Air Infiltration Review

a quarterly newsletter from the IEA Air Infiltration and Ventilation Centre

International Energy Agency – AIVC

Vol. 9, No. 3, May 1988

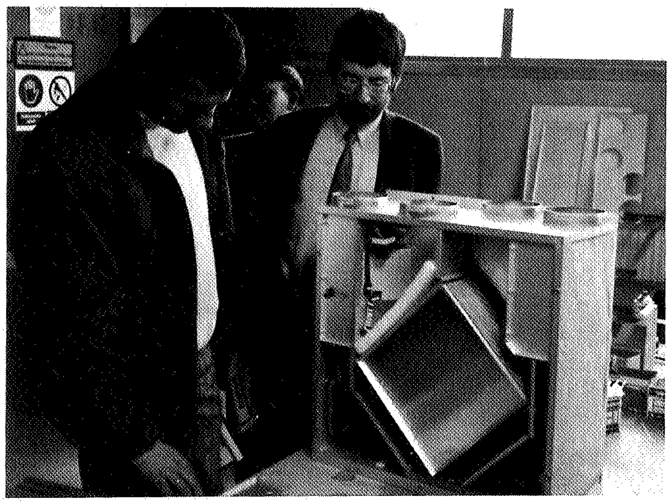
AIVC Workshop Focuses on Measurement Techniques

Measurement Techniques Workshop

Køge, Denmark, 1988
Peter S. Charlesworth, Senior Scientist AIVC

Representatives of 12 countries attended the Air Infiltration and Ventilation Centre's Measurement Techniques Workshop, held in Køge, Denmark 21–23 March 1988. The objective of the Workshop was to review current air infiltration and ventilation measurement techniques. The Workshop was hosted by Peter Collet (Technological Institute, Copenhagen, Denmark) and the week began with a visit to Genvex, a company which has collaborated with the Technological Institute in the development of simplified mechanical ventilation systems.

The director of Genvex, Mr Svendson stated that many Danish dwellings were too airtight. This lack of infiltration and natural ventilation had led to poor indoor air quality. In turn this had created a number of problems, specifically; condensation on windows, mould, rot and fungus on window frames, damp patches on walls behind furniture and house mites in mattresses and carpets. In order to try and overcome these problems Genvex have designed a range of balanced mechanical ventilation systems. It was claimed that these systems significantly improve indoor air quality and, due to the incorporation of a cross flow heat exchanger, do not necessarily place an excessive heat load on the building.



Tour of Genvex production facilities

After a tour of the Genvex production facilities, Workshop participants had an opportunity to view balanced mechanical ventilation systems in use in two kindergartens. These buildings had suffered from indoor climate problems and after research by the Technological Institute mechanical ventilation systems were installed. Indoor air quality problems had been reduced thus providing a better internal environment for pupils and teachers.

The measurement techniques workshop itself was introduced by David Harrje from Princeton University, USA. David's own experience of measurement techniques ranges from the development of a complex constant concentration tracer gas system to simple techniques which can be used to examine a large number of buildings in a cost effective manner. He stated that dedication to the advancement of air flow measurement techniques had been central to the interests of the AIVC since its inception in 1979. The first AIVC conference (1980) was devoted to measurement techniques and since that time air flow measurement horizons have expanded to search for not only an understanding of outdoor air entering and leaving a building but also how that air circulates, through both natural and forced means, between various parts of the building. The Workshop was seen as a forum for discussion and was an ideal opportunity for research workers to share ideas and experiences of infiltration and ventilation measurement techniques.

Workshop participants

A number of technical papers were then presented under the Chairmanship of Willem de Gids (TNO, Netherlands). Peter Charlesworth (AIVC, UK) described the Air Infiltration and Ventilation Centre's Measurement Techniques Guide. Peter stated that measurement techniques were the fundamental means of acquiring a greater understanding of air infiltration and ventilation, in that they enable primary dates to be obtained from the examination of existing structures. In recognition of this the Air Infiltration and Ventilation Centre was producing a document titled 'A Guide to Air Exchange Rates and Airtightness Measurement Techniques'. The guide will deal primarily with the measurement of air change rate, interzonal air flows and air leakage characteristics with the general aim being to increase awareness of measurement techniques and their application. Further details of this Guide will be published in the August edition of Air Infiltration Review.

Peter Warren (Building Research Establishment, UK) brought participants up to date on airtightness measurement standards by describing the International Standards Organisation (ISO) standard titled 'Measurement of Building Airtightness using Fan Pressurisation'. Peter stated that this was an international standard and that ventilation demands and airtightness requirements varied from country to country. Hence the ISO standard would address only the practical aspects of the fan pressurisation technique itself, thus allowing national standards to dictate such matters as how the building should be prepared and what internal volume should be measured. The document is currently in draft form and will be published as a full standard in the near future.

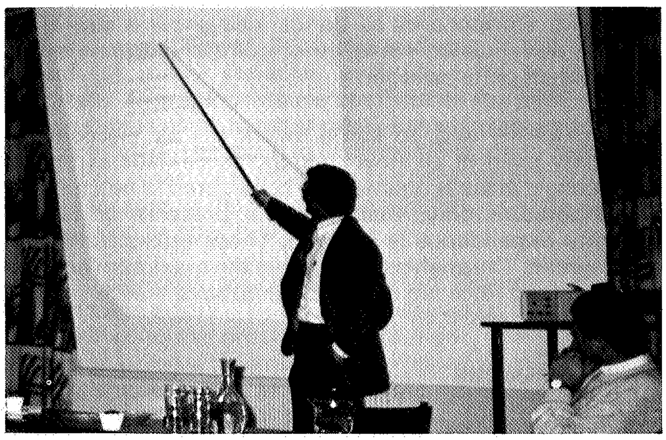
Marianna Louma (Technical Research Centre, Finland) discussed testing the performance of outdoor air inlets designed for residences equipped with mechanical extract ventilation. New building regulations in Finland will increase the use of outdoor air inlets in buildings equipped with mechanical extract ventilation systems. The Technical Research Centre tested the performance, in terms of draught production, sound attenuation and condensation/frost formation of several air inlets marketed in Finland. Based on these tests a proposal, about the type of rules which should be applied when testing the suitability of air inlets, was made. In general, it was concluded that controlled outdoor air intake by this method is only possible in airtight dwellings.

The theme of airtightness measurements was resumed by Peter Wouters (Building Research Institute, Belgium) who described the use of advanced single fan pressurisation techniques for determining leakage distribution in buildings. Peter stated that often whole building pressurisation does not provide enough information to meet the needs of a particular application. Without having to substantially increase the equipment requirements much more information can be gained using the techniques developed at the Research Institute. Peter described some of these techniques and cited specific examples where they had been used in actual buildings.

Attention was then turned to tracer gas techniques. John Shaw (National Research Council, Canada) described an automated Sulphur Hexafluoride tracer gas sampling system which is capable of taking (and analysing) air/tracer samples from up to 16 separate locations in a time interval of about four minutes. The system has been used both in a test room, to study the mixing of tracer gas and room air with no internal mixing fans, and on site to examine the air distribution of a mechanically ventilated eight storey office building.

Peter Collet (Technological Institute, Denmark) described the history of the development of the constant concentration tracer gas (CCTG) method. He then described current CCTG equipment which is capable of the simultaneous evaluation of air flow rates in up to 15 different zones of a building. Peter then presented some case studies where the CCTG system had been used to solve practical problems in a variety of building types.

Several presentations were made on the subject of the perfluorocarbon tracer (PFT) technique. This method often referred to as the 'passive' technique, was developed at Brookhaven National Laboratory (BNL). Russel Dietz, who instigated the development of the technique, provided an overview of the use of PFT's in ventilation measurements. He discussed potential advantages and disadvantages of the PFT technique and compared the performance of the PFT method with other tracer technologies. The intercomparison of techniques was based on short-term (field collection of air samples of 15 minutes or less duration, with subsequent laboratory determination of air flow rates) and real-time (field collection of multizone air samples of only a few minutes duration followed by in-the-field determination of flow rates) measurements. He concluded that PFT technology appeared to have the lowest field materials and man power requirement costs and, in addition, is the only technology capable of being applied in both short-term and real-time modes.



Russell Dietz delivers paper on PFT techniques

Max Sherman (Lawrence Berkeley Laboratory (LBL) (USA) discussed the analysis of errors associated with the passive ventilation measurement technique. The LBL study was based on mathematical models combined with typical weather data to calculate how an ideal passive ventilation measurement system would perform. It was found that the passive technique significantly under predicts the average ventilation rate and the use of multiple tracers accomplishes marginal improvement. He concluded that inadequate mixing was found to be a major impediment to the interpretation of the results and could completely invalidate the measurement.

Russel Dietz then described work performed at Princeton Univeristy, USA, designed to assess the potential of the PFT method as used in a multi-family building. Measurements were made over a two week period using three types of tracer gas. The PFT measurements were compared with simultaneous measurements of air flow rates using a constant concentration tracer gas measurement system. The results of this study are currently being analysed and a report will be presented at a future AIVC meeting.

A similar intercomparison study was made in Ontario, Canada. This research work was described by John Shaw. The study evaluated the passive tracer technique for a period of 30 days. Ten tests were conducted in conjunction with a continuous sulphur hexafluoride injection tracer gas system in six experimental houses. When the air change rate was maintained at a constant value the two measurement methods showed good agreement. If the air change rate was varied throughout the test the two methods were not in as close agreeement, with measured values differing by as much as 0.26 air changes per hour. It was concluded that in cases of constant ventilation rate the PFT method was suitable for evaluating the average air change rate.

The final formal presentation was by Max Sherman, who described a newly developed multi-gas constant concentration tracer gas instrument. This system uses a mass spectrometer as an analyser and is capable of sampling, analysing and controlling up to five separate tracer gases. This system is one of the most sophisticated in use and can provide detailed information about air change rates and interzonal air flows.

After each formal presentation a discussion about the current topic was held. At the end of the Workshop a general discussion was led by Max Sherman. This centred mainly on the PFT technique and the intercomparison of measurement techniques. Proceedings and discussion notes are currently being compiled and will be published shortly as an AIVC Technical Note. Full details of availability will be published in the August edition of Air Infiltration Review.

MOVECOMP

A Multizone Infiltration and Ventilation Simulation Program

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Introduction

A program calculating both the infiltration/inter-zonal air flows and the ventilation flow rates can be used for a wide range of applications, from simply studying the air change rate to the interaction between building and ventilation system. Using this tool, engineers and architects could gain valuable information on many different topics.

As no methods exist to accurately determine either the leakage paths and their characteristics or the pressure coefficients for external walls, an air infiltration program is most suitable for parametric studies. Here, the change of a parameter is more interesting than its absolute value.

An infiltration and ventilation simulation program should accurately determine the flow rates in a reasonable time. Furthermore, the model should have few limitations and be flexible enough to simulate different types of buildings and ventilation systems.

A 1984 survey showed that no such complex program was available. A long term project started shortly afterwards at the Royal Institute of Technology to develop Movecomp. This paper briefly describes the program, the model it is based on, and the solving algorithm.

Description of Building and Ventilation System

To get a complete picture of the air flows in a building, any model must take both the building and the ventilation system into consideration. Furthermore, to obtain accurate results these two parts have to be described in detail. The user should not be restricted in this sense by limitations in the model. Therefore, the possibilities to describe the building and the ventilation system must be flexible without any serious limitations. Ideally, any types should be possible to handle. The 1984 survey showed that most models could not meet that demand of flexibility.

When developing Movecomp effort was devoted to making it possible to describe most buildings without any significant limitation. Flow paths can therefore be specified wherever; the distribution and number of leaks are arbitrary.

Furthermore, the rooms do not need to be in a specific configuration or height; corridors and shafts can be mixed with ordinary rooms as desired. The ventilation system may be described with a similar degree of flexibility. The system can be specified in detail with ten well-defined components, arranged in almost any practical configuration. If it is not considered to be important to simulate the entire system, then fixed outlet and inlet flow rates can be given.

Figure 1 shows, as an example, a description of a two-zone building and its exhaust/supply ventilation system. The thin bars represent the major flow paths in the structure.

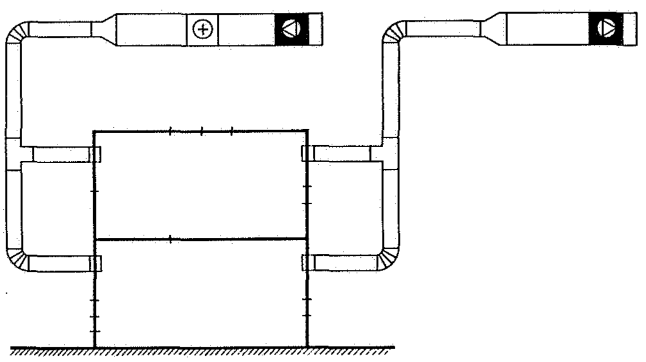

Figure 1: Description of a building and its ventilation system.

Simulation of Building and Ventilation System

It can be expected from a numerical point of view that a model simulating the buliding and ventilation system simultaneously is more time efficient than if the two parts are treated separately. Therefore, the building and the ventilation system are simulated as one common network of nodes and flow paths. Room and duct junctions are represented as nodes. In each node there has to be a mass flow balance under assumed steady-state conditions. Leaks and ducts are represented as flow paths. The mass flow versus pressure difference characteristic for each one of these paths has to be determined from measurements and/or experience.

Flow through leaks are simulated with a simple power function but extended with a correction for density and viscosity changes. A power function is in agreement with measurement although it does not reflect the change of flow regime. The added correction is important. The mass flow rate can change as much as 30%. Of this change, the contribution from the viscosity can be between 0 and 40% depending on the flow regime. Flow through large vertical openings where a two-way flow often exists is also possible to approximate. The opening is then considered to consist of several smaller openings.

Flow through ducts and components in the system are simulated by the traditional concept of friction or loss factor and the dynamic pressure of the flow. There are built-in algorithms for ten standard components. All flows are considered to be turbulent because laminar flow is not common in forced ventilation systems. Besides this, most loss factors are experimentally determined at high Re-number. To exclude laminar flow also means that the transition zone between laminar and turbulent flow which is less well known, is avoided. Just because the flow is considered to be turbulent does *not* necessarily mean that the flow rate is proportional to the square root of the pressure difference. For straight ducts and most common combinations of air velocities and duct dimensions, the friction factors are functions of the flow rates. The loss factors for components as bends also show a strong Re-number dependence while other components are almost independent of Re-number.

The air density and, to some extent the air viscosity are frequently used in air flow models. Systematic errors are introduced if these properties are considered to be a function of temperature only, that is if the pressure or relative humidity dependence is ignored. These errors have been investigated. The analyses show that the maximum errors in the main flow rates are of the magnitude of +/–2% which is mainly due to moist air.

Driving Forces

The driving forces for the air flows are thermal forces resulting from differences in air densities both within the building and to the outside, wind forces, and fan forces. Describing the driving forces accurately is as important as describing the building and the ventilation system thoroughly. Again the fewer limitations the model has the better. Any steady-state model does however, have some fundamental restrictions on this point. These models can never strictly take into account the phenomenon associated with dynamic driving forces. However, several approaches have been made to add corrections to steady-state models so that air flows caused by dynamic wind can be estimated. Such corrections, if acceptable, can easily be included in a flexible model.

Temperatures and temperature gradients may be specified in each room separately. The program does not include any thermal model, consequently, these variables have to be given as inputs. The different air temperatures throughout the duct system are automatically calculated according to the current air flow rates.

Figure 2 shows that an internal thermal gradient can be important for the flow pattern in a building. The building consists simply of a shaft with equally distributed leaks. The *average* indoor temperature is equal to the outdoor temperature but has a linear gradient. Thus, if the indoor temperature is simulated as one single temperature no flow will occur across the outer walls. However, if the temperature can be described more in detail, the result is according to the figure. The flow pattern here is owing to the internal gradient only, no other driving forces are present.

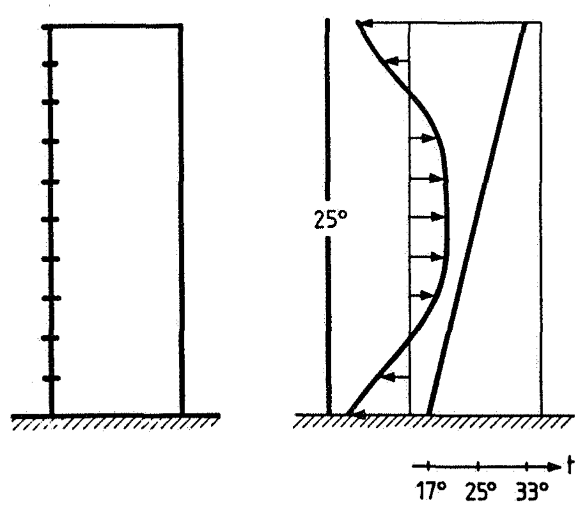

Figure 2: Example of influence of thermal gradient.

The wind pressures on the outer surfaces of the building depend on many variables and are hard to measure accurately. Average pressure coefficients for each surface are sometimes used. In other cases a more exact pattern has to be simulated. The input to Movecomp is made according to this, thus pressure coefficients can be given in any pattern over the facades of the building. In addition, both on and off-site wind can be specified.

Fan characteristics are often neglected. However, this can result in large errors. The flow rates delivered by many fans are sensitive to the pressure across them. Therefore, each fan can be given a separate fan characteristic of an almost arbitrary shape as long as the pressure rise across the fan is strictly decreasing with the flow rate. Since ventilation system and fans can be simulated in detail, the behaviour of different types of ventilation systems can be studied under various conditions.

Solving Algorithm

The mass balances, the characteristics of the flow paths, and the driving forces make up a non-linear system of equations which has to be solved. For infiltration models, the most common solving algorithm for this non-linear system of equations is Newton-Raphson. However, the nature of Newton Raphson creates problems when the dominant leak in the zone has an exponent close to one-half and/or the start approximation is not close enough to the solution. The results can either be diverging iterations or very slow convergence. These problems are usually solved with an under-relaxation chosen according to experience only. So far, no systematic method in choosing the relaxation has been introduced in this field. The algorithm used in Movecomp is based on Newton-Raphson but also takes advantage of the special properties of the non-linear equations to obtain an efficient algorithm based on ideas from non-linear optimization. This approach has been successfully used which will be shown below.

Figure 3 shows a comparison of the calculation time, in a relative scale, between Newton-Raphson (N-R) and Movecomp (M-N-R) for a two-zone building. The air forced through the building must pass two facades and one internal door. All three leakage openings have a flow exponent of one-half; the two facades have the same flow coefficient K_f.

The curve representing Newton-Raphson describes the characteristic problem with the method when the flow coefficient ratio K_f/K_d is well away from unity. Movecomp on the other hand does not show any significant change in calculation time for different ratios of the leakage openings. The absolute sizes of the openings do not have any significant influence on these results.

Even though this is a simple network, numerically it can be a hard problem. It is therefore suggested that this network is adapted as a test case for multizone infiltration models.

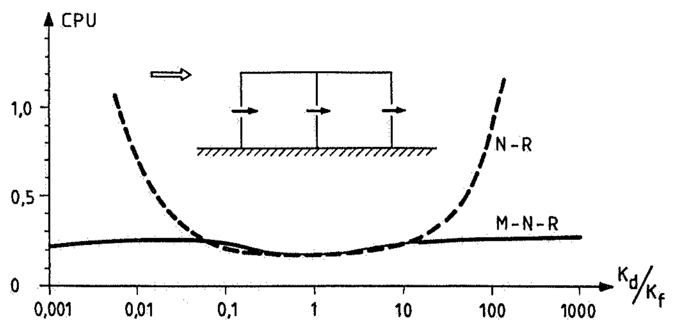

Figure 3: Calculation time for Newton-Raphson and Movecomp

Parametric Studies

The good convergency features make the program suitable for parametric studies. One or several parameters are changed systematically in steps to get knowledge about some special properties. Parametric studies thus require many measurements or calculations, maybe thousands. Measurements that would have taken an unreasonably long time to do or would even have been impossible to perform, can be simulated fast and accurately.

To be able to use any infiltration program on a specific building, there must be accurate methods to determine the leakage paths and their characteristics. The most recent work done with the program has been to estimate the errors of measured path characteristics. This work has been conducted at the Lawrence Berkeley Laboratory, USA and is a typical example of an extensive parametric study.

It is known that the technique to determine the coefficients of the flow equation from pressurization with blower doors is sensitive to wind fluctuations. Calculations were made to quantify this sensitivity for coefficients for internal walls. In general, the higher the mean wind speed the higher turbulence can be expected. At each mean wind speed the wind can be considered to be log-normal distributed. Wind speeds are randomly taken from these distributions and the standard deviation for the coefficients of each mean wind speed is calculated. With the criteria of a maximum acceptable standard deviation, the highest mean wind speed has been determined for a typical three story building. These results are planned to be published at the ninth annual AIVC meeting in Belgium, September 1988.

Input/Output

The input to a multizone model can be extensive if the building is going to be simulated in detail, which often is the case. The input must therefore be structured and arranged in logical parts. The input is arranged in several tables and thus not of an interactive type. Tables give a good overview of the input compared to the interactive type of input for an experienced user. For a beginner, on the other hand, the interactive type of input probably has several advantages.

The output can be even more extensive than the input but is highly dependent on the actual program. The output can include declarations of many other variables besides the air flow rates. Furthermore, these variables can be treated statistically or in any other way. Besides this, information about the progress of the calculation itself can be included. It is therefore desirable and often necessary to be able to select both type and amount of output in each individual case or simulation. Here, the amount of output can be chosen from a menu that contains several levels of each type of output to suit the user's needs.

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An Overview of Research Activity on Ventilation in Italy

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Introduction

In Italy, until the oil crisis, air infiltration, airing and ventilation were considered mainly from the indoor air quality viewpoint. Energy related topics were considered to be less important. Codes and standards, resulting from hygiene-oriented research, established minimum values of air change rates, depending on room or building designation.

Actually, given the poor quality of average Italian window systems, these requirements could be easily met in naturally ventilated residential buildings. There were few problems even in the windless regions of the Po valley, where almost 75% of the Italian heating demand is concentrated. Whenever natural ventilation was not sufficient, the occupant would provide some extra outdoor air by opening the windows (airing).

However, the absence of insulating materials in walls and roofs and the use of single glazed windows caused very high conduction losses, outmatching by a factor of four to six the ventilation losses, even in large buildings. In any case, the relatively mild climate made this issue fairly unimportant.

The dramatic increase of oil prices in the mid seventies did not lead directly to any substantial improvement of the energy efficiency of the existing building stock. This was mainly due to the relatively low number of owner-occupants in Italy, and the related fatal distinction between those who pay for retrofitting a building and those who save money out of the heating bill: a question yet unresolved in Italy.

Around the end of the seventies, however, a compulsory regulation (Law 373, 1976) came into force. This was aimed at reducing the energy consumption for space heating of newly built residential and commercial buildings by limiting the installed power of the heating plant. In particular, this law specifies the maximum admissable value of transmission heat losses as a function of climate (heating degree-days) and shape of the building (surface-to-volume ratio). In the case of ventilation heat losses, a conventional maximum value of 0.5 ach is specified for all buildings.

This upper limit often conflicted with previous standards, which specified minimum ach values according to the space designation. Moreover, no standard provides any information about how to relate the envelope design to the ventilation requirements. This is particularly crucial when the building is naturally ventilated (the usual case for residential buildings in Italy).

The tendency in new constructions was to use insulating materials which gave a substantial reduction in conduction heat losses. As a result, especially for large buildings in the northern area (in which average u-values of less than 1.4 W/m^{2}K were imposed), ventilation losses, in spite of the conventional reduction to 0.5 ach, became an important part of the energy budget.

There was no knowledge of the actual Italian buildings, but there were strong suspicions that ventilation heat losses could now be as high as 40% of the total heat losses. Some energy conscious designers started installing more airtight double-glazed windows, especially in the northern regions.

The final result was that in many of these buildings, low indoor temperatures (mainly due to the imposed practice of night temperature set-back), cold bridges (arising from incorrect placing of insulants), low naturally induced Δ p's (due to low wind velocities), and airtight envelopes, all contributed to dramatic condensation effects, with mould and fungus growth.

These reasons explain why, especially for indoor air quality reasons, the 'ventilation issue' now enjoys renewed concern among Italian researchers. A short description of previous and ongoing research in Italy is given in the following sections.

Experimental Research

Air Permeability Testing

Pressurization tests have been performed on windows since the mid sixties. Currently there are at least ten laboratories which officially certify windows in terms of airtightness, this is according to the Italian standard UNI-EN 42. The standard defines three categories (A1, A2, A3), depending on whether the window permeability at 50 Pa is below 60, 20, or 7 m^3/(h m^2).

In order to evaluate the effect of craftmanship and window assembling techniques, ISTEDIL, the Research Institute of Building Constructors, is performing an extensive measurement campaign in the field. This work is done by means of a portable device for component pressurization tests.

An original and interesting technique to quantify window airtightness has been developed by the IENGF (National Institute of Electrical Engineering 'Galileo Ferraris'): this technique is based on the correlation observed between air permeability and sound transmission through windows. Unfortunately, the accuracy of the method depends strongly on the type of window, and is not always satisfactory (Brosio et al, 1980).

The strong interest in window permeability rather than other components of buliding envelopes as a whole is due to the fact that the particular construction techniques adopted in Italy lead to air leaks in the envelope being mostly concentrated in and around the window system (including the roller blinds box). Walls themselves and wall joints are usually fairly tight.

This explains why overall pressurization tests are seldom applied to buildings. However, such techniques are customary for testing the air permeability of automobiles (Vacchelli, 1985).

Tracer Gas Techniques

The first systematic laboratory campaign with tracer gases was performed at the Politecnico di Torino by Cali, Fracastoro and Vacchelli (1986). Previous experience has been gained by one of the authors at the Swedish Institute for Building Research, under the guidance of Sandberg (1984). The aim of the experimental campaign was to assess the accuracy of the decay technique under different experimental situations (mixing procedures, air change levels, number of sampling points, air immission techniques). Nitrous oxide and (less extensively) water vapour, were used as tracer gases. A summary of the results is shown in Tables 1 and 2. An attempt to establish a correlation between the degree of mixing and the measurement accuracy was also done during the investigation.

Table 1: Number of air change in different experimental conditions

	n = 0.50			n = 1.00			n = 2.00		
	Position of the grid			Position of the grid			Position of the grid		
	A	B	C	A	B	C	A	B	C
Point									
1	0.63	0.66	0.65	1.15	1.16	1.13	2.19	2.15	2.13
2	0.61	0.57	0.59	0.99	0.98	1.13	1.88	2.04	2.00
3	0.62	0.65	0.64	1.12	1.15	1.13	2.17	2.15	2.13
4	0.62	0.65	0.63	1.12	1.13	1.11	2.20	2.12	2.16
5	0.64	0.65	0.65	1.13	1.15	1.12	2.16	2.14	2.15
6	0.63	0.66	0.63	1.12	1.14	1.13	2.16	2.15	2.16

Table 2: Air changes measured using water vapour as a tracer gas

Reference value	0.53	1.06	1.59	2.38	3.18
Measured value	0.87	1.30	1.54	1.82	2.83
Percent deviation	+64%	+23%	–3%	–24%	–11%

Large ventilation test chambers are currently under construction or in the planning stage at the Politecnico di Torino and at the University of Basilicata (Potenza). These will be used to test the accuracy of tracer gas methods under different experimental procedures, to investigate the diffusion of pollutants within inhabited spaces and to test the performance of demand-controlled ventilation systems.

In-the-field investigations with tracer gases have been extensively performed by De Bortoli et al (1985), which assessed the air change rates in 15 homes using SF6 and bag sampling. However, the number of research units which are able to carry out air infiltration measurements using even the simplest tracer gas technique is, at the moment, still very small.

Occupant Behaviour

A large and exhaustive investigation was made in 1979 within the Progetto Finalizzato Energetica of the National Research Council in order to assess the behaviour of the Italians with respect to the heating system operation. This study contained the results of a questionnaire distributed to 10,000 families, concerning the frequency and duration of window opening in each room of their apartment (CNR. 1979).

The investigation showed that airing by window opening is very common in Italy: 85 to 90% of the people open the windows during the heating season for 40 to 65 minutes per day as a means of improving the air quality.

Air Infiltration Models

Research on theoretical models concerning air infiltration is still in its early stages. An analytical one-zone model with constant pressure on each horizontal plane was first implemented by Cali and Fracastoro (1979). A simplified formula for the evaluation of the air flow through a single – and two-sided opening, in the absence of wind, was developed by Agnoletto (1981).

Monaco et al (1980) established the first simplified procedure for the calculation of the seasonal average air changes per hour in a building. This model requires that the permeability and area of windows, the wind zone, and the building height be known.

Following this same line, Fracastoro and Pagani (1987) deduced from an analytical model including the effect of horizontal partitions, the infiltratiion volume flow rate in a large number of different buildings in different situations. The results were fitted into simple monomial formulae which provided the 'equivalent pressure difference', i.e., the homogeneous infiltration. This was determined as a function of building typologies, terrain conditions, wind velocity, outdoor air temperature, and 'internal resistance flow coefficient'. The structure of the formulae was derived from dimensional analysis.

Conclusions

Research on air infiltration and indoor air quality has been stimulated, in Italy, by the problems caused by the incorrect application of the Law for energy saving in buildings. When some external action (as a compulsory design code) alters the well established equilibrium of a complex system (such as building construction practice), unexpected problems may easily arise. The technical community has now to play an important role in overcoming the present situation. This can best be achieved by promoting research aimed at developing design codes, testing standards and on-site checking procedures in the ventilation and air quality sector.

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9th Annual Conference

EFFECTIVE VENTILATION

12-15 September 1988 – Novotel, Gent, Belgium.

The AIVC's 9th Annual Conference focuses on the development, needs and operational performance of new ventilation techniques. A wide range of topics within this general theme is covered and the conference is specifically aimed at the dissemination and transfer of current research results. It should therefore appeal to those engaged in ventilation research and to the specialist wishing to develop and exploit new ideas.

Included within the theme are presentations on

- air flow patterns and ventilation efficiency
- energy performance
- air quality aspects
- occupant considerations
- future trends
- case studies
- ventilation measurement techniques

In view of the success at previous AIVC conferences of poster and demonstration sessions, increased emphasis is being placed on such presentations this year. In addition to posters, video, computer and other demonstrations are being organised. Regardless of the method of presentation, full technical papers will be published in the conference proceedings.

The City of Gent in Belgium is ideally situated for this International Conference. Full hotel accommodation, all meals, return transport from Brussels Airport and a technical visit to the Belgian Building Research Institute are included in the registration fee of £300 sterling.

The provisional programme for the conference is as follows:

SESSION 1 MONDAY 12 SEPTEMBER

Opening and Keynote Address

Natural Airflows between Roof, Subfloor and Living Spaces.
Mark Bassett (NEW ZEALAND)

Experimental Analysis of the Air Diffusion in a Large Building.
A Fissore and P Nusgens (BELGIUM)

Determination of Ventilation Efficiency Based upon Short Term Tests.
R Anderson and M Mehos (USA)

Ventilation Strategies in the Case of Polluted Outdoor Air Situations.
L Trepte (FED. REP. of GERMANY)

Ventilation Generated by a Fluctuating Pressure Differential.
B Sahin, C Clark, A J Reynolds and R Wakelin (UK)

Air Motions in the Vicinity of Air-supply Devices for Displacement Ventilation.
H M Mathisen (NORWAY)

SESSION 2 TUESDAY 13 SEPTEMBER

Integral Inverse Contaminant Dispersal Analysis and Tracer Techniques.
J Axley and A Persily (USA)

Commercial Building Ventilation Measurements Using Multiple Tracer Gases.
W J Fisk and R J Prill (USA)

Constant Concentration Measurement with 2 Tracers.
B Kvisgaard and P F Collett (DENMARK)

Multiple PFT Tracer-determined Air Flow and Duct Leakage in a Forced-air Equipped Condominium.
R N Dietz, R W Goodrich, T W D'Ottavio, D J Spandau and G I Senum (USA)

Extended Testing of a Multi-family Building Using Modified Constant Concentration Methods.
D L Bohac, D Feuermann and D T Harrje (USA)

Examination of Two Techniques for Measuring Inter-zonal Air Leakage.
M Herrlin (SWEDEN) and M Modera (USA)

Using a Guarded Zone Pressurization Technique to Measure Air Flow Permeabilities of a Multi-zone Building.
J-M Furbringer, C Roecker and C-A Roulet (SWITZERLAND)

Technical Visit to Belgian Building Research Institute

SESSION 3 POSTERS AND DEMONSTRATIONS

Buoyancy Driven Air Flows through Semi-open Doors.
A T Howarth and I L Jennett (UK)

The Large Area Quantitative Visualisation Method of Air Streams.
G Gottschalk, P Tanner and P Suter (SWITZERLAND)

Displacement Ventilation by Different Types of Diffusers.
P V Nielsen (DENMARK)

A Comparison of Upward and Downward Air Distribution Systems.
D J Croome, Zhao-Xi Lin and D Rowlinson (UK)

Air Heating Systems in Airtight Multi-family Residential Buildings.
P O Jagbeck, G Werner and K Engvall (SWEDEN)

Further Studies of Passive Ventilation Systems – Assessment of Design and Performance Criteria.
R E Edwards and C Irwin (UK)

Zone to Zone Multi-tracer Gas Measurements: Laboratory Calibration and Values of Air Flows Up and Down Stairs in Houses.
M Eid, J Littler, S Riffat and J Walker (UK)

Development of an Efficient Control Algorithm for a Multi-zone Constant Concentration Tracer Gas Air Infiltration Measurement System.
R Compagnon, A Kohler, C Roecker and C-A Roulet (SWITZERLAND)

A Study of the Ventilation Characteristics of a Suspended Floor.
J P Lilly, J M Piggins and R J Stanway (UK)

Long-term Airtightness of Low Energy Prairie Houses.
M E Lux (CANADA)

Numerical Simulation of Indoor Turbulent Air Flows Caused by Cross-ventilation and its Model Experiments.
Jun-ichiro Tsutsumi, T Katayama, T Hayashi, Q Zhang and H Yoshimizu (JAPAN)

Multi-zone Contaminant Dispersal Analysis Using an Element Assembly Approach.
J Axley (USA)

A Numerical Study of Buoyancy Driven Flows of Mass and Energy in a Stairwell.
A Zohrabian, M R Mokhtarzadeh-Dehghan and A J Reynolds (UK)

A Simplified Approach of Air Infiltration in Multi-zone Buildings.
D Caccavelli, J J Roux and F Allard (FRANCE)

SESSION 4 WEDNESDAY 14 SEPTEMBER

Air Leakage between Apartments.
P Levin (SWEDEN)

Evaluating the Air Infiltration Induced by Heating Appliances.
G V Fracastoro and M Masoero (ITALY)

Indoor Formaldehyde Levels in Energy-efficient Homes with Mechanical Ventilation Systems.
M Riley and P Piersol (CANADA)

Recirculation of Air in Dwellings.
W F de Gids and J C Phaff (NETHERLANDS)

Effective Ventilation in Offices: The Occupant's Perspective.
I D Griffith, J Huber and A P Baillie (UK)

Future Trends: A Ventilation Concept for Future Dwelling-houses.
M Luoma and R Kohonen (FINLAND)

Investigation of the Indoor Air Quality, Airtightness and Air Infiltration Rates of a Statistically Random Sample of 78 Houses in Winnipeg.
G K Yuill and G M Comeau (CANADA)

SESSION 5 POSTERS AND DEMONSTRATIONS

A Cp Data Bank for Filtration and Ventilation Calculations.
K Balazs (HUNGARY)

Analysis of the Influence of Topography on the Exposure of Buildings.
J-A Hertig and J Ehinger (SWITZERLAND)

The Influence of a Controlled Natural Ventilation on the Indoor Radon Decay Products Concentration: A Case Study.
Ch Schuler, R Crameri, D Furrer and W Burkart (SWITZERLAND)

IEA Annex 14: Energy and Condensation.
E Senave (BELGIUM)

Examinations about the Air Humidity in Lived Dwellings Depending on Different Air Ventilation Systems Using a New Characteristic Value.
Dr Schmickler (FED. REP. OF GERMANY)

The Effect of Various Mechanical Ventilation Systems on Indoor Air Quality and Moisture Control in Residential Buildings – Two Case Studies.
C A Lane (US)

Field Experiences of Airborne Moisture Transfer in Residential Buildings.
J Oldengarm (NETHERLANDS)

The Study of the Effects of Window Opening on House Ventilation.
L E Alevantis (USA)

Ventilation Habits in Residential Buildings.
H Erhorn (FED. REP. OF GERMANY)

Performance of Ventilation System in Low Energy Houses.
M Egedorf and B Kvisgaard (DENMARK)

Flow Conditions in a Mechanically Ventilated Room with a Convective Heat Source.
P Heiselberg and P V Nielsen (DENMARK)

Ventilation and the Level of Indoor Contaminants in a Modern Office Building.
R Grot and A Persily (US)

The Application of Mathematical Modelling to the Evaluation of Building Ventilation Systems.
R Grot, J Fang and T Kurabuchi (US and JAPAN)

Demonstration of AIVC Bibliographic Database – AIRBASE.
J Blacknell (UK)

SESSION 6 THURSDAY 15 SEPTEMBER

Passive Ventilation and a Statistical Assessment.
M D A E S Perera, R R Walker and R G Tull (UK)

Market Analysis of Sensors for Use in Demand Controlled Ventilating Systems.
W Raatschen (FED. REP. OF GERMANY)

Ventilation Design for a Bus Station.
M J Holmes and T Salusbury (UK)

Ventilation and Air Quality in Belgian Buildings: A State of the Art.
P Wouters, D l'Heureux, P Voordecker and R Bossicard (BELGIUM)

Overview of Conference and Current Research Discussion Session and Summing Up

To ensure a place at this conference, please contact:

Martin W Liddament, Air Infiltration and Ventilation Centre,
c/o Operating Agent, Oscar Faber Consulting Engineers,
Marlborough House, Upper Marlborough Road,
St. Albans, Herts. AL1 3UT, Great Britain.
Tel: 0344 53123 (National), +44 344 53123 (International)

Special Announcement:

AIVC TO RELOCATE

TO WARWICK UNIVERSITY SCIENCE PARK

As part of a re-organisation of its activities, the Air Infiltration and Ventilation Centre will be re-locating to a new site on the Science Park of the University of Warwick. Because of problems in co-ordinating start and finish dates for the accommodation, the AIVC will be located at the temporary address given below for a period of about 3-4 months, beginning on June 1st 1988. The staff at the Centre will remain unchanged, and AIVC will continue to be run under the overall management control of Oscar Faber as Operating Agents for the IEA. Full details of the new site will be given in the next issue of AIR.

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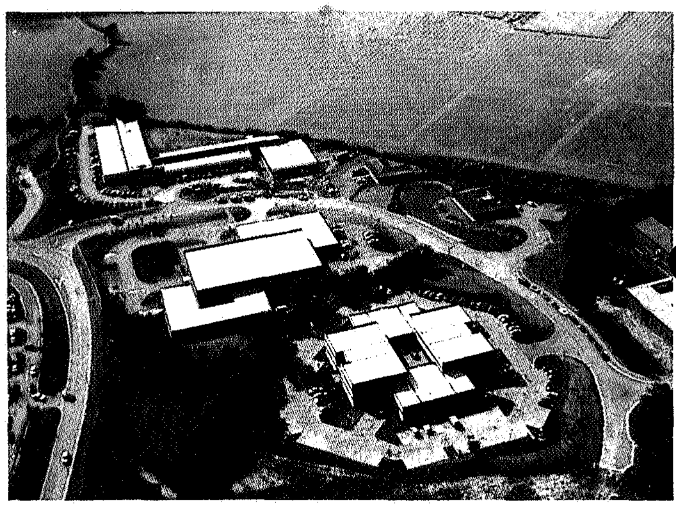


University of Warwick Science Park

Ventilation Through a Single Opening in a Scale Model

By R.D. Crommelin and E.M.H Vrins
Department of Indoor Environment,
TNO Division of Technology for Society,
Netherlands

1. Introduction

Little is known about the ventilation through one single window in an enclosed space. It is important to gain more knowledge in this field. This kind of ventilation can be investigated by measurements in buildings or in scale models in a wind tunnel. We chose for measurements in a scale model, because in this way the influence of various factors such as velocity, window dimensions etc. on the ventilation can be examined systematically. However, a disadvantage is that the results refer to a room and window opening which are much smaller than in reality. It is necessary, therefore, to examine the influence of possible scale effects on the measuring results by measurements in existing buildings and homes. By simulating as well as possible the atmospheric turbulence in the wind tunnel we tried to reduce the scale effect to a minimum.

In this investigation, only the isothermal ventilation caused by the wind is examined. Thermal effects on the ventilation are not considered.

2. The Scale Model in the Wind Tunnel

For the measurements a cubical model of 0.3 x 0.3 x 0.3 m^3 was used. If required the model could be enlarged in one horizontal direction using perspex auxiliary pieces measuring 0.3 x 0.3 m^2 in cross section. This model consisted of transparent material (perspex) so that the air flow in the model could be made visible with smoke. The model was placed on a circular disk in the bottom of the wind tunnel. This disk could be rotated so that the inflow direction of the model could be varied.

The wind tunnel measured 1.1 x 1.1 m^2 in cross section, the wind velocity could be varied from 0 to 10 m/s. One of the side walls of the model had a square or a rectangular opening allowing exchange between the inside and the outside air.

The turbulence of the wind was simulated using laths in a zigzag pattern according to Jensen's method [1] in [5] it is described in detail how the atmospheric turbulence in a wind tunnel can be simulated.

The ventilation rate in the model was determined by the tracer gas method using N_2O as a tracer gas.

3. The Phenomenon of Turbulent Air Exchange Through an Opening

The inflow and outflow of air through an opening in an enclosed space has been studied by making the turbulent flow in the window opening visible with smoke.

Turbulences cause simultaneous positive and negative pressure differences in the window plane in relation to the pressure at the inside. These pressure differences change in place and time. The ventilation occurs by simultaneous inflow and outflow of air caused by the pressure differences. Figure 1 shows the air flow in a simplified way.

The turbulences in the window opening are caused by passing eddies rotating in alternating directions. These eddies are generated by the building or, in our case, by the model and the environment.

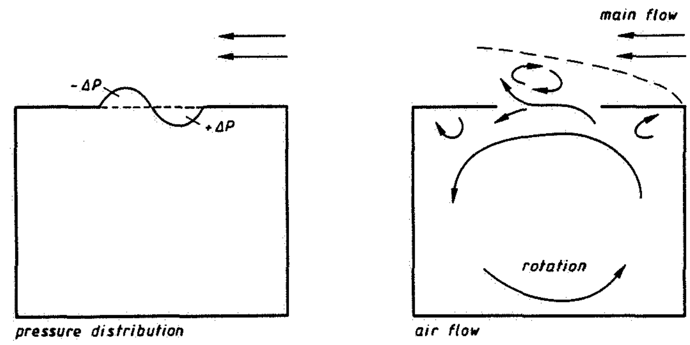


Figure 1a: Flow through the window opening at time t_1

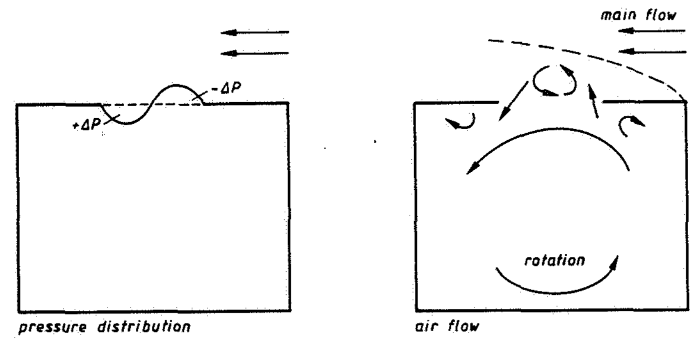


Figure 1B: Flow through the window opening at t_2

4. Factors Influencing the Ventilation Through One Single Opening

4.1. Wind Velocity

In Figure 2 the ventilation is plotted against the air velocity in the wind tunnel [2].

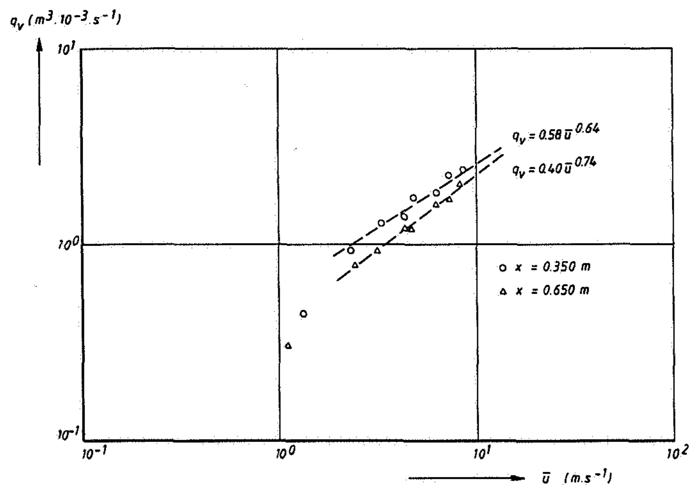


Figure 2: Ventilation against average wind velocity

We worked with two lengths upstream of the opening: 0.35 m and 0.65 m. The air flows parallel to the window opening. The following relation has been found between the ventilation and the average air velocity:

- upstream length 0.35 m: $q_v = 0.58\ \bar{u}^{0.64}$ ($\bar{u}$ in m/s, q_v in dm^3/s).
- upstream length 0.65 m: $q_v = 0.40\bar{u}^{0.74}$.

With the smaller length the ventilation is stronger because the eddies and the turbulence are more intense than with the larger length. This result is different from Bot's findings in ventilation measurements in glass houses [3]. He found that the ventilation is directly proportional to the wind velocity. In our measurements probably the scale effect plays a role, namely the fact that the air inside the model is brought in a rotating motion by the outside air flow. This rotating motion is rather strong in our case because the walls of the model are smooth at the inside.

4.2 Wind Direction

Figure 3 shows the ventilation as a function of the wind direction.

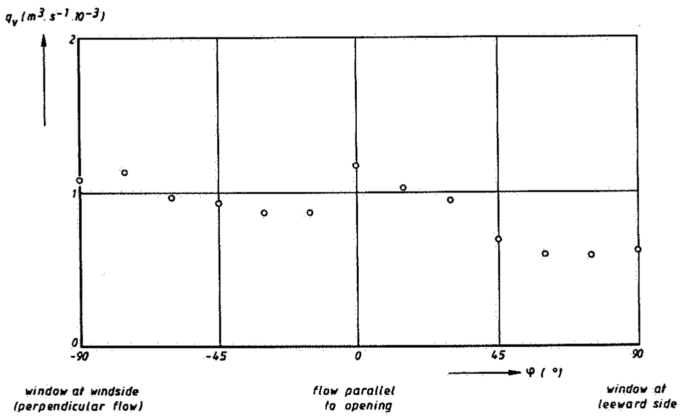


Figure 3: Ventilation as a function of the wind direction

If the flow is parallel to the window (=0°), ventilation is at a maximum. When the façade is turned from the wind the ventilation decreases gradually. If exceeds 60° there is a lee area and ventilation is at a minimum. If the façade is turned towards the wind ventilation first decreases fast because the air flow along the opening becomes more stable and the intensity of the turbulence (eddies) decreases. Turning the façade further towards the wind an area of overpressure is created. The ventilation attains a maximum for = –75° when the turbulence is somewhat stronger than if the inflow of the air is perpendicular to the façade. It should be taken into account that the fluctuations in the wind direction are smaller than in reality because of the side walls of the wind tunnel.

4.3 Building Variables

The influence of the model length upstream of the façade and the influence of the roughness of the façade on the ventilation have also been investigated. It appears that small roughnesses of the façade have no influence on the ventilation. Large roughnesses, at the size of the window opening, can cause eddies which influence the ventilation.

Figure 4 shows the influence of the façade length in the upstream direction on the ventilation. With a small façade length, ventilation is strongest because the influence of the eddies generated at the head façade is largest. From figure 4 it appears that this eddy extends to 1 metre along the façade. After that the air flow adheres to the façade again. This is illustrated in Figure 5.

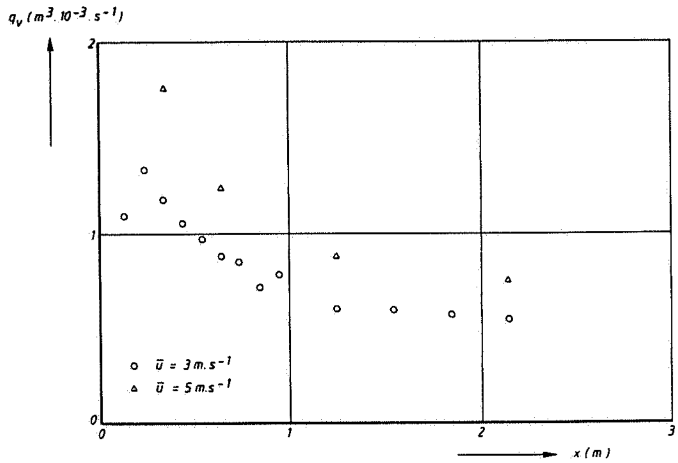


Figure 4: Ventilation as a function of the façade length upstream

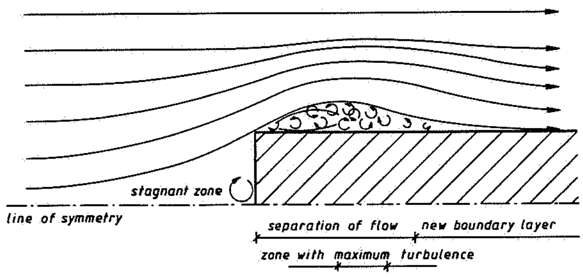


Figure 5: Flow pattern along the building with the mainflow parallel to the window wall (view from above)

4.4. Window Size

Measurements have been made at a window area varying from 0.0019 to 0.0225 m^2 and an aspect ratio (width to height ratio) between 0.16 and 6. The air velocity in the wind tunnel was invariably 3 m/s. Figure 6 gives the results of the measurements.

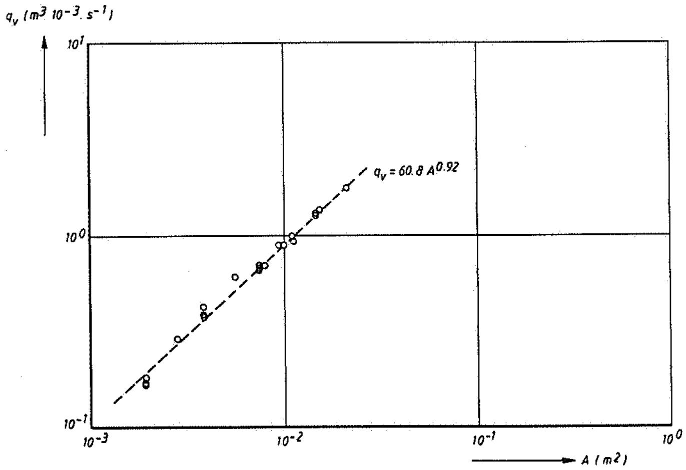


Figure 6: Ventilation as a function of the window size

The following relation is found between ventilation and window size:

$q_v = 60.8.A^{0.92}$ (q_v in dm^3/s, A in m^2).

It is seen that the ventilation is not exactly proportional to the window opening, but somewhat less. The aspect ratio apparently has no influence on the ventilation.

4.5. Window Vanes

Window vanes were simulated by plates at the size of the window opening fixed by hinges at one side of the window opening. The ventilation through the window depends on the angle of opening of the window vanes and the flow direction.

Measurements were taken at three positions of the vane; see Figure 7.

- with the hinges in a horizontal position;
- with the hinges in a vertical position, opening at the wind side;
- with the hinges in a vertical position, opening at the lee side.

As can be aspected ventilation is strongest in the second case. The results agree with those found by Warren [4].

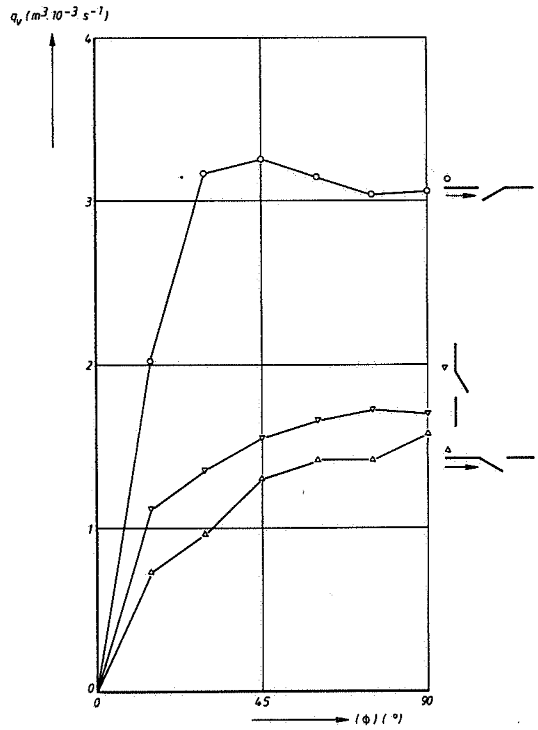


Figure 7: Ventilation against the window vane angle for different kinds of window vanes

5. Dimensionless Ventilation

Because ventilation increases nearly proportionally to the wind velocity and the wind opening it is easy, in practice, to define a dimensionless ventilation:

$$F = \frac{q_v}{A\bar{u}}$$

In Figure 8, F is plotted against the Reynolds number which is defined as:

$$Re = \frac{A^{0.5}\,\bar{u}}{V}$$

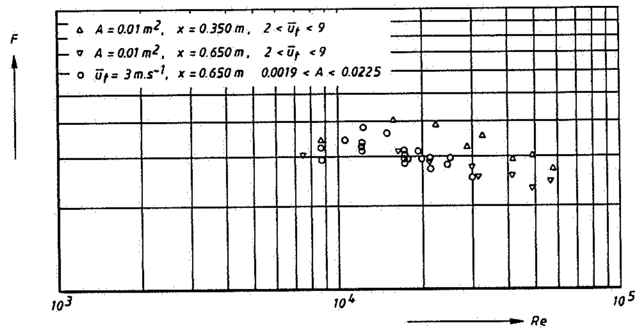


Figure 8: Dimensionless ventilation as a function of the Reynolds number

Values of F were plotted for two series of measurements, for which A = 0.01 m^2 with $\bar{u}$ varying from 2 to 9 m/s. The upstream lengths were 0.35 and 0.65 m, respectively (see Section 4.1).

Values of F were also plotted for $\bar{u}$ = 3 m/s with A varying from 0.0019 to 0.0225 m^2 (see Section 4.4).

Both when varying the wind velocity and when varying the window dimensions, F decreases for increasing Re numbers if Re exceeds 10^4. This is probably caused by the increasing rotation flow in the model at increasing Re numbers.

The measuring results when varying the window size suggest for Re > 10^4 the following relation between F and Re (see Section 4.4): $F \sim Re^{-0.16}$. The results when varying the air velocity (see Section 4.1) suggest the relations:

$F \sim Re^{-0.36}$, for an upstream length of 0.35 m;
$F \sim Re^{-0.26}$, for an upstream length of 0.65 m.

Because the range of Re is restricted in each series, there is no reason to give an empirical formula for F.

In practice, F can be considered as constant having a value of about 0.03. This applies when the direction of flow is the façade.

The values for F are about the same as those found by Warren for the model with a square opening and increased turbulence in the wind tunnel [4].

A theoretical minimum for F can be deduced from Görtler's and Reichardt's publications: $F_{min} = 0.013$.

A theoretical maximum for F can be found assuming that air enters through half the opening at a velocity $\bar{u}$ and flows outside through the other half: $F_{max} = 0.5$.

A value of F = 0.03 indicates that the effective air velocity in a window opening is 6% of the velocity of the main flow. This applies to a flow directed along the opening. For other inflow directions the ventilation and consequently the effective velocity in the opening are lower (see Section 4.2). The ventilation attains a minimum if the opening is at the lee side. This minimum is half of the ventilation for flow along the opening. So, the effective velocity in the opening in this case is about 3% of the velocity of the main flow.

These values apply to the measurements in the cubical model. In reality, it concerns homes. The dimensions of these are much larger and their geometry is much more complicated (e.g. slating roofs). Consequently, in reality, the values found for F may be different. Therefore, values for F should be validated by field measurements.

De Gids and Phaff [6] give the following empirical formula deduced from the measurements on homes, for the ventilation through an open window:

$$q_v = 0.5\,A(0.001\,u^2 + 0.0035.H.\Delta T + 0.01)^{1/2}$$

where u = the meteorological wind velocity.

For isothermal ventilation the second term is 0. For a wind velocity 0 there is still a ventilation of q_v = 0.05 A due to incidental fluctuations which, in practice, always occur and cannot be simulated in a model.

For an average meteorological wind velocity of about 5 m/s, with this formula, q_v = 0.09 A m^3/s is found. For F = 0.03, q_v = 0.15 A m^3/s.

6. The Relation Between Ventilation and the Pressure Fluctuations in the Window Opening

In Figure 9 the standard deviation of the pressure fluctuations from the average pressure difference between the window opening and the centre of the model is plotted against the air velocity in the wind tunnel.

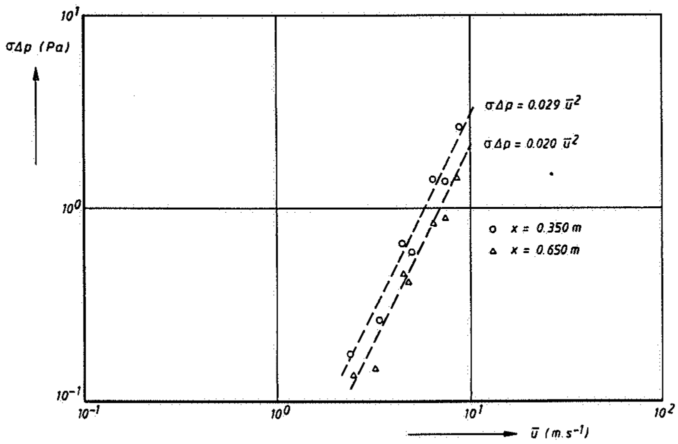


Figure 9: Standard deviation of the pressure fluctuations in the plane of the window opening against the average wind velocity at half the height of the wind tunnel

The upstream lengths of the opening were 0.35 m and 0.65 m. The pressure fluctuations, ΔP, were proportional to $\bar{u}^2$, as could be expected. From the measuring results the following empirical formulas are found:

$\Delta P = 0.029\,\bar{u}^2$, for an upstream length of 0.35 m;
$\Delta P = 0.020\,\bar{u}^2$, for an upstream length of 0.65 m.

From these measurements and the ventilation measurements at different air velocities (Section 4.1) a relation can be derived between the ventilation and the pressure fluctuations [2]:

– $q_v = 1.80\,(\Delta P)^{0.32}$ for an upstream length of 0.35 m;
– $q_v = 1.72\,(\Delta P)^{0.64}$ for an upstream length of 0.65 m.

Such empirical relations are very important because with their help the rather extensive tracer gas measurements may be replaced by the much simpler pressure measurements.

7. Frequency Spectra (Open and Closed Window)

Figure 10 represents the frequency spectrum of the pressure fluctuations as a function of the wave number for an inflow length of 0.35 m. For all velocities, owing to the window, there is a sharp peak at wave numbers of 10 to 20 m^{-1}. Such a peak is a resonance peak caused by the window opening.

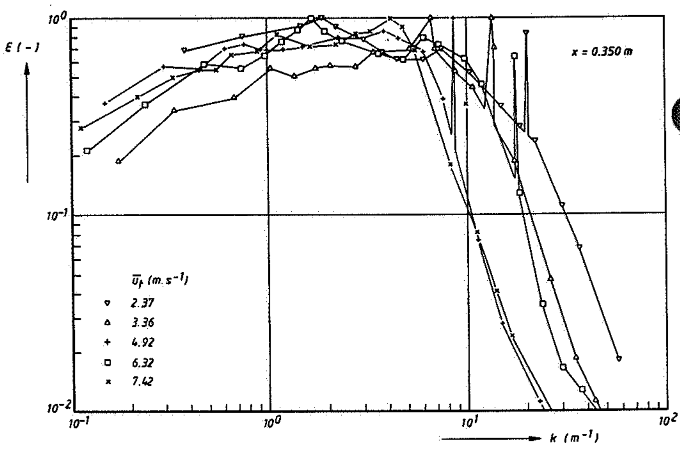


Figure 10: Spectrum of the pressure fluctuations in the plane of the window opening for an upstream façade length of 0.350 m

The turbulence spectrum is built up as follows:

$0.7 < K < 1.5\ m^{-1}$: eddies in the stagnant zone;

$2.0 < K < 5{,}0\ m^{-1}$: eddies caused by interactions between the air flow and the building (model);

$8.5 < K < 20\ m^{-1}$: eddies caused by interactions between the air flow in the boundary layer and the inside air near the window opening.

The shape of the spectrum remains about the same at increasing velocity but the energy decreases faster at higher wave numbers. Eddies caused by interactions between the air flow and the building contribute most the ventilation.

For an upstream length of 0.65 m the influence of the eddies from the stagnant zone in front of the model is much less noticable. The influence of the eddies caused by interaction between the air flow and the building on the ventilation is larger.

This explains the different exponents of ū in the relations between q_v and ū. So, the ventilation cannot only be explained from the air velocity, the window dimensions and the flow direction, but also the intensity of turbulence and the build up of the turbulence spectrum will have to be taken into account.

8. Conclusions

Considering the results of this research an estimation can be made of the ventilation through a window opening of an enclosed space. To this end the wind velocity and the wind direction must be known. The ventilation through an open window depends on the local turbulence. Therefore, for a more accurate determination of the ventilation the intensity of turbulence and the frequency spectrum must be taken into account and, besides the wind and the window dimensions also the position of the window is important.

At increasing air velocities, an increasing, rotating air motion occurs in the model which, in general, does not occur in reality. Probably, this rotating air flow results in a reduction of the ventilation.

9. List of Symbols

A	surface area of window	[m^2]
F	dimensionless ventilation ($F = q_v/A\bar{u}$)	[-]
K	wave number (K = frequency/$\bar{u}$)	[m^{-1}]
q_v	volume flow	[m^3s^{-1}] of [dm^3s^{-1}]
Re	Reynolds number ($Re = \bar{u}l/V$)	[-]
u	velocity	[$m\ s^{-1}$]
x	upstream length of the façade	[m]
V	kinematical viscosity	[m^2s^{-1}]
ΔP	standard deviation of the pressure fluctuation in relation to the average value	[Pa]
	angle	[°]
¯	average value	

10. References

[1] Jensen, M. and M. Franck
Model-scale tests in turbulent wind
The Danish Technical Press, Copenhagen, 1963.

[2] Vrins, E.
Ventilatie door een geopend raam als gevolg van turbulente luchtsromen
(Ventilation through an open window resulting from turbulent flows)
Thesis report, Technical University of Eindhoven, 1986.

[3] Bot, G.P.A.
Greenhouse climate: physical processes to a dynamical model
Ph.D. Thesis, Wageningen University, 1983.

[4] Warren, P.R.
Ventilation through openings on one wall only
Proc. International Centre for Heat and Mass Transfer seminar 'Energy Conservation in Heating, Cooling, and Ventilating Buildings'
Hemisphere Publishing Corporation, 1977, Washington, p.189-206.

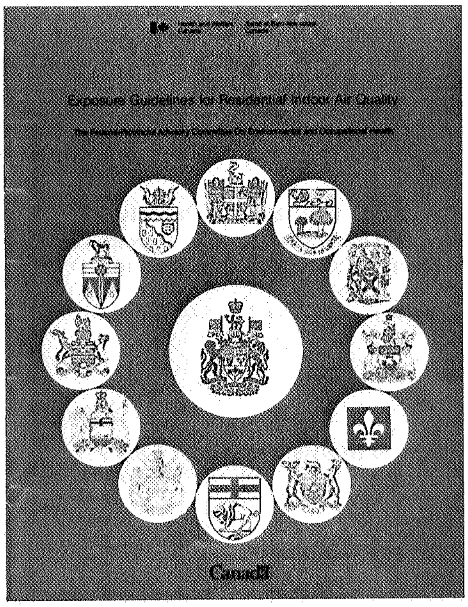
[5] Vrins, E.
Windtunnel simulation of the atmospheric boundary layer with several terrain roughness
Thesis report, Technical University of Eindhoven, 1986.

[6] De Gids, W. and J.C. Phaff
Ventilation rates and energy consumption due to open windows
Air Infiltration Review 4 (1982), No. 1 (November), p.4-5.

Book Review

Exposure Guidelines for Residential Indoor Air Quality

A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health
Health and Welfare
Canada, April 1987



It is now recognised that non-industrial indoor environments can contribute significantly to human exposure to airborne pollutants. This is particularly true in countries such as Canada where long cold winters and hot summers result in considerable periods of time being spent in climate-controlled buildings. Also, within the past few years, incentives have been given to reduce the consumption of energy, particularly oil, in buildings by reducing the rate of air exchange, installing additional insulation and using alternative sources of energy. Such measures are likely to raise the concentrations of some contaminants in indoor air above those found in outdoor air and so have aroused the concerns of public health authorities, those concerned with building standards and home construction, and the general public. In April 1979, the World Health Organisation convened a meeting of experts to discuss the health aspects of indoor air quality. This group recommended that health authorities draw up guidelines for indoor concentrations of air contaminants to protect the health of occupants of homes.

In June 1980, The Ontario Deputy Minister of Health requested that a federal-provincial study be undertaken to establish standards for air quality in new housing. A proposal to convene a Working Group on Indoor Air Quality was formally tabled at the October 1980 meeting of the Federal-Provincial Advisory Committee on Environmental and Occupational Health and subsequently agreed to by the Deputy Ministers of Health.

The Federal-Provincial Working Group on Indoor Air Quality was requested by the Advisory Committee to consider 'a definition of acceptable air quality', the need for 'objective and/or maximum acceptable concentrations for specified substances' and a 'specification of ventilation rates, or recirculation criteria'. The scope of the work was to be restricted to 'domestic premises' and recommendations were to be developed to protect the general public assuming exposure assuming for 24 hours per day (ie continuous).

The Working Group met for the first time in September 1981. During the subsequent four years, the scientific literature on 18 substances, or groups of substances, was collected and reviewed to arrive at the guidelines and recommendations made in this document. A guideline for radon will be published separately.

Forthcoming Conferences

1. Energy '88
   The 2nd International Congress on Energy
   5–10 June 1988
   Tiberias (on the shores of the Sea of Galilee)
   Israel

   Further details from:

   Congress Secretariat
   International Congress on Energy
   International Ltd
   PO Box 29313
   65121 Tel Aviv
   Israel

2. ASHRAE Annual Meeting
   25–29 June 1988
   Ottawa, Ontario, Canada

   Further details from:

   Ms Margot Rayburn
   ASHRAE Housing Bureau
   c/o Canada's Capital Visitors and Convention Bureau
   222 Queen Street, 7th Floor,
   Ottawa, Ontario, Canada K1P 5V9
   Tel: (613) 237-5150

3. PLEA '88
   Passive and Low Energy Architecture
   'Energy and Buildings for Temperate Climates'
   A Mediterranean Regional Approach
   27–31 July 1988
   Porto, Portugal

   Further details from:

   PLEA '88
   Av. Antunes Guimaraes, 102-1 Sala 7
   4100 Porto
   Portugal
   Tel: (02) 67 85 88
   Telex: 27323 FEUP P

4. Healthy Buildings '88
   CIB Conference in Stockholm, Sweden
   5–8 September 1988

   Further details from:

   CIB/Healthy Buildings '88
   c/o Stockholm Convention Bureau
   PO Box 6911
   S-10239 Stockholm
   Sweden

5. 9th AIVC Conference
   'Effective Ventilation'
   12–15 September 1988
   Novotel Hotel, Gent, Belgium

   Further details from:

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   Old Bracknell Lane West
   Bracknell, Berkshire RG12 4AH
   Great Britain
   Tel: + 44 344 53123
   Telex: 848288 BSRIAC G

6. Ventilation '88
   2nd International Symposium on Ventilation for Contaminant Control
   20–23 September 1988
   Imperial College of Science and Technology
   London, Great Britain

   Further details from:

   Ventilation '88
   British Occupational Hygiene Society
   1 St. Andrew's Place
   Regent's Park
   London NW1 4LB
   England

7. Symposium on Air Change Rate and Air Tightness in Buildings
   17–18 April 1989
   Atlanta, Georgia
   USA

   Further details from:

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Air Infiltration Review
Quarterly newsletter containing topical and informative articles on air infiltration research and application. Also gives details of forthcoming conferences, recent acquisitions to *AIRBASE* and new AIVC publications. *Unrestricted availability, free-of-charge.*

Recent Additions to *AIRBASE*
Quarterly bulletin of abstracts added to *AIRBASE*, AIVC's bibliographic database. Provides an effective means of keeping up-to-date with published material on air infiltration and associated subjects. Copies of papers abstracted in 'Recent Additions to *AIRBASE*' can be obtained from AIVC library. *Bulletin and copies of papers available free-of-charge to participating countries* only.*

GUIDES AND HANDBOOKS

AIC-AG-1-86 – Liddament, M.W.
'Air Infiltration Calculation Techniques – An Applications Guide'
A loose-leaf handbook divided into six chapters covering empirical and theoretical calculation techniques, algorithms, references and glossary of terms. *Available free-of-charge to participating countries* only, via your national Steering Group representative.*

HANDBOOK – Elmroth, A., Levin, P.
'Air infiltration control in housing. A guide to international practice'
An international guide to airtightness design solutions of great practical value to all those concerned with the design of pollution – free dwellings with low energy demands. *Unrestricted availability. Price £12.50 hard copy. Also available in microfiche £10.00.*

TECHNICAL NOTES

AIC-TN-5-81 – Allen, C.
'AIRGLOSS: Air Infiltration Glossary (English edition)'
Contains approximately 750 terms and their definitions related to air infiltration, its description, detection, measurement, modelling and prevention as well as to the environment and relevant physical processes. *Available free-of-charge to participating countries.* Price: £10 to non-participating countries.*

AIC-TN-5.1-83, AIC-TN-5.2-84, AIC-TN-5.3-84, AIC-TN-5.4-88 – Allen, C.
'AIRGLOSS': Air Infiltration Glossaries (German, French, Italian and Dutch) Supplements.

AIC-TN-6-81 – Allen, C.
'Reporting format for the measurement of air infiltration in buildings'
Produced to provide a common method for research workers to set out experimental data, so assisting abstraction for subsequent analysis or mathematical model development. May be used directly for entering results and as a useful checklist for those initiating projects. Example of use of format is included as an appendix. *Available free-of-charge to participating countries.* Price: £6 to non-participating countries.* (Being reprinted.)

AIC-TN-10-83 – Liddament, M., Thompson, C.
'Techniques and instrumentation for the measurement of air infiltration in buildings – a brief review and annotated bibliography'
Four-section bibliography contains review papers, information on tracer gas techniques, pressurization methods and miscellaneous approaches. In addition the report contains a list of manufacturers of instrumentation currently being used in air infiltration investigations. *Available free-of-charge to participating countries.* Price: £15.00 to non-participating countries.*

AIC-TN-11-83 – Liddament, M., Allen, C.
'The validation and comparison of mathematical models of air infiltration'
Contains analysis of ten models developed in five participating countries. These range in complexity from 'single-cell' to 'multi-cell' approaches. Also contains numerical and climatic data for fourteen dwellings compiled to produce three key datasets which were used in model validation study. *Available free-of-charge to participating countries.* Price: £15.00 to non-participating countries.*

AIC-TN-12-83 – Liddament, M.
Superseded by TN19 (see below).

AIC-TN-13-84 – Allen, C.
'Wind Pressure Data Requirements for Air Infiltration Calculations'
An up-to-date review of the problems associated with satisfying the wind pressure data requirements of air infiltration models. *Available free-of-charge to participating countries.* Price: £20.00 (price includes copy of TN-13.1) to non-participating countries.*

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'1984 Wind Pressure Workshop Proceedings'
Report of written contributions and discussion at Workshop held in March 1984, Brussels. *Available free-of-charge to participating countries.* Also available to non-participating countries (see note at TN-13 above).*

AIC-TN-14-84 – Thompson, C.
'A Review of Building Airtightness and Ventilation Standards'
Lists and summarises airtightness and related standards to achieve energy efficient ventilation. *Available free-of-charge to participating countries* only.*

AIC-TN-16-85 – Allen, C.
'Leakage Distribution in Buildings'
Examines those factors which can influence leakage distribution, including building style, construction quality, materials, ageing, pressure and variations in humidity. *Available free-of-charge to participating countries.* Price: £20.00 to non-participating countries.*

AIC-TN-17-85 – Parfitt, Y.
'Ventilation Strategy – A Selected Bibliography'
Review of literature on choice of ventilation strategy for residential, industrial and other buildings. *Available free-of-charge to participating countries.* Price: £20.00 to non-participating countries.*

AIC-TN-18-86 – Parfitt, Y.
Superseded by TN22 (see below).

AIC-TN-19-86 – Charlesworth, P.
'1986 Survey of current research into air infiltration and related air quality problems in buildings'
Fourth worldwide survey by AIVC containing over 200 replies from 19 countries. Produced in two sections: an analysis in tabular form of survey results, followed by reproduction in full of research summaries and list of names and addresses of principal researchers. *Available free-of-charge to particpating countries* only.*

AIC-TN-20-87
'Airborne moisture transfer: New Zealand workshop proceedings and bibliographic review'
Proceedings of AIVC's Moisture Workshop, held at BRANZ New Zealand in March 1987, with bibliographic review. *Available free-of-charge to participating countries* only.*

AIC-TN-21-87 – Liddament, M.W.
'A review and bibliography of ventilation effectiveness – definitions, measurement, design and calculation'
Reviews definitions of ventilation efficiency and outlines physical concepts, measurement methods and calculation techniques. Includes bibliographic and list of author affiliations. *Available free-of-charge to participating countries* only.*

AIC-TN-22-87 – Blacknell, J.
'A subject analysis of the AIVC's bibliographic database – AIRBASE', 5th edition
Comprehensive register of published information on air infiltration and associated subjects. The articles are indexed, and full bibliographic details of the 2,600 documents are given. Also includes the AIRBASE Thesaurus, as well as a list of principal authors.
Available free of charge to participating countries only.*

AIC-TN-23-88 – Dubrul, C.
'Inhabitants' behaviour with regard to ventilation'
This report summarises the IEA annex VIII study into the behaviour of occupants with regard to ventilation. It assesses the extent to which the actions of occupants can be modified in order to minimise energy use yet maintain adequate indoor air quality. Chapters cover observational techniques, energy loss due to window opening, reasons for window opening and the resultant energy savings from modified use of windows. *Price: £15.00 to participating countries, £25.00 to non-participating countries.*

LITERATURE LISTS – Listing of abstracts in *AIRBASE* on particular topics related to air infiltration.

- No. 1 Pressurization – Infiltration Correlation: 1. Models (17 references).
- No. 2 Pressurization – Infiltration Correlation: 2. Measurements (26 references).
- No. 3 Weatherstripping windows and doors (30 references) - updated.
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- No. 5 Domestic air-to-air heat exchangers (25 references).
- No. 6 Air infiltration in industrial buildings (51 references) - updated.
- No. 7 Air flow through building entrances (22 references).
- No. 8 Air infiltration in commercial buildings (28 references).
- No. 9 Air infiltration in public buildings (10 references).
- No. 10 Humidity- Carbon Dioxide- and Demand Controlled-Ventilation (32 references).
- No. 11 Occupancy effects on air infiltration (15 references).
- No. 12 Windbreaks and shelter belts (30 references) - updated.
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- No. 1 'Instrumentation and measuring techniques'.
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Published by

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Old Bracknell Lane West,
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ISBN: 0143-6643

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