiency is found for one air terminal device.

KEYWORDS pollutant, air change rate, tracer gas, ventilation efficiency, instrument

**#NO 3146 Flow conditions in a mechanically ventilated room with a convective heat source.**

AUTHOR Heiselberg P, Nielsen P V  
BIBINF in: "Effective Ventilation", 9th AIVC Conference, Gent, Belgium, 12-15 September, 1988. in English  
ABSTRACT The ventilation of a test room ( $L \times W \times H = 5.4 \times 3.6 \times 2.4$  m) with a wall mounted heat source is investigated for two different air terminal devices. The properties of each air terminal device are described by measuring the velocity decay of the primary wall jet below the ceiling. The velocity distribution in the plume above the heat source has been measured at different heat loads as a function of the distance to the wall and the distance to the heat source. The measurements have led to an estimate of the maximum velocity in the plume and of the volume flow rate as a function of the heat load and the distance to the heat source. In order to find the influence of the convective heat source on the flow conditions in the room, the velocity distribution in the occupied zone and the normalized concentration

distribution along a vertical line through the middle of the room has been determined as a function of the specific flow rate and the heat load. The convective heat source is found to have significant influence on the flow conditions in the room. This paper shows lower velocities in the occupied zone and a more uniform concentration distribution in the room.

KEYWORDS airflow, mechanical ventilation, convection heating, mathematical modeling

**#NO 13314 Temperature and velocity measurements on a diffuser for displacement ventilation with whole field methods.**

AUTHOR Linden E, Cehlin M, Sandberg M  
BIBINF UK, Oxford, Elsevier, 2000, proceedings of Roomvent 2000, "Air Distribution in Rooms: Ventilation for Health and Sustainable Environment", held 9-12 July 2000, Reading, UK, Volume 1, pp 491-496, 4 figs, refs.  
ABSTRACT In this study the instantaneous temperatures and velocities close to a diffuser for displacement ventilation have been recorded using whole-field measuring techniques. The air temperatures were measured indirectly by the use of a low thermal mass screen in conjunction with infrared thermography. The measuring screen was mounted parallel to the airflow, acting as a target screen. By using the thermal images the size of the near zone was also calculated. To determine air movements a whole field method called particle streak velocimetry (PSV) was used. Images of tracks created by small, low-density particles, suspended in the air, were analyzed using computerized image processing to obtain the velocities. The

experiment took place in a climate chamber in which the wall and air temperatures were controlled. The diffuser was located in the centre of one of the walls. The tests were conducted for a supply flow of 15 l/s and a temperature difference between the inlet air and the room air of 4°C and of 6°C. This paper deals with the results obtained from the two whole-field measurement methods. The results show that the two whole-field measurement methods can be good tools for visualizing and measuring air velocities and temperatures in rooms. These techniques could be used in the work of improving the indoor climate.

**KEYWORDS** Indoor climate, whole field measurement methods, air velocity, air temperature, digital infrared camera, temperatures, diffuser, displacement ventilation, infrared thermography, 2D particle streak velocimetry (PSV), digital pictures, particle tracking.

## **6.4 Airflow through Fans, Heat Exchangers and Fresh Air Inlets**

**#NO 1204 Methods for the measurement of airflow rates in ventilation systems.**  
**Metoder for matning av luftfloden i ventilations installationer.**

**AUTHOR** The Nordic Ventilation Group  
**BIBINF** Publication T32:1982 Swedish Council for Building Research 1982 in Swedish  
**ABSTRACT** Describes methods for measuring airflow rates and air velocities in buildings, with the aim of formulating identical rules within the Nordic countries for the inspection and adjustment of ventilation systems.

**KEYWORDS** airflow, ventilation, measurement technique

**#NO 4070 Field measurements of air velocity: pitot traverse or vane anemometer?**

**AUTHOR** Howell R H, Sauer H J  
**BIBINF** USA, Ashrae J, March 1990, pp46-52, 4 figs, refs. in English  
**ABSTRACT** A rotating vane anemometer at a downstream coil face can provide the same accuracy as an induct pitot tube traverse.  
**KEYWORDS** air velocity, anemometer, measurement technique

**#NO 4115 Airflow rate through a heat exchanger coil: comparison of measurements made with a rotating vane-anemometer and a tracer-gas technique.**

**AUTHOR** Riffat S B  
**BIBINF** UK, Loughborough University of Technology, Dept of Civil Engineering, Building Services Group, to be published in Applied Energy, [1990], 11 pp, 2 figs, 4 refs. in English  
**ABSTRACT** This work compares measurements of airflow rate through a heat-exchanger coil made with a rotating vane-anemometer and a tracer-gas technique. The two sets of measurements were generally in good agreement. The tracer-gas technique was found to be simpler to use in practice and has additional advantages as it does not require detailed specification of the coil or actual density of air.  
**KEYWORDS** airflow, heat exchanger, tracer gas, measurement technique

**#NO 4799 Airflow measurements at coil faces with vane anemometers: statistical correlation and recommended field measurement procedure.**

AUTHOR Sauer H J, Howell R H  
BIBINF USA, ASHRAE Transactions,  
Vol 96, Part 1, 1990, pp 502-511, 15  
figs, refs. in English

ABSTRACT A procedure for measuring the volume flow rate of air through a heating or cooling coil is presented. When a pitot-tube traverse is impossible or impractical, the rotating vane anemometer procedure described and verified here will provide volume flow rates with similar uncertainty in the results. The rotating vane anemometer procedure was shown to produce estimates of volume flow rate at coil faces with plus or minus 7%. The procedure is valid in a velocity range of 100 to 1100 fpm, and upstream disturbances such as elbows, partially blocked coils, dampers, and fan blasts had virtually no effect on the accuracy of using the K-factor procedure as long as the measured velocities were positive and relatively uniform.  
KEYWORDS airflow, measurement technique, anemometer

**#NO 4835 Measurement of airflow in HVAC systems using tracer-gas techniques.**

AUTHOR Riffat S B, Holmes M  
BIBINF UK, AIVC 11th Conference, "Ventilation System Performance", held 18-21 September 1990, Belgirate, Italy, Proceedings published March 1990, Volume 1, pp 195-214, 10 figs, 3 refs. in English

ABSTRACT This paper describes the use of tracer-gas techniques to measure airflow in a rectangular duct and a HVAC system. Experimental procedures are discussed for the application of the constant injection, pulse injection and decay techniques using N<sub>2</sub>O and SF<sub>6</sub> as tracer gases. This paper also describes a new tracer-gas system with variable

sampling speed that was used to measure the decay of tracer-gas concentration. A comparison is presented between tracer-gas measurements and those made with a pitot tube and a hot wire anemometer.  
KEYWORDS airflow, air conditioning, tracer gas

**#NO 5146 Performance testing of HVAC systems using tracer gas techniques.**

AUTHOR Cheong K W, Riffat S B  
BIBINF UK, Loughborough University of Technology, Civil Engineering, 1991. in English

ABSTRACT The constant-injection and pulse-injection techniques were used to measure airflow in a duct and small-scale HVAC system. Tracer-gas measurements were compared with measurements made using a pitot-tube. The concentration of SF<sub>6</sub> tracer gas, velocity and static pressure distributions were measured in the duct and HVAC system for various Reynolds numbers. Results indicated that the flow rate obtained using the pulse-injection technique is in closer agreement with values obtained using the pitot-tube than results obtained using the constant-injection technique. This paper also describes the development of a tracer-gas system that has high-sampling frequency and could be used for measurement of airflow in HVAC systems.

KEYWORDS performance testing, tracer gas, air conditioning

**#NO 13774 The use of rotating vane anemometers to measure inlet grille velocities.**

AUTHOR Saunders J, Johnson A, Fletcher B  
BIBINF in: "Progress in Modern Ventilation", Proceedings of Ventilation

2000, Volume 2, proceedings of the 6th International Symposium on Ventilation for Contaminant Control, held Helsinki, Finland, 4-7 June 2000, Finnish Institute of Occupational Health, Helsinki, Finland, 2000, pp 204-207, 3 figs, 1 tab, 1 ref.

**ABSTRACT** The vane anemometer is often used to make measurements on fume cupboards, booths and at inlet and outlet grilles to measure velocities and calculate volume flow rates. However, its use at grilles presents a problem in that because of the nature of the flow, especially at inlet grilles, the velocity indicated by the anemometer is not the true velocity. Air emerges from the grilles in an array of jets and it is found that the effect of this is to make the instrument over-read. In the case of grilles under pressure (i.e., inlets), the range of applicability of correction factors supplied by the ACGIH manual is very limited, especially in relation to the open area, i.e., 70% open area or greater. Many grilles, especially at air inlets, but also on benches with perforated inlet and exhaust surfaces, can have open areas considerably less than 70%. No advice is given for rotating vane anemometers. An investigation was carried out at the UK Health and Safety Laboratory to identify the problems in the use of vanes at inlet grilles and to determine the likely correction factors for a wide range of mesh geometries and open areas. Concludes that vane anemometers used

at inlet grilles with open areas less than 80% over-read. As the open area decreases, the percentage speed over-read increases. For grilles of equal open area and the same perforation shape, the size and/or spacing of the holes effects the variation of air speed with distance from the grille. The grille perforation hole shape affects the over-read.

**KEYWORDS** instrumentation, anemometer, inlet grille

### **Development of a Simple Device for Field Airflow Measurement of Residential Air Handling Equipment, Phase I and Phase II**

**AUTHOR** Larry Palmiter and Paul Francisco

**BIBINF** Ecotope Final Report for DOE, June 2000

**ABSTRACT** This report presents the results of the development of a new, fast and accurate device for measuring the airflow through a residential air handler. The device is a calibrated plate that can be inserted into a filter slot in place of the filter. The pressure drop across the plate is measured and entered into a simple discharge coefficient equation to estimate the flow rate. This project was done in two phases. The first portion was a proof of concept phase in which the goal was an accuracy of  $\pm 10\%$  of the actual flow. The second phase was for refinement of the design to improve manufacturability and ease-of-use and to test the device in a variety of systems in actual homes