OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

**17th AIVC Conference, Göteborg, Sweden,
17-20 September, 1996**

The Influence of Outdoor Air Vents and Airtightness on Natural Ventilation - Calculations Based on Measurements

Åke Blomsterberg

Swedish National Testing
and Research Institute
Box 857
S-50115 Borås
Sweden

Synopsis

Many modern buildings in the Nordic countries have mechanical ventilation. Passive stack ventilation is, however, an accepted ventilation system in the Nordic countries according to the current building codes. The building authorities need to be able to supply guidelines on natural ventilation systems in modern buildings, in order to fullfill the requirements on a healthy indoor climate at a reasonable energy cost. Therefore a project was initiated by the Nordic committee on building regulations. The aim of the project was to present functional and technical requirements on natural ventilation systems.

The paper discusses the influence of outdoor air vents and airtightness on passive stack ventilation for Nordic dwellings. Calculations, based on measurements, were performed for a one storey one-family house, a 1½-storey one-family house and two apartments in a three-storey building. Cumulative distributions of ventilation rates for a year were calculated, using a multi-zone air flow model, for individual rooms. It is shown that the ventilation rate will vary very much, without any interaction from the occupants or an automatic control system. A modern system for passive stack ventilation must include a system for control of the air flows in order to avoid excessive use of energy and inadequate indoor air quality.

1. INTRODUCTION

Most modern buildings in the Nordic countries, especially in Sweden, have mechanical ventilation. During the last couple of years natural ventilation is being discussed very much in the Nordic countries. Natural ventilation (passive stack ventilation) is an accepted ventilation system in buildings in the Nordic countries according to the current building codes. The building authorities need to be able to supply guidelines on requirements which should be made on a natural ventilation system in modern buildings, in order to fullfill the requirements on a healthy indoor climate to a reasonable energy cost. Therefore a project was initiated by the Nordic committee on building regulations. The main purpose was to present functional and technical requirements on natural ventilation systems (Säteri 1996), but also:
- summing up of current studies
- description of the real performance of natural ventilation systems
- control alternatives
- influence of outdoor air vents and airtightness
- design of natural ventilation systems
- requirements on outdoor air vents and passive stacks
- ventilation measurements

This paper discusses the influence of outdoor air vents and airtightness on passive stack ventilation for Nordic dwellings. Calculations, based on measurements, were performed using a multi-zone air flow model.

2. THE DWELLINGS TESTED

A one-storey one-family house with basement (total floor area 158 m²) was examined, as this type is a very common type of house with passive stack ventilation. Most of these houses were built before 1970. Many houses built later on are equipped with exhaust fan ventilation and built as a 1½-storey house without basement. A conventional 1½-storey house (floor area

119 m²) was therefore converted (in theory) from mechanical exhaust to passive stack ventilation, and examined. An conventional apartment building (floor area/apartment 56 m²), built during the fifties, was also chosen, of which all have passive stack ventilation. The passive stacks were designed to remove air from bathrooms and kitchens, to the outside. All examined dwellings have been tested i. e. pressurization, tracer gas measurements etc..

3. METHODS

A multi-zone model, MOVECOMP, was used as a tool for further evaluating the measurements (Herrlin 1987, Bring 1988). In the program the building and its ventilation system is modelled. The model consists of pressure nodes connected to each other with flow paths. The nodes are different zones and duct components, while the flow paths are different leakage paths and ducts. The air flows are calculated by seeking a flow balance in each node. Mass balance has to be achieved.

In the calculations weather data from the reference year 1971 from Stockholm was used. The entire year was reduced to 100 combinations of different outdoor temperatures and wind speeds with frequencies for every combination. Wind pressure coefficients from wind tunnel studies were used (Chien 1951, Wirén 1985).

For the calculations the dwellings were divided into different zones, where each zone is a room. The distribution of leakage paths is based on IR-scans and knowledge about the construction technique in question. In most cases the leakage has been distributed between exterior walls, ceiling and floor according to each components area. For each facade the assumption was made that 25 % of the leakage is located 0.1 m above the floor, 50 % 1.2 m above the floor (representing windows) and 25 % 2,3 m above the floor. Windows, exterior doors and doors to bathrooms were assumed to be closed. All other doors were assumed to be open. Bathroom doors have an opening for transferred air. Interior walls and intermediate floors were assumed to be airtight.

4. RESULTS

A previous comparison of measured and calculated ventilation rates showed for the examined one-family houses, that MOVECOMP can overpredict the outdoor air ventilation with 15 - 40 %, but can make a reasonable estimation of the variation in ventilation rate over time (Blomsterberg 1990). It should therefore be possible to use MOVECOMP for the parametric studies presented in the following chapters.

4.1 A one-storey house with basement, Svaneholm

The first calculation was carried out with the ventilation system as installed, which means e. g. no outdoor air vents in kitchen and bedroom. The airtightness (excl. outdoor air vents) was assumed to be 3 ach at 50 Pa. This calculation resulted in a yearly average outdoor air ventilation rate of 0.22 ach, if the pressure coefficient for the top of the passive stacks is 0.0 and 0.30 ach if the pressure coefficient is - 0.3 (see table 4.1). In the bedrooms the outdoor air ventilation rate is lower than 0.3 ach during 90 % of the year (see figure 4.1). According to the current Swedish Building Code the outdoor air ventilation should be 4 l/(s person), which corresponds to 1.1 ach for bedroom 1 and 0.8 ach for bedroom 3 i. e. the ventilation is too low.

Table 4.1 Calculated outdoor air ventilation for the Svaneholm house. The airtightness (excl. outdoor air vents) is 3 ach at 50 Pa.

Total passive stack area, cm^2	Total outdoor air vent area, cm^2	Pressure coefficient, passive stack	Yearly average ± variation, ach	Max, ach	Min, ach
700	150	0,0	0,22 ±0,08	0,59	0,01
700	150	-0,3	0,30 ±0,11	0,81	0,02
700	300	-0,3	0,32 ±0,12	0,94	0,11
1050	300	-0,3	0,37 ±0,13	0,98	0,12
1050	425	-0,3	0,42 ±0,16	1,32	0,14
1050	740	-0,3	0,54 ±0,22	2,05	0,17
1050	1050	-0,3	0,65 ±0,29	2,71	0,18

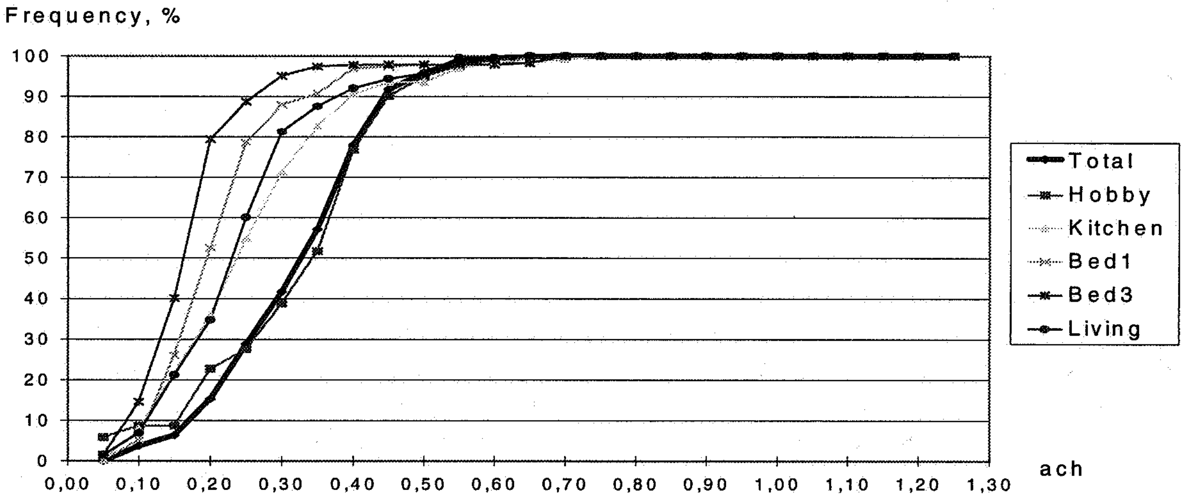

Figure 4.1 Cumulative distribution of outdoor air change rates in the Svaneholm house. The passive stack pressure coefficient is - 0.3, the total area of outdoor air vents 150 cm² and the ventilation system is according to the Swedish Building Code of 1967, but no outdoor air vents in kitchen, living-room and bedrooms.

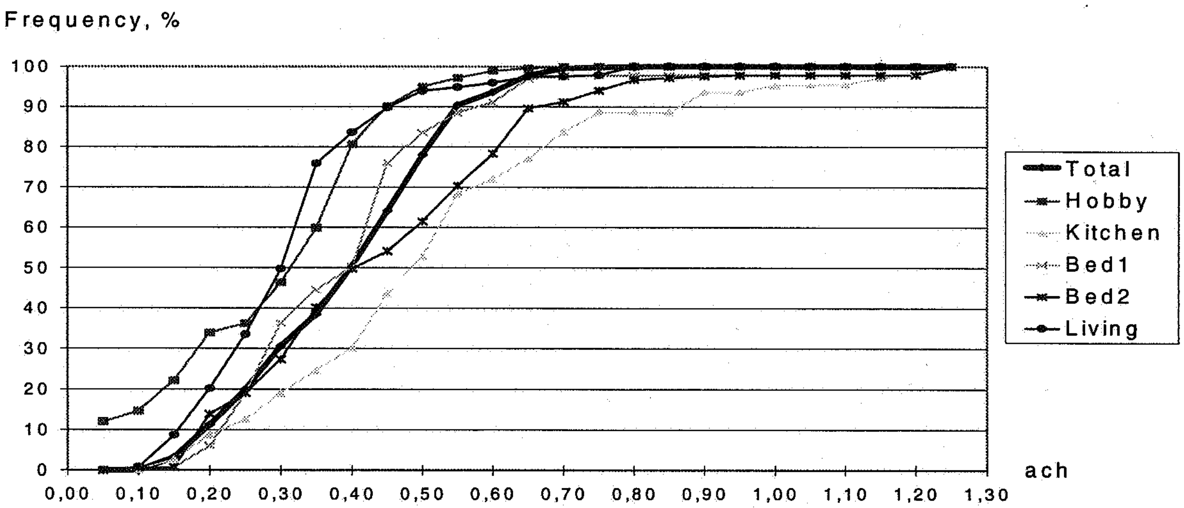

Figure 4.2 Cumulative distribution of outdoor air change rates in the Svaneholm house. The total area of outdoor air vents is 300 cm² and of passive stacks 1050 cm².

If the ventilation system was designed according to the Swedish Building Code of 1967, which means that outdoor air vents are added to kitchen and bedroom, the yearly average ventilation rate will increase from 0.30 to 0.32 ach. If the passive stacks are designed according to new recommendations (Boverket 1994), which means that the cross section is increased from 700 cm² to 1050 cm², then the ventilation rate is increased by another 0.05 ach, to 0.37 ach. For the bedrooms this means that during 75 % of the year the ventilation is lower than 0.5 ach (see figure 4.2). Calculations show that the outdoor air vents have to have a total area of appr. 700 cm² to arrive at a yearly average total ventilation of 0.5 ach (see table 4.1 and figure 4.3). During a substantial part of the year the ventilation will then be too low and other parts of the year too high. If the outdoor air ventilation is to be higher than 0.5 ach during 75 % of the year the outdoor air vents have to have a total area of at least 1050 cm² (7 cm²/(m² floor area)) (see figure 4.4). During some parts of the year the ventilation will then be very high, up to 2.7 ach.

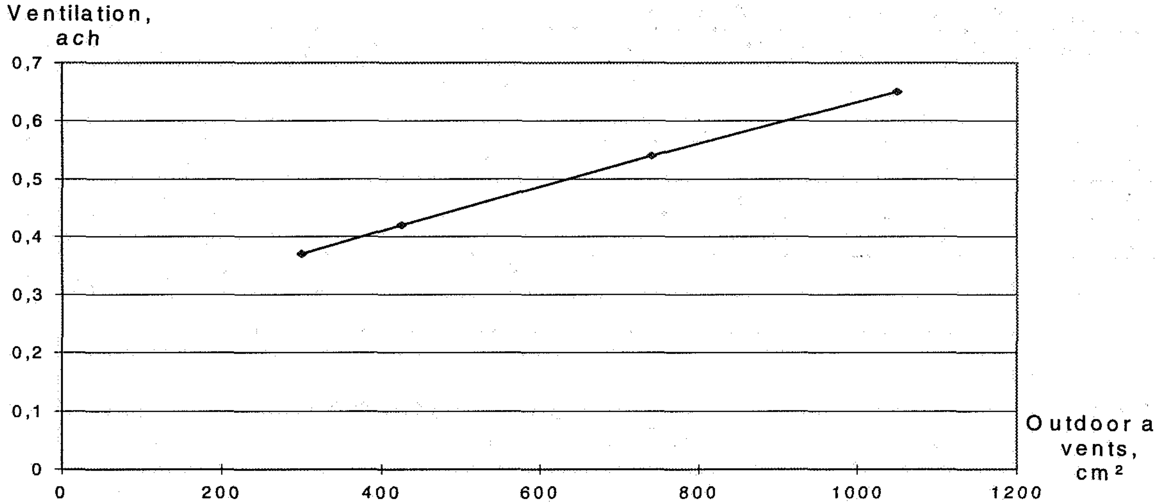

Figure 4.3 Yearly average total outdoor air ventilation as function of the total area of the outdoor air vents for the Svaneholm house with a total passive stack area of 1050 cm².

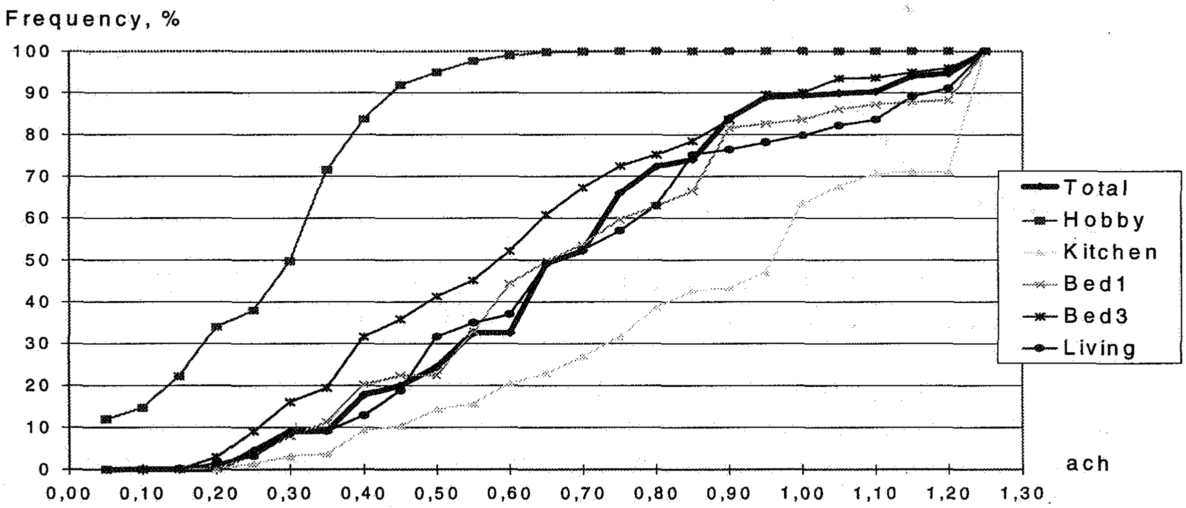

Figure 4.4 Cumulative distribution of outdoor air change rates in the Svaneholm house. The total area of outdoor air vents is 1050 cm² and of passive stacks 1050 cm².

4.2 A 1½-storey house with crawl-space, Lättbygg85.

The first calculation was carried out with a ventilation system designed according to the Swedish Building Code of 1967. The airtightness of the building envelope is assumed to be 3 ach (excl. outdoor air vents) at 50 Pa. The outdoor air vents were the same as for the original exhaust fan ventilation system. This calculation resulted in a yearly average outdoor air ventilation of 0.34 ach, if the pressure coefficent at the top of the passive stack is 0.0 and 0.41 ach if the pressure coefficient is - 0.3 (see table 4.2). The Lättbygg85 house has a higher ventilation rate than the Svaneholm house thanks to e. g. an open staircase between ground and first floor. In two of the bedrooms the ventilation rate is lower than 0.3 ach during 60 % of the year (see figure 4.5). According to the current Swedish Building Code the outdoor air ventilation rate should be 4 l/(s and person), which for the master bedroom corresponds to 1.2 ach and for one of the smaller bedrooms 1.1 ach i. e. the ventilation is too low.

Table 4.2 Calculated outdoor air ventilation for the Lättbygg85 house. The airtightness (excl. outdoor air vents) is 3 ach at 50 Pa.

Total passive stack area, cm²	Total outdoor air vent area, cm²	Pressure coefficient, passive stack	Yearly average ± variation, ach	Max, ach	Min, ach
700	70	0,0	0,34 ±0,12	1,01	0,03
700	70	-0,3	0,41 ±0,15	1,19	0,03
1050	70	-0,3	0,45 ±0,16	1,22	0,03
1050	225	-0,3	0,63 ±0,23	1,87	0,04
1050	610	-0,3	1,01 ±0,37	3,20	0,07

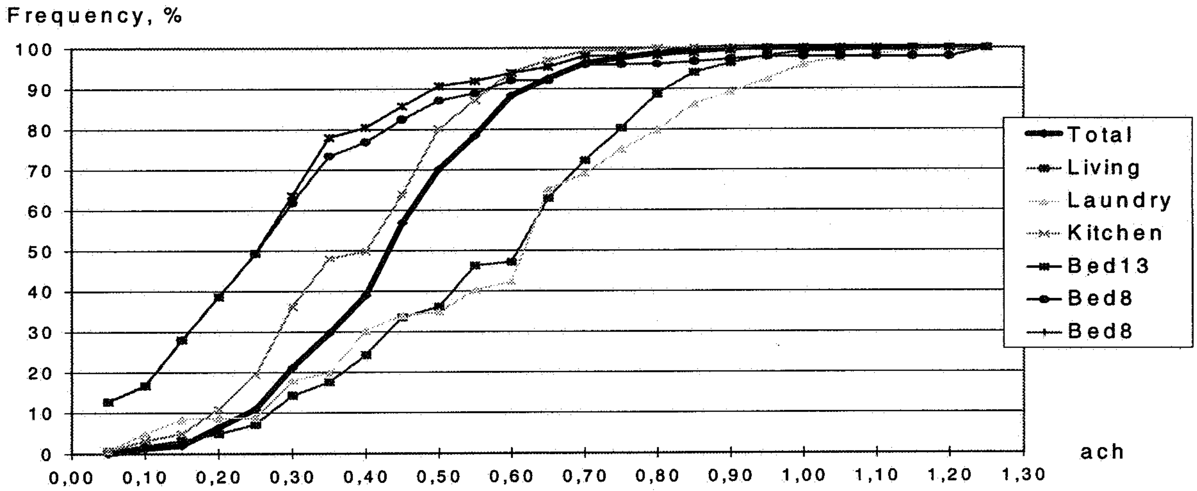

Figure 4.5 Cumulative distribution of outdoor air change rates in the Lättbygg85 house. The ventilation system is according to the Swedish Building Code of 1967.

If the passive stacks are designed according to new recommendations (Boverket 1994), which means that the cross section is increased from 700 cm² to 1050 cm², then the ventilation rate is increased by another 0.05 ach, to 0.45 ach. For two of the bedrooms this means that during 90 % of the year the ventilation is lower than 0.5 ach (see figure 4.6). Calculations show that the outdoor air vents have to have a total area of 115 cm² to arrive at a yearly average total ventilation of 0.5 ach (see table 4.2 and figure 4.7). If the outdoor air ventilation is to be

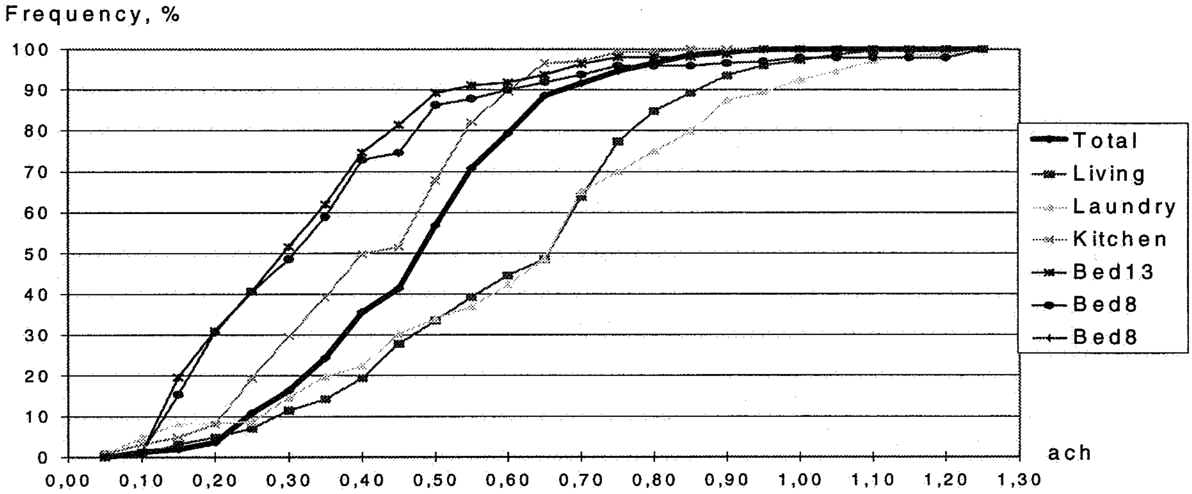

Figure 4.6 Cumulative distribution of outdoor air change rates in the Lättbygg85 house. The total area of outdoor air vents is 70 cm² and of passive stacks 1050 cm².

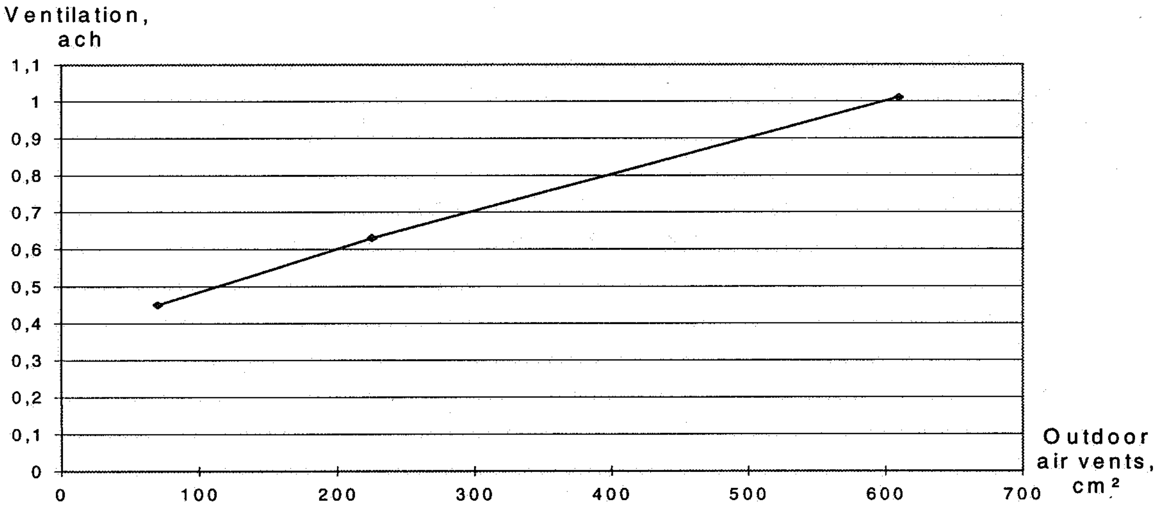

Figure 4.7 Yearly average total outdoor air ventilation as function of the total area of the outdoor air vents for the Lättbygg85 house with a total passive stack area of 1050 cm².

higher than 0.5 ach during 75 % of the year the outdoor air vents have to have a total area of at least 225 cm² (2 cm²/(m² floor area)) (see figure 4.8). During some parts of the year the ventilation will then be very high, up to 1.9 ach.

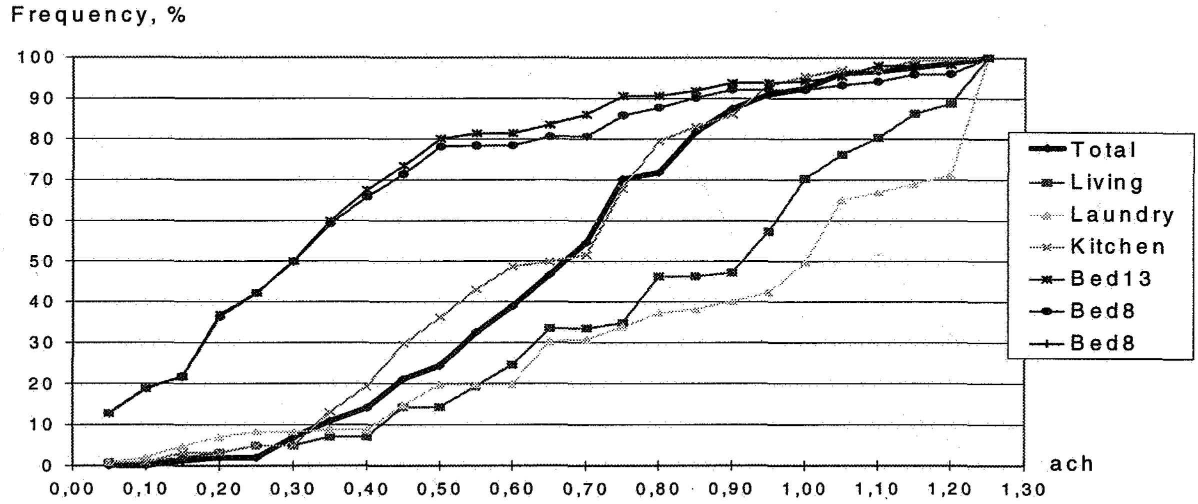

Figure 4.8 Cumulative distribution of outdoor air change rates in the Lättbygg85 house. The total area of outdoor air vents is 225 cm² and the total passive stack area 1050 cm².

4.3 An apartment building with three storeys, Sjöbo

The first calculation was carried out with the ventilation system as originally designed. The airtightness of the building envelope is assumed to be 1 ach (excl. outdoor air vents) at 50 Pa. This calculation resulted in a yearly average outdoor air ventilation of 0.48 ach for an apartment on the third floor, if the passive stack pressure coefficent is - 0.3 (see table 4.3). In the bedroom the ventilation rate is lower than 0.3 ach during 50 % of the year (see figure 4.9). According to the current Swedish Building Code the outdoor air ventilation rate should be 2 x 4 l/(s and person) for the bedroom i.e. 0.8 ach. The ventilation is too low in the bedroom.

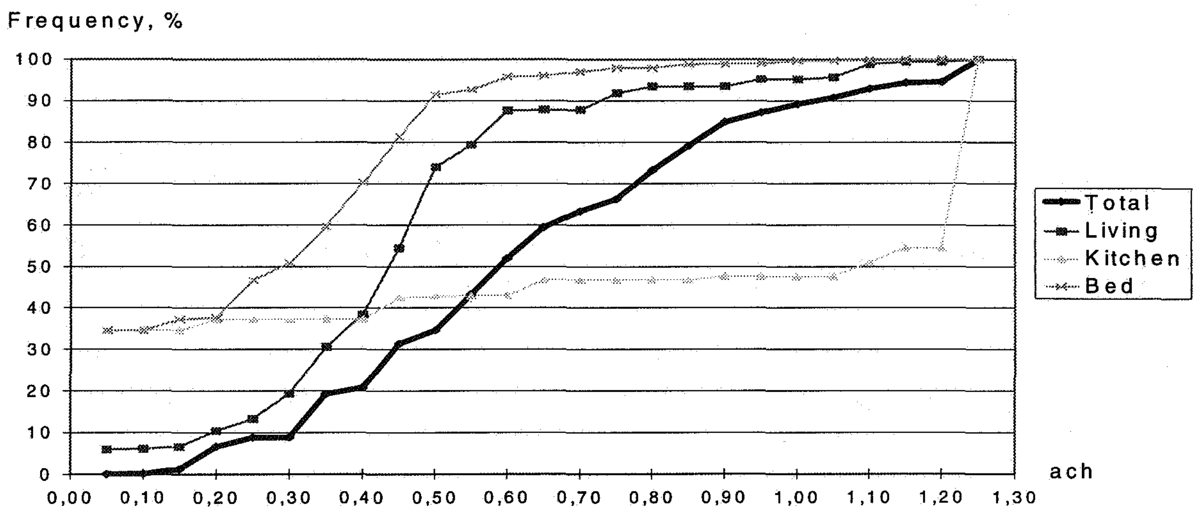

Figure 4.9 Cumulative distribution of outdoor air change rates in the apartment. The total area of outdoor air vents is 155 cm² and of passive stacks 500 cm².

If the passive stacks fullfill the new recommendations (Boverket 1994), the total cross section area is still 500 cm². The total outdoor air vent area has to be 175 cm² to arrive at a yearly average total ventilation of 0.5 ach (see table 4.3 and figure 4.10). If the outdoor air ventilation is to be higher than 0.5 ach during 75 % of the year the vents have to be at least 245 cm² (4 cm²/(m² floor area)) (see figure 4.11). At times the ventilation will be 4.3 ach.

Table 4.3 Calculated outdoor air ventilation for the apartment on third floor. The airtightness (excl. outdoor air vents) is 1 ach at 50 Pa.

Total passive stack area, cm²	Total outdoor air vent area, cm²	Pressure coefficient, passive stack	Yearly average ± variation, ach	Max, ach	Min, ach
500	155	-0,3	0,48 ±0,37	3,78	0,0
500	245	-0,3	0,59 ±0,39	4,26	0,0
500	385	-0,3	0,75 ±0,43	5,04	0,0

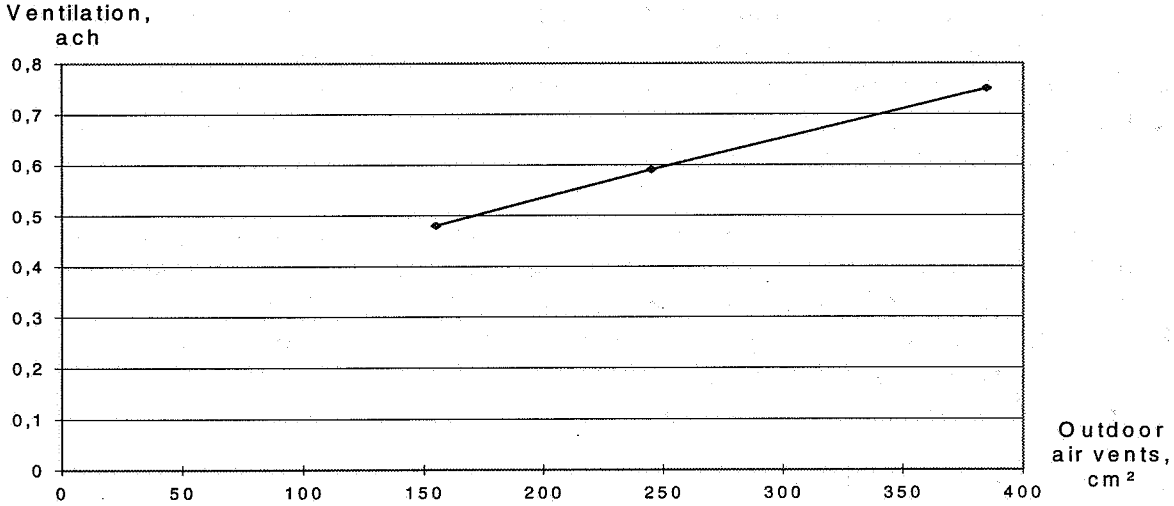

Figure 4.10 Yearly average total outdoor air ventilation as function of the total area of the outdoor air vents for the apartment on third floor with a total passive stack area of 1500 cm².

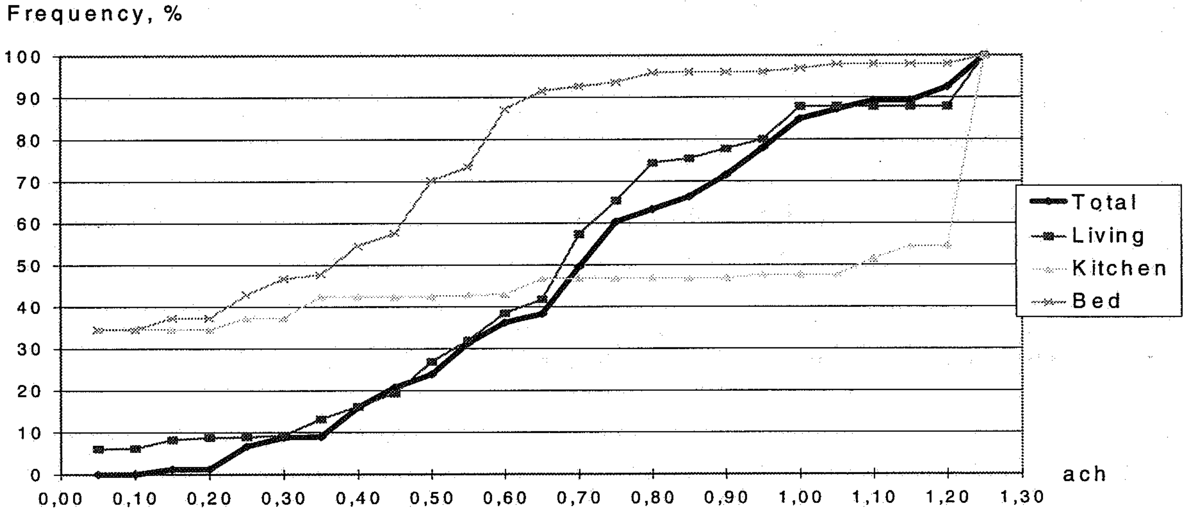

Figure 4.11 Cumulative distribution of outdoor air change rates in the apartment on third floor. The total area of outdoor air vents is 245 cm² and the total passive stack area 500 cm².

5. CONCLUSIONS

A conventional design of a passive stack ventilation system for a dwelling, which fullfills today´s requirement on airtightness (3 ach for detached house and 1 ach for apartments at 50 Pa), result (according to calculations) in a dwelling, which some part of the year has too low an outdoor ventilation rate. During the winter the total outdoor air ventilation will be too high. The variations in outdoor air ventilation rates during the year can be much larger for individual rooms than for the entire dwelling. In a 1½-storey house the rooms upstairs can during the winter have an outdoor air ventilation, which is very low.

Calculation for representative dwellings show that to arrive at a reasonable outdoor air ventilation e. g. that the total outdoor air ventilation rate for a dwelling is higher than 0.5 ach during 75 % of the year (reference year 1971 for Stockholm), a one-family house or an apartment should have outdoor air vents with an area somewhere between 2 and 7 $cm^2/(m^2$ floor area). The total area of the passive stacks should be larger than the total area of the outdoor air vents. The area of the outdoor air vents depends on the type of dwelling, one-family house with one or two storeys or where the apartment is located in the building. This kind of dwelling will, however, during a major part of the winter have too high a ventilation rate i. e. some kind of control of the outdoor air vents and passive stacks is necessary. The ventilation is too low mainly during the summer. During this part of the year (25 %) the ventilation can be improved by airing and/or fan assistance.

The design of a passive stack ventilation system should be based on a dwelling, which fullfills today´s requirement on airtightness and thereafter the size of the outdoor air vents and passive stacks is determined, in order to ensure that most of the ventilating air flows through the ventilation system and thereby is controllable. A modern system for passive stack ventilation must include a system for control of the air flows in order to avoid excessive use of energy and inadequate indoor air quality.

6. REFERENCES

Blomsterberg, Å., 1990. Ventilation and airtightness in low-rise residential buildings - Analyses and full-scale measurements. Swedish Council for Building Research, D10:1990, Ph. d. thesis, Stockholm, Sweden.

Boverket (National Board of Housing, Building and Planning), 1994. Passive Stack Ventilation - Handbook. Karlskrona, Sweden (in Swedish)

Bring, A., Herrlin, M., 1988. Users Manual - MOVECOMP-PC(R)-An Air Infiltration and Ventilation System Simulation Program. Bris Data AB, Saltsjöbaden.

Chien, N., Feng, Y., Wang, H., Siao. T., 1951. Wind-tunnel studies of pressure distribution on elementary building forms. Iowa State University, Iowa City, USA.

Herrlin, M., 1987. Luftströmning i byggnader - en beräkningsmodell. Kungliga Tekniska Högskolan, Installationsteknik, Stockholm.

Säteri, J., Bergsoe, N., Blomsterberg, Å., Skåret, E., 1996. Natural Ventilation. NKB (Nordic committee on building regulations) utskotts- och arbetsrapporter 1996:01 (in Swedish, Danish, Norwegian), Helsinki, Finland.

Wirén, B.G., 1985, Effects of Surrounding Buildings on Wind Pressure Distributions and Ventilation Losses for Single-Family Houses - Part 1: 1½ Storey Detached Houses. National Institute for Building Research, M85:19, Gävle, Sweden.