INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
community systems programme

Technical Note AIVC 39

A Review of Ventilation Efficiency

February 1993

Air Infiltration and Ventilation Centre
University of Warwick Science Park
Sovereign Court
Sir William Lyons Road
Coventry CV4 7EZ
Great Britain

This report is part of the work of the IEA Energy Conservation in Buildings & Community Systems Programme.

Publication prepared by
Annex V Air Infiltration and Ventilation Centre

Document AIC-TN-39-1993
ISBN 0 946075 68 9

Participating countries:

Annex V
Belgium, Canada, Denmark, Germany, Finland, France, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, and United States of America

Distribution: Annex V only

Additional copies of this report may be obtained from:

The Air Infiltration and Ventilation Centre
University of Warwick Science Park
Barclays Venture Centre
Sir William Lyons Road
Coventry CV4 7EZ
Great Britain

A Review of Ventilation Efficiency

Martin Liddament

Contents

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this programme.

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognized in the IEA, and every effort is made to encourage this trend.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by *):

I Load Energy Determination of Buildings*
II Ekistics and Advanced Community Energy Systems*
III Energy Conservation in Residential Buildings*
IV Glasgow Commercial Building Monitoring*

V Air Infiltration and Ventilation Centre
VI Energy Systems and Design of Communities*
VII Local Government Energy Planning*
VIII Inhabitant Behaviour with Regard to Ventilation*
IX Minimum Ventilation Rates*
X Building HVAC Systems Simulation*
XI Energy Auditing*
XII Windows and Fenestration*
XIII Energy Management in Hospitals*
XIV Condensation*
XV Energy Efficiency in Schools*
XVI BEMS - 1: Energy Management Procedures*
XVII BEMS - 2: Evaluation and Emulation Techniques
XVIII Demand Controlled Ventilating Systems*
XIX Low Slope Roof Systems
XX Air Flow Patterns within Buildings*
XXI Thermal Modelling
XXII Energy Efficient Communities
XXIII Multizone Air Flow Modelling (COMIS)
XXIV Heat Air and Moisture Transfer in Envelopes
XXV Real Time HEVAC Simulation
XXVI Energy Efficient Ventilation of Large Enclosures
XXVII Evaluation and Demonstration of Domestic Ventilation Systems

Annex V Air Infiltration and Ventilation Centre

The IEA Executive Committee (Building and Community Systems) has highlighted areas where the level of knowledge is unsatisfactory and there was unanimous aggreement that infiltration was the area about which least was known. An infiltration group was formed drawing experts from most progressive countries, their long term aim to encourage joint international research and increase the world pool of knowledge on infiltration and ventilation. Much valuable but sporadic and uncoordinated research was already taking place and after some initial groundwork the experts group recommended to their executive the formation of an Air Infiltration and Ventilation Centre. This recommendation was accepted and proposals for its establishment were invited internationally.

The aims of the Centre are the standardisation of techniques, the validation of models, the catalogue and transfer of information, and the encouragement of research. It is intended to be a review body for current world research, to ensure full dissemination of this research and based on a knowledge of work already done to give direction and firm basis for future research in the Participating Countries.

The Participants in this task are Belgium, Canada, Denmark, Germany, Finland, France, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States of America.

1. Introduction

Ventilation plays a key role in the dilution and removal of pollutants within occupied spaces. Minimum requirements are frequently set to meet the metabolic needs of occupants. Added to these requirements are those needed to dilute other sources of internal pollutant such as tobacco smoke, moisture and emissions from furnishings and the building fabric.

Unfortunately, ventilation can impose a high energy load which often represents a significant proportion of a building's energy needs. Furthermore, ventilation systems are expensive to install and maintain, and occupy valuable floor space. Consequently, there can be considerable economic and environmental advantages in minimising pollutant emissions, to reduce ventilation needs, and in developing efficient ventilation systems.

The concepts of ventilation efficiency provide a useful method of quantifying the performance of a ventilation system, both in providing fresh air to occupants and in diluting and removing pollutants derived from contaminant sources within a building. The AIVC has produced a series of reports on this topic including, most recently, Technical Notes by Sutcliffe (1990) and Brouns and Waters (1991). These reports have focused on the fundamental equations and derivations of ventilation efficiency and are therefore necessarily complex. The purpose of this report is to introduce a purely descriptive account of ventilation efficiency and to illustrate its general purpose and value. An attempt is also made to outline the strengths and limitations of ventilation efficiency and to provide an insight into the way this activity may be developed to assist in the design and evaluation of efficient ventilation systems. No attempt has been made to present the numerical derivation of definitions since these are presented in the previous AIVC studies. Instead, this report is aimed at giving a non mathematical analysis for those wishing to seek further guidance on this topic.

This report begins by reviewing some basic questions about ventilation efficiency. The subject is then presented in greater detail and ends with an example of the prediction of ventilation efficiency in an office enclosure. Emphasis is given to the range of applicability and limitations of ventilation efficiency methods.

2. An Outline of Ventilation Efficiency

Answers to some basic questions about ventilation efficiency are presented in this section. The purpose is to give a brief summary of the topic.

2.1 What is Ventilation Efficiency?

Ventilation Efficiency may be regarded as a series of indices or parameters which characterise the mixing behaviour of air and the distribution of pollutant within an enclosure. These two aspects may be subdivided into indices of air change efficiency and contaminant removal effectiveness respectively. Ventilation efficiency is based on an evaluation of the 'age' of air and on the concentration distribution of pollutant within the air. Some indices are based on room averaged values, while others refer to specific points or locations. This has important consequences because while room values provide some guidance to the overall performance of a ventilation system, point values indicate regions where localised poor ventilation might occur.

2.2 What does Ventilation Efficiency Do?

The concepts of ventilation efficiency provide a method to quantify the performance of a ventilation system in terms of both providing fresh air to occupants and in diluting and removing internally generated pollutants.

2.3 What is its Range of Applicability?

Ventilation efficiency may be applied to entire buildings, single zones or locations within a single zone (eg the 'breathing zone').

2.4 How are Indices of Ventilation Efficiency Determined?

At present, ventilation efficiency parameters are normally determined by measurement methods using tracer gas. In theory, it should be possible to use air flow simulation or computational fluid dynamic (cfd) techniques.

2.5 What are the Current Shortcomings?

Measurement techniques are too complex for routine use in buildings under normal conditions of occupancy. Also, results are building specific. Very little information can be used to provide guidance for other buildings or alternative ventilation strategies. Measurements are necessary to evaluate each combination of ventilation rate, thermal loading, room layout and occupancy pattern.

These concepts are difficult to apply to naturally ventilated or leaky structures because of the difficulty in defining inlet and outlet locations.

The subject of ventilation efficiency is made unnecessarily complex by the lack of uniformity in terminology. Frequently, terms are interchanged or different terms are used to describe the same concepts. Therefore it is important to check definitions carefully.

2.6 How can the Shortcomings be Overcome?

The main shortcomings could be overcome by using calculation methods. This must be seen as a long term goal, however, since much more development is needed before numerical models can be regarded as sufficiently robust and accurate to simulate the complexities of fully furnished, occupied spaces. An example of the use of cfd to predict indices of ventilation efficiency is presented in this report.

2.7 How can Ventilation Efficiency be used in Design?

Measurements on scale models may provide one design solution but this approach would be restricted to specialist laboratories; it would not provide the designer with a readily accessible tool. Calculation techniques offer good prospects once they have been sufficiently adapted and validated.

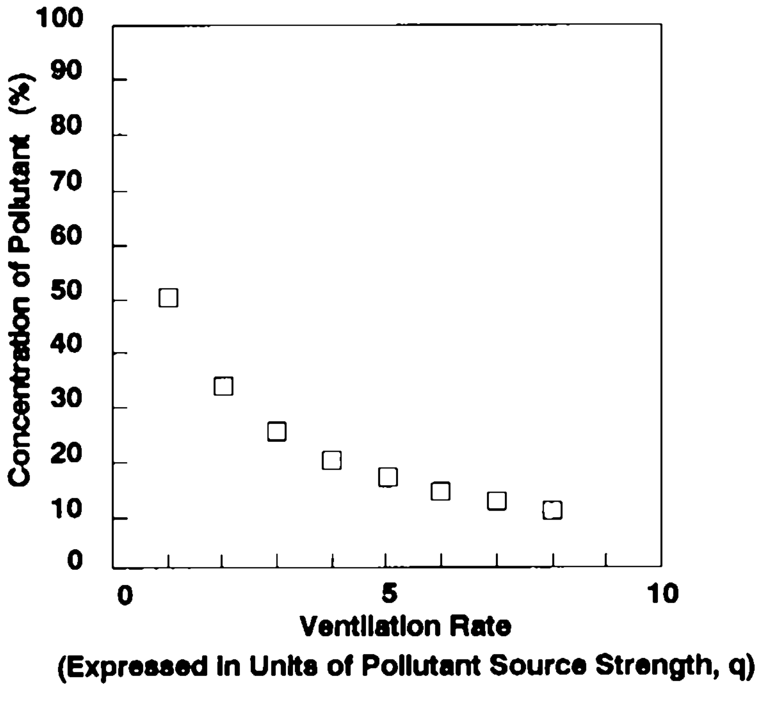
3.0 Basic Concepts

In considering ventilation efficiency, it is important to have an understanding of some of the basic elements; these include:

3.1 Ventilation

Ventilation is the act of supplying clean air to a zone to satisfy the need for such air. If ventilation air is assumed to mix perfectly and instantaneously with the air and pollutant within a zone, then, for a fixed pollutant emission rate, the steady state concentration of pollutant within that space will be a function of the ventilation rate. Figure 1 illustrates the equilibrium concentration of a pollutant of source strength q m3/s for a range of ventilation rates. For a given source strength, the steady state pollutant concentration reduces as the ventilation rate is increased. Provided the source strength is known, it is an easy task to calculate the ventilation rate necessary to maintain the concentration of pollutant to any threshold level. The argument in favour of using ventilation to control pollutant concentration is therefore obvious.

Figure 1 Relationship Between Ventilation Rate and Pollutant Concentration



3.2 Mixing of Air

Difficulties may arise with this simplistic approach to ventilation if the mixing of air is not uniform. Spaces may exist within an enclosure where ventilation air does not penetrate.

In addition, mixing or dilution ventilation is often not the preferred choice. Instead, it can be preferable to remove pollutants at source by local extraction, since this reduces the risk of such contaminants entering the occupied zone. Dilution ventilation in large spaces may also not be appropriate since the breathing zone will normally only represent a small part of the enclosure. The concepts of ventilation efficiency are particularly important when, either by design or otherwise, mixing is not uniform.

3.3 Interaction of Ventilation System with Room Characteristics

The adequacy of a ventilation system in satisfying fresh air needs is, therefore, influenced by the rate of supply and by the mixing behaviour of air. In reality, much can happen to prevent the desired mixing pattern from being achieved. Mixing characteristics will be a function of many parameters, including:

- the scale of turbulence.
- room layout and dimensions.
- the distribution and magnitude of infiltration paths.
- inlet and outlet configuration.
- diffuser characteristics.
- inlet air velocity and supply rate.
- the location and size of heat sources and sinks.

Thus the pattern of air flow is a combination of room characteristics and ventilation system characteristics. As a consequence, this pattern will almost always be unique to each individual enclosure and will continuously vary in response to changes in ventilation rate, infiltration rate and thermal variations (buoyancy forces). The concepts of air change efficiency provide a measure of the degree to which the mixing of air takes place under any single set of conditions.

3.4 Pollutants

The spatial concentration of pollutant is a function of the pattern of air flow (air change efficiency), the location of pollutant source within the space, its emission characteristics, absorption or chemical decay behaviour, density and discharge momentum. Thus the pollutant distribution is also unique to each enclosure. Pollutant dilution and removal may be described in terms of contaminant or pollutant removal effectiveness.

3.5 Natural Ventilation and Air Infiltration

Natural ventilation is still a common approach for many buildings located in less severe climatic areas. Increasingly, natural ventilation design has become more rigorous but the rate and flow pattern of ventilation will always be dependent on prevailing weather conditions. This means that there can be a wide variation in air flow pattern over time. Air infiltration also contributes to the magnitude and pattern of flow in leaky buildings. Only when a building is reasonably airtight does the pattern of flow become dominated by the ventilation system. In principal, the concepts of ventilation efficiency can be incorporated to accommodate natural ventilation and air infiltration but this is an extremely complex task.

4.0 Air Change Efficiency - Fundamental Definitions

Air change efficiency is concerned with the mixing behaviour of ventilation air. Definitions of air change efficiency are independent of and are not concerned with the distribution or characteristics of internal pollutants. They are simply expressions of the spatial distribution of the age of air. A complete derivation and measurement description of terms associated with air change efficiency is presented by Sutcliffe (1990). Many of these definitions derive from the work of Sandberg (1981), Skaret (1984) and Sandberg and Skaret (1985). The purpose of this section is to outline and describe some of the fundamental definitions; these include:

4.1 Specific Flow

The essential requirement for optimum indoor air quality is sufficient ventilation to ensure that the concentration of internal pollutant is kept to a minimum. Thus the starting point for an analysis of air change efficiency is the rate of ventilation itself. Traditionally, the ventilation rate has been expressed in terms of "air changes/hour. Unfortunately, this expression tends to give the erroneous impression that air is completely replaced at the given air change rate. In general, this is not the case. While fresh air can be supplied at the given 'air change rate' the 'displaced' air is normally a mixture of 'old' and 'new' air. For this reason, the expression 'air change rate' is often replaced by the expression 'specific flow'.

4.2 Nominal Time Constant

The time in which air is present at a location holds the key to virtually all aspects of ventilation efficiency. A long presence (old air) can normally be associated with poor indoor air quality. All enclosures have a time constant which represents the minimum time in which air, once entering the enclosure, will remain. This is the 'nominal time constant'. It is the inverse of the specific flow and hence is completely derivable from basic knowledge of the ventilation rate and the volume of enclosure. It is invariant, regardless of internal flow pattern or pollutant properties.

4.3 The 'Age' of Air

Once air enters an enclosure, it is assumed to 'age'. For example, air is 30 minutes 'old' when it has been inside an enclosure for 30 minutes. The following 'ages' have important applications:

- Local Mean Age

The local mean age of air at an arbitrary point, 'P', is the average time it takes for air, once entering an enclosure (time = 0), to reach point 'P'.

- Room Mean Age

Room mean age of air is the average age of air in the room. It is the average of the local mean ages for all points.

4.4 Air Change Time

The air change time is the time it takes, air once entering an enclosure, to be completely replaced. It is shown by Sandberg and Sjoberg (1983) that the air change time is equal to twice the room mean age of air.

4.5 Air Change Efficiency

Air change efficiency is the percentage ratio between the nominal time constant and the air change time. Since the minimum possible air change time is equal to the nominal time constant, all other values will be less than 100%.

4.6 Coefficient of Air Change Performance/ASHRAE Ventilation Efficiency

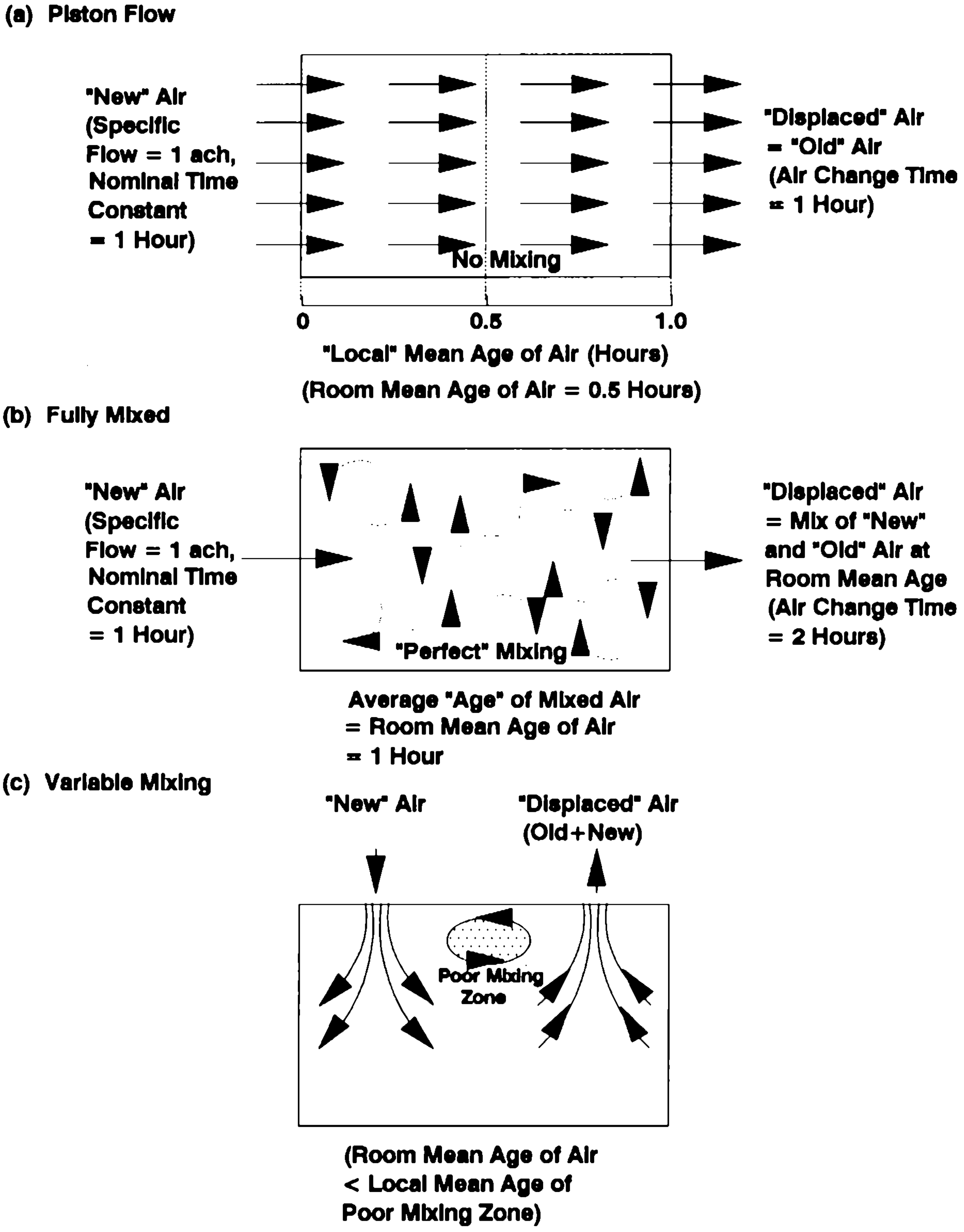
The coefficient of air change performance is equivalent to the ASHRAE Standard 62 definition of ventilation efficiency. It is defined as the percentage ratio of the nominal time constant to the room mean age. Since room mean age is equal to half the air change time, it follows that the coefficient of air change performance is twice the value of air change efficiency and can, therefore, have a maximum value of 200%.

These basic air change efficiency terms are summarised in Figure 2. Figure 2a illustrates a flow pattern in which no mixing takes place. The incoming air 'displaces' the air which is already present and the local mean age of air increases linearly as it flows horizontally through the enclosure. Assuming a nominal time constant of one hour, the room mean age is 0.5 hours, the air change time is one hour and the air change efficiency is 100%. Figure 2b refers to an example of 'complete mixing'. The nominal time constant is again 1 hour but the local mean age is uniform throughout the space at the room mean age of one hour. The air change time is two hours and the air change efficiency falls to 50%. Figure 2c illustrates an example of poor mixing. 'New' air can completely bypass the poor mixing zone, resulting in the age of air within this zone becoming large. The room mean age and, hence, the air change time will also increase, resulting in an air change efficiency of less than 50%. It is important to note that, while the room mean age will indicate a problem, only knowledge of the local mean age throughout the entire space will reveal the location of poor mixing.

5.0 Contaminant Removal Effectiveness

Contaminant removal effectiveness is concerned with the movement and dilution of contaminants within a space. Indices of contaminant removal effectiveness are dependent on both the characteristics of air flow (air change efficiency) and on the characteristics of the pollutant. Definitions of pollutant or contaminant removal effectiveness are largely analogous to those of air change efficiency. Key definitions are described in this section while a more rigorous review is presented by Brouns and Waters (1991). Indices include:

Figure 2 The "Age" of Air



5.1 Nominal Time Constant of Contaminant

The nominal time constant of contaminant is the average time it takes for contaminant to flow from its source to the exhaust duct or outlet. It is equivalent to the ratio of the volume (or mass) of contaminant in the enclosure and the volumetric (or mass) injection rate.

5.2 Local Air Quality Index

The local air quality index is the ratio between the concentrations of pollutant at the exhaust and at any point 'P' within the enclosure.

5.3 Contaminant Removal Effectiveness

Contaminant removal effectiveness is a room average or zone average value given by the ratio between the steady state concentration of contaminant at the exhaust and the room or zone average value. For complete mixing , the contaminant concentration is uniformly distributed and thus the contaminant removal effectiveness is unity or 100%. For piston flow, the contaminant removal effectiveness will be greater or equal to unity, depending on the location of the pollutant source. When short circuiting occurs, the room average pollutant concentration will tend to be greater than that at the exhaust point, and thus the contaminant removal effectiveness will range between zero and unity.

5.4 Contaminant Removal Efficiency

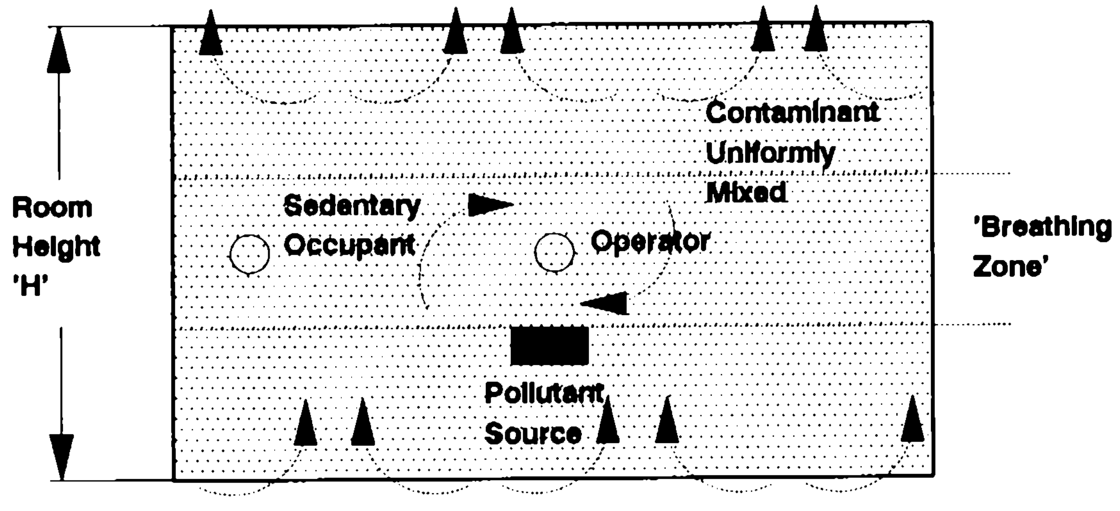
The contaminant removal efficiency is a normalised version of the contaminant removal effectiveness. Complete mixing of pollutant within the space gives a value of 0.5; piston flow gives a value between 0.5 and unity; short circuiting gives a value between zero and 0.5.

Remaining indices of pollutant removal effectiveness may be derived from these basic definitions.

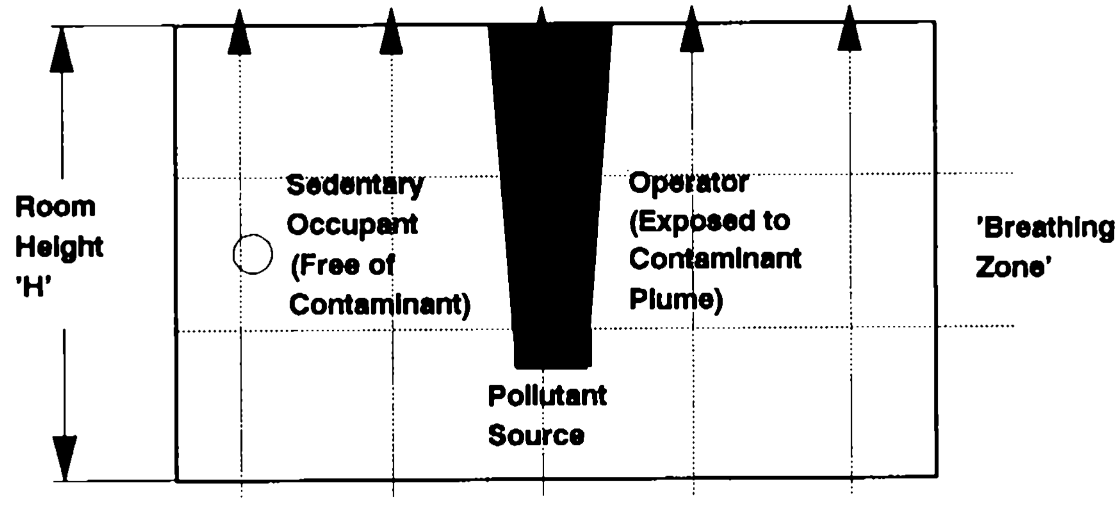
Examples of the application of indices of pollutant removal effectiveness are depicted for two idealised flow regimes in Figure 3. This figure illustrates a ventilated office, in which an apparatus (e.g. a photocopier) produces some pollutant. Two occupants are present within the space, one of whom is standing over the equipment, while the other is some distance away. In Figure 3a, uniform mixing is assumed. The local air quality index is uniform throughout the space and the contaminant removal effectiveness is unity. In practice, this means that both occupants receive the same dose of pollutant and the pollutant strength will be a function of the ventilation rate, as depicted in Figure 1. In the second example, vertical piston flow is assumed. The pollution from the electrical equipment is now entrained in a plume of relatively high concentration. The air quality index in the vicinity of the equipment operator reduces substantially, since he is now receiving a considerable increase in pollution. On the otherhand the remote occupant is experiencing a much higher air quality index since very little pollutant is present elsewhere in the room. This example emphasises the need to consider very

Figure 3 Influence of Ventilation Strategy on the Distribution of Contaminant Concentration

(a) Fully Mixed Air Movement



(b) Vertical Piston Flow Air Movement



carefully the approach to ventilation and to the siting of supply and exhaust points in relation to the source of pollution.

These two very idealised examples represent the limit of analysis that is possible without introducing measurement or calculation methods to determine air flow and pollutant behaviour. Methods to evaluate more complex examples are outlined in the next section.

6.0 Evaluation of Ventilation Efficiency Indices

6.1 Measurement Methods

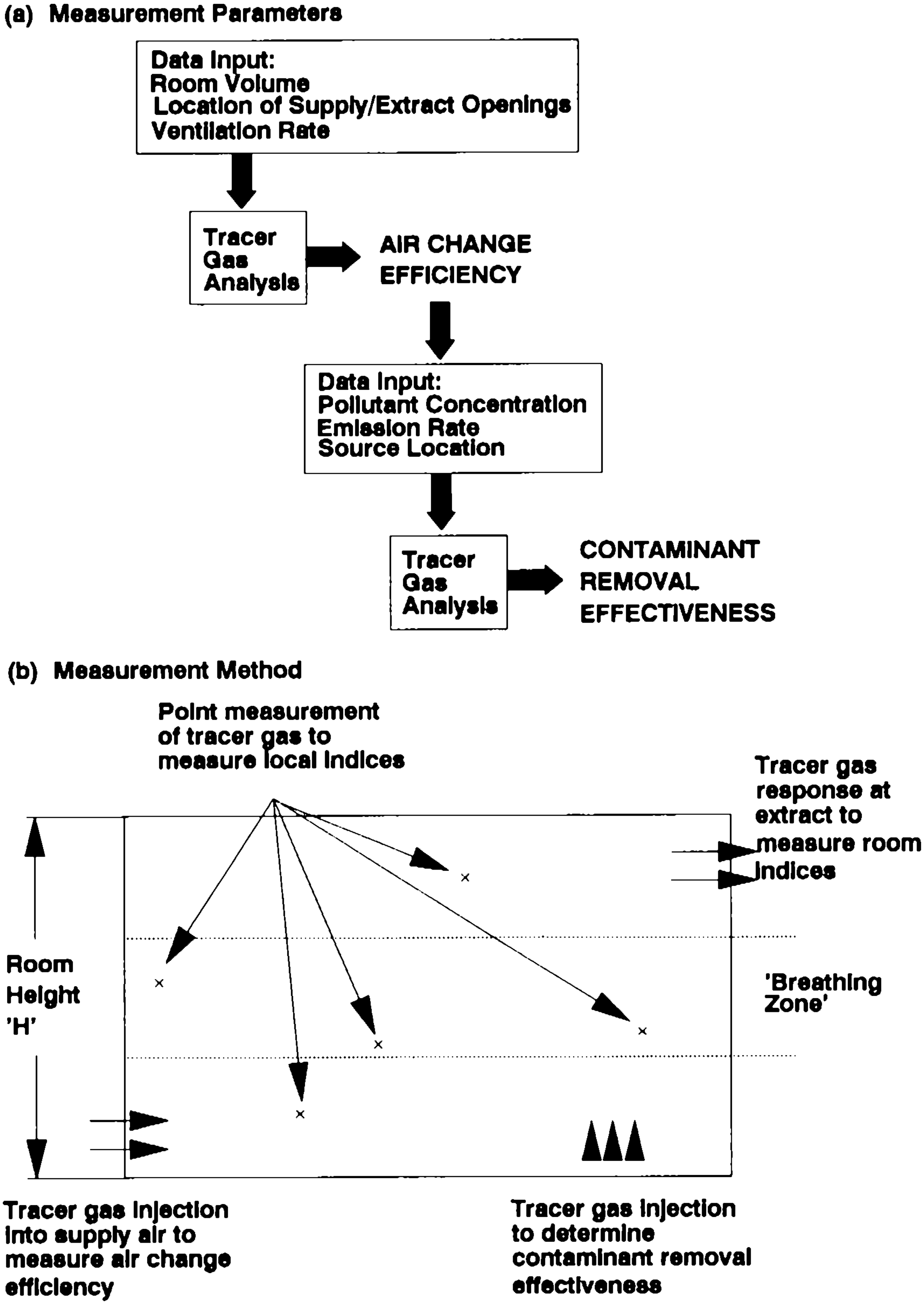
Indices of ventilation efficiency have largely been derived from measurement analysis involving the use of tracer gas. Detailed descriptions are given by Sutcliffe (1990) and Brouns and Waters (1991). More information on measurement techniques is presented by Roulet and Vandaele (1991).

The basic measurement steps for evaluating air change efficiency are summarised in Figure 4a. Tracer gas may be introduced as a pulse into the supply duct and the time response to tracer concentration at the exhaust may be used to evaluate room average values (Figure 4b). Alternatively, a 'step up' technique is possible in which tracer gas is injected at a uniform rate into the supply air. Zero 'age' is represented by the start of injection. When supply injection is not possible, a tracer decay technique may be used in which an entry time of zero age for the air is represented by the start of the concentration decay. Local indices can only be evaluated by making measurements of the time response of tracer concentration at the locations of interest (eg the 'breathing' zone.

Contaminant removal effectiveness is similarly evaluated using tracer gas to represent the pollutant source strength and location. Pulse, step-up and decay techniques may be applied.

The fundamental draw back of measurements is that they can only be made in existing structures. Unfortunately, since flow and pollutant patterns are often unique to each enclosure, measurement methods are often inappropriate as design tools. It is, perhaps, for this reason that, while ventilation efficiency as a concept is well developed, it has had relatively little applicability in routine design analysis. Exceptions include test chamber measurements which may be used to provide general design guidance, especially when flow is dominated by forced convection. Examples include the analysis of cooker hood performance or semi enclosed industrial extract systems. However, once buoyancy forces and/or infiltrating air flow interacts with mechanically induced flow, the resultant air flow pattern becomes unique. Scale model analysis also offers a possible design approach but this is frequently beyond the scope of most design offices. Measurement methods are therefore essentially restricted to research applications and to diagnostic analysis. Measurements also provide a valuable database for future validation analysis.

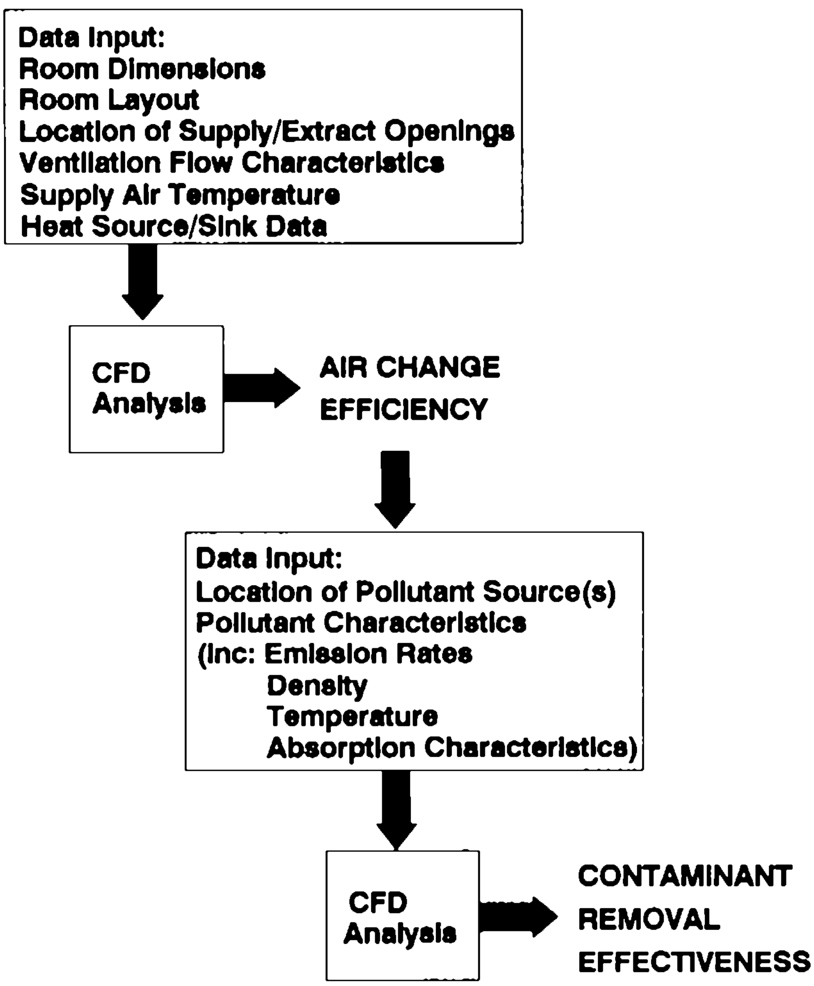
Figure 4 Measurement of Ventilation Effectiveness



6.2 Calculation Methods

Recently, computational fluid dynamics (cfd) have become available for the prediction of air flow and pollutant transport in enclosed spaces. In theory, cfd methods have the potential to completely replicate measurement methods and therefore ventilation efficiency indices may be evaluated as part of the design process. In cfd analysis, the flow domain is approximated by a grid system of control volumes in which equations representing air flow and pollutant transport equations are solved by numerical analysis. Even a coarse grid will typically have several thousand control volumes and therefore a complete profile of the age of air and pollutant distribution throughout the space may be derived. A rigorous treatment of this topic is presented by Shih (1984), while a general review of cfd methods is presented by Liddament (1991). The steps for calculating ventilation efficiency are summarised in Figure 5 and are virtually identical to those needed for measurement.

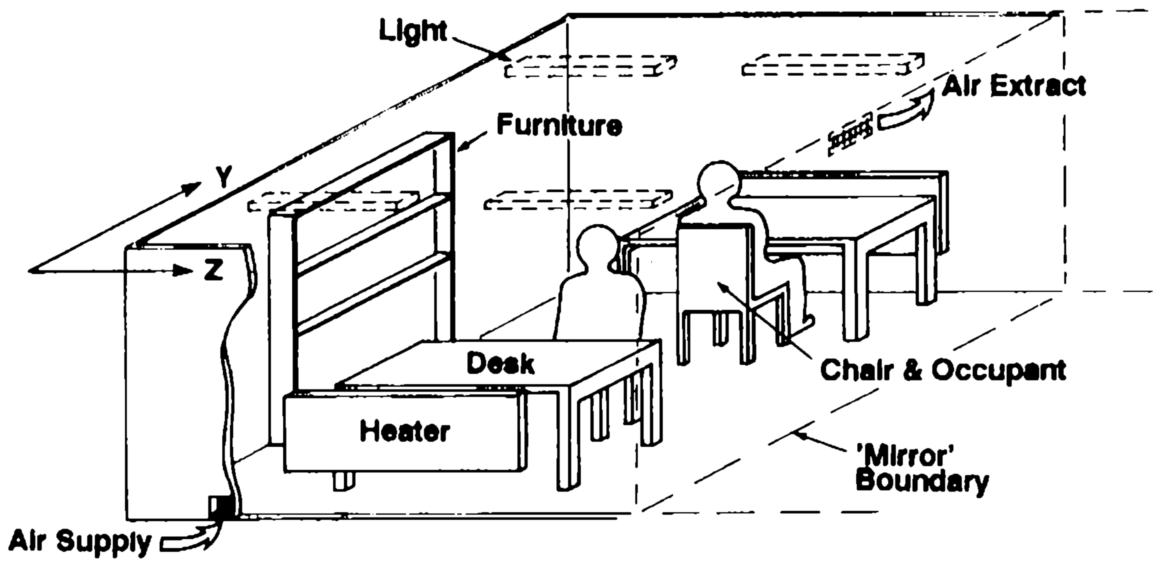
Figure 5 Calculation of Ventilation Effectiveness



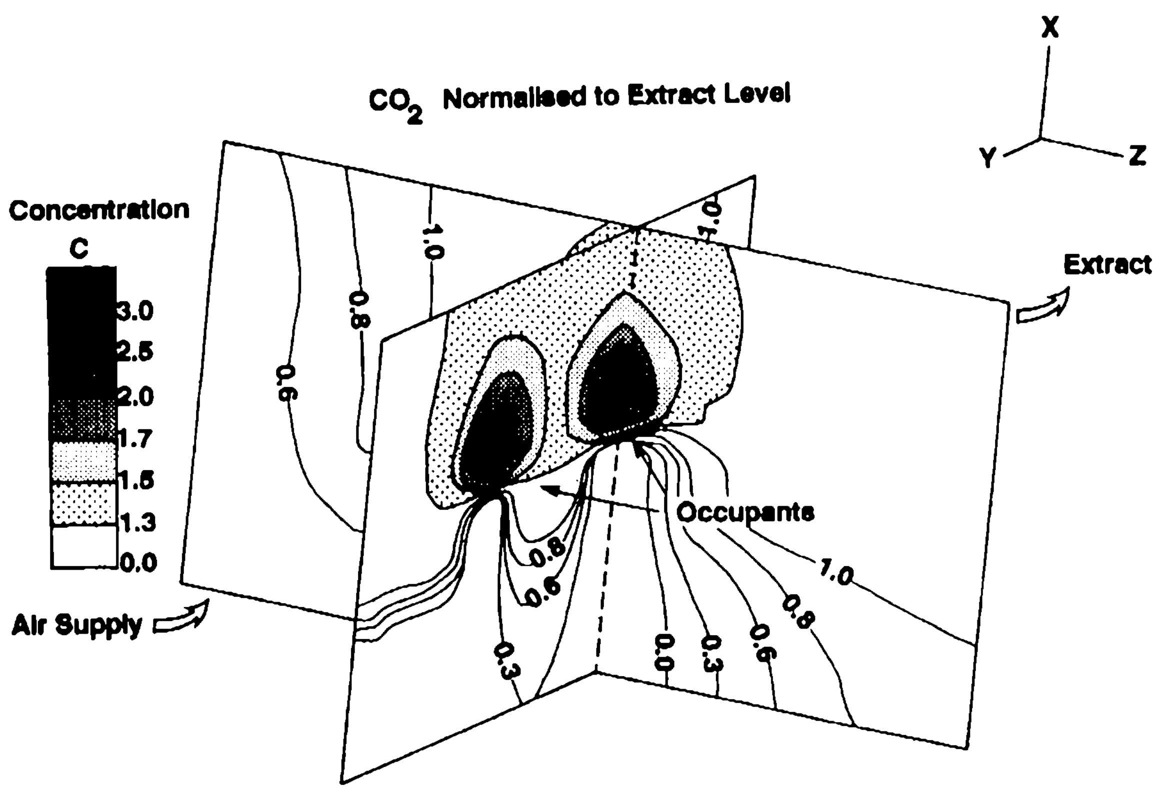
An example of the use of cfd to predict indices of contaminant removal effectiveness in an office is presented in Figure 6. Figure 6a illustrates a section of office with two occupants and associated furniture, lighting, ventilation and heating. Ventilation is

Figure 6 Calculation of Contaminant Removal Effectiveness

(a) Room Layout



(b) Pollutant Distribution (Carbon Dioxide)



supplied at low level and is balanced by extract at ceiling level. Heat is generated by space heaters, lighting and occupants, and is balanced by conduction losses through each of the vertical walls. This configuration is thus one of non isothermal, mixed convection. Public domain codes EXACT3 and CONTAM3 (Kurabuchi et al 1991) were used to analyse air flow and pollutant transport respectively. Simulations were performed on a 486 PC system operating at 33MHz with a WEITEK co-processor. The model was used to predict the distribution of metabolic carbon dioxide within the space. From this, the contaminant removal effectiveness, the contaminant removal efficiency and the local air quality index of the breathing zone were derived.

A carbon dioxide concentration contour plot for this example is illustrated in Figure 6b. This represents the concentration in two planes, one of which cuts through the two occupants in the Y plane and the other cutting through the far occupant in the Z plane. The emissions from these occupants can be clearly observed as can the effect of the displacement ventilation system.

Numerical results are summarised in Table 1.

Table 1 Calculated Contaminant Removal Effectiveness Indices

Carbon Dioxide Concentrations: (Normalised with respect to exhaust values)	
Exhaust Concentration	1.0
Room Average Concentration	0.6
Maximum Concentration	3.0
Location of Maximum Concentration:	Above Occupants
Calculated Indices:	
Contaminant Removal Effectiveness	1.67
Contaminant Removal Efficiency	0.62
Local Air Quality Index (breathing zone)	0.33

This example illustrates the potential of numerical air flow methods for use in the analysis of air flow and pollutant transport in a fairly complex office environment. Different pollutant sources and locations, as well as variations in room layout and ventilation strategy may be analysed with relative ease. Results, however, are dependent on the many assumptions needed to operate such a code. These include discretisation density, boundary flow characteristics, turbulent intensities and specification of the pollutant characteristics. Such aspects currently require much subjective judgment. Little is yet known about the sensitivity of these various parameters to the final result because relatively little validation and assessment analysis for real buildings has taken place. Furthermore, air infiltration is largely ignored in cfd analysis, yet many buildings are still relatively leaky. Without the inclusion of infiltration effects, results will almost certainly be unreliable. For these reasons, much further verification work is needed before cfd methods may be used with confidence. Existing measurement data provides a good opportunity for verifying the role of cfd in the prediction of indices of ventilation efficiency.

7.0 Conclusions

(1) The pattern of air flow can have a considerable influence on ventilation performance, indoor air quality, the thermal environment and comfort.

(2) Ventilation efficiency provides a method for assessing air flow and ventilation performance within an enclosure. The concepts of ventilation efficiency may be subdivided into air change efficiency and contaminant removal effectiveness. Air change efficiency characterises the mixing of incoming air with that which is already present. Contaminant or pollutant removal effectiveness quantifies the efficiency with which internal pollutant is diluted and removed.

(3) These concepts can be applied to whole buildings, individual rooms or zones, and to specific locations within a zone.

(4) Flow patterns tend to be transient, and vary according to the interaction of momentum and buoyancy forces. The distribution of pollutant is a function of the location and emission characteristics of the pollutant source. Ventilation efficiency indices are therefore unique to an individual enclosure and may vary in response to changes in ventilation rate and thermal conditions.

(5) Definitions of ventilation efficiency are based on the 'time' that air or pollutant is present at a location. This involves the concept of the 'age' of air. Virtually all definitions can be derived from knowledge of the ventilation rate and the age of air.

(6) Ventilation efficiency has evolved from measurement analysis based on observing the time varying behaviour of a tracer gas. Measurement techniques are essential for diagnostic and evaluation studies. Results could also provide a valuable validation database. However, since ventilation efficiency is often unique to each enclosure, measurement analysis generally has a limited design role. Exceptions include general design guidance for well defined flow regimes or results derived from scale models.

(7) Computational Fluid Dynamics could emulate measurement techniques and therefore have a design role. Before this can happen, however, the credibility of CFD needs to be improved by good validation and by adaption for use in the design office.

8.0 References

ASHRAE 1989. ASHRAE Standard 62-1989, Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

Brouns, C. and Waters, R. A guide to contaminant removal effectiveness. Technical Note AIVC 28.2. Air Infiltration and Ventilation Centre. Warwick, UK. December 1991.

Kurabuchi, T.;Fang, J. B. and Grot, R. A. 1990. A numerical method for calculating indoor airflows using a turbulence model. NISTIR 89-4211, National Institute of Standards and Testing. Washington, US. January 1990.

Liddament, M. W. 1991. A review of building air flow simulation. Technical Note AIVC 33. Air Infiltration and Ventilation Centre, Warwick, UK. 1991.

Roulet, C-A, Vandaele L, Air Flow Patterns within Buildings: Measurement Techniques. Technical Note AIVC 34. Air Infiltration and Ventilation Centre. Warwick, UK. December 1991.

Sandberg, M. 1981. What is ventilation efficiency?. Building and Environment, Vol. 16. 1981.

Sandberg, M and Sjoberg, M. 1983. The use of moments for assessing air quality in ventilated rooms. Building and Environment, Vol. 18. 1983.

Sandberg, M. and Skåret, E. 1985. Air change and ventilation efficiency - new aids for designers, Swedish Institute for Building Research, 1985.

Skåret, E. 1984. Ventilation efficiency - A survey of concepts of ventilation effectiveness. SINTEF report STF15 A84057, Trondheim, Norway. 1984.

Shih, M. T. 1984. Numerical heat transfer. Series in computational methods in mechanics and thermal sciences. Hemisphere Publishing Corporation. US. ISBN 0-89116-257-7. 1984.

Sutcliffe, H. 1990. A guide to air change efficiency. Technical Note AIVC 28. Air Infiltration and Ventilation Centre, Warwick, UK. February 1990.

THE AIR INFILTRATION AND VENTILATION CENTRE was inaugurated through the International Energy Agency and is funded by the following thirteen countries:

Belgium, Canada, Denmark, Germany, Finland, France, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and United States of America.

The Air Infiltration and Ventilation Centre provides technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock.

Air Infiltration and Ventilation Centre

University of Warwick Science Park,
Sovereign Court,
Sir William Lyons Road,
Coventry CV4 7EZ,
Great Britain.

Telephone: +44 (0) 203 692050
Fax: +44 (0) 203 416306

Operating Agent for International Energy Agency, The Oscar Faber Partnership, Upper Marlborough Road, St. Albans, UK

Printed by Information Press Ltd Oxford England