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The CEN Work on Calculation Methods for the Determination of Air Flow Rates in Dwellings

by Viktor Dorer,

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Introduction

In the frame of the European standardization work, an ad hoc group of CEN TC 156, WG2 'Mechanical and natural powered residential ventilation', is presently working out calculation methods for the determination of air flow rates for dwellings. A first draft standard has been prepared and is currently under revision by the working group and experts of the national CEN shadow committees. Since the draft with its annexes is rather comprehensive, this article summarizes only roughly the basic assumptions and the methods developed so far, without giving the definitions and equations in detail. For this, the reader is referred to the draft standard.

Content of the draft standard

In the draft standard, methods are presented to calculate air flows for the whole dwelling as well as room air flow rates, both for single family houses and individual apartments. The methods may be used for applications such as energy loss calculations, heat load calculations and indoor air quality evaluations. Natural as well as mechanical extract and balanced ventilation systems are considered. Flows due to window opening are also considered, but only as a single sided effect (no cross ventilation). Depending on the application and the building type, only outdoor air flow rates or both outdoor and internal flows are considered. For these different applications, the same basic methods apply. Nevertheless the input parameter values have to be selected according to the requirements set out for the specific application. Informative annexes of the standard provide

a) a selection of input data (such as leakage values, wind pressure coefficients) and guidance for the selection of climatic data as well as window opening factors

b) calculation examples for both single and multifamily houses as well as comparison with results from measurements and calculation with single and multizone models

c) a bibliography.

In this issue

Input data

The input data needed for the three calculation methods are largely identical. Information on the following main aspects of the building, the dwelling under consideration, the ventilation system and the external conditions is needed to use the methods outlined in the draft standard:

Building and dwelling:

- the type of building
- the building height
- the shielding from the wind
- the number of facades of the dwelling which are exposed to wind
- the air leakage of the dwelling
- the distribution of the air leakage over the envelope

Ventilation system:

- the type of system (natural, mechanical extract or mechanical balanced system)
- the capacity of the ventilation system
- - natural ventilation openings
- - mechanical flows
- the time these provisions are assumed to be used

Finally the climatic data have to be known.

Calculation method for whole house air flow rates

For the determination of the whole house air flow rates, two methods are given.

The first method is an explicit method. This means that if all the input data are known one can carry out the calculation procedure step by step.

The second method is the implicit method. This method is based on a single zone model using a simple flow balance equation that has to be solved iteratively for the unknown internal pressure. This solving process normally requires a computer. The advantage of this method is that the interactions between the wind induced flow, the stack induced flow and the flows from the mechanical system are considered correctly. Due to the nonlinearity of these interactions, the explicit method needs many empirical and approximative factors to characterize these interaction effects.

The methods given must be declared as simplified methods when comparing them e.g. to multizone air flow models available today.

The explicit method

It is assumed, that the air flow is dominated by a single leakage and that across this leakage there is an effective pressure difference, which is a summation of windward and leeward pressures. The internal pressure is assumed to be close to the leeward side pressure.

Default values for wind pressure coefficients, valid for a wind sector of approx. $\pm$ 60^{o} to the facade axis, are given in the standard . The wind direction is not considered more specifically.

The basic procedure for the calculation is shown in Figure 1. The total flow is composed of additive flow terms accounting for the natural flows, the flows of the mechanical system, the flows due to airing and combustion appliances, and, for apartments, also for internal flows.

Natural flows due to stack and wind are calculated separately for leakage and purpose provided openings as a powerlaw function of the flow coefficient and the pressure. For both stack and wind induced infiltration flows, an additional factor accounts for the leakage distribution effects. Ducts are considered for stack pressures of both infiltration and purpose provided flows.

Air
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Review

Editor: Janet Blacknell

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Conclusions and opinions expressed in contributions to Air Infiltration Review represent the author(s)' own views and not necessarily those of the Air Infiltration and Ventilation Centre.

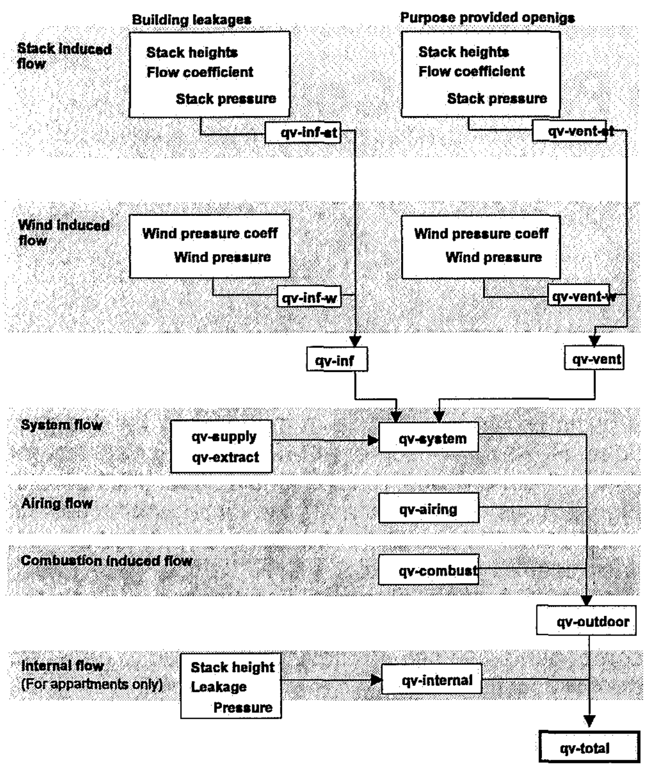


Figure 1

For mechanical extract and balanced systems respectively, the interaction with the natural flows is considered.

Airing is treated as a single sided, single room ventilation effect through open window and doors. Cross-ventilation effects are not considered.

Combustion induced flows are determined by a factor which accounts for the fact that a certain proportion of the natural or extract flow may be used to cover the additional flow needed for the combustion process, by a factor which considers whether the combustion air flow is separated from the room (closed system) or not, by the specific air flow per fuel type needed for the combustion process and the proportion of time the combustion appliance is activated.

For the determination of the internal flow in an apartment, information on the leakage distribution and thus on neutral pressure level in the staircase is necessary.

Open/closed ducts and windows, and intermittent operation of the mechanical system are all considered in the resulting flow by time weighted addition of the respective flows.

The implicit method

This method is based on a single zone model. This means that the dwelling is represented by one zone with one temperature and one pressure value. This zone pressure value has to be determined iteratively based on a flow balance equation for all flows entering and leaving this zone. The model is based on the same input parameters as needed for the explicit method. Nevertheless, *individual leakage values for the facades* and the roof have to be determined as percentages of the overall leakage. Guidance for the selection of cp-coefficient values at the external nodes is given in an annex of the draft standard.

In order to model stack driven flows correctly, distributed leaks may be modelled by two individual, vertically separated leakages. This is especially important for natural systems with no vertical duct.

The building can be modelled in a more complex way, taking into account more than two facades. In this case though, the relevant information on the leakage and wind pressure distribution must be available.

The implicit method can also be applied to apartment building types.

Besides the unknown pressure in the zone under consideration, also the pressure in the staircase is unknown. Therefore, this building type is normally treated using multizone air flow models. Nevertheless, two *extreme cases can be calculated using the method in* the standard: a) The staircase is not considered as a part of the building, b) The staircase is considered as a part of the zone ($p_{staircase} = p_{zone}$). Flows for both cases must be calculated and the results be considered according to the specific application.

Calculation method for room air flow rates

The method gives total flow rates for an individual room in the dwelling. To perform the calculations, the whole dwelling flows must be determined first, using the methods outlined above.

It is assumed that the internal doors to the room under investigation are closed. More than one room may be considered as one zone if the internal partitions are removed or the connecting doors open.

The calculation procedure is applicable to heat load calculations only, giving conservative high flow rate values.

For indoor air quality evaluations, information on internal flows is needed that can only be determined by multizone modelling. For energy calculations, room air flow values are not considered to be relevant.

References

Draft standard CEN TC 156/ WG2/N203 : 'Calculation Methods for the Determination of Air Flow Rates in Dwellings', 16. Oct. 1995

Lattice Gas Methods - Fluid Dynamics from Particle Collisions

by Malcolm Orme, Air Infiltration and Ventilation Centre

Introduction

Lattice gas methods have been devised to assist in understanding the properties of real fluids. Potentially, therefore, they could provide an alternative to conventional computational fluid dynamic (CFD) analysis for predicting air flow patterns. This new approach approximates reality by constraining motions and collisions of fluid 'particles' to a 'lattice', where each particle represents a finite mass of fluid. Simplification takes place by reducing the near infinite motion characteristics of a real fluid to a very restricted set of discrete particle speeds and directions.

A typical lattice for flow in 2-dimensions is illustrated in Figure 1. Particles are restricted to moving along propagation lines and collide only at the intersections ('nodes') of these lines. Each collision must observe Newton's laws of motion, namely that momentum and mass are conserved. Various outcomes of particle collisions are possible. In some cases the direction of particle flow changes, while in others no change in direction occurs. Typically, the solution algorithm incorporates a 'look-up table', in which all the possible outcomes of collisions are stored.

This article presents an example of the application of the lattice gas approach, and outlines some of the essential concepts. The example is based on a method proposed by Frisch, Hasslacher, and Pomeau (1986), known as an FHP model.

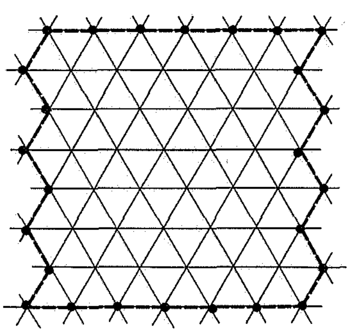


Figure 1: Example hexagonal lattice

Lattice Geometry

A highly symmetric lattice is needed to ensure that vorticity (rotational motion of a fluid) is realistically simulated. Hardy et al (1972, 1973, 1976) showed that a basic rectangular lattice is inadequate for this purpose. However, Frisch et al (1986) concluded that for flow in 2-dimensions, a hexagonal lattice, illustrated in Figure 1, is satisfactory. Three-dimensional flow is more difficult to model, but has been simulated using a 'face centred hyper-cubic' (FCHC) lattice. (See Frisch et al, 1987.) Although particles must move along the propagation lines, the velocity (i.e. speed and direction) components can nevertheless be resolved to generate the full flow field.

Analogous to wind tunnel experiments, lattice flow has to be scaled to correspond to the correct flow regime (i.e. laminar, transitional, or turbulent flow). This is characterised by the Reynolds number. By increasing the number of nodes, and hence the Reynolds number, features such as the onset and development of turbulence automatically emerge. A disadvantage is that turbulent flow currently requires many thousands of nodes.

Collision Rules

A set of collision rules must be specified. These fall into the categories of 'trivial' collisions, which result in no change in direction of colliding particles, and 'non-trivial' collisions, involving a change of direction of some or all of the particles. Collisions throughout the entire lattice are assumed to occur simultaneously and at 'unit' time steps. Following collision, they then arrive at their new nodes. The resultant propagation of particles simulates the movement of fluid throughout the space.

In 2 dimensions, using an FHP model, there are 64 possibilities for a collision at each node. The outcome of each possible collision is chosen so that the number of particles present before and after is preserved. In addition, the total of the momenta of all the particles involved remains constant. The number of particles and the momentum should be the only conserved quantities in any collision. As a consequence, some collisions result in more than one outcome. When this happens, the outcome is selected at random. The complete set of non-trivial collision rules, as proposed by Hénon (1987), is given as follows, and results in up to 72 distinct outcomes:

1. head-on (2 particles) - 3 possibilities, each with 2 possible outcomes (see Figure 2a),

2. triple (3 particles) - 2 possibilities, each with 2 possible outcomes (including 1 trivial, see Figure 2b),
3. head-on with spectator (3 particles) - 12 possibilities, each with 1 possible outcome (see Figure 2c), and
4. binary head-on (4 particle) - 3 possibilities, each with 2 possible outcomes (see Figure 2d).

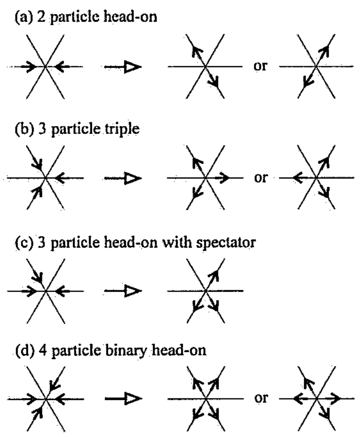


Figure 2: Collision rules - any orientation

Boundaries

Perimeter obstructions to flow (e.g. walls, floors, and ceilings) and internal obstructions (e.g. furniture and people) are realised by setting 'solid boundary nodes'. Implementing the condition of 'no-slip' (i.e. zero parallel fluid velocity) at such boundaries is illustrated in Figure 3. On reaching a solid surface, particles are returned along the same propagation line.

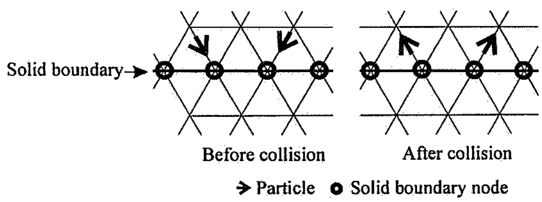


Figure 3: Implementation of no-slip condition at solid boundaries

Flow boundaries (e.g. open doors, windows, ventilation systems) are represented by a variety of means. For example, it is possible to introduce 'forcing rules' to simulate a linear pressure gradient, as shown in Figure 4. This involves imposing directional flow on the lattice particles by introducing additional *x*-momentum at random lattice locations. The strength of pressure gradient is increased by adding to the number of nodes and the number of time steps at which forcing is applied. The mass flow rate into the space (i.e. the number of particles entering the lattice per time step) must be balanced by an identical mass flow rate out of the space.

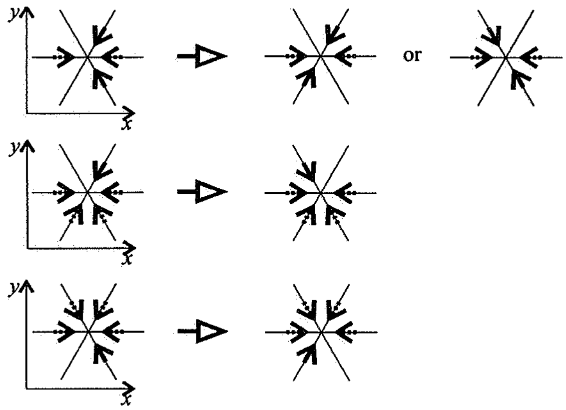


Figure 4: Forcing rules to simulate a pressure gradient

Interpretation of Lattice Dynamics

In order to convert the discrete motions of particles into physically meaningful quantities, it is useful to partition the lattice into a number of rectangular 'domains'. For each domain, the average mass and momentum densities of particles must be determined. The average mass density of particles is given by the number of particles within a domain divided by the number of domain nodes. (For a 2-dimensional hexagonal lattice, the overall value should be between 0 and 3 particles per node, otherwise the fluid would have unphysical behaviour.) The average momentum density is determined by summing the spatial co-ordinate components of the momentum of all the particles within a domain and, again, dividing by the number of domain nodes. An evaluation of the average particle velocity within each domain is then made from these quantities.

Viscosity is the resistance to flow that a fluid exerts on itself when adjacent regions of the fluid move with different velocities. For any lattice gas model, the viscosity and hence Reynolds number of the fluid depends on the average mass density.

Initialising a Simulation

The lattice must be sized to set the characteristic Reynolds number of the problem to be studied. For this model, the maximum obtainable Reynolds number for a given lattice size occurs when there is an average of about 2.0 particles per node, for the complete set of collision rules stated above. An initial particle distribution defining the true mass density of the lattice is established. This implies an initial momentum distribution, from which the calculation proceeds by running the model over a number of unit time steps.

In general, simulations must be run until transient disturbances caused by the initial conditions have disappeared. This is likely to be a large multiple (e.g. greater than 10) of the number of time steps taken for a particle, moving at the average velocity, to have 'propagated through the system'. At this stage a consistent pattern of flow may begin to emerge.

An Air Flow Example

The above concepts have been incorporated into a simplistic 2-dimensional example, as illustrated in Figure 5. A 2-dimensional office space is modelled using 400 x 400 lattice nodes, and 40 x 40 domains (each of 10 x 10 lattice nodes). The average mass density of the lattice is 2.4 particles per node, yielding low Reynolds number flow.

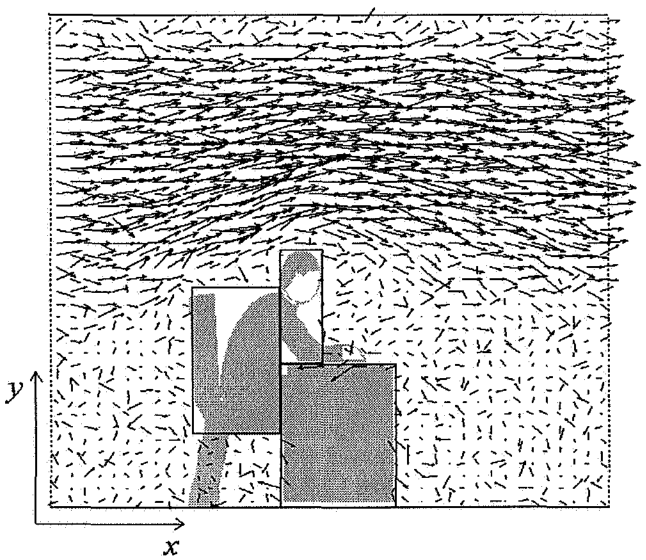


Figure 5: Example simulation

The upper and lower boundaries are solid, and there is a no-slip condition at these edges. Particles reaching one side of the lattice are fed back into the other side, with identical velocity and at the same *y*-value. A block of three adjacent solid rectangles provides an internal obstacle to flow, which is a crude representation of a person sitting at a desk. A no-slip condition is also present at these boundaries.

The air flows under isothermal forced convection, as provided, for example, by a balanced mechanical ventilation system. The driving force for the flow is provided by a linear pressure gradient (in the *x*-direction in Figure 5), implemented with the forcing rules shown in Figure 4.

Figure 5 shows the resultant velocity field after 100000 unit time steps (which required approximately 4 hours computation time on a 100 MHz Intel Pentium based computer). It should be noted that the Reynolds number is perhaps too low for a full-scale ventilation system. Clearly, therefore, this example is very idealised, but nevertheless the potential for predicting flow using this approach is demonstrated.

Conclusions

The lattice gas method presented may be used to produce qualitative features of physical fluid behaviour. In the short term, the method is likely to be limited to low Reynolds number applications. In the longer term, current limitations imposed by the high storage and processing requirements needed for turbulent flow analysis must be overcome. This may be possible by compressing the data stored to represent the lattice. Current work to overcome high processing requirements includes using lattice models with parallel computers (e.g. Krafczyk and Rank, 1995), to which they are well-suited.

The method has the positive characteristic that, subject to the constraint of the discrete nature of the lattice, arbitrarily complex boundaries can be included without increasing the time needed for computations. It is also possible to track either individual or groups of particles, so that, for instance, pollutant transport may be studied. This approach dispenses with the need to solve the Navier-Stokes equations. Furthermore, since turbulence develops naturally in lattice gas methods, artificial turbulence models, as incorporated into conventional CFD techniques, are unnecessary. To conclude, the lattice gas technique may prove to be a useful tool for air flow analysis, especially with recent developments allowing for the inclusion of buoyancy effects (e.g. see Chen et al, 1989, and Burges and Zaleski, 1987).

References

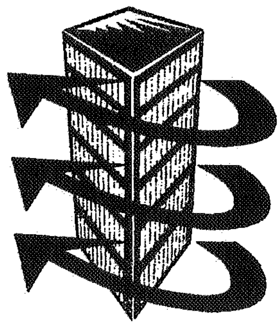
1) Burges C, and Zaleski S, "Buoyant Mixtures of Cellular Automaton Gases" *Complex Systems*, Vol 1, No 1, pp 31 - 49, 1987.
2) Chen S, Lee M, Zhao K H, and Doolen G D, "A Lattice Gas Model with Temperature", Physica D, Vol 37, pp 42 - 59, 1989.
3) Frisch U, Hasslacher B, and Pomeau Y, "Lattice-Gas Automata for the Navier-Stokes Equation" *Physical Review Letters*, Vol 56, No 14, pp 1505 - 1508, 1986.
4) Frisch U, d'Humières D, Hasslacher B, Lallemand P, Pomeau Y, and Rivet J-P "Lattice Gas Hydrodynamics in Two and Three Dimensions" *Complex Systems*, Vol 1, No 4, pp 649 - 707, 1987.
5) Hardy J, and Pomeau Y, "Thermodynamics and Hydrodynamics for a Modelled Fluid" *Journal of Mathematical Physics*, Vol 13, p 1042, 1972.
6) Hardy J, Pomeau Y, and de Pazzis O, "Time Evolution of a Two-Dimensional Model System: I. Invariant States and Time Correlation Functions" *Journal of Mathematical Physics*, Vol 14, p 1746, 1973.
7) Hardy J, de Pazzis O, and Pomeau Y, "Molecular Dynamics of a Classical Lattice Gas: Transport Properties and Time Correlation Functions " *Physical Review A*, Vol 13, p 1949, 1976.
8) Hénon M, "Isometric Collision Rules for the Four-Dimensional FCHC Lattice Gas" *Complex Systems*, Vol 1, No 3, pp 475 - 494, 1987.
9) Krafczyk M and Rank E, "A Parallelized Lattice-Gas Solver for Transient Navier-Stokes-Flow: Implementation and Simulation Results", International Journal for Numerical Methods in Engineering, Vol 38, pp 1243 - 1258, 1995.

AIVC

AIR INFILTRATION AND VENTILATION CENTRE

17th AIVC Annual Conference

17th - 20th September 1996



Optimum Ventilation and Air Flow Control in Buildings

Preliminary Announcement

Good indoor air quality and energy efficiency is critically dependent on well designed ventilation systems. The objective of this conference is to review current research and design approaches aimed at fulfilling ventilation needs. The conference is open to all member countries of the ECBS Implementing Agreement* and also to authors of accepted papers from other non-member countries.

Papers will be presented on the following topics:

- ventilation solutions for large buildings (commercial, public, etc.)
- passive cooling
- achieving optimum air distribution
- ventilation case studies
- evaluation of ventilation performance
- developments in housing
- systems for building retrofit
- innovative technology
- developments in calculation and measurement methods

Conference Venue

The conference is to be held at the Hotel 11, Gothenburg, Sweden, situated on the waterfront at Eriksburg, a former shipyard in the heart of the Port of Gothenburg which is currently undergoing sympathetic renewal and development. The hotel is easily reached, by either car or bus, via Lundbyleden, a major access road, or by the frequent Alvsnabben ferry service from Central Gothenburg, which stops at the hotel quay side. An inclusive package is offered at a total cost of £550 (reduced to £500 for fees received by 31st July 1996).

Exhibition Space

There will be a central exhibition site prominently situated in the foyer of the conference hall.

For further information please contact Rhona Vickers at the AIVC (address on back page).

**Australia, Belgium, Canada, Denmark, Germany, Greece, Finland, France, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Poland, Sweden, Switzerland, Turkey, UK, USA*

Instrumentation for Tracer Gas Detection: a Primer

by Martin Liddament, Air Infiltration and Ventilation Centre

Tracer gas concentration is measured using a gas analyser. These can be extremely complex and costly systems which add considerably to the expense of performing a tracer gas test. Various types of systems exist and it is vital that the correct detector is chosen for the gas and gas concentration used.

Infra red (IR) detection

These are some of the most robust of detection systems and make use of the characteristic of a gas to absorb infra red radiation of a characteristic wave length. Various IR detection methods are possible as summarised in Figure 1.

Infra-red is commonly used to measure nitrous oxide and carbon dioxide. It may also be used to detect sulphur hexafluoride and other halon gases but not at the minute concentrations that are possible using other methods (such as gas chromatography with electron capture).

Mass spectrometry

Mass spectrometry enables the concentrations and identity of a mix of gases to be simultaneously measured. The pressure of the sample is first reduced to approximately 10 to 5 Pa. It then enters the spectrometer where it is ionised by an electric field of variable radio frequency. The resonant frequency of ions is dependent on charge to mass ratio; this is unique to each molecule and element. Only those that are resonant to the tuned radio frequency reach a detector where they are detected by an electron multiplier. This produces a signal which is proportional to the number of ions that reach the detector. Up to seven gases may be detected simultaneously in a detection period of a few milliseconds.

Gas chromatography with electron capture or flame ionisation

Gas chromatography is used to separate gases before their concentration is measured. This is essential for multi-tracer gas testing or when it is difficult for a detector system to distinguish between tracer gas and other constituents of air (e.g. sulphur hexafluoride in oxygen).

A gas chromatograph consists of a heated tube or column filled with gas adsorbing material (adsorbent). A pulse of mixed gases, such as room air with tracer gas, is injected into the column and is flushed through it with an inert carrier gas. Each of the component gases in the mix propagate through the tube at a different rate, this flow rate being a characteristic of the adsorption and de-adsorption affinity of each of the gases to the particular adsorbent. Component gases, therefore become separated and emerge from the exit of the columns at different times (see Figure 2). Once the gas has emerged, its concentration is measured using one of the following techniques:

Electron capture

Some gases, particularly halogens, capture electrons. This property has been successfully utilised in detecting tracer gases such as sulphur hexafluoride and PFs. A small radioactive source is used to generate a cloud of electrons in an ionisation chamber. A

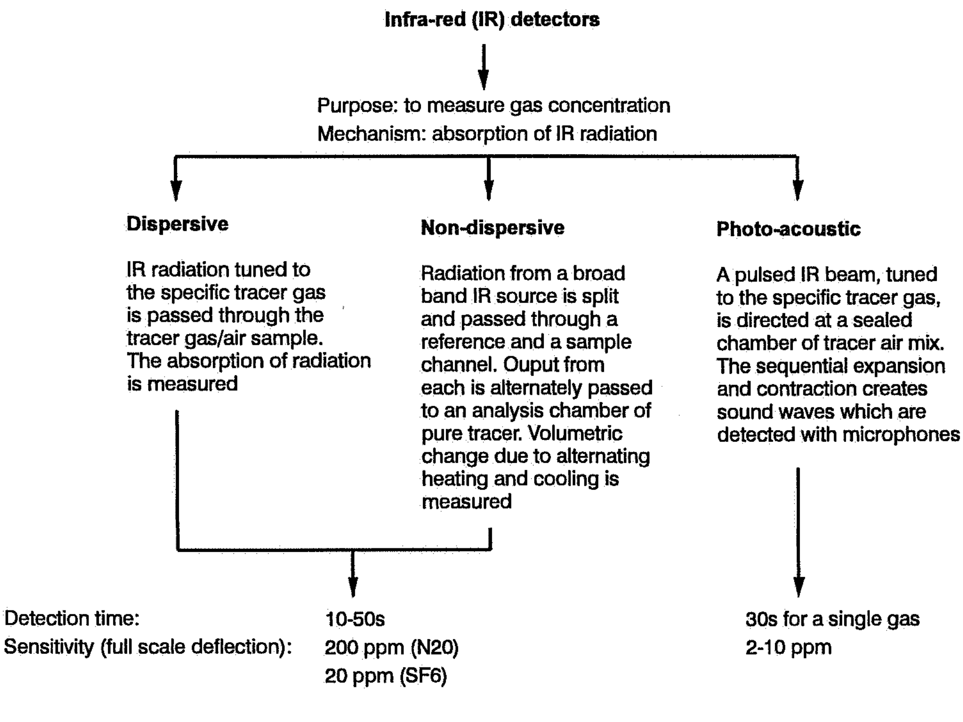


Figure 1: Infra red detection methods

pulsed voltage is applied across the chamber, inducing a flow of current. As the sample gas is introduced, the current falls in direct proportion to the number of electrons captured. Depending on the type of gas, concentrations in the parts per billion and parts per trillion range can be measured.

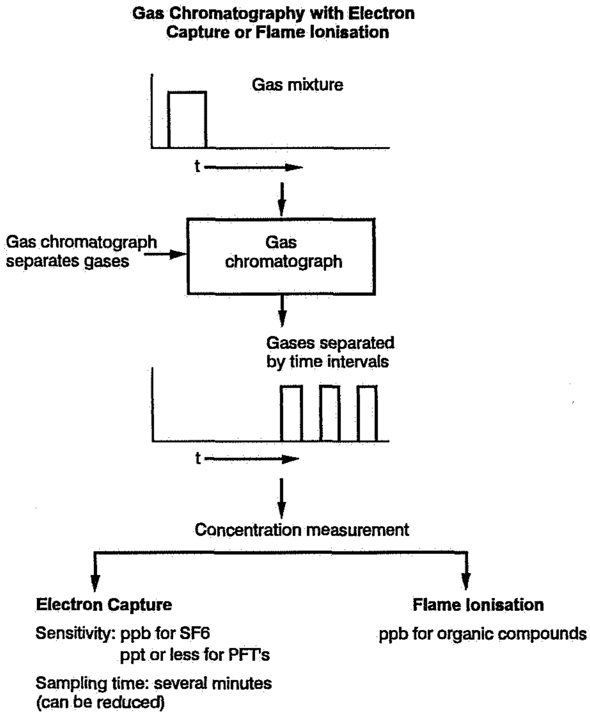


Figure 2: Gas chromatography

Flame ionisation detector

Ions are produced when certain compounds are burnt in a mixture of hydrogen and air. These are collected by a pair of polarised electrodes and the resultant current is measured. This detector cannot distinguish between gases or types of ion, it is therefore imperative that only the gas to be detected is passed through to the sensor. It has good sensitivity to organic compounds and is rugged and reliable. Flame ionisation is not now used much for tracer gas detection although, in the past, this technique has been used with methane.

Theoretical outline

Theory and equations

If an inert gas that is not normally present in the atmosphere is released and is perfectly mixed within a leaky enclosure, the concentration of gas at any instant in time is given by the continuity equation:

$$\underbrace{V\frac{dC}{dt}}_{\text{Term 1}}+\underbrace{QC}_{\text{Term 2}}=\underbrace{F}_{\text{Term 3}}$$

where

V = effective volume of enclosure (m^3);

C = concentration of tracer gas;

Q = air flow rate (m^3/s or kg/s);

t = time (s);

Hence the air flow rate, Q, may be determined if all the remaining parameters are known. Several test configurations enable Q to be evaluated; these include:

Concentration decay

If a fixed quantity of tracer gas is uniformly distributed into a space, its concentration will reach a peak level given by $C_{(0)}$. Subsequently, as the seeded air becomes diluted with incoming (unseeded) air, the concentration of tracer gas will gradually decay. Since, after distribution of the gas, the injection rate, F, becomes zero, term 3 from the continuity equation is eliminated. Integration of Terms 2 and 3 yields:

$$C_{(t)}=C_{(0)}e^{\frac{Q}{V}t}$$

where:

$C_{(0)}$ = tracer gas concentration at start of test;

$C_{(t)}$ = tracer gas concentration at time, t, after start of test.

The air change rate, (Q/V), is given by the logarithmic gradient of the tracer gas concentration curve. This can be readily determined by plotting the tracer gas concentration decay over time on logarithmic paper.

Constant concentration

If the emission rate of tracer gas, F, is continuously adjusted such that the concentration of tracer remains constant, term 1 of the continuity equation is eliminated. The air flow rate is then given by:

$$Q=\frac{F}{C}\quad (m^3/s \text{ or } kg/s)$$

Thus the air flow rate, Q, is directly proportional to the tracer gas emission rate.

Constant emission

If tracer gas is released at a constant rate, all terms in the continuity equation remain and integration yields:

$$C_{(t)}=\frac{F}{Q}+\left(C_{(0)}-\frac{F}{Q}\right)e^{-\frac{Q}{V}t}$$

While the test is relatively easy to perform, analysis of the data can be complicated. If, however, driving forces remain constant, a steady state concentration will be reached and analysis will reduce to that of the constant concentration approach.

Long term (inverse) average

The constant emission method can further be applied to the calculation of an average inverse air change rate which has proved useful for passive tracer gas testing. Rearranging the continuity equation and averaging over time yields:

$$\left(\frac{V}{Q}\frac{dC}{dt}\right)+(C)=\left(\frac{F}{Q}\right)$$

If it is assumed that the air change time (i.e. the inverse of the air change rate) is small compared to the averaging period and that the emission rate of tracer, F, is constant, then:

$$\left(\frac{V}{Q}\frac{dC}{dt}\right)\rightarrow 0\,and\,(F)=F$$

hence

$$\left(\frac{1}{Q}\right)=\frac{(C)}{F}$$

From the above, the inference is often made that:

$$(Q)=\frac{F}{(C)}$$

Such an assumption is only valid if the average air change rate is constant throughout the averaging period. In practice, this averaging method provides insufficient weighting to peaks in air change rate that may result, for example, from airing by window opening or high infiltration rates induced by transient driving forces. This method, therefore, while probably being acceptable for tight buildings in which air change is dominated by controlled ventilation, may give misleading underestimates in buildings in which air change is dominated by air infiltration or natural ventilation.

References

A more detailed survey of the above is available in the "AIVC Guide to Ventilation" by Martin Liddament. Information can also be found in AIVC Technical Note 34, Air Flow Patterns: Measurement Techniques.

AIVC Web Page Grows in Popularity

Use of the Web Page is increasing all the time

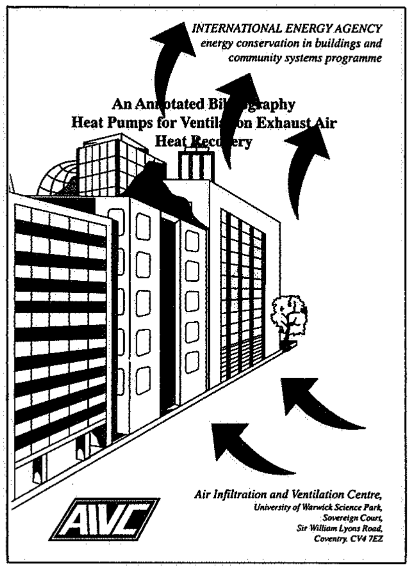
The AIVC's new World Wide Web Homepage (http://www.demon.co.uk/aivc//) has proven very popular over the months since it was activated, with almost five hundred enquirers since October 1995. The AIVC Web pages contain a preview copy of Air Infiltration Review, a listing of 250 of the latest items added to Airbase and the AIVC library, AIVC conference details, and an AIVC publications order form and listing. Thanks to the Homepage, browsers as far afield as Mexico and Korea have been able to view the services we provide, and the AIVC is gaining in popularity.

If you have any suggestions for material you would like to see on the Web pages, please don't hesitate to let us know.

Heat Pumps for Ventilation Exhaust Air Heat Recovery

A New Annotated Bibliography from the AIVC
by Mark Limb, AIVC Scientist

The AIVC's series of annotated bibliographies aims to review and technically assess current literature and provide a concise but in depth overview of particular subjects. The latest addition to this series summarises research into the use and application of heat pumps in ventilation heat recovery systems. It is aimed at design professionals, researchers and engineers who have an interest in heat pumps in ventilation systems.



The document is divided into six main sections.

Contents:

Heat pumps are defined in the introduction by ASHRAE as devices that extract heat from one substance and transfer it to another portion of the same substance or to a second substance at a higher temperature. In the case of heat pump heat recovery from ventilation air, heat is extracted from a source, usually waste heat in the extract air, and transferred to a suitable source, usually the domestic hot water system or alternatively space heating system of the ventilation supply air. In section two of this document, the distinction is made between the two main types of heat pumps, i.e., vapour compression and absorption heat pumps, and a brief explanation of their relevant operational cycle is given. Section two also defines the Coefficient of Performance and contains a brief note on the use of relevant working fluids and the Montreal Protocol.

The main body of this bibliography outlines those papers that describe the use and installation of heat pumps in real buildings. Section three concentrates on residential examples and section four focuses on other buildings such as swimming pools and commercial establishments.

The most common configuration in all buildings is an air-to-water type system, with the heat pump located in the exhaust duct transferring waste heat to the hot water circuit. Air-to-air heat pumps are also popular, where heat is transferred to the supply air as a form of preheat. Novel configurations such as "Dynamic Insulation" incorporating heat pumps have also been included in this bibliography as well as the use of heat pumps in swimming pools, schools, shops and offices.

In conclusion the studies outlined demonstrate that for typical residential air-water heat pumps COP's of between 2 and 3.5 are possible, and in extremely favourable cases they can be as high as 5. While for residential air-to-air heat pumps COP's of between 2 to 5 were reported. Where combined heat pumps and heat exchangers are utilised COP's can reach slightly over 5. For commercial buildings, typical COP's range from 2 to 3, while for swimming pools examples have quoted around 1.7. These examples demonstrate the potential for heat pump technology to further enhance the energy efficiency of our buildings.

This document contains 47 references, which are all available to participating countries from the AIVC's Bibliographic database, AIRBASE. To order your copy of this and other publications, please return the order form enclosed with this newsletter.

David Harrje

With much sadness we report the death of David Harrje in December of last year. David was very active in the founding days of the Air Infiltration and Ventilation Centre and continued with strong support right up to our most recent conference. Throughout the 1970's and 80's David was responsible for ventilation related research at the Center for Environmental Studies, Princeton University. Early activities included taking a leading role in the New Jersey 'Twin Rivers' project aimed at monitoring and understanding energy use in dwellings. An important practical result of this study was the successful development, implementation and replication of retrofit measures for reducing building energy consumption. A further outcome was the availability of data for use in the performance testing of building energy simulation models.

David was very much involved in the development and evaluation of many measurement systems. This included the design of a portable 'House Doctor' package for use in the rapid evaluation of building air-tightness and infiltration performance. Incorporated into this system was one of the first 'blower doors' for air-tightness testing and an infrared scanner, for use with the blower door, to trace sources of air leakage. Other measurement tools in which David played a significant development role included automated tracer gas systems and tracer 'bag' sampling techniques.

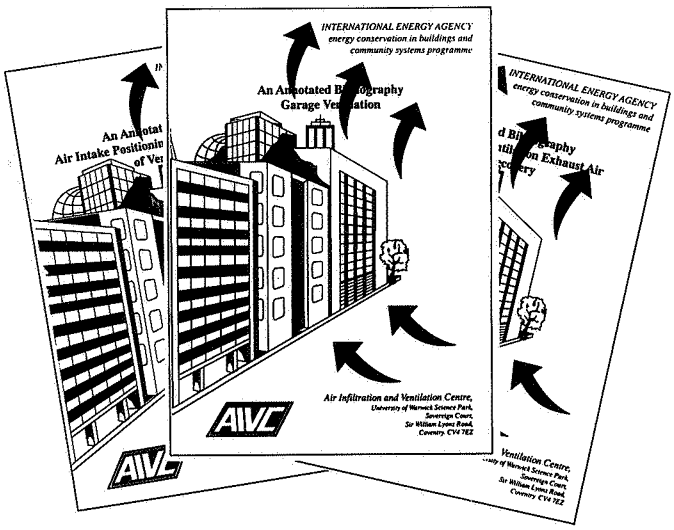
David was also very active in the application of research. Areas included studies into indoor air quality, radon mitigation techniques, 'passive' cooling methods and the use of wind-breaks to reduce air infiltration.

Much of David's work has been applied to set a new generation of performance standards for energy efficiency, ventilation and good indoor air quality. Many of the diagnostic and measurement techniques that were developed at Princeton are now in routine use throughout the world.

David's support and enthusiasm for the AIVC will be sadly missed.

(A bibliography of David Harrje's air infiltration and ventilation papers is available from the AIVC)

Bibliographies in the AIVC Series



Ventilation and Infiltration Characteristics of Lift Shafts

Garage Ventilation
Summarises research into the health, energy and design aspects of the various systems used in garage ventilation.

Natural Ventilation
Covers the main elements of natural ventilation research, the fundamental equations, driving forces and associated factors, as well as useful reports which focus on modelling and calculating natural ventilation air flows.

Air Intake Positioning to avoid Contamination of Ventilation Air

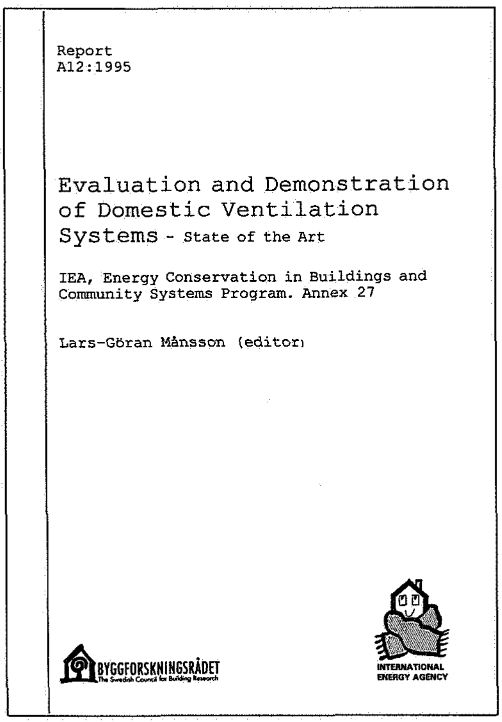
New Publication from the IEA
Energy Conservation in Buildings and Community Systems Programme

Evaluation and Demonstration of Domestic Ventilation Systems - State of the Art

Annex 27

Edited by Lars-Goran Mansson

Published by the Swedish Council for Building Research,
Report A12:1995, ISBN 91-540-5731-0



Report
A12:1995

Evaluation and Demonstration of Domestic Ventilation Systems - State of the Art

IEA, Energy Conservation in Buildings and Community Systems Program. Annex 27

Lars-Göran Månsson (editor)

BYGGFORSKNINGSRÅDET
INTERNATIONAL ENERGY AGENCY

Eight countries are cooperating in this ongoing project. The main goal is to develop tools to make it possible to predict the consequences of installing a particular ventilation system.

The present report, based on about 300 references, gives the basis for making assumptions as input in the computer models that will be used. In the report data is given on housing and the development of the number of persons per dwelling past, today, and in the future. Information is also given on the residents' behaviour. Various pollutants indoors are discussed and both peak and average values are given.

The use of computer models for predicting indoor air quality by the use of multi zone models, energy calculations, sensitivity analysis of the thermal comfort equation, how to express ventilation efficiency, noise consequences, life cycle costing and illustrating reliability by comparing three different ventilation systems, are also discussed.

Eight chapters as follows:

- ***Summary;***
- ***Introduction;***
- ***Statistical Data on Housing;***
- ***Ventilation Performance;***
- ***Standards and Reasons Behind;***
- ***Pollutant Loads;***
- ***Evaluation Approach;***
- user behaviour and perception
- energy models
- IAQ models
- thermal comfort model (draught model)
- ventilation efficiency
- life cycle costing
- noise
- reliability
- ***Conclusion***

This new report is available from the Air Infiltration and Ventilation Centre, Price £25.00 including postage and packing.

Recent Additions to Airbase - Reviews

Two library items recently added to the AIVC's Airbase database are highlighted below. The proceedings are available for loan from AIVC Information Services: please see the new Recent Additions for a full listing of contents, with abstracts.

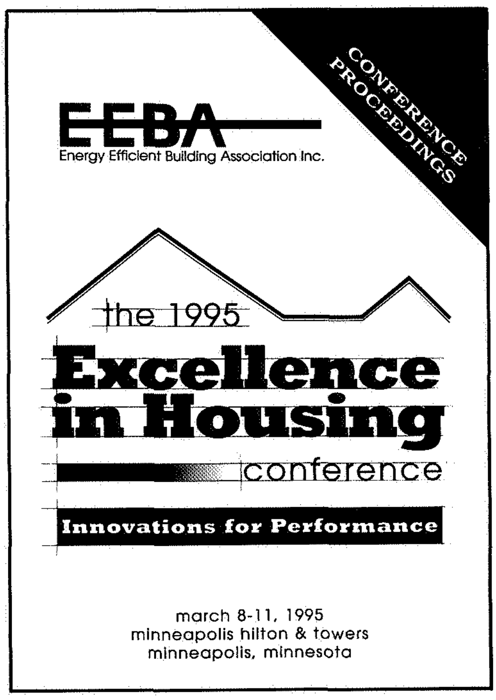
Review

Proceedings

The 1995 Excellence in Housing Conference Innovations for Performance

Held March 8-11, 1995, Minneapolis Hilton & Towers, Minneapolis, Minnesota, USA

Published by the Energy Efficient Building Association, 1829 Portland Avenue, Minneapolis, MN 55404-1898, USA



This conference collects together papers in six subject headings;

- good construction practice;
- advanced building science;
- utility/marketing;
- indoor air quality;
- remodelling, rehab and miscellaneous;
- and sustainable building practice.

Some of the more noteworthy papers are listed here:

- The process of building a healthier house with air tight construction combined with hybrid mechanical systems.
- Affordable energy efficient housing.
- Dry basements through the selective use of thermal insulation and moisture-resistant materials.
- A case study: energy consumption patterns in a manufactured housing community.
- The unplanned impacts on houses by powered attic ventilators.
- Affordable housing in the South - barriers to making it energy efficient.
- Mold, moisture, and indoor air quality: a cold climate perspective.
- Healthy indoor environments through passive ventilation using integral window ventilating systems/devices.
- Radon reduction through solar ventilation: design and evaluation.
- House depressurization/backdrafting/carbon monoxide poisoning.
- Summer humidity = year around poor indoor air quality.
- Household contaminants and household exhaust and ventilation device usage.
- Superinsulation rehab or multi-family buildings.
- HOT2000 version 7 and AUDIT2000.
- Environmental and economic impacts of various residential building products, construction methods, and design choices.
- Sustainability and the Rocky Mountain region of the National Park Service.
- Exploring alternatives to the disposal of residential construction waste.
- The ideal house: integrating affordability, energy and environmental efficiency, air quality and disaster resistance.

Review

IAI Indoor Air International

International Conference on Indoor Air Pollution

Edited by L Weber, Institute of Occupational and Social Medicine, University of Ulm

Held at the University of Ulm, Germany, 5-7 October 1994

Published by: Indoor Air International,
The International Association for Indoor Air Quality,
Postfach 2, CH-4467, Rothenfluh, Switzerland

Papers which may be of interest in the eight chapter sections of the proceedings are noted below:

Chapter 1: Chemical pollutants, sources, interactions and dispersion; analytical methodology in relation to indoor exposure

- Indoor-outdoor comparison on VOCs: infiltration from outdoor air.
- The history and present time on the loading of buildings with formaldehyde.
- Measurement and CFD modelling of aerosol particles in buildings.
- The SCG assay - its evaluation for possible application in indoor air pollution monitoring.

Chapter 2: Chemical pollutants, sources etc

- Indoor chemical sources: VOC pollution from paint solvents.
- Indoor air pollution by PCBs - the contribution of wall paints in a technical building. A case study.

Chapter 3: Indoor Air Quality in Relation to Heating, Cooling and Ventilation

- Ways to improve indoor air quality in working areas.
- Efficient exhaust systems to protect the health of workers.
- Air recirculation energy saving systems.
- Contribution to the radiation exposure of the radon into a ten floor block building.
- Domestic radon exposure: can we apply experience obtained from uranium miners?
- Anaesthesiologic procedures and environmental pollution in nonventilated work areas.
- Diffusion of anaesthetic gases through plastic materials, used in anaesthesia.
- Public health assessment of air cleaners.

Chapter 4: Health Effects and Risk Assessment

- Indoor air quality and health, a "pragmatic view".
- Evaluation of the effect of dust and gas emissions from external sources upon the composition of the open pit indoor environment.
- Indoor climate in schools in relation to asthma and sick building syndrome.

Chapter 5: Sick Building Syndrome - Case Studies

- The sick building syndrome in a hospital: a case study.
- Sick building syndrome in an office caused by perfume.

Chapter 6: Environmental tobacco smoking

- Environmental tobacco smoke (ETS) exposure in homes with and without smokers.
- Assessment of the everyday benzene exposure of non-occupationally exposed nonsmokers.

Chapter 7: Pyrolysis Products in Indoor Air

- Health risks from combustion products in indoor air.
- Influence of air quality in operating theatre due to laser surgery.
- Airborne particulate debris from medical laser tissue treatment.
- A model for virus spread through laser application.
- Detection of pollutants and process analysis in laser medicine by laser spectroscopic methods.

Chapter 8: Posters

- New design criteria respecting the nonuniformity of hygrothermal environment.
- Effect of the air exchange on formaldehyde concentrations in indoor air.
- Calculation of exhaust rate for capture of contaminant from a source of diffusional type.

Forthcoming Conferences

7th Biennial Colloquium on Computational Fluid Dynamics
UMIST, Manchester, UK
2-3 May 1996
Contact:
Mrs I Bowker, UMIST, Mechanical Engineering Department, PO Box 88, Manchester M60 1AD, UK
Tel: +44 (0)161 200 3702
Fax: +44 (0)161 200 3733
email irene.bowker@umist.ac.uk
Topics: turbulence modelling; numerical methods; aerodynamic flows; internal flows; combustion and two-phase flows.

7DBMC
7th International Conference on the Durability of Building Materials and Components
19-23 May 1996
Stockholm, Sweden
Contact: Executive Secretariat 7DBMC, Division of Materials Technology, Department of Built Environment, Royal Institute of Technology, PO Box 88, S-801 02 Gavle, Sweden,
Tel: +46 26 14 78 00,
Fax: +46 26 14 78 01

ESM 96
10th European Simulation Multiconference
2-6 June 1996
Budapest, Hungary
Contact:
The Society for Computer Simulation International European Simulation Office,
c/o Philippe Geril, University of Ghent, Coupure Links 653, B-9000 Ghent, Belgium
Tel: (office) +32 9 233 7790
Tel + Fax (Private) +32 59 800804
Fax: +32 9 233 4941
email philippe.geril@rug.ac.be
www http://hobbes.rug.ac.be/~scs

World Renewable Energy Congress IV
15-21 June 1996
Denver, Colorado, USA
Contact: Prof Ali Sayigh, Director General of Wren, 147 Hilmanton, Lower Earley, Reading RG6 4HN, UK,
Tel: +44 (0)1734 611364, Fax: +44 (0)1734 611365

Roomvent '96
5th International Conference on Air Distribution in Rooms
July 17-19 1996
Yokohama, Japan
Contact: Conference Secretariat, Roomvent '96, Murakami and Kato Laboratory, Institute of Industrial Science,
University of Tokyo, 7-22-1 Roppongi, Minato-ku, Tokyo, 106 Japan
Tel: +81 3 3402 6231 x 2575
Fax: +81 3 3746 1449

PLEA 96 Louvain-la-neuve
The 13th International Conference on Passive and Low Energy Architecture
Building and Urban Renewal
July 16-18 1996
Louvain-la-neuve, Belgium
Contact: Professor A De Herde,
Architecture and Climate,
1 Place du Levant,
B-1348 Louvain la Neuve,
Belgium
Tel: +32 10 47 21 42
Fax: +35 10 47 45 44
email: deherde@arch.ud.ac.be

Indoor Air '96
7th International Conference on Indoor Air Quality and Climate
July 21-26 1996
Nagoya, Japan
Contact: Dr Koichi Ikeda, Indoor Air '96,
The Institute of Public Health, 6-1, Shirokanedai 4-chome,
Minato-ku, Tokyo 108, Japan
Tel: +81 3 3441 7111 x 275
Fax: +81 3 3446 4723
email: indair@limura.arch.waseda.ac.jp

Profiting from Energy Efficiency
ACEEE 1996 Summer Study
August 25-31 1996
Asilomar Conference Center, Pacific Grove, California, USA
Contact: American Council for an Energy-Efficient Economy,
1001 Connecticut Avenue, NW, Suite 801,
Washington, DC 20036, USA

ECCOMAS 96
Second ECCOMAS Conference on Numerical Methods in Engineering/ Third ECCOMAS Computational Fluid Dynamics Conference
9-13 September 1996
Paris, France
Contact: ECCOMAS 96, Universite de Paris VI, Laboratoire d'Analyse Numerique, Tour 55-65, 5eme etage, 4, Place Jussieu, 75252 Paris Cedex 05, France,
Tel: +33 1 44 27 11, Fax: +33 1 44 27 72 00,
email: eccomas96@ann.jussieu.fr

Optimum Ventilation and Air Flow Control in Buildings
17th Annual AIVC Conference
17-20 September 1996
Hotel 11, Gothenburg, Sweden
Contact: Rhona Vickers at the AIVC

AIVC Publications Order Form

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[ ] Recent Additions to AIRBASE				[ ] 11th £35		[ ] BIB2	[ ] BIB5
[ ] Please add me to your mailing list				[ ] 12th £50		[ ] BIB3	
Technical Notes[2]				[ ] 13th £50		IEA Information	
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[ ] Handbook*		[ ] TN25*	[ ] TN32*	[ ] 15th £50		[ ] IEA Publications List	
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[ ] TN16*	[ ] TN23*	[ ] 28.2*	[ ] TN36	[ ] TN39	[ ] TN42	[ ] TN45	
New Publication - AIVC Guide to Ventilation £50 [ ]				[ ] AIRBASE bibliographical database £150.00[3]			
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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 35 onwards and the annotated bibliographies are available *to participants only,* free of charge, unless provided as a photocopy (£15.00).

* These Technical Notes 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, Switzerland, 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 9,000 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.demon.co.uk/aivc/

TECHNICAL NOTES

(Unlisted technical notes have been superceded)
Applications Guide (1986) Air Infiltration Calculation Techniques
Handbook (1983) Air infiltration control in housing
TN 11 (1983) Validation and comparison of mathematical models
TN 13 (1984) Wind pressure data requirements
TN 13.1 (1984) 1984 Wind Pressure Workshop Proceedings
TN 16 (1985) Leakage Distribution in Buildings
TN 17 (1985) Ventilation Strategy - A Selected Bibliography
TN 20 (1987) 'Airborne moisture transfer: workshop proceedings
TN 21 (1987) Review and bibliography of ventilation effectiveness
TN 23 (1988) Inhabitants' behaviour with regard to ventilation
TN 24 (1988) AIVC Measurement Techniques Workshop
TN 25 (1989) Subject analysis of AIRBASE
TN 26 (1989) IEA Annex IX 'Minimum ventilation rates
TN 27 (1990) Infiltration and leakage paths in single family houses
TN 28 (1990) A guide to air change efficiency
TN 28.2 (1991) A guide to contaminant removal effectiveness
TN32 (1991) Reporting guidelines for airflows in buildings
TN33 (1991) A review of building air flow simulation
TN34 (1991) Air flow patterns: measurement techniques.'
TN35 (1992) Knoll B 'Advanced ventilation systems - state of the art and trends.'
TN 36 (1992) Limb M J 'Airgloss Air Infiltration Glossary'.'
TN 37 (1992) Liddament M W, 'A Strategy for Future Ventilation Research and Applications',
TN 38 (1992) Limb M J 'AIRGUIDE: Guide to the AIVC's Bibliographic Database'.
TN 39 (1993) Liddament M W "A Review of Ventilation Effeciency".
TN 40 (1993) Kendrick J F, "An Overview of Combined Modelling of Heat Transport and Air Movement".
TN 41 (1993) Wilson D and Walker I, "Infiltration Data from the Alberta Home Heating Research Facility".
TN 42 (1994) Limb M J, "Current Ventilation and Air Conditioning Systems and Strategies".
TN 43 (1994) Limb M J "Ventilation and Building Airtightness: an International Comparison of Standards, Codes of Practice and Regulations".
TN 44 (1994) Orme M S, " An Analysis and Data Summary of the AIVC's Numerical Database".
TN45 (1994) Irving S, "Air-to-Air Heat Recovery in Ventilation".
TN 46 (1995) Limb M J, "1994 Survey of Current Research"
TN 47 (1995) Colliver D, "Energy Requirements for Conditioning of Ventilation Air".
Liddament M. W, AIVC Guide to Ventilation (1996)

ANNOTATED BIBLIOGRAPHIES

(Participants only - price see order form)
BIB1 (1993) Ventilation and infiltration characteristics of lift shafts and stair wells
BIB2 (1994) Garage Ventilation: Summarises research into the health, energy and design aspects of the various systems used in garage ventilation.
BIB3 (1994) Natural ventilation: Covers the main elements of natural ventilation research, the fundamental equations, driving forces and associated factors, as well as useful reports which focus on modelling and calculating natural ventilation air flows.
BIB4 (1995) "Air intake positioning to avoid contamination of ventilation air"
BIB5 (1996) "Heat pumps for ventilation exhaust air heat recovery"

AIVC CONFERENCE PROCEEDINGS

AIVC Conference Proceedings nos 1-9 are available as individual papers, or in microfiche form. Details of contents can be forwarded on request.
10th 'Progress and trends in air infiltration and ventilation research' Espoo, Finland, 1989;
11th 'Ventilation System Performance' Belgirate, Italy, 1990;
12th 'Air Movement and Ventilation Control within Buildings', Ottawa, Canada, 1991, 3 volumes.;
13th 'Ventilation for Energy Efficiency and Optimum Indoor Air Quality', France, 1992;
14th 'Energy Impact of Air Infiltration and Ventilation', Denmark, 1993
15th 'The role of ventilation', Buxton, UK, 1994
16th 'Implementing the results of ventilation research', Palm Springs, USA, 1995.

IEA ENERGY CONSERVATION IN BUILDINGS - REPORTS FROM OTHER ANNEXES

IEA Energy Conservation News Twice yearly newsletter of the IEA Energy Conservation in Buildings Programme
Publications A publications brochure for the various annexes can be provided on request 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.

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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: +1 301/990-4192, email apersily@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

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AIVC

Head of Centre Martin W Liddament

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