VENTILATION AND INDOOR AIR QUALITY IN FIVE ESTONIAN RESIDENTIAL BUILDINGS: A COMPARISON WITH SCANDINAVIAN CONDITIONS

L.E. Ekberg[1], M. Kraenzmer[1] and P. Nõmmeots[2]

[1]Dept. of Building Services Engineering, Chalmers University of Technology, Sweden
[2]Thermal Engineering Department, Tallinn Technical University, Estonia

ABSTRACT

Measurements of ventilation rates and indoor climate parameters were carried out in five Estonian residential buildings. The purpose of the study was to investigate potential differences between residences in former eastern Europe and Scandinavia, as regards the indoor environment. Air change rates were measured both during wintertime and springtime, and the air temperature and relative humidity were monitored both outdoors and indoors over extended periods of time. A variety of both organic and inorganic air pollutants were measured using both passive sampling and continuous monitoring. The air change rate in the Estonian buildings studied seem to vary more with the outdoor climate than what is typically the case, for example, in Swedish buildings. Furthermore, at low outdoor air temperatures the ventilation rates found in the studied Estonian buildings are substantially higher than what is typically found in Swedish residential buildings. Emissions from indoor sources is the reason for the relatively high indoor concentrations of aromatic compounds measured.

INTRODUCTION

In recent medical studies, geographic differences between former eastern Europe and western Europe have been observed as regards atopic diseases and sensitisation. For instance, a low prevalence of atopic diseases and sensitisation among school children in former eastern Europe has been observed, while the same type of health problems are quite frequent and increasing in the western world [1]. It has been put forward that the increasing prevalence of allergies is connected to factors as urbanisation, industrialisation, an increased standard of living and also to a deteriorated indoor environment. However, a common hypothesis is that differences in the indoor environment are not alone the explanation, but that they may contribute to the observed health effects.

Major studies of ventilation and indoor climate in residential buildings have been carried out both in Sweden and Norway [2,3,4]. The observation that a large fraction of the residences do not fulfil the building code requirements regarding ventilation rates is common for these studies. In the Norwegian study, 36% of the residences had ventilation rates below the building code requirement, and the differences between single- and multi-family houses were rather small. In the Swedish study, about 55% of the apartments in multi-family buildings, and as much as 85% of the single-family houses had ventilation rates below the building code requirement. In both Norway and Sweden the building code requirement corresponds to a specific airflow rate of 0,35 $l/s,m^2_{floor}$ (which, in turn, corresponds to an air change rate of about 0,5 h^{-1}). In Table 1, the results of the previously mentioned Swedish and the Norwegian studies are summarised together with results from a Finnish and a Danish study [5, 6].

Table 1. Mean ventilation rates measured in Nordic residential buildings [4].

	Mean ventilation rate (l/s, m^2)			
Type of building and ventilation system	**Sweden (n=1143)**	**Norway (n=344)**	**Denmark (n=123)**	**Finland (n=242)**
Single-family houses				
natural ventilation	0.23	0.47	0.24	0.28
exhaust ventilation	0.24	0.44	0.38	0.31
balanced ventilation	0.29	-	-	0.35
Multi-family buildings				
natural ventilation	0.33	0.51	-	0.43
exhaust ventilation	0.39	0.42	0.4	0.47
balanced ventilation	0.40	-	-	0.42

The Swedish study, which was carried out during the period November -91 to April -92, showed indoor air temperatures typically between 19°C and 24°C, while the relative humidity typically was found below 30%RH in multi-family buildings and above 45% RH in many single-family houses.

The present paper summarises measurements of ventilation rates and indoor climate parameters carried out in five Estonian residential buildings [7]. The results are compared with results from the previously published Swedish study referred to above. The paper does not contain any attempt to analyse possible medical implications of the findings.

For comparison, it should be mentioned that previously, the building standard used in Estonia (the old Soviet standard) stated a general demand on minimum ventilation in residential buildings of 3 $m^3/h,m^2_{floor}$. In addition, demands were formulated for bathrooms (25 m^3/h) and kitchens (60-90 m^3/h depending on the type of stove being used). At present a new national Estonian building standard is being developed. Meanwhile, the Swedish, Finnish, German and British standards are being used, which, in practice, means that the basic ventilation demand is 0,5 h^{-1}.

MATERIALS AND METHODS

The investigation was carried out in five different residential buildings, which were located in different parts of Tallinn, the capital of Estonia. Some characteristics of the buildings and apartments are summarised in Table 2. Buildings A-C are typical Estonian concrete multi-family buildings, and buildings D-E are small houses with 1-2 dwellings.

Table 2. Summary of some characteristics of the buildings and dwellings studied.

Building	Year of construction or renovation	Number of floors	Investigated dwelling located on:	No. of rooms	No. of occupants	Ventilation	Environment
A	1962	5	5th floor	3	2	N	intensive traffic
B	1980	5	4th floor	2	2	N	intensive traffic
C	1986	9	2nd floor	3	4	N	intensive traffic
D	1997 (1937)	2	1st floor	2	3	N / E_b	green area
E	1995 (1931)	3	1st floor	3	5	N / E_b	close to wood industry

N - natural ventilation
E_b - exhaust air fan in the bathroom (for intermittent operation)

Air change rates were measured, both during wintertime and during springtime, in all five residences, using an active tracer gas method. The measurements were carried out as concentration decay measurements using dinitrogen oxide as tracer gas, measured with an infra-red gas analyser (Miran, model 101). The winter measurements were carried out during the second half of February, and the spring measurements during the end of April and beginning of May, 1998.

The air temperature and relative humidity were monitored both outdoors and indoors over extended periods of time, using a set of small integrated devices for measurement and data-logging (Intab, model Tiny Talk 2).

The concentrations of nitrogen dioxide (NO_2) and a variety of organic substances were measured both outdoors and in the indoor air of all five residences using passive sampling. Additional passive sampling of ozone (O_3) and sulphur dioxide (SO_2) were carried out in two of the residences. All passive samplers were exposed for about one week in the middle of March, 1998. The NO_2 samplers were analysed chemically at the Clinical Research Center at the University Hospital of Linköping in Sweden, while all other passive samplers were analysed at the Swedish Environmental Research Institute in Göteborg.

Continuous monitoring of carbon monoxide (CO), carbon dioxide (CO_2), the total concentration of hydrocarbons (THC) and formaldehyde (HCHO) was carried out in one of the buildings over a one week period in the middle of March, 1998. For these measurements a Brüel & Kjær, type 1302 gas analyser, operating by the principle of photoacoustic spectroscopy (PAS) was used. The gas analyser was completed with a computerised manifold system for automatic switching between measurement locations indoors and outdoors. By this method indoor and outdoor concentrations of the gases mentioned were measured in sequence with a time resolution of about five minutes.

RESULTS

As can be seen in Table 3, ventilation rates in the interval 0.3-2.0 air changes per hour were observed (given as average values for the entire dwelling). In all cases the ventilation rates were substantially higher during the measurement period in the winter, than during the spring. The outdoor air temperature during the winter measurement was between -1°C and -7°C. During the spring measurement the outdoor temperature was between +17°C and +22°C, except for building E (+10°C).

During all ventilation measurements except one, the wind speed was low (0-2 m/s). The exception is the winter measurement in building C, during which the wind speed was about 8 m/s, and the air change rate obtained at this occasion was the highest observed in the investigation (2 h^{-1}).

For buildings A-D the air change rate measured during the winter is more than twice the value obtained during the spring measurement. In all four cases the difference in outdoor air temperature between the two measurement periods is greater than 20°C. In contrast, building E shows only a small difference between the winter and the spring measurements. One reason for the quite high air change rate in building E during the spring measurement may be explained by the fact that the outdoor temperature was only +10°C during this measurement (compared to -3°C during winter measurement). Another reason may be that in this particular building the main exhaust air duct was cleaned between the two measurement periods.

Table 3. Results of the air change rate measurements. The given air change rates are average values for the entire dwelling.

	Building designation - Air change rate (h^{-1})				
	A	**B**	**C**	**D**	**E**
Winter	1.3	1.2	2.0	1.3	1.3
Spring	0.6	0.5	0.3	0.6	1.1

Figure 1 shows the result of a recalculation of the air change rate values given in Table 3 to air flow rates expressed in ($l/s,m^2_{floor}$). The calculation is carried out with a room height of 2,3 m.

Separate ventilation measurements carried out in the bathrooms gave air change rates typically above 2 h^{-1}. In several cases the air change rates in the bathrooms were as high as 10-12 h^{-1}, also in bathrooms without exhaust air fans.

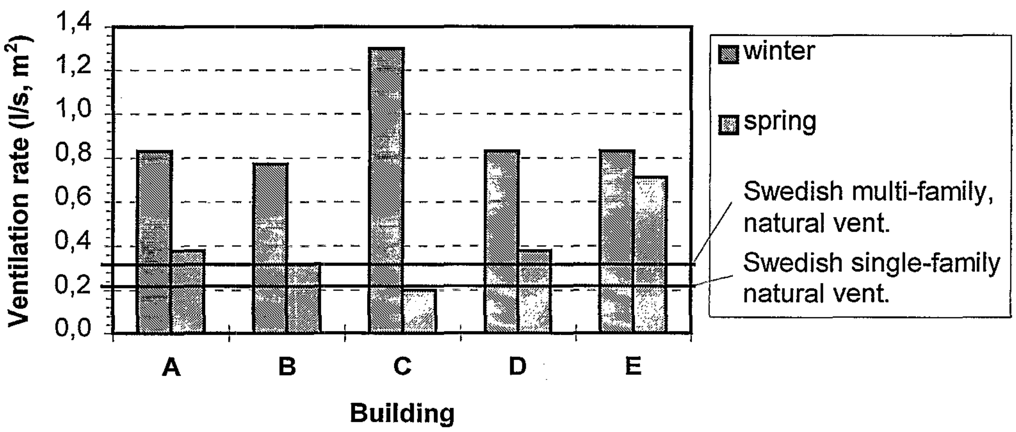

Figure 1. Results of the air change rate measurements. The values are given in ($l/s,m^2_{floor}$) and are calculated from the measured air change rates given in Table 3 using a room height of 2,3 m. The horizontal lines represent ventilation rates for Swedish naturally ventilated dwellings according to [2].

The average indoor temperatures measured in each dwelling range from 20.5°C to 24.0°C, which is similar to what has been found typical for Swedish residential buildings [3]. The lowest indoor temperatures are typically found between 20°C and 21°C, except in building D where low indoor temperatures of about 16°C frequently occurred. Indoor temperature peaks between 25°C and 28°C were recorded in several of the buildings.

The average indoor relative humidity measured in each dwelling was found to be between 20%RH and 40%RH, which seems to be similar to what has been observed in Swedish multi-family houses. According to [3], many of the Swedish single-family houses show a somewhat higher indoor relative humidity. Peaks of the relative humidity up to about 60% RH were observed occasionally in the studied Estonian buildings and these peaks were mainly associated with washing and drying of clothes indoors.

The results of the passive sampling of air pollutants are summarised in Table 4. Although outdoor concentrations of O_3 were found above 50 µg/m³, the indoor O_3 concentrations were close to zero. The values in the table also show that the indoor/outdoor (I/O) concentration ratio for SO_2 was about 0,05. Also for NO_2 a substantial sink effect was observed, with I/O concentration ratios between 0,35 and 0,67. Only in one dwelling (A), the I/O concentration ratio was found to be above unity (1,15). It is worth to note that a gas stove was used frequently in that particular dwelling.

The indoor concentrations of most of the organic pollutants measured were low. However, some compounds were found at concentrations up to 55 µg/m³. These higher indoor concentrations were apparently caused by internal sources in the dwellings. For instance, the concentrations of toluene were significantly higher indoors than outdoors in all of the buildings. Also mp-xylene was found indoors at concentrations substantially higher than outdoors. Indoor sources of benzene were indicated in building A and D and indoor sources of ethylbenzene were indicated in buildings A, C and D. Building D deviates from the other buildings with generally higher indoor VOC concentrations. The explanation is probably that this particular dwelling was newly renovated and that an adjacent dwelling was in the process of renovation during the measurement period.

Table 4. Concentrations measured by passive sampling in the five residences.

Gas	**Building designation** - concentrations in (µg/m₃)									
	A		**B**		**C**		**D**		**E**	
	indoor	outdoor	indoor	outdoor	indoor	outdoor	indoor	outdoor	indoor	outdoor
O_3	1,1	52,2	0,0	56,8	-	-	-	-	-	-
SO_2	0,6	9,6	0,3	6,6	-	-	-	-	-	-
NO_2	3,9	3,4	0,9	2,4	2,5	3,7	1,3	3,1	1,5	3,9
toluene	25,6	7,3	9,4	4,1	32,7	6,8	55,5	6,8	16,1	6,5
mp-xylene	8,8	3,4	4,0	1,8	14,7	3,1	27,7	3,1	3,5	2,4
benzene	5,7	3,3	2,3	2,4	3,7	3,4	9,7	4,1	2,4	3,3
o-xylene	4,4	1,3	1,9	0,7	5,8	1,2	10,8	1,2	1,7	0,9
ethylbenzene	2,5	0,9	1,2	0,5	4,2	0,9	8,6	0,9	1,0	0,7
butylacetylene	2,1	0,2	1,7	0,1	1,4	0,0	11,6	0,0	11,0	0,8
nonane	2,0	0,6	2,8	0,3	2,1	0,4	19,4	0,3	1,7	0,4
octane	1,2	0,5	1,3	0,2	1,2	0,4	3,2	0,3	1,0	0,4

The continuous monitoring in building B between Mach 13 and March 20, 1998 showed indoor CO_2 concentrations of up to about 850 ppm, while the outdoor CO_2 concentration was about 390 ppm. The same instrument also revealed that the indoor concentration of formaldehyde was quite constant around 0,2 ppm, which indicates an indoor source of formaldehyde. The outdoor formaldehyde concentration was close to zero.

The outdoor CO concentration varied with time within the range 0,5-2 ppm, and a clear co-variation between the indoor and outdoor CO concentrations was observed, see Figure 2. The variation of the outdoor CO concentration is probably due to emissions from traffic on the streets close to the building. At several occasions, the indoor CO concentration was considerably higher than that outdoors, which is an indication of an indoor CO source. However, no tobacco smoking or other combustion took place in the dwelling investigated, and one explanation might be that pollutants are being spread within the building, between dwellings.

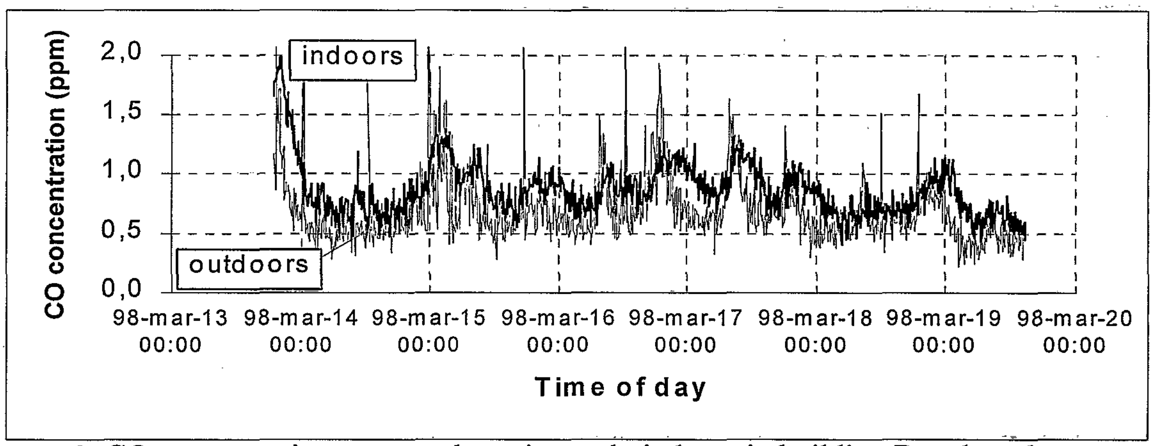

Figure 2. CO concentration measured continuously indoors in building B and outdoors.

DISCUSSION

The air change rates in the Estonian buildings studied vary more with the outdoor air temperature than what can be expected in Swedish buildings. Furthermore, at low outdoor temperatures the ventilation rates observed in the Estonian buildings are substantially higher than what is typically found in Swedish residential buildings. Both the average indoor temperature and relative humidity are similar to what can be considered typical for Swedish residential buildings. The concentrations of most of the pollutants measured are low, however, emissions from indoor sources is the reason for considerable indoor concentrations of aromatic compounds, especially toluene.

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