ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER 21

ESTIMATION OF RATE OF AIR INFILTRATION BASED ON FULL-SCALE WIND PRESSURE MEASUREMENTS

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SUMMARY

Natural and forced ventilation are directly and indirectly influenced by the pressure distribution around a building. The paper presents the results of full-scale pressure measurements on a typical Swedish timber house.

The rate of air infiltration has been calculated by employing the values obtained from full-scale pressure distribution, air leakage characteristics and temperature differences. The results are compared with the actual ventilation obtained from tracer gas measurements.

1. INTRODUCTION

Wind and temperature induced pressure differential and air leakage characteristics are some of the essential parameters needed in the estimation of air flow through a building.

The present day approach of employing pressure coefficients or shape factors given in the code of practice on wind loads is not strictly correct for application in the air flow studies. The main objection is that these shape factors are for calculating maximum wind loads based on extreme wind speeds. 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.

In theory the pressure coefficients are nondimensionalised factors independent of the wind velocity and are derived by assuming that Bernouilli's law for laminar flows holds. In reality the pressure distribution is governed by the wind speed and direction which vary in time and space. The separation of flow from the building alters the flow field and the pressure distribution on the sides and the rear of the building is influenced by the size of the structure and the surrounding environment.

Generally the pressure coefficients are derived from wind tunnel studies and calibration with full-scale measurements is lacking. The lack of full-scale data on the pressure distribution and the air tightness characteristics of a building poses one of the major problems in assigning numerical values to various parameters needed in the theoretical models.

In order to fill this gap, full-scale wind pressure measurements have been carried out on typical Swedish detached houses located in different types of surface roughness categories. Results of measurements on two test houses have previously been published in references 1 and 2. This paper presents some of the latest series of pressure measurements on the 3rd test house located in a mixed type of terrain.

2. DESCRIPTION OF THE TEST HOUSE

The test house is a 1½-storey prefabricated timber house and is designed according to Swedish standard SBN 80. Ventilation is introduced by means of a mechanical exhaust system complemented with fresh air supply intakes located in the windows.

The structure is located in an area with a few scattered houses on one side and low hills on the other. It is representative of "open" and "semi-urban" site conditions. Figures 1 and 2 show the test house together with the surroundings.

Figure 1 The test house

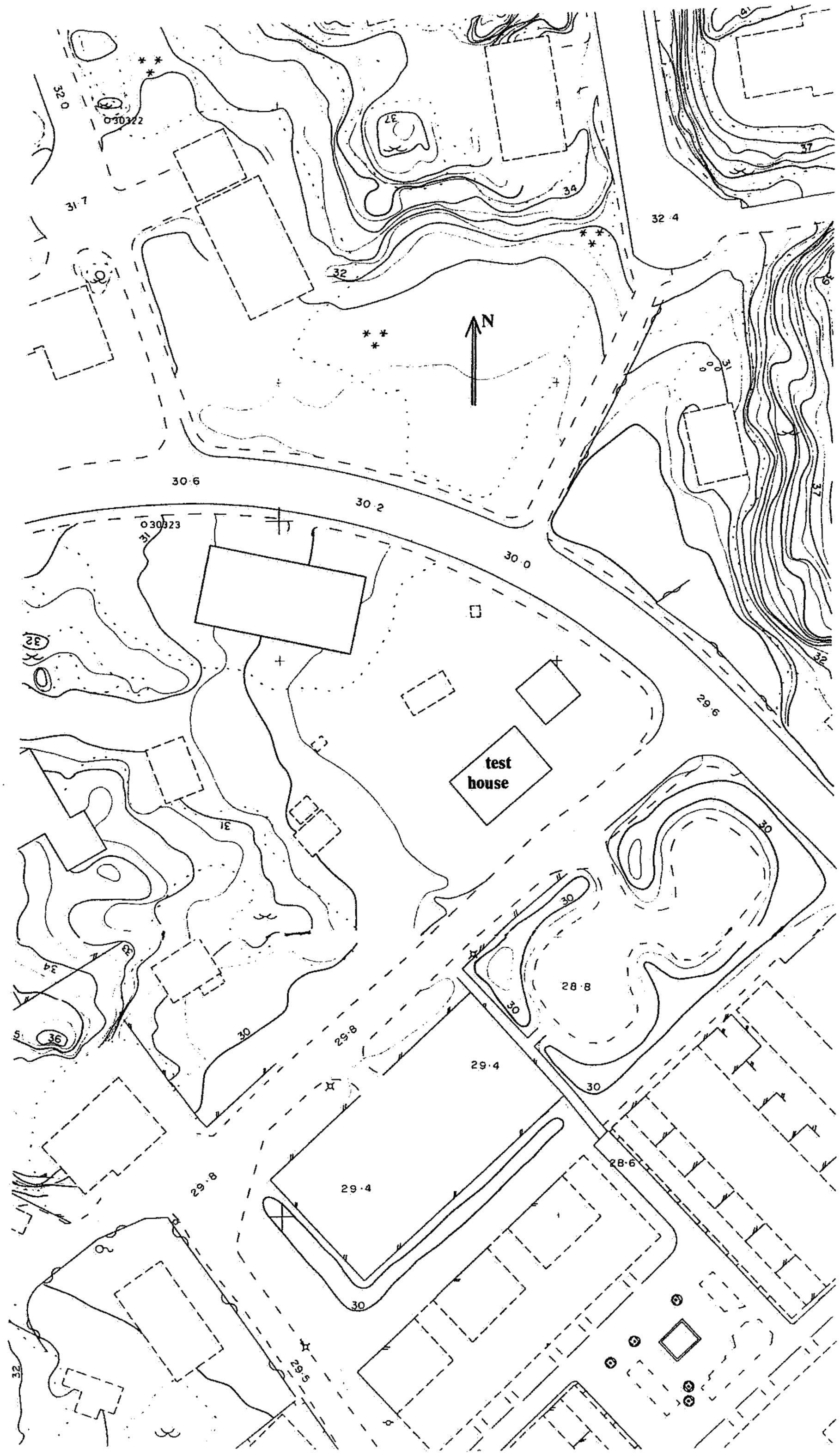

Figure 2 The surroundings around the test house

3. DESCRIPTION OF INSTRUMENTATION

The pressure measurements have been conducted with the help of a open type fluid manometer, which directly registers the difference between external and internal pressures. Plastic tubes, of same lengths, are used in connecting the manometer to the holes in the wooden panels, which are mounted flush with external walls.

The pressure distribution on the structure is registered by photographing the multimanometer every 10th second. Each series of measurements contains approximately 30 photographs. Data is obtained by scanning these photographs with the help of an electronic pen and storing it on a computer for further analysis. The advantage of this system is that the pressure distribution at all the points on the house can be obtained simultanously. The walls and the roof of the house are divided into 100 segments as shown in figure 3 and the pressure is measured approximately at the centre of each element.

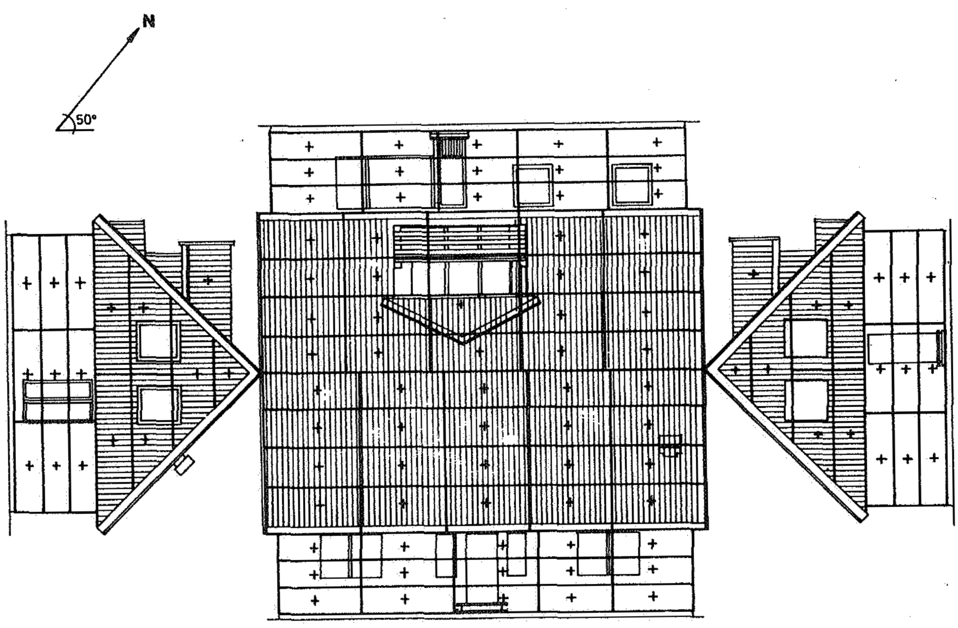

Figure 3 Elements and measuring points

4. EVALUATION OF PRESSURE COEFFICIENTS

The pressure coefficients are obtained for each segment by relating the measured values to the dynamic pressure at the roof level and are defined as

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

where

C_p = pressure coefficient
p_{ext} = external pressure
p_{int} = internal pressure
$p_{st,ref}$ = reference static pressure
V = free stream wind velocity
ρ = Air density

The pressure coefficients recommended in the Swedish Standards, SBN 80 are shown in figure 4. Figure 5 gives an example of the mean pressure distribution on the test house obtained by averaging over 27 recordings. It can be noted that there is a considerable difference between the measured and the recommended values.

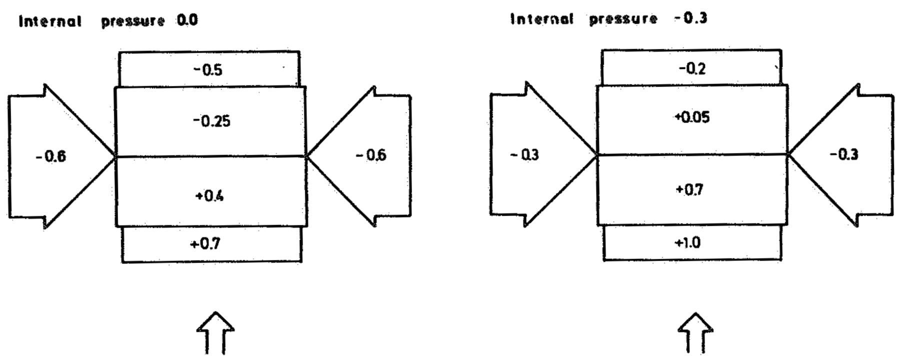

Figure 4 Pressure coefficients from the code of practice, SBN 80

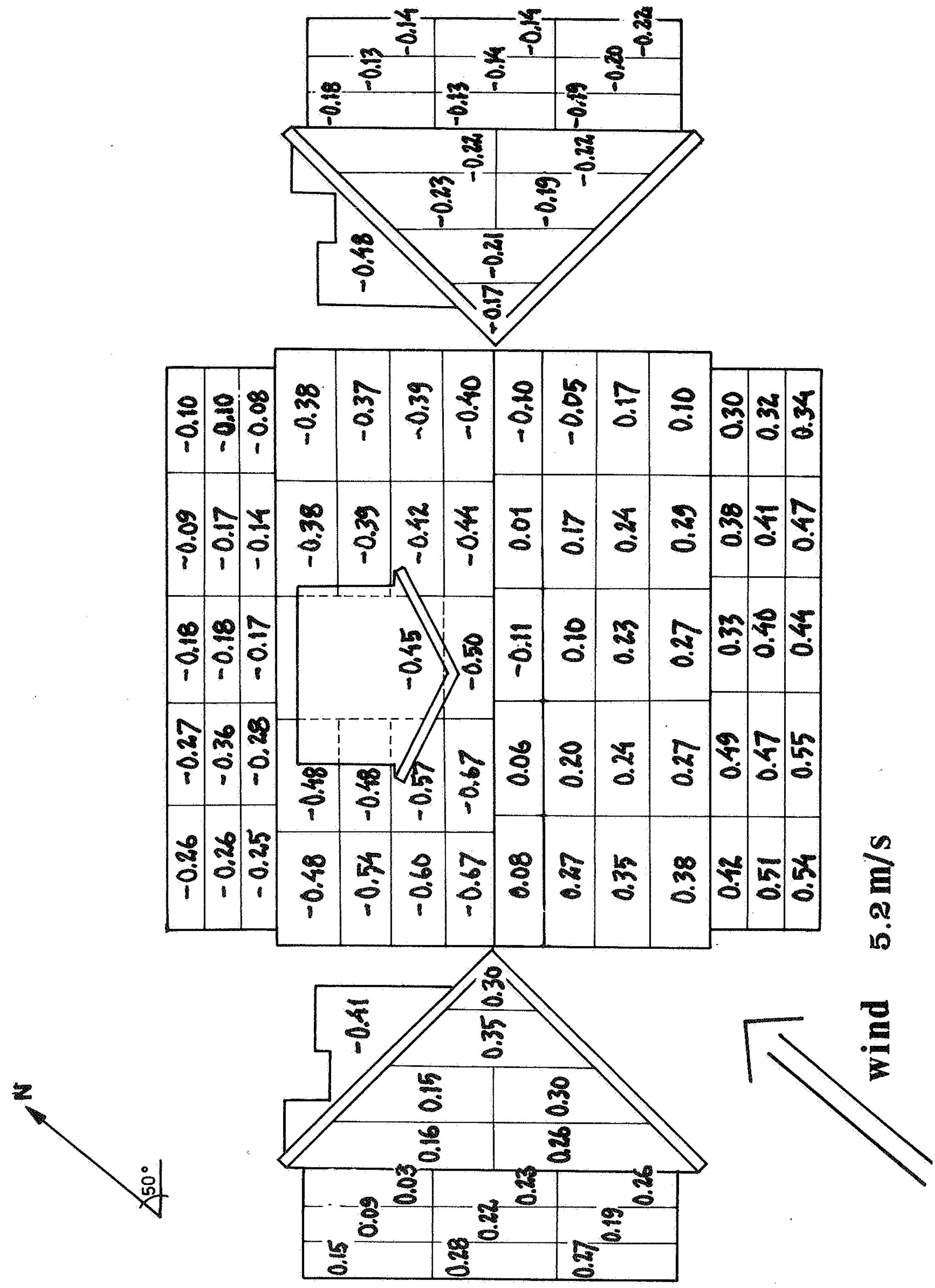

Figure 5 Pressure coefficients based on full-scale measurements

5. CALCULATION OF AIR INFILTRATION THROUGH THE BUILDING

In this section calculations of air infiltration through the test house are carried out by employing the measured pressures or pressure coefficients. A simple model describing the pressure distribution ΔP_i due to wind and temperatures over an element i can be written as:

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

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)

T_i = inside temperature (K)

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:

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

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

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

$$q_i = A_i \cdot K_i \cdot \Delta P_i \cdot |\Delta P_i|^{\beta-1} \qquad (4)$$

Where K_i represents 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 Pa$^\beta$) and ΔP_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

$$q_T = q_{TM} + \sum_{i=1}^{N} q_i \quad \text{for positive } \Delta P_i$$
$$q_F = q_{FM} + \sum_{i=1}^{M} q_i \quad \text{for negative } \Delta P_i \qquad (5)$$

where

q_{TM} = forced inflow due to mechanical ventilation

q_{FM} = forced outflow due to mechanical ventilation

N = total number of segments subjected to positive pressures

M = total number of segments subjected to negative pressures.

As the in and outflow must be balanced, sometimes it may become essential to introduce a correction term as given below in equation (6). Need for this parameter arises from the fact that the actual permeability characteristics and the reference static pressure cannot be measured accurately.

$$q_T \cdot T_i = q_F \cdot T_u + \varepsilon \qquad (6)$$

6. CALCULATION OF DISCHARGE FACTOR

The discharge factor K_i in equation (4) represents the permeability characteristics of element i . In reality, it is not possible to measure the leakage properties of every segment and therefore a total discharge factor, K_B is established for the whole area, A_B of the 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. The expression for the evaluation of factor K is then given by

$$\mu = (\Sigma K_i \cdot A_i) \cdot \Delta^{\beta} = K_B \cdot A_B \cdot \Delta^{\beta} \qquad (7)$$

where μ is the rate of air flow and Δ is the applied pressure of 50 Pa. The effect of wind and temperature is neglected compared with the forced pressure difference.

Figure 6 shows a relationship between the rate of air flow μ and the forced pressure difference Δ. The two curves indicate the influence of open and closed ventilation system on the air flow throughout the house. For low-rise buildings, the Swedish code prescribes that maximum rate of infiltration should be three changes per hour at a mean pressure of 50 Pa.

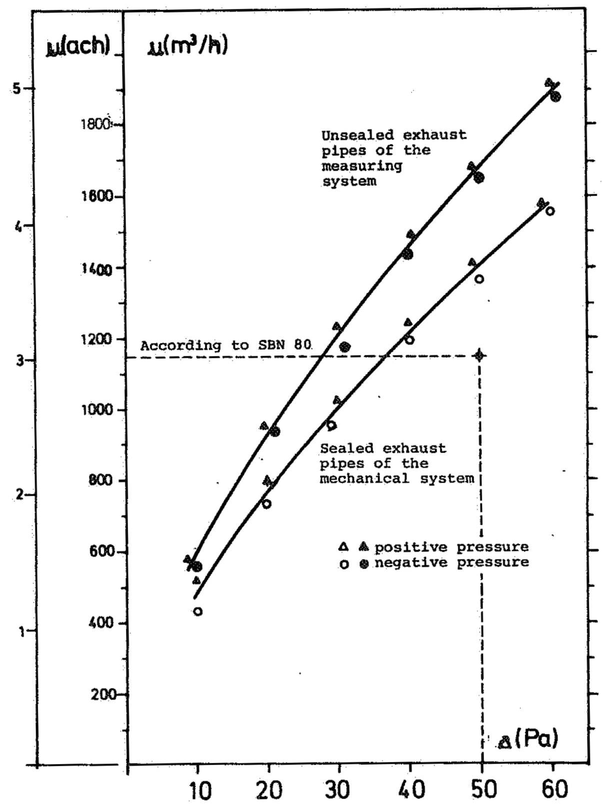

Figure 6 Pressurization tests

It should be observed that in these measurements, the mechanical exhaust system is not operating and that the pressurization tests have been performed by considering both the sealed and unsealed exhaust pipes of the mechanical system as shown in figure 6.

7. RESULTS AND DISCUSSIONS

The pressure distribution and the amplitude and direction of wind velocity are measured under different operating conditions of the mechanical exhaust system and the natural ventilation. The rate of air flow is also measured with the help of tracer gas during the same period.

Figure 7 shows the influence of mechanical exhaust ventilator on the pressure distribution. The full lines in the figure denote the pressure for non-operating ventilator, while the dashed lines indicate the case of normally operating ventilator. It is clear from the figure that the mechanical ventilation system hardly influences the pressure distribution around the house. This may be attributed to the fact that the mechanical exhaust system is working under the designed capacity of 0.5 changes per hour, which does not fulfil the requirements specified by the Swedish standards. The actual exhaust air, measured with a hot-wire anemometer, is approximately 0.3 changes per hour.

Figure 8 illustrates the influence of mechanical and natural ventilation on the rate of air flow measured by tracer gas and calculated air change rate based on the pressure distribution on the walls and the roof. Four different cases of natural and forced ventilation are studied as shown in table 1.

Table 1 Different combinations of natural and mechanical ventilation studied during the measurements

Case NO	Position of mechanical ventilator	Position of openings under the windows
1	closed and sealed	closed
2	closed and sealed	open
3	open	closed
4	open	open

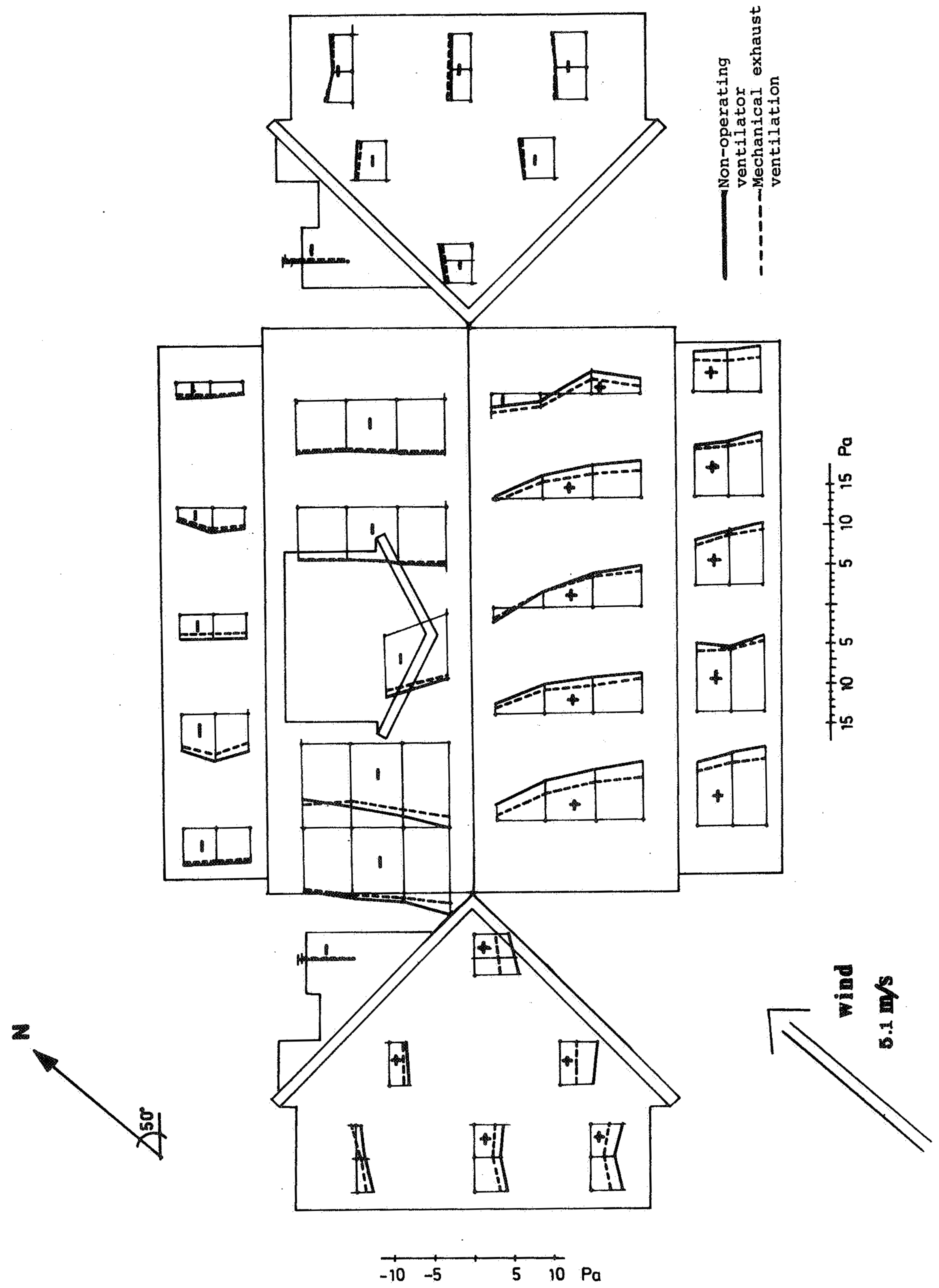

Figure 7 Pressure distribution on the walls and the roof

Examination of figure 8 shows that the rate of air flow measured by the tracer gas method is less than that obtained by the use of expressions (4) and (5). The difference in the two types of measurements indicates that the model for calculating the air flow based on pressure measurements is not adequate. It seems that the calculation model in its present form fails to reflect the behaviour of the system and needs some further modification. Of course, this tentative statement is true only if the tracer gas measurements are carried out in a systematic and professional manner.

The calculations based on the application of the code of practice are far in excess of those given by tracer gas and the wind pressure method. This is, as earlier mentioned, due to the fact that pressure coefficients from the code are really meant for calculation of wind loads and not for calculating the rate of air infiltration.

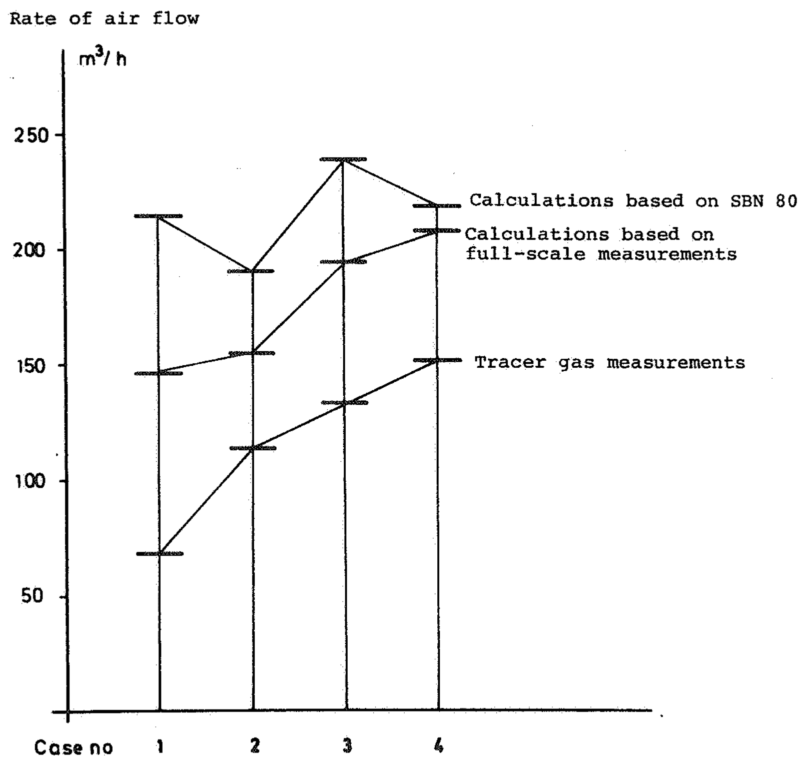

Figure 8 Measured and calculated rate of air flow

It can be of interest to study a relationship between the air flow and the actual wind velocity. This has been done by plotting a nondimensionalised factor γ versus wind velocity V in figure 9. γ is the ratio of the calculated flow Q derived from pressure distribution and air flow μ at 50 Pa based on pressurization test. Results are shown for the three houses situated in different types of surface roughness conditions. It can be noted that the values of γ are related to V in a rather distinct manner. It seems that it may be possible to estimate Q for a given velocity if an empirical relationship between γ and V can be established. This entails further full-scale measurements over a wide range of wind velocities.

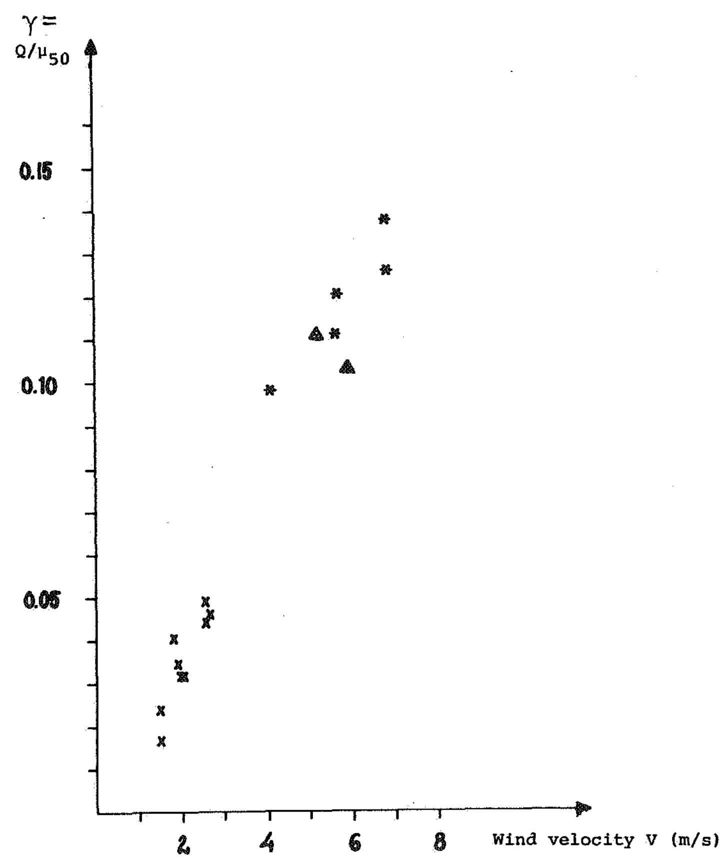

Figure 9 Relationship between ventilation losses and wind velocity

The study has shown the inadequancy of the existing calculating model when used in conjunction with full-scale measured data. It seems that further efforts are needed to correlate the experimental and theoretical models.

8. ACKNOWLEDGEMENTS

The work reported in this paper has been sponsored by the Swedish Council for Building Research. The authors gratefully acknowledge the award of the grant for this project.

9. REFERENCES

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