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#948

Air infiltration problems in ventilation systems

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ABSTRACT

In this paper, the latest results of air infiltration research in Finland are presented. The aim of this research is to increase the knowledge of the influences of air infiltration on energy consumption, ventilation and indoor climate. The principles of a calculation model for predicting the interconnection between airtightness and air change rate are briefly described. Measurement methods are presented briefly, except a new method using existing fans in blocks of flats for pressurization. The airtightness of Finnish buildings has been recently improved. Attention is paid to construction details, some of which are presented. Finally, possibilities of draughtless and controlled fresh air intake through the building envelope are discussed.

RESUME

Le présent document comporte les derniers résultats obtenus en Finlande dans le domaine de la recherche d'infiltration d'air. Cette recherche vise à augmenter la connaissance des effets qu'exerce l'infiltration d'air sur la consommation d'énergie, sur la ventilation et sur l'air ambiant. Les principes de calcul pour déterminer la corrélation entre l'imperméabilité à l'air et le taux de renouvellement d'air sont brièvement présentés. Les méthodes de mesurage sont présentées en peu de mots, sauf une nouvelle méthode basée sur l'utilisation des ventilateurs déjà existantes dans les immeubles en vue de la pressurisation. L'imperméabilité à l'air des bâtiments a été récemment améliorée en Finlande. Une attention particulière a été portée sur les détails de construction dont certains se trouvent présentés. Enfin, la possibilité d'assurer une introduction d'air frais contrôlée et sans courants d'air nuisibles, se produisant par l'enveloppe du bâtiment, est présentée.

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INTRODUCTION

When heating energy was cheap, infiltration was not a great problem. Draught was easily compensated for with rising indoor temperatures - and if the room became too warm, windows were opened. After the energy crisis temperatures were decreased, draughty windows were carefully sealed, and mechanical ventilation systems were often cut off - this caused many problems for air quality, and also moisture problems in structures. It became necessary to learn more about air flows in buildings - infiltration and ventilation.

The infiltration research started in the Technical Research Centre of Finland at the beginning of 1979. The research work is financed by the Ministry of Trade and Industry. The aim of this research is to give such requirements and guidelines that sufficiently good indoor climate and thermal comfort could be achieved by economical and energy-saving ventilation. The research is divided into three main projects:

- calculation model: airtightness - ventilation rates
- the technique and economy of airtight structures
- airtightness requirements and measurement methods

The research will continue until December 1982 - but some new projects including testing long-time performance of airtight structures and joints are beginning, continuing up to 1988.

VENTILATION SYSTEMS IN FINLAND

Single-family houses and row houses

The tradition of naturally ventilated small houses has continued nearly unchanged until the mid-seventies. Small amounts of mechanical exhaust systems, and a few balanced ventilation systems with heat recovery have been installed every year. Since 1976, the rapid development of warm air heating systems has changed the situation - it is easy and economical to combine the system with mechanical supply and exhaust ventilation plus heat recovery. In such cases, the importance of airtightness is quite clear. Today, one third of small house builders choose this kind of system - it means about 10000 installations per year, the rest choose natural ventilation plus extract hood fan in kitchen (used during cooking only).

Blocks of flats

Multi-storey apartment buildings, built before 1960, have primarily natural ventilation. Since 1960, mechanical exhaust ventilation has become clearly dominating. Balanced fully mechanical systems have never been very popular, and they have remained only "experimental". Yet, some production development projects on heat recovery systems are being carried out. Improved airtightness has caused air quality problems especially in bedrooms.

Other buildings

Offices, schools, hospitals, industrial buildings etc. have primarily fully mechanical ventilation systems, but the maintenance of the systems is sometimes very poor. However, the airtightness of these buildings should be generally very good. Infiltration problems exist mainly in older buildings and industry, where continous opening of doors is often necessary.

Conclusion

It is obvious that every year a greater part of new buildings has mechanical ventilation systems, and the importance of well-insulated airtight structures is increasing. The demand of fresh air is generally at least 0,5 air changes per hour.

MAIN PRINCIPLES OF AIRTIGHTNESS REQUIREMENTS

The envelope and the ventilation system of a building shall work as one unit so that

- the air quality in different rooms is sufficiently good
- this air quality is achieved using reasonable air flows so that energy is not wasted
- air flows (mechanical, natural or leakage) do not cause draught problems
- the pressure conditions are controlled →
  - no air flows from "dirty" rooms to "clean" rooms
  - slight underpressure indoors, to avoid moisture-caused damages.

But, the ventilation system shall not be too complicated - it must work properly also in practice.

The requirements, which must be easily verified by measurements, will be given for

- whole buildings
- parts of buildings
- structures
- structural joints
- supply air intake (if not mechanical)

PRINCIPLES OF THE INFILTRATION CALCULATING MODEL

There is no universal interconnection between the airtightness and the air change rate of a building - the ratio between infiltration during average weather conditions and air change rate measured by pressure test varies depending on many parameters. A mathematical model for predicting the interconnection is necessary to solve the influence of each single parameter (e.g location of untight spots of building envelope and influence of air leakage characteristics of structures), which is impossible by field measurements.

The theoretical model

The basis of the model is presented in ref (1). Briefly, it is based on the conservation of mass principle, the mass flow balance for a room being:

$$m_+ + m_{h+} + m_{v+} + m_- + m_{h-} + m_{v-} = 0 \qquad (1)$$

where

m_+ is the mechanical supply air flow
m_- is the mechanical exhaust air flow
m_{h+} is the air flow into the room through the building envelope
m_{h-} is the air flow from the room through the building envelope
m_{v+} is the air flow into the room through the partition walls
m_{v-} is the air flow from the room through the partition walls

Each air flow is depending on the pressure differences between the room and its surroundings. The air leakage flows can be written generally as follows

$$Q = f(\Delta p) \qquad (2)$$

The leakage flow Q can generally be determined as follows:

$$\Delta p = bQ + aQ^2 \qquad (3)$$

When the pressures in the surrounding rooms, and on the outside walls, and the air flows of the mechanical ventilation system are known, it is possible to calculate the flow equilibrium of the room (pressure at the medium height of the room) using the equilibrium equation. The flow equilibrium of a building exists when the flow equilibrium equations for each room are simultaneously valid.

The calculations include the following parts:

- calculation of the pressure conditions in a building
- calculation of the air leakage flows between the rooms and through the building envelope
- calculation of ventilation and its energy consumption.

In addition, the calculations may include a comparative part where the calculation results are compared with the airtightness or ventilation requirements.

Practical testing of the model

The model is tested in two detached houses and one block of flats. In one of the detached houses, very thorough measurements were carried out, also for development of measurement methodics. According to the first calculations the model is working "well enough" - but in larger buildings many simplifications are required for input data, which probably makes the model less realistic.

The calculations and development of the infiltration model are still going on and it is too early to present any calculated interconnection between airtightness and air change rates.

MEASUREMENT METHODS

"Traditional" methods

For airtightness measurement in small houses, the pressure method (2) is generally applied. The leakages are localized by either thermography (3) or by smoke test. Air change rates, also infiltration especially in buildings using air re-circulation, are measured using tracer gases (2) - decay or constant flow. No new versions of these traditional measurement methods have been developed in Finland, but we have found it necessary to develop the following two methods.

Simple pressurization method for blocks of flats
For blocks of flats, or other multi-cell buildings, the original pressure method is either too slow (flat by flat), or requires too heavy measurement equipment. The elimination of leakages into/from other flats will often be too complicated. These problems can be avoided by using existing fans, supply or exhaust, for pressurization or depressurization (every new multi-storey building has at least an exhaust fan). Air flows in each supply or exhaust unit, and outdoor-indoor plus flat-stairway pressure differences are measured. Generally, the measurement procedure is quick and easy. The principle of the method is shown in Fig. 1.

The accuracy of the method is not high, but it shall be a method for practical purposes, not for research only, to show if the building envelope is airtight enough (pressure differences high, 30 to 100 Pa, small deviation) or too leaky (difficult to create a measurable pressure difference). Simultaneously, the test can also show if the ventilation system is properly adjusted or not.

Measurement of local air leakages
Figure 2 shows the equipment for the collector chamber method to measure local air leakages. The method is used for field measurements, and it is the only way to get quantitave information about infiltration from structures, and especially structural joints.

The method has high accuracy, if the outdoor conditions are steady during the measurements. It is almost impossible to obtain the same pressure in the chamber and in the room during wind fluctuations.

However, a building has also kilometres of different structural joints. It is therefore necessary to develop a statistical analysis to evaluate the local leakages (or the quality of workmanship in structural joints) so that

only a few measurements are required. Such a method is being developed. The measurement procedure can still remain very slow, and the practical applications of the method will be limited (to cases of complaint or maybe rooms where almost absolute airtightness is required). Even so, the existence of the method is important for the user of the building.

The collector chamber method can easily be applied in laboratory conditions - for development and quality control of structures and structural joints.

Other methods
To complete the infiltration measurements air flows, pressure differences and air velocity shall often be measured to control the total performance of ventilation. In some cases, also air quality shall be controlled. In the future, it may be necessary to develop easier methods for measurement of air change rates or infiltration - so that people could estimate if their homes are airtight enough.

INFILTRATION AND STRUCTURES

According to the pressurization measurements, the airtightness of new detached houses has improved during the last two years. The average infiltration at 50 Pa suction is about 4/h (which is still above the Swedish requirement). The most problematic structural joints are shown in fig. 3.

Prefabricated building elements have good airtightness. Infiltration depends more on the quality of workmanship and also on the control of the construction.

How airtight will a building be after five - ten - or fifty years, if it is now new and very airtight? Nobody knows. The ageing of airtight layers, joint materials etc. should be carefully studied, both in laboratory (e.g. accelerated tests in varying climates) and by field tests.

CONTROLLED AIR SUPPLY THROUGH THE BUILDING ENVELOPE

If the building has no mechanical supply air ventilation, the supply air intake is generally very uncontrolled. Improved airtightness has caused air quality problems especially in bedrooms. Therefore, new methods of supply air intake have been examined, thermal comfort as the main parameter.

The most promising alternatives, the supply air window (see fig. 4) and porous element were examined in a test room.

The tests showed that by development of the examined alternatives it is possible to take all the supply air needed through the building envelope in a controlled way, without comfort problems, and without risks of significant condensation and exfiltration, but only in dwellings where 0,5 air changes per hour is sufficient. If the ventilation rate required is higher, or varies with time, the control of air velocities and pressure conditions becomes very difficult. The use of supply air windows increases the risk of condensation on the inner pane, but using triple-glazed windows the risks are not very serious. In existing buildings, the supply air window is the only practical way of controlled air supply.

The control of pressure conditions becomes difficult in high-rise buildings - because of the stack effect (2 Pa per metre if outdoor air temperature is about - 20°C), and in buildings having only natural ventilation.

CONCLUSIONS

The developments in building materials and constructions and the energy crisis are little by little showing the way to:

- airtight buildings
- controlled ventilation.

This is the only way to secure both sufficient and energy-saving ventilation, without draught problems, and without damage to the structures.

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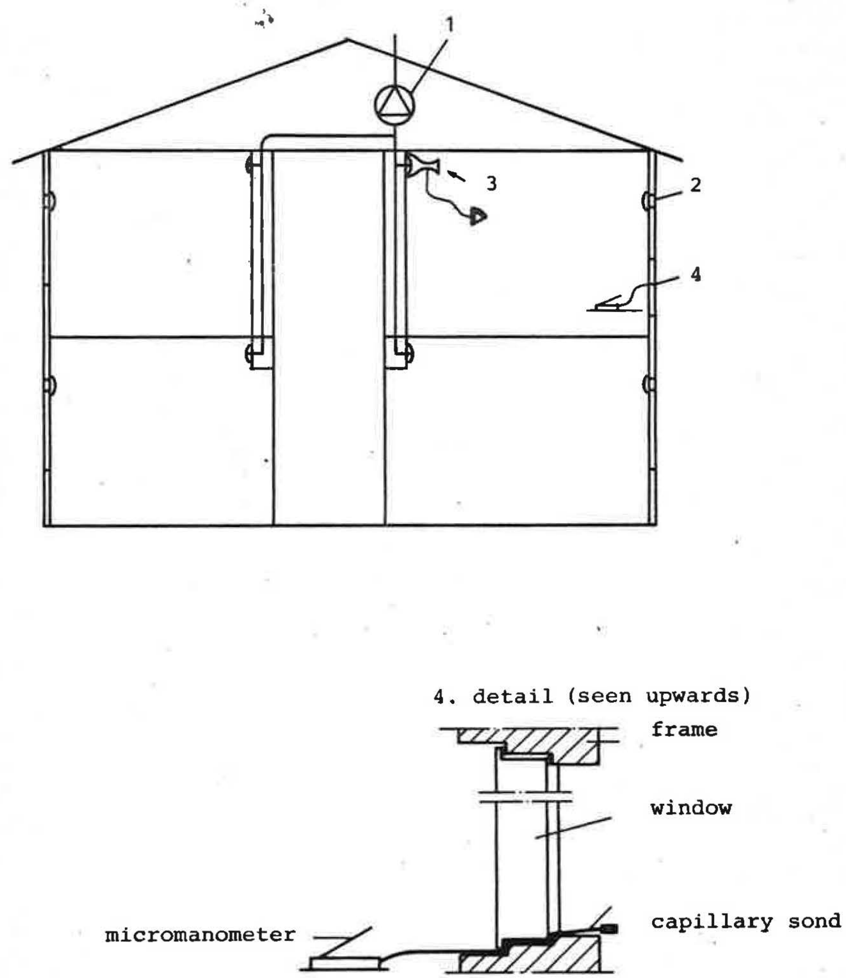

FIG. 1. PRESSURE TEST USING EXISTING FAN.

1. Exhaust fan. Max effect during the test
2. Supply units. Taped for test
3. Air flow measurement (rooms)
4. Measurement of pressure difference.

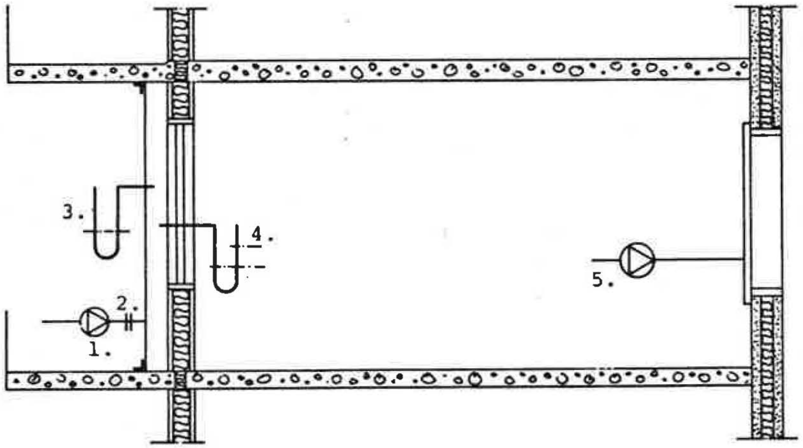

FIG. 2 . MEASUREMENT OF TOTAL AIR LEAKAGE FLOW OF A BALCONY WALL (COLLECTOR CHAMBER METHOD).

1. Adjustable fan
2. Measurement of air flow rate (orifice plate)
3. Pressure difference between collector chamber an outdoor air (electric micromanometer)
4. Pressure difference across the structure (microma
5. Auxilary fan (adjustable)

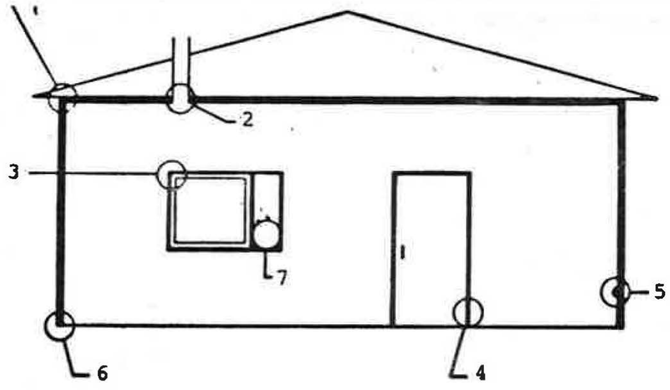

FIG. 3 . PROBLEMATIC CONSTRUCTION JOINTS OF A DETACHED HOUSE.

1. Eaves
2. Penetrations for heat and ventilation
3. Window jamb joints to outside wall
4. Outdoor jamb joints to outside wall
5. Penetrations for electricity
6. Bottom joists joint to outside wall
7. Airing panel

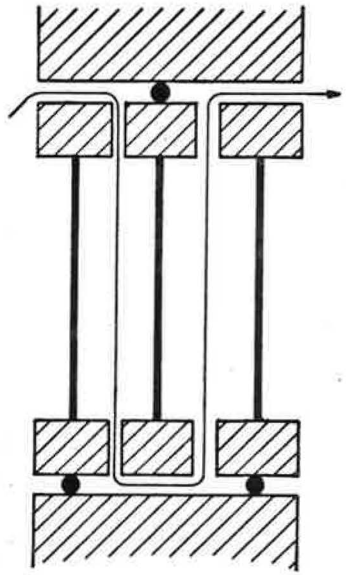

FIG. 4. AIR INTAKE THROUGH A TRIPLE-GLAZED SUPPLY AIR WINDOW.