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Correction of Tracer Gas Measurement Results for Climatic Factors.

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1 SYNOPSIS

This paper deals with the problem of the weather influence on ventilation rate for naturally ventilated buildings with purpose provided openings and vertical shafts. Hitherto, it has not been possible to predict the ventilation rate or to extrapolate it for other weather conditions than the measured ones, without permorming a heavy calculation exercise by means of running a computer program.

In the paper a prediction as well as an extrapolation procedure is outlined . The procedures are based on generalized output data from a single zone infiltration and ventilation model (AIDA). The generalizations are made up by means of two simple equations in which the n50, difference between indoor and outdoor temperature, wind velocity and a simple description of the purpose provided ventilation devices are input parameters.

Validation work is in progress and the results regarding this will be reported at the end of 1992.

2 BACKGROUND

Measurements of building ventilation performed by means of tracer gas technique are often related to specific occasions with their specific outdoor climatic conditions.

In order to be able to use such measurement data, for estimating the ventilation rate for naturally ventilated buildings during a more extended time base, the heating season or a standard condition e.g., it is necessary to have a calculation or estimation procedure for such an extrapolation.

There are at least two principal approaches possible for the extrapolation. The first one would be purely statistical by frequent experimental studies of the ventilation rate under different prevailing climatic conditions for a set of typical buildings. The second approach would involve use of a theoretical model for the extrapolation, also taking into account the air tightness performance of the house.

The statistical approach is associated with heavy work in performing detailed measurements on different types of buildings. Probably the work needed to be done is far too extensive to be a realistic alternative for practical use.

The theoretical approach would also involve detailed measurements - apart from the theoretical work with a model - on a set of buildings, in order to validate the model used. However the number of measurements could be limited, compared to the pure statistical approach.

A theoretical model for the calculation of the ventilation rate of a building, based on wind data, temperature data and air tightness data for the building was presented by one of the authors in 1980; KRONVALL (1980). It was anticipated that this model, more or less modified, could form the basis for the kind of extrapolation needed.

We distinguish between extrapolation and prediction whereas a prediction model must form the basis for extrapolation.

3 APPROACH

The theoretical model, mentioned above, is based on the use of the following equation (eq. 1). This is taken as a point of aparture for the present discussion.

$$n = n_{50} / 50^{b} * (c_1 * (\Theta_{int} - \Theta_{ext}) + c_2 * u^2)^{b} \qquad \text{(eq. 1)}$$

where:

n = ventilation rate due to infiltration (ach) through the building envelope and purpose provided openings in the envelope.

n_{50} = specific air leakage at 50 Pa (ach) including the influence of purpose provided openings and flues

b	= flow exponent from pressurisation curve (-)
c_1	= model coefficient (Pa/°C)
c_2	= model coefficient (Pa/(m/s)^2)
Θ int	= indoor air temperature (°C)
Θ ext	= outdoor air temperature (°C)
u	= wind velocity at 10 m above ground (m/s)

The rationale of the model is the "power law" for air flow through a permeable building component e.g. The equation for the "power law" is:

$$Q = a * \Delta p^{b} * A \qquad \text{(eq. 2)}$$

where:

Q	= rate of air flow through the building component (m3/s)
a	= flow coefficient ($m^3/(s*m^2*Pa$^b)
Δp	= pressure difference (Pa)
b	= flow exponent (-)
A	= area of the building component (m^2)

The envelope of the building is considered as permeable and the purpose provided openings are also included in the leaking system. This average leakiness of the building is described in the factor $n50 / 50^{b}$ in the model. The average pressure difference across the envelope of the house is described by the factor $(c_1 * (\Theta_{int} - \Theta_{ext}) + c_2 * u^2)$. The exponent b describes the air leakage characteristic of the envelope.

In order to test the feasibility of the model, a number of calculations were performed with a single zone infiltration simulation model - the AIDA model; LIDDAMENT (1989). A good ability of comprising the results of AIDA calculations for a set of buildings and for a set of different wind and temperature combinations would then be a proof of the feasibility of the model.

If this is shown to be succesful it would be possible to predict the ventilation rate of more or less arbitrarily chosen types of buildings once the air tightness behaviour, the ventilation arrangements and the weather conditions (wind and temp diff) were given.

Normally only the air tightness performance of the envelope (i.e. the n50-value) is known or estimated. More seldomly is the value of the exponent in the power-law expression known. Tentatively there is a correlation between the n50-value and the value of this exponent, so that for low n50-values the exponent value would be close to 1.0 and for high n50-values the exponent value would be close to 0.5. Furthermore, the n50-value for the air leakage behaviour af the envelope only is not suitable for eq. 1. In this equation the n50-value should represent the air leakage behavior for the envelope <u>and</u> purpose provided ventilation openings, such as air terminal devices for supply of outdoor air and vertical shafts for weather driven exhaust of air from the building. Thus for prediction use of the model (eq. 1) it is necessary to have a procedure for modifying the "normal" n50 and exponent values to new, modified ones.

So far we have been discussing eq. 1 for prediction use only. For extrapolation use - from one weather condition to another - the following equation is used (indexes: 1 = first weather condition, 2 = new weather condition):

$$n_2 = n_1 * [(c_1*(\Theta_{int,2} - \Theta_{ext,2}) + c_2*u_2^2) / (c_1*(\Theta_{int,1} - \Theta_{out,1}) + c_2*u_1^2)]^{b} \qquad \text{(eq. 3)}$$

4 DATA USED FOR SIMULATIONS

For the simulations with the AIDA program a set of "significant" building types were chosen; a **1 storey detached house, a 1 1/2 storey detached house** and three different flats in a 3 storeys multi-family house. These include a **non-through flat on the ground floor and on the top floor**, and finally a **through flat on the top floor.**

General data for the simulations were:

Wind: at weather station

Terrain /shielding conditions: urban — options were:
- open countryside
- scattered windbreaks
- urban
- city

Floor: solid (airtight)

Wind pressure coefficients: according to the AIVC Calculation Techniques Guide (LIDDAMENT 1986)

Specific data for each type of building are shown in table 1.

The following parameters were given different values in the different calculations:

- **n50**
- **exponent b**
- **wind direction** (perpendicular to or along face wall)

For each set of the parameters above calculations were performed for **wind velocities** of 0 to 10 m/s and **temperature differences** between 0 and 40 degC.

Table 1. Specific data for each type of building, used for simulations with the AIDA computer program.

	Detached houses --->		Flats ------------------------------>		
	1 storey	1 1/2 st	Non thru Gr floor	Top fl	Through Top fl
Building height (m)	4.8	6.5	9.0	3.0	3.0
Eaves height (m)	2.5	2.5	2.5	2.5	2.5
Roof pitch angle (deg)	30	45	0	0	0
Building length (m)	15	15	9	9	7
Building width (m)	8	8	9	9	12
Building volume (m3)	300	540	203	203	210
Number of airtight comp.	0	0	4	4	3
Number of vent openings	7	7	3	3	4
Vent 1					
Location	front	front	front	front	front
Height (m)	2.0	2.0	2.3	2.3	2.3
Area (cm2)	60	60	90	90	60
Vent 2					
Location	rear	rear	ceiling	ceiling	rear
Height (m)	2.0	2.0	10.0	10.0	2.3
Area (cm2)	60	60	100	100	60

cont...

Vent 3					
Location	left	left	ceiling	ceiling	ceiling
Height (m)	2.0	2.0	10.0	10.0	4.0
Area (cm2)	30	30	100	100	100
Vent 4					
Location	right	right			ceiling
Height (m)	2.0	2.0			4.0
Area (cm2)	30	30			70
Vent 5					
Location	ceiling	ceiling			
Height (m)	4.8	6.5			
Area (cm2)	100	100			
Vent 6					
Location	ceiling	ceiling			
Height (m)	4.8	6.5			
Area (cm2)	100	100			
Vent 7					
Location	ceiling	ceiling			
Height (m)	4.8	6.5			
Area (cm2)	100	100			

5 RESULTS

5.1 Generalization of computed ventilation rates by means of the model (equation 1)

A set of significant calculation results obtained by running the AIDA program is shown in figure 1 to 6.

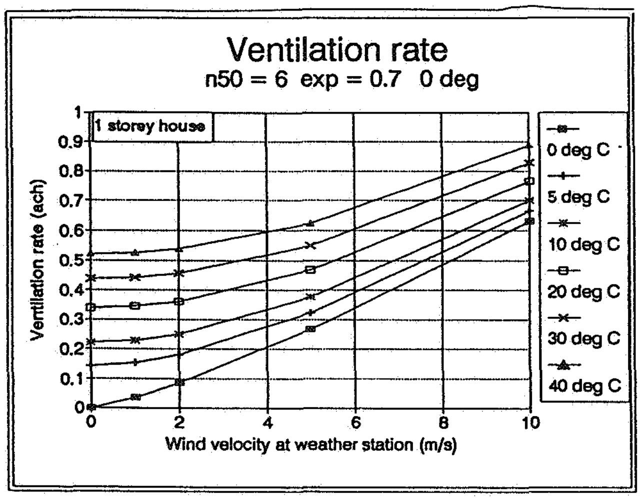


Figure 1

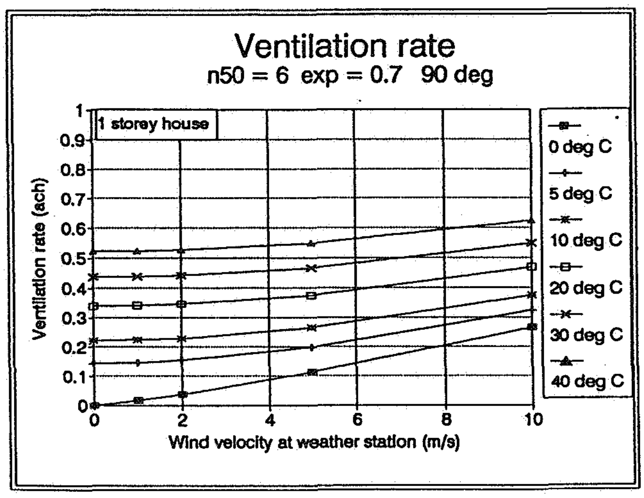


Figure 2

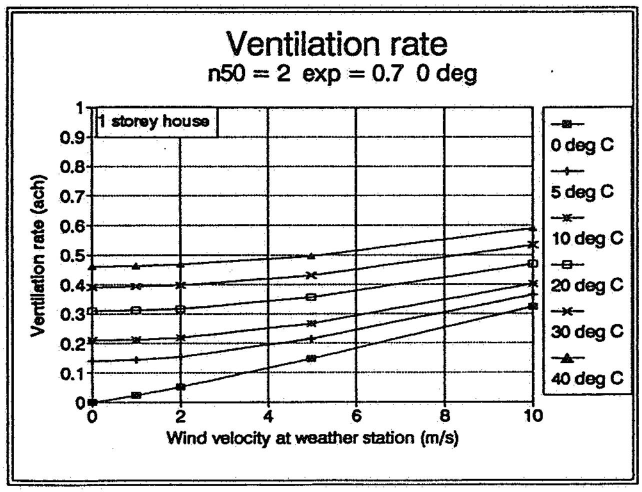


Figure 3

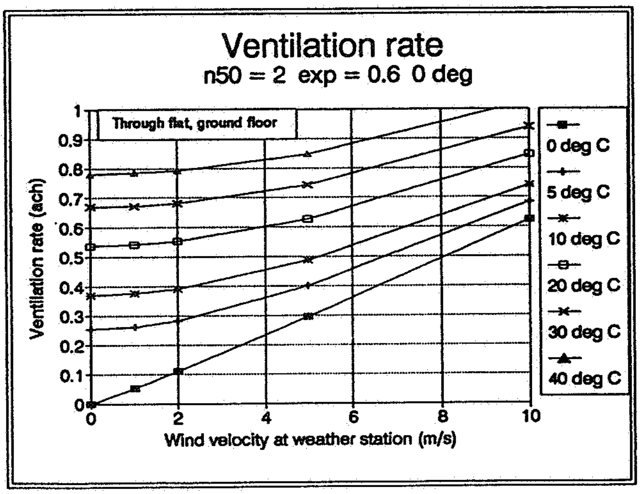


Figure 4

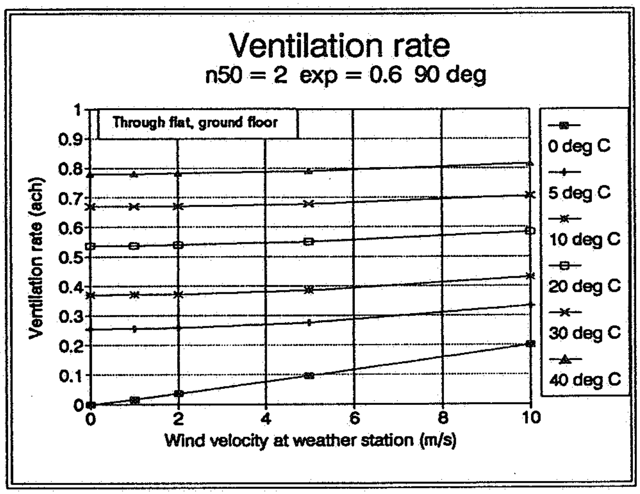


Figure 5

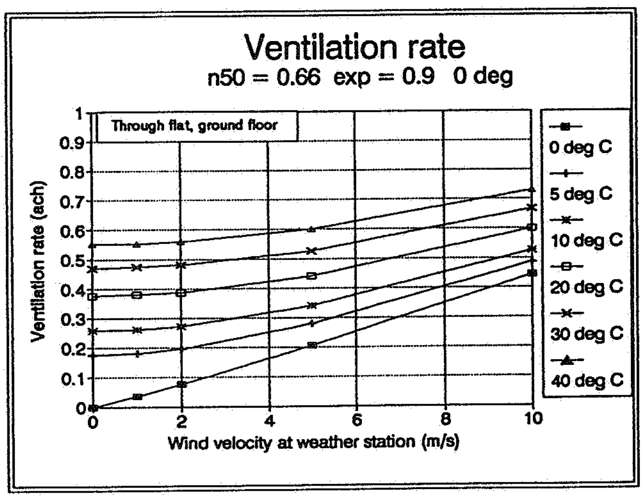


Figure 6

In order to generalize the computation results by means of using equation 1, it is essential to include the impact of the purpose provided ventilation openings on n50 and the exponent. The modification was made in such a way that the calculated air flow rates for purpose provided openings for pressure differences between 0 and 50 Pa were added to the flow rate calculated by means of the original n50 and b values. Curve fitting using the least-square method finally gave the modified values . (These modified values correspond to those obtained when a pressurization test with open purpose provided openings is performed.)

The calculated values of the ventilation rate for different wind velocities and temperature differences were placed in a spread-sheet (QUATTRO® PRO 4.0). This program has an ability of optimization, based on linear-programming technique, which was used in order to settle the values of c_1 and c_2 in the model (equation 1).

First the value of c_1 (the temperature coefficient) was estimated by putting c_2 equal to 0 (fixed) for the case that the wind velocity was 0 m/s. Then the program calculates the value of c_2 that best satisfied the model in the least squares sense. For control purposes the squared residuals (differences between calculated ventilation values acc. to the model and those from the AIDA calculations) were summed up and a mean value was calculated. The square root of this obtained mean square error for a case was in the range of 10^{-2} - 10^{-3}. Thus, it could be stated that **the model (equation 1) describes the outputs of the infiltration and ventilation model AIDA quite well and in a very handy way.**

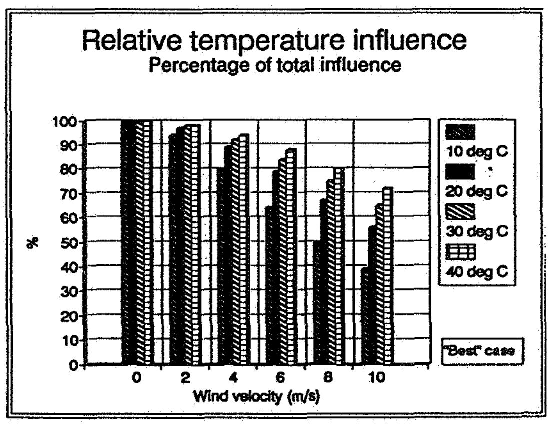
The values of the coefficients c_1 and c_2 for the different cases are shown in table 2.

Table 2. Coefficients c_1 and c_2 for different simulation cases. 0 deg corresponds to the case when the wind direction is perpendicular to the facade and 90 deg to wind along the facade.

Type of building	Tempe- rature	———>	Wind	———	———	———	———>
	c_1	———>	c_2 ——— 0 deg	——— 0 deg	——— 90 deg	——— 90 deg	———>
	mean	**highest lowest**	**mean**	**highest lowest**	**mean**	**highest lowest**	**mean**
Houses							
1 storey	**0.018**	0.024 0.009	0.005	0.007 0.004	0.002	0.003 0.001	**0.004**
1 1/2 st	**0.022**	0.035 0.007	0.010	0.014 0.007	0.006	0.008 0.004	**0.008**
Flats							
Ground	**0.051**	0.057 0.040	0.013	0.016 0.011	0.002	0.002 0.001	**0.008**
Top	**0.013**	0.016 0.011	0.008	0.009 0.006	0.001	0.001 0	**0.005**
Top through	**0.013**	0.015 0.009	0.004	0.005 0.003	0.001	0.001 0.001	**0.003**

As can be seen in table 2 the mean of the coefficient c_1 takes a value of 0.017 +/- 0.005 for all cases except for the flat on the ground floor where $c_1 = 0.05$. This is reasonable as the ventilation shaft is higher in this case. The c_2 values are around 0.005 with some variation for all cases, which is reasonable also because of the fact that the wind influence was modelled in the same way for all cases.

The wind influenced coefficient c_2 is lower than the temperature influenced coefficient c_1. Thus, it might be tempting to use the model for prediction without involving the wind effect. In order to see whether this is possible or not a calculation was made of the relative influence of temperature only in the expression for the wind and temperature influence in equation 1. The results are shown in figure 7.



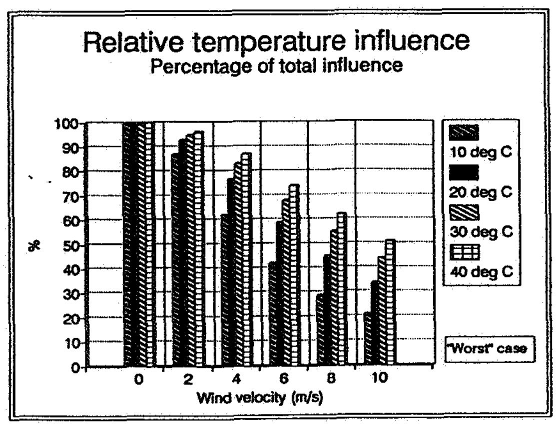


Figure 7. Relative temperature influence.
"Best case" corresponds to the case with the smallest difference between c_1 and c_2, i.e. the non-through flat on the top floor.
"Worst case" corresponds to the greatest difference, i.e. the flat on the ground floor.

It is obvious for the "best" case, which is significant for buildings on the ground and higher up in i multi-storey building, that the wind-driven ventilation is of relatively low importance compared to the temperature-driven - at least for lower wind velocities (< appr. 4 m/s). For the case with a flat on the ground floor this is obviously not valid.

5.2 Outline of a prediction procedure

Using equation 1 for prediction of the ventilation rate in a building involves the following parameters to be settled:

n50 — The air permeability parameter which also should reflect the influence of purpose provided openings.

b — The flow exponent corresponding to n50 above.

Θint - Θext — The temperature difference between in- and outdoor

u — The wind velocity.

Normally only the n50 value for the building envelope itself (with purpose provided openings sealed) is available or is estimated based on emperical knowledge and/or "help-shemes" (Such ones are under preparation and are going to be included in the AIVC Numerical Database, to be published late 1992).

Originally a hypothesis was that - due to different flow characteristics for large and small (resp.) openings or cracks - there is a correlation between the n50-value and the value of the exponent b, so that for low n50-values the exponent value would be close to 1.0 and for high n50-values the exponent value would be close to 0.5.

This hypothesis was tested by analysing some 30 pressurization test results - more or less arbitralily chosen. The result is shown in figure 8. From only a quick look at the figure it is obvious that the hypothesis should be rejected.

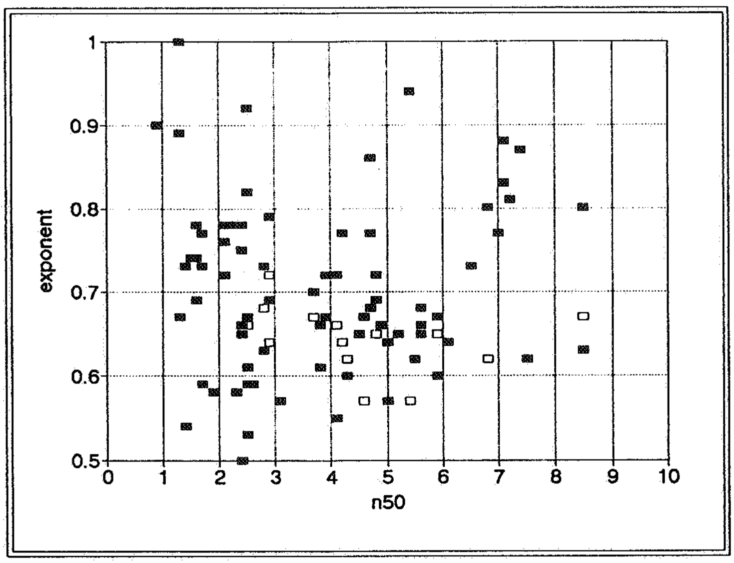


Figure 8. Exponent values plotted versus n50-values.

Apperently, when making predictions, a value for the exponent must be chosen. According to general experience and figure 8, a value of 0.7 would be reasonable. Based on this assumption, a set of diagrams, figures 9 - 12, were made up for the estimation of an n50 value and an exponent value which are modified for the influence of purpose provided openings. Three different levels were chosen for the total area of purpose provided openings, wiz. 100, 200 and 300 cm2.

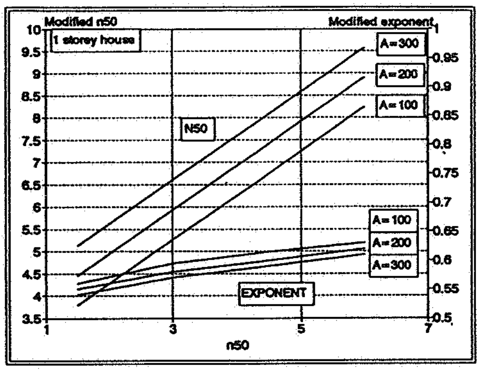


Figure 9

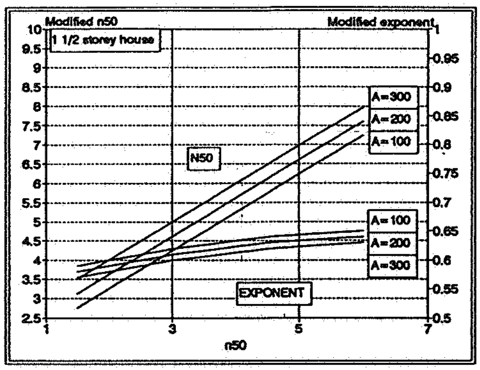


Figure 10

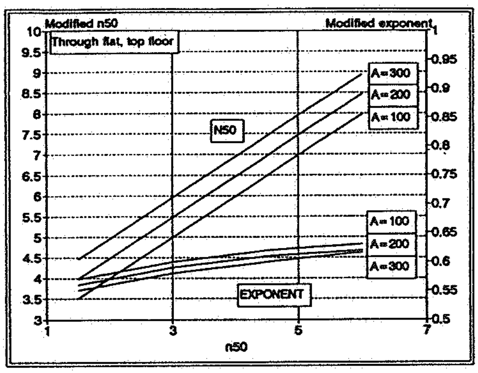


Figure 11

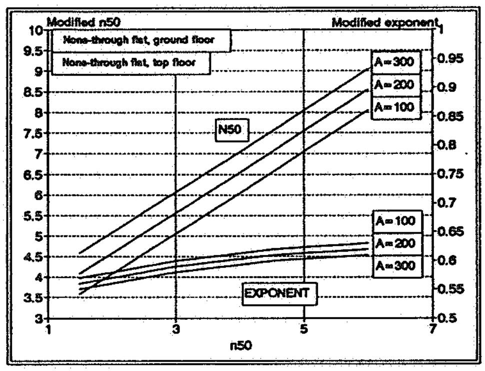


Figure 12

EXAMPLE

Estimate the ventilation rate in a one storey detached house in an urban area with n50=4.5 ach at 50 Pa. The wind velocity at a weather station in the vicinity is 4 m/s and the difference between outdoor and indoor temperature is 23.5 degC. The total area of purpose provided openings is 200 cm2.

The n50 value does not account for purpose provided openings, so it has to be modified for use in equation 1. This is done by means of using the diagram in figure 9. From this it can be seen that the modified n50 will be 7.3 ach at 50 Pa and the modified exponent 0.60.

c_1 and c_2 are taken from table 2 ; c_1=0.02, c_2=0.004.

Now equation 1 gives the solution:

$$n = 7.3/50^{0.60} * (0.02*23.5+0.004*4^2)^{0.60} = 0.48 \text{ ach}$$

5.3 Outline of an extrapolation procedure

As outlined in chapter 3 , it is possible go get an expression for extrapolation from one weather condition to another simply by dividing equation 1 for the extrapolated condition (2) with the equation for the base case (1), eq. 3.

It can be seen that n50 no longer influences the calculations. This is reasonable since the base case (1) gives the relative level of the ventilation rate for the house and the extrapolation only adjusts for the extrapolated condition.

6 FURTHER DEVELOPMENT AND VALIDATION

It is apparent that a validation exercise must be carried out in order to test the feasabilty of the models, both the model for prediction (eq. 1) and the model for extrapolation (eq. 3). The purpose of this paper is merely to present an outline of a possible way to make simple predictions and extrapolations on ventilation rates in not too complicated buildings, which can be treated as a single zone.

An excellent opportunity to carry out such a validation (and possibly adjustment) work will be given via a current investigation of the energy performance and indoor climate of Swedish houses, undertaken by the National Swedish Institute for Building Research. 1 600 randomly selected Swedish single and multy family houses have been investigated by inspections and measurements on site, during 1991-92.
NORLÉN et al (1991) & STYMNE et al (1991). Among many other things, the ventilation rate has been measured in each of the houses for 3 - 4 weeks by means of a passive tracer gas technique (PFT) developed at the institute. STYMNE & ELIASSON (1991). Furthermore, a sub sample of some 100 buildings out of the 1600 ones are being studied more extensively regarding ventilation e.g.. In this sub sample the ventilation is measured also by means of tracer gas decay method. This will give an opportunity to estimate the occupant's behaviour with regard to ventilation for the houses tested with the passive technique. Finally a small group of 19 buildings out of the total sample, naturally ventilated with vertical shafts, is studied very extensively by means of repeated decay tracer gas and PFT measurements under different weather conditions. These measurements form an excellent basis for validation of the extrapolation model (equation 3).

These validation exercises will take place during late summer and autumn of 1992 and will be reported in the end of 1992.

7 ACKNOWLEDGEMENTS

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