The AIVC of the 20th Century

Martin Liddament

Reading, UK
mwliddament@gmail.com

SUMMARY

This report reviews the activities of the AIVC during its first twenty years of operation. It identifies key projects and addresses them in the context of research activities and associated issues of the time. Early issues included the need for energy conservation and reducing air infiltration loss. Much work concentrated on assessing the performance of numerical models and acquiring input and validation measurement data. Towards the end of the period attention focused towards energy efficient ventilation systems for good indoor air quality and comfort. Calculation and measurement needs of the time are described.

KEYWORDS

Air infiltration, calculation methods, measurement methods, historical review.

1 BACKGROUND

In the wake of uncertainty over oil supply, the International Energy Agency (IEA) was established in 1974 as an autonomous body within the Organisation for Economic Cooperation and Development (OECD). One element of its activities was for participants to undertake cooperative activities in energy research, development and demonstration with the primary objective of reducing dependency on fossil fuel.

Energy consumption in buildings was identified as a significant consumer of energy and was an area offering the potential for a considerable reduction in energy use. To address this an Executive Committee for Energy Conservation in Buildings and Community Systems (ECBCS) was formed with a responsibility for encouraging various exercises to predict, more accurately, energy use within buildings through a series of task based Annexes.

Air infiltration into buildings was quickly identified as an area about which least was known. To address this, Annex 5 the Air Infiltration Centre (AIC), was established by the ECBCS in 1979. Its aim was to provide an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock. These activities were extended to the field of ventilation, as a whole, and became the Air Infiltration and Ventilation Centre (AIVC) in August 1986. Funding was provided by member countries who chose to join the Centre. Many Annexes have subsequently been established within the ECBCS with several associated with the work of the AIVC. The AIVC fulfilled its objectives through a programme of technical activities, the provision of an information centre and dissemination.

This report summarises the work and outcomes of the AIVC between 1979-2000, as well as its interaction with associated Annexes and other projects. It further attempts to outline the progression of interest from minimising energy use to interests in improving knowledge about air and pollutant transport as well as improving health, comfort and indoor air quality.

1.1 The AIVC Steering Group

The work of the Centre was assisted through a Technical Steering Group appointed by member Countries. This Group provided expertise and assistance to the staff of the Centre as well as providing a conduit to relevant research and activities in member countries. This approach has undoubtedly been instrumental in the success of the AIVC.

2 INFORMATION ACTIVITIES

Without access to Google and modern bibliographic information systems, finding relevant information in 1979 was not a as simple as in 2019. To overcome this, a computerised bibliographic database, AIRBASE, was established on a 'mainframe' computer in 1980. This could be interrogated through keyword or free text searching on author, title or abstract fields. Initially this was only accessible at the AIVC and searches were undertaken, internationally, by request, usually by telex. In 1985 the AIVC acquired two IBM AT desktop personal computers and were able to transfer AIRBASE to floppy disks running on the DOS operating system. These disks were updated quarterly and sent to any organisation in member countries that wanted direct access to AIRBASE. Also, direct searching was possible via a modem link established in February 1983. Subsequently, AIRBASE was made available on CD-ROMs. Information for AIRBASE was derived from data and resources provided by the Steering Group, regular surveys of research and by direct library research.

3 DISSEMINATION ACTIVITIES

The AIVC disseminated information through a strong publication programme.
Publications included:

- Technical Notes based on work undertaken at the Centre and by associated Annexes within ECBCS;
- Technical Guides;
- Bibliographic Reviews based on topical information contained within AIRBASE;
- Quarterly Newsletter Air Infiltration Review (AIR);
- AIVC Website, the AIVC Website was established in September 1995.

The Centre also organised annual conferences and workshops and hosted visiting specialists.

4 TECHNICAL ACTIVITIES

4.1 Model Validation

A fundamental initial task of the AIVC was to undertake a programme to 'validate' mathematical models of air infiltration. This progressed in five stages, these being to:

- Select appropriate mathematical models;
- Establish the data needs of each model;
- Prepare suitable high-quality datasets based on measurements made on site;
- Use the available data to compare modelled results with actual infiltration measurements;
- Identify key parameters.

It is through this activity and the activities of related research organisations and universities that developments in ventilation in the AIVC's early years can best be reviewed.

To 'validate' a model substantial monitoring data are required including:

- Building dimensions and layout;
- Building permeability or leakage value (airtightness test data);
- Continuous monitoring of actual infiltration rate (tracer gas measurements);
- Simultaneous monitoring of driving forces (indoor temperature, outdoor temperature and wind speed).

These were difficult data to obtain since very few projects simultaneously monitoring all these had been undertaken. A total of ten 'physical' models were selected which were based on the solution of the equations of flow through openings in the building structure. Complexity ranged from simplified single zone methods, in which the interior of the building was assumed to be at a single uniform pressure, to multizone approaches, in which the interior was divided into individual rooms or zones. Not surprisingly, very few complete datasets were available, and analysis was restricted to three naturally ventilated dwellings, each of which was configured for whole building ventilation monitoring (i.e. with internal doors open). Within the limitations of measurement errors, all the models produced results that were consistent with measured ventilation rates (mostly within 25%) for these fairly simplistic configurations. Full details of the work and results are described in AIVC TechNote 11 (Liddament and Allen 1983).

4.2 Air Infiltration Calculation Techniques Guide

The numerical modelling activity spawned many associated activities that governed the early technical work of the Centre. The first was compiling the background and basic theory of mathematical model themselves into an Applications Guide published in 1986 (Liddament 1986). The intention was to provide both researchers and designers with a detailed background to air infiltration modelling and to give guidance on the application of modelling techniques in design. Associated calculations included infiltration heat loss, air flow rates, pressure distribution and pollutant concentrations.

4.3 AIVC's Numerical Database

Numerical data, collected as part of the Centre's mathematical studies, were subsequently compiled into a numerical database. This was developed in response to a need to establish a core numerical data source, suitable for design purposes and model validation.

The database was presented in three sections i.e.

- Component leakage data;
- Whole building leakage data
- Wind pressure evaluation.

A full description of the database and an analysis of the data was published as a technical note (Orme et al 1994).

5 RELATED NUMERICAL MODELLING

Advancing mathematical modelling of air infiltration and ventilation was a theme that continued throughout the 1980's, much of which involved related Annexes. These included the following:

5.1 The COMIS Multizone Project (ECBCS Annexes 20 and 23)

In 1988 an international project COMIS (Conjunction of Multlzone Infiltration Specialists) was initiated at Lawrence Berkeley Laboratory's Applied Science Division. Its task was to develop a detailed multizone infiltration program taking crack flow, HVAC-systems, single-sided ventilation and transport mechanisms through large openings into account. The final aim was to produce an up-to-date user-friendly program suitable for researchers and building professionals.

This task was subsequently incorporated into ECBCS Annex 20 Airflow patterns in buildings and then, ECBCS Annex 23 Multizone airflow modelling. Multi-gas tracer measurements and wind tunnel data were used to check the model. Monitoring and comparisons were made on nine buildings, each presenting several cases.

From comparisons with measurement, it was concluded that:

- When proper input is provided, air and contaminant flows, resulting from infiltration through cracks and ventilation systems, are properly predicted by COMIS and similar programs.
- Air and contaminant flows through large openings (that is openings presenting two-way flows) can be calculated, but the result may not be close to reality. This is especially true in case of wind and when the building structure acts as a thermal reservoir.
- In general, global air flow rates through the building are predicted more accurately than inter-zonal flow rates.

A major difficulty identified by the work of Annex 23 was the tendency of modelling programs to user error. This is partly due to the complexity of the required input data but may also be due to the lack of understanding by users of the underlying mechanisms of air flow, resulting in an incorrect definition of the problem to be solved. COMIS attempted to overcome this with a carefully designed user interface. A technical summary of this work is presented by Warren (Warren 2000).

5.2 CONTAM

A second major international multizone model originating from the 1980's is CONTAM. This began with work by Walton (1983) on a computer algorithm for predicting inter room air flow as well as flow through small and large openings. This then evolved into the National Bureau of Standards (now NIST) "General Indoor Air Pollution Concentration Model Project" initiated in 1985 (Axley 1985). This first incarnation version became CONTAM86. Since then CONTAM has gone through many iterations and is in current use today.

5.3 Computational Fluid Dynamics (CFD) IEA Annex 20 airflow patterns within buildings

Computational fluid dynamics to predict air flow patterns in rooms and other spaces had its beginning in the late 1970's. As affordable computer power became more available CFD became an attractive observation and design tool. The Centre published a short summary Technical Note on the topic in 1991 (Liddament 1991) but it became a main task for IEA Annex 20 which was completed in 1992.

An objective of this work was to determine the reliability of computer prediction of the flow field within a room. To resolve this, a test room was set up with identical instrumentation in five countries. Tests were performed for various flow regimes and measurement results were compared with CFD simulations. From this it was concluded that CFD simulations are useful when:

- Values of difficult to measure variables are needed in all points of the flow field;
- Studying the sensitivity of small changes of conditions;
- predicting airflow patterns for critical projects.

It was also concluded that CFD predictions can predict room air movement with sufficient realism to be of use to design practice (Lemaire 1993). At the time of this work, it was concluded that further work was required to model supply jets, turbulence and thermal wall functions. The application of CFD has since significantly expanded within the building sector across the entire research and practitioner field.

6 MEASUREMENT TECHNIQUES

In all the above studies measurement were essential and measurement methods made significant advances during the 1980's and 90's. Key measurement parameters included:

6.1 Tracer gas to measure air infiltration rate and ventilation

Tracer gas monitoring is an essential method for measuring ventilation and infiltration under ambient conditions. In essence the process is fairly straight forward: an inert, non-toxic gas is released into a space and its concentration is monitored as it disperses and eventually leaves the building through the ventilation process. Throughout the 1980's real time monitoring in test houses, as well as occupied spaces, took place. Techniques included tracer decay, constant concentration, constant emission and multi tracer methods. There were also long-term monitoring techniques using 'passive emission' samplers. Simpler methods included monitoring the concentration of metabolic carbon dioxide emissions from building occupants.

Common tracer gasses were:

- Nitrous oxide;
- Carbon dioxide;
- Per Flouro Compounds (PFCs);
- Sulphur hexafluoride (SF_6);
- Freon.

The complexity of monitoring systems generally restricted applications to the research sector, making it unattractive for general application. Also, SF_6, PFC's and Freon are significant greenhouse gasses with no significant decomposition. Consequently, their use is now restricted. Similarly, nitrous oxide is no longer considered as non-toxic. As a consequence, the use of tracer gas monitoring has declined. The exception is the monitoring of carbon dioxide, which is now inexpensive and can be used to assess the adequacy of ventilation in occupied spaces.

6.2 Whole building and component airtightness measurements

The airtightness or permeability value of a building is essential for modelling and design purposes.

In the late 1970's, whole building leakage monitoring was relatively uncommon. However. towards the end of the 1970's, the Swedish Government introduced airtightness requirements for housing (SBN 1980). The requirement for single houses was that airtightness should not exceed 3 air changes/hour at an induced indoor-outdoor pressure difference of 50 Pa (3 ac/h_{50}). Typically, this was measured by removing an external door and replacing it with a fan that could drive enough air to monitor the required airtightness value. The 50 Pa pressure standard has largely remained the same to this day, although the use of air change rate has given way to permeability (which expresses leakage in terms of the surface area of the building façade). A pressure difference of 50 Pa was primarily selected because it was generally above the value of natural driving forces (at least for low rise buildings) but not so high that it could force joints in the façade to open or close. Also, it sets a reasonable flow capacity for fans. Initially, blower fans were laboratory designed but, by 1983, 'blower doors', as recognised today, were in use. Giant trailer born fans for larger buildings were also in use by 1980.

Pressurisation techniques had additionally been developed during this period to measure leakage across specific components or facades. These include multiple fans and component test rigs. Although novel in the early 1980's blower door methods are now in common use.

6.3 Wind Pressure

The wind induced pressure across infiltration openings is a key component of an infiltration calculation. It is not possible to measure this directly but, instead, it is commonly related to wind speed (at a specified reference height) in terms of a wind pressure coefficient. These are derived from wind tunnel testing. Throughout the 1980's much wind tunnel analysis was undertaken to derive wind pressure values. In the early days of the AIVC mathematical modelling study, wind pressure coefficient data were largely derived from the wind tunnel testing of Bowen (1976) and Wiren (1985).

6.4 Air Infiltration Measurement Techniques Guide

Information on tracer gas testing, airtightness measurements and associated techniques was compiled into an AIVC measurement techniques guide, published in 1988 (Charlesworth 1988). This was subsequently updated to include further measurement detail, covering a wider range of cases and theory, by Roulet and Vandaele in 1991 (Roulet and Vandaele in 1991).

7 HANDBOOK: AIR INFILTRATION CONTROL IN HOUSING – A GUIDE TO INTERNATIONAL PRACTICE

A handbook (Elmroth 1983) was prepared by the Swedish participant of the AIVC to review international practice on airtight construction. Its objective was to understand air leakage routes through construction joints and to identify mechanisms for securing airtightness. Each construction joint was identified and an airtightness solution presented. This publication followed an earlier Swedish handbook on airtightness and thermal insulation (Carlsson et al 1981) that defined the future building air tightness design practice for new housing in Sweden.

8 ASSOCIATED VENTILATION ANNEXES AND RESEARCH

During the 1980's and 90's other important topics and projects evolved, many of which have important applications today. Several of these were picked up by associated Annexes of the ECBCS and some of the final reports were subsequently published by the AIVC as Technical Notes. These topics included the growing interest in indoor air quality and comfort as well as energy efficient ventilation systems. Topics included:

8.1 Inhabitants behaviour with respect to ventilation, Annex 8

This occupational study was managed by TNO in The Netherlands and was aimed at identifying the motivation of occupants in controlling their indoor climate, as well as assessing potential energy savings if behaviour could be modified. There are numerous important conclusions but results showed that there were considerable differences between household in sensitivity to temperature variation, on the whole ventilation behaviour was found to be highly weather dependent and the greater the interest of inhabitants in controlling energy use the more positively they responded to advice. Results are presented by Dubrul (1988).

8.2 Minimum ventilation rates and measures for controlling indoor air quality, Annex 9

This project focused on researching the minimum ventilation rate needed to maintain good air quality for a range of common indoor pollutants. It considered the source characteristics and adverse effect of pollutants, along with control measures for limiting concentrations and appropriate ventilation strategies. The details and results are reported by Trepte and Haberda (Trepte and Haberda, 1989).

8.3 Ventilation efficiency and pollutant removal effectiveness

Once buildings became more airtight, attention turned to indoor air quality and comfort. Improved ventilation systems were designed that were aimed at providing clean air more efficiently, such as by using displacement rather than conventional mixing ventilation. In turn this meant that, in certain climates, heating and cooling could be provided using chilled ceilings and 'low' temperature heating systems. Issues included the supply and spread of clean air and removal of polluted air from occupied spaces. Various definitions that quantify these concepts began to emerge in the mid 1980's. Explanations of these evolving definitions were compiled into a series of Technical Notes (Sutcliffe 1990, Brouns and Waters 1991 and Liddament 1993).

8.4 Demand controlled ventilation - intelligent ventilation systems for indoor air quality control, Annex 18 demand controlled ventilation systems

As air quality sensors became less expensive, interest increased in developing demand control ventilation systems. The principle objective of this task was to develop an efficient ventilating system by a demand control based on analysis of the ventilation effectiveness and proposed ventilation rates for different users in different cases in domestic, office and school buildings. The project also involved work on field studies, sensor location and ventilation strategies. Details and results are published by Mansson et al (Mansson et al 1997).

8.5 Other ECBCS ventilation related projects

There were several other ECBCS projects that were related to the activities of the AIVC. These included:

Annex 25 Realtime HEVAC simulation, Annex 26 Energy efficient ventilation of large enclosures and Annex 27 Evaluation and demonstration of domestic ventilation systems. Project reports for these activities as well as recent projects (and all past activities) can be found on the ECB (formerly ECBCS) website (www.iea-ebc.com).

8.6 European NatVent Project - Overcoming barriers to low energy natural ventilation

This EU project was supported by the AIVC and was aimed at encouraging the use of natural ventilation in moderate to colder climates. Of interest was the targeting of buildings and countries where summer overheating from solar and internal gains could be significantly reduced by low energy design and good natural ventilation. It also addressed buildings in noisy and polluted locations. NatVent's main objective was to provide practical solutions and guidance and thus encourage the wider uptake of natural ventilation technologies. As part of the project, hourly monitoring of indoor climate took place in nineteen mainly large commercial and public buildings located in participating countries. A detailed summary of the project is presented by Kukadia (1999).

8.7 AIVC Guide to Energy Efficient Ventilation

A task of the AIVC, towards the end of this period, was to produce a Guide to Ventilation (Liddament 1996). This was aimed at providing background knowledge, in the form of an easy to read primer, for policy makers and practitioners that needed basic information. The structure was a descriptive approach with equations restricted to a minimum and only included in the final chapter. Some summary data were included as appendices, along with a simple algorithm to allow basic infiltration and ventilation calculations. Topics covered basic definitions, indoor air calculations, comfort, energy impact, design criteria, ventilation, cooling, filtration, ventilation efficiency, maintenance, measurement methods and calculation techniques.

9 CONCLUSIONS

The AIVC presented a unique opportunity to develop and promote an understanding in energy efficient ventilation. In its early years it established a bibliographic and numerical database to assist researchers and practitioners. Much of the compiled data has been used in practice and incorporated into computer codes.

Initially, the Centre's task focused on minimising air infiltration energy loss. Over time, however, the AIVC evolved to respond to indoor climate, comfort and air quality concerns.

During the 1980's, there were considerable advances in mathematical model development and measurement techniques. Tracer gas was especially important for infiltration measurements, while pressurisation techniques were developed for airtightness testing. Mathematical model development included advances in multi-zone methods and CFD. Towards the end of this period, demand for tracer gas monitoring reduced. In part, this was, perhaps, as a consequence of limitations on permitted tracer gas as well as expense and complexity. Possibly, the increasing availability of low cost carbon dioxide sensors enabled rudimentary tests on the adequacy of ventilation to be made without the complication of a full tracer gas test.

By the 1990's computational fluid dynamics had grown in popularity and may have began to replace measurement methods for some applications. Work by Annex 20 has done much to understand and develop approaches to secure reliable results.

Throughout the 1990's, interest expanded into indoor air quality, health and thermal comfort. Particularly, parameters evolved to quantify the quality of ventilation in relation to these issues.

Throughout this period, the Centre interacted with IEA and other groups undertaking ventilation related activities.

The active technical support provided by the Steering Group was instrumental to the success of the AIVC.

10 REFERENCES

Allen, C. (1981) *Reporting format for the measurement of air infiltration in buildings.* AIVC TN 6.

Axley, J. (1987) *Indoor air quality modeling phase2 report CONTAM 86 including User Manual.* NBSIR 87-3661 NIST (Formerly NBS).

Bowen, A. J. (1976) *A wind tunnel investigation using simple building models to obtain mean surface wind pressure coefficients for air infiltration estimates.* Report no. LTR LA 20N, National Aeronautical Research Establishment, Canada.

Brouns, C., Waters J.R. (1991) *A guide to contaminant removal effectiveness.* AIVC TN 28.2.

Carlsson, B., Elmroth, A., Engvall, P-A. (1981) *Airtightness and thermal insulation –building design solutions,* Svensk Byggtjänst.

Charlesworth, P. S., (1988) *Air Exchange rate and airtightness measurement techniques – an application guide.* AIVC ISBN 0 946075 38 7.

Dubrul, C. (1988*) Inhabitants' behaviour with regard to ventilation.* AIVC TN 23.

Elmroth, A. (1983) *Air infiltration control in housing – A guide to international practice*. AIVC Handbook HNBK.

Feustel, H. E. et al. (1990) *Fundamentals of the multizone air flow model- COMIS.* AIVC TN 29.

Kukadia, V. (1999) *European NatVent Project. Air Infiltration Review* Vol 20 No2. AIVC.

Mansson, L. G., Svennberg S. A. (1997) Annex 18: *Demand controlled ventilation systems – Annex 18,* Technical Synthesis Report, IEA-EBC.

Lemaire, A. D. (1993) *Annex 20: Room air and contaminant flow evaluation of computational methods. Subtask 1 Summary Report*, ISBN 90-6743-298-9, TNO, The Netherlands.

Liddament, M.W. (1991) *A review of building air flow simulation. AIVC* TN 33.

Liddament, M.W., Allen, C. (1983) *The validation and comparison of mathematical models of ventilation.* AIVC TN11.

Liddament, M.W. (1993) *A review of ventilation efficiency.* AIVC TN 39.

Liddament, M.W. (1986) *Air infiltration calculation techniques – an application guide.* AIVC

Liddament, M.W. (1996) *A guide to energy efficient ventilation.* AIVC

Orme, M. et al (1994) *An analysis and summary of the AIVC's numerical database*. AIVC TN 44.

Roulet, C.A., Vandaele, L. (1991) *Air flow patterns: measurement techniques.* AIVC TN 34.

SBN (1980) *Thermal insulation and airtightness Chapter 33.* Svensk Byggnorm med Kommentarer, Statens Planverk, Sweden.

Sutcliffe, H. (1990) *A Guide to air change efficiency.* AIVC TN 28.

Trepte, L., Haberda, F. (1989) *Minimum ventilation rates and measures for controlling indoor air quality*. AIVC TN 26.

Walton, G. (1983) *A computer algorithm for estimating Infiltration and inter room air flows.* Report NBSIR 83-2635 NIST (Formerly NBS).

Warren, P. (2000) *Summary of IEA Annex 23 Multizone Airflow Modelling (COMIS) within the Energy Conservation in Buildings and Community Systems Programme*. Document TSR-06-2000 ISBN 1902177 155. IEA-ECB Energy in Buildings and Community.

Wiren, B.G. (1985) *Effects on surrounding buildings on wind pressure distributions and ventilation losses for single-family houses. Part 1: 1 1/2-storey detached houses.* Nat. Swed. Inst. for Build. Res., Bulletin M85:19, 1985.