Air
Infiltration
Review

a quarterly newsletter from the IEA Air Infiltration and Ventilation Centre

International Energy Agency - AIVC

Vol. 18, No. 1, December 1996

Why CO_2?

Martin Liddament reviews some of the current knowledge about the use of metabolically produced CO_2 in indoor air quality evaluation and control.

Background

The concentration of metabolically produced CO_2 in a space has become a popular indicator of indoor air quality. Increasingly, it is used to control ventilation systems and as a measure of compliance with various Codes and Standards. There is underlying concern, however, that such measurements could give erroneous information and that there may be a general misconception about the significance of metabolic CO_2. The purpose of this note is to summarise recent contributions on this topic, with specific reference to a Seminar and Forum on metabolic carbon dioxide which took place earlier this year at the Atlanta ASHRAE meeting. The reasons for so much interest in CO_2 were summarised at this meeting by Andrew Persily of the US National Institute of Science and Testing (NIST). He emphasised that carbon dioxide is metabolically produced and can therefore be associated with the presence of occupants. Also it is relatively easy and inexpensive to measure, and it is fairly stable in that it is not especially reactive or absorbed by surfaces. In principle CO_2 can be used to evaluate the ventilation rate, determine the proportion of outdoor air that is blended with recirculated air and provide an indication of perceived indoor air quality.

CO_2 and Toxicity

The health and toxicity implications of carbon dioxide were reviewed by Michael Hodgson, MD of the University of Connecticut Health Sciences Center. His research indicates that, despite largely untested reports to the contrary, there is no physiological evidence that CO_2 has any metabolic influence at concentrations below about 8500 ppm. Between 8500 -10,000 ppm the tidal flow of air through the lungs is increased and above 34,000 ppm the respiratory system becomes more rapid. At 40-45,000 ppm sweating occurs and at about 50,000ppm anxiety is induced. He also reported that in the 19th century, CO_2 was used as a narcotic for surgery, where concentrations approaching 500,000 ppm (50%) were needed. Under all but extreme occupancy conditions, therefore, the removal of CO_2 from a space on grounds that it in itself influences health cannot normally be regarded as an issue.

In this issue

Metabolically Produced CO_2

Carbon dioxide is produced as part of metabolism. The rate of production is fairly well defined and is dependent on the level of metabolic activity. Examples are illustrated in Table 1 (BS5925,1990). On this issue, Michael Hodgson noted that, for any specific activity, production rate increases with body weight, reflecting the greater level of physical effort which must be applied. He also noted that physically fit people are able to do a greater level of work for each unit of CO_2 produced.

Activity	Metabolic Rate (W)	CO_2 Production Rate (l/s)
Sedentary Work	100	.004
Light Work	100-300	.006-.012
Moderate Work	300-500	.012-.020
Heavy Work	500-650	.020-.032
Very Heavy Work	650-800	.026-.032

Table 1 Energy Production Levels and Emission Rates of Carbon Dioxide for Various Levels of Metabolic Activity (Based on BS5925:1990)

Outdoor or Background CO_2 Concentration

Carbon dioxide is a constituent of the outdoor air and evidence suggests that its ambient concentration is gradually increasing. Actual outdoor concentration is dependent on locality and varies from between approximately 350 ppm, away from urban areas, to approximately 400 ppm in city environments.

Indoor or Room Concentration of CO_2

The indoor concentration of carbon dioxide depends on the outdoor level and the production rate of CO_2 within the space. In the office, this extra contribution is primarily assumed to result from metabolism, but in the home open gas cookers could make a further significant contribution. Strictly, to determine the contribution to CO_2 generated in a space, the *difference* between the indoor concentration and the outdoor concentration should be measured. However, for approximate purposes, an outdoor value of between 350-400 ppm is usually assumed. It is important to be aware, however, that, for precision analysis, some authors, when refering to indoor CO_2 concentration, automatically subtract the outdoor value (i.e they give the *difference* value). On the otherhand most standards, that refer to an acceptable indoor CO_2 concentration, refer to the *absolute* or *total* room concentration.

Steady State Concentration

Metabolically produced CO_2 behaves like any other pollutant in that for a given level of occupancy and rate of ventilation, its concentration will asymptotically rise to a 'steady state' value. At steady state, the concentration will depend on both the outdoor air ventilation rate and the CO_2 production rate, while the time taken to reach steady state concentration will depend on the 'air change' rate alone. The approximate relationship between steady state concentration (absolute) and ventilation rate is illustrated in Figure 1. If steady state concentration has been achieved, and the level of activity is known then, provided there is no other source of generation, the measured CO_2 concentration provides an indication of the amount of 'fresh' outdoor air being supplied to each occupant.

Transient Concentration

More often than not, steady state concentration is not reached. Either the volume of enclosed space is so large that it would take many hours to achieve or the level of occupancy is continually varying. Under these circumstances a 'spot' measurement of CO_2 can become meaningless. Various techniques have been developed, however, to estimate ventilation rate from the transient CO_2 concentration. Persily (1996, 1994), has investigated this in detail and offers several solutions. This aspect has also been addressed by the US Environmental Protection Agency (EPA), following concern that too much reliance is placed on transient spot measurements. John Girman of the EPA indoor environmental division described work involved in looking at the errors associated with spot measurements and devising methods to improve upon ventilation estimated from CO_2 measurements. The main areas of error were concerned with the

Air
Infiltration
Review

Editor: Janet Blacknell

Air Infiltration Review has a quarterly circulation of 3,500 copies and is currently distributed to organisations in 40 countries. Short articles or correspondence of a general technical nature related to the subject of air infiltration and ventilation are welcome for possible inclusion in AIR. Articles intended for publication must be written in English and should not exceed 1,500 words in length. If you wish to contribute to AIR, please contact the Air Infiltration and Ventilation Centre. Please note that all submitted papers should use SI units.

time it takes to reach steady state, assumptions about the rate of CO_2 generation and fluctuations in outdoor concentration. Below about 3 air changes/hour approximately three hours is needed to achieve a steady state condition, however, work in progress Mudarri (1996) highlights how allowances can be made for the non attainment of steady state conditions based on the duration and level of occupancy. For improved accuracy, more precise knowledge is needed about metabolic generation rate, for example the ratio of production for men and women in similar activity is approximately 1:0.76. Such allowances have been incorporated by Mudarri into a 10 Step Guide to estimating air change rate from relatively straightforward parameters.

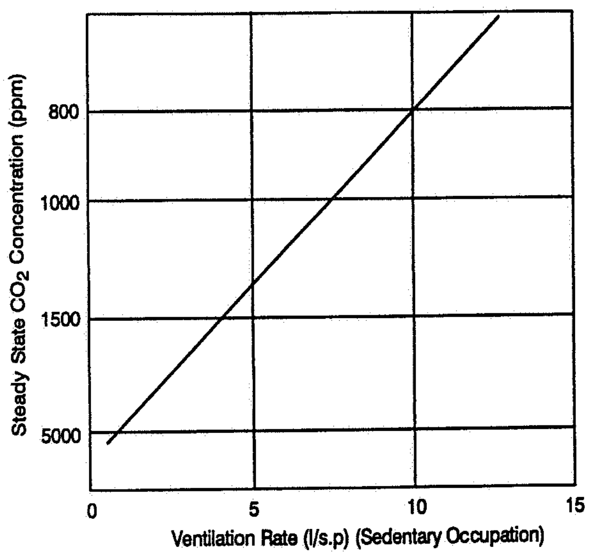

Figure 1: Metabolic carbon dioxide

Room Concentration and 'Perceived' Indoor Air Quality

Andrew Persily reviewed some of the background to the interest in CO_2 including its relationship with peoples' perception of indoor air quality, principally in relation to odour. He cited a number of examples indicating the relationship between CO_2 concentration and body odour. Particularly, there was consistent data linking CO_2 concentration with the percentage of people 'visiting' a space who were 'dissatisfied' with the level of odour (ppd). This linkage is associated with the actual CO_2 concentration measured rather than the steady state value. Typically, 20% ppd corresponds to a CO_2 concentration of 650 ppm above the outdoor value (i.e. approximately 1000 ppm actual CO_2 concentration (Figure 2).

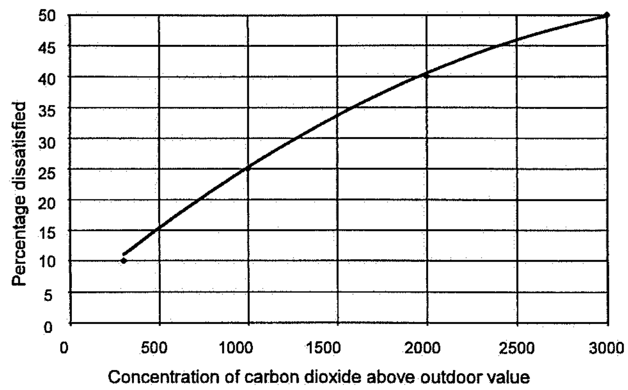

Figure 2: Metabolic Carbon Dioxide as an Indicator of Acceptable Indoor Air Quality

Measuring CO_2

Various techniques are available for the measurement of carbon dioxide, a summary of which was presented by Richard Stoner of Solomat Neotronics. Further information is also described in Chapter 11 of the Guide to Ventilation (Liddament 1996). Techniques vary from precision mass spectrometry to inexpensive detection tubes that undergo colour change in reaction to the presence of carbon dioxide. Probably the most common method for demand control systems is non-dispersive infra-red detection which makes use of the property of a gas to absorb energy from an infra-red light source. The resultant heat generated is detected as a volumetric change. This absorption property is also applied to photo-acoustic detection in which absorption from a pulsed infrared source, tuned to the specific characteristics of CO_2, is translated to a sound wave. The sound intensity is related to gas concentration. Both systems have a resolution of typically +/- 50 ppm and suffer from drift caused by dust on optics and a gradual deterioration in lamp performance. Other methods include potentiometric in which CO_2 is diffused into an electrolyte resulting in a change in applied voltage and amperometric based on the electrochemical diffusion of CO_2 across a membrane into an electrolyte. Again sensitivity is typically +/- 50-100 ppm and drift can be significant. Sensor life can also be limited.

Problems and experiences associated with the measurement of metabolically produced CO_2 were further highlighted at an informal forum aimed at assessing the role of CO_2 measurements as a means of estimating outdoor air ventilation rates. Experiences indicated significant instrument drift. One monitored study showed that after a few months a system having a set point of 1000 ppm did not react until the actual concentration had reached 1800 ppm. Several contributors emphasised the need for regular instrument calibration. The conclusion, therefore, must be that any demand control sensor must contain provision for simple (possibly automatic) calibration. In short, an unattended system will fail, probably within only a few months.

'Demand' Control Ventilation

Notwithstanding problems associated with monitoring metabolic CO_2, it has become a popular component of demand control ventilation systems. This formed part of a major Research Task (Annex 18) of the International Energy Agency's Implementing Agreement for Energy Conservation in Buildings and Community Systems (Mansson 1990).

Conclusions

Carbon dioxide is largely non-toxic with evidence suggesting that concentrations as high as 10,000 ppm or more have no significant health effects.

For normal conditions of occupancy, however, measured CO_2 concentrations significantly above 1000 ppm provide an indication of inadequate ventilation for comfort and may mean that the ventilation rate is inadequate to dilute other, more harmful pollutants that may be present. In this sense, the monitoring of CO_2 concentration can make a valuable contribution to IAQ assessment.

Unfortunately, a measurement of concentration (especially a 'spot' measurement) at or below 1000 ppm does not necessarily provide an indication of the adequacy of ventilation since there may be other pollutants present or insufficient time has elapsed to provide a steady state reading, or the building may be at reduced occupancy.

If CO_2 is continuously monitored then it is possible to evaluate the adequacy of air change by considering the rates of growth and decay in concentration as the occupancy level varies.

For More Information and References

Liddament M W, "A Guide to Energy Efficient Ventilation, AIVC, 1996
Mansson L-G, "Demand Controlled Ventilating System: State of the Art Review", Swedish Council for Building Research, 1990
Mudarri D, "Interpretation of CO_2 measurements in buildings", US EPA, draft report, April 26, 1996.
Persily A K, "A study of ventilation and carbon dioxide in an office building", Ashrae Transactions, Vol 100, Pt 2, 1994.

Ventilation Literature Database Reaches Ten Thousand

by Janet Blacknell

Ten Thousand Papers

From small beginnings housed on a shelf in an office at the Building Research and Information Association in Bracknell, UK, the AIVC's bibliographic database has emerged as one of the most popular and user friendly sources of specialist information on ventilation and its related subject areas. All those years ago, the database started out as a subset of air infiltration related records from its parent database, Ibsedex. In those days access was via telephone modem and the database used the now cumbersome and outdated software, Status. A far cry, one could say, from the ten thousand record strong library of today with its easy to use IdeaList software and multiple formats - CD or diskette, using Windows or Dos. The name "Airbase" was coined in its early days, and seems to have proved memorable and popular despite the occasional query from non-ventilation related agencies!

Ten Thousand Enquiries!

Seventeen years ago the Air Infiltration and Ventilation Centre was set up under the auspices of the International Energy Agency. The bibliographic database was central to its brief, and together with its library and information service has proved its value over the years with a total of well over ten thousand enquirers consulting the services and 100,000 items of literature sent out over the period.

Sources are many and varied, including a variety of journals, reports from research and commercial organisations, conference proceedings, the AIVC's own publications, which can be provided on loan, and other items discovered through literature searches performed on larger databases and through the World Wide Web. Another major source is of course our own information service users, many of whom contribute their own work as it is published, and help to keep the emphasis on new and up to date research.

Information Products and Full Library Support

Airbase acts as a source of information for a variety of information products coming from the AIVC, such as technical notes, annotated bibliographies and literature lists. Searches on a wide number of topics are performed for enquirers.

Around 100 copies of Airbase are in current use. Users receive updates every three months, when the database is updated. At a cost of £150 to purchasers in participating countries, and with full library service backup, Airbase is a low cost and highly valuable resource.

For more information and a sample disk with your own personal search results, please contact the AIVC, or visit our web pages.

Flow Simulation Using Computational Fluid Dynamics - A Cost Effective Tool for Flow Simulation

by Geoff Whittle, Simulation Technology Ltd.

Introduction

Computational fluid dynamics (CFD) is increasingly being used at the design stage for the evaluation of air distribution and smoke control systems in a wide range of building types.

CFD computer software operates by numerically solving the equations governing fluid flow [1]. These comprise conservation statements for mass, momentum, energy and turbulence parameters. The equations contain partial derivatives, are highly non-linear and require an iterative solution procedure to yield results.

What must be defined when using CFD software?

The process of running CFD software involves defining the factors which drive the flow (boundary conditions) such as supply air diffusers, natural ventilation openings, exhaust locations and flow rates, heat gains, and hot or cold surfaces together with any objects or obstructions in the space. These are mapped to a computational grid which forms three-dimensional volumes of space completely filling the enclosure to be modelled. The equations are solved at each one of these 'control volumes', usually called 'cells' in 'finite-volume' codes and 'elements' in the alternative 'finite-element' codes. Historically, the finite-volume approach was developed in cartesian (rectangular) geometries. The finite-element method has traditionally allowed more complex and hence realistic geometries to be modelled although the developments which have taken place in CFD mean that many of the old distinctions have become blurred. More accurate techniques for numerically integrating the flow equations coupled with complex geometry capability in finite-volume codes provide a similar level of functionality to the traditional finite-element approach. Finite element codes themselves are changing, further reducing the distance between them.

The user has control over the grid and it is the resolution of the grid which can have an important influence on the accuracy of results. The finer the grid the better but the longer it will take to achieve a solution. A typical grid will comprise many thousands of 'cells' [2, 3]. Most commercial CFD software uses the finite-volume approach to form the numerical integral of the partial differential equations. Regarding complexity of modelling, much can still be done with cartesian geometry representations - taking advantage of the much easier model building and faster execution speed.

In using CFD, which places major demands on computer processor speed and RAM (memory), there is always a compromise to be made between accuracy and speed of solution. However, CFD software is becoming more user-friendly and computers very much faster such that high-specification PC's (e.g. fast 486's, Pentium and Pentium Pro) can be particularly cost-effective in running CFD codes and contributing successfully within the time-frame of the design process.

How are the results presented?

Once a solution is obtained the results can be viewed in graphical form as flow patterns (vector plots), temperature and smoke contours, etc. (An example is shown in Figure 1.) The numerical values can be interpreted to make judgements about the acceptability of the thermal environment in terms of air velocities, temperatures, temperature gradients and ventilation effectiveness. In fire modelling it is temperatures and the development and movement of smoke which is the focus of interest either in a 'steady-state' form or evolving with time.

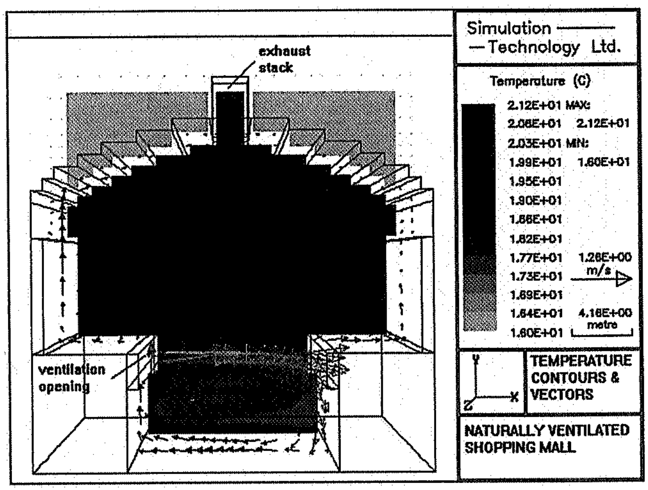

Figure 1: Results presented in graphical form

Are CFD results realistic?

Validation is always an issue with any computer calculation method. With CFD the issue is more complex than usual because of the influence the user can have over the quality of results. This is particularly important in the context of setting boundary conditions, defining the computational grid and procuring converged solutions in high Rayleigh Number (highly buoyant) flow fields within an acceptable computation time. Turbulence modelling is also still an area requiring more research and development. Here, it is the 'k-epsilon' model which is still the 'industry standard' for engineering calculations. Despite the ever present need for more work, sufficient validation has already been done such that, with experience and care, one can have a good level of confidence in the quality of the results [4]. (Much analysis has taken place in IEA ECBCS Annex 26 "Air Flow in Large Enclosures" to evaluate the performance of CFD and to determine the conditions under which it is applicable [5].)

Examples

Figures 1, 2 and 3 show example results from three different types of CFD simulations. The first simulation, Figure 1, is of temperatures and flow patterns in a three-dimensional model of a naturally ventilated shopping mall. The ventilation system comprises low level openings with flow entering from the left in the Figure and exiting at high level through the roof exhaust stack. The outdoor temperature is 16 °C. Occupancy, lighting and solar gains elevate the temperature up to approximately 21 °C at high level. Here, the CFD code used has predicted the natural ventilation flow rate based on external wind pressures, stack (buoyancy) effect and the resistance of the openings.

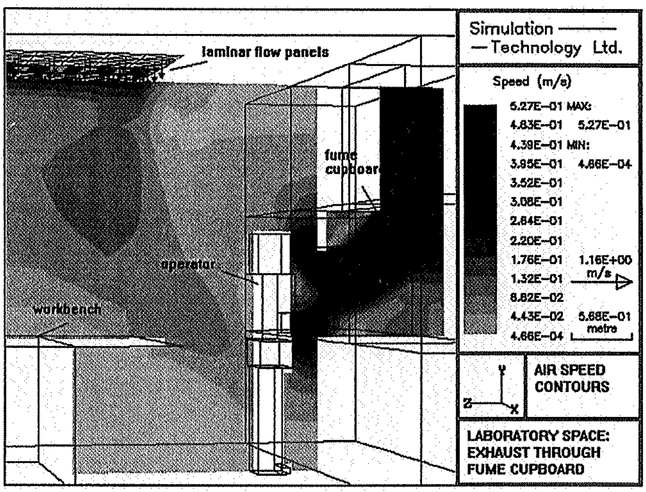

Figure 2: Flow in a laboratory space ventilated by laminar flow panels in ceiling

The second example, shown in Figure 2, represents flow in a laboratory space ventilated by laminar flow panels in the ceiling. The exhaust air is taken through a fume cupboard extract. The Figure shows speed contours, illustrating the acceleration of flow into the fume cupboard and the wake-influence due to the proximity of the operator. Both the room air distribution and the fume cupboard containment effectiveness are being examined here.

In the third simulation, Figure 3, the development of temperatures and smoke concentrations is predicted in the atrium and occupied areas of a multi-floor office building. Outdoor air enters the atrium at ground level and natural smoke vents allow the smoke to escape at roof level. The temperature stratification in the smoke layer can be seen. At ground level, the volume of outside air entering the building maintains a clear layer, and on the upper floors it is noticeable that floor supply air diffusers (which remain in operation supplying fresh air) are helping to minimise the full impact of the smoke temperatures. From the information generated by CFD judgements can be made regarding the safety and escape of occupants.

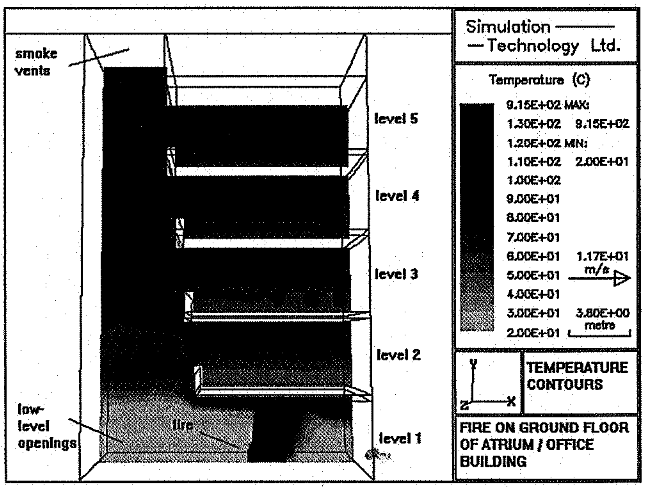

Figure 3: Development of temperatures and smoke concentration in the atrium and occupied areas of a multiflow office building

Conclusions

Fortunately, much of the complexity of a user-friendly CFD code is transparent to the user, who need not concern him/herself about partial differential equations. What is important, though, is that the user is able to properly describe the application to be modelled, to ensure that the solution obtained satisfies certain criteria regarding grid resolution and the consequent residual errors in the solution, and then exercise engineering ability in interpreting the results. An advantage of CFD is that, if necessary, improvements can readily be made to the air distribution design or smoke control system and the calculation re-run.

The question of cost-effectiveness is particularly important. Historically, such computer codes have been too expensive and too difficult to use to make a substantial impact in the buildings and construction industry. Now, however, CFD software prices are falling and performance and usability increasing such that acquiring an in-house CFD capability or, indeed, commissioning external CFD studies can be a realistic and relatively low-cost option giving a substantial return in the quality of the project.

References

1. S V Patankar, *Numerical heat transfer*, Hemisphere, Washington (1980).
2. G E Whittle, "Computation of air movement and convective heat transfer within buildings" *Int. J. Ambient Energy*, (1986).
3. P J Jones and G E Whittle, "Computational fluid dynamics for building air flow prediction - current status and capabilities", *Building and Environment*, Vol. 27, No. 3, pp 321-338 (1992).
4. Room air and contaminant flow, evaluation of computational methods, Subtask-1 Summary report, International Energy Agency, Annex 20, TNO Building and Construction Research, PO Box 29, 2600 AA Delft, The Netherlands (December 1993).
5. M W Liddament, "Two Air Flow Studies Completed", *Air Infiltration Review*, Vol. 17 No. 4 (September 1996).

Dr Geoff Whittle is Managing Director of Simulation Technology Ltd, PO Box 4211, Streatley-on-Thames, Reading RG8 9YQ, United Kingdom. Tel: +44 (0) 1491 875070, Fax: +44 (0) 1491 875171,

Email: simtech@patrol.i-way.co.uk.

International Energy Agency's Air Infiltration and Ventilation Centre

18th Annual AIVC Conference

Ventilation and Cooling

Greece

23rd - 26th September 1997

First Announcement and Call for Papers

Abstracts of approximately 300-500 words are invited from authors of AIVC and non-AIVC countries on the following or related topics and should be submitted by February 17th, 1997.

Specific areas of interest include:

ventilation for cooling

night cooling

architectural strategies

strategies for non residential buildings

strategies for dwellings

impact of air infiltration achieving acceptable indoor comfort

calculation for design

measurement methods

For up to date information about this conference and other AIVC activities, contact the Centre's World Wide Web Home Page.

New AIVC Technical Note Due Out This Month,
A New Analysis on Ventilation and Cooling, by Steve Irving
Please place your forward orders now

Optimum Ventilation and Air Flow Control in Buildings

17th - 20th September 1996, Hotel 11, Gothenburg, Sweden

Conference Report by Malcolm Orme

The 17th Annual AIVC Conference was convened this year at Hotel 11 in Gothenburg, in western Sweden. For the first time, an invitation was extended to all participating countries of the IEA Energy Conservation in Buildings and Community Systems Programme. This resulted in over 100 delegates attending 4 sessions of oral presentations based on submitted papers and a further 3 poster sessions, a total of 59 presentations from 15 countries.

Keynote Speaker and the Opening Session

The Keynote Speaker at the Conference, Bertil Pettersson, Director General of the Swedish Board for Building Research, stated in his address that much of the world's energy is obtained and used in a non-sustainable way. He continued by stressing that existing energy supplies must be used more efficiently and renewable energy sources should be further exploited. Citing the example of Sweden, he indicated that while the total floor area of the Swedish residential and service sector building stock had increased by about 40% from 1970 to 1995, the total energy consumption had remained roughly constant. This implied that the specific energy consumption (energy used per unit of floor area) had decreased by approximately 25% during the same period. Furthermore, he also outlined the benefits of International Energy Agency collaborative research with the aim of decreasing total energy consumption. The benefits that he observed included:

- shared costs,
- pooled resources,
- the avoidance of mistakes and duplicated efforts, and
- the development of a common understanding of technical methods.

The first paper in the opening session, called "Optimum ventilation and air flow control in buildings?", examined the overall theme of the Conference, and was presented by Tor-Göran Malmström (Royal Institute of Technology, Sweden). In this paper he explained the factors affecting indoor air quality. In particular, he emphasised that internal pollutant sources should first be controlled and then the quality of the air entering the room should be verified. He then continued by discussing how air flow control can be used to determine the quality and rate of air exchange.

This session also included a paper by Bjørn Larsen (The Vekst Foundation, Norway) explaining his computerised method for balancing ventilation systems, a practical demonstration of which was also given at the Conference. The method he described makes it possible to pre-set ventilation terminals at the factory to desired pressure loss characteristics (achieved by damper positioning). In this way, mechanical ventilation systems can be balanced before they have been installed.(Figure 1)

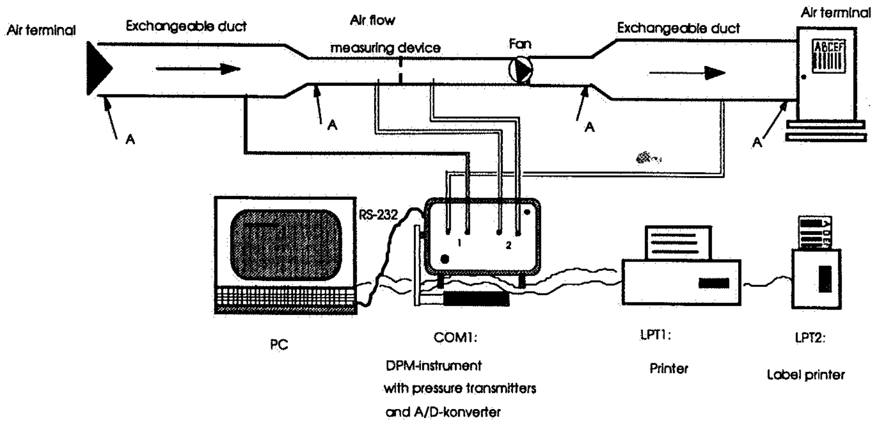

Figure 1 A "DPM machine" for presetting air terminals

Offices and Other Non-Residential Buildings

Two contributions from the UK Building Research Establishment focused on office buildings. Martin White discussed the efficiency of single-sided and cross ventilation in office spaces, while Brian Webb considered summer cooling for office-type buildings by night ventilation. Although not restricted in application to non-residential buildings, Matheos Santamouris (University of Athens, Greece) reported on the progress of the natural ventilation studies made within the European PASCOOL project. This included single-sided and cross ventilation, as well as flow through large internal openings in the context of natural ventilation for cooling. The project has resulted in the development of several applicable calculation tools. Passive cooling was also the subject of other presentations from Greece, Sweden and Switzerland.(Fig 2)

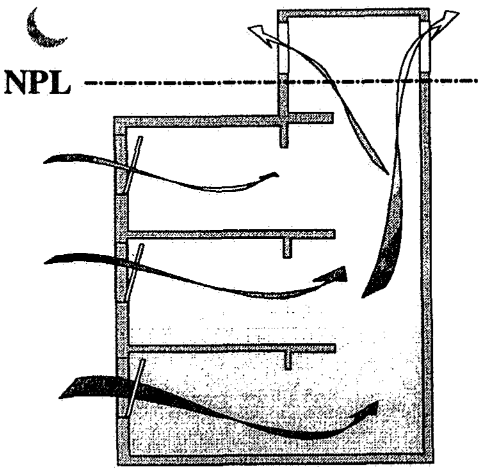

Figure 2: Cooling improvement for night cooling system

Mikko Suokas (Fincoil-teollisuus Oy, Finland) advised on how to reduce draught problems in cooled working rooms. His view was that the 'throw' from air-cooling devices should stay close to the ceiling for as long as possible, without interference from either beams, light fittings, or walls. In this way, the cooled air mixes better with the existing room air, without causing draughts in the occupied zone.

Peter Wouters from Belgium (BBRI) expanded on the subject of non-residential ventilation. In "Ventilation requirements in non-domestic buildings and energy efficiency", voted as the Best Paper at the Conference, he proposed that ventilation rate requirements for non-domestic buildings may vary by up to a factor of 10 depending on whether or not the levels of emissions from the building materials are taken into account. This, he argued, could potentially have a large consequent effect on energy consumption. Anders Nilson (Bengt Dahlgren AB, Sweden) also considered energy efficiency, specifically in office buildings, with an energy and system analysis study.

Public Assembly Buildings

Findings from measurements made in a cinema (with a downwards mixing ventilation system) were reported by Yonghui Jin (Narvik Institute of Technology, Norway). 'Step-up' and 'step-down' tracer gas measurements enabled the calculation of local and room air change efficiencies, which indicated that close to perfect mixing was occurring. Carbon dioxide concentrations were found to vary linearly with the number of occupants. The design of another type of public assembly building, in this case a naturally ventilated concert hall, was discussed by Robert Cohen (HGA Consulting Engineers Ltd, UK). This project used computational fluid dynamics to decide the size and locations of the ventilation openings. In addition, a dynamic thermal model was used to confirm that the likely number of hours per year above a certain temperature level was acceptable.(Figure 3)

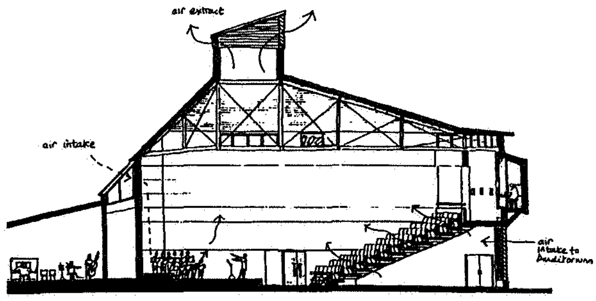

Figure 3: Building section

Ventilation of Transportation-Related Structures

Certain presentations at the Conference examined ventilation of structures intended for transportation-related purposes. Willem de Gids (TNO, Netherlands) described how a dynamic ventilation model had been used to improve the design of a ventilation system in a train tunnel with a shopping centre above, thus improving air quality in the centre and reducing cleaning costs (Figure 4). The problems associated with the cooling and ventilation of a high speed underground transportation system were outlined by Peter Rosemann (Swiss Federal Institute of Technology, Switzerland). This major project plans to link the major Swiss cities with a train network involving partially evacuated tunnels (to reduce aerodynamic drag). In addition, design guidelines for ventilation systems for pollution control in large semi-enclosed bus terminals were presented. Concerning this work, Joanna Yiu (Polytechnic University, Hong Kong) indicated that industrial occupational exposure limits were the most applicable existing guidelines to deal with the pollutants contained in diesel fuel exhausts. However, she did not consider them to be ideal, because they are based on working conditions only for healthy adults.

Statistical Analysis

In his poster, Jerzy Sowa (Warsaw University of Technology, Poland) compared different methods of incorporating stochastic factors into deterministic models of indoor air quality. Approaches taken used time series data as inputs to contaminant dispersal models, Monte-Carlo analysis, and a stochastic differential equation model. The mean values of pollutant concentration found with all three methods were very similar. However, the spread of the results as measured by the standard deviation showed a wide variation. Related work was described by Krystyna Pietrzyk (Chalmers University of Technology, Sweden). She explained how probability density functions of the air change rate in a single family house had been derived, with two-parameter Weibull distributions assumed for the wind velocity. The air change rates were found to approximately follow either normal or log-normal distributions depending on the wind direction.

Johnny Kronvall (J&W Consulting Engineers, Sweden) has been investigating system safety analysis as a method of finding "the probability that a ventilation system provides certain required air flow rates in each occupied part of a building during the time between scheduled maintenance occasions." He suggested that this is a promising technique for judging the reliability of mechanical ventilation systems. But, he cautioned that data for the mechanical reliability of individual components would need to be collated for it to be practical.

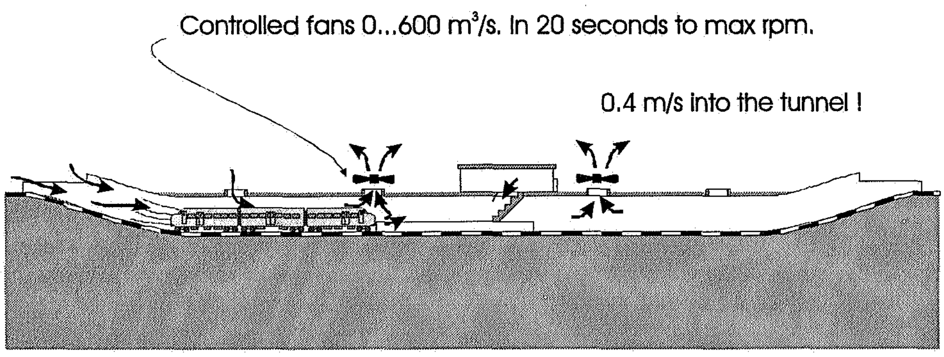

Figure 4: Tunnel with fans

Applicability of Crack Flow Equations

Two of the fundamental assumptions concerning the applicability of crack flow equations have been investigated by researchers in the UK and the USA. An experimental study of crack flow with varying pressure differentials was the subject of a presentation given by Steve Sharples (University of Sheffield, UK). He proposed that the results confirmed the often assumed view that it is acceptable to consider average steady-state pressure differentials in place of time-varying differentials. Another important issue discussed at the Conference was that the application of experimentally measured airtightness data (typically measured at greater than 10 Pa pressure difference) to numerical models often relies on an extrapolation down to the pressure differences (typically less than 10 Pa) encountered due to natural driving forces. The power law is an appropriate method for extrapolating from measured airtightness data to lower pressure differences was the conclusion reached by Max Sherman (Lawrence Berkeley National Laboratory, USA).

Measures of Ventilation Performance

Lars Ekberg (Chalmers University of Technology, Sweden) spoke about how he has been checking ventilation rates by carbon dioxide monitoring. Again from Seden, Björn Hedin (Lund Institute of Technology) introduced a new model to extract more information from standard tracer gas measurements of ventilation air flows. The effect of recirculation on air change effectiveness (sometimes called the coefficient of air change performance) was the subject of a contribution by Clifford Federspiel (Johnson Controls Inc, USA). He proposed a relative measure of air change effectiveness that can be used to take into account the age of supply air when the fraction of recirculated air is greater than zero. An advantage of this measure, he argued, is that it can identify systems in which 'short-circuiting' is occurring.

Karl Janssens from Belgium (Catholic University of Leuven) gave an account of laboratory tests for the determination of 'local specific fresh air flow rates' in an imperfectly mixed ventilated air space. In addition, work from France and the UK reported on measurements and modelling respectively for calculating the pollutant removal effectiveness and air change efficiency for various ventilation strategies.

External Contaminants and the Internal Distribution of Pollutants

Vina Kukadia, (Building Research Establishment, UK) presented the outcome of a pilot study designed to find the effect of external atmospheric pollution on indoor air quality. Another external pollutant, radon, is of continuing concern and in connection with this, Pirjo Korhonen (University of Kuopio, Finland) has compared indoor levels of radon between workplaces and homes located nearby in different parts of Finland. Certain features of particulate pollution interactions with indoor surfaces were explained by Miriam Byrne (Imperial College, UK), who has been carrying out measurements and modelling for risk assessment and contaminant control. Also at the Conference, George Walton (NIST, USA) demonstrated the latest version of his multizone airflow and contaminant dispersal model, CONTAM96, which includes a graphical user interface.

Dwellings

The work of members of the European Standards Committee CEN TC156 (Ventilation) was reported by Andrew Cripps (Building Research Establishment, UK) with his paper on calculation methods for the determination of air flow rates in dwellings. Two delegates from Sweden each talked about residential ventilation. One of these was Per Levin (Royal Institute of Technology, Sweden), who outlined the development of a simple occupancy-controlled exhaust air ventilation system. The other was Åke Blomsterberg (Swedish National Testing and Research Institute, Sweden), who discussed the influence of outdoor air vents and airtightness on natural ventilation.

Max Sherman (Lawrence Berkeley National Laboratory, USA) proposed the most appropriate types of residential ventilation systems for the different regions of the USA. This was based on modelling for various levels of airtightness of the dwelling stock to predict resultant energy consumption while still meeting ventilation requirements. On a connected subject, Don Stevens (Stevens and Associates, USA) identified the evolution of ventilation in manufactured housing in the north-western United States. The findings from a measurement survey of the indoor air quality of 30 houses with distributed heating systems in Quebec were given by Denis Parent (Hydro-Québec, Canada). He concluded that during the milder part of the heating season only the minority of the tested houses had adequate ventilation, with an improvement during the colder part. Also, there didn't seem to be a significant correlation between building airtightness and indoor air quality.

IEA ECBCS Annex 27

Other contributions on dwellings concerned products of the continuing work of IEA ECBCS Annex 27 "Evaluation and Demonstration of Domestic Ventilation Systems". Peter Op't Veld (Cauberg-Huygen Consulting Engineers, Netherlands) gave an overview of his assessment of aspects of noise and ventilation systems. This covered the transmission of outdoor noise, noise generated by ventilation system components and the impact of a system on sound transmission in or between dwellings. His work for this Annex has produced a simplified tool for the selection of ventilation systems based on the criteria of noise. Also as part of Annex 27, Lars-Göran Månsson (LGM Consult AB, Sweden) outlined the progress made in developing a simplified tool for evaluating domestic ventilation systems' ability to provide an acceptable indoor air quality.

Multi-zone calculations of air flows and tracer gas measurements in dwellings were compared by Charlotte Svensson (J&W Consulting Engineers, Sweden). This forms part of the Swedish contribution to Annex 27. The study highlighted the good agreement that can be obtained between measurements and calculations when the input parameters of the model are consistent with the experimental configuration. Along similar lines, Jacques Riberon (CSTB, France) gave an account of a comparison of ventilation systems performances in residential buildings made with the model SIREN.

Innovative Technologies

Conventionally, air dehumidification has been achieved by refrigerative systems. However with current environmental concerns, alternative approaches are being sought. As part of an investigation of dehumidification by absorption, Jürgen Röben (University of Essen, Germany) described a theoretical model of an open cycle dehumidification process using hygroscopic materials to absorb the moisture.The Best Poster at the Conference was awarded to Peter Hansson (Royal Institute of Technology, Sweden) for his poster, "A technique to improve the performance of displacement ventilation during cold climate conditions". He has devised a method of using warm air extracted at ceiling level to heat cold surfaces and so improve ventilation efficiency and thermal comfort by reducing downdraught.

Guest Speaker and Close of Conference

The Guest Speaker at the Conference Banquet was Professor Enno Abel of Chalmers Institute of Technology, who in addition presented the Best Paper and Best Poster awards. Willem de Gids (TNO, Netherlands) and Martin Liddament (AIVC, UK) summed-up and closed the Conference. The AIVC would like to extend thanks to the Conference Participants and also to the companies who exhibited their products (LHG Kanalflakt, Boverket, Scandfilter, Pentiaq AB and Stifab AB).

Forthcoming Conferences

PLEA 1997 Kushiro
The 14th International Conference on Passive and Low Energy Architecture Bioclimatic Design in Cold Climates
January 8-10 1997
International Conference Hall, Kushiro, Japan
Secretariat, PLEA 1997 Kushiro Conference, Kenchikukaikan 3F, Shiba 5-26-20, Minato-ku, Tokyo, 108 Japan Tel: +81 3 3798 5122 Fax: +81 3 3798 5130

Building Energy: Insuring a Sustainable Future
March 12-15, 1997
Redisson Hotel and Conference Center, Cromwell, Connecticut, USA
NESEA, 50 Miles Street, Greenfield, MA 01301-3212, USA Tel: 413 774 6051 Fax: 413 774 6053

Cold Climate HVAC
30 April - 2 May, 1997
Reykjavik, Iceland Skogarhild 18 IS 101 Reykjavik, Iceland

CIB TG8 Second International Conference Buildings and the Environment
9-12 June 1997
Paris, France
Scientific Secretariat Dr Sylviane Nibel ENEA Department CSTB 84, Avenue Jean Jaures, BP 02 77421 Marne la Vallee Cedex 2 France Tel: +33 (1) 64 68 8301 Fax: +33 (1) 64 68 83 50 email nibel@cstb.fr

ITEEC 97 Third International Thermal Energy & Environment Congress
9-12 June 1997
Marrakesh, Morocco
Send abstracts to: Dr F Haghighat Centre for Building Studies Concordia University 1455 De Maisonneuve Blvd W Montreal, Quebec, H3G 1M8 Canada Fax: 514 848 7965 For general information: Prof A Mir Ecole Superieure de Technologie BP 33/S Agadir, Morocco Fax: 212 8 22 78 24 or 212 8 22 72 60

1997 ACEEE Summer Study on Energy Efficiency in Industry "How Industry will produce energy efficiency services in the 21st century"
July 8-11, 1997
Sheraton Saratoga Springs, New York, USA
Debbie Giallombardo, ACEEE Conference Office, 1001 Connecticut Ave NW, Suite 801, Washington DC 20036, USA Tel: 202 429 8873 Fax: 202 429 2248 email ace3-conf@amail.pnl.gov www http://crest.org/aceee

Clima 2000 '97
August 30 - September 2, 1997
Brussels, Belgium
Clima 2000 '97, c/o SRBII, Ravenstein 3, B-1000 Brussels, Belgium Tel: +32 2 5117469 Fax: +32 2 5117597

Building Simulation '97 International Building Performance Simulation Association
September 8-10 1997
Fifth International Conference Prague, Czech Republic
Secretariat Building Simulation '97 Faculty of Mechanical Engineering Dept of Environmental Engineering Czech Technical University in Prague Technicka 4 166 07 Prague 6 Czech Republic Tel/Fax +42 2 2435 5616 email bs97@fsid.cvut.cz

Ventilation '97 5th International Symposium on Ventilation for Contaminant Control
14-17 September 1997
The Westlin Hotel, Ottawa, Ontario, Canada
Ventilation '97, ACGIH, 1330 Kemper Meadow Dr., Cincinnati, Ohio 45240, USA Tel: (513) 742 2020 Fax: (513) 742 3355 email ACGIH_mem@pol.com

Ventilation and Cooling
International Energy Agency's Air Infiltration and Ventilation Centre - 18th Annual AIVC Conference
23 - 26 September 1997
Greece
Mrs Rhona Vickers, Conference Organiser, AIVC, Sovereign Court, University of Warwick Science Park, Coventry CV4 7EZ, Great Britain

AIVC Publications Order Form

Name .... Date ....

Address (including country) ....

....

....

Telephone/Fax ....

Price and availability: please see notes at foot of page

Periodicals[1]				Conference Proceedings		Annotated Bibliographies[2]	
[ ] Air Infiltration Review				[ ] 11th £35		[ ] BIB1*	[ ] BIB4
[ ] Recent Additions to AIRBASE				[ ] 12th £50		[ ] BIB2*	[ ] BIB5
[ ] Please add me to your mailing list				[ ] 13th £50		[ ] BIB3*	[ ] BIB6
Technical Notes[2]				[ ] 14th £50		IEA Information	
[ ] Applications Guide*		[ ] TN24*	[ ] TN31*	[ ] 15th £50		[ ] IEA News	
[ ] Handbook*		[ ] TN25*	[ ] TN32*	[ ] 16th £50		[ ] IEA Publications List	
[ ] TN11*	[ ] TN17*	[ ] TN26*	[ ] TN33*	[ ] 17th £50		[ ] Add to mailing list?	
[ ] TN13*	[ ] TN20*	[ ] TN27*	[ ] TN34*	[ ] TN37*	[ ] TN40	[ ] TN43*	[ ] TN46
[ ] 13.1*	[ ] TN21*	[ ] TN28*	[ ] TN35*	[ ] TN38*	[ ] TN41	[ ] TN44	[ ] TN47
[ ] TN16*	[ ] TN23*	[ ] 28.2*	[ ] TN36*	[ ] TN39	[ ] TN42	[ ] TN45	
New Publication - AIVC Guide to Ventilation £50 [ ]				[ ] AIRBASE bibliographical database £150.00[3]			
Discount available for multiple orders - please enquire				[ ] Numerical database £75.00[3]			

I enclose a cheque drawn on a UK bank, and made payable to Oscar Faber Group UK Ltd - AIVC/
Please debit my Master/Visa card (delete as appropriate) (PREPAYMENT REQUIRED):

for the sum of: £ ....

Signed ....

Master/Visa Card No ....

Expiry Date ....

Notes

1 Air Infiltration Review and Recent Additions to Airbase are available free of charge to participants. Non participants may subscribe to Air Infiltration Review, price £25 per annum.

2 Technical Notes 39 onwards and the annotated bibliographies are available *to participants only,* free of charge, unless provided as a photocopy (£15.00).

* Starred items are available on loan (free), as a microfiche, or for £15.00 in hard copy. (The hard copy version will be sent unless otherwise stated.)

3 Plus UK Value Added Tax (VAT) at 17.5%. *Available to participants only.*

\- All prices are in UK pounds Sterling

\- **Participating countries** are: Belgium, Canada, Denmark, Finland, France, Germany, Netherlands, New Zealand, Norway, Sweden, UK and USA.

AIVC Publications

PERIODICALS

Air Infiltration Review. Quarterly newsletter containing topical and informative articles on air infiltration research and application.
Recent Additions to AIRBASE. Quarterly bulletin of abstracts added to AIRBASE, AIVC's bibliographic database.

AIRBASE DATABASE

AIRBASE the AIVC's bibliographical database, containing over 10,000 records on air infiltration, ventilation and related areas, is available as a diskette package for your personal computer.

NUMERICAL DATABASE

Contains airtightness data which are particularly applicable to the evaluation of construction design, ventilation strategies, energy impact of ventilation, the performance of standards and recommendations, the influence of climate and calculation techniques.

WORLD WIDE WEB

The AIVC's home page holds Air Infiltration Review, publications and conference details and a searchable database based on the current edition of Recent Additions. The address is http://www.aivc.org/

TECHNICAL NOTES

Air Infiltration Calculation Techniques, 1986, Applications Guide
Air infiltration control in housing, 1983, Handbook
Validation and comparison of mathematical models, 1983, TN 11
Wind pressure data requirements, 1984, TN 13
Wind Pressure Workshop Proceedings, 1984, TN 13.1
Leakage Distribution in Buildings, 1985, TN 16
Ventilation Strategy - A Selected Bibliography, 1985, TN 17
Airborne moisture transfer: workshop proceedings, 1987, TN 20
Review and bibliography of ventilation effectiveness, 1987, TN 21
Inhabitants' behaviour with regard to ventilation, 1988, TN 23
AIVC Measurement Techniques Workshop, 1988, TN 24
Subject analysis of AIRBASE, 1989, TN 25
Minimum ventilation rates, IEA Annex IX 1989, TN 26
Infiltration and leakage paths in single family houses, 1990, TN 27
A guide to air change efficiency, 1990, TN 28
A guide to contaminant removal effectiveness, 1991, TN 28.2
Reporting guidelines for airflows in buildings, 1991, TN 32
A review of building air flow simulation, 1991, TN33
Air flow patterns: measurement techniques.', 1991, TN 34
Advanced ventilation systems, 1992, TN35
Airgloss Air Infiltration Glossary, Limb M J, 1992, TN 36
A Strategy for Future Ventilation Research and Applications, Liddament M W, 1992, TN 37
AIRGUIDE: Guide to the AIVC's Bibliographic Database, Limb M J, 1992, TN 38
A Review of Ventilation Effeciency, Liddament M W, 1993, TN 39
An Overview of Combined Modelling of Heat Transport and Air Movement, Kendrick J F, .1993, TN 40
Infiltration Data from the Alberta Home Heating Research Facility, Wilson D and Walker I, 1993, TN 41
Current Ventilation and Air Conditioning Systems and Strategies, Limb M J, .1994, TN 42
Ventilation and Building Airtightness: an International Comparison of Standards, Codes of Practice and Regulations, Limb M J, 1994, TN 43
An Analysis and Data Summary of the AIVC's Numerical Database, Orme M S, 1994, TN 44
Air-to-Air Heat Recovery in Ventilation, Irving S, 1994, TN45
1994 Survey of Current Research, Limb M J, 1995, TN 46
Energy Requirements for Conditioning of Ventilation Air, Colliver D, 1995, TN 47
Guide to Energy Efficient Ventilation, Liddament M W, 1996

ANNOTATED BIBLIOGRAPHIES

(Participants only - price see order form)
Ventilation and infiltration characteristics of lift shafts and stair wells, 1993, BIB1
Garage Ventilation, 1994, BIB2
Natural ventilation, 1994, BIB3
Air intake positioning to avoid contamination of ventilation air, 1995, BIB4
Heat pumps for ventilation exhaust air heat recovery, 1996, BIB5

AIVC CONFERENCE PROCEEDINGS

Earlier AIVC Conference Proceedings are available as individual papers. Contents pages can be forwarded on request.
'Ventilation System Performance' Belgirate, Italy, 1990, (11th)
'Air Movement and Ventilation Control within Buildings', Ottawa, Canada, 1991, 3 volumes, (12th)
'Ventilation for Energy Efficiency and Optimum Indoor Air Quality', France, 1992, (13th)
'Energy Impact of Air Infiltration and Ventilation', Denmark, 1993, (14th)
'The role of ventilation', Buxton, UK, 1994, (15th)
'Implementing the results of ventilation research', Palm Springs, USA, 1995, (16th)
'Optimum ventilation and air flow control in buildings', Stockholm, Sweden, 1996, (17th)

IEA ENERGY CONSERVATION IN BUILDINGS BOOKSHOP

IEA Energy Conservation News Twice yearly newsletter of the IEA Energy Conservation in Buildings Programme
ECBCS Publications A list of bookshop publications is available free of charge.

LITERATURE LISTS

(Available to participants only - free of charge)
1) Pressurisation - infiltration correlation: 1. Models.
2) Pressurisation - infiltration correlation: 2. Measurements.
3) Weatherstripping windows and doors. **4)** Caulks and sealants.
5) Domestic air-to-air heat exchangers. **6)** Air infiltration in industrial buildings. **7)** Air flow through building entrances.
8) Air infiltration in commercial buildings. **9)** Air infiltration in public buildings. **10)** Carbon dioxide controlled ventilation.
11) Occupancy effects on air infiltration. **12)** Windbreaks and shelterbelts. **13)** Air infiltration measurement techniques.
14) Roofs and attics. **15)** Identification of air leakage paths.
16) Sick buildings. **17)** Flow through large openings. **18)** Control of cross contamination from smokers. **19)** Location of exhausts and inlets.
*For list of participating countries see back page.

Representatives and Nominated Organisations

Belgium

*P. Wouters, Belgian Building Research Institute (WTCB/CSTC), rue de la Violette,21-23, 1000 Brussels, Belgium. Tel: +32 2-653-8801 Fax: +32 2-653-0729

P. Nusgens, Université de Liège, Laboratoire de Physique du Bâtiment, Avenue des Tilleuls 15-D1, B-4000 Liège,Belgium. Tel: +32 41 66 56 74 Fax: +32 41 66 57 00

Canada

*M. Riley, Buildings Group, Energy Efficiency Division, Efficiency and Alternative Energy Branch, Energy, Mines and Resources Canada, Ottawa, Ontario, K1A 0E4 Canada Tel: +1 613-996-8151 Fax: +1 613-996-9416

J. Shaw, Inst. for Research in Construction, National Research Council, Ottawa, Ontario, Canada K1A 0R6 Tel:+1 613-993-1421 Fax: +1 613 954 3733

Duncan Hill, Research Division, Canada Mortgage and Housing Corporation, Montreal Road, National Office, Ottawa, Ontario, Canada K1A 0P7 Tel: +1 613-748-2309 Fax:+1 613 748 2402

Denmark

*O. Jensen, Danish Building Research Institute, P.O. Box 119, DK 2970 Hørsholm, Denmark. Tel: +45-42-865533 Fax: +45-42-867535, email: olj@sbi.dk

P.F. Collet, Technological Institute, Byggeteknik, Post Box 141, Gregersensvej, DK 2639 Tastrup, Denmark. Tel: +45 42-996611 Fax: +45-42-995436

Finland

*J Sateri,Senior Research Scientist, VTT Building Technology, Indoor Climate, PO Box 1804, FIN-02044 VTT (Espoo), Finland Tel: +358 9 4564710, Fax: +358 9 455 2408, email: jorma.sateri@vtt.fi

FiSIAQ, Finnish Society of Indoor Air Quality and Climate, PO Box 87, FIN-02151 Espoo, Finland, Tel: +358 9 451 3606, Fax: +358 9 451 3611, email siy@hut.fi

France

*P Hérant, ADEME, 500 Route des Lucioles, Sophia Antipolis, F- 06565 Valbonne, France Tel: +33 93 95 79 47 Fax: +33 93 65 31 96

Ph. Duchêne-Marullaz, CSTB, 84 Ave. Jean Jaurès, BP 02 Champs sur Marne, 77421 Marne la Vallée, Cedex 2, France Tel: +33-1 64 68 83 13 Fax: +33-1 64 68 83 50

Germany

*Prof. Dr.-Ing. F. Steimle, Universität Essen, Universitätsstr. 15, 45141 Essen, Germany, Tel: +49 201 183 2600, Fax: +49 201 183 2584

J. Gehrmann, Projektträger BEO - Biologie, Energie, Okologie, KFA Jülich, Postfach 19 13, 52425 Jülich, Germany Tel: +49 2461 614852, Fax: +49 2461 613131

G Mertz, Fachinstitut Gebäude Klima e.V., Danziger Strasse 20, 74321 Bietigheim-Bissingen, Germany Tel: +49 7142 54498 Fax: +49 7142 61298

Netherlands

*W.F. de Gids, TNO Building and Construction Research, Dept of Indoor Environment, Building Physics and Systems, P.O. Box 29, 2600 AA Delft, Netherlands, Tel: +31 15 260 8427 (Direct: +31 15 2608472) Fax: +31 15 260 8432, email: w.degids@bouw.tno.nl

New Zealand

*M. Bassett, Building Research Association of New Zealand Inc (BRANZ), Private Bag, Porirua, New Zealand. Tel: +64-4-2357600 Fax: +64 4 2356070

Norway

*J.T. Brunsell, Norwegian Building Research Institute, Forskningsveien 3b, PO Box 123, Blindern, N-0314 Oslo 3, Norway. Tel: +47 22-96-55-00 Fax: +47-22-965725, e-mail jorn.brunsell@byggforsk.no

H.M. Mathisen, SINTEF,Division of App Thermodynamics, N-7034 Trondheim, Norway. Tel: +47 73-593000 Telex: 056-55620

Sweden

*J. Kronvall, J&W Consulting Engineers AB, Slagthuset, S-21120 Malmo, Sweden, Tel: +46 40108200, Fax: +46 40108201

J Lagerström, Swedish Council for Building Research, Sankt Goransgatan 66, S-112 33, Stockholm, Sweden Tel: +46 8-6177300 Fax: +46 8-537462

UK

*MDAES Perera, Environmental Systems Division, Building Research Establishment, Garston, Watford, WD2 7JR , UK Tel:+44(0)1923 664486, Fax: +44(0)1923 664095, e-mail pererae@bre.co.uk

M W Liddament (Operating Agent), Oscar Faber Group UK Ltd, Marlborough House, Upper Marlborough Road, St. Albans, Herts, AL1 3UT, Great Britain. Tel: +44(0)181-7845784, Fax: +44(0)181-7845700

USA

*M. Sherman, Indoor Air Quality Division, Building 90, Room 3074, Lawrence Berkeley Laboratory, Berkeley, California 94720, USA. Tel: +1 510/486-4022 Telex: 910-366-2037 Fax: +1 510 486 6658 e-mail:MHSherman@lbl.gov

A. Persily, Building Environment Division, Center for Building Technology, Building 226, Room A313, National Institute for Standards and Technology, Gaithersburg MD 20899, USA. Tel: +1 301/975-6418 Fax: +1 301 975 5433, email andrew.persily@.nist.gov

J. Talbott, Department of Energy, Buildings Division, Mail Stop Ce-131, 1000 Independence Avenue S.W., Washington D.C. 20585, USA. Tel: +1 202/586 9445 Fax: +1 202 586 4529/8134

*Steering Group Member

Published by
Air Infiltration and Ventilation Centre
University of Warwick Science Park
Sovereign Court
Sir William Lyons Road
Coventry CV4 7EZ, UK

ISSN 0143 6643
Tel: +44(0)1203 692050
Fax: +44(0)1203 416306
email: airvent@AIVC.org
http://www.aivc.org/

Head of Centre Martin W Liddament, BA, PhD.

Operating agent for IEA is Oscar Faber Group UK Ltd