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INFILTRATION AND VENTILATION; RESEARCH IN FINLAND

1. INTRODUCTION

In Finland the share of ventilation is about one half of the energy losses in buildings. According to general opinion there is unnecessarily high air change rates in buildings. In dwellings, 0,5 air changes per hour can generally be regarded as sufficient to satisfy the demand of fresh air.

The reason of too high ventilation rates can be the untightness of the building envelope and/or unnecessarily high mechanical ventilation. Air leakages can also cause draught problems in rooms and thus extra heating effect is needed.

The supply air should be taken in through certain controlled points in all ventilation systems, either mechanically or through the untight spots of building envelope. This is necessary to secure both sufficient and energy-saving ventilation.

To solve these problems, wide research projects (see fig. 1) of airtightness and ventilation have been started in Finland. The aim of this research work is to develop airtightness requirements to provide for an appropriate performance of the envelope and ventilation system in the building.

In fig. 2, the annual energy balance of a typical block of flats is shown. Some characteristics of various ventilation systems are shown in fig. 3.

INVESTIGATIONS CARRIED OUT IN TECHNICAL RESEARCH CENTRE OF FINLAND RELATED TO INFILTRATION AND VENTILATION

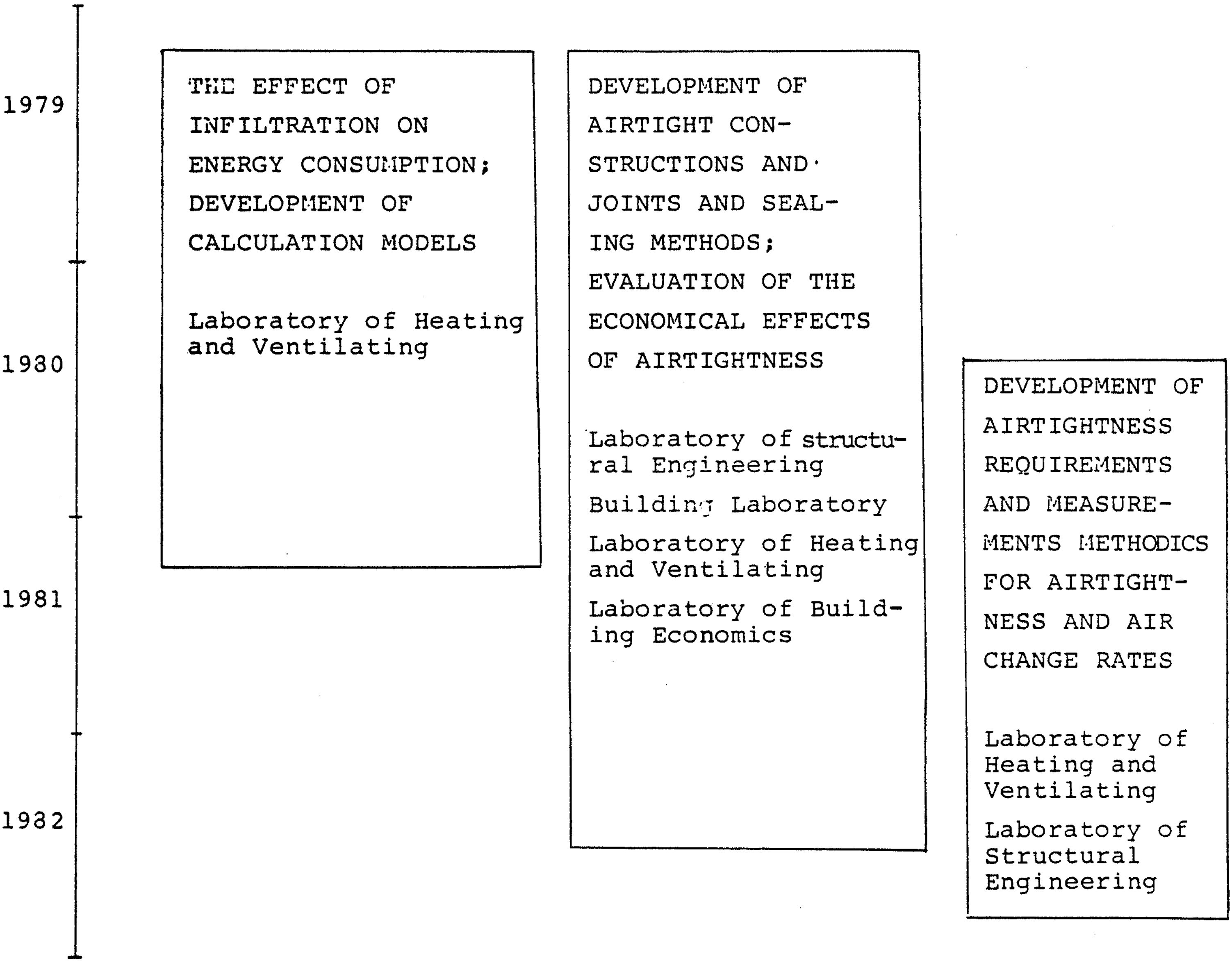


Fig. 1

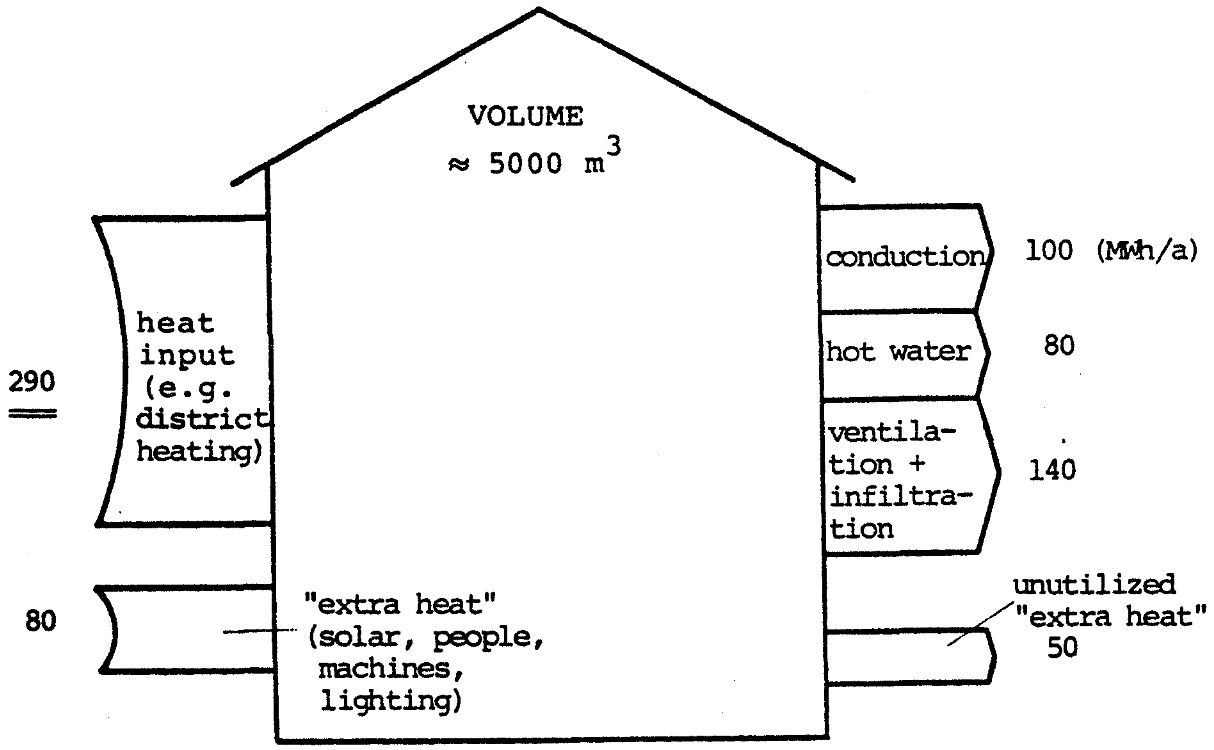
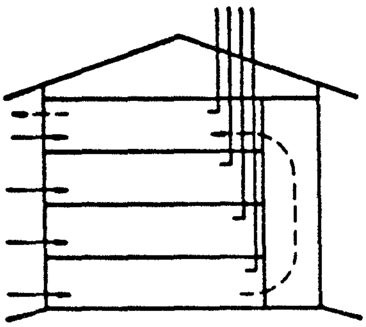


Fig. 2

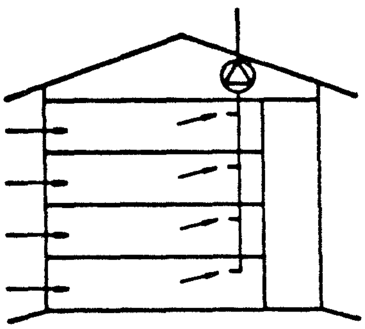
With regard to the performance of ventilation the building envelope of the building and the ventilating system are to be considered as one unit.

Natural ventilation:



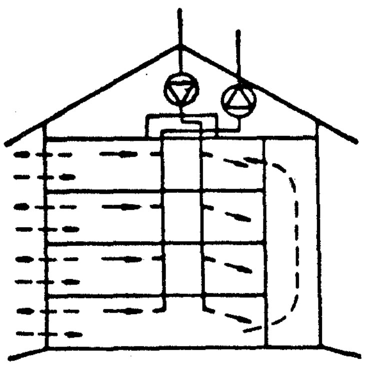
- based on differences in air density
- ineffective in summer
- in windy weather air flow through the building from windward side to the leaward side
- air flows from ~~that~~ flat to flat via the stairway (hygienical problems)
- intake of fresh air through untight spots in the walls and/or using outdoor air intakes

Mechanical exhaust:



- special attention should be paid to the intake of outdoor air
- slight air flow through the exterior walls (tight buildings)
- air flow from the stairway to the flats may be considerable

Mechanical air supply and exhaust:



- air flow through the external walls may be considerable, if the building is not tight
- air flow between the flat and the stairway is possible depending on the pressure conditions in the stairway
- heat recovery from exhaust air to supply air is possible

Fig. 3. Ventilating system and building envelope considered as one unit.

2. AIRTIGHTNESS REQUIREMENTS AND MEASUREMENT METHODS

2.1 Development of airtightness requirements

Basis for requirements (see fig. 4)

- energy economy
- thermal comfort and indoor climate
- regulations in order to protect the consumer.

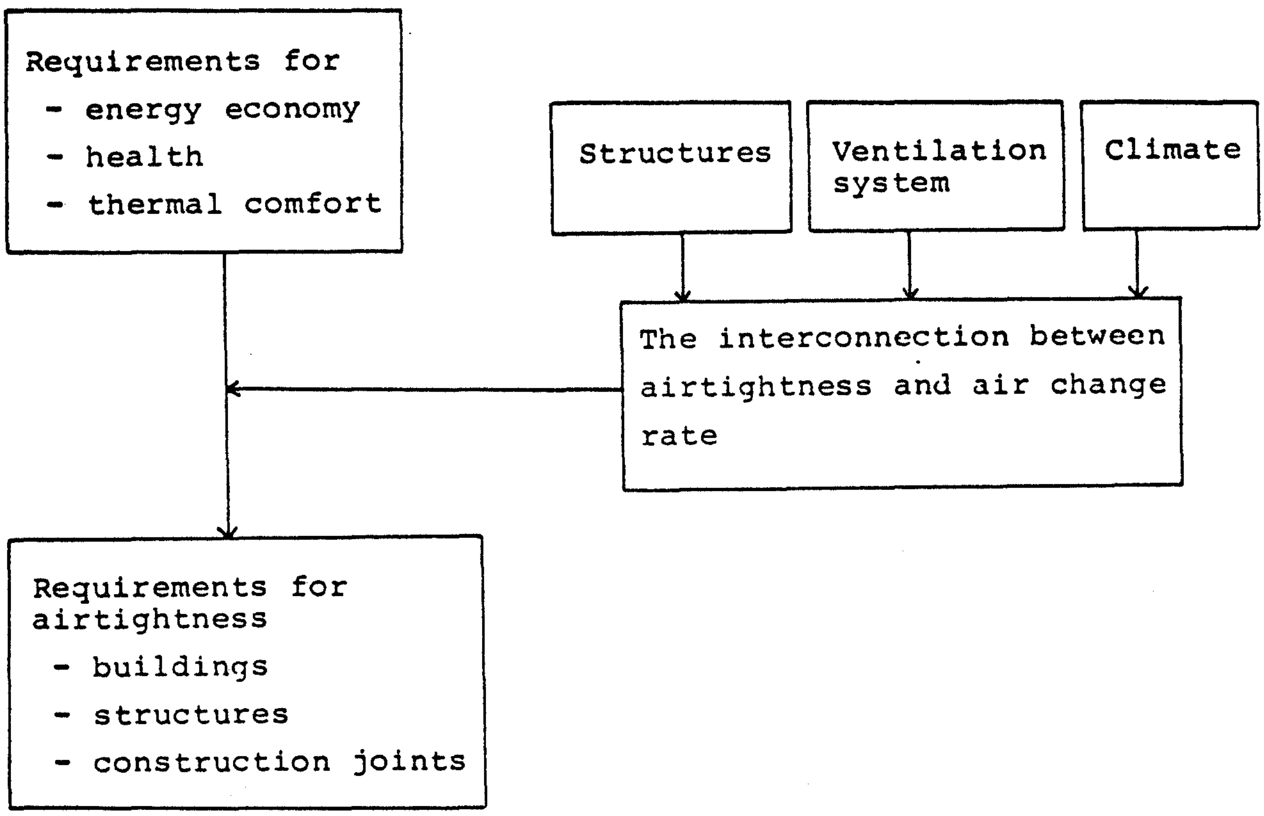


Fig. 4

Airtightness requirements shall be given for

- entire buildings
- building parts (e.g. flat)
- structures (e.g. windows)
- structural joints.

A sufficient airtightness should be verified by measurements.

The Laboratory of Heating and Ventilating carries out measurements according to the following methods.

2.2 Measurement methods

A. Measurement of total airtightness using pressure test

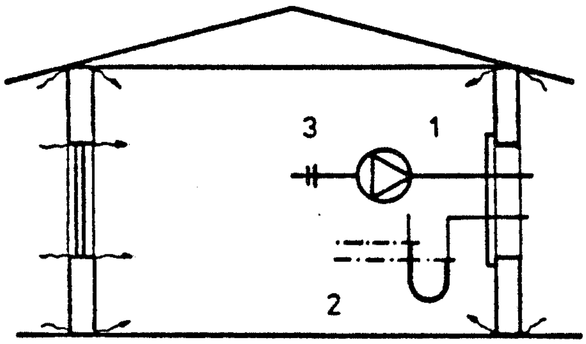


Fig. 5

1. Fan
2. Pressure difference indoor-outdoor
3. Measurement of air flow.

Description of method:

- a pressure difference is generated in the space to be measured using a fan
- the air flow of the fan and the pressure difference are measured
- the air flow of the fan (total air leakage) is given as a function of the pressure difference
- the ventilation openings are closed during the test.

B. Localization of air leakages with smoke test

- Description of method:
  - smoke test is generally carried out in connection with pressure test
  - test smoke is injected from a smoke ampoule to the vicinity of a possible air leakage point
  - the smoke is ejected from the wall surface to the leak flow
  - the smoke test may be completed with temperature and velocity measurements of air flow.

C. Measurement of local air leakages with collector chamber method

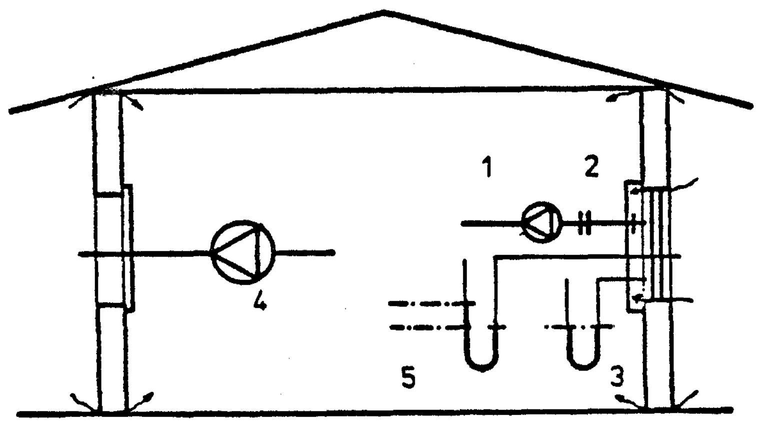


Fig. 7

1. Fan used in measurements
2. Measurement of air flow
3. Pressure difference collector chamber - indoor air
4. Auxiliary fan
5. Pressure dirrerence outdoot - indoor

Description of method:

- the object to be measured (e.g. a window) is covered with the collector chamber
- a certain pressure difference is generated in the room using the auxiliary fan
- the air flow in the fan (1) is regulated so that there will be no pressure difference between the room and the chamber
- the local air leakage (the air flow of the fan (1) is given as a function of the pressure difference indoor - outdoor.

D. Measurement of the pressure conditions in the building

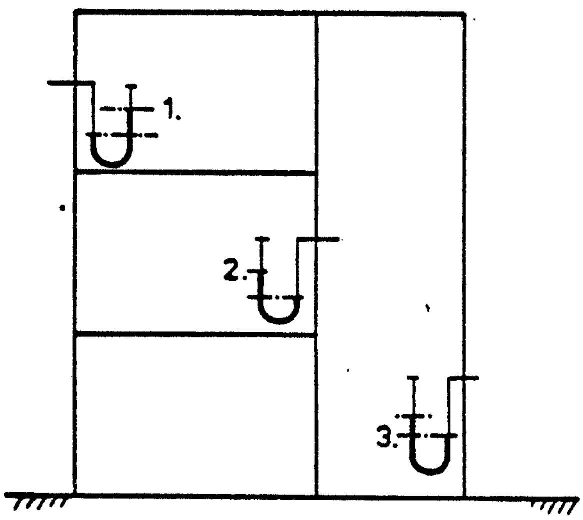


Fig. 8

The pressure differences to be measured according to the figure above are:

1. from room to outdoors
2. from room to stairway
3. from stairway to outdoors.

Other alternatives may also occur (e.g. in offices):

from room to corridor

form corridor to stairway

The pressure differences are generally measured with a micro manometer.

Use of test results:

- as basic data for calculating the infiltration
- for evaluating the airtightness
- for evaluating the performance of the ventilating system.

E. Measurement of air change rates using tracer gas test

Description of method:

Tracer gas is injected into the supply air or into the room and its decreasing concentration is measured with a gas analyzer as a function of time. The most general tracer gases are:

H_2, N_2O, SF_6

3. PREDICTING THE INTERCONNECTION BETWEEN AIR TIGHTNESS AND VENTILATION

3.1 The theoretical basis

It is reasonable to start a theoretical survey of air infiltration problems by studying the ventilation of a single room. The different elements of ventilation of a room can be divided as follows:

a. The air flows of the mechanical ventilation:
   - supply air flow, $\dot{m}_{\oplus}(i)$
   - exhaust air flow, $\dot{m}_{\ominus}(i)$

b. The air leakage flows:
   - the air leakage flows through the outside walls of the room:
     air flow into the room, $\dot{m}_{n\oplus}(i)$
     air flow from the room, $\dot{m}_{n\ominus}(i)$

The flow into the room is denoted by plus and the flow from the room by minus. The number of the room is denoted by index i.

Applying the conservation of mass principle to the air flow mechanism of the room under steady state wind conditions the flow equation of the room is:

$$\dot{m}_{\oplus}(i) + \dot{m}_{n\oplus}(i) + \dot{m}_{v\oplus}(i) + \dot{m}_{\ominus}(i) + \dot{m}_{n\ominus}(i) + \dot{m}_{v\ominus}(i) = 0 \qquad (1)$$

In other words:

The sum of the air flows entering the room is equal to the sum of the escaping ones.

This simple physical law is the basic principle at the calculation procedure studying the interconnections between air tightness and ventilation.

The total air mass flow of a room is equal to the sum of the air flows entering the room:

$$\dot{m}_t(i) = \dot{m}_{\oplus}(i) + \dot{m}_{n\oplus}(i) + \dot{m}_{v\oplus}(i) \tag{2}$$

The outdoor air flow of a room can be defined as follows:

$$\dot{m}_{out}(i) = B \cdot \dot{m}_{\oplus}(i) + \dot{m}_{n\oplus}(i) \tag{3}$$

In the equation 3 the factor B denotes the share of the outdoor air in the supply air flow of the room. The energy consumption and the required heating effect of ventilation depends on the outdoor air change.

The air infiltration of the building and the pressure conditions between the rooms are determined on the basis of the leak characteristics of wall structures and the use of the building. The leakage flow for one leakage point can be calculated using the crack flow equation, whose general form can be written as follows:

$$\dot{V} = f(\Delta p) \tag{4}$$

where $\dot{V}$ is the leakage air flow (m^3/s, m^3/m^2s, m^3/ms), Δp is the pressure difference across the construction in Pa.

The calculated or measured leakage flow of a structure or its component or joint can be expressed:

a. as the total leakage of construction, m^3/s:
   - for a window
   - for a door
   - for a wall or its part

b. as a leakage per surface area, m^3/m^2s:
   - for a wall or its part

c. as a leakage calculated per crack length, m^3/ms:
   - for window cracks
   - for door cracks
   - for joint cracks

Generally the following crack flow equation is applied:

$$\dot{V} = C \cdot \Delta p^{n} \qquad (5)$$

where $\dot{V}$ is crack flow (m^3/s, m^3/m^2s, m^3/ms)
C a constant
Δp the pressure difference measured across the construction in Pa
n flow exponent.

The value of exponent n varies between 0,5...1,0 depending on the dynamic character of the flow:

$n = 1,0$ for laminar flow
$n = 0,5$ for turbulent flow.

Physically a more correct form for the leakage equation would be:

$$\dot{V} = b \cdot \dot{V} + a \cdot \dot{V}^2 \qquad (6)$$

where a and b are constants.

The equation 6 is accurate enough to be applied for practical pressure differences measured in buildings (-50...+50 Pa). The constants a and b can be determined for each crack by means of crack flows measured at two pressure differences:

e.g: point 1 $\Delta p \approx 10$ Pa
point 2 $\Delta p \approx 50$ Pa

In theoretical calculation the basic element consist of a separate crack restricted as to its location and known as to its leak characteristics. The total leakage flows are achieved by summing up the leak flows of the separate elements, as follows:

The leak flow of an element:

- amount, kg/s
- direction, + into the room
  - from the room

↓

The total leak flows calculated for a wall:
- amount, kg/s
- direction: into the room through the wall
  from the room through the wall.

+

The total leak flows calculated for the outside walls and partition walls:
- amount, kg/s
- direction, into the room through the outer walls, $\dot{m}_{n\oplus}(i)$
  from the room through the outer walls, $\dot{m}_{n\ominus}(i)$
  into the room through the partition walls, $\dot{m}_{v\oplus}(i)$
  from the room through the partition walls, $\dot{m}_{v\ominus}(i)$

When the pressures in the surrounding rooms, 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 calculation principle of the interconnection of the airtightness and ventilation of a building can be summarized as follows:

I The air leakage of a separate crack is calculated using a crack flow equation which describes accurately enough the crack flow in practical conditions.

II Determination of the flow equilibrium equation for a separate room.

III Calculating the flow equilibrium for the building in a way enabling a simultaneous validity of the flow equilibrium equations for the separate rooms.

The following basic data and end conditions are needed in the calculations:

- the pressure distribution outside the building
- estimated internal pressure distribution at the beginning of the calculation
- the air flows of the ventilation devices in case they are not determined in the calculations.

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 objective data or the requirements.

In a model (appendix 1) being developed for the calculation of infiltration and ventilation the air leakage characteristics of structures are described using the equation 6. In solving the equation group is used an application of Brown´s method /1/. The calculation consist of two programs:

- the air leakage model
- the air duct model.

Both these programs can be used independently as separate calculation models or they can also be combined and used together as a whole calculation system. The development of the duct model is mainly completed (exhaust air flows)./2/. The air leakage model is still under development as to its output data and calculation of energy consumption data. Also the method used in the solution of the equation group should be accelerated.

References:

/1/ Brown: A Quadratically convergent Newton-like method based upon Gaussian elimination, Siam J. numer.anal, vol. 6 No 4, Dec. 1969

/2/ Ahvenainen S.: Determination of the air flow conditions in an exhaust ventilation system with a computer program LVI-lehti 31(1979)6, s. 58...62. (In Finnish, with English summary).

4. NATURAL VENTILATION AND HUMAN BEHAVIOUR

4.1 Ventilation requirements

Ventilation requirements, which are given in the National Building Code of Finland, are based on the following criteria:

	min. air change rate
- removal of human odours	
- without recirculation	0,8/h
- with recirculation	0,2/h
- removal of moisture	0,3/h
- removal of radio active impurities	0,5/h
- removal of tobacco smoke	2,0/h

The minimum air change rate allowed is everywhere at least 0,5/h. Possibilities to reduce air change rates with more effective filters are not known well enough.

It is obvious that in natural ventilation systems the air quality does not always fulfill the minimum requirements. Also, the natural ventilation is mostly fully uncontrolled.

4.2 Air supply through the building envelope

Air supply shall be
- fully controlled in all weather conditions
- draughtless

With today´s requirements for thermal comfort, the possibilities of air supply through the building envelope are very small. Tiny crack flows (1-2 m^3/m h per crack width) can cause problems, see fig. 9, and are often combined with cool convective flows. Theoretically, the air supply can be arranged in a satisfactory way, using a supply air window (fig.10), where parts of window sealings are taken off. In practice, however, the performance of such windows is often unsatisfactory because a very well-balanced mechanical exhaust ventilation is needed to secure appropriate air flow directions; in high-rise buildings the supply air windows cannot be recommended (max. 4-5 storeys) because of exfiltration and condensation risks.

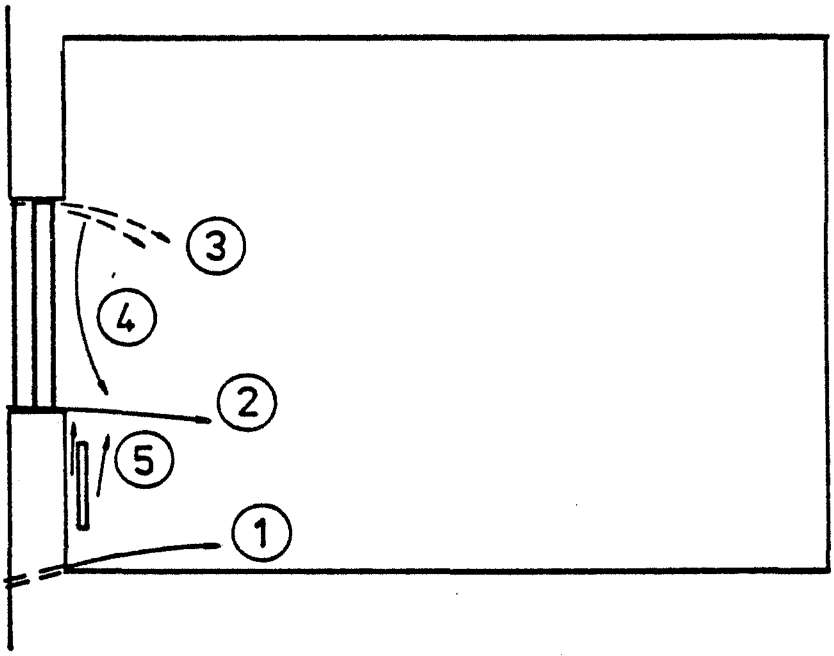


Fig. 9

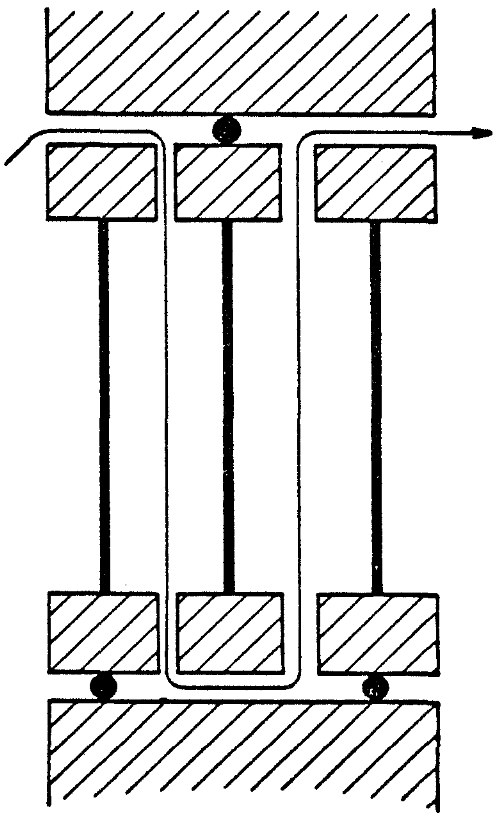


Fig. 10

4.3 Natural ventilation in old buildings

It is obvious that in new buildings with good airtightness, natural ventilation systems have more disadvantages than advantages.

In older buildings the situation is not so clear. It is often difficult, expensive, or even practically impossible to build mechanical exhaust or balanced systems in older buildings, especially in very old massive office buildings.

In the beginning of this year,several research projects have started in Finland to find appropriate solution in these problems. In some massive old buildings, measurements will be carried out in various outdoor climates to find out e.g.:

- air change rates, by tracer gas measurements
- airtightness of windows, using collector chamber method
- concentration of radon and other impurities in room air
- natural exhaust air flows in office rooms
- mechanical exhaust air flows from toilets etc.
- pressure conditions in several rooms in each storey.

It is possible that, in certain cases, satisfactory room air qualities can be achieved by mainly natural ventilation, or "soft" mechanical ventilation, e.g.:

- mechanical exhaust from "dirty" rooms
- temporary airing (a window opened for 3-5 minutes once or twice during office hours)
- fans in conference rooms etc.

CALCULATION MODEL FOR THE AIRTIGHTNESS AND NATURAL VENTILATION OF BUILDING

1. The theoretical basis of the calculation model

In a building different rooms, the untight spots of the surrounding walls of the rooms and ventilation ducts constitute the flow net of the building.

Outside pressure forces - thermal pressure and wind forces - cause together with the ventilation system pressure differences and air flows:

- in ventilation ducts
- in ductlike spaces
- through the untight spots in the building between the rooms and outdoor air as well as between the rooms.

Dynamic flow and leak characteristics of different flow components can be described by flow equations and graphs. When we know the external pressure distribution of the building, we can calculate the air leakage flows and ventilation at equilibrium (see chapter 4). The general flow chart of the calculation model is presented in figure 1.

The basic crackflow equation used in our calculation model is of the following form:

$$\Delta p = c_l \cdot \eta_m \cdot \dot{V} + c_t \cdot \rho_m \cdot \dot{V}^2 \qquad (1)$$

$\dot{V}$ air flow through the crack (m^3/s, m^3/ms, m^3/m^2s)

Δp is the static pressure difference across each crack, Pa

c_l flow resistance coefficient (of the laminar flow area, m^{-3} m^{-2}, m^{-1})

η_m dynamic viscosity of the flowing air, kg/ms

c_t flow resistance coefficient (of the turbulent flow area, m^{-4}, m^{-2}, m^0)

ρ_m density of the flowing air, kg/m^3

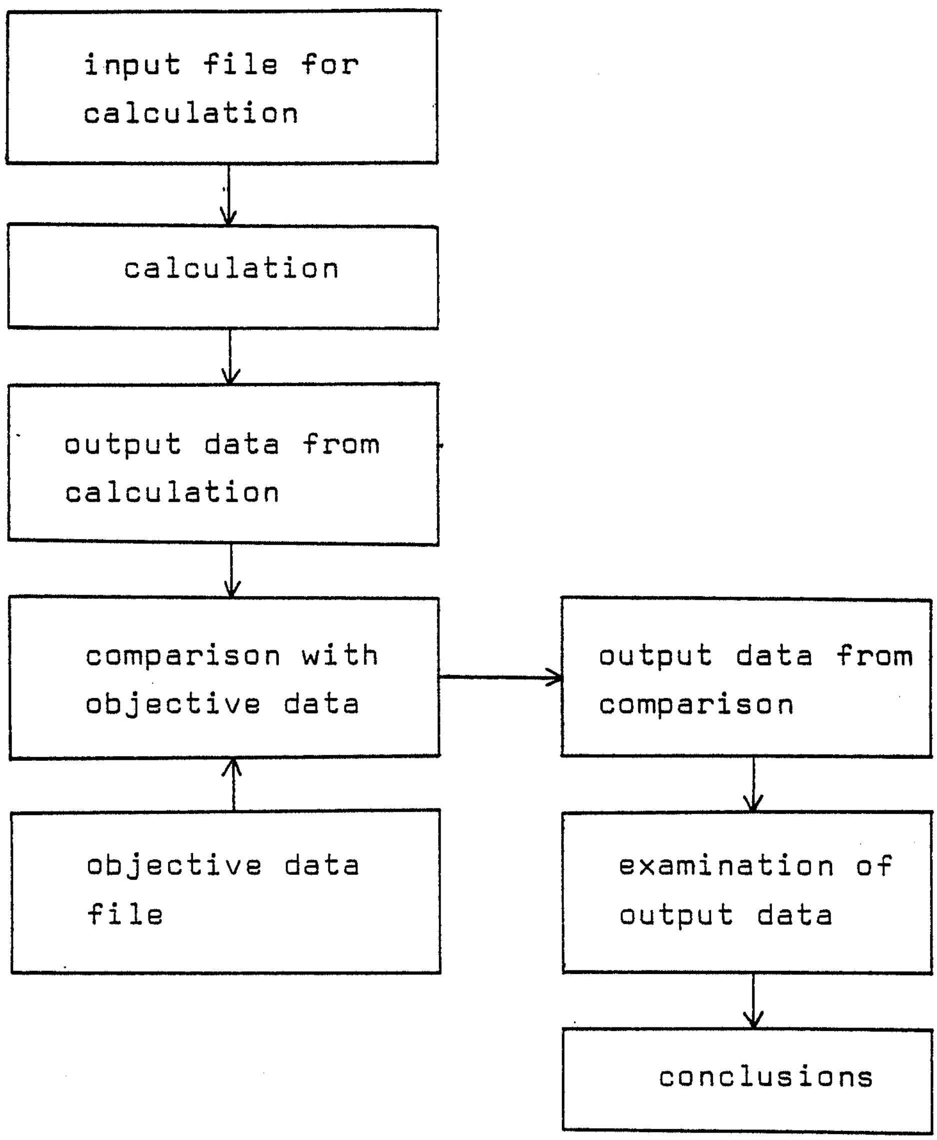


Figure 1. Flow chart for the calculation method for airtightness and ventilation of buildings.

2. Input data for calculation

Exact calculation of airleakage and ventilation requires a considerable amount of rather detailed data on the untight spots in the building and exact information of the ventilation devices. The input data required for the calculation can be divided as follows:

a. microclimate: data on the meteorological conditions around the building such as wind speed and direction and outdoor temperature

b. cracks: their location, dimensions and leak characteristics

c. ventilation system: location, dimensions, set amounts and flow characteristics of ventilation devices

d. pressure coefficients on the external surfaces of the building at different wind conditions

e. assumed inside pressure distribution of the building at the start of the calculation

f. other input information.

3. The output data of the calculation and comparison with objective data

The output data of the calculation can be devided as follows:

- air flows of the ventilation devices
- airleakage through the external surfaces of the building
- air flows inside the building
- internal pressure distribution of the building
- pressure distributions on the external surfaces of the building.

On the part of the different output data we can place functional requirements, which are led in numerical form to the objective data file such as:

- the permitted pressure differences across the walls
- flow requirements to internal air flows
- need for ventilation in different rooms
- the permitted airleakage of the external walls.

The output data are compared with the objective data.
On the basis of the output data from the comparison it can be said whether the ventilation of the building has met the requirements in the conditions examined and how large are the deviations from the objective values.

4. The calculation principle for calculation the flow equilibrium of the buildings

The input data given for calculation are:

- the outside pressure distribution on the building (remains unchanged during the calculation)
- the airflows of the ventilation devices, which are supposed to be realized at the start of the calculation (set air flows).

The inside pressure distribution of the building is obtained by solving flow equations of each room:

The sum of air flows into the room is equal to the sum of the air flows out from the room.

Continuous and pressure equations are then established for the different parts of the duct net, from which the changes in air flows of ventilation devices can be calculated.

If the air flows of the ventilation devices change, the inside pressure distribution is recalculated with the air flows obtained. If deviations are significant, calculation is continued until equilibrium is reached. The principle of the calculation procedure is presented in figure 2.

5. Utilization of the calculation model

The reliability of the theoretical model is tested by comparing it with experimental research results. The model will be further developed on the basis of experimental research.

The theoretical model is then used to investigate the effects of and relationships between the partical factors influencing ventilation. The output data of the calculation can be used as a basis for the examination of the energy economy of ventilation, to develop the measurement methodology of airtighness of buildings, determination of requirements, and product development.

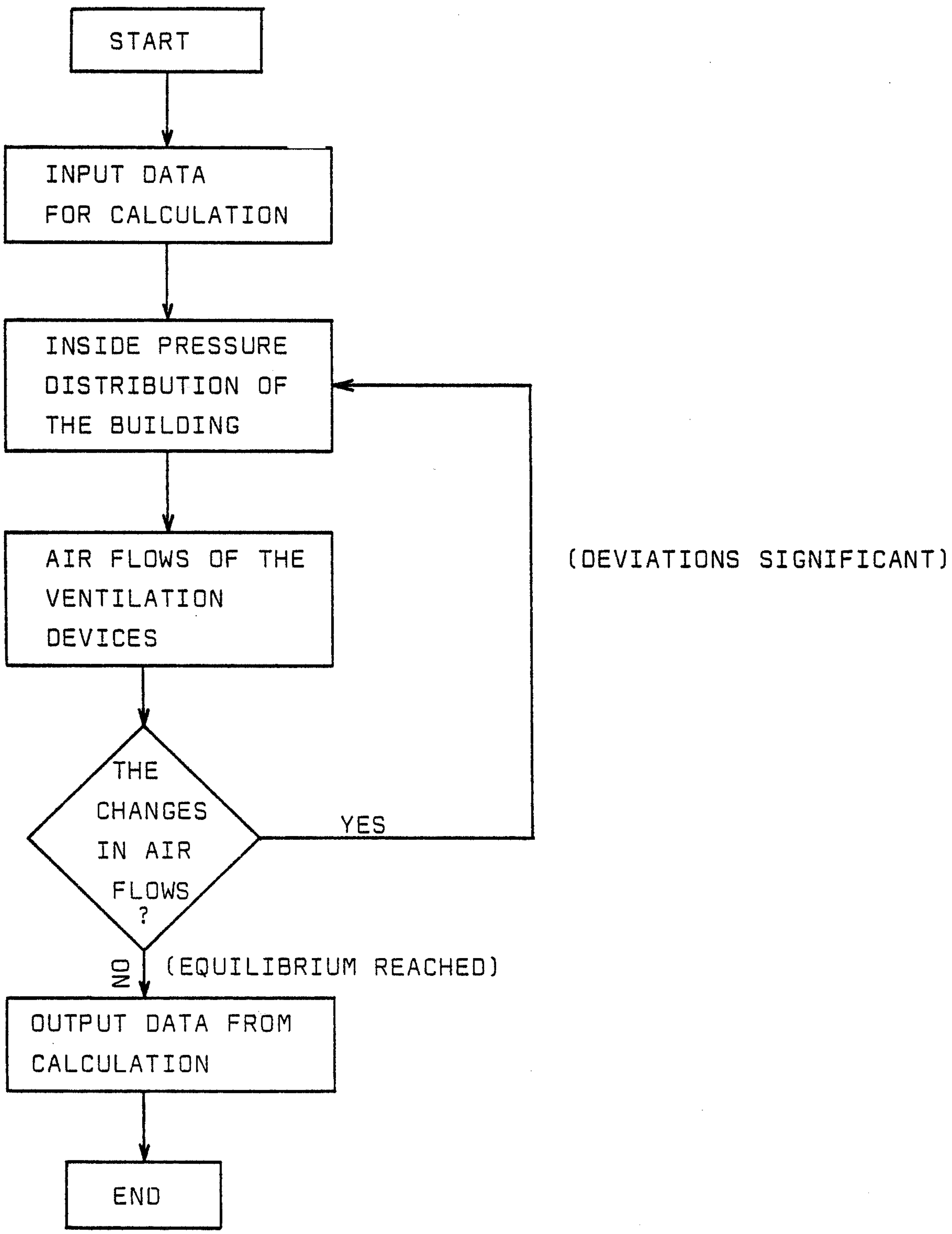


Figure 2. The calculation principle for calculation the flow equilibrium of the building.