The indoor climate and energy consumption of educational buildings

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Abstract: - The indoor climate of classrooms influences both students' comfort as well as learning performance. Four renovated schoolhouses with mechanical ventilation and a kindergarten with natural ventilation have been investigated. The study paid special attention to the carbon dioxide concentration in classrooms and the indoor air quality in group rooms in the kindergarten. The cumulative duration graph clearly shows high levels of carbon dioxide in the classrooms and in the kindergarten playrooms. Also data on the energy consumption of the school buildings and its reduction potential are presented. Air change in classrooms was determined by the change in carbon dioxide levels. The survey showed that in most classrooms the carbon dioxide level at the end of a class exceeds the normal level several times. At the same time, ventilation in classrooms is very much lower than normal. The situation is due to the poor economic situation of schools, as well as the modest level and bad adjustability of HVAC. In naturally ventilated kindergarten playrooms the CO2 concentration ranges to 2,500 ppm.

Key-Words: - Indoor climate, CO2 level in classrooms and kindergartens, cumulative graph, air change, specific energy consumption

1 Introduction

Poor indoor air quality (IAQ) in indoor spaces such as classrooms can have adverse effects on the students' and teachers' comfort and pupils' learning performance.

Over short time scales (hours), poor IAQ causes discomfort, loss of attention and learning ability problems. On the ohter hand, sufficient ventilation rates in classrooms have been shown to improve the performance of students, e.g. in maths and reading tests (Fig. 1).

Over a longer term (days and weeks), epidemiological studies have shown a link between poor IAQ and the frequency of asthmatic symptoms in school children [1].

Several studies have revealed poor IAQ in many schools and kindergartens worldwide as indicated by:
- The air change rate (ACR) is not sufficient and generally much lower than mandatory design requirements.
- Indoor concentrations of a number of volatile compounds (e.g. formaldehyde, toluene, benzene, etc.) are much higher than the corresponding outdoor concentrations (Fig. 2) [3],

- During classroom occupation, the indoor concentrations of carbon dioxide (CO2) can rapidly reach the recommended limit values, and this is caused by an inadequate level of ventilation [4].
A study in the UK found that building and decorating activities caused concentrations of some VOCs to exceed the recommended air quality guidelines [3].
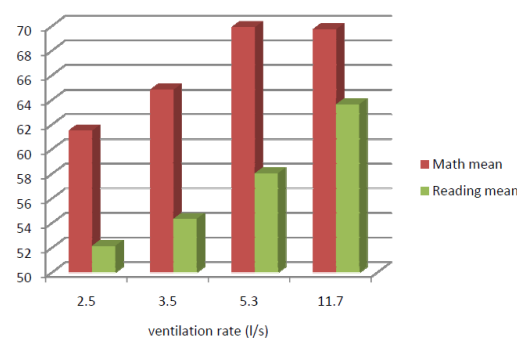

Fig. 1. Performance of students in primary schools according to ventilation rates (l/s) (based on [2] the results of maths and reading tests
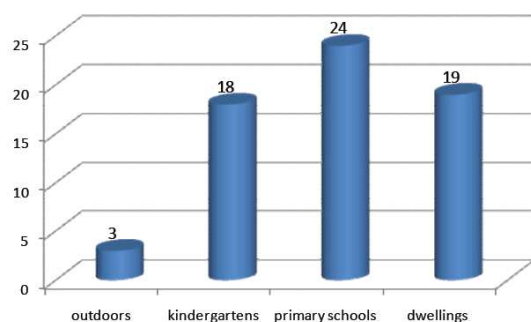
Fig. 2. Weekly mean concentrations of formaldehyde (μg.m-3) outdoors and indoors in Rhône-Alpes kindergartens and primary schools, France and in French dwellings [6]

In the Netherlands several studies in primary schools showed that the CO_2 concentration exceeded 1000 ppm more than 80% of the time [5].

The school provides a major indoor environment for children away or apart from their home as they may spend about 10 hours per day at school [7].

Indoor air pollutants might increase the chance of both long and short term health problems among pupils and staff, reduce teachers' productivity and degrade pupils' learning environment and comfort [8].

Studies done in the United States [9] indicated that good air quality in schools has enhanced attendance and reduced health problems among pupils.

Research conducted on five classrooms in Hong Kong has indicated that with inadequate ventilation the maximum CO_2 level may reach 5900 μl/l during a class [10].

Many factors affect indoor air pollution levels, such as maintenance activities, the presence of contaminant sources (e.g. building materials, furnishings and equipment), the levels of contamination outdoors, the season, indoor humidity and temperature, and ventilation rates [11].

IAQ problems can be attributed to various phases of the building process, including poor site selection, choice of materials, roof design, poor construction quality, improper installation or any number or combination of other factors [12].

Poor ventilation was another common issue that affected school occupants. Low ventilation rates generally increase the risk between health symptoms and ventilation rates or CO_2 concentrations. Seppanen et al. [13] found that some increases in ventilation rates up to 20 L/s per person decreased the prevalence of SBS symptoms or improved the perception of IAQ. Wargocki et al. [14] found that air-conditioned buildings may increase the risk of SBS systems compared to those that are naturally ventilated.

ASHRAE [15] recommends a minimum ventilation rate of 8 L/s-person for classrooms. Provided the typical occupant density is 33 per 90 m2 and the ceiling height is 3m, the current ASHRAE standard would require an air change rate of about 3 air changes per hour (ACH) for a classroom.

Clements-Croome et al. [16] in their research of eight primary schools in the United Kingdom revealed that pupils' work and performance increased by 7% due to the intervention of fresh air supply from 0.3-0.5 to 16 L/s per person. This is supported by [17], in which small ventilation air flow rates will reduce not only comfort, but also schoolchildren's learning performance in classrooms. Improving classroom conditions can substantially improve the performance of school work by children [18].

Carbon dioxide concentrations are often used as a surrogate of the rate of outside supply air per occupant.

Indoor CO_2 concentrations above 1000 ppm are generally regarded as indicative of ventilation rates that are unacceptable with respect to body odors. Concentrations of CO_2 below 1000 ppm do not always guarantee that the ventilation rate is adequate for removing air pollutants from other indoor sources [16].

It is difficult to adequately characterize indoor CO_2 concentrations since they are a function of occupancy and ventilation rate, both varying similarly to the function of time. Grab samples or other short-term measurements may be inadequate to provide information on the long-term ventilation conditions in schools. The most common building factors associated with indoor environmental complaints are related to Heating Ventilation and Air Conditioning (HVAC) systems. The recommended ventilation rate for a classroom is 8 L/s /person with a specified maximum occupancy of 50 persons per 1000 ft^2 for schools [19]. Thermal comfort in kindergarten was studied by Fabri [20]. Children sensitivity to indoor environmental pollution is dealt with Roda et al [21].

The paper presents the results of the study of the indoor climate and energy consumption in four renovated school buildings, which show significant shortcomings in the indoor air quality of the educational buildings.

2 Method

Air change in a room can be determined by the CO_2 concentration change using equation (1) [4]

$$\frac{L}{V} \cdot \tau = -\ln \frac{\frac{m}{L} + C_v - C}{\frac{m}{L} + C_v - C_o} \qquad (1)$$

where

m - carbon dioxide generation in the room,

L - air change in the room,

V - volume of the room or design volume,

C_v - carbon dioxide concentration in external air (in supply air),

C - carbon dioxide concentration in room air (in exhaust air),

C_o- carbon dioxide concentration in the air of the room at the beginning of human activity,

τ - time.

Table 1 General data and heat consumption of the studied schools

School	Number of students	Number of classrooms	Heating area m²	U-value of walls/roof W/(m²K)	Specific heat consumption (designed savings*) kWh/(m² a)	Specific electricity consumption (designed savings) kWh/(m² a)
No1	715	33	4662	0.26/0.22	98 (-14.6)	22.2 (-0.8)
No2	763	42	5466	0.18/0.18	80 (-40)	40 (-1.5)
No3	638	34	4586	0.31/0.24	118 (-5.7)	41 (-12.9)
No4	780	43	6628	0.28/0.22	74 (+3.3)**	28.4 (+2)**

* Determined on the basis of simulations
** To keep normal indoor climate both heat and electricity consumption increase.

3.1 Secondary school no 1

Monitoring conducted during the heating season showed that the temperature in classrooms was over 21°C, 75% of the time and more than 24°C under 5% of the time. Only 60% of the time during the heating season is the relative humidity level of air within normal limits. The situation with CO_2 levels is much worse, the measurements showed that the maximum CO_2 level for 32 classrooms is from 1285 to 3999 ppm. Figure 3 shows the CO_2 levels during a school day on a duration diagram.

Studies show that air change in the classroom determined by the formula (1) has a good coincidence with the actual situation.

The air change results determined by the formula (1) show good coincidence with the measured values.

3 Results

The article presents the results of the study of the indoor climate and energy consumption of renovated schools with mechanical ventilation in Tallinn, Table 1.

Table 1 shows heat and power consumption results of the studied schools and savings related to the renovation.
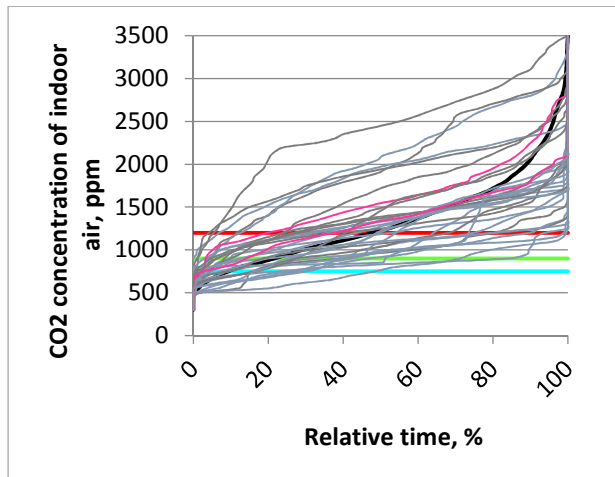
Fig.3. Cumulative graph of the CO2 level in classrooms

In all the studied classrooms the final concentration of carbon dioxide was higher than the required threshold exceeding it by 375-3100 ppm, despite the fact that the school has a mechanical ventilation system, which works from 6:00 to 14:00 on weekdays. Figure 3 shows that during 50% of the study time the concentration of CO2 in the indoor climate exceeds class III requirement - 1,200 ppm. Thus it can be concluded that the ventilation system does not work according to the designed air flow rates. The study showed that the ventilation air flow rates were 1.5 to 2 times lower than the design value - 3 l/(s·m²).
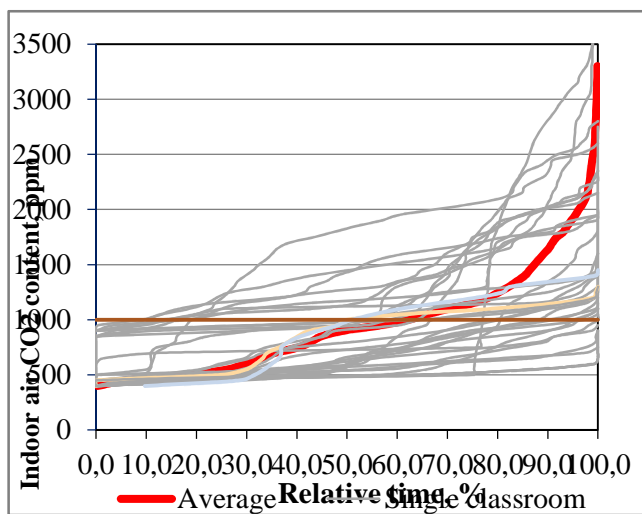
3.2 Basic school no 2

Fig.4 Cumulative graph of CO2 concentration in classrooms

Indoor climate measurements in 46 rooms showed that the internal temperature meets the requirements 90% of the time. Prolonged exposure measurements showed that the indoor temperature is not significantly affected by the change in external temperature. In winter (January, February), the measurements showed that the relative humidity is below 25% over 50% of time. The cumulative duration graph of carbon dioxide concentration is shown in Fig.4. The figure shows that the CO2 level was below 1000 ppm 65% of the time on average. However, in many classrooms this level was exceeded considerably. In 30% of the classrooms the CO2 level was approximately 900 ppm already at the beginning of the school day, which refers to insufficient air change. This is confirmed by the comparison of the designed and measured air flow rates, Fig. 4.
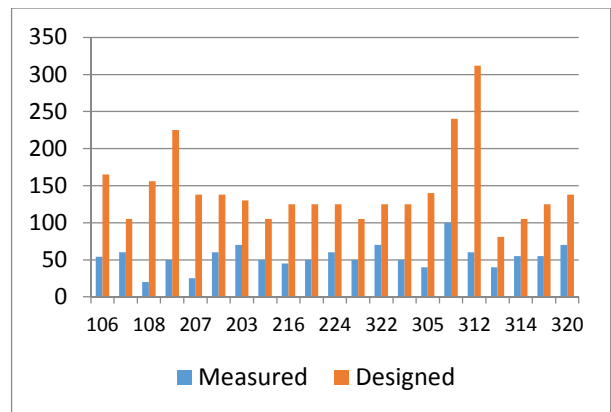

Fig. 5 Measured and designed air flow rates l/s in different classrooms

Fig. 5 shows that the measured air flow is generally less than 50% of the design value, which causes high concentrations of CO2 in classes.

3.3 Secondary school no3
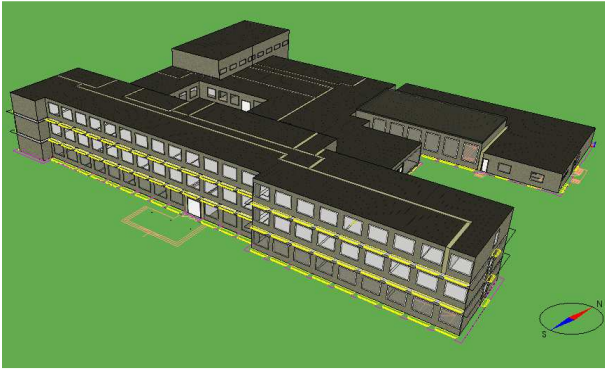The 3D view of the school building is presented in Figure 6.

Fig.6. 3D view of the school building

The air temperature corresponded to standard EVS-EN 15251 Class II 90% of the time. The relative humidity was within the limits of 25 ... 45% 80% of the time. CO2 measurement results show that the CO2 concentration in classrooms was more than 1000 ppm over 70% of the time. Table 2 shows the determined and designed air change data in different classrooms.

Table 2. Calculated and designed air change in classrooms

Class	Air change $l/(s \cdot m^2)$	Air change per student $l/(s \cdot in)$	Designed air change $l/(s \cdot m^2)$
103	0.5	1.5	3.0
104	0.5	1.6	3.0
106	0.5	1.5	3.4
107	0.4	1.1	2.8
111	0.4	1.3	2.8
202	1.8	4.7	2.0
205	1.3	4.5	3.8
209	1.0	4.0	3.2
225	1.7	4.4	3.9
226	1.3	3.2	4.0
302	1.3	4.5	3.1
304	1.6	4.1	3.95

Table 2 shows that in most rooms the air change is significantly lower than the design value and does not ensure the required indoor climate.

3.4 Secondary school no 4

This is a typical school building built in the 1970s, which was renovated 6 years ago. The air temperature corresponds to standard EVS-EN 15251 Class II 77% of the time. The relative humidity is within the limits of 25 ... 45% 85% of the time. The CO2 concentration in classrooms is below 1,000 ppm 60% of the time, but most of it is the time outside classes. During the classes the peak CO2 level is from 2000 to 4000 ppm and the CO2 level is more than 1000 ppm as a rule. The air flow rates in classes are on average 2.4 times lower than the design value of 3 l/(s m2). This is the reason for very high CO2 concentration during classes.
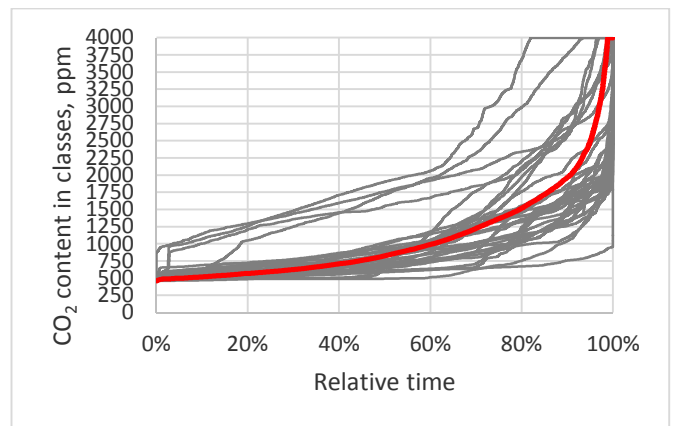

Fig.7. Cumulative graph of CO2 concentration in classrooms (Secondary school no 4), the red line is the average value

3.5 Kindergartens

It is known that many kindergartens are located in 30-40-year old partially renovated (windows, roof, heating system) buildings. In the children's playrooms, there is no mechanical ventilation. The kitchens have mechanical ventilation. These are typical buildings, which usually have 12 groups, see Fig. 8.

Fig.8 Kindergarten "Child"

The survey results are presented for kindergarten "Child" (262 children, heated area 2142 m², 12 groups), where the special heat energy consumption is 183 kWh/m². The proposed savings potential is about 50%.

The cumulative curves of the indoor climate parameters in the kindergarten - the air temperature, relative humidity and carbon dioxide concentration - are shown in Figures 9, 10, 11.
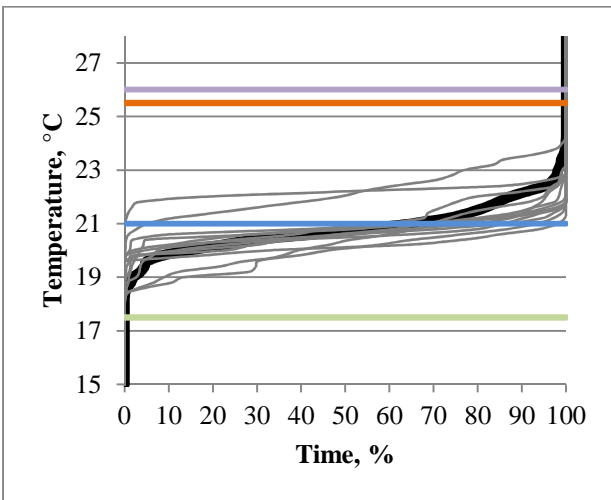

Fig.9. Cumulative graph of indoor temperature during the heating period: dark line - average value

Generally satisfactory, with the exception of a few group rooms where the temperature should be higher in the morning.
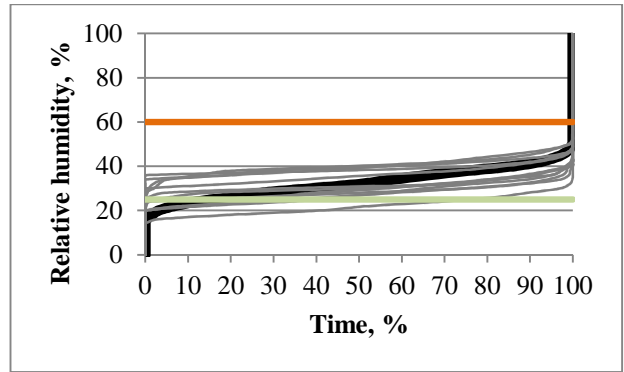

Fig.10 Cumulative graph of relative humidity during the heating period: dark line - average value
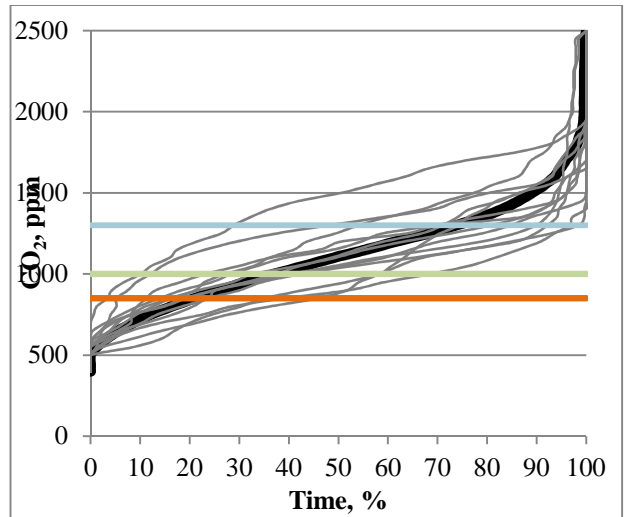
Mostly satisfactory, with the exception of low frost.

Fig.11 Cumulative graph of CO2 concentration: dark line - average value

The figure shows that nearly 70% of the working time the CO2 level in the playrooms exceeds the normal level - 1000 ppm. Similar high CO2 concentration is typical of the majority of the nurseries where the ventilation has not been renovated.

In some kindergartens, in some areas, there are problems with radon, Fig.12.
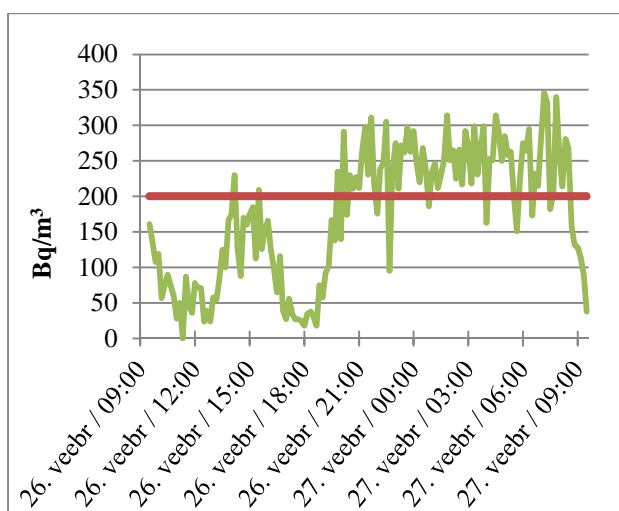
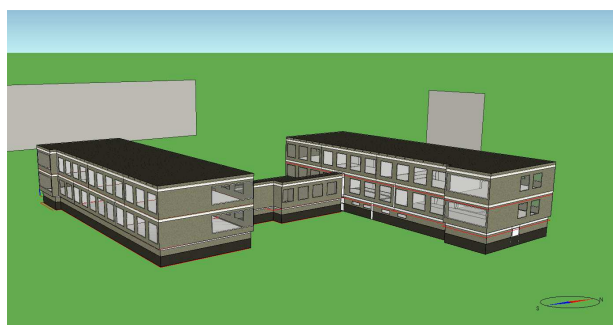Fig.12. Radon concentration in the kindergarten (February 2013)

Fig.13 Simulations of energy consumption before and after the renovation have been carried out in the kindergarten

4 Conclusion

The studied schools have been renovated and the energy consumption has significantly reduced, but the indoor air CO2 levels exceed the required levels, even several times. At the same time, the indoor air temperature is satisfactory. The reason for this is the poor performance of mechanical ventilation. On the one hand, this is due to the poor economic situation, schools will seek cost savings by reducing the air flow rates and the operating time of the ventilation. On the other hand, the level of renovation is less than optimal. There are particular weaknesses in utility management.

To improve this situation it is necessary to raise the quality of renovation and the operational level of HVAC.

The indoor air climate in the playrooms and bedrooms of the kindergarten needs rapid improvement, especially in the areas with cold climate. One possibility here is to use a low-noise room AHU to raise the air change to the necessary level.

In the current situation, the indoor climate during the classes in the studied schools and in the kindergarten playrooms does not meet the requirements EN 15251:2007, to a larger or smaller extent.

Acknowledgement

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