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

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Introduction

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

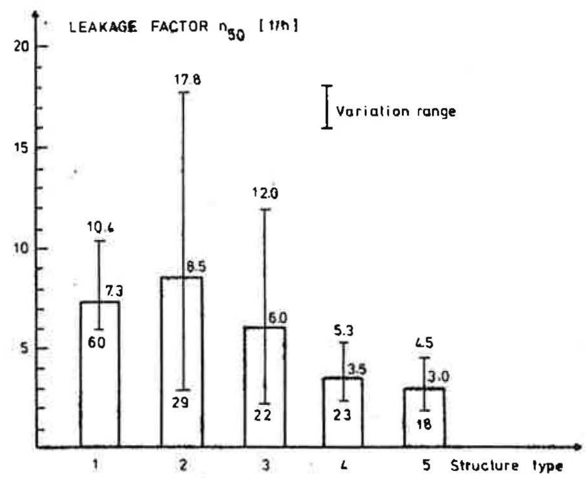
- simulation and measurement of air-leakage rates in building components and in buildings as a whole
- airtightness and indoor air quality (thermal comfort)
- thermal effects of air flow in building components.

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 cm³/ms	15,1 cm³/ms
2. Joints between frame and casement	19,4 cm³/ms	61,4 cm³/ms
3. Vertical joints between elements	10,0 cm³/ms	44,0 cm³/ms
3. Bottom joists joint to outside wall	31,6 cm³/ms	133,3 cm³/ms
3. Roof joists joint to outside wall	13,1 cm³/ms	38,9 cm³/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).

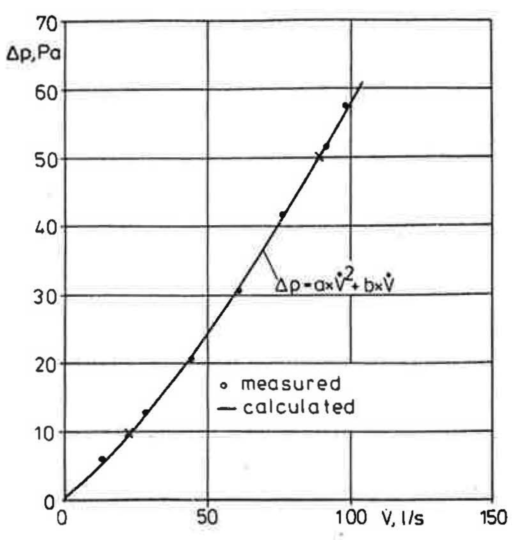


Fig. 2. Relationship between pressure difference and total air leakage of building envelope. Coefficients of quadratic flow equation were fitted by the experimental values at 10 Pa and 50 Pa (x)

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.

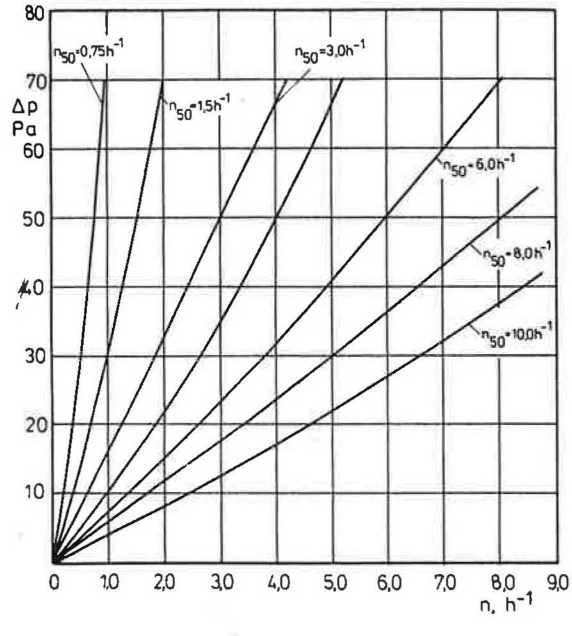


Fig. 3. Predicted pressure test curves for a detached house with masonry walls

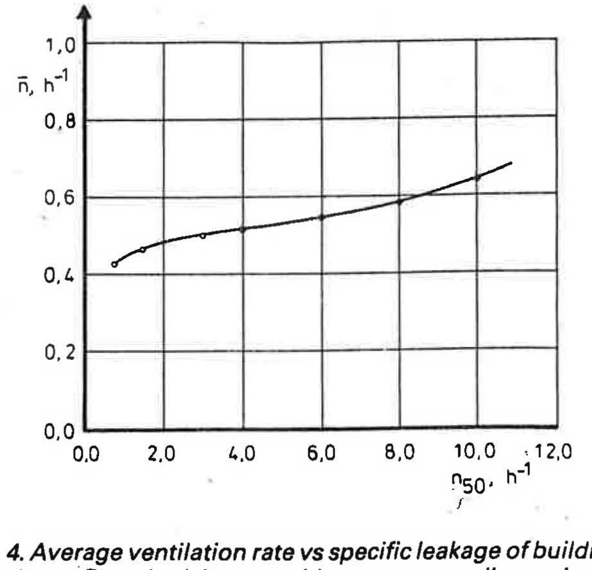


Fig. 4. Average ventilation rate vs specific leakage of building envelope. Detached house with masonry walls equipped with natural ventilation system (kitchen fan used one hour/day). Calculation period from 1st October to 30th April

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.

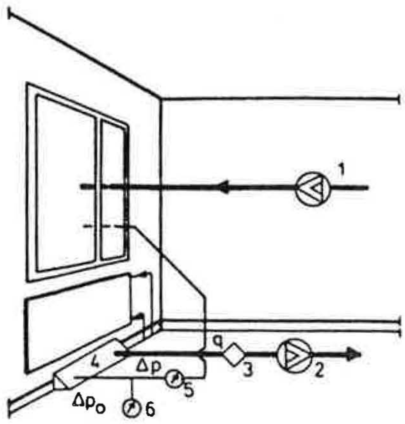
The interconnections between the nodes in the network contain any type of resistive elements, e.g. single resistance, leak, friction, as well as pressure sources. This means that simultaneous solution of the air-infiltration and the ventilation duct system is possible. The primary application of the 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 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.



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_0 between collector chamber and room (zeroing indicator).

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

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.

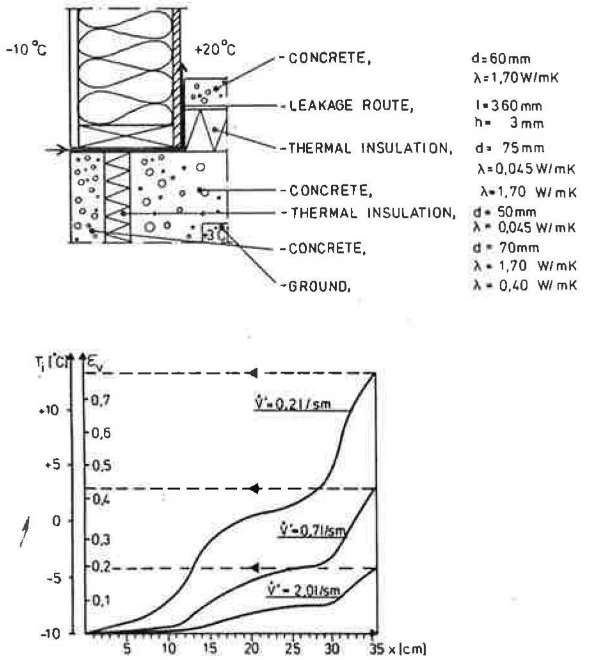


Fig. 6. Heating of leakage air in crack between wall and foundation structure

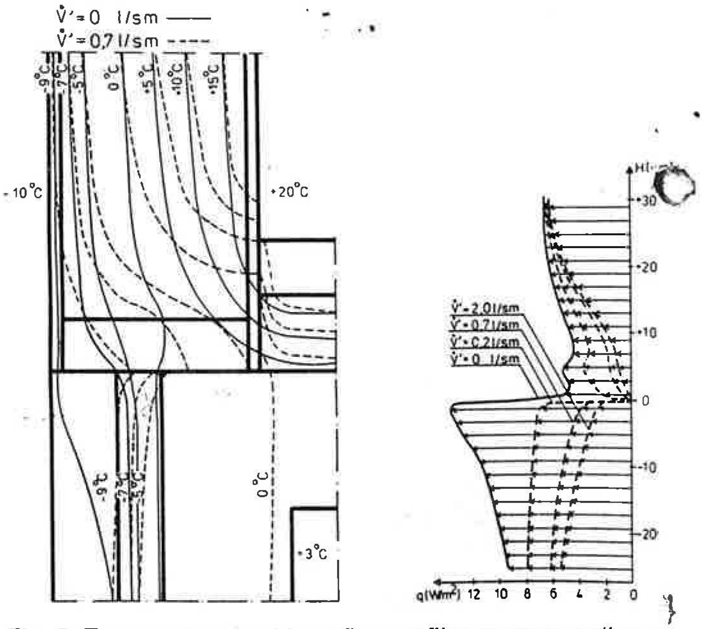


Fig. 7. Temperature and heat flux profiles corresponding to figure 6

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.

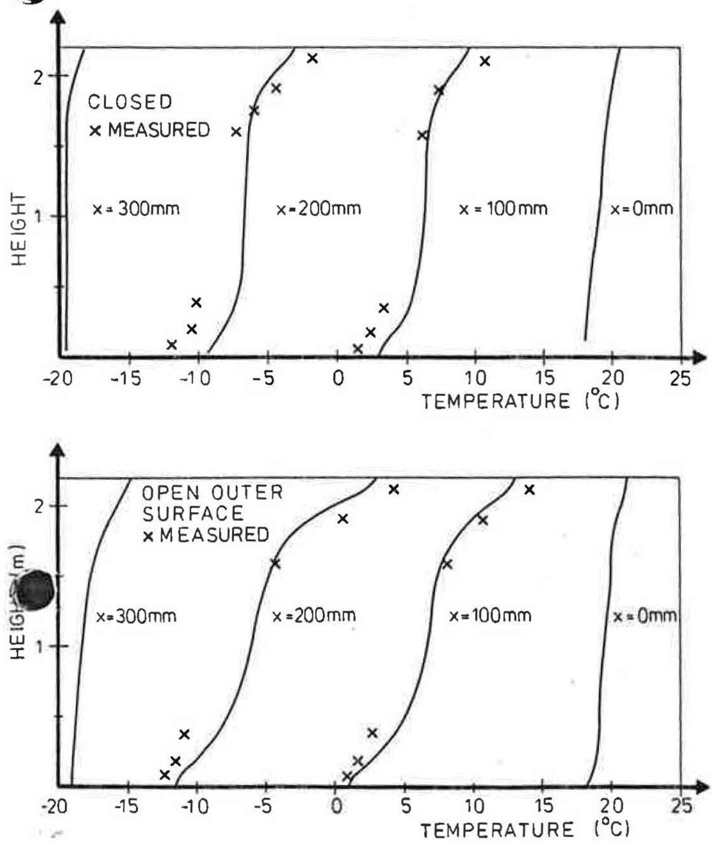


Fig. 8. Temperature profiles in a closed and semi-open space filled with fibrous insulating material

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

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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. Goteborg, 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
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