VENTILATION –THE CHALLENGES AND ACHIEVEMENTS

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ABSTRACT

Major ventilation developments covering systems, measurements and design methods have taken place over the last 25 years. Our understanding about the impact of ventilation on the indoor environment and energy use has also evolved. This paper outlines these developments. Many future challenges are considered including minimum ventilation rates, energy efficient cooling, cost effective heat recovery and the development of calculation techniques.

BACKGROUND

The 1970's marked a decade of energy crisis resulting in doubt about the sustainability of existing energy supply. To provide a common framework for addressing this issue, twenty-one of the world's leading economies formed the International Energy Agency. Its task was to develop a strategy for security of future supply. To evolve this process, key areas within the supply and end-use sectors were separated into Implementing Agreements (IA's). Since approximately 40% of primary energy use was identified as being associated with buildings, this area was assigned its own IA, named Energy Conservation in Building and Community Systems (ECBCS). Aware of the considerable yet uncertain impact of air change on energy use, the ECBCS inaugurated the Air Infiltration Centre in 1979 with the stated aim of encouraging joint international research and to increase the world pool of knowledge on infiltration and ventilation. The overall objectives of the Centre were: standardisation of techniques, the validation of models, the cataloguing and transfer of information and the encouragement of research. Within this framework the AIC initiated the development of a model validation programme and an information dissemination service. The Centre initially operated from the offices of the Building Services Research and Information Association in Bracknell, England under the headship of Peter Jackman. The founding member countries were Canada, Denmark, Italy, the Netherlands, Sweden, Switzerland, the United Kingdom and the United States of America. Since then many other countries have taken part in the success of the Centre including: Belgium, the Czech Republic, Finland, France, Germany, Greece, New Zealand and Norway. In recognition of the important impact of ventilation in the energy equation, the Centre was renamed the Air Infiltration and Ventilation Centre in 1986.

The purpose of this paper is to outline the ventilation achievements and associated challenges over the proceeding 25 years.

THE EARLY CHALLENGE: VENTILATION, ENERGY AND AIR QUALITY

Energy Impact and Building Airtightness: In its early days the challenge of the Centre concerned the energy impact of infiltration. This is because evidence pointed towards poor air tightness and associated uncontrolled air-driven losses from buildings as a source of significant energy waste. Achieving air tightness was a major goal in many countries and a task of the Swedish participant of the Centre was to produce a handbook entitled "Air Infiltration Control in Housing - A Guide to International Practice" (Elmroth et al 1983). This reviewed airtight construction methods in the AIC Member Countries and provided guidelines for improving construction techniques. In 1980 Sweden became the first country to introduce a quantifiable building airtightness requirement. This initial regulation covered dwellings and specified the maximum number of air changes per hour allowable at a test pressure of 50 Pa. This 50 Pa reference pressure is now almost universally applied for air leakage evaluation on the basis that:

- It is practical to achieve by fan pressurisation;
- Under calm conditions results are not affected by ambient driving forces;
- The 50 Pa reference pressure is not so high that it artificially distorts the size of leakage openings.

The air change rate specification, however, is now steadily giving way to a specific leakage value defined as the leakage in m^3/s for each m^2 of envelope area. Also, an equivalent leakage area is applied in some countries. Assessing the energy impact of airflow (and related fan energy) from buildings remained a major task of the Centre that culminated in a publication on the energy impact of air change (Orme 1998).

Ventilation and Air Quality: Although energy was of prime concern, within the context of an IEA activity, air quality issues were addressed at an early stage. At the 2nd AIVC Conference, Wanner (1981) outlined the results of odour tests carried out in a test chamber and the use of metabolic CO_2 as an indicator of acceptable IAQ. This provided some early guidance on how much ventilation could be cut back as a means of reducing energy consumption. At the same time it was important to distinguish between both the need for ventilation and the need to inhibit uncontrolled infiltration losses. Arne Elmroth emphasised these differences in the August 1980 issue of Air Infiltration Review where he introduced the concept of "Build Tight - Ventilate Right" - an expression that is still widely used today.

Discussion on minimum ventilation rates is also very much a topic of the moment, especially when ventilation impacts on capital and operational costs. Typical minimum values are 8 - 10 L/s.p (sometimes much lower) although values as high as 25 L/s.p are being recommended (Wargocki et al. 2002). The setting of a universally agreed minimum ventilation rate is therefore an uncompleted task. A possible reason is that there is a lack of clear understanding by policy and decision makers. In many instances these see health as an issue combined with the need for cost cutting and energy reduction. From the perceived evidence, minimising cost favours lowering ventilation rates and putting less emphasis on providing peak comfort ventilation. Only by linking lower ventilation rates with tangible health consequences (e.g. increased spread of illness, poor reaction time and an increase in work-place accidents etc.) will policy makers begin to take note. Thus issues such as odour intensity and CO_2 concentration must be equated with identifiable adverse health and efficiency effects rather than with comfort alone.

Outdoor Air Quality: While ventilation plays an important role in securing good indoor air quality, it is ineffective if the supply (outdoor) air itself is not clean. It is not practicable to imagine that contaminated outdoor air can be suitably cleaned by artificial means on a population wide basis. Within Europe air quality requirements are covered by European Air Quality Framework Directive 96/62/EC (and subsequent 'daughter directives), which is aimed at securing a cleaner environment. A further key issue includes the siting of air intakes to avoid local sources of contaminant. This aspect is now covered by various codes and standards.

THE DEVELOPMENT OF CALCULATION TECHNIQUES

Calculations form a fundamental part of any prediction or design activity. It is therefore essential that such tools function correctly and that users understand how to apply them. An important early task of the Centre was to make an assessment of available ventilation tools. Calculation techniques include:

Zonal (Network) Models: By the end of the 1970's various multizone type network models had been developed as well as simplified single zone approaches. Such models are used to quantify the flow rate of air through openings and can thus predict the passage of air as it enters and flows through the building. They are therefore invaluable for calculating energy dissipation due to air change and may be used for basic air quality assessments. Due to lack of field data, evaluation of these models had not been possible. To overcome this, AIVC member countries pooled their data together to develop common datasets that could be used to assess model performance. Initial model results showed over sensitivity of calculated air change with wind speed and this was tracked down to inappropriate wind pressure coefficients, used to convert the impact of wind impinging on a building to wind induced pressure. Published data of the day largely related to wind loading values for isolated buildings whereas the observation buildings were all surrounded by adjacent buildings and structures. To overcome this, a search for more appropriate wind pressure data was made. This revealed the work of Bowen (1976) and Wirén (1985). Subsequent modelling results were promising. These results were published as a Technical Note (Liddament and Allen 1983). From this beginning the ECBCS supported further work on improving the applicability of network models through the development of the COMIS multizone program (Allard et al 1990). Complementary work took place and is still on-going at NIST (2004). This work includes a fully downloadable model. Recent new research is focussing on the development of more accurate numerical expressions for flow through large openings and for flow through openings at oblique angles to the wind (IJV 2004). Currently multi zone models are used by specialist organisations to evaluate ventilation design, however, their use is not widespread in the design office.

Computational Fluid Dynamics: CFD methods are used to calculate airflow, contaminant and temperature fields within a defined space. They may also be used to predict the external flow field. The ECBCS has taken a strong role in determining the applicability CFD models for building air flow studies through Annexes 20 and 26 (Moser 1992, 1998). Without these collaborative tasks it would be unlikely that the performance of CFD methods in building studies would have been as well understood. CFD has now captured the imagination of design offices throughout the world. This, certainly in part, is because much use has been made of graphical processing to produce vivid output. There is no question that they provide a valuable insight into flow behaviour, representing one of the greatest design advances over the last 25 years. However, there are still questions about their validity under all circumstances. Perhaps the greatest difficulty is the representation of turbulence since computational time and size limitations restricts the general ability to represent turbulence directly. Instead, various turbulence models need to be applied. Other issues concern reliable representation of boundary conditions - especially of flow from diffusers, and the simulation of thermal transfer from surfaces.

Combined Thermal and Ventilation Modelling: Modelling the thermal behaviour of buildings is well established but, even today, ventilation and infiltration may be incorporated in these models as a single value or simple schedule. Because this component can account for up to 50% of the energy loss, it rather devalues the level of detail used in complex thermal models to predict the remaining components of heat loss. Similarly, ventilation models make simplified assumptions about the temperature conditions. There is therefore a strong attraction to combine the two approaches. This is an area that the AIVC investigated and facilities to provide a coupled solution are beginning to become available (e.g. ESRU 1997).

THE DEVELOPMENT OF MEASUREMENT TECHNIQUES

Tracer Gas Techniques: Measurement techniques formed the topic of the Centre's first conference held in 1980. This early assessment was of importance because it provided the framework for acquiring data for the Centre's evaluation of calculation techniques. Many of the techniques presented at this conference are still in use today. For ambient monitoring, SF_6 tracer gas, multi tracer analysis, electron capture detection and computer controlled automation had been developed and validated. Subsequent to this conference developments have included long term averaging (using passive emitter and sample tubes) and monitoring of metabolic carbon dioxide. In the 1980's, measurements in occupied spaces using nitrous oxide as a tracer gas was not uncommon. Also SF_6 was sometimes used in the relatively high ppm range required for infrared detection equipment. While not known to be toxic at the concentrations used, SF_6 is a significant greenhouse gas while nitrous oxide is an anaesthetic. More recently, regardless of toxicity issues, the use of alien gases at any concentration, in occupied spaces, is becoming less acceptable to the public. Thus frequent use is now made of metabolic CO_2 concentration monitoring. In fact CO_2 sensors are becoming so reliable and inexpensive that they are beginning to be installed on an almost routine basis in some buildings as part of a demand controlled ventilation approach.

Pressurisation Techniques: Pressurisation techniques, in the form of blower doors as well as high capacity fans for large buildings, were also introduced at the first conference. Since then pressurisation testing has become common. For example, in the UK, Building Regulations requires that all non-residential buildings of 1000m^2 floor area and above be pressure tested for air leakage.

Wind Tunnel Measurements: The use of wind tunnel models has evolved to keep pace with theoretical and design demands. Not only are wind tunnels used for wind pressure assessment but also they are now used to measure flow through simple building structures and to observe the characteristics of flow through openings of varying size. This work has improved our understanding and representation of flow through openings. Wind tunnels are also used to determine the pattern of pollutant concentration arising from traffic and other pollutant sources.

Flume Models: In addition to wind tunnels, salt bath or flume models have become important tools to evaluate the performance of complex naturally ventilated structures.

DEVELOPMENTS IN VENTILATION STRATEGIES

In the 1970's, ventilation was essentially divided between natural and full mechanical systems. Often natural ventilation meant little more than relying on air infiltration combined with openable windows and, perhaps, vents. Scandinavian and some other countries, however, had quite a sophisticated stack driven approach to natural ventilation.

Mechanical systems were common in larger buildings, especially in severe climatic regions characterised by low winter temperatures and high summertime temperature and humidity. Because the primary purpose of mechanical ventilation was thermal conditioning, relatively large volumes of well mixed air, (compared to occupancy needs) were required. To avoid huge losses of conditioning energy, therefore, a significant proportion of air was recirculated. Since this recirculation technology was well developed it was rapidly imported to large buildings in many other climate zones and is still widely used today. However the high energy, maintenance and capital needs of these systems, combined with inherent air quality concerns about air recirculation has brought into question its suitability for milder climates where high outdoor temperature and humidity is less of a problem. There has hence been a large transformation in the implementation of ventilation systems.

Ventilation Effectiveness: A groundbreaking paper was presented by Mats Sandberg (1982) at the Centre's third conference. This work provided a mathematical representation of the mixing of ventilation air and the distribution of pollutant concentration in a space. It also enumerated the age of air at individual locations and the average age of air within a space. Once these parameters had been defined, by means of equations, it then became possible to develop and understand the performance of alternative ventilation strategies.

Displacement Ventilation: An outcome was the development of displacement ventilation systems, aimed at minimising mixing and, instead, directing fresh supply air directly to occupants. As a consequence, for a given ventilation rate, it was possible for occupants to receive less polluted air than was achievable by conventional mixing ventilation. Developmental research was aimed at meeting the heating and cooling needs in buildings serviced by displacement ventilation. As a consequence conventional ventilation driven air conditioning systems gave way to chilled beams and ceilings.

Natural Ventilation, Mixed Mode Ventilation and Passive Cooling: Throughout the 1980's there was, perhaps, a movement away from natural ventilation in favour of a totally mechanically controlled environment. Where climates were less severe, occupant reaction tended to be negative. Also there were concerns over poor comfort and sick building syndrome. As a consequence, purpose designed natural ventilation systems began a renaissance. Key studies included the European NatVent Study (Kukadia et al 1998) while, within the ECBCS, Annex 35 “HYBVENT” was initiated on hybrid ventilation systems (Heiselberg 2002). These projects also explored the role of thermal mass and night cooling to provide a measure of daytime cooling. These developments have had a fundamental impact on questioning the need for full mechanical ventilation. In many climates, by meeting the majority of cooling needs by passive means, central mechanical air conditioning can give way to localised and/or intermittent cooling.

Heat Recovery: A promise of the 1980’s was exhaust air heat recovery. Demonstrated systems showed recovery rates in excess of 90% while latent heat recovery was also possible. In severe winter climate countries, such as parts of Scandinavia and Canada, there is growing popularity in heat recovery. In Finland, for example, a measure of heat recovery has become compulsory. Elsewhere, the promised benefit has yet to be fulfilled. Capital, running and maintenance costs are the primary issues that still need to be resolved.

Demand Controlled Ventilation (DCV): The potential of DCV formed the work of ECBCS Annex 18 (Mansson 1997). DCV has subsequently had a major impact on air quality and energy performance. $CO_{2,}$ humidity, PIR, temperature and other detectors, when used appropriately, can all assist in securing a healthy and comfortable indoor environment. The controls technology necessary to secure DCV hardly existed in 1979 but are now widely available.

CONCLUSIONS

The AIVC has presided over a period in which air change accounts for approximately half of the energy dissipation from buildings in industrialised countries and as much as 20% of total primary energy consumption. Above all ventilation is the final arbiter of indoor air quality.

The original rationale of the Centre was concerned with energy efficiency, especially in relation to air infiltration. Over the intervening years airtightness standards and construction practice has evolved to ensure reduced uncontrolled loss of air. Equally ventilation systems and control methods have developed to the point that energy efficient ventilation can be provided to meet the varying loads imposed by occupants. Also monitoring equipment has become relatively inexpensive, hence routine monitoring of CO_2, foe example, to ensure maintenance of minimum ventilation requirements, is becoming a reality.

Many challenges still remain however; these include:

Policy and Education:

- There is a need to educate the policy and decision maker, especially in relation to how much ventilation is required. This should entail definitive research into the impact of ventilation on occupant health and efficiency rather than purely on odour and comfort;
- Ventilation design in practice can still be poor. There are many examples of poor ventilation design and resultant lack of climate achievement. The necessary knowledge exists within the domain of the specialists but is lacking in various areas of general practice.

Technical Challenges:

- Multizone modelling: Network models have not captured the same enthusiasm by the design office as CFD yet they are very definitely used in support of design work by specialists. Commercial equivalents need to be developed that offer comparable interfaces and output graphics as the current generation of CFD models;
- Model Boundary Conditions: For CFD and network models alike, there are still many uncertainties about boundary conditions. These include turbulence parameters, wind pressure values, and the characteristics of flow through openings;

- Ventilation Strategies: Ventilation systems should be designed to utilise the outdoor environment to its full potential;
- Heat Recovery: Despite the promise, the market has not yet judged these systems to provide a good return, particularly in less severe climates. Effort is needed to reduce the operational cost.

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