IMPACT OF CO_2 CONCENTRATION ON INDOOR AIR QUALITY AND CORRELATION WITH RELATIVE HUMIDITY AND INDOOR AIR TEMPERATURE IN SCHOOL BUILDINGS IN SERBIA

by

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Original scientific paper
DOI: 10.2298/TSCI150831173L

Previous studies have shown that poorly ventilated classrooms can have negative impact on the health of children and school staff. In most cases, schools in Serbia are ventilated naturally. Considering their high occupancy, classroom air quality test determines the level of air pollution, after which it is possible to implement corrective measures. The research presented in this study, was conducted in four schools which are located in different areas and have different architecture designs. Measurements in these schools have been performed during the winter (heating season) and spring (non-heating season) and the following results were presented: indoor air temperature, relative humidity, and carbon dioxide concentration. These results show that the classroom average concentration of carbon dioxide often exceeds the value of 1500 ppm, during its full occupancy, which indicates inadequate ventilation. Measurement campaigns show that carbon dioxide concentration increased significantly from non-heating to heating season in three of the four schools. Analysis of measurements also determined high correlation between relative humidity and carbon dioxide concentration in all schools in winter season. This fact may constitute a solid basis for the fresh air supply strategy.

Key words: *indoor air quality, schools, carbon dioxide, relative humidity, indoor air temperature, ventilation rate*

Introduction

Indoor air quality (IAQ) became a widely recognized issue that attracts researcher and occupant's attention towards improving the air quality inside schools and other educational buildings [1-10]. The indoor air quality is expressed by the air ventilation rate, or by the CO_2 concentration level above outdoor one, according to current EU and Serbian legislative.

The IAQ can be defined by its impact on human health, comfort and productivity. The IAQ is especially important in schools in order to enhance children's learning ability and their performance [1]. In the period of 24 hours the most of their time children spend in home microenvironment, while in school microenvironment children usually spend 6-8 hours per weekday. Thus, providing good IAQ is very important for their health, learning ability, and productivity. Consequently, good IAQ has a long-term effect on children's future development. Poor IAQ in school buildings can cause health problems with children, who are far

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more sensitive to the effects of air pollution than adults, and can also have negative effects on the school staff [8, 11]. According to recent studies, more than a third of children in Europe suffer from asthma or allergies. Each year, the frequency of respiratory diseases is increasing, especially in central and southeast Europe [12].

The IAQ is under influence of numerous outdoor air pollution sources such as traffic, industrial, construction and combustion activities. Indoor sources such as ventilation equipment, furniture, human factors, and activities (number of pupils in the classroom, class durations, breaks between classes, *etc.*) also greatly influence IAQ. The CO_2 is the common indicator of air quality in buildings including schools [7, 13-17]. Indoor air temperature and humidity are key indicators of occupant's thermal comfort but IAQ is also very important [18]. Thermal insulation of buildings and building's orientation significantly influences indoor air temperature and thermal comfort [19], until indoor air temperature optimization provide possibility for energy saving [20]. High level of relative humidity may cause additional problem in school environment, due to influence on condensation and mould. Mould formation in schools is unhealthy for children and other occupants [21, 22].

The European indoor climate normative adopted in Serbia, SRPS EN15251 [23], takes into account different allowed CO_2 concentrations above the outdoor one. Table 1 presents the CO_2 concentrations and required amount of fresh air per person or per square meter of effective area for different categories of outdoor air, according to SRPS EN 15251 [23].

Table 1. Allowed CO_2 concentrations relative to category of outdoor one and building categories according to required amount of fresh air (SRPS EN 15251:2007)

Category	CO_2 above outdoors, [ppm]	Fresh air per person [l/s per person]	Airflow for building emissions pollutions [$ls^{-1}m^{-2}$]		
			Very low polluting building	Low polluting building	Non-low polluting building
I	350	10	0.50	1.00	2.00
II	500	7	0.35	0.70	1.40
III	800	< 4	0.20	0.40	0.80
IV	> 800	–	–	–	–

Griffiths and Eftekhari [4] demonstrated that the classroom required more than just trickle ventilation in order to maintain levels of CO_2 bellow 1500 ppm. Also they show that teaching staff and pupils usually control the ventilation into the classrooms by the thermal comfort parameters rather than air quality.

Bako-Biro *et al.* [1] showed that learning can be affected by the elevated level of indoor air pollutants including CO_2 due to inadequate ventilation encountered in classrooms. There have been many studies in the last few years that evidence high levels of CO_2 in classrooms and low ventilation rate.

The aim of this study, was to compare the IAQ during heating season (HS) and non-heating season (NHS) in selected schools in Serbia. Sampling sites are located in different surroundings, urban (traffic/industrial/residential), and rural. Schools dating from different period of construction (older than 40 years) and different period of reconstruction (ten years ago, more than ten years ago or never). The IAQ was determined by the set of continual CO_2 concentration measurements.

According to Serbian standard [23], II category is recommended for school buildings. In school microenvironment, CO_2 and the relative humidity is greatly produced by children. In mechanically ventilated buildings, the IAQ parameters are under control, while in naturally ventilated schools, higher correlation between CO_2 concentration, relative humidity, and indoor air temperature should be expected. During heating period, in order to maintain constant indoor air temperature, natural ventilation becomes less frequent which implies lower indoor air flow. Thus, investigation of CO_2 and relative humidity correlation is important for the ventilation control, particularly natural one, since the natural ventilation removes air with pollution [24].

Methodology

Sampling site description and measurement period

The object of this paper, is the analysis of CO_2, indoor air temperature (T) and relative humidity (RH) level and their variability, in four elementary schools in Serbia. First three schools were located in urban area and last one is located in rural area.

For all selected schools, two sampling campaigns were performed during one week (working days only, from Monday morning to Friday evening). The first campaign was performed during HS, each school for one week, in the period from December 2011 until February of 2012. The second campaign was performed during NHS in May of 2012. All schools were naturally ventilated. The air could enter and exit the classrooms continuously through doors, windows, cracks, and other openings. The schools are different considering its age, construction, and size. The main parameters of the selected schools are given in tab. 2. Each selected classroom had one external wall, one side is in contact with an internal corridor and the other two walls are in contact with the adjacent classrooms.

Table 2. Details of selected schools

Parameter	School A	School B	School C	School D
Location	Beograd	Zaječar	Bor	Zlot
Monitored classrooms	A1, A2, A3	B1, B2, B3	C1, C2, C3	D1, D2, D3
Classroom area, [m^2]	72, 68, 72	56, 63, 60	60, 60, 60	24, 32, 54
Classroom volume, [m^3]	288, 272, 288	182, 205, 195	210, 210, 210	96, 128, 167
Average occupation, [pupil/classroom]	24, 28, 21	29, 18, 31	20, 28, 16	14,18, 28
Location, [–]	Urban, residential	Urban, traffic	Urban, industry	Rural
School working hours, [h]	8-19	8-20	spring (8-19) winter (8-16)	8-16
Year of construction	1971	1892	1979	1839
Type of window	Aluminum-double glazing	Wood-double glazing	Aluminum-double glazing	Wood-double glazing
Windows area, [m^2]	22, 18, 22	15, 10, 10	14, 14, 14	3, 4.5, 8
Type of floor	Stone or ceramic tiles	Synthetic smooth	Synthetic smooth	Wood or laminate parquetry

Measuring instruments

The CO_2 concentration levels were recorded every ten minutes using the Testo 435 devices, with the precision of 50 ppm, and range of 0-5000 ppm for indoor concentration levels and the Testo 445 device with precision of 50 ppm, and range of 0-10000 ppm for outdoor concentration. The equipment was calibrated at the beginning of each measuring activity. Indoor CO_2 sampling device was located about one meter above the floor, away from doors and windows, thus avoiding possible disturbances by the air stream.

Calculation of air exchange rates

In this study, it is assumed that air in the classrooms is well mixed. The classrooms are naturally ventilated which is common for majority of public buildings in Serbia. Ventilation rates can be calculated using measured indoor and outdoor CO_2 concentration. Single zone assumes complete mixing with specific volume such that air is exchanged with the outdoor environment through one or more of its boundaries. In the absence of filtering mechanisms, volume flow rate processes are described by the mass balance eq. (1):

$$G\mathrm{d}t + QC_v\mathrm{d}t - QC\mathrm{d}t - V\mathrm{d}C = 0 \tag{1}$$

where G is the CO_2 generation in the classroom, Q – the air volume flow rate, V – the room volume, C_v – the CO_2 concentration in outdoor air (in supply air), and C – the CO_2 concentration in the classroom (in exhaust air).

For mechanically ventilated as well as for well mixed naturally ventilated spaces, the mass balance of CO_2 concentration can be expressed as eq. (2) [25, 26]:

$$V\frac{\mathrm{d}C}{\mathrm{d}t} = QC_0 - QC(t) + G(t) \tag{2}$$

In order to estimate the air change with the least possible parameters it is assumed that the classroom is unoccupied, $G = 0$ and Q/V is air exchange rates (AER).

Thus, based on these presumptions AER were calculated using eq. (3) which is the same like tracer gas decay method. This is one of the most commonly used equations for the measurement of the air change rates reported in a great number of studies. In this study, the tracer gas used was CO_2 which is measured by Testo equipment's. Calculation of the average air change rates for each classroom in all schools was done based on attenuation of CO_2 concentration (decay method). This calculation has been performed using eq. (3) in period when the classrooms were empty, doors and windows closed at the end of school day.

$$AER = \frac{1}{t}\ln\left(\frac{C(0) - C_o}{C(t) - C_o}\right) \tag{3}$$

Results and discussion

Rise of CO_2 concentration levels in the classrooms in two schools during the first class is presented in fig. 1. Mean outdoor CO_2 concentration level for school C was 424 ppm in HS and 575 ppm in NHS. Mean outdoor CO_2 concentration level for school D was 524 ppm in HS and 608 ppm in NHS. Indoor CO_2 concentrations above 1000 ppm are generally unacceptable with respect to body odors [7]. Maximum CO_2 concentration level is set to 5000 ppm, while it is recommended that CO_2 level remains below 1000 ppm [27]. Figure 1 show that CO_2 concentration in school D during HS reached 1000 ppm very fast, 10 minutes after first class started, and raised up to 2000 ppm after 45 minutes. The CO_2 concentration exceeded the recommended value of 1000 ppm in both schools. During HS campaign performed in school D, CO_2 concentration of 1000 ppm was exceeded after the first class and daily mean value was about 2000 ppm on each school day. In other cases, value of 1000 ppm was also exceeded, but not during the first class and mean daily values were about 1000 ppm. The reason for very high CO_2 concentration during first class in heating period for school D, can be explained by the fact that children in rural areas arrive at school much earlier before the beginning of the class.

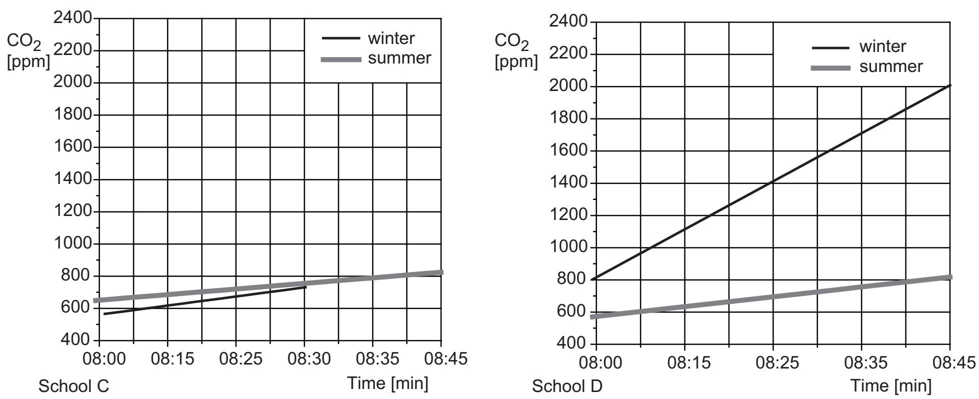

Figure 1. The rise of CO_2 levels during the first class in school C (left) and D (right)

Figures 2 and 3 show a continuous plot of CO_2 concentration in two different Serbian classrooms (B1 and D3) during HS, a similar trend of CO_2 concentration has in NHS. In schools A, B, and C daily level of CO_2 concentration increases from the moment when pupils enter in classroom and reached a peak value at the end of the morning shift. After that CO_2 concentration level decreases during the break, between the shifts, when the classrooms are mostly unoccupied. The CO_2 concentration increases again when the classes in the afternoon shift begins. School D, which is located in rural area, has only one shift which starts at 8:30 a. m. and ends at 2 p. m. When the shift is finished the level of CO_2 concentration aims to equilibrate with the outdoor level of CO_2 concentration.

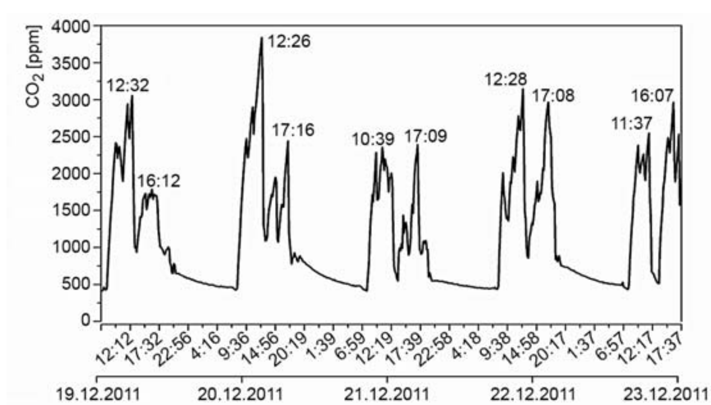

Figure 2. CO_2 concentration in school B, class B1 in HS (two shifts)

In addition to occupancy and indoor activity of occupants the quality of indoor air is conditioned by window opening frequency *i. e.* natural ventilation and outdoor concentration of CO_2. Extremely high and low outdoor temperatures imply lack of natural ventilation, which prevents the flow of fresh air indoors. Table. 3 presents mean and range outdoor air parameters (temperature, relative humidity, and outdoor concentration of CO_2).

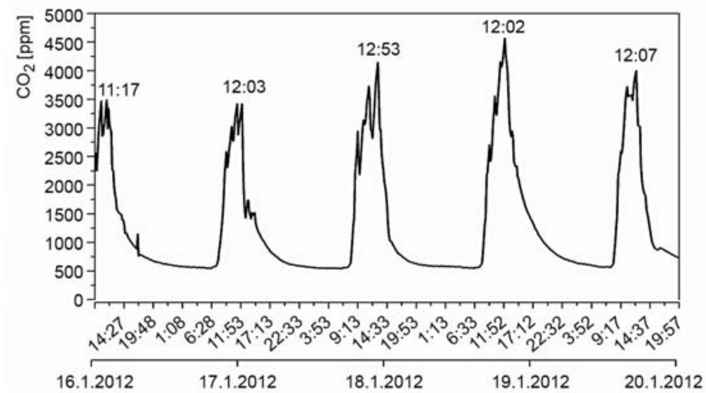

Figure 3. The CO_2 concentration in school D, class D3 in HS (one shift)

Table 3. Mean and range outdoor air parameters during school day

Parameter	Value	Heating season				Non-heating season			
School		A	B	C	D	A	B	C	D
Period		03.2012	12.2011	02.2012	01.2012	05.2012	05.2012	05.2012	05.2012
T, [°C]	Mean	10.0	2.5	-12.4	0.9	23.0	23.7	13.9	19.9
	Range	–1.4-17.1	–3.0-13.0	–17-8.0	–4.7-7.3	3.3-28.5	9.9-35.2	8.4-20.2	14.5-23.2
RH, [%]	Mean	51.1	78.2	74.9	63.5	54.7	43.2	69.2	68.0
	Range	27.7-84.6	56.2-100	64.0-84.7	52.1-96.0	36.9-92.3	22.4-88.3	49.9-90.3	54.6-86.3
CO_2 [ppm]	Mean	844	943	424	524	474	423	575	609

During heating period, the case of school C has extreme values. The lowest measured outdoor temperature (around –17 °C) directly affects window opening frequency *i. e.* natural ventilation. On the other hand, its mean measured concentration of outdoor CO_2 has the lowest value (424 ppm) compering the other three cases. All these parameters affect indoor air quality and they will be addressed in further analysis.

Table 4 presents mean values of CO_2 concentration, relative humidity, and indoor air temperature in classrooms during the schooldays in all schools for heating season. The mean values of parameters are based on the recorded ten minute values for the whole school day including break. According to the requirements notified in standard EN 15251 [23], the mean indoor/outdoor ratio value for all classrooms during the sampling period of the HS, at schools A and B were classified in the I, at school C in the III, and school D in the IV category.

Table 5 presents CO_2 concentration, relative humidity, and indoor air temperature mean values in classrooms during the sampling campaign of NHS for all schools. The I category of the mean indoor/outdoor ratio value of NHS was achieved in schools A, B, and C. The IV category was achieved in school D during both HS and NHS.

Building Bulletin 101 [27] specifies that the minimum supply of external air should be at least 3 l/s per person in all teaching and learning spaces during their occupancy. During

Table 4. Mean concentrations of CO_2 [ppm], relative humidity *RH* [%], and indoor air temperature *T* [°C] for HS, measured over the school day in the classrooms

School and classroom	Monday			Tuesday			Wednesday			Thursday			Friday		
	CO_2	*RH*	*T*	CO_2	*RH*	*T*	CO_2	*RH*	*T*	CO_2	*RH*	*T*	CO_2	*RH*	*T*
A class A1	1374.0	33.9	20.4	1625.5	39.5	21.3	1120.1	42.0	20.5	1246.3	38.2	21.5	695.6	30.8	21.3
A class A2	1095.2	30.3	20.3	1095.2	34.9	20.5	1259.0	40.6	21.8	1032.5	36.1	21.7	738.6	31.2	21.6
A class A3	1099.2	29.9	21.1	1147.2	33.3	21.6	1363.0	39.2	22.7	994.4	27.6	25.8	831.7	24.8	25.8
B class B1	1632.5	41.9	21.4	1770.6	47.3	21.5	1378.5	35.6	20.6	1733.7	40.7	20.9	1529.1	35.6	21.3
B class B2	940.0	31.0	21.6	898.2	34.6	20.7	997.3	27.7	20.2	972.2	28.8	21.2	836.6	26.6	20.8
B class B3	1139.0	32.5	22.6	1177.1	41.6	21.0	1189.7	34.8	19.3	1201.8	32.3	21.6	1182.7	31.2	22.0
C class C1	1112.0	30.4	16.3	1092.6	28.6	15.7	1210.5	29.0	16.6	1053.4	28.0	14.5	1109.7	30.9	14.6
C class C2	1234.9	30.7	18.5	1261.1	28.1	17.9	1224.3	27.8	17.8	1334.1	30.5	15.9	1255.3	31.8	15.3
C class C3	863.6	25.8	18.2	983.9	25.5	18.6	916.6	24.6	18.1	908.2	27.3	15.3	990.4	30.6	15.3
D class D1	1475.1	43.2	15.5	1606.2	44.4	15.4	1919.8	48.2	16.9	1605.5	44.7	17.2	1427.5	49.4	18.0
D class D2	2197.6	52.3	16.4	2007.3	47.8	17.4	2771.0	52.6	18.7	2771.0	52.6	18.7	2543.1	51.9	18.9
D class D3	2130.5	45.1	15.5	2011.4	44.5	16.0	2416.6	46.8	17.9	2754.0	48.9	18.7	2302.9	49.1	19.7

Table 5. Mean concentrations of CO_2 [ppm], humidity *RH* [%], and indoor air temperature *T* [°C] for NHS, measured over the school day in the classrooms

School and classroom	Monday			Tuesday			Wednesday			Thursday			Friday		
	CO_2	*RH*	*T*	CO_2	*RH*	*T*	CO_2	*RH*	*T*	CO_2	*RH*	*T*	CO_2	*RH*	*T*
A class A1	973.4	54.3	22.3	1112.7	62.6	22.2	719.0	60.0	22.9	535.8	54.5	23.8	525.3	54.7	24.5
A class A2	1102.1	54.4	22.8	995.3	58.1	22.7	958.9	57.5	23.7	588.6	52.2	24.8	603.3	52.4	25.6
A class A3	606.5	51.6	22.0	727.3	58.7	22.1	788.7	60.5	22.8	576.8	55.2	24.1	477.9	52.0	25.8
B class B1	802.3	38.6	28.0	931.9	39.1	28.2	585.0	39.2	24.7	976.2	50.3	25.2	903.7	45.0	26.1
B class B2	641.8	43.0	25.9	575.8	41.6	25.0	623.0	38.6	25.5	641.7	47.9	24.9	649.0	44.8	26.4
B class B3	916.7	47.0	24.9	664.2	45.3	23.7	776.8	42.3	24.3	776.7	51.5	24.2	762.3	46.0	26.5
C class C1	938.6	52.8	21.2	1089.8	62.3	20.1	1015.9	59.3	20.3	961.2	53.5	20.2	1121.5	56.9	19.2
C class C2	1503.8	57.3	21.7	1559.9	61.8	20.9	1135.0	57.0	20.6	924.9	49.6	20.1	922.6	55.6	18.6
C class C3	1025.8	49.9	22.7	1111.5	58.3	20.9	1206.8	58.8	20.7	923.6	52.5	19.9	1129.4	57.1	19.0
D class D1	1614.2	64.6	22.3	1929.1	70.3	22.3	2181.9	73.0	22.1	1286.6	68.3	22.2	1201.5	71.1	21.9
D class D2	n/a	74.6	21.0	1416.1	76.0	20.6	1406.5	75.7	20.8	1453.4	75.3	20.6	2700.9	80.6	21.3
D class D3	1026.9	62.8	22.4	1260.7	72.3	22.0	1014.3	73.1	21.0	978.9	64.4	23.5	978.9	64.4	23.5

the HS mean air change rates in schools C and D were mostly lower than recommended, which points out that ventilation is inadequate, tab. 6. Furthermore, a ventilation rate of 8 l/s per person for common number of occupants should be achievable at any time and in that case

CO_2 concentration level will generally remain below 1000 ppm. However, this study shows that the average level of CO_2 in the classroom often exceed the recommended level of 1000 ppm during the class. The ventilation rates are:
– under requirements in school A and B in both seasons,
– below the minimum requirements of 3 l/s per person during HS for school C, and
– below the minimum requirements in both seasons for school D.

Low ventilation rate and high CO_2 concentration in old school buildings can be connected to the wood/coal burning stove used for heating, which leads to the generation of CO_2 during the combustion process. Similar observations have given Ghita and Catalina [28].

Table 6. Mean air change rate for different seasons in l/s per person

Classroom	School A		School B		School C		School D	
	HS	NHS	HS	NHS	HS	NHS	HS	NHS
Class 1	8.34	10.90	4.62	4.11	2.95	7.70	1.51	1.90
Class 2	8.68	7.25	6.42	5.07	1.50	2.78	1.85	1.62
Class 3	13.36	9.61	8.43	3.36	3.43	5.21	1.06	6.00

The correlation between CO_2 concentration with relative humidity and indoor air temperature was calculated only for period when classrooms are occupied. In each school, mean outdoor air temperature during heating period was between –12.4 °C (January-February) and +10 °C (March). During non-heating between +13.9 °C and +23.7 °C (May), (tab. 3). Daily mean indoor air temperatures during HS were between 14.5 °C and 25.8 °C, while they varied between 18.6 °C and 28.2 °C during NHS, shown in tabs. 4 and 5.

In the naturally ventilated schools many indoor air parameters depend significantly on outdoor air conditions, mostly on temperature. Relative humidity is much lower inside than outside the classrooms during HS. When the outdoor air temperature is high enough, windows are usually open which implies small difference between indoor and outdoor humidity. In HS, when the outdoor air temperature is low, windows are usually open only during breaks. Apart from that, windows remain closed and occupant's contribution to higher level of CO_2 and *RH* occurs as the consequence of exhalation. On the other hand, central heating system directly lowers level of *RH* in classrooms.

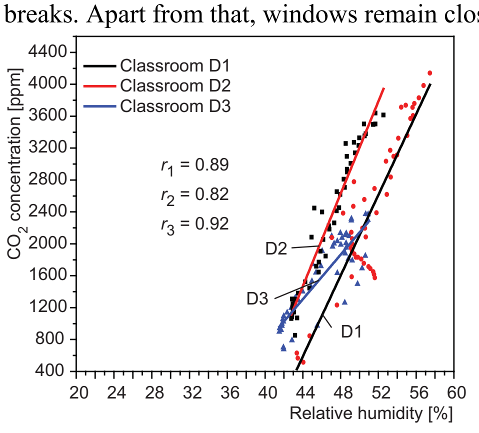

Figure 4. Correlation coefficient (*r*) between mean values of *RH* and CO_2 during five school days for classrooms in school D

The correlation coefficient (r) between CO_2 and *RH* was calculated for each classroom during weekdays when the air quality parameters were collected. The correlation coefficients were calculated for HS, as it is higher than for non-heating period. In school D, the highest CO_2 and *RH* correlation coefficient between 0.80-0.95 has been noted (figs. 4 and 5). The other three schools have the correlation coefficient between 0.62-0.95.

The correlation coefficients between indoor air parameters were calculated for each classroom during schooldays. It was identified as significant for heating season. The correlation between CO_2 and relative humidity is important for the ventilation control, particularly natural one. The results are shown in tab. 7. In school D accumulation of CO_2 and *RH* is bigger than in other schools due to lower air change rate. Humidity reduction decreases CO_2 in the classroom, but this assumption can significantly affect central heating. The central heating caused dry air, as it can be seen in tabs. 3 and 4 for a given school. This fact shows us that ventilation should be controlled by CO_2 sensors, because their work is not interfered by other factors except students and teachers who are the only source of CO_2 in this case.

In the oldest school, D, with the highest correlation coefficient between CO_2 concentration and *RH*, similarly very high correlation between CO_2 concentration and indoor air temperature was identified. In schools A and B, with the highest ventilation rate, correlation coefficient between CO_2 concentration and indoor air temperature was notified as the smallest (fig. 6).

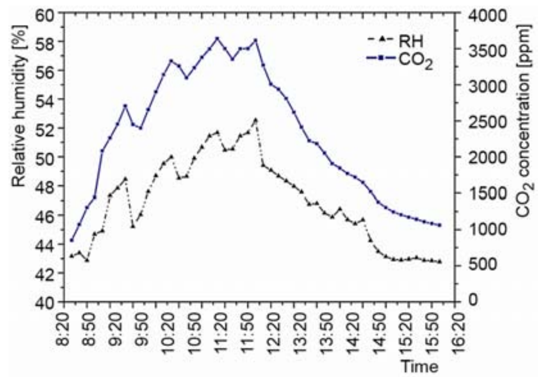

Figure 5. Values of relative humidity and CO_2 during occupied period in school D during HS

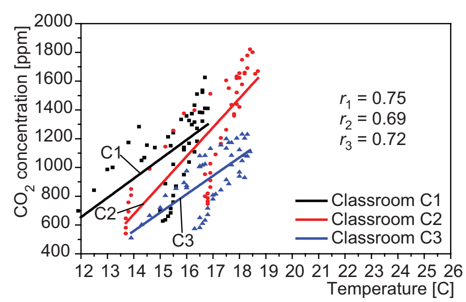

Figure 6. Correlation coefficient (*r*) between mean values of air and CO_2 during five school days for classrooms in school C

Table 7. Correlation coefficients between *RH*-CO_2 and *T*-CO_2 in the investigated schools for HS

School	Class	*RH*-CO_2		*T*-CO_2	
		Equation	Correlation coef.	Equation	Correlation coef.
A	1	122.37x-2702.58	0.81	837.32x-5534.3	0.67
	2	75.86x-1584.09	0.78	234.8x-3932.5	0.74
	3	93.28x-2229.69	0.77	98.54x-1219.3	0.29
B	1	49x-511.26	0.83	190.9x-2859.6	0.73
	2	77.53x-1276.12	0.63	206x-3376.3	0.69
	3	68.88x-1064.69	0.77	70.8x-328.3	0.52
C	1	86.1x-1378.52	0.80	134.3x-957.2	0.75
	2	108.67x-1967.4	0.77	201.3x-2143.3	0.69
	3	71.23x-972.79	0.82	127.6x-1228.2	0.72
D	1	139.48x-4831.66	0.89	539.9x-7368.4	0.87
	2	253.08x-10547.7	0.82	746.7x-11020.3	0.84
	3	289.59x-11272.5	0.92	819.2x-12124.6	0.93

Conclusions

The CO_2 concentration in school classrooms greatly contributes to IAQ. In the naturally ventilated schools low IAQ appears to be a problem not only in the older, but also in newly constructed buildings.

The objective of this study, was to compare the IAQ during HS and NHS, diurnal variations and investigation of CO_2 and relative humidity correlation as an important parameter for the ventilation control in selected schools in Serbia. The indoor and outdoor measurements were performed during five working days in each school, using Testo devices for measuring CO_2, *T,* and *RH*. The increased CO_2 concentrations during school day and their correlation with *RH*, indicate that inadequate ventilation has very bad impact on IAQ.

Results obtained in this study confirm that the variability of CO_2 concentrations during HS and NHS are caused by the dissimilar ventilation practices in different part of year. During warm, NHS, the indoor CO_2 concentrations are strongly influenced by the outdoor CO_2 concentrations due to increased ventilation rates, as well as the fact that windows are opened more frequently than in heating period. During cold period of year, CO_2 concentrations in classrooms are under influence of the number of occupants and their activity as well as ventilation practice. This research also has shown that the correlation between CO_2 concentration with relative humidity and indoor air temperature may be indicator of fresh air supply strategy.

The study also pointed out:

- the breaks between classes are too short (between 5 and 20 minutes) to allow the CO_2 concentration to drop enough to reach the outdoor level,
- pupils who remain inside the classrooms during breaks contribute to further increase of CO_2 concentration. Furthermore, CO_2 concentration increase can be rapid when physical activity of children is much higher, as it is during break, in comparison of the scenario during the class when physical activity is minimal,
- the main reason for high CO_2 concentration level in the classrooms and low air exchange rates in naturally ventilated schools is inadequate ventilation, number and duration of periods when windows are open,
- correlation between CO_2 concentration and relative humidity indicates possibility of the same origin for both parameters, and
- the results of the current study also show the need for a management strategy for monitoring of CO_2 concentration level and AER in the school buildings.

Acknowledgment

The sampling program and basic analyses of this research was carried out in the scope of the "SINPHONIE – Schools Indoor Pollution and Health: Observatory Network in Europe" project (2010-2012). The further analyses were produced under project III42008 (2010-2015) which is financed by the Ministry of Education, Science and Technological Development of Serbia**.**

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Paper submitted: August 31, 2015
Paper revised: October 10, 2015
Paper accepted: October 15, 2015