Air Infiltration Review

a quarterly newsletter from the IEA Air Infiltration Centre

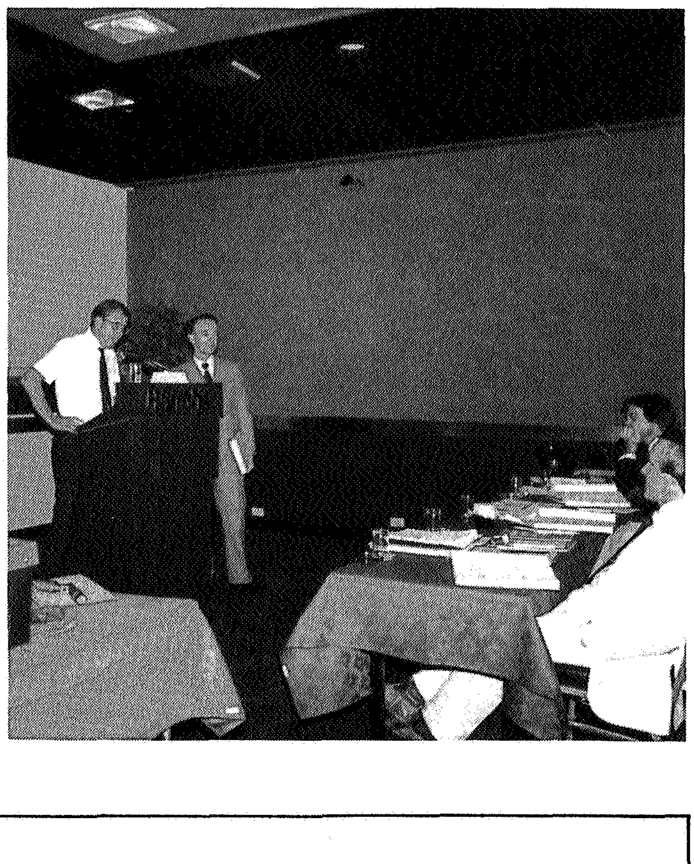
Volume 6 No. 1, November 1984

AIC 5th ANNUAL CONFERENCE

'The Implementation and Effectiveness of Air Infiltration Standards in Buildings' – a Conference Report

Reno, Nevada in the United States provided a colourful setting for the Air Infiltration Centre's 5th annual conference. In recognition of an urgent need to implement, as effectively as possible, research knowledge in the design, construction and retrofit of buildings, the theme of the conference was devoted to air infiltration standards. Over 70 attendees from 12 countries were attracted to the meeting including invited speakers from Japan and Germany.

The keynote address was presented by John Millhone, Director of the Office of Building Energy Research and Development at the Department of Energy in Washington DC, USA. The focus of the address was on the role of air infiltration in energy conservation. John highlighted the significance of this topic by pointing out that a 1% reduction infiltration and ventilation rates would reduce annual US energy costs by approximately $300 million. He went on to state that the thrust of American infiltration and ventilation research is intertwined with many energy conservation research activities, the most current of which is commercial building systems integration. Other important areas include retrofit of existing buildings, indoor air quality studies and residential building systems. It was recommended that the most important contribution that those engaged in air infiltration and ventilation research could now make was to show how their knowledge can be used to design, build and operate energy efficient buildings that offer healthy, productive and attractive environments for their occupants.



Inside this issue . . .

This theme was taken up by Peter Jackman of the Air Infiltration Centre who provided an overall review of current airtightness and ventilation standards in twelve countries. He pointed out that increasing attention to the reduction of energy consumption in buildings and greater awareness of the need to maintain acceptable indoor air quality has led to the development of standards.

The approaches of individual countries to the question of airtightness standards and the consequences of such standards were highlighted by several authors. Max Sherman from the Lawrence Berkeley Laboratory in the USA concentrated on a proposed new ASHRAE standard for airtightness. This standard incorporates an airtightness classification scheme which, it is hoped, will ultimately be used to label the tightness of all types of buildings. Another important feature of this standard is that the recommended level of airtightness will be dependent on the climatic zone in which the building is located. Jørn Brunsell from the Norwegian Building Research Institute analysed current Norwegian standards and indicated that these had little effect on the basic construction principles for most buildings; the main problem was to ensure that ventilation needs were properly satisfied. Willem de Gids from TNO, Delft, described the current approach in the Netherlands to airtightness. He indicated the desired level of airtightness for acceptable natural ventilation in the Dutch climate and indicated some of the difficulties being experienced with over-tight houses. An architects' and energy consultants' point-of-view on the Swiss energy performance standard for energy conservation in buildings was put forward by Conrad Brunner from Switzerland. He pointed out that the standard leaves aspects such as air infiltration reduction to the planner whose main objective is to satisfy the overall energy demands of the standard. Methods of achieving this standard were described.

In the wake of recent concern over the level of indoor air pollution, investigations into minimum ventilation rates have become particularly important. This aspect was covered by several papers. Lutz Trepte of Dornier Systems in Germany described the IEA Annex IX programme on this subject, while David Harrje from Princeton University in the USA traced the history of the ASHRAE Standard 62 on ventilation for acceptable indoor air quality. In the latter presentation attention was devoted to present revisions to the standard with emphasis on ventilation efficiency, the handling of particulates and problems concerning the wide variability in residential ventilation rates. The discussion on this standard was continued by David Grimsrud from the Lawrence Berkeley Laboratory in California, USA who dealt with procedures concerning the use of target concentrations of indoor air contaminants as a basis for deciding the adequacy of ventilation rates. Indoor air quality in commercial buildings was discussed by Elia Sterling from TDS Ltd., Canada who concentrated on the compilation of baseline data for assessing the ventilation needs of office buildings, and by Bryan Smith of Brunel University in the UK who described the use of carbon dioxide monitoring to control ventilation rates according to occupancy. Indoor air quality in relation to the airtightness of dwellings was the subject of papers by Jorma Railio from Finland and Richard Helmeste from Canada. The first of these two contributions concentrated on the difficulty of introducing airtightness requirements without first considering guidelines for ventilation arrangements. Typical problems being encountered in tight Finnish houses included insufficiently ventilated bedrooms and the build-up of pollutants. Contaminant build-up in houses was taken up in further detail in the second contribution with particular reference to radon and formaldehyde.

Some airtightness measurement methods are themselves subject to standards and one such approach was discussed by John Haysom from Scanada Consultants Ltd. in Canada. This standard, yet to be implemented, concerns the fan depressurization method and the analysis of data to present airtightness performance in the form of equivalent leakage area. A technique for the calibration of building pressurization devices was described by Andrew Persily from the US National Bureau of Standards in Washington DC. This facility enables the flow rate through a pressurization fan to be accurately determined as a function of fan speed.

Several authors concentrated on the effectiveness of air infiltration standards as a means of conserving energy. Martin Liddament from the Air Infiltration Centre analysed the influence of climate on both ventilation needs and the cost effectiveness of airtightness measures. The objective of his paper was to show that universal standards may not necessarily be appropriate and it is necessary for each country to pay careful attention to its own individual requirements. Ake Blomsterberg from the National Testing Institute in Borås, Sweden also concentrated on the influence of climate on airtightness requirements. He described the results of measurements and calculations which showed the influence that climate had over ventilation rates in buildings. His recommendation was that of complete airtightness and the use of mechanical ventilation to satisfy fresh air needs. The need to provide mechanical ventilation in airtight houses was taken up by Magnus Herrlin from the Royal Institute of Technology in Stockholm, Sweden. His contribution was devoted to analysing the performance of various ventilation techniques for dwellings.

There was also strong representation from Sweden on the performance of methods to achieve airtightness. Wall construction techniques for new dwellings were described by Lars Goran Mansson from the Swedish Council for Building Research, while Carl Axel Boman from the Swedish Institute for Building Research analysed the performance of both new and retrofit techniques. Johnny Kronvall from the Swedish National Testing Institute analysed the constancy of airtightness measures for periods up to 4½ years.

Other contributions concentrated on varied topics. Gunnar Lundqvist from Arhus University, Denmark dealt with occupant reactions to well-sealed buildings, particularly in relation to possible indoor air quality problems. Robert Dumont from the National Research Council in Canada presented a paper authored by John Shaw from the same organisation on the performance of passive ventilation systems in airtight homes. Finally, Hiroshi Yoshino from Tohoku University in Japan, analysed various calculation techniques used to relate building airtightness to air infiltration rates.

As with previous AIC conferences, a significant proportion of time was set aside for discussion. The final discussion session dealt with proposed standards, lack of uniformity of standards, the calibration of measurement techniques and problems associated with airtight buildings. Much of this discussion is reported in detail in the supplement to the conference proceedings.

A total of 21 papers presented at the conference have been published in a bound volume, price £16 inclusive of post and packing, available direct from:

The Air Infiltration Centre
Old Bracknell Lane West
Bracknell
Berkshire
RG12 4AH
Great Britain

A supplement containing additional papers and discussion notes will be available shortly at no additional charge.

6th AIC Conference

'Ventilation strategies and measurement techniques'

Call for Papers

Papers are invited for the 6th AIC Conference due to be held in the Netherlands from 16–19 September 1985. For all types of buildings, papers are expected to cover:

- design options for ventilation and adequate indoor air quality
- parameters of ventilation efficiency
- methods of achieving energy efficient ventilation performance
- effect of infiltration on ventilation effectiveness
- air exchange between spaces
- variable ventilation rate systems
- ventilation performance in occupied buildings
- methods of monitoring ventilation performance
- novel infiltration and ventilation measurement techniques
- developments in instrumentation

Papers should demonstrate some novel technical approach within the above subject areas but should not have an explicit commercial bias.

Please submit abstracts of relevant papers to the AIC office to reach there no later than Friday 15 February 1985. The abstracts will be subjected to review in March 1985 and accepted papers will be required, typed in print-ready form, by 5 July 1985. Whereas attendance at the Conference is restricted to AIC funding countries (see back page), submissions from non-funding countries are welcome and, if the abstracts are accepted, the authors will be invited to participate in the Conference.

Review of Air Infiltration Research in Finland

Reijo Kohonen, Lic.Tech., Seppo Ahvenainen, Lic.Phil., and Pekka Saarnio, M.Sc.Tech.
Laboratory of Heating and Ventilating
Technical Research Centre of Finland, Espoo, Finland.

Introduction

In Finland, there are three main topics in the field of air infiltration research:

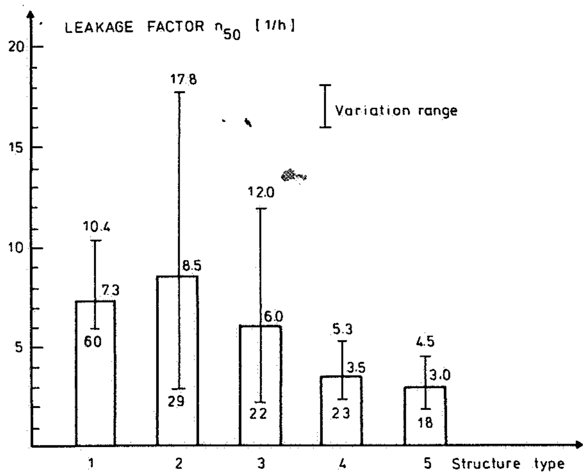
- simulation and measurement of air-leakage rates in building components and in buildings as a whole
- airtightness and indoor air quality (thermal comfort)
- thermal effects of air flow in building components.

The research work is mainly carried out at the Technical Research Centre of Finland. Both simulation and experimental methods have been developed during the last five years. The research work was started at the beginning of 1979 and aimed at developing methods for measuring the airtightness of buildings. Methods for determination of leakage functions of building components and simulation methods were also studied[1]. Since then, various pilot projects have also been carried out concerning controlled supply air intake through building envelopes, verification of the validity of an air leakage simulation model and of measurement techniques.

The current interest is to study the effects of air flow on the thermal performance of structures and buildings as a whole. Projects aimed at introducing supply air systems with draughtless air intake will also be continued.

Airtightness and infiltration rates of Finnish buildings

Pressure tests have been carried out in a large number of small houses, and an essential part of the results have been compiled as leakage data. Figure 1 summarizes the measurements, made mainly in 1980 and 1981. In the newest houses, the airtightness is, on average, further improved so that the average leakage factor at 50 Pa is about 3 to 4 ac/h.



Key:
1. Older wooden houses, sawdust insulation.
*2. New wooden houses built on site.
*3. Prefabricated wood element houses.
*4. Concrete element houses.
5. Lightweight concrete houses.
*With mineral wool insulation.

Fig. 1. Leakage factors at 50 Pa for detached houses

In larger buildings, some pressurization measurements have been made using the installed fans. At 50 Pa, the leakage factor in new building types is very often less than 1 ac/h.

Field measurements on local air leakages have been carried out using the collector chamber method[2]. Variations in local airtightness have been high, even in airtight buildings, which clearly shows the importance of the control of workmanship.

Examples of the average specific leakage rates of structural joints representing good quality airtightness are given in Table 1.

Table 1. Specific leakage rates of structural joints representing good quality airtightness. Measurements made with collector chamber method

Joint Type	10 Pa	50 Pa
1. Window frame joists joints to outside wall	5,8 cm^3/ms	15,1 cm^3/ms
2. Joints between frame and casement	19,4 cm^3/ms	61,4 cm^3/ms
3. Vertical joints between elements	10,0 cm^3/ms	44,0 cm^3/ms
3. Bottom joists joint to outside wall	31,6 cm^3/ms	133,3 cm^3/ms
3. Roof joists joint to outside wall	13,1 cm^3/ms	38,9 cm^3/ms

Key:
1. Sealing with polyurethane foam.
2. Double sealing (inner and outer frame sealed).
3. Wooden construction.

Calculation models for airtightness and ventilation systems

A multi-cell calculation model has been implemented for simulation of the interconnection between airtightness and air change rate. A quadratic flow equation is used in the model, a method which can be used for a single leakage path as well as the whole building envelope. Steady-state flow equations are applied to each leakage path to solve the mass flow balance of the building. Outside pressure distribution is calculated by using the mean values of wind pressure coefficient for each wall area and wind sector. The momentary wind pressure fluctuations are not taken into account in the calculations.

The physical reliability of the model was verified by comparing the results of calculations with those of the measurements in an existing building. The airtightness of various leakage paths was measured with the collector chamber method. The total airtightness of the building envelope, calculated with leakage data measured in the building, agreed well with the values measured with the pressure test. Good agreement was also obtained between calculated and measured infiltration rates (see figure 2).

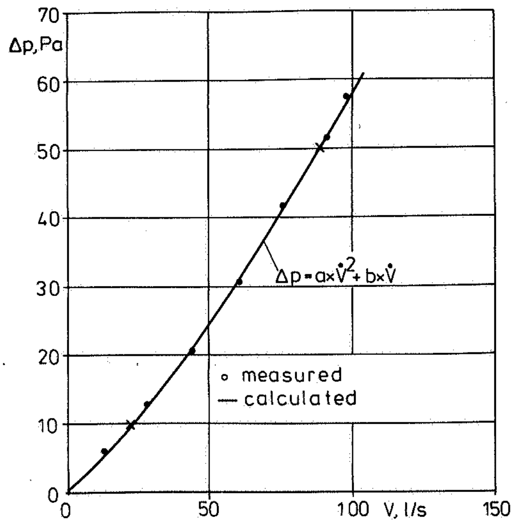


Fig. 2. Relationship between pressure difference and total air leakage of building envelope. Coefficients of quadratic flow equation were fitted by the experimental values at 10 Pa and 50 Pa (x)

As an example, pressure test curves calculated by the model of a detached house with masonry walls are presented in figure 3. The number of different leakage sites used to describe the air leakage characteristics of the building envelope was about 200. The share of the total air leakage of the building envelope calculated for various leakage sites at 50 Pa pressure difference is presented in Table 2.

The dependence of the average ventilation rate on the airtightness of the building envelope is presented in figure 4. The calculation period was 7 months (from 1st October to 30th April). The building was equipped with a natural ventilation system.

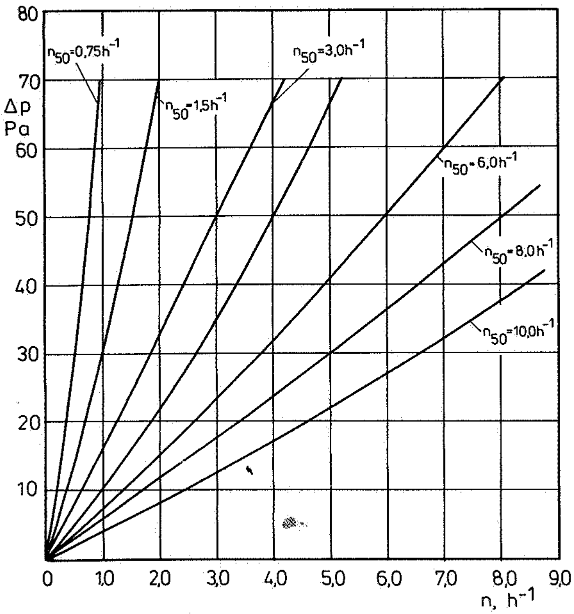


Fig. 3. Predicted pressure test curves for a detached house with masonry walls

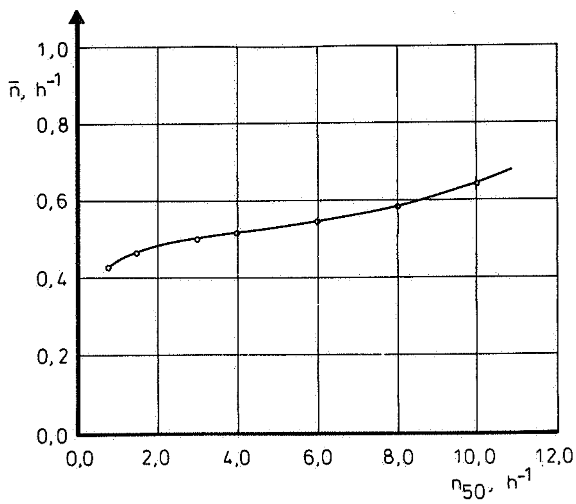


Fig. 4. Average ventilation rate vs specific leakage of building envelope. Detached house with masonry walls equipped with natural ventilation system (kitchen fan used one hour/day). Calculation period from 1st October to 30th April

Table 2. Distribution of total air leakage of various sites of the building envelope at 50 Pa pressure difference. Calculated for a detached house with masonry walls

Leakage site	Air change number n_{50}	
	$0{,}75\,h^{-1}$	$1{,}5-10\,h^{-1}$
– Roof joists joints to outside wall and joints between ceiling boards	24,0%	52–54%
– Window and door frame joists joints to outside wall	29,9%	2–15%
– Joints between frame and casement	16,0%	7–8%
– Penetrations of ceiling	12,7%	12–13%
– Electrical boxes	17,4%	11–14%

According to the calculations the model is working 'well enough'. Differences between the calculated and measured values are related to insufficient and erroneous input data rather than incorrect calculation principle. In larger buildings many simplifications are required for input data, which probably makes the model less realistic.

Another air infiltration model developed at VTT is based on a general hydraulic network analysis. The corresponding computer programe ANNE is based on the analogy between hydraulic and electrical systems. The network equation system is formulated using topological matrices. These topological matrices are formed immediately after the description of the interconnections between nodes and branches in the network. The equation formulation is based on a loop (or mesh) method, which uses the branch flows as primary unknown variables.

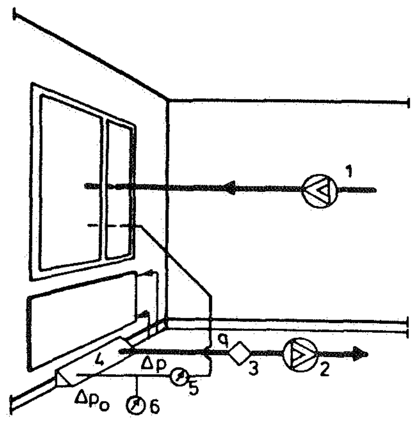
The interconnections between the nodes in the network contain any type of resistive elements, e.g. single resistance, leak, friction, as well as pressure sources. This means that simultaneous solution of the air-infiltration and the ventilation duct system is possible. The primary application of the present version of ANNE is for the analysis of flow pipe networks; the air flow version is still under development. Due to the efficient numerical algorithm and memory-saving computer implementation, it is believed that the program can solve large air flow network problems using moderate computer processing times.

Methods for measuring airtightness

The local airtightness in buildings is determined by the collector chamber method, where the room or the whole building is pressurized and the air leaking through the target area is collected by a pressure compensated chamber and discharged through a flow rate measurement devcice. An example of the test arrangement is shown in figure 5.

Instructions for local airtightness measurements and a sampling inspection method were developed as NORDTEST project 176-79[2]. The instructions are based on the collector chamber method developed at the Technical Research Centre of Finland (VTT). The object to be measured can be in any building or structure, which is exposed to pressure difference. However, the surface of the object must be directly accessible on the measurement side. Sampling inspection is used for structures which have equal tightness requirements and are of similar construction. Instructions for the measurement of local airtightness and the sampling and inspection procedure have been described in reference 3.

A new method for airtightness measurement in larger buildings has been developed. For blocks of flats, or other multi-cell buildings, the original pressure method is either



Key:

1. Adjustable auxiliary fan.
2. Adjustable measurement fan.
3. Volume flow meter (e.g. orifice plate).
4. Collector chamber.
5. Micro-manometer for the test pressure difference Δp.
6. Micro-manometer for the pressure difference Δp_o between collector chamber and room (zeroing indicator).

Fig. 5. Measurement of air leakage of joint between outer wall and floor

too laborious (flat by flat), or requires extensive measurement equipment. The elimination of leakages into/from other flats will often be complicated. These problems can be avoided by using existing supply or exhaust fans for pressurization or depressurization. Air flows in each supply or exhaust unit are measured as well as outdoor-indoor and flat-stairway pressure differences. The accuracy of the method depends on the devices used to measure air flow. Available methods in most cases are accurate enough for practical purposes, i.e. show if the building envelope is sufficiently airtight (pressure differences high, 30 to 100 Pa, small deviation) or too leaky (difficult to create a measurable pressure difference). In some cases the test can also show whether or not the ventilation system is properly adjusted. From recent experience, it is quite clear that this method is applicable in small houses, e.g. semi-detached or terraced, as well as taller buildings having good airtightness and mechanical ventilation – no 'test fans' will be necessary there.

The method has been applied in a new office building which consists of about 1000 office rooms. Outdoor-indoor pressure difference was measured from 68 points at various floors. The specific leakage of the building envelope, estimated by using the results of the outside under- and over-pressure operating conditions, was about 0,5 ac/h. When the exhaust fans were run at full capacity, the ouside over-pressure averaged 150 Pa. The measurements were carried out in about three man-days (including preparations).

Controlled supply air intake through building envelope

During the last few years airtight buildings have been planned and built in Finland. In many cases old buildings have been made tighter. The low energy consumption of these buildings may be due to better insulation and reduced ventilation rate. When the building envelope is airtight, the performance of ventilation may be poor if there is no controlled supply air intake. High concentrations of impurities such as radon and formaldehyde may occur, and the moisture content of indoor air may be high. Living in these buildings is uncomfortable.

To avoid the problems of uncontrolled air supply, there have been many efforts to develop systems and devices to control the supply air intake through the building envelope, both for new and existing buildings. The problems can be solved easily in new construction as various devices can be installed in walls, etc. In existing buildings, the installation of new equipment in the walls can usually be done only as part of a major retrofit project. One such possibility is to replace the windows with a better quality product.

Among the several alternatives for the intake of outdoor air to a ventilated space, is the supply air window which provides a designed path for the airflow. The window itself may be double- or triple-glazed casement type with various weatherstripping possibilities. The air may be taken in through the airspace between the window panes or through designed holes in the sash. The incoming air is warmed by heat escaping through the window.

According to the results of recent research work[4], about 6,0 dm^3/s of outdoor air per m^2 window area can be taken in without draughts through a wooden frame window with double-glazing. The incoming air was heated to about halfway between the inside and outside air temperatures. Draughts in the room were mainly at ankle level and the air current along the floor could be considered dominant. The best alternative was where air was taken from the air space into the room through holes in the upper sash of the inner pane with a deflector directing the air upwards.

Airtightness requirements and recommendations

In the Finnish Building Code there are at present, no requirements or standards concerning the airtightness of building envelopes. As a result of the research work, a preliminary suggestion for airtightness requirements was presented both for new and existing buildings. In developing the suggestion, the performance and costs of the construction and ventilation systems, necessary to achieve good airtightness and sufficient controlled ventilation, are taken into account. The deviations from the Swedish requirements are not significant (though given only as guidelines), but we have found it necessary to add the following recommendations:

- leakages through cracks and joints should be limited in order to avoid local draughts
- the supply air routes through the building envelope should be presented in the design
- certain requirements for the supply air intake devices should also be given.

Prefabricated building elements generally have good airtightness. Infiltration depends more on the quality of workmanship than on the structural materials. The control of construction is also important.

The development of airtightness requirements should be based on detailed calculations, measurements and international discussions. The interconnections between the building envelope and construction must be taken into account. In the Finnish climate, the best performance (good indoor climate with minimum energy costs) can be achieved by a controlled ventilation system in which controlled supply air routes through the building envelope are included – but the uncontrolled infiltration should be insignificant.

Thermal effects of air flows in building components

The thermal performance of building components is strongly affected by internal air flows. Natural convection in a closed space has been widely studied. Combined natural and forced convection is obviously more significant for the thermal performance of wall structures than purely natural convection flows. In principle, two different cases can be distinguished:

(i) airflow through structures from outside to inside or vice versa

(ii) airflow through structure from outside to outside.

In the first case, the incoming air will warm up and the transmission heat flow will be smaller at the outer surface of the structure than that without leakage flow. Depending on the ventilation system this would be advantageous or disadvantageous in a thermal sense. If the leakage were from inside to outside then the transmission heat flux would be greater than in the undisturbed case. Figure 6 shows the temperature profiles of air leaking through joints of the wall structure and foundation. Figure 7 illustrates the corresponding temperature and heat flux patterns in the structure.

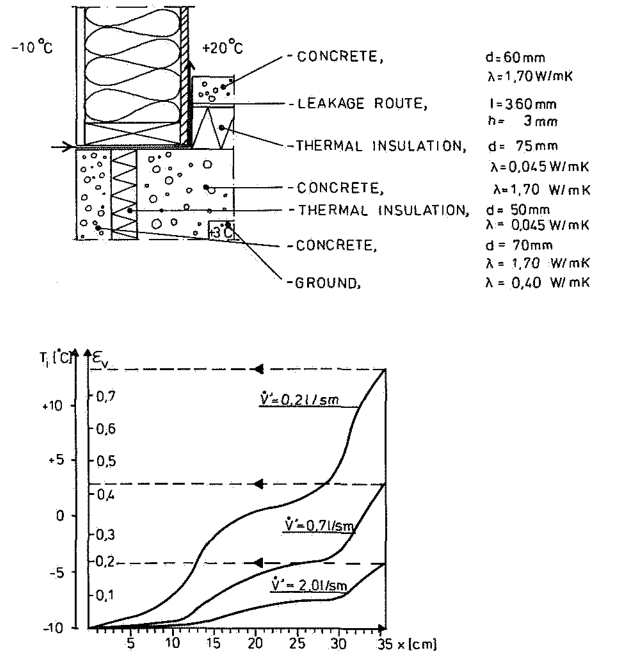


Fig. 6. Heating of leakage air in crack between wall and foundation structure

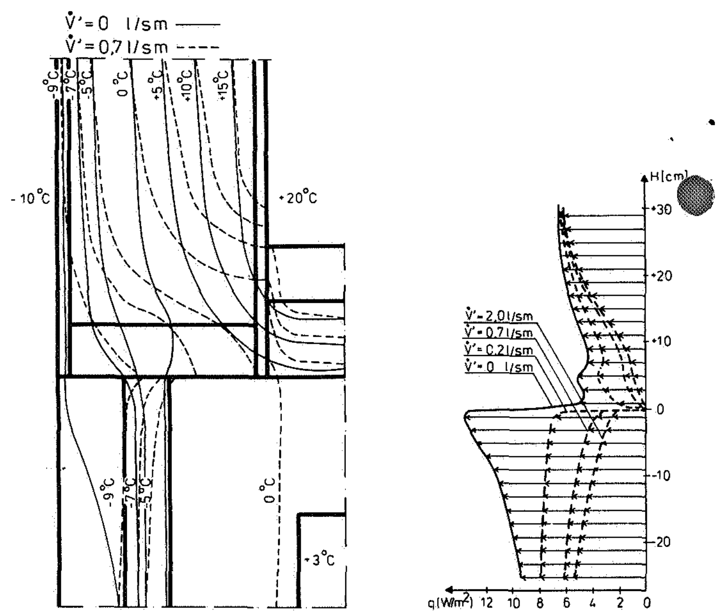


Fig. 7. Temperature and heat flux profiles corresponding to figure 6

These results were obtained by computer simulation. According to the preliminary results it was found that the heating of incoming air is of significant importance. The recuperation ratio may rise to 0.5 – 0.8, which means that the heating load of incoming air is much less than is commonly assumed. The heating of incoming air will be afforded a more detailed study in a project to be started in 1985.

If the leakage route were through the building structure from outside to outside, then the convection heat transfer would cause extra heat losses. As previously stated, the phenomena of natural convection in a closed space have been widely studied and it is known under which conditions natural convection will support extra heat losses. In practice, some air leakage nearly always occurs through structures as pure natural convection conditions very seldom exist. Figure 8 gives temperature profiles in a 0.3 x 2.2m wall with and without an airtight layer at the cold side. As shown, the calculated and measured temperature profiles are in good agreement. These results themselves show that even with extreme care, the thermal performance of insulation is far from ideal. Furthermore, convection flow is strongly increased when the structure becomes more leaky and when the total pressure gradient is increased.

In practice, wind may cause significant pressure gradients within the building envelope, which result in poor thermal performance. The effects of wind (pressure) can, however, be reduced using a continuous ventilating air gap with flow restrictions at the inlet and outlet. According to the measurements in a test house, the wind pressure gradients in a ventilation gap may be reduced to one tenth by this means. The results of simulations and experiments carried out in laboratory and field (concerning the thermal effects of air flow in building structures) will be reported in the next few months.

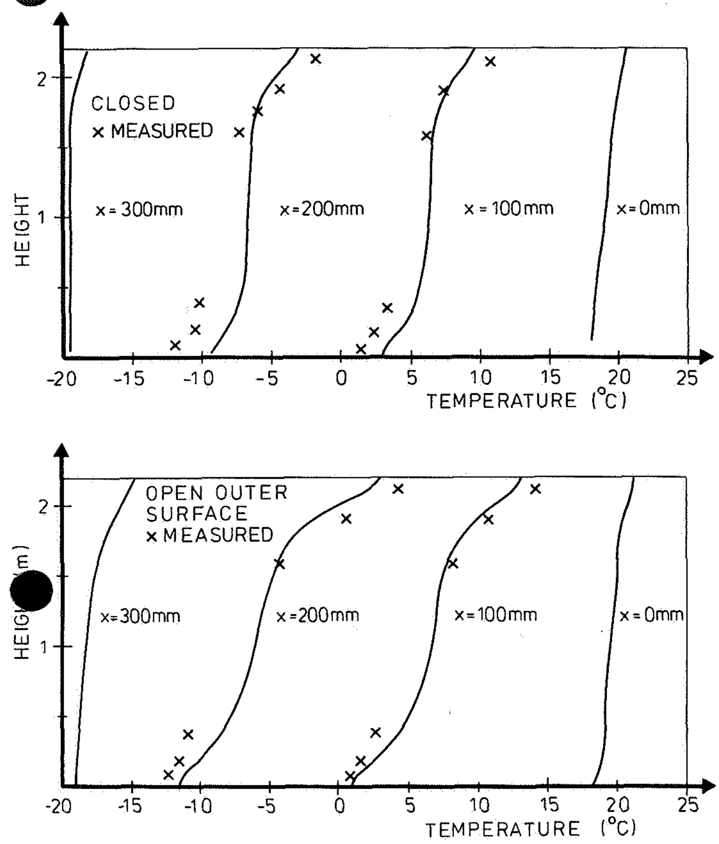


Fig. 8. Temperature profiles in a closed and semi-open space filled with fibrous insulating material

Conclusions

Knowledge about the airtightness of Finnish buildings has been signficantly increased during the last five years. But there are still problems to be solved. Areas which need supplementary research are:

- correlation between airtightness, air change rates and thermal performance
- air change rates in various rooms in an airtight building
- arrangement of supply air intake through the building envelope in airtight buildings
- durability of the airtightness of buildings and structural joints
- moisture problems due to air leakage.

Many problems concerning air quality have also been discussed recently, and they have been found to be associated with airtightness, ventilation or air infiltration. Increased co-operation is needed between structural and HVAC engineers in the design and construction of buildings. Structures and ventilation systems influence each other – the calculation models are a useful tool in approaching the design as a whole. Requirements and standards on indoor climate, control of pressure conditions and air flow etc., need further development.

References

1. Railio, J., Saarnio, P. and Siitonen, V.,
Air infiltration research in Finland. Espoo 1980.
Technical Research Centre of Finland, Laboratory of Heating and Ventilating, Report 52, 26p + app. 12p.
2. Siitonen, V.,
Measurement of local airtightness in buildings. Espoo 1982.
Technical Research Centre of Finland, Research Notes 125. 17p + app. 12p.
3. Local airtightness.
Standard NT BUILD 220. Nordtest method.
4. Korkala, T., Saarnio, P. and Siitonen, V.,
Air intake arrangements of the supply air window from the view point of comfort and ventilation efficiency.
Windows in Building Design and Maintenance. Göteborg, Sweden, 13–15 June 1984. Proceedings appendix, Part 2.

Book Review

Infiltration, Energy Conservation and Indoor Air Quality
Michael S. Krzaniak, Carleton University, Canada

This publication contains a detailed review of the significance of air infiltration in terms of both building heat loss and indoor air quality in Canadian dwellings. The value of air-to-air heat recovery units as a means of minimising ventilation heat loss is also considered.

The first section describes air infiltration mechanisms and includes a table of common leakage sites, listed in terms of relative significance. This is followed by an analysis of ventilation heat loss calculations. The importance of fresh air exchange is emphasised and it is pointed out in the text that air infiltration is often the only source of make-up air in dwellings. As a consequence, it is possible that airtightness measurements may result in unacceptable levels of indoor air quality. The concept is introduced of the 'problem home' in which high concentrations of pollution occur and the common characteristics of such homes are described. Pollutants are classified in terms of 'carcinogens', 'anoxins' such as carbon monoxide and 'irritants' such as odours. The health effects of many pollutants falling within each category are described in detail and the ventilation rates necessary to minimise harmful effects are discussed.

The prospect of reducing the heating load by using air-to-air heat recovery systems is considered both from thermal and economic viewpoints. The advantages and disadvantages of various types of heat exchangers are analysed and the thermal performance of each is assessed.

It is concluded that, in general, heat exchangers are effective in conserving energy and in improving indoor air quality, but their performance will vary according to the type of pollutant, the choice of heat exchanger and the methods of installation. In terms of cost effectiveness it is argued that, at current prices, the installation of such devices is not normally economically feasible.

This publication ends with a comprehensive bibliography; it is available price $12 (Canadian) from: Dr. J.T. Rogers
Department of Mechanical and Aeronautical Engineering
Carleton University, Ottawa, Ontario, K1S 5B6, Canada

The Influence of Air Leakage on the Condensation Behaviour of Lightweight Roofs

H. Hens and F. Vaes
Laboratory of Building Physics
Katholieke Universiteit, Leuven, Belgium

Introduction

This paper deals with the research on interstitial condensation in lightweight roofs, caused by air leakages. Discussed are the theoretical background, the admittance measurements and the experimental work on roofs.

Theoretical modelling[1]

Normally, the condensation behaviour of construction elements such as walls, roofs and floors is predicted by Glaser's method. One of the hypotheses of this method concerns the driving force of vapour transfer – *diffusion only.* Laboratory research over a long period and observations in situ show that, for heavy constructions and constructions without cavities (as long as the initial moisture condition is properly taken into account), the moisture content remains below the critical value. If attention is paid to a good choice of climatological conditions, i.e. calculating with a condensation-sol-air outside temperature, the calculated prediction compares favourably with actual measurements. Nevertheless, research in problem buildings with lightweight, flat or sloped roofs shows either a nil or poor correlation between the Glaser prediction of observed interstitial condensation in the roof and reality. Important differences are:

- condensation in roof sections where, according to Glaser's method, this is not possible
- much more condensation than calculated
- with sloped roofs, a remarkable correlation between 'slope with interstitial condensation' and wind direction
- condensation appears to be a quick-reacting phenomenon, while diffusion is a very slow process.

The reason for these contradictions seems to be the leakage of warm inside air through the roof to the outside, the driving forces being wind pressure and temperature differences. The calculation model therefore needs a broader basis, taking into account moisture transfer not only by diffusion but also by air flow. So a three-step stationary *convection + diffusion* model was developed (KONVEK[1]):

Step 1

Calculation of the air flow through a construction element using as the material or layer property, the airflow *admittance* and the difference in wind pressure (no thermal stack) as the boundary condition. The calculations are based on the mass-conservation law and the flow equation:

$$\phi_{m,a} = A \times \Delta p_a \times A$$

where A = airflow-admittance of a material, layer, leak or cavity – A being $f(\Delta p_a)$ (s/m)

Δp_a = the pressure difference (Pa).

A difference technique is used, resulting in a system of linear equations with variable coefficients.

Step 2

Calculation of the temperature distribution and heat fluxes using the following equation for each point of the difference grid:

$$\Sigma\phi_i + \Sigma(\phi_{m,a,i} \times h_i) = 0$$

where ϕ_i = the heat flow by conduction (W)

$\phi_{m,a,i} \times h_i$ = the enthalpy-flow, coupled to the air flow

Step 3

Calculating the vapour pressure distribution, vapour fluxes and condensation/drying rate, using the following equations for each point of the difference grid:

$$\Sigma\phi_{m,i} + \Sigma\left(\phi_{m,a,i} \times \frac{x_i}{1 + x_i}\right) + \phi_m^{c,d} = 0$$

$$x_i \leqslant x_s$$

$$x_i = 0{,}622\ \frac{p_i}{p_a - p_i}$$

where x_i = vapour concentration (kg/kg)

$\phi_m^{c,d}$ = condensation or drying rate

p = vapour pressure

Steps 2 and 3 also lead to a system of linear equations, now with constant coefficients. The same is true for Step 3 with the vapour concentration or the condensation drying rate as variables, depending on $x_i \leqslant x_s$. An iteration between Steps 2 and 3 becomes necessary, depending on high, or nil, condensation.

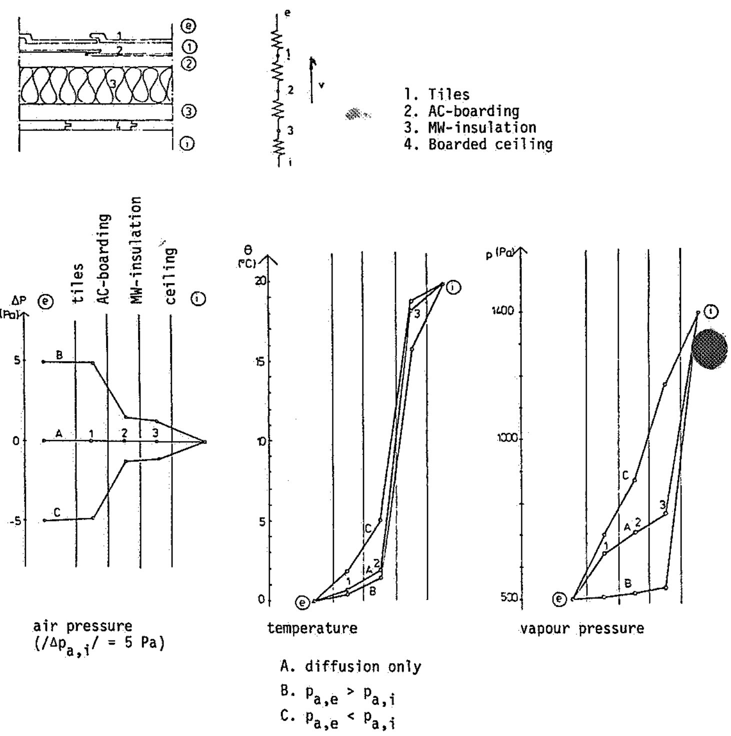


Figure 1

With the new *convection + diffusion* model, different sloped roof sections were considered (1-dimensional calculations) (see figure 1). The results show that

- with air leakage, the temperature and vapour pressure distribution in a construction element change drastically
- condensation also takes place on surfaces other than those found with Glaser's method

- for low pressure differences ($p_{a,i} > p_{a,e}$), the condensation rate grows rapidly with rising pressure difference to reach a maximum for a given difference and reduces to zero for still higher pressure differences
- as soon as air leakage plays a part, the impact of diffusion practically disappears.

Air Leakage Measurements[2,3]

An important material or layer property, used in the *convection-diffusion* model, is the air flow admittance *A*. Hydraulics show that $A(\Delta p_a)$ fits fairly well with a function:

$$\Delta p_a \leqslant \Delta p_{a,cr} \qquad A = C^t = A_o$$

$$\Delta p_a > \Delta p_{a,cr} \qquad A = a\,(\Delta p_a)^b$$

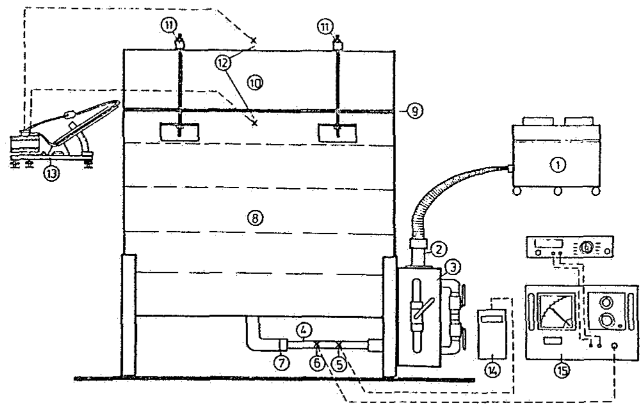
In the context of a research program on sloped roofs, $A(\Delta p)$ has been measured for different roofing materials, ceiling systems and roof-sections, with a one-chamber under-pressure box 0,72 m^3 in volume and with a measuring surface of 0,87 m^2 (see figure 2). The box is coupled to an industrial extractor by a ducted supply with a flow rate measuring device. The air flow is regulated by a system of valves. The pressure difference over, and the air flow through, the element under test are measured. The results are given in Table 1. An important conclusion to be drawn from these results is that a tiled roof acts as a very air-open system.

Table 1. Air flow admittance for roofing materials, ceiling systems and different roof-sections

	a (s/m)	b	$p_{a,cr}$ (Pa)	A_o (s/m)
Roofing Material				
Ceramic tiles (single closing)	0,011	–0,045	0,2	0,012
Ceramic tiles (double closing)	0,013	–0,51	0,2	0,029
Concrete tiles	0,0064	–0,46	0,04	0,028
Slates	0,0042	–0,21	0,32	0,0053
Metal tiles	0,0016	–0,41	1,1	0,0016
AC-slates	0,0014	–0,303	1,24	0,0013
Corrugated AC plate	0,00073	–0,362	4	0,00044
Ceiling				
Board ceiling	0,00038	–0,26	2,9	0,00028
Gypsum board	$3{,}1.10^{-5}$	–0,19	59,2	$1{,}4.10^{-5}$
Roof Sections				
Tiles-insulation-vapour barrier-board ceiling				
Vapour barrier 'Airtight'	$1{,}45.10^{-5}$	0		
'Air-open'	$1{,}62.10^{-4}$	–0,292		

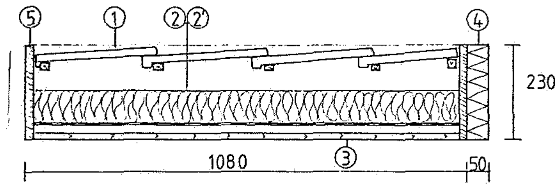
Experiments on roofs[3]

To prove the validity of the air leakage model, two hot box – cold box experiments on sloped roof sections were set up (see figure 3).



Key:
1. Industrial extractor.
3. Valves.
5,6. Air velocity meters.
8. Underpressure box.
10. Sample.
13. Pressure difference meter.
15. Measuring devices.

Figure 2. Under-pressure box



Key
1. Tiles.
2,2'. Insulation layer with vapour barrier, correctly or incorrectly installed.
3. Boarded ceiling.

Figure 3. Sloped roof sections

Roofs (from underside to upperside)

- a boarded ceiling
- air cavity
- insulation layer, d = 60 mm, with vapour barrier (in the *first roof* the vapour barrier is correctly installed, in the *second roof* it is not)
- air cavity
- ceramic tiles.

Studied parameters

- airtightness of the insulation layer with vapour barrier (see above)
- airtightness of the ceiling (during the measuring period, after 10 weeks, a 20 mm diameter leakage hole was drilled in both ceilings)
- pressure difference over the roof (during the measuring period, after 16 weeks, the pressure difference was brought from 1 Pa to 7 Pa ($p_{a,i} > p_{a,e}$).

Boundary conditions:

	θ °C	p Pa	Δp_a Pa
Warm (inside)	20,2	1570	1 to 7
Cold (outside)	1,2	570	1 to 7

Measuring results:

Roof	Week	Δp_a	Condensation Y/N	Surface?	Rate kg/(m²d) x 10^{-3}
1. (Airtight vapour barrier)	1–10	1,5	N		
	11–16 (+ leak in ceiling)	1	N		
	17–19 (+ leak in ceiling)	7	N		
2. (Airleaks in vapour barrier)	1–10	1,5	N		
	11–16 (+ leak in ceiling)	1	Y	Underside tiles	33
	17–19 (+ leak in ceiling)	7	Y	Underside tiles	120

These experimental results were in good accordance with the *diffusion + convection* calculations, taking into account an 'inside' airflow through the roof and an 'outside' airflow under the tiles (tiles = 'air open').

Conclusions

From practical experience and theoretical and experimental research, it seems clear that in many cases for lightweight, flat and sloped roof structures interstitial condensation is, to a large extent, coupled with air leakage (warm inside air with a higher vapour concentration passing through the roof). Therefore, the most important design rule should not be 'use a vapour barrier' but 'construct an airtight ceiling system'. In many cases where this is impossible, an airtight barrier at the warm side of the insulation is needed. So, it is better to talk about a *vapour + air* barrier:

Vapour-tight = using a suitable material

Airtight = no leaks

The research also shows that the influence of ventilation on energy consumption is only one aspect of the whole air leakage problem. Nevertheless, information is needed concerning:

- the wind pressure distribution inside and outside a building, with low wind velocities
- the influence on that distribution of changes in airtightness in the building envelope.

References

1. Vaes, F.
Hygrothermal behaviour of lightweight, externally ventilated roofs.
Report research program KUL-TCHN-IWONL, Leuven 1984 (in Dutch).
2. Hens, H.
Moisture behaviour of sloped roofs.
Report research program KUL-WTCB-IWONL, Leuven 1984 (in Dutch).
3. Lecompte, J., Mulier, G.
Airtightness and moisture flow through sloped roofs.
Leuven 1984 (in Dutch).

Indoor Air '84

20 – 24 August 1984
Stockholm, Sweden

The main outcome of this five day conference was probably indigestion – *both technical and physical*. The former resulting from a total of 300 presentations on subjects ranging from the optimum environment in operating theatres to the effect of artificial electrical fields on cows. The latter because the programme extended from 8.30am to 6.30pm with little or no mid-day break.

Whereas the first conference in this series on indoor climate held in 1978 was mainly concerned with the thermal environment, the emphasis of this conference was very much biased towards indoor air quality. The papers were separated into five volumes. Volume 1 contained the 15 Keynote Addresses and these provided general coverage of the main topics under the title 'Recent advances in the health sciences and technology'. In addition, some papers on policy and regulatory issues were included.

The second group of papers was entitled 'Radon, passive smoking, particulates and housing epidemiology'. Of these, the subject of passive smoking seemed to generate most controversy with some indicating the need for more research to determine the risks associated with involuntary smoking while others, somewhat passionately, claiming that the evidence of damage to health is unequivocal.

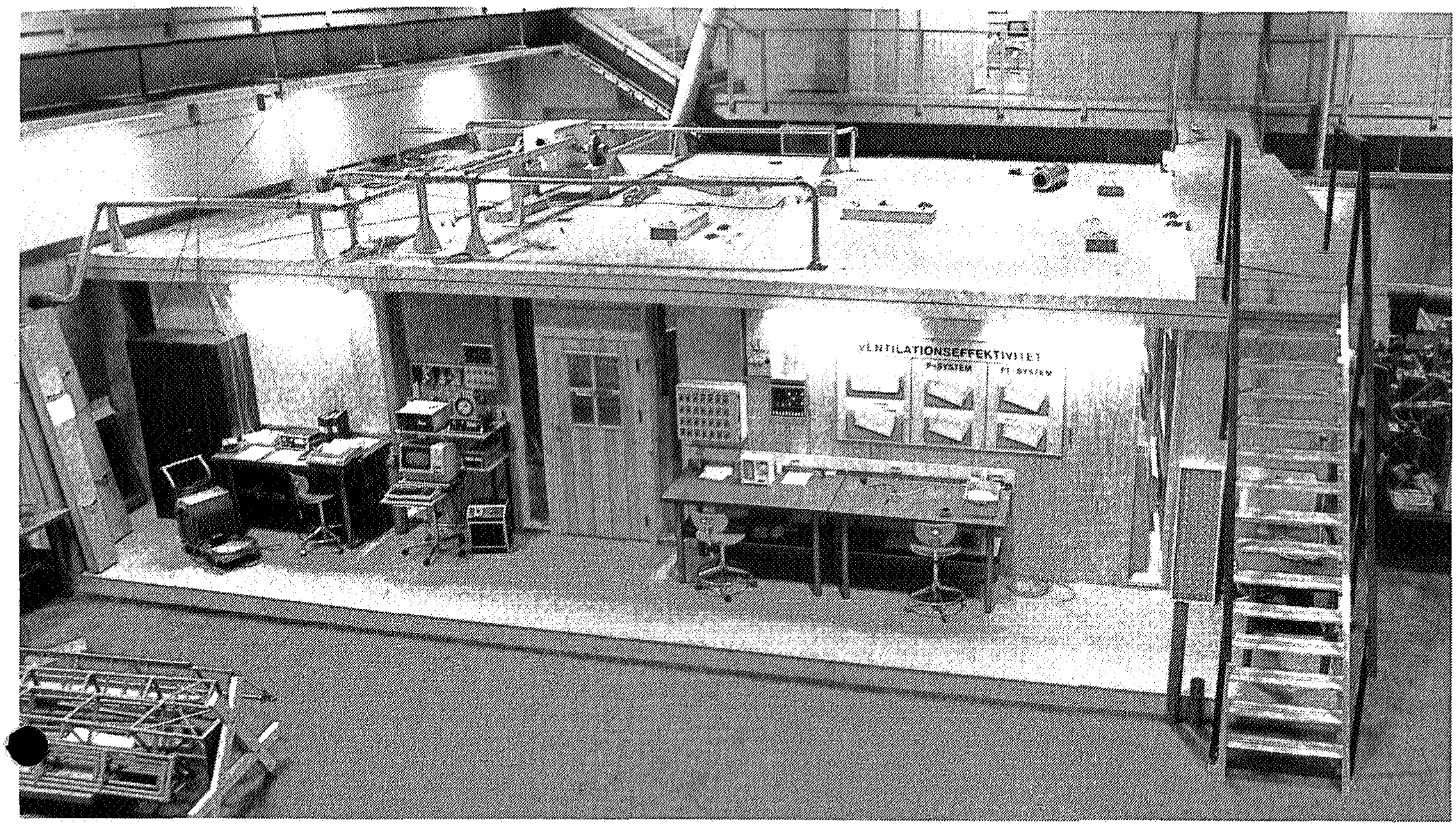
Studies relating to formaldehyde were reported in papers grouped in Volume 3 'Sensory and hyper-reactivity reactions to sick buildings'. This group also included papers on allergens and micro-organisms as well as the effects of ionization. Sensory and physical reactions to odours and respiratory irritation were also discussed.

The subject of personal exposure was considered more thoroughly in Volume 4. In addition to consideration of sampling and analytical techniques, papers were presented on exposure to nitrogen oxides, carbon monoxides, and other gaseous pollutants. Pollution associated with particular appliances such as unvented kerosene heaters was also included. This category was entitled 'Chemical characterisation and personal exposure'.

The fifth volume 'Buildings, ventilation and thermal climate' encompassed papers dealing with technical solutions to the provision of acceptable indoor air quality and thermal environment. Such topics as ventilation criteria, efficiency and measurement were included here. The papers on thermal climate related to requirements for comfort, the impact on occupant performance and instrumentation.

The papers on ventilation efficiency again emphasised the need to consider the pattern of room air movement when designing for the effective removal of airborne contaminants. Recent research on the rate of ventilation required to minimise the perception of body odour was also reported. It was concluded that a ventilation rate of eight l/s per person was needed. On the other hand, to avoid undue risk from ambient tobacco smoke, one author concluded that a ventilation rate of 2700 l/s was required!

One's initial reaction to the Conference was of almost total despair at the multitude of pollutants that invade the air we breathe and potentially produce undefined risks to our health and well-being. This reaction was tempered with the conclusion that, at least in most buildings, the internal environment was generally satisfactory and that relatively few were known to cause problems of discomfort and ill-health. Perhaps soon there will be a more positive approach so that researchers will be concerned not just about the avoidance of unwanted contaminants but about the provision of a stimulating atmosphere that will enhance both the well-being and performance of the occupants.



An Indoor Test House

Mats Sandberg
National Swedish Institute for Building Research
Gävle, Sweden

Introduction

The test house is located in the Institute's laboratory hall. This new facility (see above) will mainly be used for the study of alternative ventilation strategies in tight houses. However it will also be used for basic air infiltration research.

The main reason for building the house indoors, is to obtain a controlled environment both with regard to the ambient temperature and the flow rate of outdoor air supplied. Therefore the house is well suited for use in connection with the development of different measuring methods and in particular the determination of their accuracy (the accuracy of methods for measuring the infiltration rate is more or less unknown at present).

Technical description

The house has five 'rooms' (see figure 1) and a total volume of 176 m^3 while the total floor area is 70 m^2. One wall of the house consists of the existing south facade of the laboratory hall. In the wall on the opposite side there is a cooling chamber. The air temperature in this chamber can be reduced to −25°C. The house is heated by electrical radiators or by heating the supplied ventilation air, and can alternatively be ventilated by forced or natural ventilation. Natural ventilation is simulated by heating the house to a higher temperature than the ambient air. To increase the stack effect the house is equipped with a 'ventilation' stack (not shown above) connected to outdoors.

Both above and below each internal door there are adjustable gaps. The air movement in the doorways is shown by releasing smoke (see figure 2). To enable inspection from outside there are several strips of glass in the building envelope. The following quantities are normally monitored in each room:

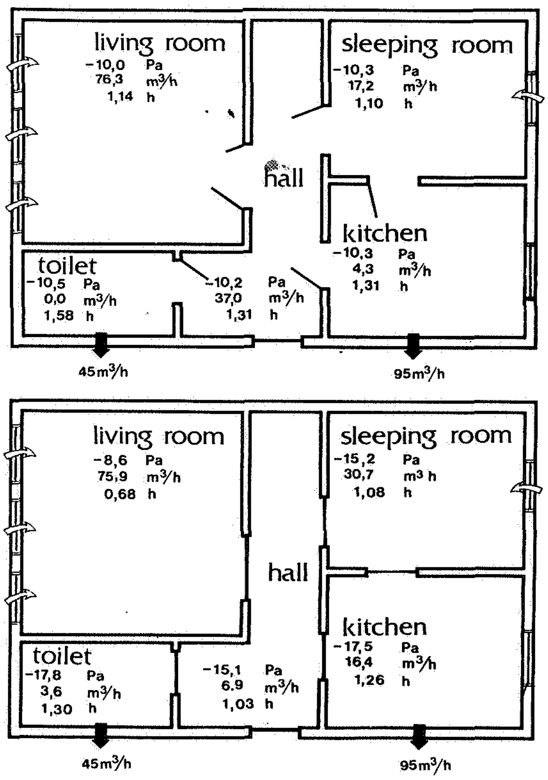


Figure 1

- temperature
- pressure
- tracer gas concentration (N_2O)
- CO_2 concentration.

The whole measuring sequence is controlled by a computer which also starts and stops the mixing fans.

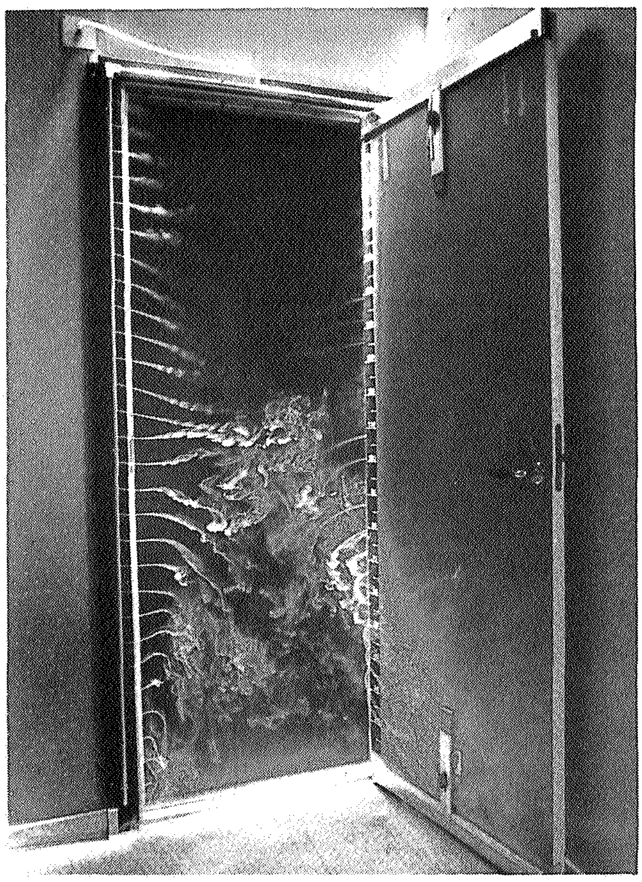


Figure 2

Ventilation efficiency studies

When the performance of different ventilation schemes are evaluated, the measuring sequence in each room is normally as follows:

- temperature
- pressure
- flow rate of outdoor air
- mean age of air
- a repeat measurement of temperature and pressure.

The total flow rate of outdoor air to each room is measured by the constant concentration tracer-gas method. An example of results obtained with a mechanical extract system in operation is shown in figure 2.

In the first case all internal doors were open and in the second they were closed. The slot ventilators in the living and the sleeping rooms were open and the air was extracted from the kitchen and the toilet. The total flow rate of outdoor air amounted to 140 m^3/h which corresponds to a nominal time constant (the total volume divided by the total flow rate of air) equal to 1.25 h. In figure 1, the pressure (reference is the laboratory hall), the predicted flow rate of outdoor air and finally the mean age of the air is given for each room. When the doors are closed the mean-age of the air in the whole house drops from 1.28 h to 1.03 h. This implies that the air present in the house is replaced (exchanged) by new air more rapidly when the internal doors are closed.

Methods for determining the infiltration rate

The accuracy of different tracer gas methods is being explored as a part of the main project. Determination of the total infiltration rate by the decay method is based on the assumption that complete mixing is achieved in the whole ventilated space. When this is so the mean-age of the air at every point in the room is equal to the nominal time constant. Tests carried out with two mixing fans in the living room and one fan in the other rooms show that the variations of the mean-age of the air between the rooms lie in the range 10–30%. However the slope of the decay curve reflects a mean-value and therefore the variations of the slopes are less (5–20%).

The advantages of the more expensive constant concentration method are claimed to be as follows:

- the prediction of the total flow rate with a high degree of accuracy
- the prediction of the amount of air entering each separate room
- the prediction of the time dependent infiltration rate.

The results shown in figure 1 indicate that the total flow rate is predicted with an accuracy between 3–5%. However, when it comes to the second point above, i.e. the distribution of the air entering the house, the accuracy seems to be much lower.

It is difficult to understand why the total infiltration rate to the hall should be much greater when the doors are open compared with when all internal doors are closed. However, it should be stressed that these results are very preliminary.

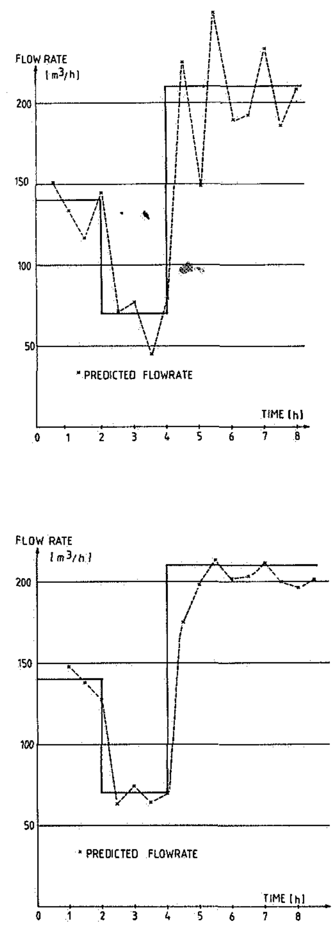


Figure 3

An example of the constant concentration method's ability to predict a time varying total infiltration rate is shown in figure 3. The response to a step change in total infiltration rate is shown. The predicted value constitutes an average over a time period of half an hour. In the first figure a control algorithm with a proportional and integration part has been adopted. In the other figure a derivation term has been added in the former control algorithm.

Order Form

Name ....

Organisation ....

Address ....

....

		Non-participants £ sterling	Participants £ sterling
Please add my name to your mailing lists as follows:			
Air Infiltration Review .... copies	(quarterly)	Free	Free
Recent Additions to *AIRBASE* .... copies	(bi-monthly)	Not available	Free
Please forward the following publications:			
Technical Note AIC-TN-1-80 .... copies		Not available	Free
AIC-TN-5-81 .... copies		10.00	Free
AIC-TN-5.1-83 .... copies		7.50	Free
AIC-TN-5.2-84 .... copies		7.50	Free
AIC-TN-6-81 .... copies		6.00	Free
AIC-TN-10-83 .... copies		Not available	Free
AIC-TN-11-83 .... copies		Not available	Free
AIC-TN-12-83 .... copies		Not available	Free
AIC-TN-13-84 .... copies		Not available	Free
AIC-TN-14-84 .... copies		Not available	Free
AIC-TN-15-84 .... copies		Not available	Free
Literature List No. 1 .... copies		Not available	Free
No. 2 .... copies		Not available	Free
No. 3 .... copies		Not available	Free
No. 4 .... copies		Not available	Free
No. 5 .... copies		Not available	Free
No. 6 .... copies		Not available	Free
No. 7 .... copies		Not available	Free
No. 8 .... copies		Not available	Free
No. 9 .... copies		Not available	Free
No. 10 .... copies		Not available	Free
No. 11 .... copies		Not available	Free
1st Conference Proceedings .... copies		35.00	35.00
2nd Conference Proceedings .... copies		15.00	15.00
3rd Conference Proceedings (2 vols.) .... copies		23.50	23.50
4th Conference Proceedings (2 vols.) .... copies		16.00	16.00
5th Conference Proceedings .... copies		16.00	16.00
Handbook .... copies		12.00	12.00

I enclose a cheque made payable to BSRIA (AIC) for: £ .... drawn on a UK bank

Signed ....Dated ....

3rd fold (insert in Flap A)

Air Infiltration Centre
Old Bracknell Lane West
Bracknell
Berkshire
RG12 4AH
Great Britain

1st fold

2nd fold (Flap A)

AIC Publications List

PERIODICALS

Air Infiltration Review
Quarterly newsletter containing topical and informative articles on air infiltration research and application. Also gives details of forthcoming conferences, recent acquisitions to *AIRBASE* and new AIC publications.
Unrestricted availability, free-of-charge.

Recent Additions to *AIRBASE*
Bi-monthly bulletin of abstracts added to *AIRBASE*, AIC's bibliographic database. Provides an effective means of keeping up-to-date with published material on air infiltration and associated subjects. Copies of papers abstracted in 'Recent Additions to *AIRBASE*' can be obtained from AIC library.
Bulletin and copies of papers available free-of-charge to participating countries only.*

TECHNICAL NOTES

AIC-TN-1-80 – Manning, S.
'The distribution of air leakage in a dwelling – a brief review', 4pps.
Contains a review of 15 papers describing measurements of the distribution of air leakage in a dwelling. The results of leakage measurements made in 81 buildings are summarized.
Available free-of-charge to participating countries only.*

AIC-TN-2-80 – Superseded by AIC-TN-7-81.

AIC-TN-3-81 – Superseded by AIC-TN-8-82.

C-TN-4-81 – Superseded by AIC-TN-10-83.

AIC-TN-5-81 – Allen, C.
'AIRGLOSS: Air infiltration glossary (English edition), 124pps.
Contains approximately 750 terms and their definitions. They are related to air infiltration, its description, detection, measurement, modelling and prevention as well as to the environment and relevant physical processes. Translations of the glossary from English into languages of participating countries will appear in due course.
Available free-of-charge to participating countries. Price: £10 to non-participating countries.*

AIC-TN-5.1-83 – Allen, C.
'AIRGLOSS: Air Infiltration Glossary (English-German/Deutsch-Englisch) Supplement' 58pps.
A supplement containing translations of the terms published in AIRGLOSS.
Available free of charge to participating countries. Price £7.50 to non-participating countries.*

AIC-TN-5.2-84 – Allen, C.
'AIRGLOSS: Air Infiltration Glossary (English – French/Français – Anglais) Supplement'
A supplement containing translations of the terms published in AIRGLOSS.
Available free-of-charge to participating countries. Price £7.50 to non-participating countries.*

C-TN-6-81 – Allen, C.
eporting format for the measurement of air infiltration in buildings', 56pps.
Produced to provide a common method for research workers to set out experimental data, so assisting abstraction for subsequent analysis or mathematical model development. May be used directly for entering results and as a useful checklist for those initiating projects. Example of use of format is included as an appendix.
Available free-of-charge to participating countries. Price: £6 to non-participants.*

AIC-TN-7-81 – Superseded by AIC-TN-12-83.

AIC-TN-8-82 – Superseded by AIC-TN-15-84.

AIC-TN-9-82 – Superseded by AIC-TN-11-83.

AIC-TN-10-83 – Liddament, M., Thompson, C.
'Techniques and instrumentation for the measurement of air infiltration in buildings – a brief review and annotated bibliography', 60pps.
Four-section bibliography contains review papers, information on tracer gas techniques, pressurization methods and miscellaneous approaches. In addition the report contains list of manufacturers of instrumentation currently being used in air infiltration investigations.
Available free-of-charge to participating countries only.*

AIC-TN-11-83 – Liddament, M., Allen, C.
'The validation and comparison of mathematical models of air infiltration', 124pps.
Contains analysis of ten models developed in five participating countries. These range in complexity from 'single-cell' to 'multi-cell' approaches. Also contains numerical and climatic data for fourteen dwellings compiled to produce three key datasets which were used in model validation study.
Available free-of-charge to participating countries only.*

AIC-TN-12-83 – Liddament, M.
'1983 Survey of current research into air infiltration and related air quality problems in buildings'
3rd worldwide survey by AIC, containing over 170 replies from 22 countries. Produced in two sections: an analysis in tabular form of survey results, followed by reproduction in full of research summaries, and appendix containing names and addresses of principal researchers.
Available free-of-charge to participating countries only.*

An up-to-date review of the problems associated with satisfying the wind pressure data requirements of air infiltration models.
Available free-of-charge to participating countries only.*

AIC-TN-14-84 – Thompson, C.
'A Review of Building Airtightness and Ventilation Standards', 74pps
Lists and summarises airtightness and related standards to achieve energy efficient ventilation.
Available free-of-charge to participating countries only.*

AIC-TN-15-84 – Thompson, C.
'A subject analysis of the AIC's bibliographic database – *AIRBASE.*' 3rd Edition, 104 pps.
Comprehensive register of published information on air infiltration and associated subjects. The articles are indexed by subject and full bibliographic details of the 1276 papers are given. A list of principal authors is also included.
Available free-of-charge to participating countries only.*

LITERATURE LISTS – Listing of abstracts in *AIRBASE* on particular topics related to air infiltration.

- No. 1 Pressurization – Infiltration Correlation: 1. Models (17 references).
- No. 2 Pressurization – Infiltration Correlation: 2. Measurements (26 references).
- No. 3 Weatherstripping windows and doors (24 references).
- No. 4 Caulks and sealants (24 references).
- No. 5 Domestic air-to-air heat exchangers (25 references).
- No. 6 Air infiltration in industrial buildings (14 references).
- No. 7 Air flow through building entrances (22 references).
- No. 8 Air infiltration in commercial buildings (28 references).
- No. 9 Air infiltration in public buildings (10 references).
- No. 10 CO_2 controlled ventilation (13 references).
- No. 11 Occupancy effects on air infiltration (15 references).

CONFERENCE PROCEEDINGS

- No. 1 'Instrumentation and measuring techniques'.
  1st AIC Conference, 6–8 October, Windsor, Berkshire, UK, 372pps, £35.00 sterling.
- No. 2 'Building design for minimum air infiltration'.
  2nd AIC Conference, 21–23 September 1981, Stockholm, Sweden, 216pps, £15.00 sterling.
- No. 3 'Energy efficient domestic ventilation systems for achieving acceptable indoor air quality'.
  3rd AIC Conference, 20–23 September 1982, London, UK, 432pps.
  Supplement to 3rd AIC Conference Proceedings (contains five additional papers, one amended paper, discussion), 160pps. Total cost £23.50 sterling.
- No. 4 'Air infiltration reduction in existing buildings'.
  4th AIC Conference, 26–28 September 1983, Elm, Switzerland, 342pps.
  Supplement to 4th AIC Conference Proceedings (contains one additional paper plus discussion) 52pps. Total cost £16.00 sterling.
- No. 5 'The implementation and effectiveness of air infiltration standards in buildings'.
  5th AIC Conference, 1–4 October 1985, Reno, Nevada, USA. 376pps. £16.00 sterling.

HANDBOOK – Elmroth, A., Levin, P.
'Air infiltration control in housing. A guide to international practice', 410pps.
An international guide to airtightness design solutions of great practical value to all those concerned with the design of pollution-free dwellings with low energy demands.

**The participating countries are: Belgium, Canada, Denmark, Finland, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States of America.*

Representatives and Nominated Organisations

Belgium

*P. Caluwaerts,
Belgian Building Research Institute,
Lombard Street 41,
1000 Brussels.
Tel: 02-653-8801/02-511-0683
Telex: 256 82

P. Nusgens,
Université de Liège,
Laboratoire de Physique du Bâtiment,
Avenue des Tilleuls 15-D1,
B-4000 Liège,
Belgium.
Tel: 041-52-01-80
Telex: 41746 Enviro B.

Canada

*R. Dumont,
Division of Building Research,
National Research Council,
Saskatoon,
Saskatchewan,
Canada S7N 0W9.
Tel: 306-665-4200
Telex: 074 2471

J. Shaw,
Division of Building Research,
National Research Council,
Ottawa,
Canada K1A 0R6.
Tel: 613-993-1421
Telex: 0533145

J.H. White,
Research Division,
Canada Mortgage and Housing Corporation,
Montreal Road,
National Office,
Ottawa, Ontario,
Canada K1A 0P7.
Tel: 613-748-2309
Telex: 053/3674

Denmark

*P.F. Collet,
Technological Institute,
Byggeteknik,
Post Box 141,
Gregersensvej,
DK 2630 Tastrup, Denmark.
Tel: 02-996611
Telex: 33416

Finland

*S. Ahvenainen/R. Kohonen,
Technical Research Centre,
Laboratory of Heating and Ventilation,
Lampomiekenkuja 3,
SF-02150 Espoo 15,
Finland.
Tel: 00-4561
Telex: 122972

Netherlands

*W. de Gids,
Institute for Environmental Hygiene – TNO,
P.O. Box 214,
Delft,
Netherlands.
Tel: 015-569330
Telex: 38071

New Zealand

*H.A. Trethowen,
Building Research Association of New Zealand Inc
(BRANZ),
Private Bag,
Porirua,
New Zealand.
Tel: Wellington 04-357600
Telex: 30256

Norway

*J.T. Brunsell,
Norwegian Building Research Institute,
Box 322,
Blindern,
N-0314 Oslo 3,
Norway.
Tel: 02-46-98-80

S. Uvsløkk,
Norwegian Building Research Institute,
Høgskoleringen 7,
N-7034 Trondheim – NTH,
Norway.
Tel: 07-59-33-90

Sweden

*L.G. Månsson,
Swedish Council for Building Research,
St. Göransgatan 66,
S-112 33 Stockholm,
Sweden.
Tel: 08-540640
Telex: 10398

F. Peterson,
Royal Institute of Technology,
Dept. of Heating and Ventilating,
S-100 44 Stockholm,
Sweden.
Tel: 08-7877675
Telex: 10389

Switzerland

*P. Hartmann, EMPA,
Section 176,
Ueberlandstrasse,
CH 8600 Duebendorf,
Switzerland.
Tel: 01-823-4276
Telex: 53817

The Oscar Faber Partnership (UK)

*S. Irving,
The Oscar Faber Partnership,
Marlborough House,
Upper Marlborough Road,
St. Albans,
Herts, AL1 3UT,
Great Britain.
Tel: 0727-59111
Telex: 889072

H. Danskin,
Building Research Energy Conservation
Support Unit (BRECSU),
Building Research Establishment,
Bucknalls Lane, Garston,
Watford,
Herts, WD2 7JR,
Great Britain.
Tel: 0923-674040
Telex: 923220

BSRIA,
Old Bracknell Lane West,
Bracknell,
Berks, RG12 4AH,
Great Britain.
Tel: 0344-426511
Telex: 848288

USA

*M. Sherman,
Energy and Environment Division,
Building 90, Room 3074,
Lawrence Berkeley Laboratory,
Berkeley, California 94720,
USA.
Tel: 415/486-4022
Telex: 910-366-2037

*R. Grot,
Building Thermal and Service Systems Division,
Centre for Building Technology,
National Bureau of Standards,
Washington D.C. 20234,
USA.
Tel: 301/921-3470

J. Smith,
Department of Energy,
Buildings Division,
Mail Stop GH-068,
1000 Independence Avenue S.W.,
Washington D.C. 20585,
USA.
Tel: 202 252-9191
Telex: 710 822 0176

D. Harrje,
Centre for Energy and Environmental Studies,
Princeton University,
Princeton, New Jersey 08544,
USA.
Tel: 609-452-5190 5467

*Steering Group Representative.

AIC

Published by

Air Infiltration Centre,
Old Bracknell Lane West,
Bracknell,
Berkshire, RG12 4AH,
Great Britain.

ISSN: 0143-6643

Tel: National 0344 53123
International +44 344 53123

Telex: 848288 (BSRIAC G)

Head of AIC: Peter J. Jackman,
BTech CEng MIMechE FCIBS

Operating Agent: The Oscar Faber Partnership