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Pressure Distribution Around Low Rise Buildings

by

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SUMMARY

Estimation of rate of air flow through low rise buildings is essential for economical and efficient functioning of heating and ventilating systems. Natural and forced ventilations are directly and indirectly influenced by the pressure distribution around a building. The paper presents the results of full scale pressure measurements on two test buildings and shows their importance in the study of air infiltration.

INTRODUCTION

Knowledge about pressure distribution around a structure is important not only for wind induced loads but also in the study of air circulation within the building, acceptable level of comfort for the inhabitants and for efficient and economical use of heating and ventilating systems.

One of the major difficulties in estimating air infiltration rates in buildings is lack of full scale data on pressure distribution on various structural shapes located in different types of surface roughness categories. In order to fill this gap, two building structures of different shapes and situated in different environments have been studied by registering the mean pressure distribution and calculating the rate of air leakage due to openings.

The measured mean pressure coefficients have been compared with the values given in the Swedish code of practice and found to vary considerably depending on the shape and location of the house. Even the rate of air infiltration through the building is found to be different from the values advocated by the standards.

DESCRIPTION OF THE TEST HOUSES

Wind pressure measurements on two different types of family houses situated in terrain representative of "open" and "semi-urban" types of surface roughnesses have been studied. Figure 1 shows the location of measuring sites in relation to meteorological station.

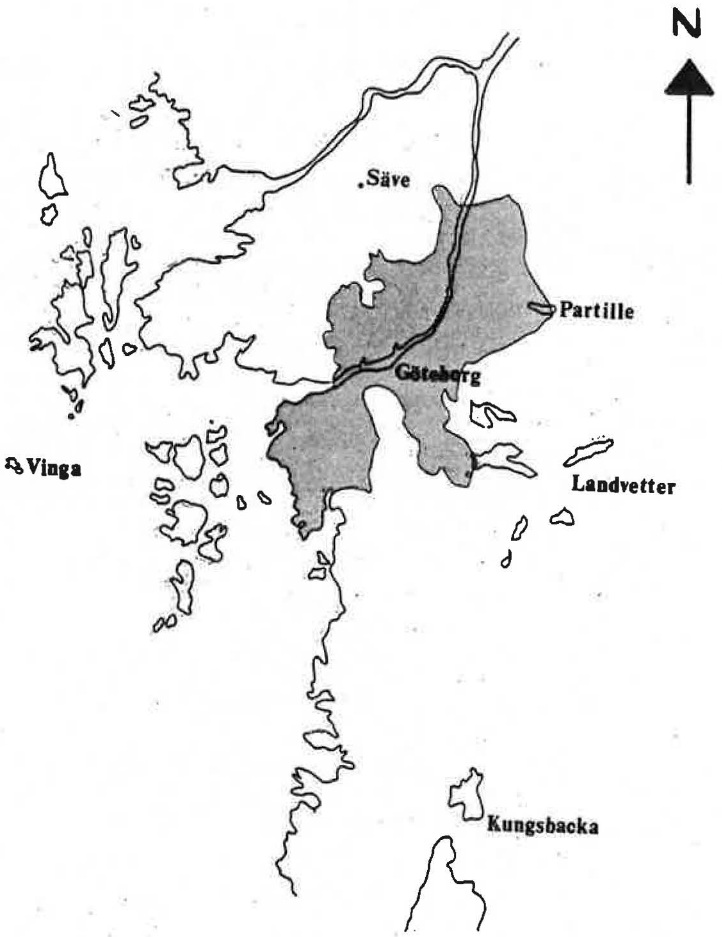

Figure 1 Location of sites in relation to meteorological stations.

The first test house (Partille) is of old type construction and built in 1946. The house is located in a densely populated area surrounded by low rise buildings (semi-urban) as shown in figure 2. The building is 1 1/2 plan with the lower part built in stone and the upper storey consisting of vertically-standing wooden panels. The insulation characteristics of the house are of poor quality, implying a high rate of air infiltration through the structure.

The second test house (Kungsbacka) is a newly-built prefabricated timber house with two floors. The house was built in 1978 and is designed according to the Swedish Standard SBN 75. The structure is located in an area with a few scattered houses and is representative of "open" site conditions (see figure 3). The house is well insulated and is fitted with a mechanical ventilation system for air outlets.

DESCRIPTION OF INSTRUMENTATION

The pressure measurements have been conducted with the help of fluid multimanometer. The measuring system consisted of aluminium panels with dimension 18 x 120 mm mounted on the walls in such a manner that the aluminium section fits in the space between the lock and the panel system, figure 4.

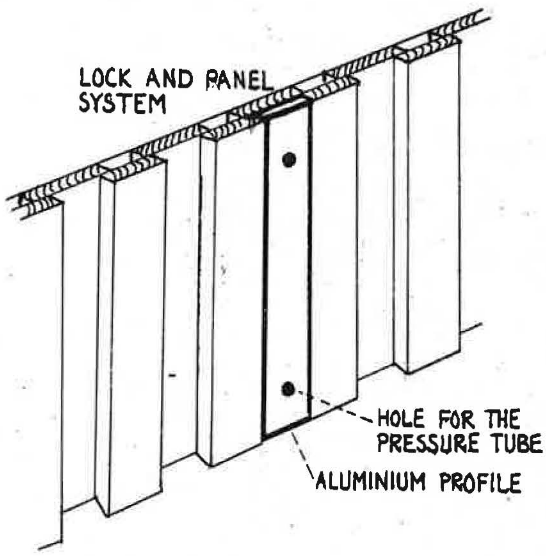

Figure 4 Aluminium profile

In other words, the panels are flush with the walls. The pressure tubes are connected to the aluminium profile by introducing a small slit at the back of the section. All the tubes are carried through a single small opening in the cellar and are connected to the open-type multimanometer inside the house.

Aluminium profiles were used in order to avoid drilling holes in the walls of the houses. This was due to the fact that the houses were occupied by the owners at the time of measurement and any damage to the property would have excluded any future investigations.

The multimanometer is of open type, which means that the measured pressure at a point is the difference between the external and the internal pressures.

The walls and the roofs of the houses were divided into 24 elements, as shown in figure 5, and the pressure was measured approximately at the centre of each element. The pressure coefficients were obtained for each segment by relating the measured values to the dynamic pressure at the roof level.

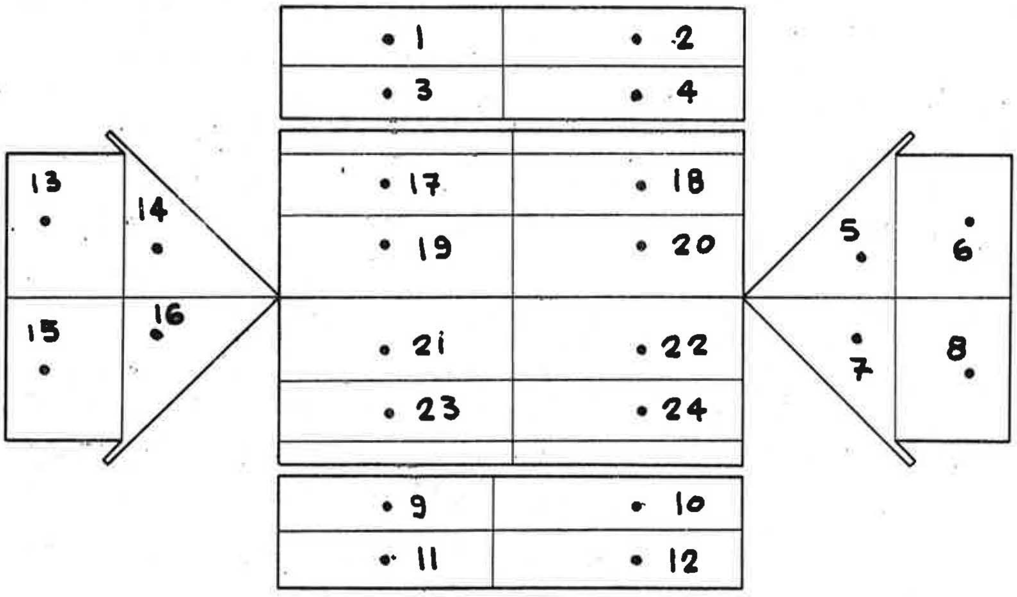

Figure 5 Elements and measuring points.

Figure 2 Test house "Partille"

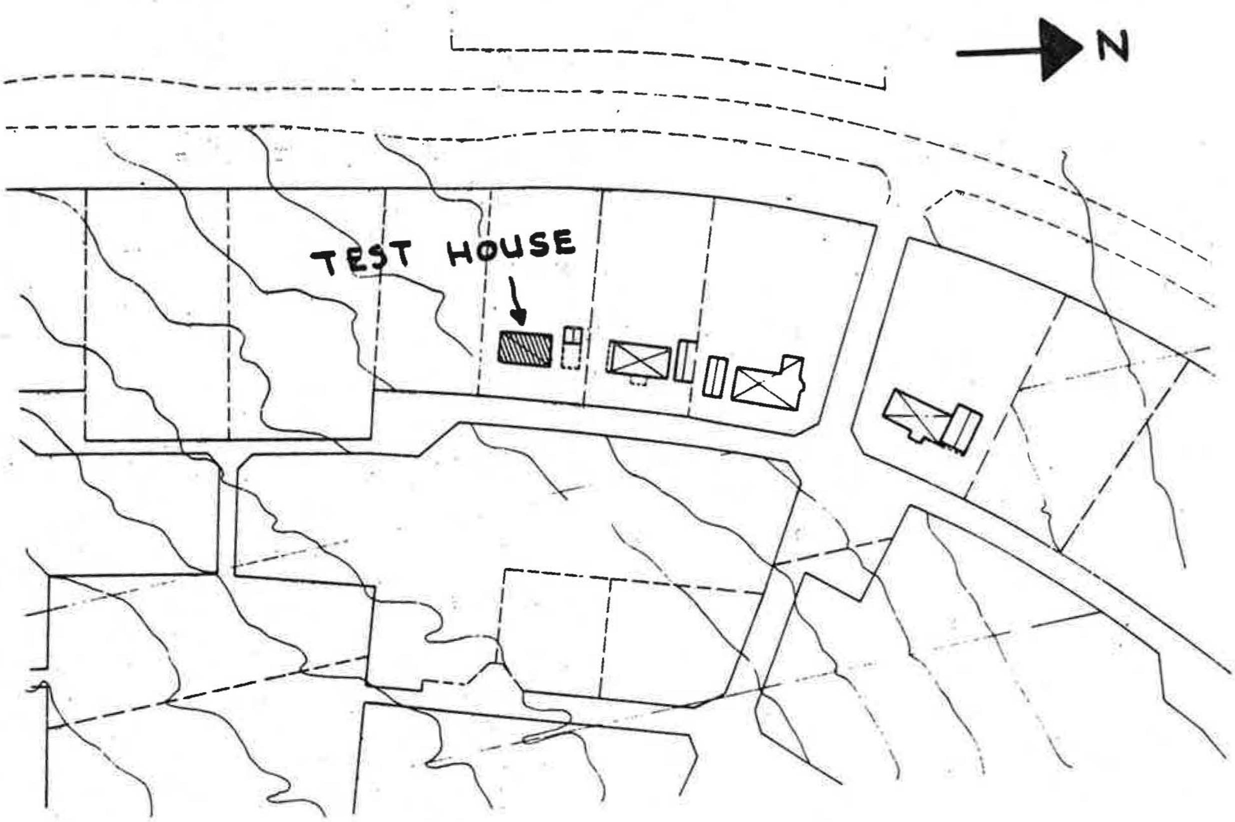

Figure 3 Test house "Kungsbacka"

The pressure distribution on the structure was measured by photographing the multimanometer at an interval of 3 seconds. A programme is developed by which the pressure coefficients can be obtained by scanning these photographs with an electronic pen and storing the data on the computer. The advantage of this system is that pressure distribution at any number of points on the house can be obtained simultaneously. A large numer of photographs were taken and the pressure coefficients C_p were derived which represents the pressure distribution on the test houses at any particular time.

The wind velocity was measured from 3-cup anemometer mounted on a mast away from the house.

EVALUATION OF PRESSURE COEFFICIENTS

The pressure coefficients C_p were obtained from the following relationship

$$C_p = \frac{(p_{ext} - p_{int}) - (p_{st,ref} - p_{int})}{1/2\ \rho\ V^2} \qquad (1)$$

where

p_{ext} = External pressure

p_{int} = Internal pressure

$p_{st,ref}$ = Reference static pressure

V = Free stream wind velocity at the roof ridge level

ρ = Air density

Figures 6 and 7 show the mean pressure distribution on the two test houses obtained by averaging over a large number of recordings. The pressure coefficients are also compared with those recommended in the Swedish Standards and it can be noted that there is a considerable difference between the measured and the recommended values.

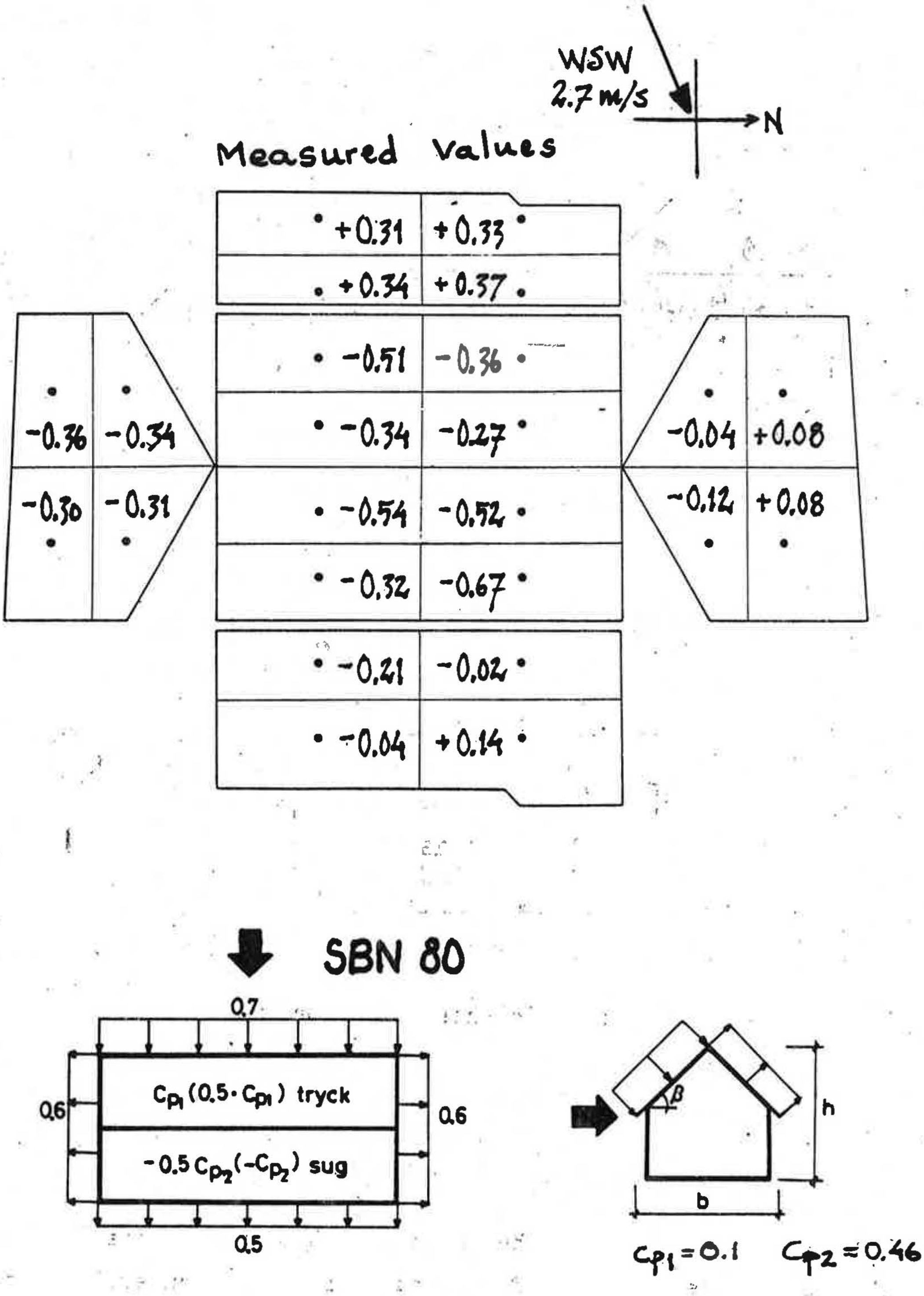

Figure 6 Pressure coefficients - Partille

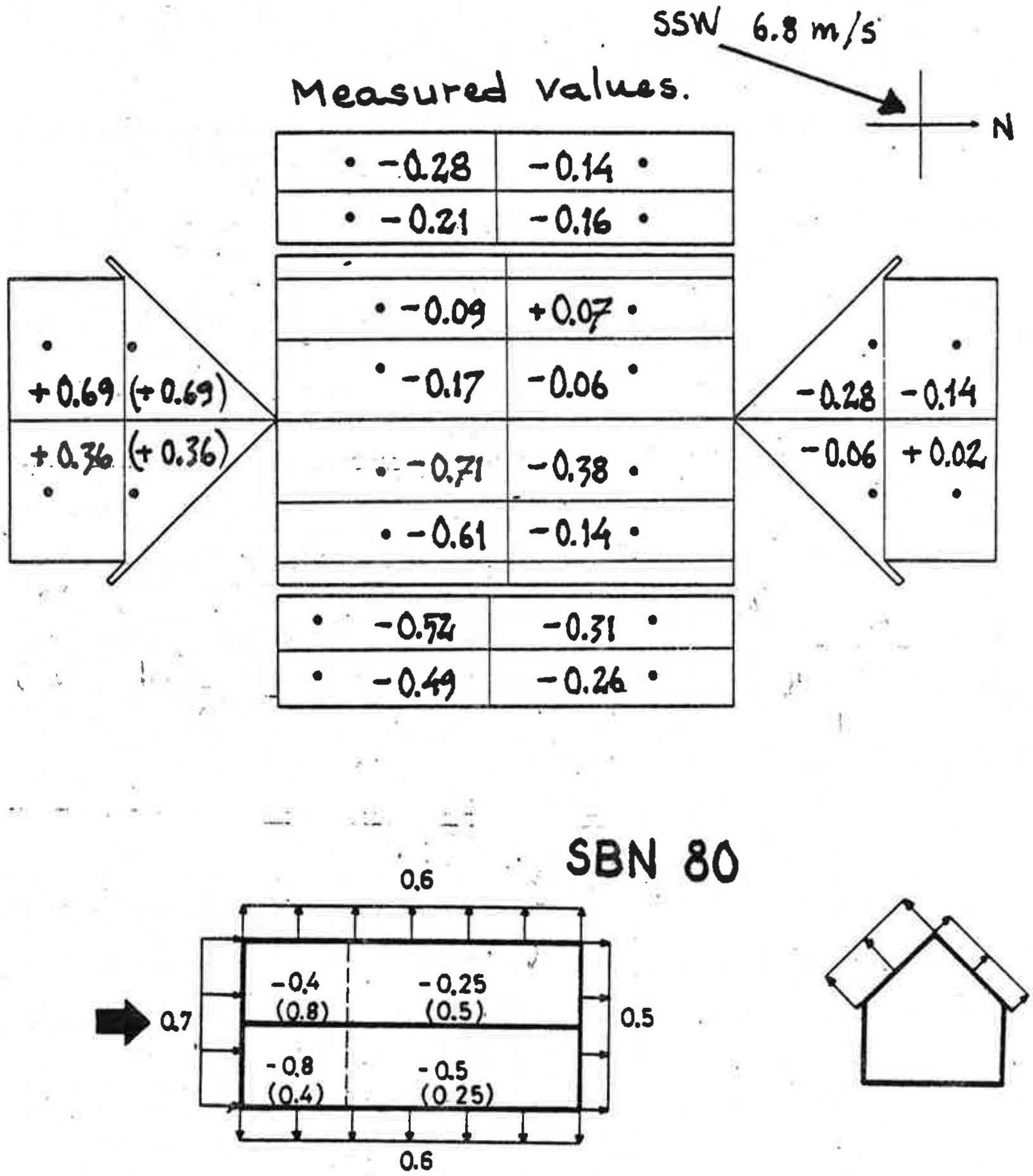

Figure 7 Pressure coefficients - Kungsbacka

It may be mentioned that the pressure coefficients given in the code of practice are generally for calculating wind-induced loads for maximum wind velocities. Their relevance in the design of heating and ventilating systems is doubtful as the pressure distribution at low wind speeds may not be the same as for high winds.

CALCULATION OF AIR INFILTRATION THROUGH THE BUILDING

In this section calculations of air infiltration through the two test houses are carried out be employing the measured pressure coefficients and the results are compared with the values obtained from the code of practice SBN 80. A simple model describing the pressure distribution ΔP_i due to wind and temperatures over an element i can be written as:

$$\Delta P_i = \underbrace{P_{wi}}_{\text{wind effects}} \underbrace{- \rho \cdot g \cdot 273 \left(\frac{1}{T_o} - \frac{1}{T_i}\right) Z_i}_{\text{temperature effects}} \qquad (2)$$

where

ΔP_i = total pressure distribution over element i (Pa)

ρ = air density (kg/m^3)

g = acceleration (m/s^2)

T_o = outside temperature (K^o)

T_i = inside temperature (K^o)

Z_i = height of element i from a reference level (m)

Expression (2) can also be written in terms of the pressure coefficients C_p and the free stream velocity V at the top of the structure as:

$$\Delta P_i = \frac{1}{2} \rho V^2 C_{pi} - \rho g 273 \left(\frac{1}{T_o} - \frac{1}{T_i}\right) Z_i + \Delta P_r \qquad (3)$$

ΔP_r is difference between the static reference and the internal pressure (Pa)

or in a simplified form:

$$\Delta P_i = 0.6 V^2 C_{pi} + 0.04 (T_o - T_i) Z_i + \Delta P_r \qquad (4)$$

Air flow through an area A_i of element i can be written as

$$q_i = A_i K_i (\Delta P_i)^{\beta} \tag{5}$$

where K_i represent the discharge factor per unit area for element i. The units for various quantities in expression are $q_i(m^3/s)$, $A_i(m^2)$, $K_i(m/s\ P_a^{\beta})$ and $\Delta P_i(Pa)$. β varies between 0.5 (turbulent flow) to 1.0 (laminar flow) depending on the flow characteristics.

The total infiltration through the house is obtained by adding up positive and negative components of the pressure distribution separately together with forced airflow due to mechanical ventilation.

The total inflow q_T and the total outflow q_F from the building can be written as

$$\begin{aligned} q_T &= q_{TM} + \sum_{i=1}^{n} q_i \text{ for positive } \Delta P_i \\ q_F &= q_{FM} + \sum_{i=1}^{n} q_i \text{ for negative } \Delta P_i \end{aligned} \tag{6}$$

where

q_{TM} = forced inflow due to mechanical ventilation
q_{FM} = forced outflow due to mechanical ventilation
n = total number of segments.

CALCULATION OF DISCHARGE FACTOR

The discharge factor K_i in equation (5) represents the permeability characteristics of element i. In reality, it is not possible to measure the leakage properties of every segment and therefore a discharge factor K is calculated for the whole structure. The standard procedure for establishing the value of K is to measure the rate of air flow through the building at a specified pressure of 50 Pa. The expression for the evaluation of factor K is then given by

$$\mu = (\Sigma\ K_i\ A_i)\ \Delta^{\beta} \tag{7}$$

where μ is the rate of air flow and Δ is the applied pressure of 50 Pa.

Generally the discharge factors for the external walls and the roof segments are grouped separately. This is done in order to reflect the different degree of tightness of the walls and the roof.

Expression (7) can be written in terms of leakage characteristics of the external walls as

$$\mu = K_w\ (\alpha\ \Sigma\ A_{Ri} + \Sigma\ A_{wi})\ \Delta^{\beta} \tag{8}$$

where K_w is the discharge factor for the external walls. A_{wi} and A_{Ri} are the surface areas of wall and roof elements. α is defined as the ratio of the discharge factor for the roof K_R and the wall K_w.

$$\alpha = \frac{K_R}{K_w} \tag{9}$$

The discharge factor K_w can be derived from equation (8) as

$$K_w = \mu\ /\{\alpha\ \Sigma\ A_{Ri} + \Sigma\ A_{wi})\ \Delta^{\beta}\} \tag{10}$$

Substitution of values of K_w and K_R in equations (5) and (6) gives the total in and outflow from the building.

RESULTS AND DISCUSSION

Figure 8 shows the influence of pressure and leakage distributions on the rate of air flow through the two test houses. Examination of the figure indicates that the air flow through the building is a function of the total leakage properties of the house and is independent of the relationship of leakage characteristics of the walls and the roof. In other words, it is not important for calculation purposes to know the ratio of the discharge factors for the roof and the walls as the rate of air flow is hardly affected.

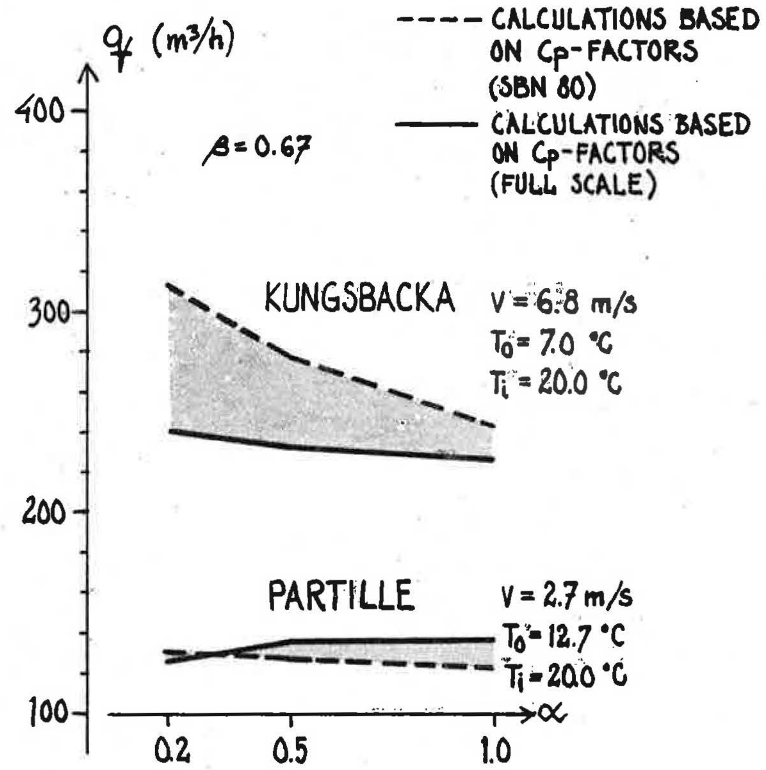

Figure 8 Calculated air flow.

Value of β is obtained from pressurization tests on the two houses. Figure 9 shows the rate of air flow for various values of pressures and the exponent β is derived from these curves and is approximately 0.67.

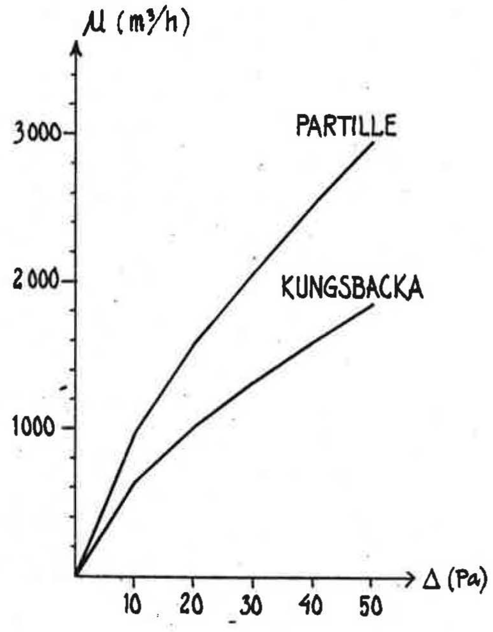

Figure 9   Pressurization tests.

Comparison between the measured and the calculated values of air flow shows that the "Kungsbacka" house gives rate of flow which is less than that given by the use of standard SBN 80, while the "Partille" house gives similar values as recommended in the code of practice.

It is not possible to draw any general conclusions from these limited full scale measurements, but it does indicate that the influence of distribution of leakage characteristics may be replaced by a single parameter. Furthermore the rate of air flow is influenced by the pressure distribution. Full scale measurements on houses of different shapes and located in different types of surface roughness are needed for establishing general rules for design of heating and ventilating systems.