PAPER 9

AIR FLOWS IN BUILDING COMPONENTS

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1 INTRODUCTION AND BACKGROUND

Knowledge of air tightness behaviour of buildings and building components is essential if a proper climate protection is to be achieved. Attempts to predict air infiltration rates and air flows in building components on the whole, and also intentional flows, have hitherto been difficult to perform. Therefore, often rough methods of calculating air flow rates have been used. Knowledge of surface roughness and the magnitude of the influence of this property for different flow cases has been poor. Permeability data concerning building materials have been - and still are - uncertain.

Quite a lot of effort has been spent on research concerning natural convection, both in building components and rooms. Apart from only a few early works, the concept of forced convection has been investigated just little until very recently, say the last five to ten years.

In Kronvall (1980) the aim has been to:

- o investigate how, and to what degree the concept of fluid mechanics can be applied to problems concerning air flows in building components caused by forced convection
- o produce calculation routines capable of handling also large and complex flow and pressure distribution problems
- o investigate and interpret present knowledge of air leakage behaviour of buildings and building components
- o investigate the influence of non steady state pressure difference acting on a building component
- o design and test an experimental procedure for determination of surface roughness of plates
- o expand the knowledge of the magnitude of the surface roughness of building materials
- o study experimentally the magnitude of entrance and bend losses in duct flow.

In this paper two important sections of the report mentioned above has been selected for presentation - one dealing with computorized analysis of flow resistance networks and another one dealing with different ways of describing air leakage characteristics of building envelopes.

Reports on computer calculations of air flows in building components are extremely rare. In most cases the reported works have been limited to a certain flow problem and the calculation procedures have been designed exclusively for the problem in question. Hence the computer programs used normally are afflicted by severe lacks of universal applicability.

Calculations of great complex networks of flow resistances are very timeconsuming and sometimes impossible to perform by hand. A systematic computerized calculation procedure can be obtained by means of a proper computer program. Such a one, called JK-CIRCUS, was written for this research project. Parts of the computer program originates from a program designed for analysis of electrical circuits; Anderson (1978). The solution procedure involves the following stages:

o The flow problem geometry is split up into finite parts - components.

o The admittance, defined below, of each component is calculated.

o The computer calculates the potentials, p(Pa), in all nodes and flow rates, $q(m^3/s)$, through all components.

The computer program works with the concept of admittance. This property, A, is defined by:

$$q_{v,\,x}\left[m^3/s\right] = A_x \left[m^3/(s \cdot Pa)\right] \cdot \Delta p_x \left[Pa\right]$$

Hence the admittance, A, is a linear operation on the pressure difference, Δp, across a component returning the flow rate, q.

In the case of (air) flow problems a component may be either of

o a pressure difference between two nodes (active component)

o a piece of permeable material (passive)

o a piece (in the flow direction) of a duct (passive)

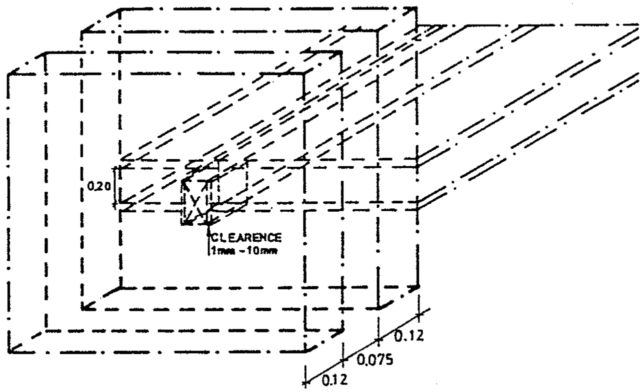
o a single resistance (e.g. entrance, exit, bend loss) (passive).

A flow chart of the computer program is shown in FIG. 2.a.

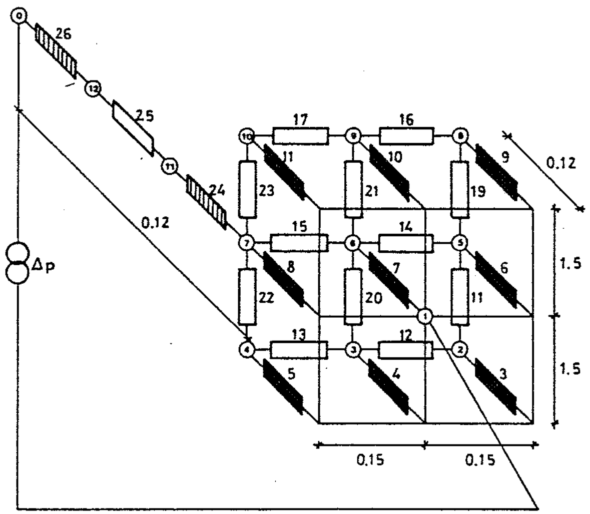
Example:

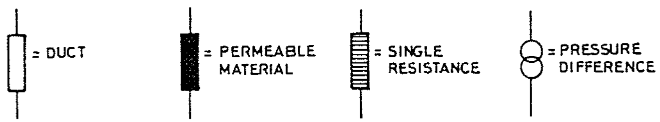
Cavity brick wall with beams penetrating the inner leaf.

This is a typical design in many countries. If the cavity wall has a bad air tightness and the clearance around the beams is large there is a certain risk of discomfort in the house caused by movements of cold air in the intermediate floor.



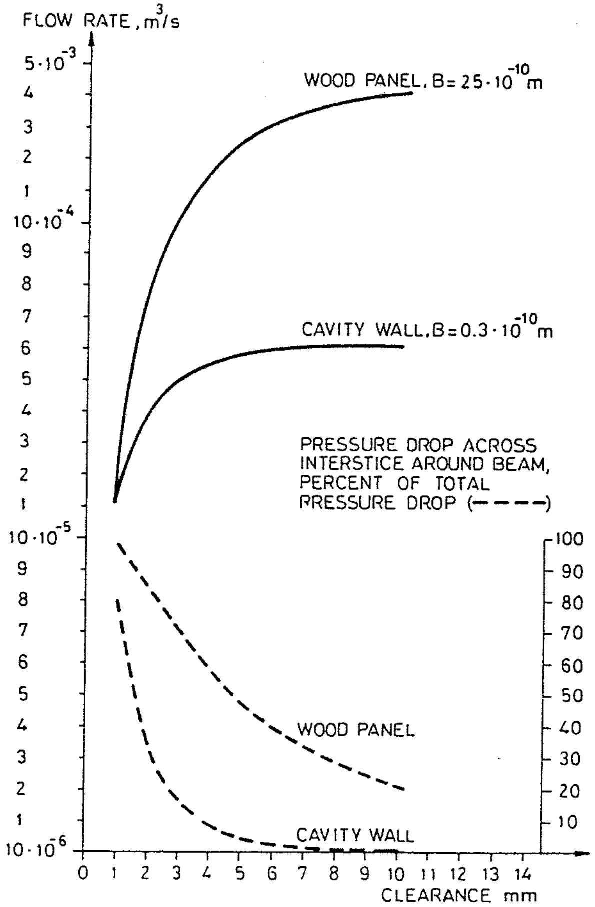
A part of the wall (height 3.00 breadth 0.30 m) was chosen to represent the "flow area" of the wall corresponding to the clerance on one of the two long sides of the beam end. The back wall itself is assumed to be air tight. The network used for the analysis is outlined below.





The roughness, ε, was put at = 0.005 m in the cavity and 0.001 m in the interstice. Test pressure difference was 20 Pa.

The resulting flow rate through the interstice around the beam is shown in the following figure as well as the percentage of the pressure drop across the interstice compared to the total drop. An alternative wall material (wood panel) is added too as comparison.



The building envelope is here considered to consist of the total climatic shelter of a building. The knowledge of air leakage characteristics of building envelopes of different buildings has been extended substantially during the last few years. This is due to a high degree to the rapidly increasing use of the pressurization technique to test the airtightness of whole buildings.

The pressurization procedure establishes a relationship between pressure difference across the building envelope and resulting leakage rate.

In most cases the result is given as a leakage curve.

From pressurization practice it can be observed that the shape of the leakage curve differs from house to house. The extremes of the shape are a parabolic curve on one hand and a straight line on the other. It is tempting to claim that this corresponds to complete turbulent flows in the flow paths of the envelope and complete laminar flow respectively. While the second statement is reasonable, the first one is quite dubious, since other phenomena than turbulence may cause the flow rate to be proportional to the square root of the pressure difference. Obviously, since single resistances like entrance, bend and exit losses operate on the square of the average velocity in the flow path, turbulence is not the only reason. This will be discussed more in detail below.

A versatile way of describing the relationship between leakage rate and pressure difference is to use a <u>power function</u>

$$q_{v,\ tot} = \alpha \cdot \Delta p^{\beta} \qquad (3.a)$$

where

α is a flow rate coefficient, $m^3/(s \cdot Pa^{\beta})$

β is a flow exponent, $0.5 \leq \beta \leq 1$

It is sometimes claimed that this expression is in conflict with a proper description of the physics of the flow. Of course, such an objection is correct and perhaps it would have been wiser to use a <u>quadratic equation</u> of the form

$$\Delta p = c_1 \cdot q_{v,\ tot} + c_2 \cdot q_{v,\ tot}^2 \qquad (3.b)$$

where the relative contributions of laminar flow on the one hand and orifice and single resistances and turbulent flow on the other could be shown.

A third way of making the description, used especially in the Anglo-Saxon countries, is by using the concept of <u>equivalent leakage area</u>, A_{eq}, defined as follows i.e. an equation for <u>turbulent flow</u> through a sharp-edged opening in a thin wall.

$$A_{eq} = \frac{q_{v,\ tot}}{C_d \cdot \sqrt{\frac{2\ \Delta p}{\rho}}} \qquad (3.c)$$

Thus the leakage behaviour of the building envelope is described as an area, A_{eq}, producing a certain flow rate $q_{v,\ tot}$, at a certain pressure difference, Δp. The choice of Δp seems to be rather arbitrary. C_d is a coefficient of discharge usually given the value of 0.6. A_{eq} has a constant value in an interval of Δp only if the leakage flow is proportional to the square root of the pressure differences in the interval.

Some researchers use a <u>leakage function</u>, $f_l(\Delta p)$ defined as:

$$q_{v,\ tot} = f_l(\Delta p) \cdot \Delta p \qquad (3.d)$$

The observant reader realizes of course immediately that this is nothing but an "overall" admittance of a building envelope.

The leaky envelope of a building may be considered to consist of a rich variety of different flow paths from tiny cracks and airpermeable material to relatively large (hidden) openings. It is possible to simulate the air leakage characteristic of a house by assuming arbitrary combinations of different flow paths. For the case of pure crack/duct flow, an example of such a simulation is shown in FIG. 3.a.

Perhaps the most astonishing thing about this simulation lies in a comparison between the leakage rates of different leaks. Though quite long - 20 to 70 running-metres - the narrow cracks No. 1-6 with widths between 0.075 and 1 mm create only minor contributions to the total leakage. Wider cracks, (5 to 10 mm), however, have a substantial influence on the total leakage, even though their lengths are quite small (1 to 5 running-metres).

The total leakage curve of figure 3.a will be analysed in accordance with the four different ways of description reviewed above.

Power function approach

The result of a least squares curve fit to a power function was:

$$q_{v,\ tot} = 0.047 \cdot \Delta p^{0.57}\ (m^3/s)$$

In addition, for each 5 Pa-interval (except the first one - being 1-5 Pa) the exponent β is displayed in the figure.

The exponent, β, wa[s ca]lculated as

$$\beta = \frac{\ln(\frac{q_{v,1}}{q_{v,2}})}{\ln(\frac{\Delta p_1}{\Delta p_2})} \qquad (3.e)$$

Thus the exponent of the potential expression seems to have a rather constant value for all pressure differences. High leakage rates seem to be caused by quite few, large leaks. The dimensions of these are big enough to create either turbulent flow or a flow such as in and outlet effects become considerable. It is obvious that the duct width has a very great influence on the leakage rate. Once a leak of large dimension is introduced:

- o the total leakage rate increases strongly,
- o the exponent β of the total flow curve is altered,
- o the value of β - in the total flow curve - does not vary much in different pressure difference regimes.

Quadratic equation approach

The result of a least squares curve fit to a quadratic equation was:

$$\Delta p = 16.7 \cdot q_{v,\ tot} + 238.1 \cdot q_{v,\ tot}^2$$

which shows that the influence of the second term is considerable.

Equivalent leakage area approach

The equivalent leakage area can be written:

$$A_{eq} = \frac{1}{C_d \cdot \sqrt{\frac{2}{\rho}}} \cdot \frac{q_{v,\ tot}}{\sqrt{\Delta p}} \qquad (3.f)$$

For $C_d = 0.6$ and $\rho = 1.25\ kg/m^3$ the equivalent leakage area was calculated for different pressure differences. The result is shown in FIG. 3.b.

From the figure it can be seen that at low pressure differences the equivalent leakage area decreases strongly. The value of A_{eq} at 1 Pa differs from that of 50 Pa by around 25%. This is the case even though the exponent formula in the power expression approach was found to be quite close to 0.5. If $\beta = 0.5$ the A_{eq}-value must be constant by definition. For narrow cracks the deviations from a constant A_{eq} value are likely to be larger still, of course.

Leakage function approach

According to definition the leakage function $f_1(\Delta p)$ simply equals the ratio between leakage rate and corresponding pressure difference. The resulting curve for the present example is shown in FIG. 3.c.

Obviously the leakage function varies within a large interval, and it seems to be rather high at small pressure differences. This behaviour was also found in field studies reported from the Lawrence Berkeley Laboratories, Grimsrud et al (1979).

The results may be explained if different basic duct/crack flow cases are studied. The figures 3.d-f are based on calculations of flow rate through ducts of different widths and with different values of total single resistance loss factors.

The figures show distinctly the influence of single resistances such as entrance, bend and exit losses. From figure 3.f in which $\Sigma\xi_{single} = 0$ it is obvious that the leakage function has a constant value until the flow turns over from laminar flow at Re > 2300. This will not happen at all at low pressures provided the ducts are not too large (< 10 mm). Real ducts/cracks in fact have entrances and exits and the flow direction may be changed too. Thus the assumption of $\Sigma\xi_{single} = 0$ cannot hold in practice.

The figures 3.d and 3.e show how different magnitudes of $\Sigma\xi_{single}$ influence the shape of the leakage function curves. Introducing single resistances implies that:

- o the value of the leakage function for a specific crack width decreases
- o the leakage function can become non-linear and non-constant even though Re > 2300
- o the maximum value of the leakage function occurs at $\Delta p = 0$ and equals the value corresponding to the case when $\Sigma\xi_{single} = 0$.

General remarks

The analysis above show that there is a relationship between leak dimensions and degree of discrepancy from linear flow characteristic. Hitherto this has not been taken into account as far as pressurization test practice is concerned. Instead of concentrating the effort on giving a leakage rate value at 50 Pa only, it would be worthwhile to investigate the shape of the leakage characteristic too. If considerable deviations from linearity is observed when the pressurization test is performed, a short time spent on looking around in the house in order to detect some few leak paths with large dimensions could in many cases probably be very profitable.

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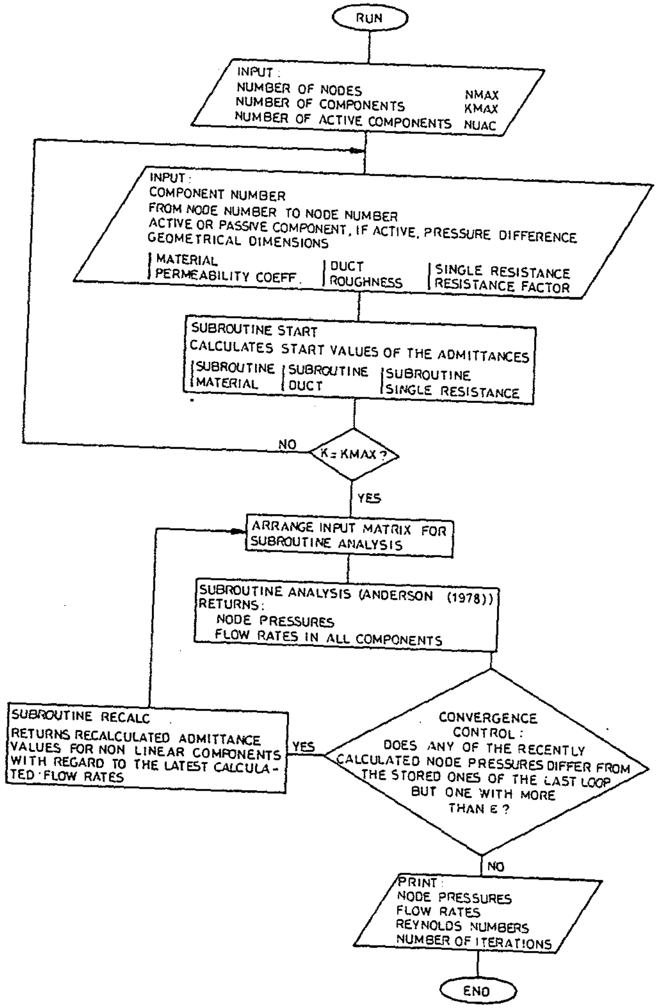
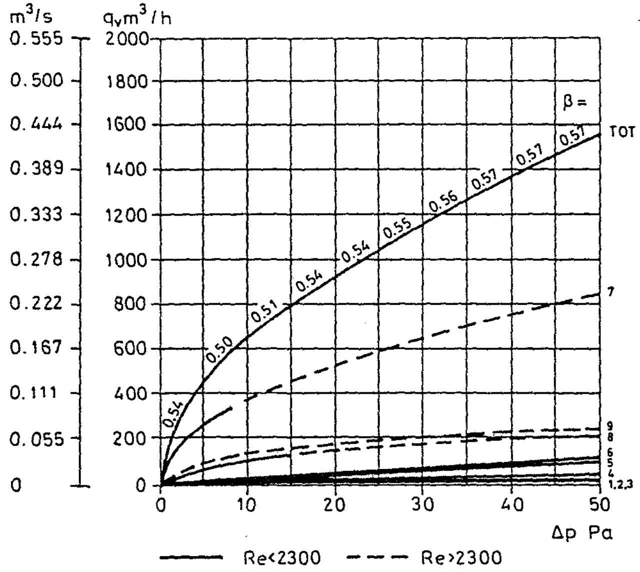


FIG. 2.a. Computer program JK-CIRCUS. Flow chart.



DESCRIPTION OF FLOW PATHS:

FLOW PATH NUMBER	1	2	3	4	5
LENGTH IN FLOW DIRECTION (m)	0.25	0.225	0.20	0.175	0.15
WIDTH (m)	0.000075	0.0001	0.00025	0.0005	0.00075
LENGTH (m)	70	60	50	40	30
ROUGHNESS (m)	0.0000075	0.00001	0.000025	0.00005	0.000075

FLOW PATH NUMBER	6	7	8	9
LENGTH IN FLOW DIRECTION (m)	0.125	0.10	0.075	0.05
WIDTH (m)	0.001	0.0075	0.005	0.01
LENGTH (m)	20	5	2	1
ROUGHNESS (m)	0.0001	0.00075	0.0005	0.001

FIG. 3.a. Simulated leakage characteristic of a house assuming crack/duct flow only. $\Sigma\xi = 1.5$.

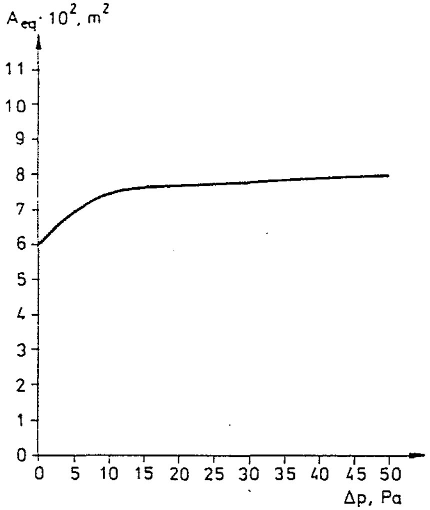


FIG. 3.b. Equivalent leakage area for house envelope leakage in accordance with figure 3.a.

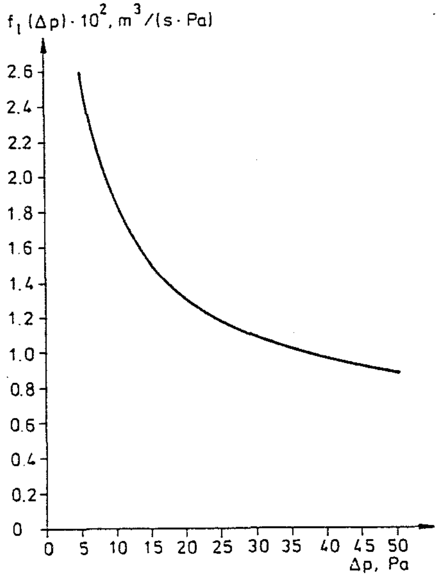


FIG. 3.c. Leakage function for house envelope leakage in accordance with figure 3.a.

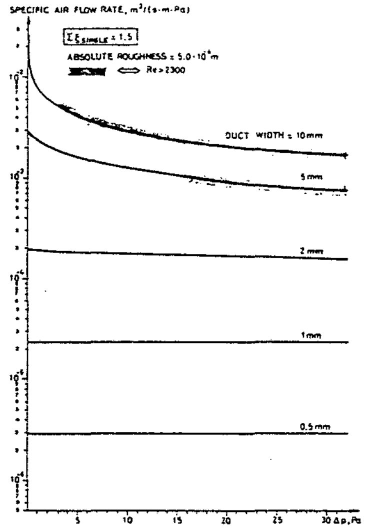


FIG. 3.d.

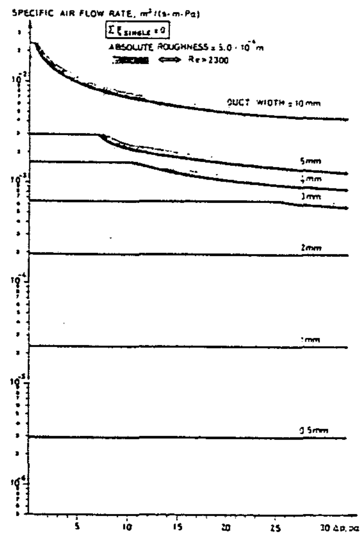


FIG. 3.e.

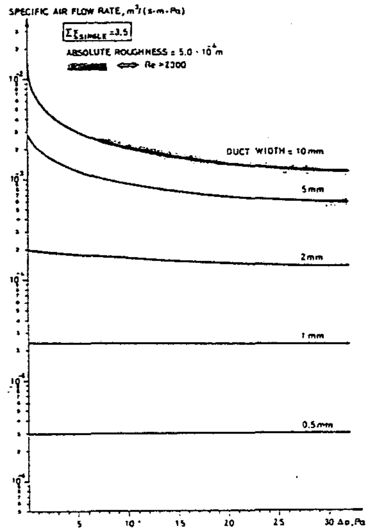


FIG. 3.f

FIG 3.d. - 3.f.
Air flow through ducts of different widths with length 0.2 m in flow direction for different single resistance values from 0 to 3.5.