PAPER 14

CORRELATING PRESSURIZATION AND INFILTRATION RATE DATA – TESTS OF AN HEURISTIC MODEL

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1 BACKGROUND

In many countries we now have some years of experiences of testing houses for airtightness using the pressurization/depressurization technique. The main purpose of the test in most cases has been a performance control of the air tightness of the house. It was expected, however, that in future the test result should give an estimate of the infiltration rate of the building too. For example in a paper from 1978 (1) the author claims that: "To make such a relationship reliable many measurements on different types of houses with both the pressurization- and tracer gas methods must be made and reasonable corrections for the wind- and temperature influence of the tracer gas measurements must be found".

Since then, valuable contributions to the knowledge of these matters have been given, see for example (2), (3)! It is, however, quite obvious that there cannot exist a simple relationship (for example via a coefficient) as the test result from one of the tests is not dependent on the prevailing weather conditions while the other certainly is dependent on them.

2 CALCULATION MODELS

The problem of correlating pressurization data to infiltration data is very complex and almost all the present knowledge of air infiltration and even more should preferably be used. For the treatment of the problem you use measurement results from two most different measurement methods, with a series of measurement and interpretation problems. Furthermore you want to make a mathematical analysis based on these measurements and have to make a number of sometimes quite dubious assumptions.

The building may be considered to be a part of a system which consists of acting forces, an airleaking building and a ventilation system. Fig 1.

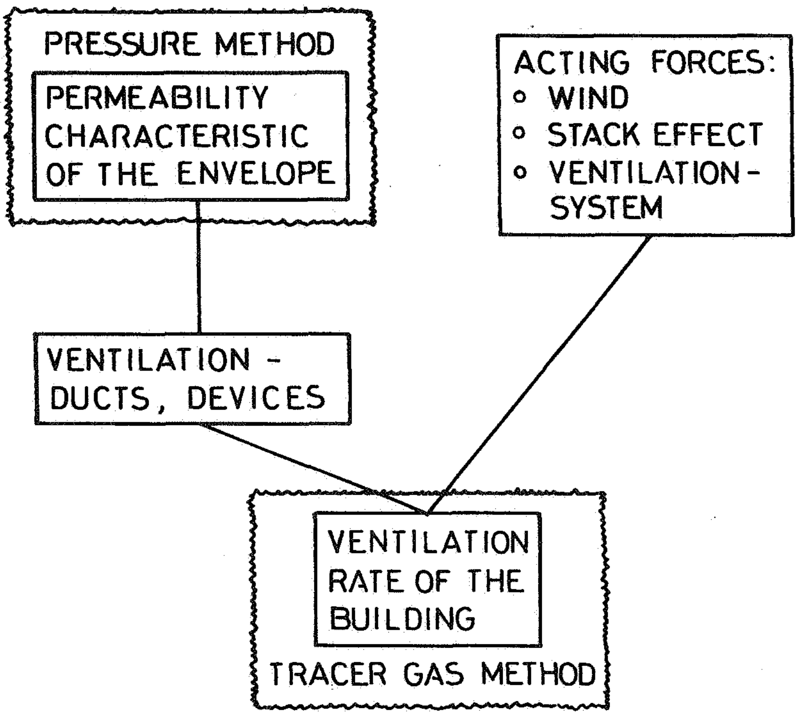

Figure 1.

Two characteristics may be settled by testing - a permeability characteristic of the envelope with the pressurization test and the ventilation rate of the building at the prevailing weather conditions (wind and temperature difference) when the test is carried out.

The test methods themselves introduce errors in a calculation model. Both accuracy and precision of the test methods should be taken into account. These matters have been discussed in (4) where it is stated that the probable error of the pressurization test according to Swedish practice is less than 4% when using electrical manometers and a recorder and 8% when using liquid manometers. The probable error of the tracer gas test depends heavily on the measurement time (decay measurement) but can for reasonable measurement times ($\simeq$ 1,5 h at a ventilation rate of 0,2 ac/h) be around 5%. The figures given above refer to measurement accuracy only. Matters influencing precision - that is the probability of obtaining the same measurement value on some other occasion - are not taken into account. For the pressurization test such matters are:

- o weather dependence (limitations are stated in the method description)
- o ageing durability of the tightness behaviour of the envelope.

For the tracer gas test the following factors are influencing the measurement precision:

- o the weather (wind and temperature differences)
- o the degree of "perfect" mixing of the tracer gas
- o the degree of fluctuation of wind speeds.

The last factor in fact initiates the question of the validity of the measurement. Do we in other words measure the quantity we want information about or do we perhaps measure something (quite) different? However, this may be more of interest from the ventilation effectiveness point of view than that of energy aspects.

One way of analysing the problem is to compare a value of the ventilation rate calculated with a calculation model - for example according to (5) - with a measured value. This procedure is outlined in figure 2.

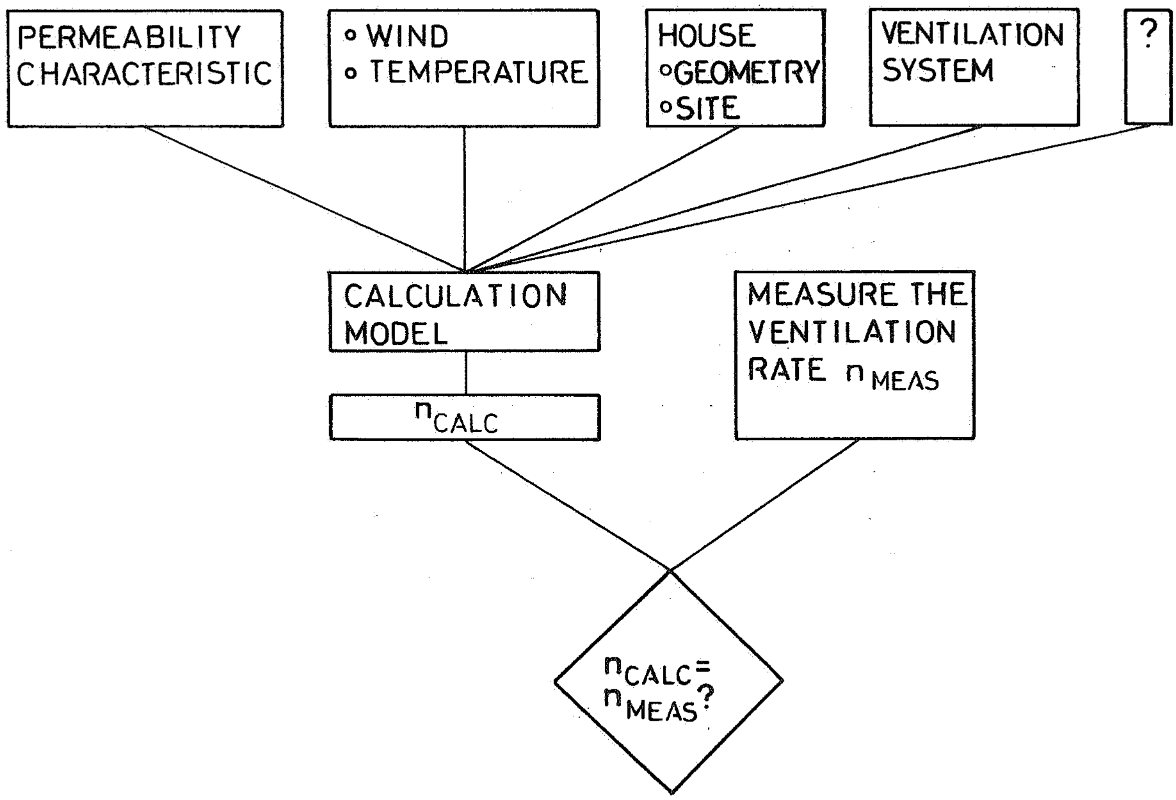

Figure 2. Comparing calculated and measured ventilation rate. Principal sketch.

Such an analysis must be based on detailed knowledge of the input factors.

Doing such a procedure for a number of different houses over and over again should, according to my opinion, teach us a lot of the mechanisms of air infiltration in a most effective way. It should help us to get a feeling for the sensitivity of the system to changes in various input parameters.

Being aware of the difficulties (and costs) of this procedure and in the absence of a fully developed calculation model a more heuristic approach is going to be discussed below. The principle of the method is shown in figure 3.

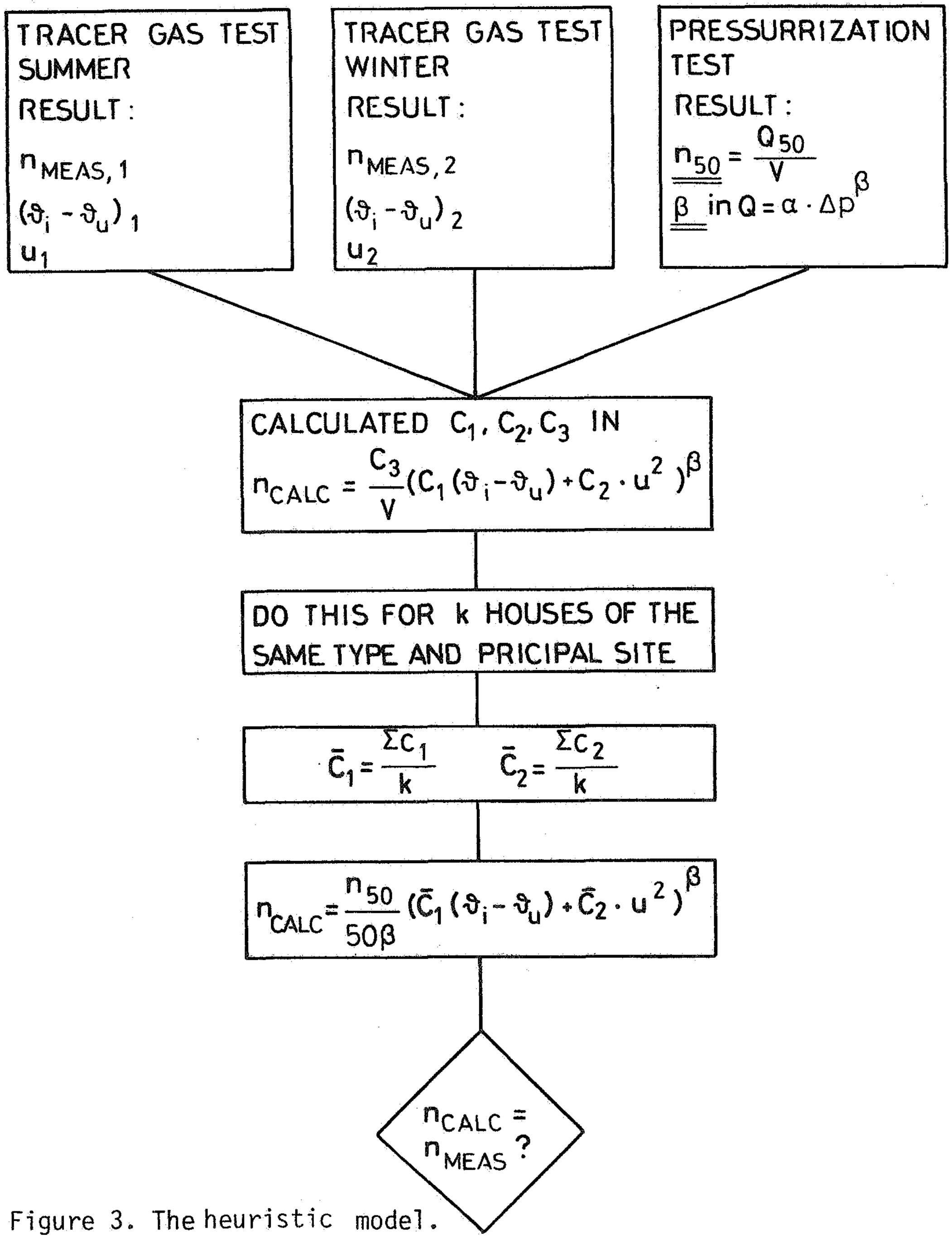

Figure 3. The heuristic model.

In words this means that you start with a pressurization test value and tracer gas test values from two very different weather conditions - preferably summer and winter. Such values should be available for at least some tens of houses of the same type and principal site.

The measured values are "forced" into the model

$$n_{CALC} = \frac{C_3}{V} \left(C_1(\vartheta_i - \vartheta_u) + C_2\, u^2\right)^{\beta} \qquad (1)$$

which is based upon

$$Q = \alpha \cdot \Delta p^{\beta} \qquad (2)$$

By identification it is obvious that:

$Q = n_{CALC} \cdot V$; the ventilation flow; infiltration <u>or</u> exfiltration (3)

$\alpha = C_3$ a flow coefficient (4)

$$\Delta p = (\underbrace{C_1\ (\vartheta_i - \vartheta_u)}_{\text{STACK EFFECT}} + \underbrace{C_2\ u^2}_{\text{WIND}}) \qquad (5)$$

In (1) to (5)

n_{CALC} = calculated air change rate, ac/h
V = building volume, m^3
ϑ_i = indoor temperature, ^oC
ϑ_u = outdoor temperature, ^oC
u = wind velocity at a reference point, m/s
C_1 = model coefficient, Pa/K
C_2 = " , $Pa/(m/s)^2$
C_3 = " , $(m^3/h)/Pa^{\beta}$

C_3 and β are obtained from the pressurization test:

$$\frac{C_3}{V} = \frac{n_{50}}{50^{\beta}} \qquad (6)$$

where

n_{50} = resulting leakage divided with the volume of the house at pressurization to 50 Pa, ac/h

β = flow exponent in the relationship $Q = \alpha \cdot \Delta p^{\beta}$ fitted to the measured values.

C_1 and C_2 are solutions to the following equation system where $n_{MEAS,1}$ and $n_{MEAS,2}$ stand for measurement values of the ventilation rate at two occations.

$$n_{MEAS,1} = \frac{n_{50}}{50^{\beta}} (C_1(\vartheta_i-\vartheta_u)_1 + C_2\, u_1^{2})^{\beta} \qquad (7)$$

$$n_{MEAS,2} = \frac{n_{50}}{50^{\beta}} (C_1\ (\vartheta_i-\vartheta_u)_2 + C_2\, u_2^{2})^{\beta} \qquad (8)$$

Thus:

$$C_1 = \frac{\dfrac{n_{MEAS,2} \cdot V}{C_3} \cdot e^{-\beta} - \dfrac{n_{MEAS,1} \cdot V}{C_3} \cdot e^{-\beta} * u_2^{2} \,/\, u_1^{2}}{(\vartheta_i-\vartheta_u)_2 - (\vartheta_i-\vartheta_u)_1 * u_2^{2}/u_1^{2}} \qquad (9)$$

$$C_2 = \frac{\dfrac{n_{MEAS,1} \cdot V}{C_3} \cdot e^{-\beta} - C_1(\vartheta_i-\vartheta_u)}{u_1^{2}} \qquad (10)$$

A number of implicit assumptions have been made above.

For the treatment of data from each house:

To begin, outside the house it is assumed that the wind conditions at a reference height near the house is a representative value for determining the wind pressures acting at it.

The leakage paths of the envelope of the house is assumed to be evenly distributed over the total envelope. The possible error introduced with this assumption may be large but the effect is difficult to predict.

The pressure distribution is assumed to be even all over the envelope which definitely is not the case in reality. The implications of such an assumption are difficult to predict too.

The exponent of the leakage function is set to a constant value for all pressure differences. Some authors have claimed that this is not at all the case (2), (5). Their opinion is that the exponent is close to 1,0 (laminar case) at low and close to 0,5 (turbulent case) at higher pressure differences across the envelope. I do not completely agree with that. It rather seems to be so that high leakage rates are caused by big leaks. The dimensions of these are big enough to create greater turbulent flow or flow with so high velocities that in- and outlet effects become considerable. This effect is demonstrated in figure 4 where a leaky house under pressurization test is modelled. The leaks 1 - 9 represent a variety of possible leaks with different sizes. It is obvious that the duct width has an overwhelming influence on the leakage rate. Once a leak of big dimension is introduced three things happen:

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

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

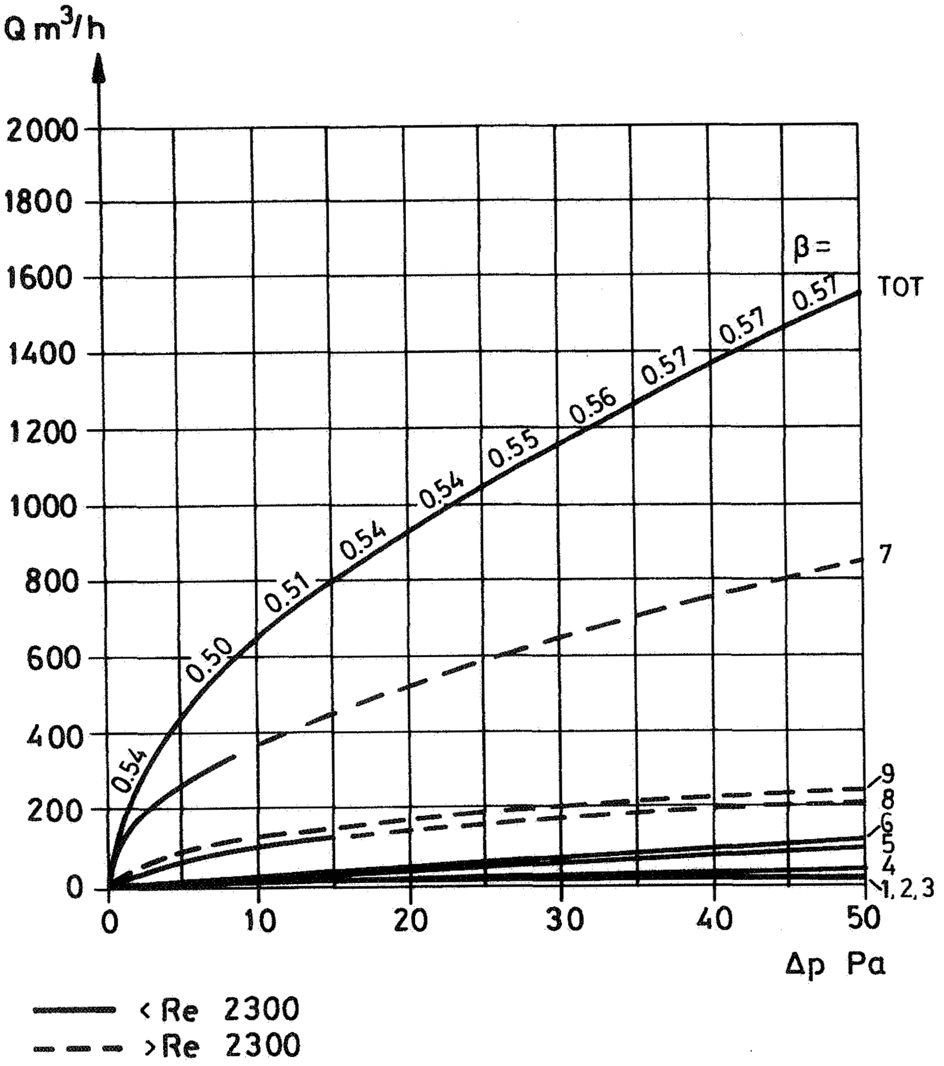

Figure 4.

For the treatment of data from all the houses:

Mean values of C_1 and C_2 from different houses are calculated. To be relevant the resulting formula may not be used for other houses and house sites than the "averaged" ones. This means that it must be one and the same type of houses and the sites may not differ to much from each other.

3 TESTING OF THE HEURISTIC MODEL

The model was tested on 19 1½-storey single-family houses. With few exceptions they were built in groups of houses in suburban areas in or around the city of Gothenburg. The measurements were carried out by the division of Structural Design at Chalmers Institute of Technology (CTH) in Gothenburg (6). The exterior and the lay-out of the houses are shown in figure 5.

The wind velocities were measured at the top of a 10 m high mast placed at an, as far as possible, open place on the windward side of the houses. The pressurization tests were performed according to Swedish practice (4). However, the leakage rate was reported at both 25 Pa and 50 Pa. This made it possible to calculate a flow exponent, β. The tracer gas test were carried out an one summer and one winter occasion. The ventilation rates chosen for this study were the values obtained when devices for ventilation etc were closed. Only the envelope of the house was involved as a leaking component.

The coefficients C_1, C_2 and C_3 were calculated for each house. The coefficient C_3 - being a leakage coefficient - is individual for each house. The means of C_1 and C_2 from the 19 houses were calculated and this results in the formula:

$$n_{CALC} = \frac{n_{50}}{50^{\beta}} \left(\overline{C_1}\,(\vartheta_i - \vartheta_u) + \overline{C_2}\,u^2\right)^{\beta} \qquad (11)$$

Two cases were studied. The first one implies the use of the wind velocities at the 10 m-level above ground as they are reported. In the second case the wind velocities at 10 m were reduced with 50% and these lower wind-velocities were used.

Figure 5. Exterior and lay-out of the houses.

Case 1. No wind reduction

This case resulted in the following expression.

$$n_{CALC} = \frac{n_{50}}{50^{\beta}} (0,026\ (\vartheta_i-\vartheta_u) + 0,010\ u^2)^{\beta} \qquad (12)$$

Plots of the expression for different wind velocities, temperature differences and exponent β-values are shown in figure 6. In this figure n_{50} is chosen to 3 ac/h. n_{CALC} for other n_{50}-values are easily calculated as n_{50} is a single factor in the expression.

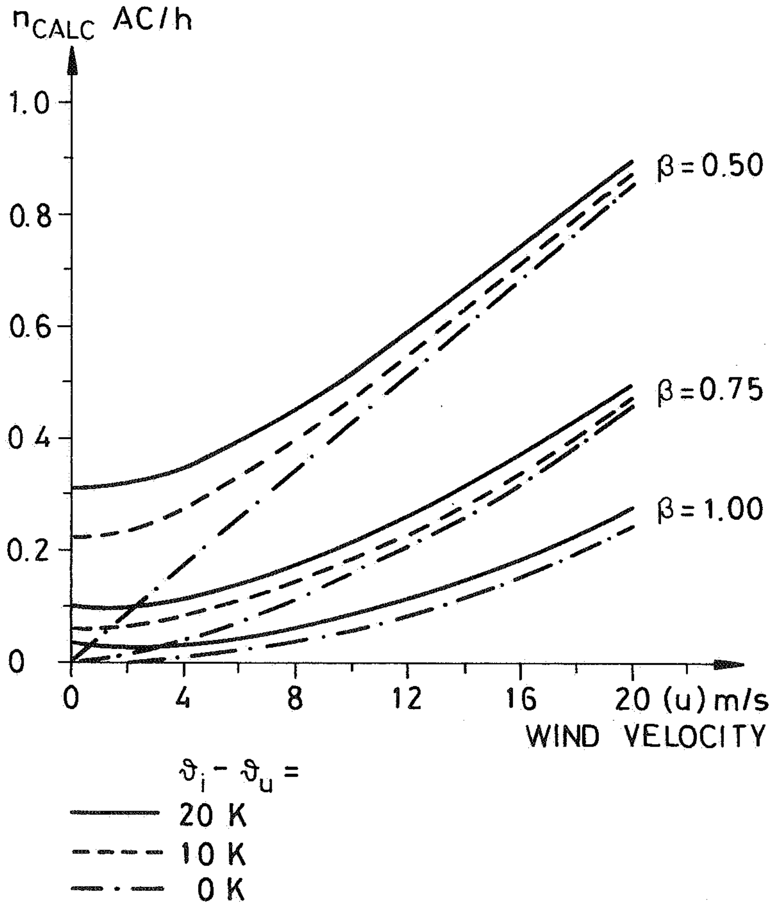

Figure 6. n_{CALC} as a function of wind velocity, temperature difference and exponent β · n_{50} = 3 ac/h. No wind reduction.

Case 2. Wind velocities at 10 m reduced with 50%

The resulting expression in this case was:

$$n_{CALC} = \frac{n_{50}}{50^{\beta}} \left(0{,}026\ (\vartheta_i - \vartheta_u) + 0{,}038\ u^2\right)^{\beta} \qquad (13)$$

Corresponding plots are given in figure 7.

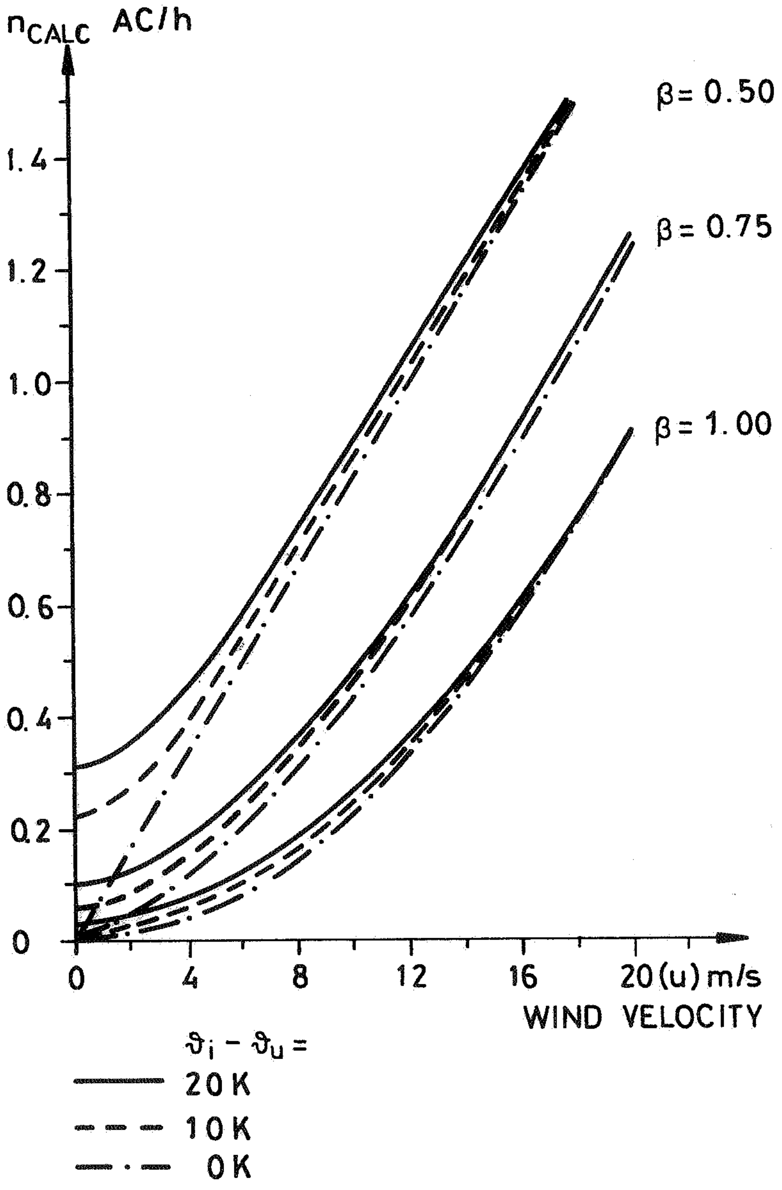

Figure 7. n_{CALC} as a function of wind velocity, temperature difference and exponent $\beta \cdot n_{50}$ = 3 ac/h. Wind velocities at 10 m reduced with 50%.

The calculated ventilation rates, n_{CALC}, were compared with the measured ones, n_{MEAS}. The result can be seen in figure 8.

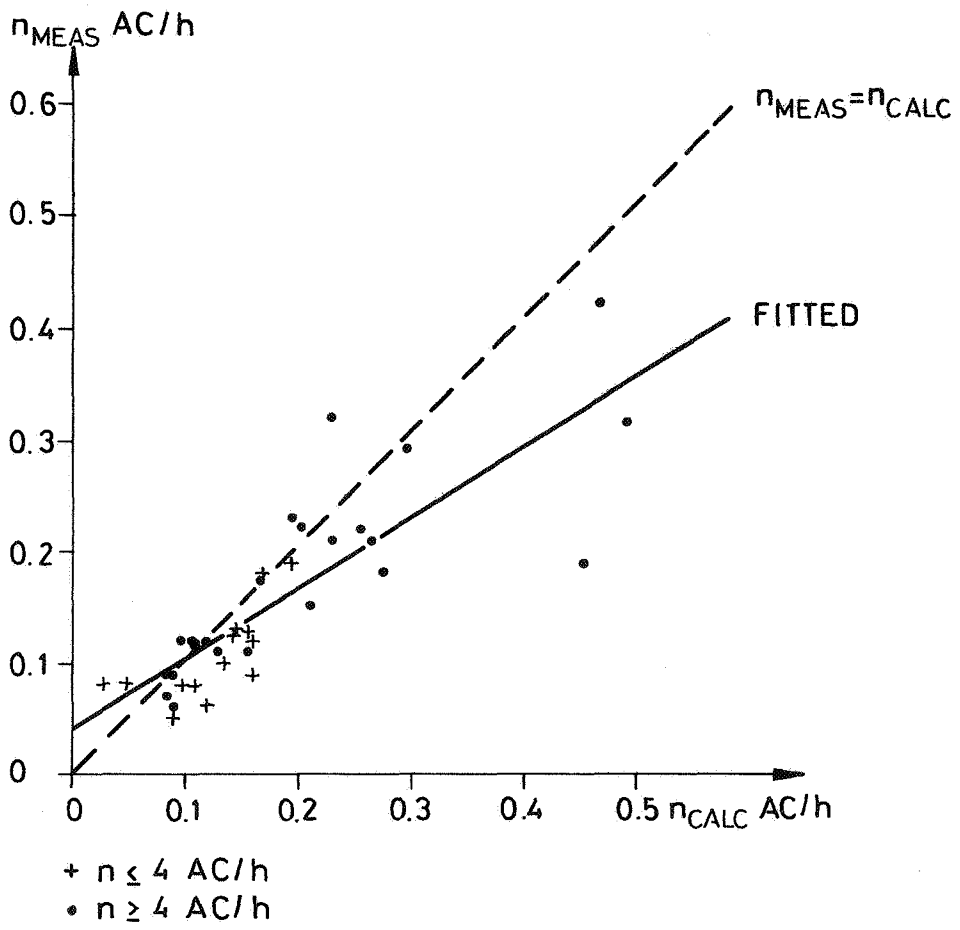

Figure 8. Calculated ventilation rates, n_{CALC}, versus measured ones, n_{MEAS}.

With the technique of linear regression the following analytical expression was obtained:

$$n_{MEAS} = 0{,}039 + 0{,}636 \cdot n_{CALC} \qquad (14)$$

4 INTERPRETATION OF THE RESULTS

With equation (1) the intention was to "force" the measured values into a model which corresponds to the mechanisms of air infiltration we are familiar with rather than to use traditional regression analysis.

The factor $C_3(m^3/h)/Pa^{\beta}$ is simply a figure describing the tightness of the house. The value of C_3 is based on n_{50} and the exponent β and differs consequently from house to house.

The factor C_1 (Pa/K) is multiplied with the temperature difference to produce a pressure difference caused by stack effect. The magnitude of the factor is affected by the height up to the neutral zone. The value of 0,026 Pa/K is quite reasonable.

The C_2-values however, seem to be rather small - 0,010 Pa/(m/s)^2 in the case with no wind reduction and 0,038 Pa/ (m/s)^2 in the case with 50% wind reduction.

Since Δp caused by wind acting on a building can be written as:

$$\Delta p = \Delta \mu \frac{\rho \cdot u^2}{2} \tag{15}$$

where $\Delta\mu$ is the difference in shape coefficients between out and inside, ρ is the density of the air (kg/m^3) and u the wind velocity (m/s). Consider the infiltration case on a cube-shaped building with wind acting perpendicular to one of the sides (the pressure side) then $\overline{C_2}$ could be written as

$$\overline{C_2} = \frac{\overline{\Delta\mu\, p} \cdot \rho}{2} \cong 0{,}6\ \overline{\Delta\mu} \tag{16}$$

Where $\overline{\Delta\mu_p}$ denotes the average difference in shape coefficients across the wall.

From this the values 0,010 resp 0,038 Pa/(m/s)^2 should correspond to

$$\overline{\Delta\mu_p} = \frac{0{,}010}{0{,}6} = 0{,}017 \quad \text{(no wind reduction)}$$

$$\overline{\Delta\mu_p} = \frac{0{,}038}{0{,}6} = 0{,}063 \quad \text{(50\% wind reduction)}$$

Since the last given value corresponds to a place with reduced wind velocity it has no meaning to compare this calculated $\overline{\Delta\mu_p}$ value with something else. This is of course due to the fact that μ should transform wind velocity in the free stream into wind pressures.

A further interpretation might be made by taking into account the fact that a rectangular building has one or two windwardfacing sides and the others are leewardfacing. If the total area on the pressure side is denoted A_p and the total area of the suction sides is denoted A_s it can be proved with a simple flow-balance equation that

$$\overline{\Delta\mu_p} = \frac{(\overline{\mu_p} - \overline{\mu_s})\,(\frac{A_p}{A_s})^{\beta}}{1 + (\frac{A_p}{A_s})^{\beta}} \qquad (17)$$

If $\overline{\Delta\mu_p}$ = 0,017, β = 0,7 and A_p/A_s is set to 1/4 then $\overline{\mu_p} - \overline{\mu_s}$ = 0,06.

The influence of the surroundings of the building and the density of the built area may be considerable. These matters are very well demonstrated in works by the people at Sheffield University (6), (7), (8). Figure 9 is taken from (7). It shows shape coefficients for windward and leeward faces of a cube-formed building where y/H is the height relative the total building height and the density being the ratio between built up and total ground area.

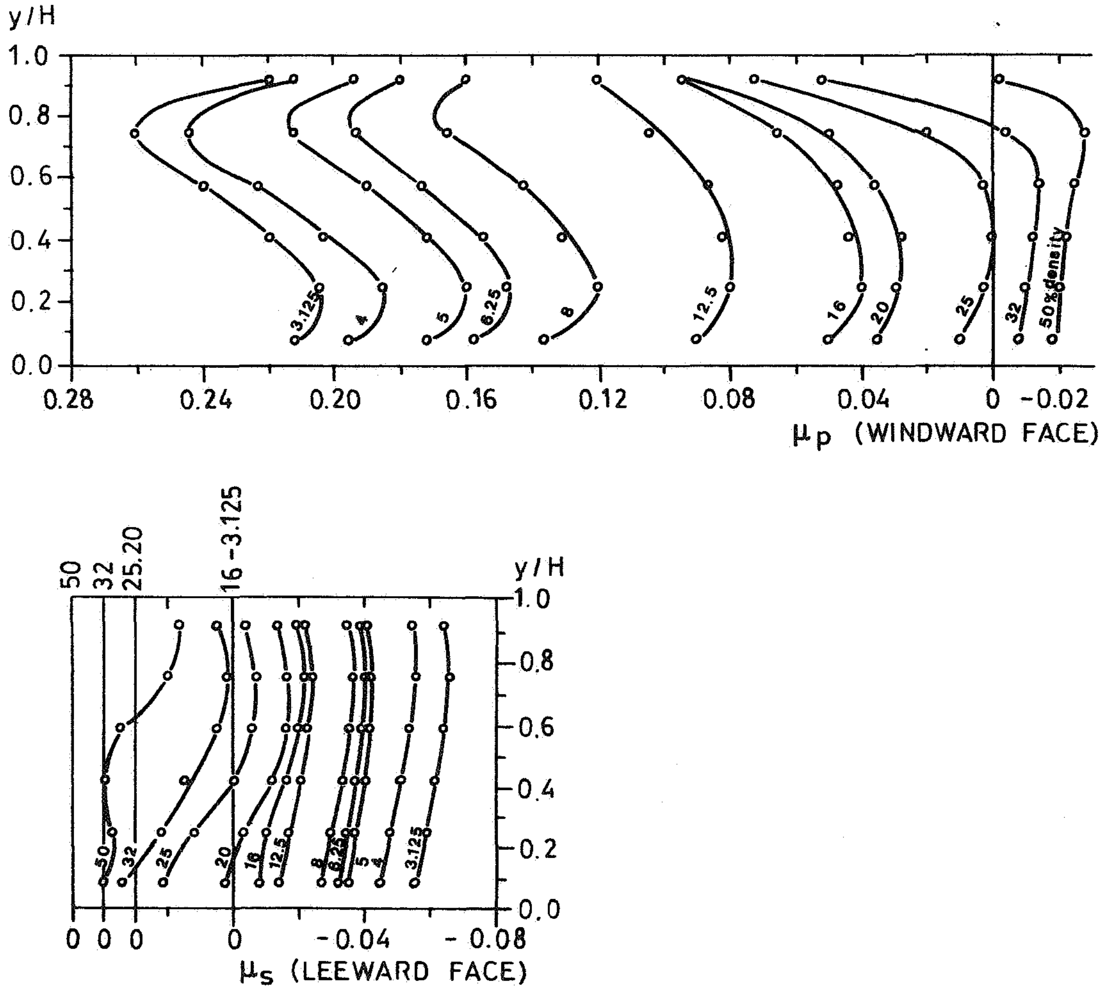

Figure 9. Distribution of mean shape coefficient on the element centre line at all densities. Source: (7).

According to these results it is obvious that a high density can reduce the values of the shape coefficients considerably. The densities of the areas where the 19 houses in this study are situated are not known but normal Swedish areas with one-family houses may have a density of say 15%. If this is the case for the houses studied the values of $\overline{\Delta\mu_p} - \overline{\Delta\mu_s}$ as calculated above seem quite reasonable.

5 SUMMARY

Much hope has been fixed upon possibilities of correlating results of pressurization tests with infiltration tests, thus making it possible to predict the ventilation rate of a building with the result of the pressurization test as a basis. This paper describes the application of an a priori designed calculation model based upon the well-established relationship $Q = \alpha \cdot \Delta p^{\beta}$ in which α and β are determined from pressurization test. Two factors operating at the temperature difference between inside and outside and the square of the wind velocity respectively determined from tracer gas tests at different seasons of the same house settles the p term. The model has been applied to 19 1½-storey single family houses. The calculated factors seem to have reasonable values. However, the density of a house group seem to have very great influence on the magnitude of the shape coefficients. This may explain why calculated mean shape factors seem to be rather low. It would have been very interesting to make similar calculations on other houses in other surroundings.

6 ACKNOWLEDGEMENTS

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