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Performance of Passive Stack Ventilation in a Single-Family House. A Computational Simulation Study

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Synopsis

The paper presents the results of a simulation study performed by means of the COMIS multizone infiltration and ventilation model. The simulations were carried out for a two-storey single-family passive-stack-ventilated house in a cold climate (Stockholm, Sweden). Main conclusions of the study include the following: it is possible - during at least 75 % of the heating season - to achieve a ventilation rate in the whole house of at least 0.5 ach or approx. 30 l/s only if the house has a leakage rate above approx. 10 m3/m2,h@50 Pa or has purpose-provided supply air devices in the facade with a total area (far) greater than 400 cm^2; that the flow rates in the vertical shafts from kitchen, WC and bathroom are small but quite stable, in the range of appr. 3-4 l/s each; that all bedrooms (on the first floor) are under-ventilated as far as outdoor air is concerned; and that the living room (on the ground floor) is the only room in the house with - in most cases - adequate ventilation.

Possibly, but this was not proven, the performance of the passive stack ventilation could be improved, especially in the bedrooms, if the air supply devices in the facade were to be placed lower than in the simulations (2.1 m above floor level) and/or each bedroom was equipped with an individual exhaust shaft combined with a more or less airtight door. In order to increase the shaft flows it would, of course, also be possible to increase the height of the shafts above roof level and/or use a cowl of a special design.

The work was undertaken as part of the IEA Annex 27 project.

Background

Within the IEA program "Energy Conservation in Buildings and Community Systems", there are several on-going international collaboration projects, one of these being Annex 27, "Evaluation and Demonstration of Domestic Ventilation Systems", MÅNSSON (ed.), (1995). The overall scope of the work in this annex is to establish a general evaluation tool, which will make it possible to pre-evaluate the overall performance of different ventilation systems for different domestic buildings in different climates. A number of performance criteria are dealt with within the annex. They include, e.g. air quality, thermal comfort, energy, noise, life-cycle costs, moisture and reliability. The Swedish part of the research in the annex covers the reliability aspect of domestic ventilation.

In this context, ***reliability*** is defined as:

the probability that the ventilation system provides certain specified air flow rates in each habitable part of the building under specific climatic conditions and during the time between scheduled maintenance occasions.

Especially with natural ventilation strategies - with or without so-called passive stacks - the influence of weather conditions on the ventilation performance is paramount.

In order to study the performance aspect of reliability, the method chosen in this project was firstly to investigate the reliability under the influence of climatic- and building-specific factors by means of computer simulations, and secondly to perform a system safety analysis on the performance of mechanical ventilation systems. The simulation procedure is going to be checked by comparing results of simulations with results of field measurements (constant concentration tracer gas and PFT measurements).

The results of the first parametric study of the performance of a passive stack natural ventilation system in a two-storey single-family house are reported in this paper.

Simulation Procedure

The computer simulations were performed by means of the multi-zone ventilation and infiltration computer program COMIS (version 3.1a). The program was originally developed as an international joint research project - Conjunction of Multizone Infiltration Specialists. The work was led by Dr. Helmut Feustel at the Energy Performance of Buildings Group at Lawrence Berkeley Laboratory's Applied Science Division. The documentation of the program includes FEUSTEL & SMITH (1992) and FEUSTEL & RAYNOR-HOOSEN, (ed.) (1990). Further development of the COMIS model has been undertaken within IEA Annex 23 during the past three years.

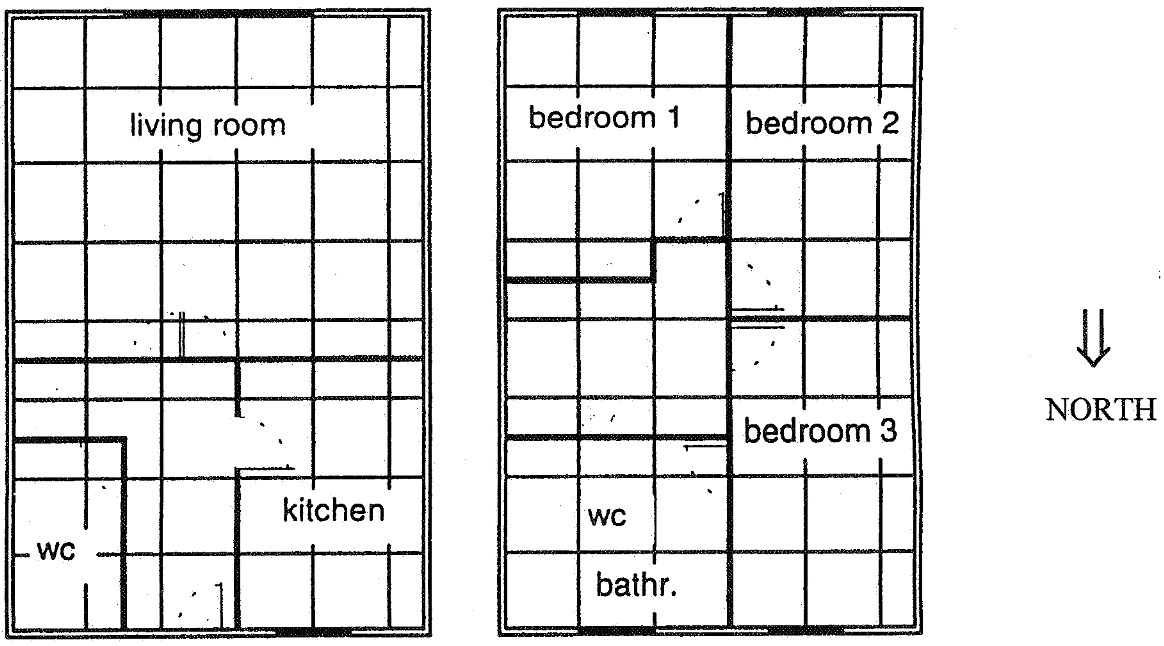
Input data for the model are based on assumptions which are described below. Essentially, the building and its ventilation system are described and the climatic conditions for which the model is to perform the calculations are given as a weather file. The output of the simulation is quite extensive, so it must be condensed in some way. For this particular case, the output was condensed by running a couple of specially dedicated computer programs, finally producing cumulative frequency diagrams. This method of expressing the simulation results coincides perfectly with the definition of reliability given above.

Simulation Assumptions

The Building and the Passive Stacks

The building modelled in the simulations is a two-storey single-family house assumed to have a low-slope roof. It is located in a built-up area with other similar houses surrounding it. The floor plan of the house is given in Figure 1. The ceiling height is 2.50 m and the intermediate floor has a thickness of 0.30 m. The overall floor area is 88 m^2 and the corresponding volume of the house is thus 88 x 2.5 = 220 m^3.

The specific leakage rate of the house envelope was chosen to be 2.5, 5.0 or 10.0 m^3/m^2,h@50 Pa. The leakage was evenly distributed over all outer walls and the roof. The house was assumed to be built on a floor slab on the ground, so no leakage paths from the ground were included in the calculations. According to Scandinavian standards, these figures correspond to a rather airtight, a leaky and a very leaky house, respectively.



Ground floor

First floor

Figure 1 Floor plan of house for simulations.

The total free area of supply air devices (placed 2.1 m above floor level) was chosen to be 0, 200 or 400 cm^2. The area was evenly distributed between the living room and the three bedrooms. The opening area was hydrodynamically treated as the area of a sharp-edged hole in a thin wall. For real devices, the nominal area should be reduced by means of a reduction factor - in many cases roughly 0.5. The three levels chosen are equivalent to closed supply vent openings, normal openings (according to building regulations in many countries) and large vent openings.

The passive ventilation shafts from the kitchen, the WC and the bathroom must be modelled as individual zones in the COMIS model (and, incidentally, in all other single- and multi-zone models). This implies that the small flow resistance in the ductwork must be included in the resistance of the air terminal devices. The flow coefficient chosen for a single exhaust air terminal device in either of the three rooms mentioned was 0.004 kg/s @ 1Pa with a flow exponent of 0.5. For the outer end of the shaft (0.5 m above roof level) the flow coefficient chosen was 0.014 kg/s @ 1 Pa.

Internal doors were assumed to be closed, except for the kitchen door. This door was treated in the model as a large opening, while the closed doors were assumed to have transferred air devices (20 mm x 700 mm) on top of, and small air gaps (appr. 2 mm) at the sides and bottom of, the door-leaf.

Climatic Conditions

The simulations for the parametric study were performed for a cold climate and for the heating season (5400 h/a). Actual weather data for Stockholm 1971 were used. The indoor temperature was chosen to be +20 °C. The weather data were condensed into 84 cases, each one consisting of an interval for corresponding values of wind velocity and temperature. In Figure 2, the frequency distribution for the weather data used is shown. The frequencies for different cases were taken into account when producing the final cumulative frequency diagrams.

Wind pressure coefficients according to Table 3.5 (ii), AIVC Technical Note 44, were used for the simulations. The wind pressure coefficient for the top of the shafts was chosen to be -0.3, according to praxis among many ventilation simulation specialists, e.g. de GIDS (1995) and with certain support in AIVC Technical Note 44, p 6.11.

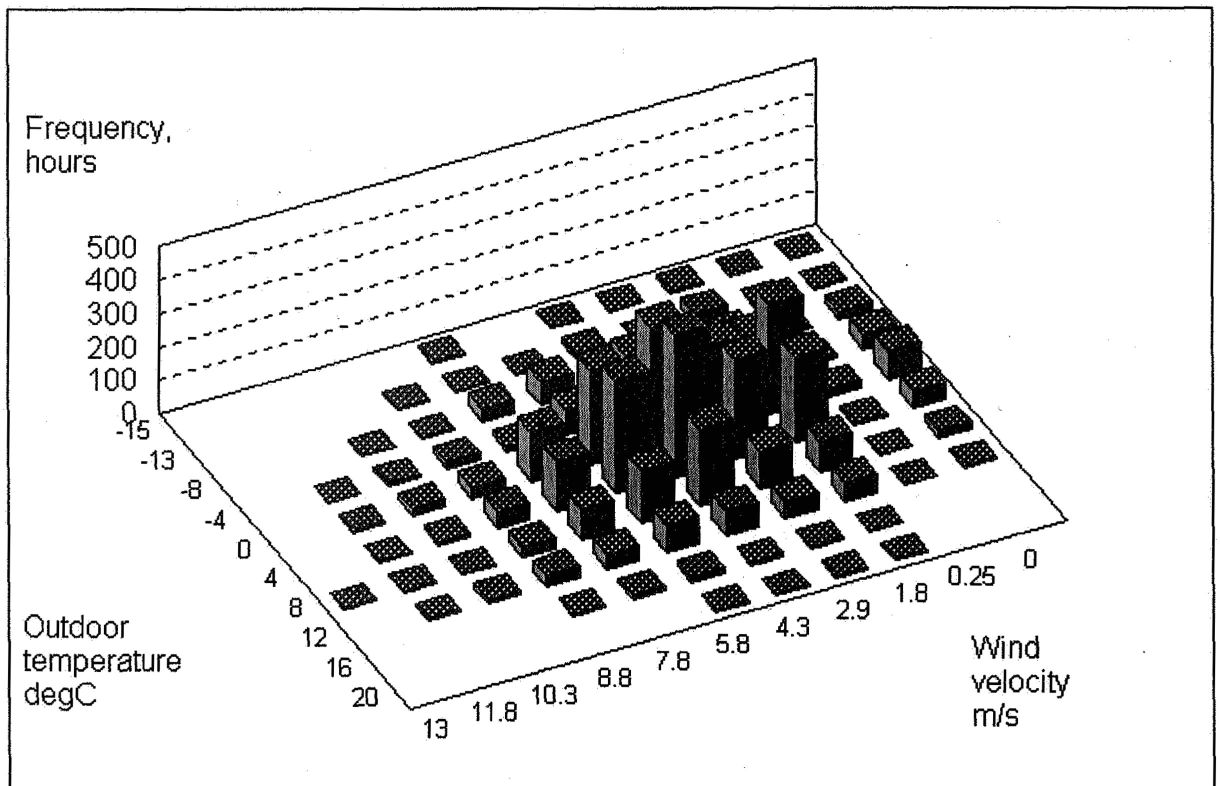


Figure 2 Frequency distribution of weather data used for the simulations.

Simulation Results

Principal Behaviour of Passive Stack Ventilation

In order to illustrate the principal ventilation behaviour in the investigated house, some initial simulations were performed. The scope of this exercise was primarily to check the air flow balances of the four habitable rooms, the shaft flows and the total air exchange for the whole house. Four weather situations, W1 - W4, were used for the simulations, see Table 1. The wind direction was chosen to be Southwest.

Wind velocity	Temp. 0 °C	Temp. 10 °C
0 m/s	**W2** Winter, calm	**W4** Spring/fall, calm
4 m/s	**W1** Winter, windy	**W3** Spring/fall, windy

Table 1 Weather conditions for the initial simulations.

The envelope leakage was chosen to be 5.0 m^3/m^2,h @ 50 Pa and the total free area of supply air devices in the facades 200 cm^2.

The air flow balances for the four habitable rooms are shown in Figure 3. When studying the diagrams, it should be kept in mind that regulations in most countries prescribe ventilation flow rates for bedrooms of the order of 4 litres per second per person (outdoor air). Air originating from locations outside the room (staircase, hall, etc.) can only in certain cases be treated as "clean" air and added to the flow of outdoor air. The most apparent limitation is associated with the presence of tobacco smokers in the house. In such cases the transferred air flow should definitely not be included in the "fresh air" supply.

In Figure 3 the shaft flows and the total air exchange of the house are also shown.

Legend for forthcoming diagrams (# 4 - 6)
L#.# A###
means:
L = Envelope leakage; 2.5, 5.0 or 10.0 m^3/m^2,h @ 50 Pa A = Total free area of supply air devices in facades; 0, 200 or 400 cm^2

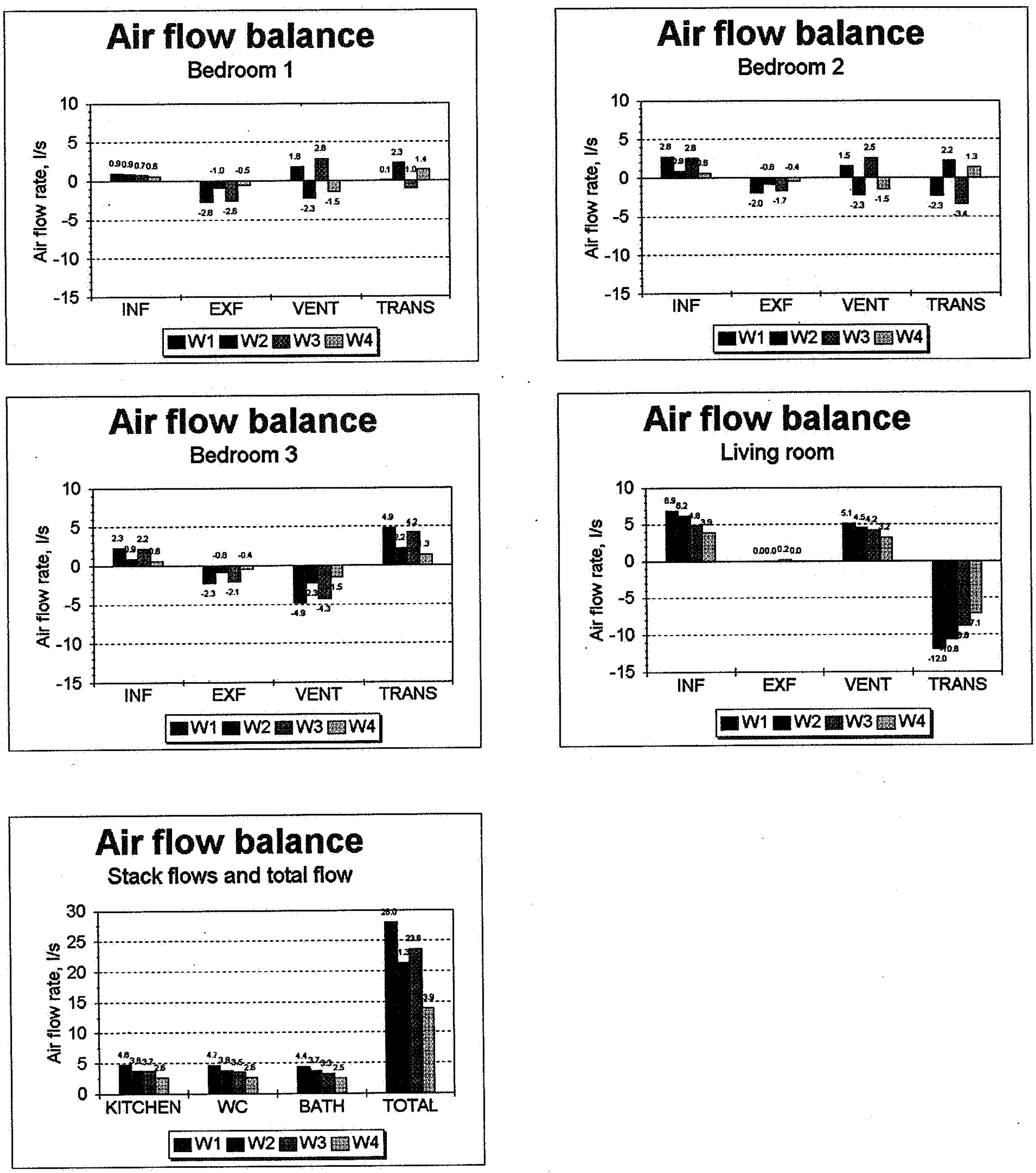


Figure 3 The air flow balances for the four habitable rooms, shaft flows and total flow.

The following comments refer to the simulation results for the different rooms, the shaft flows and the total flows.

Bedroom 1 - first floor

The room has its facade on the windward side, and the side-wall on the leeward side of the house. For all four weather conditions the bedroom is under-ventilated. In the best case, the sum of infiltrated air and ventilation air (i.e. air flowing through a supply air device in the facade) is 2.8 l/s (W3). The flow direction in the supply air inlet is reversed in the two cases when there is no wind. This indicates internal over-pressure at the supply air device level.

Bedroom 2 - first floor

The room has both its facade and side-wall on the windward side of the house. The principal ventilation behaviour is very similar to that of bedroom 1, though the infiltration rates are somewhat higher.

Bedroom 3 - first floor

The room has its facade on the leeward side, and side-wall on the windward side of the house. The fact that the supply air device is placed on the leeward side of the house has certain consequences - the air flow is reversed in the supply air device for all four weather conditions. Except for some infiltrated air, the only air flow into the room arises from transferred air from the upper hall. The outdoor air supply is limited to values below 2.3 l/s and this occurs due to infiltration through the west-facing wall of the room.

Living room - ground floor

The room has its facade and one side-wall on the windward side of the house, and one side-wall on the leeward side. For all four weather conditions, the ventilation behaviour is "favourable", i.e. the flow balance is according to optimum conditions for a ventilation system with supply air to be introduced in the house through purpose-provided ventilation openings in the facade. The outdoor air flow rate is of the order of 0.3 to 0.5 $l/s,m^2$.

Habitable rooms - general

It is concluded that, during typical winter and spring/fall conditions, a passive shaft ventilation system could create acceptable ventilation conditions on the ground floor of a two storey house in a cold climate. On the first floor, however, the ventilation performance is generally poor.

Shaft flows and total flow

The total air exchange of the house ranges from 13.9 l/s (0.23 ach) during calm spring/fall conditions, up to 28 l/s (0.46 ach) under windy winter conditions. These values correspond well to many field measurements of ventilation in houses of this type in different countries. The sum of the flows in the three shafts equals approx. half of the total air exchange in the house. If the house had been more airtight the shafts′ fraction of the total would have been higher. The individual exhaust flow rates are considerably lower (2.5 - 4.8 l/s) than those prescribed in the building regulations of most countries (approx. 10 l/s). In many passive stack ventilated houses however, there are local extract fans which can be operated occasionally, on demand.

Parametric study

As mentioned under "Simulation Assumptions" the parametric study was aimed at investigating how sensitive the ventilation performance is to different input parameter values regarding envelope leakage and area of supply air devices in facades.

The main results are shown in Figures 4 and 5, with a number of air flow rates reported under "lower quartile" and "median". The results in the figures should be interpreted as flow rates corresponding to percentages of the heating season (5400 h), i.e. 1 350 and 2 700 hours, respectively. The air flow rates (l/s) given under each percentage originate from the cumulative frequency distribution. This means that if the flow given under "lower quartile", i.e. 25 % is q, the probability of air flow rates less than q during the heating season is 25 %. This is easily seen in cumulative frequency diagrams. Some examples of such ones, for a "average" case are shown in Figure 6. **The air flow rates in figures 4 and 5 refer to the sum of infiltration flows and flow through purpose-provided openings in facades.**

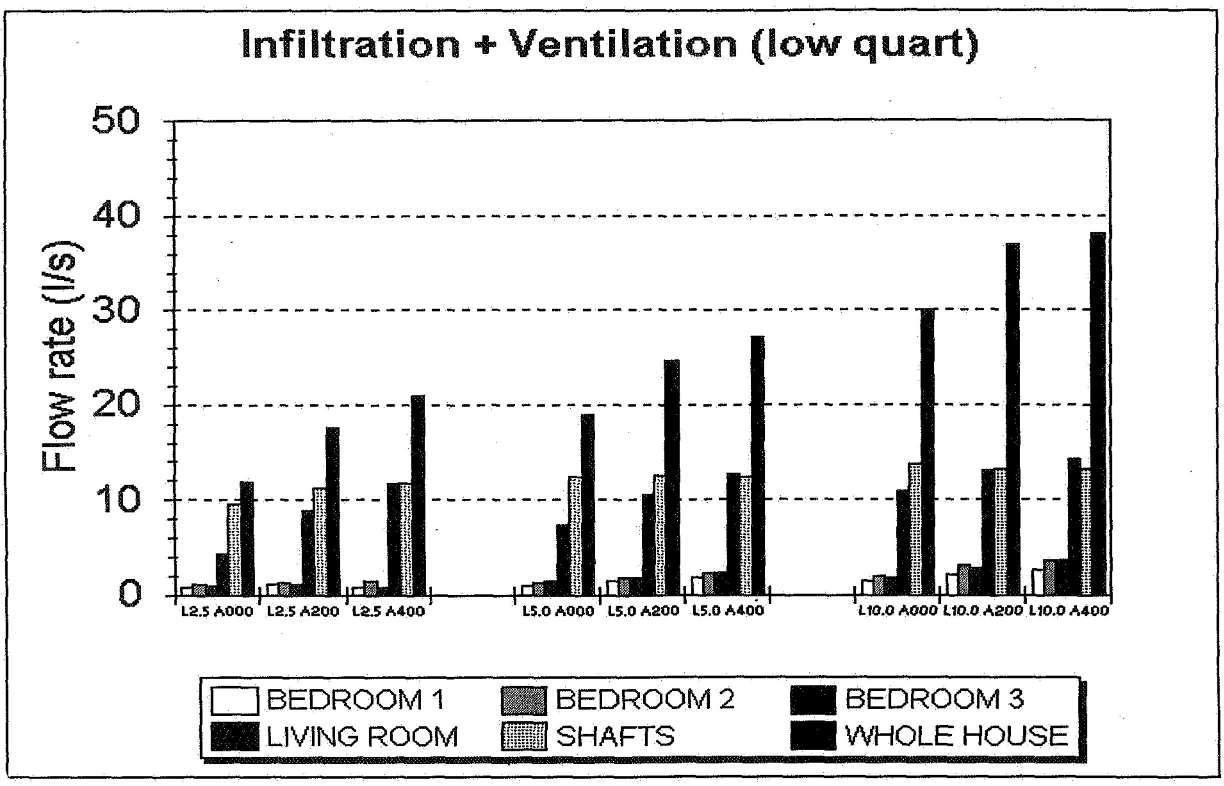


Figure 4 Infiltration + ventilation flows (lower quartile).

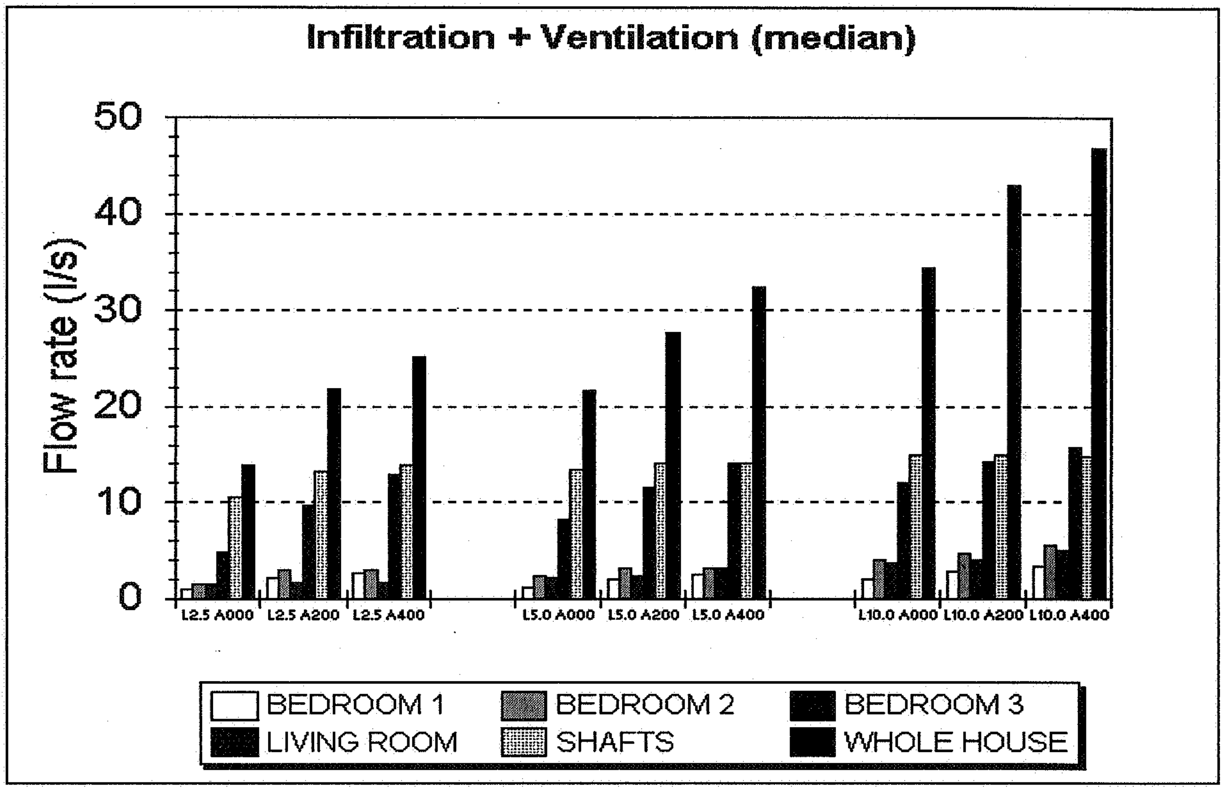


Figure 5 Infiltration + ventilation flows (median).

It could be concluded that, by using a passive stack ventilation system in a two-storey house in a cold climate (as described in the simulation assumptions) :

1 it is possible - during at least 75 % of the heating season - to achieve a ventilation rate in the whole house of at least 0.5 ach or approx. 30 l/s only if the house has a leakage rate above approx. 10 m3/m2,h@50 Pa or has purpose-provided supply air devices in the facade with a total area (far) greater than 400 cm^2,

2 the flow rates in the vertical shafts from kitchen, WC and bathroom are on average small but quite stable in the range of approx. 3-4 l/s,

3 all bedrooms (on the first floor) are under-ventilated as far as outdoor air is concerned,

4 the living room (on the ground floor) is the only room in the house with - in most cases - adequate ventilation.

Contemplating the results, it would perhaps be possible to improve the performance of the passive stack ventilation, especially in the bedrooms, if the air supply devices in the facade were placed lower than in the simulations (2.1 m above floor level) and/or each bedroom was equipped with an individual exhaust shaft combined with a more or less airtight door. In order to increase the shaft flows it would, of course, also be possible to increase the height of the shafts above roof level and/or use a cowl of a special design.

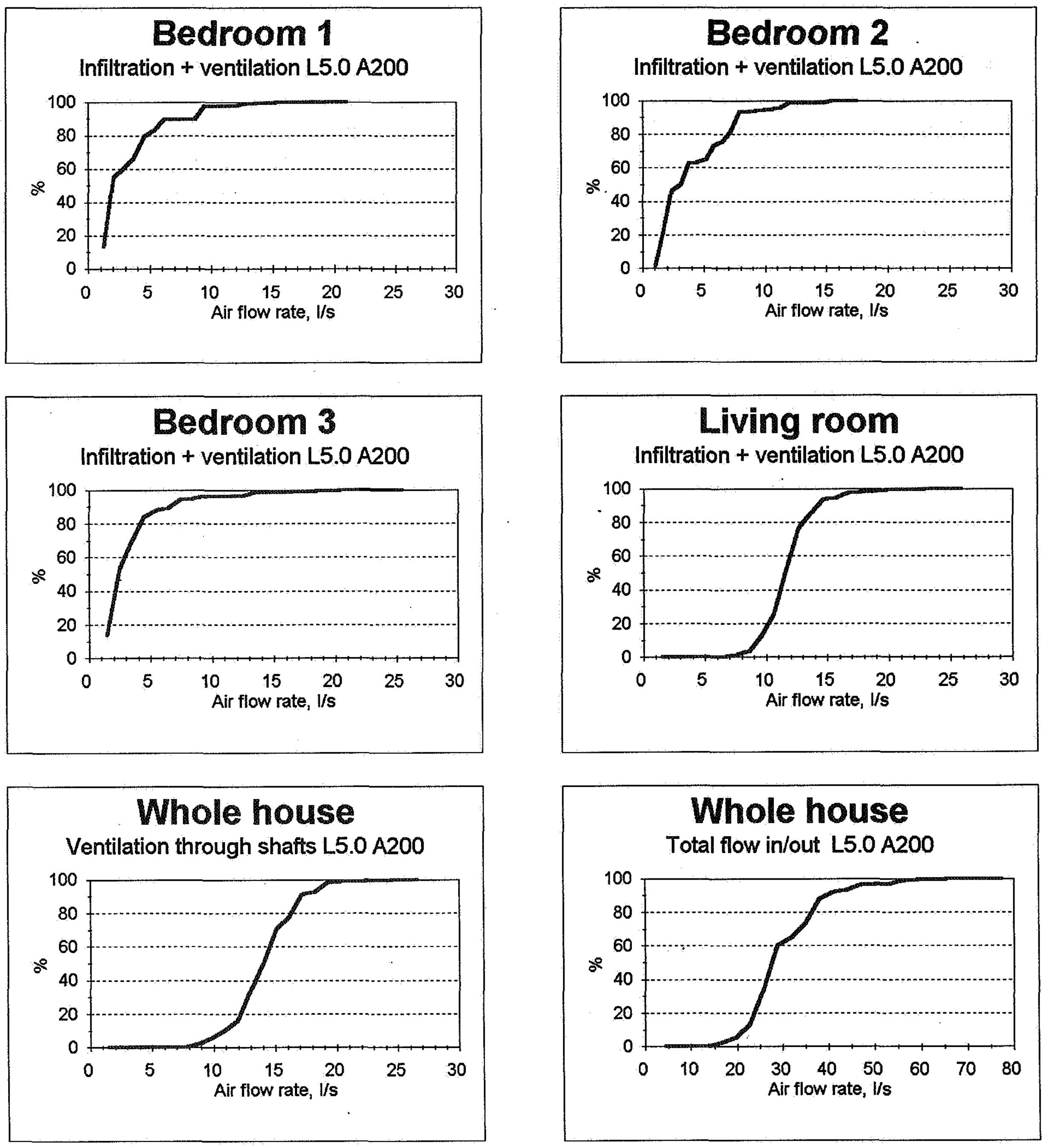


Figure 6 Infiltration + Ventilation flow rates. Cumulative frequencies.

Future work

The simulations will continue, taking into account other, warmer climates and other types of dwellings, e.g. apartments in blocks of flats.

Acknowledgements

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