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Indoor climate and ventilation in Tallinn school buildings

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Abstract. The results of indoor climate field measurements in nine Tallinn schools are analysed. In classrooms with natural ventilation, carbon dioxide level is very high, until 2 to 3 times higher than the permitted level at the end of the lesson. For having permitted carbon dioxide concentration in classrooms at the end of the lesson, the air change rate from 7 to 10 L/s per pupil is recommended.

Key words: indoor climate, school, carbon dioxide concentration, air change.

1. INTRODUCTION

Indoor air quality in school buildings is influenced by a great number of factors such as air temperature, relative humidity, air velocity, radiant temperature, emission of construction elements, texture of the surfaces, moisture damages etc. [1]. Indoor air quality may be very bad if the level of ventilation is too low. For example, in Finland, before the renovation work the content of carbon dioxide in school buildings ranged between 1200 and 2400 ppm [2]. In the US, in 9 non-complaint schools mid-afternoon CO_2 concentration ranged from about 400 to 5000 ppm [3]. CO_2 concentration exceeded the ASHRAE ventilation standard limit 1000 ppm [4] in 74% of rooms [3]. In Michigan, CO_2 peak levels reached 2700 and 3300 ppm in nonportable and portable classrooms [5].

In Sweden, in 1996 and 1997 it was reported that average indoor air CO_2 concentration in 96 classrooms was 990 ppm and the maximum was 2800 ppm (61% of schools had mechanical supply and exhaust ventilation systems) [3].

In Estonia, indoor climate in school buildings has not been sufficiently investigated, although the actual situation is unsatisfactory. In most school buildings in Tallinn ventilation systems are not renovated. Actually only passive stack ventilation and window airing of classrooms is used in these buildings. At the same time envelope elements have been partly renovated: windows have been changed as a rule and external walls in single cases renovated.

Estonian Standard EVS839:2003 [6] permits carbon dioxide concentration of 1000 ppm for category A, 1250 ppm for category B, 1500 ppm for category C, and indoor temperature in classrooms from 21 to 23 °C for category A, from 20 to 24 °C for category B and from 19 to 25 °C for category C. Relative humidity must be in the range from 25 to 45% and air velocity up to 0.2 m/s in cold season.

According to the regulation of the Estonian Ministry of Social Affairs [7], the permitted maximum carbon dioxide level in classrooms is 1000 ppm, relative humidity 30–70% and indoor temperature 19–25 °C.

According to [8], in school the fresh air supply should be at least 7 L/s per person (during light activity level) and in addition 0.7–2 L/s per m^2 of the gross floor area, depending on the materials used.

PreEN15251 (draft of an EU standard) recommended maximum value of carbon dioxide concentration in CO_2-controlled ventilation systems above the outdoor air concentration 800 ppm for category C, 500 ppm for category B and 350 ppm for category A [9].

Indoor climate is greatly influenced by the effectiveness of ventilation [10,11]. The paper concentrates on indoor climate analysis in school buildings in Tallinn in a cold season. The main object of investigation was carbon dioxide concentration and air change rate in classrooms.

At the same time indoor temperature, relative humidity (in most schools) and air velocity were registered. The duration of the measuring of parameters in classrooms was 40 min.

2. FIELD MEASUREMENTS

Field measurements were carried out in nine school buildings in November, 2005; in seven buildings there was passive stack ventilation and in two buildings renovated supply-exhaust ventilation. Indoor climate measurements were carried out in classrooms full of pupils, with closed windows. The age of the pupils was from 12 to 17 years. Indoor parameters were measured at the centre of the classroom at one point at the height of 1 m (at the height of the head) with two probes. Instruments used for measurements were Testo series 400.

The measurements showed that there were no problems with air velocity in classrooms as in most buildings there was natural ventilation.

In schools with renovated ventilation, indoor climate was satisfactory. For example, in Secondary School No. 21 the relative humidity level was stable at 25%, indoor temperature was 22–23 °C (Fig. 1) and the maximum carbon dioxide level at the end of the class was near to 1000 ppm (Fig. 2). In Mustamäe Gymnasium (Gym) the maximum carbon dioxide level at the end of the class was

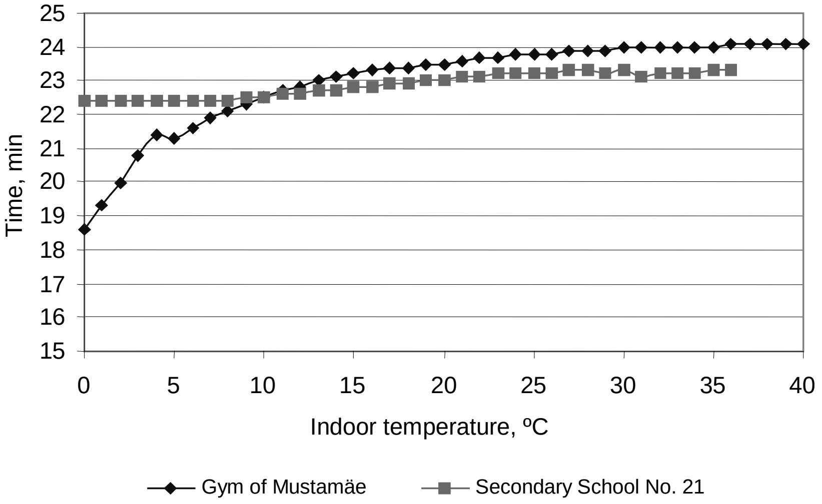

Fig. 1. Dynamics of the indoor temperature in classrooms with balanced ventilation.

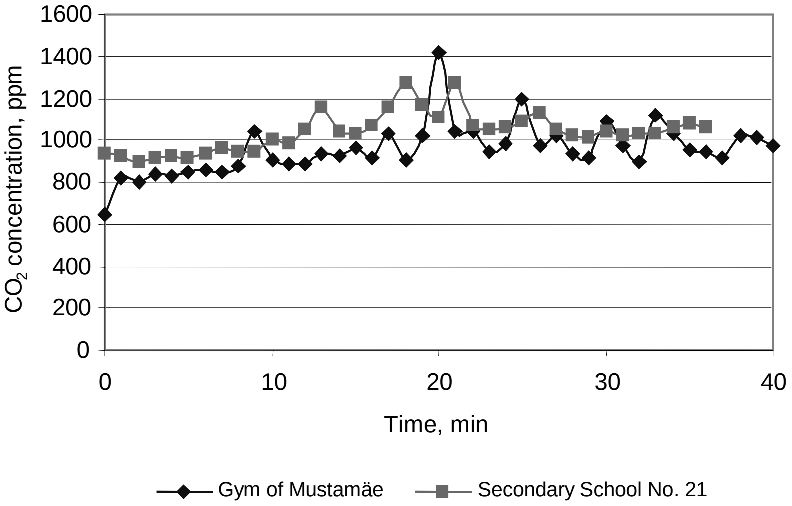

Fig. 2. Change of the carbon dioxide concentration in classrooms with balanced ventilation.

up to 1000 ppm (Fig. 2) and the rise of the indoor temperature was 5 °C (from 19 to 24 °C) (Fig. 1); air change rate in both classrooms was about 7 L/s per pupil.

In schools with passive stack ventilation, the maximum carbon dioxide level at the end of the class was high or very high, up to 3300 ppm (Fig. 3). The rise in indoor temperature was considerable, from 18 to 24 °C (Fig. 4). The level of relative humidity was good (Fig. 5). The parameters of the external air were: temperature approximately 2 °C, relative humidity 45% and carbon dioxide concentration 370 ppm. The decrease of the relative humidity in the German Gym is influenced by a considerable rise in indoor temperature during the class.

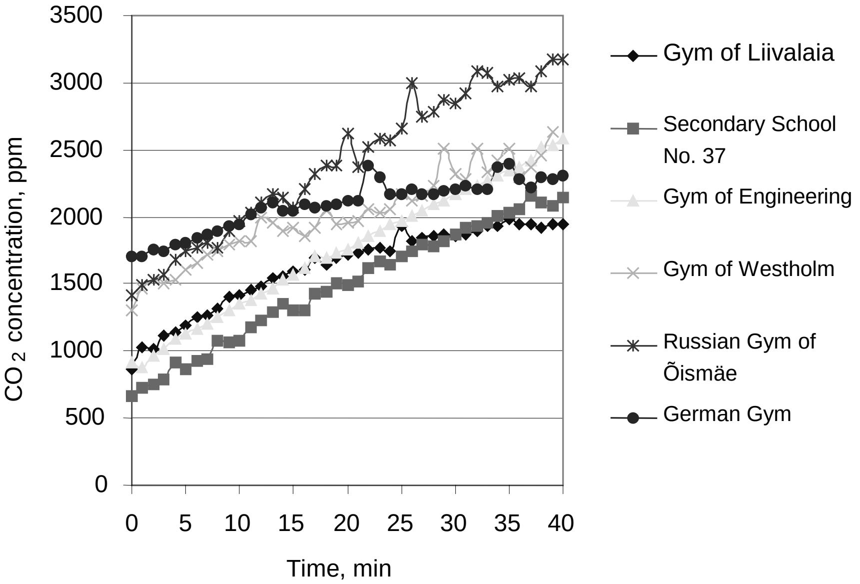

Fig. 3. Change of the carbon dioxide concentration in classrooms with passive stack ventilation.

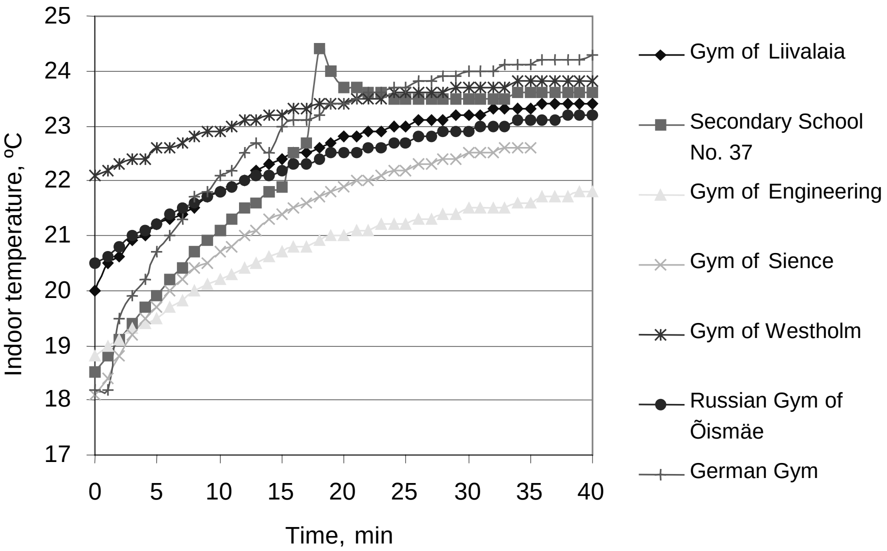

Fig. 4. Dynamics of the indoor temperature in classrooms with passive stack ventilation.

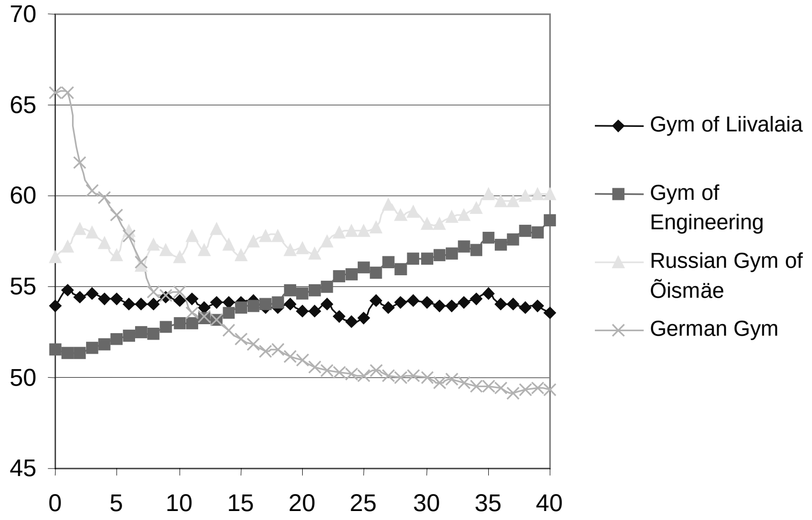

Fig. 5. Relative humidity in classrooms with passive stack ventilation.

3. ANALYSIS OF THE CARBON DIOXIDE CONCENTRATION

3.1. Carbon dioxide concentration in rooms without ventilation

First, the analysis of the classrooms without ventilation was carried out. This method of analysis is suitable for classrooms with relatively low carbon dioxide generation, which is typical for classrooms with a very low number of pupils.

The initial carbon dioxide concentration in classroom is C_0. As the lesson begins, carbon dioxide is generated with an intensity of m. In such a situation, the balance of carbon dioxide at any moment of time τ is expressed as [12]

$$m\,\mathrm{d}\tau - V\,\mathrm{d}C = 0, \tag{1}$$

where V is volume of the room, C is carbon dioxide concentration and τ is time.

By integration of equation (1) we obtain

$$\frac{m}{V}\int_0^{\tau}\mathrm{d}\tau = \int_{C_0}^{C}\mathrm{d}C. \tag{2}$$

From Eq. (2) follows

$$C = C_0 + \frac{m}{V}\tau. \tag{3}$$

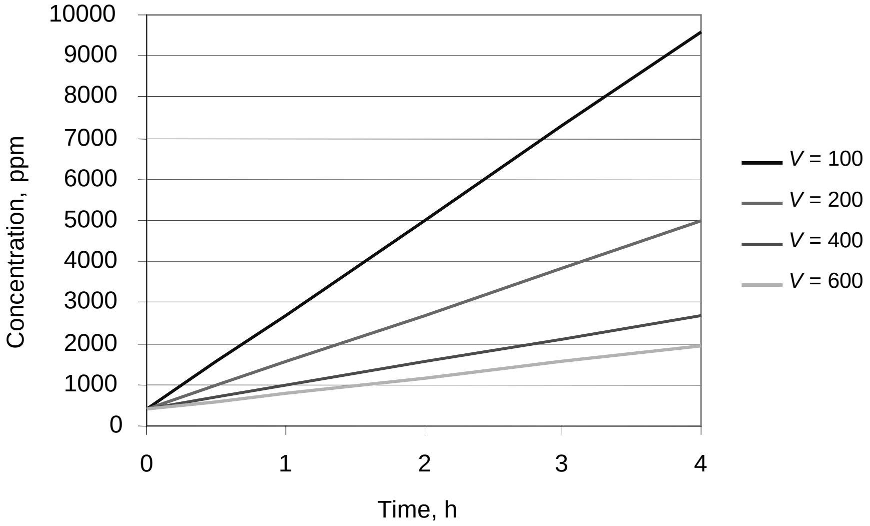

Fig. 6. The rise of carbon dioxide concentration in dependence of the room volume (the number of adult pupils is 10).

In Eq. (3), the concentration of carbon dioxide depends linearly on time. The speed of the rise of the concentration depends on the ratio m/V. Figure 6 shows the rise of carbon dioxide concentration in dependence of the ratio m/V.

The practical situation is more complicated. In spite of renovated windows and passive stack ventilation, ventilation does exist, but its rate in classrooms is very low.

3.2. The carbon dioxide concentration and ventilation

The practical situation in classrooms with passive stack ventilation is different from the preceding. Suppose that initial carbon dioxide concentration in the air of the classroom before the beginning of the lesson is C_0. As the lesson starts, carbon dioxide is generated with the intensity m. Air change rate in the classroom is relatively low. The distribution of temperature in the classroom is uniform (conditions are isothermal), supply and exhaust air flows are equal. Carbon dioxide concentration in inflow air is C_V and in outflow air C (distribution of carbon dioxide in classrooms is uniform).

We can write the balance equation [12]

$$m\mathrm{d}\tau + LC_{\mathrm{V}}\mathrm{d}\tau - LC\mathrm{d}\tau - V\mathrm{d}C = 0. \quad (4)$$

From Eq. (4) follows

$$\mathrm{d}C = -\mathrm{d}\left(\frac{m}{L} + C_v - C\right). \tag{5}$$

By integration of Eq. (4) we obtain

$$\frac{L}{V}\tau = -\ln\frac{\frac{m}{L} + C_v - C}{\frac{m}{L} + C_v - C_0}. \tag{6}$$

From Eq. (6) we can express the basic equation for carbon dioxide concentration C at time moment τ

$$C = C_v + \frac{m}{L} - \left(C_v + \frac{m}{L} - C_0\right) \cdot \left(e^{-\frac{L}{V}\tau}\right). \tag{7}$$

Using Eq. (6) or (7), it is possible to determine air change L in the room. The results of calculation of carbon dioxide concentration in investigated classrooms are presented in Table 1.

Measurement results are shown in Fig. 7.

Measurements carried out in the Secondary School No. 21 and Gym of Mustamäe are in good agreement with calculation results.

We can see that only in buildings with mechanical supply-exhaust ventilation (air change rate about 7 L/s per pupil), the rise in carbon dioxide concentration is moderate and the final carbon dioxide concentration is close to 1000 ppm.

These investigations show that the results of measuring carbon dioxide concentration make it possible to determine approximate air change rate in rooms with passive stack ventilation.

Table 1. Air change rate and the calculated rise of CO_2 concentration in different classrooms

School	Air change rate, L/s per pupil	The rise of CO_2 concentration, ppm
Gym of Mustamäe*	7.3	150
Secondary School No. 21*	6.8	150
Gym of Liivalaia	2.6	1130
Secondary School No. 32	2	1255
Gym of Engineering	2	1710
Secondary School No. 37	1.9	1550
Gym of Science	1.5	1600
Russian Gym of Õismäe	1.2	1925
German Gym**	0.7	810

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* mechanical supply-exhaust ventilation
** language class, number of pupils is 10

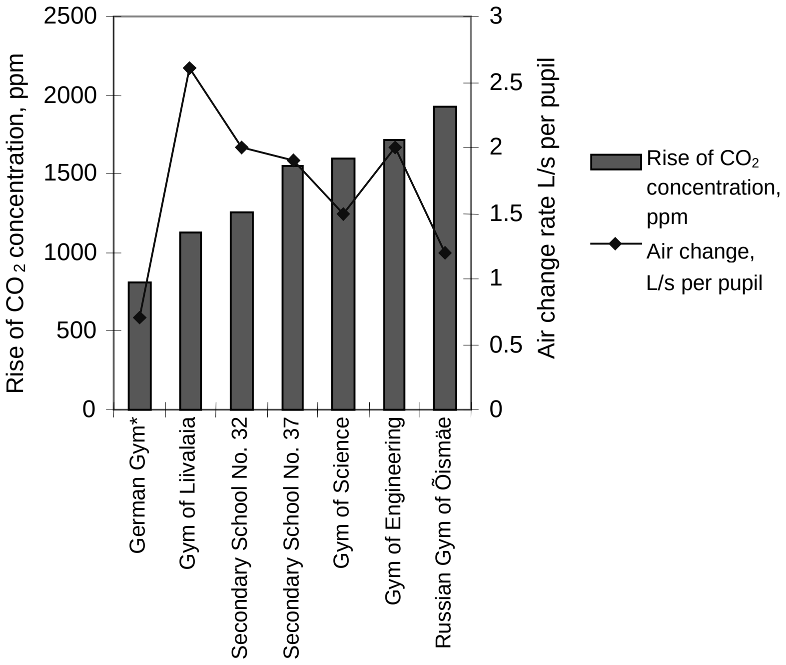

Fig. 7. The rise of carbon dioxide concentration and air change rate per pupil in different classrooms. (The German Gym classroom was only partly filled with pupils.)

4. CONCLUSIONS

In Tallinn schools with passive stack ventilation, the maximum carbon dioxide level at the end of the lesson was high or very high, up to 3300 ppm (Fig. 3). The rise in the level of carbon dioxide concentration depends on the room volume per pupil. The level of carbon dioxide depends on the effectiveness of ventilation.

The results of measuring carbon dioxide concentration makes it possible to determine the approximate air change rate in rooms with passive stack ventilation.

School buildings with non-renovated ventilation systems must be renovated. As renovation needs a lot of resources, until the renovation it is necessary to hold the number of pupils in classrooms as low as possible and to ventilate classrooms intensively during breaks.

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REFERENCES

1. School indoor air quality. Best management practice manual. November 2003. www.doh.wa.gov/ehp/ts/iaq.htm
2. Jalas, J., Karjalainen, K. and Kimari, P. Indoor air and energy economy in school buildings. *Proc. Helthy Buildings*, 2000, **4**, 273–278.
3. Daisey, J. M., Angell, W. J. and Apte, M.G. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air*, 2003, **13**, 53–64.
4. ASHRAE Standard 62-1999. ASHRAE, Atlanta, USA.
5. Godwin, C. and Battermamm, S. Indoor air quality in Michigan schools. *Indoor Air*, 2006, **16**, 459–473.
6. Eesti standard EVS 839:2003. Sisekliima.
7. Resolution of the Estonian Ministry of Social Affairs No. 109, 29.08.2003 on the health protection norms for schools. *RTL*, 2003, 99:1491.
8. Hansen, H. L. and Hansen, S. O. Education, indoor environment and HVAC solutions in school buildings – consequences of differences in paradigm shifts. www.chps.net/info/iaq_papers/PaperVI.3.pdf
9. European Standard prEN 15251, May, 2005.
10. Eesti standard EVS 845-3: 2004. Hoonete ventilatsioon.
11. Spengler, J. P. and Chen, Q. Indoor air quality in designing a helthy building. *Ann. Rev. Energy Environ.*, 2000, **25**, 567–601.
12. Bogoslovski, V. N., Novozhilov, V. I., Simakov, B. D. and Titov, V. P. *Heating and Ventilation. Part II: Ventilation*. Moscow, 1976 (in Russian).

Sisekliima ja õhuvahetus koolihoonetes

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On analüüsitud sisekliima mõõtmistulemusi üheksas Tallinna koolis. On toodud andmed klassiruumide temperatuuri, niiskuse ja süsihappegaasi muutumise kohta tunni jooksul sõltuvalt ventilatsiooni intensiivsusest. Loomuliku õhuvahetusega klassides on süsihappegaasi tase tunni lõpul 2–3 korda lubatust kõrgem. Et tagada süsihappegaasi ettenähtud tase klassides tunni lõpul, on soovitatav kasutada õhuvahetust 7 kuni 10 L/s õpilase kohta.