Indoor climate and improvement possibilities in educational premises

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SUMMARY

The results of indoor climate investigation in 7 schools of Tallinn are analyzed in the paper. In classrooms with natural air change carbon dioxide concentration at the end of the class is very high, up to 1.5...3.5 times more than permitted level. With high occupation rate in gymnasiuums of Tallinn the good indoor climate and permitted CO2 concentration at the end of the class can be provided only with the use of balanced ventilation.

INTRODUCTION

Over the last few decades, considerable attention has been directed toward the problems of indoor air quality in schools. It has become increasingly clear that exposure to contaminated indoor air may not only be unpleasant, but can have serious adverse health effects. Children of today spend increasingly more of their time in school environment. Because children breathe a greater volume of air relative to their body weight compared to adults, they may be more sensitive to indoor air pollution [1, 2]. Indoor air quality in schools is influenced by many factors, like air temperature, relative humidity, air velocity, radiant temperature, textured surfaces, activities of the occupants in the building, the season, etc [3]. The available floor area per person in classrooms, around 1.5-2.0 m², is much less than that in office rooms, where 8-10 m² per person is normal. This implies a much larger ventilation demand in schools to remove contaminated indoor air.

Indoor climate in school buildings has been researched in many countries. One of the interesting questions is the carbon dioxide level in classrooms at the end of the class. There are approximately 6000 school buildings in Finland, in which more than 700,000 people spend several hours of their time every day. Ventilation and indoor air quality of elementary and secondary schools were studied and in general the complaints about poor indoor air quality were more common in the schools with natural ventilation system than with mechanical ventilation systems, being least frequent with mechanical supply and exhaust air ventilation. Before the renovation process, the contents of carbon dioxide in the school buildings ranged between 1200...2400 ppm [4].

In 1996 and 1997 research was done about CO2 concentrations for 96 classrooms in 38 Swedish randomly selected schools, 61% of them had mechanical supply and exhaust air systems while the reminder had natural ventilation. Concentrations average was 900 ppm CO2 and the maximum was 2800 ppm [5].

The outcome of a field study in 11 primary schools in Eindhoven, the Netherlands in 2005 shows that average CO2 concentration in half of schools is near to 2000 ppm and maximum CO2 levels of 3000 or 4000 ppm in schools are no exception [6]. Indoor air quality testing in 28 classrooms in Warsaw (Poland) in 2000 shows that in most observations the maximum CO2 level was from 2000 to 4000 ppm [7].
In 1991 CO₂ measurements in a non-random study of 9 U.S. non-complaint schools showed that concentrations ranged from about 400 to 5000 ppm (mean = 1480 ppm). CO₂ concentrations exceeded the 1000 ppm ASHRAE ventilation standard [8] in 74% of the rooms [5]. In Michigan schools CO₂ peak levels reached 2700 and 3300 ppm in a non-portable and portable classrooms [9].

There is evidence that many countries have significant and serious indoor environmental problems in schools. From the educational standpoint, the indoor air quality and ventilation in school buildings may affect the health of the children and indirectly affect learning performance.

In Estonia the indoor air quality in schools has not been investigated sufficiently. In 2005 a pilot research was done in a cold season. The main reason of investigation was carbon dioxide concentration and air change level determination in classrooms with natural ventilation [10]. In most school buildings in Tallinn (about 90%) ventilation systems are not renovated, but windows have as a rule been changed and external walls in single cases renovated. Only natural ventilation and window airing of classrooms is used in unrenovated school buildings. The results of measuring carbon dioxide concentration have shown that in classrooms with non-renovated ventilation, indoor air quality is very bad. At the end of the lesson the CO₂ concentrations reach the level of about 2000...3500 ppm, in single cases even up to 4400 ppm [10]. The cause of that is very low air change; 4–5 times lower than needed and insufficient airing during breaks or the lack of it. Estonian Standard EVS839:2003 „Indoor climate“[11] permits carbon dioxide concentration 1000 ppm for category A, 1250 ppm for category B, 1500 ppm for category C and indoor temperature in classrooms 21…23°C for category A, 20…24°C for category B, 19…25°C for category C, relative humidity 25…45% and air velocity up to 0.2 m/s for cold season.

According to the regulation of the Estonian Ministry of Social Affairs [12] the permitted maximum carbon dioxide level in classrooms is 1000 ppm, relative humidity 30...70%, indoor temperature 19...25°C.

By prEN15251 recommended maximum values of carbon dioxide concentration in CO₂-controlled ventilation systems can be up to 800 ppm above the external air concentration for category C, 500 ppm for category B and 350 ppm for category A [13].

METHODS

Indoor air quality measurements were carried out in 10 classrooms of 7 typical gymnasiums in districts of Mustamae, Oismae and Center of Tallinn. The area of classrooms varied from 53 to72 m² and volume from 153 to 213 m³, the age of students from 13 to 18 years, Table 1. Density in classrooms ranged from 1.6 to 3.3 m² per person. The occupation rate in classrooms was from 44 to 92%, windows and doors were closed during the class. Information about the investigated classrooms and external air temperature and relative humidity are presented in Table 1. External air CO₂ level during the measurements was 410±30 ppm.

The duration of the measuring of parameters in classrooms was 40-45 minutes, except in the gymnasium of Sytiste, in which one class lasted 35 minutes. In same cases the change of indoor air parameters during breaks was measured. Dynamical registration of CO₂ concentrations make it possible to use CO₂ as tracer gas for air change measuring. Indoor air parameters were assessed at the breathing zone height of seated students, but about 1m away from the students. All classrooms were empty before the beginning of measurements. Initial indoor parameters are shown in Figures 1, 2 and 3.

Instruments used for measurements were Testo series 400 and 435 with probes for measuring
CO₂ concentration, relative humidity, indoor temperature and air velocity. Natural ventilation and airing during breaks were used in the investigated schools, all of the windows in classrooms had been changed, in the gymnasium of Sytiste, in addition the envelope elements had been insulated.

Table 1. The characteristic data of investigated classrooms

<table>
<thead>
<tr>
<th>School name</th>
<th>Area of classroom m²</th>
<th>Volume of classroom m³</th>
<th>Number of students</th>
<th>Age of students</th>
<th>No of class</th>
<th>Occupancy %</th>
<th>External temperature °C</th>
<th>External relative humidity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian gymn. of Oismae</td>
<td>55</td>
<td>167</td>
<td>17</td>
<td>16-17</td>
<td>2</td>
<td>0.47</td>
<td>5.0</td>
<td>95</td>
</tr>
<tr>
<td>Gymn. of Mooni 1</td>
<td>55</td>
<td>164</td>
<td>31</td>
<td>15-16</td>
<td>4</td>
<td>0.83</td>
<td>3.9</td>
<td>95</td>
</tr>
<tr>
<td>Technical Gymn. of Tallinn</td>
<td>56</td>
<td>167</td>
<td>34</td>
<td>14-15</td>
<td>2</td>
<td>0.92</td>
<td>7.0</td>
<td>99</td>
</tr>
<tr>
<td>Gymn. Liivalaia 1</td>
<td>59</td>
<td>194</td>
<td>17</td>
<td>14-15</td>
<td>6</td>
<td>0.44</td>
<td>0.3</td>
<td>98</td>
</tr>
<tr>
<td>Gymn. Liivalaia 2</td>
<td>54</td>
<td>179</td>
<td>25</td>
<td>13-14</td>
<td>7</td>
<td>0.80</td>
<td>0.3</td>
<td>98</td>
</tr>
<tr>
<td>Gymn. of Sytiste 1</td>
<td>72</td>
<td>206</td>
<td>27</td>
<td>16-17</td>
<td>2</td>
<td>0.65</td>
<td>-5.0</td>
<td>95</td>
</tr>
<tr>
<td>Gymn. of Sytiste 2</td>
<td>54</td>
<td>160</td>
<td>26</td>
<td>13-14</td>
<td>3</td>
<td>0.69</td>
<td>-5.0</td>
<td>93</td>
</tr>
<tr>
<td>Gymn. Arte 1</td>
<td>52</td>
<td>153</td>
<td>19</td>
<td>16-17</td>
<td>1</td>
<td>0.50</td>
<td>-18.0</td>
<td>83</td>
</tr>
<tr>
<td>Gymn. Arte 2</td>
<td>72</td>
<td>213</td>
<td>29</td>
<td>17-18</td>
<td>2</td>
<td>0.78</td>
<td>-18.0</td>
<td>83</td>
</tr>
<tr>
<td>Gymn. of Jarveotsa 1</td>
<td>55</td>
<td>152</td>
<td>28</td>
<td>13-14</td>
<td>4</td>
<td>0.75</td>
<td>-6.1</td>
<td>85</td>
</tr>
</tbody>
</table>

*The classroom in school investigated first  
**The classroom in school investigated secondly

RESULTS

Main attention was paid to measuring carbon dioxide concentration and air change determination in a cold period: from November 2006 to January 2007. At the same time indoor temperature, relative humidity and air velocity were registered.

The dynamic change of CO₂ concentration during the class is presented in Figure 1. The rise of CO₂ concentration in different classrooms is from 550 to 1600 ppm. Only in two classrooms the CO₂ level at the end of the class was less than 1500 ppm or near to it, but exceeded the permitted 1000 ppm [8, 12]. In different classes the rise of CO₂ concentration varies, depending mostly on the occupation rate of the classroom and the air change per student. The CO₂ concentration at the end of the class depends greatly on its initial level at the beginning of the class, the latter depending on how intensively the airing during the breaks took place.

Figure 2 shows the variable relative humidity level during the classes, ranging from 24% to 54%. As can be seen the relative humidity rises moderately and mainly stays within the permitted limits 30…70% [12]. Only in the Gymnasium of Arte (in the classroom investigated first) the relative humidity decreased, being caused by the low humidity content in external air at -18 °C, the low occupation rate of classroom and relatively high air change in classroom (when compared with other classrooms investigated). Permitted relative humidity in classrooms is achieved thanks to low air change.

Figure 3 shows the variation of indoor air temperature during the class. As can be seen the indoor air temperature ranges between 18 and 25.5 °C, which to some extent exceeds the permitted limits [12]. Only in the Gymnasium of Liivalaia the indoor temperature was too low 18-19°C.
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Fig. 1. Variation of carbon dioxide in classrooms

Fig. 2. Variation of relative humidity in classrooms
Fig. 3. Variation of temperature in classrooms

Due to natural ventilation the air velocity in classrooms investigated was low: less than 0.1 m/s.

Dynamic registering of the carbon dioxide level enables us to determine air change in classrooms. To calculate the air change the following formula was used [10]:

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

(1)

where $m$ is carbon dioxide generation in classroom, $L$ is air change in classroom, $V$ is volume of room, $C_v$ is carbon dioxide concentration in external air (in supply air), $C$ is carbon dioxide concentration in classroom air (in exhaust air), $C_o$ is carbon dioxide concentration in the air of the classroom at the beginning of the class, $\tau$ is time.

The basic equation for carbon dioxide concentration $C$ at time moment $\tau$ [10]:

$$C = C_v + \frac{m}{L} \left( C_v + \frac{m}{L} - C_o \right) \cdot \left( e^{-\frac{L}{V} \cdot \tau} \right)$$

(2)

The determined air change and other characteristic parameters of classrooms investigated are brought in Table 2. It shows that the air change is very modest: 0.3-3.9 l/s per student. With low air change and normal occupation rate the rise of CO2 concentration is remarkable – 900-1600 ppm. Only in two classrooms the CO2 concentration at the end of the class was up to 1500 ppm or near to it.
Table 2. Characteristic parameters of classrooms investigated

<table>
<thead>
<tr>
<th>Name of school</th>
<th>Air change L/s</th>
<th>Air change L/s per pupil</th>
<th>Occupation rate</th>
<th>CO₂ level at the beginning of class, ppm</th>
<th>Rise of CO₂ level, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gymnasium of Mooni</td>
<td>21</td>
<td>0.7</td>
<td>0.83</td>
<td>2160</td>
<td>1548</td>
</tr>
<tr>
<td>Gymnasium of Liivalaia (2)</td>
<td>7</td>
<td>0.3</td>
<td>0.8</td>
<td>1934</td>
<td>1540</td>
</tr>
<tr>
<td>Technical Gymnasium</td>
<td>60</td>
<td>1.8</td>
<td>0.92</td>
<td>670</td>
<td>1468</td>
</tr>
<tr>
<td>Gymnasium of Jarveotsa</td>
<td>60</td>
<td>2.2</td>
<td>0.75</td>
<td>887</td>
<td>1119</td>
</tr>
<tr>
<td>Gymnasium of Sytiste (1)</td>
<td>43</td>
<td>1.6</td>
<td>0.65</td>
<td>965</td>
<td>886</td>
</tr>
<tr>
<td>Gymnasium of Sytiste (2)</td>
<td>42</td>
<td>1.6</td>
<td>0.69</td>
<td>1467</td>
<td>932</td>
</tr>
<tr>
<td>Gymnasium of Arte (1)</td>
<td>59</td>
<td>4.0</td>
<td>0.5</td>
<td>591</td>
<td>785</td>
</tr>
<tr>
<td>Gymnasium of Arte (2)</td>
<td>62</td>
<td>2.1</td>
<td>0.78</td>
<td>1447</td>
<td>759</td>
</tr>
<tr>
<td>Russian Gymnasium of Oismae</td>
<td>61</td>
<td>3.6</td>
<td>0.47</td>
<td>686</td>
<td>868</td>
</tr>
<tr>
<td>Gymnasium of Liivalaia (1)</td>
<td>30</td>
<td>1.7</td>
<td>0.44</td>
<td>1373</td>
<td>587</td>
</tr>
</tbody>
</table>

**DISCUSSION**

With natural ventilation in classrooms and airing only during breaks it is practically impossible to keep the CO₂ concentration under the permitted limit, 1000 ppm [12], at the end of a class with full occupation rate.

With natural ventilation, the airing of classrooms during breaks is very important, without it the CO₂ level is usually over the permitted limit already at the beginning of the second class. In the classroom investigated the CO₂ concentration was 1.5 – 2 times over permitted value.

Calculations show (formula (2)) that in classrooms with average occupation rate, with an approximate air change of 1 l/s per m² and with good airing during breaks it is possible to hold the maximum CO₂ concentration on a level up to 1500 ppm. This meets the carbon dioxide C class requirements by Standard of Indoor Climate [11], but does not correspond to the regulation of the Estonian Ministry of Social Affairs [12].

In practice, to gain the acceptable indoor climate, especially as regards CO₂, windows are kept opened also during classes.

To keep the CO₂ concentration under the permitted limits in fully occupied classrooms mechanical ventilation is needed. In our practice sometimes mechanical exhaust ventilation is used with fresh air supply through the fresh air valves, but the contemporary solution is balanced ventilation.

The investment of the first solution is quite low, but maintenance costs are high and sometimes it is difficult to assure the convenient indoor climate (the danger of draught). This kind of solution requires warming up the supply air and usually needs to renovate the heating system.

With high occupation rate in gymnasiums of Tallinn good indoor climate and permitted CO₂ concentration at the end of the class can be gained only with the use of balanced ventilation [10].

It is advisable to use in a classroom displacement or wall confluent [14] ventilation, the latter increasing the efficiency of air change and reducing energy consumption.

The necessary air change should be 7-10 l/s per student [10], depending on the method used for air change.
To achieve good indoor climate and energy savings it is necessary in addition to renovating ventilation also to renovate heating systems – automatic control of heat output of heating coils is necessary.

ACKNOLEDGEMENT

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REFERENCES