Energy 77 (2014) 290–296

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Indoor CO_2 measurements in Serbian schools and ventilation rate calculation

Valentina Turanjanin*, Biljana Vučićević, Marina Jovanović, Nikola Mirkov, Ivan Lazović

Vinča Institute for Nuclear Sciences, University of Belgrade, Serbia

ARTICLE INFO

Article history:
Received 24 December 2013
Received in revised form
6 October 2014
Accepted 9 October 2014
Available online 1 November 2014

Keywords:
Ventilation rate
Schools
Carbon dioxide
IAQ (indoor air quality)

ABSTRACT

The indoor air quality in schools is very important for health and learning abilities of children. The primary indoor CO_2 source in classrooms is the respiration of school building occupants. Also, CO_2 comes from outside as a result of fossil fuels combustion. CO_2 concentration depends on a ventilation rate, size of the classroom, number of occupants and their activity and time they spend in school building. Unfortunately, ventilation rates in schools were not often measured, even in cases when inadequate ventilation caused pupils' health problems and their absence from school. The increase in indoor CO_2 concentration above the outdoor concentration is considered as a good surrogate for the indoor concentrations of bio effluents. This paper presents the research of ventilation rates in five naturally ventilated schools in urban and rural areas in Serbia during the heating season. CO_2 concentrations were measured outdoor and in three classrooms for five working days, continually. Ventilation rates are calculated based on measured concentrations of CO_2. The results have shown that classrooms in Serbian schools have inadequate ventilation during the heating period. Mean value of carbon dioxide concentration has often been exceeding 1000 ppm.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Numerous studies, related to indoor air quality in non-residential and non-industrial buildings (offices, schools, etc.), were performed in Europe, America and Asia in last decades. They have mostly indicated presence of symptoms that are generally referred to the SBS (sick building syndrome) symptoms characterized by World Health Organization as: eye, nose and throat irritation, a sensation of dry mucous membranes and skin, mental fatigue, difficulty in concentration, headache, nausea and dizziness, difficulty in breathing and tight chest, stuffy, blocked and runny nose, etc. Till 1999, twenty studies (with close to 30,000 subjects), investigated the correlation of ventilation rates with human responses, and 21 studies (with over 30,000 subjects), investigated the carbon dioxide concentration connection with these responses. They found out that ventilation rates below 10 l/s per person can enhance the appearance of SBS, and increase in ventilation rate up to 20 l/s per person can significantly decrease appearance of the symptoms. On the other hand, carbon dioxide studies have supported these with findings that carbon dioxide concentrations below 800 ppm can repress sick building syndrome [1].

Indoor air quality in teaching areas can significantly affect students' activities, especially in classes with small children age from 7 to 10 since their bodies are still developing. This age group is very susceptible to respiratory infections typically reported as SBS symptoms resulting in frequent absence from school [2,3]. In addition, their learning performance depends primarily on the mental concentration which is directly related to the fresh air level in the classroom.

During their stay in school, children are exposed to many indoor air pollutants generated from indoor sources and to air pollutants that enter the building with outdoor air. Although CO_2 itself is not an indoor air pollutant and health is affected by other contaminants, increased CO_2 concentration is an indicator of insufficient ventilation. The outdoor concentration of carbon dioxide can vary from 350 to 400 ppm [4] or higher in areas with high traffic or industrial activity. The primary indoor source of CO_2 is respiration of the students whereas the level of indoor CO_2 also depends on: the number of occupants, how long the classroom has been occupied, the entering amount of outdoor fresh air, the size of the classroom and the outdoor CO_2 concentration.

Concentration of other indoor generated pollutants, especially human bio effluents, can be roughly correlated with the difference

* Corresponding author. Laboratory for Thermal Engineering and Energy, P.O. Box 522, Belgrade 11001, Serbia. Tel.: +381 11 3408 250; fax: +381 11 2453 670.
E-mail addresses: valentin@vinca.rs (V. Turanjanin), bee@vinca.rs (B. Vučićević).

http://dx.doi.org/10.1016/j.energy.2014.10.028
0360-5442/© 2014 Elsevier Ltd. All rights reserved.

between the indoor and outdoor CO_2 concentrations in the air [5]. The high level of CO_2 concentration points to insufficient ventilation of indoor space. The level of indoor CO_2 has become widely used as an indicator of indoor air quality and surrogate for the ventilation rate measuring with relatively inexpensive real-time digital air monitoring equipment for carbon-dioxide concentration measurement. Also, CO_2 is used as an indicator of ventilation control optimization for different occupancy schedules [6]. Mean value of indoor CO_2 concentration [7] is used for evaluating the quality of ventilation. It has been concluded that the improvement of mechanical ventilation rate can directly contributes to the quick dilution of indoor air pollutants and non-uniformity of indoor pollutant distributions increase with the mechanical ventilation rate.

There is a widespread use of mechanical ventilation in the world, especially in the public buildings. Initially, the most important thing is to know the infiltration process, in order to reduce energy consumption. Reduction of energy consumption, on the other hand, may lead to significant deterioration of the indoor air quality. In order to minimize the energy along with maintaining the corresponding IAQ (indoor air quality) within a user-defined range, usually is developing optimization model [8]. The ecological aspect has become very important, so there is a need to take maximum advantage of the possibilities of natural ventilation [9].

By the ASHRAE standard, the lowest minimum of ventilation rate is 8 l/s per person and recommended ventilation rate is 10 l/s [10]. Human producing carbon-dioxide rate varies mainly with the duration and intensity of physical activity. For the sedentary activity (in offices, schools, dwellings, laboratories) metabolic rate is 1.2 [11] and corresponds to carbon-dioxide production of 0.3 l/s per person (Appendix C of Standard 62). Based on mass balance calculations and the assumption that outdoor CO_2 concentration is 400 ppm, this corresponds to a steady-state indoor concentration of approximately 900 ppm [12].

Indoor air quality research, conducted in 156 schools in Washington and Idaho during the period 2000–2001, has shown that a significant number of schools have ventilation deficiencies. They found out that 42% of regular and 66% of portable classrooms under investigation had CO_2 levels above 1000 ppm regardless of whether they had or didn't have mechanical ventilation system [13]. In 2006, research of IAQ in 10 old and 10 new classrooms in University of Tianjin in China has been performed beside dormitories, reading rooms and conference rooms. Temperature, RH (relative humidity), and CO_2 concentrations were continuously monitored for 12 h in each room, and out of the buildings simultaneously. Using decay method, AERs were derived from CO_2 concentration decay curves obtained when rooms were unoccupied. They found average air exchange rates in classrooms between 1.1 and 1.6 h^{-1} [14]. In Greece, they were investigated air flow and the associated indoor carbon dioxide concentrations in 62 classrooms of 27 naturally ventilated schools in Athens. They found that a flow rate was higher in only 23% of measured classrooms, than the recommended value of 8 l/p/s (which correspond to about 1000 ppm of CO_2 concentration), during the teaching period. About 52% of the presented classrooms had average indoor CO_2 concentration higher than 1000 ppm [15].

In Serbia, this kind of research has not been conducted before and therefore it is of great importance.

2. Method

Ventilation rates can be calculated from indoor and outdoor carbon dioxide measurements based on fact that ventilation is the only significant process for carbon dioxide removal. In naturally ventilated schools carbon-dioxide in a classroom comes with outdoor air and depends on environment. From the other side, it can be generated indoor by occupants' exhalation and strength of that source is based on the number of occupants and their activity. Taking into account that classrooms are spaces with high occupancy per square meter, indoor carbon dioxide concentration exceed outdoor concentration considerably. With the assumption that inside air is well mixed, the air exchange rates are calculated on the basis of indoor and outdoor carbon-dioxide concentrations by the decay method. The time derivative for indoor concentration of air contaminant in general [16] is given by:

$$V\frac{dC}{dt} = Q\cdot C_o - Q\cdot C(t) + S - k\cdot C(t) \quad (1)$$

Formula (1) is given in general for whichever indoor contaminant. The change in CO_2 concentration dC/dt = inflows − outflows + sources − degradation; C_o, $C(t)$ are outdoor and indoor contaminant concentrations, respectively; Q are air flow into/out of the building; S is the indoor emission source of the contaminant; k is the first-order degradation constant.

For the conservative contaminant such as CO_2, there is no degradation, i.e. $k = 0$. Besides that, if there is no indoor source of CO_2, i.e. $S = 0$, Equation (1) will become much simpler:

$$V\frac{dC}{dt} = Q\cdot (C_o - C(t)) \quad (2)$$

This assumption is valid for the period that starts at the end of the last lesson (when pupils leave the classroom) and ends when the indoor and outdoor concentrations of CO_2 are almost equal. In this case, integration of the Equation (2) will give following formula for the determination of the indoor CO_2 concentration:

$$C(t) = C_o + [C(0) - C_o]\cdot e^{-\frac{Q}{V}t} \quad (3)$$

where $C(0)$ is the indoor CO_2 concentration at time $t = 0$; Q/V is air exchange rate (AER). After rearranging, Equation (3) will give the following:

$$AER = \frac{1}{t}\ln\frac{(C(0) - C_o)}{(C(t) - C_o)} \quad (4)$$

3. Measurements

Indoor air quality is in very high correlation with outdoor air quality and depends on number of indoor (people, furniture, paints, etc.) and outdoor (industry, traffic, combustion, etc.) pollutants' sources emitting pollutants into the atmosphere with different level of intensities. Assuming that the air quality is not the same in rural and urban areas, five locations were chosen for this analysis to cover variety of environments. Monitoring of indoor and outdoor CO_2 concentrations was performed in five primary schools placed at different locations in Serbia during the heating season. One village school was chosen as a representative of rural area, three schools from towns as representatives of small urban areas and one school from the city as a representative of big urban area. The measurements were conducted in three classrooms (three indoor measuring points) and one outdoor measuring point of each school continually for five working days from Monday to Friday (including occupied and unoccupied periods of time). During occupancy, between 20 and 30 pupils, age from 7 to 10, were present in each classroom. Carbon dioxide sensors were placed in the selected classrooms at approximately about 1.1 m above the floor, away from the windows and doors, and at least 1 m from occupants. Measuring range of CO_2 sensors was between (0–10,000) ppm with accuracy of ±2% of reading. The equipment was set to collect values of CO_2 concentration every 10 min at each indoor measuring point. One set of the equipment was placed outdoor to measure outdoor CO_2 concentration at the same time interval as indoor.

Five primary schools, chosen for this analysis, were placed in different environments. Three of five selected schools were placed in the area of Zaječar town (two schools in the town and one in the adjacent village), one school was placed in the Bor town and one in the city of Belgrade. Position of selected places and schools under investigation is shown at Fig. 1.

Schools SCH2 and SCH5 were situated in Zaječar in the center and town suburb, respectively. Measurements were performed in the end of December 2011 and beginning of April 2012. School SCH1 was about ten kilometers from the town, in the rural area, in the Grljan village. Measuring period was the beginning of December 2011. Schools SCH1 and SCH5 were heated by individual coal heating plants and school SCH2 was connected to the district heating system. The Zaječar town was located in the eastern part of Serbia, in the continental climate zone with hot, dry summers and moderately cold winters. January and February were the coldest months and July was the warmest. The area of the town and its surroundings was windy (mainly northeast wind direction) and occasionally winds were coming from the direction of Carpathians and Stara Planina. The town was developed mainly as agricultural center with some food and metal processing industry. It was populated by around 44,000 inhabitants, and the district heating was poorly represented (with less than 20%). During the heating season, most of households in the town and each household in the village were heated by the individual heating stoves burning wood and coal as a fuel.

School SCH3 was situated in Bor town. This town was placed in the same climate zone as Zaječar town but it was mainly developed as an industrial town with the same population size as Zaječar, but the difference was in percentage of households connected to district heating system. The main feature of the Bor town housing stock was that it has mainly consisted of buildings, rather than individual houses. The number of district heating users was high, and consequently the number of individual heating plants was small. The measurements were conducted in the end of January and beginning of February of 2012.

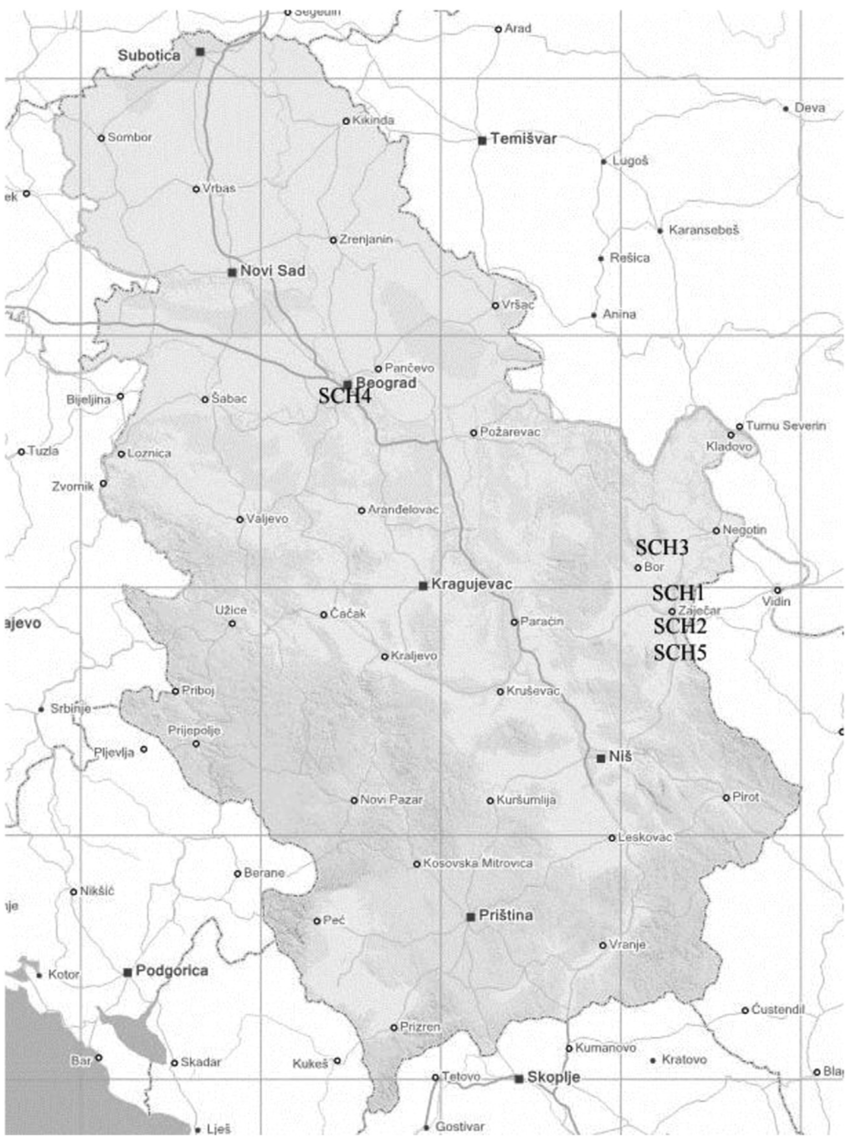

Fig. 1. Position of schools under investigation.

School SCH4 was situated in the city of Belgrade, in the area with buildings mostly connected to district heating system and measurements were done in March 2012. The Belgrade city was situated in the northern part of the country at the mouth of two big rivers Sava and Danube in the moderate continental climate with four seasons. Autumn is longer than spring, with long sunny and warm periods. Characteristic of Belgrade climate is southeast wind which brings clear and dry weather. It mostly blows in autumn and winter, usually lasting 2–3 days with average speed of 25–43 km/h. Sometimes wind strokes can reach up to 130 km/h. The wind is identified as the largest air cleaner of Belgrade.

4. Results

Fig. 2 presents a continuous plot of indoor CO_2 concentration (in ppm) in the classroom II (SCH3) and outdoor CO_2 concentration during the five day measuring campaign performed in the heating season. From the moment when pupils enter the classroom in the morning (at about 8 h), CO_2 concentration level increases and reaches the peak at the end of the morning shift. Between two shifts, when the classroom is mostly unoccupied, the level of CO_2 concentration decreases and starts to grow again at a beginning of the afternoon shift (at about 14 h). After the end of the second shift, the concentration wanes and reaches the minimum during the night as a consequence of tendency to equilibrate outdoor CO_2 level.

Fig. 3 presents a continuous plot of indoor CO_2 concentration in the class I in the village school SCH1. For all selected schools, character of the graphs representing the CO_2 concentration is more or less similar. There is obvious difference in numbers of peaks at Figs. 2 and 3. One peak corresponds to the case when classes are conducted only in one shift during the day, and two peaks to the case with two shifts (morning and afternoon).

Among classes, there are differences only in the maximum and minimum of measured values. Table 1 shows mean, maximum, and minimum values of CO_2 concentration for each school and each classroom during the period under consideration. Those values originate from the recorded values (10 min sampling time) for working days only which approximately corresponds to the period of time pupils spend in school (from 8 to 12 h for school with one shift; from 8 to 12 h and 14–18 h for schools with two shifts).

Obtained results show that the average values of CO_2 concentration during classroom occupancy mainly exceed 1000 ppm and in some classrooms even 1500 ppm, which indicates inadequate ventilation.

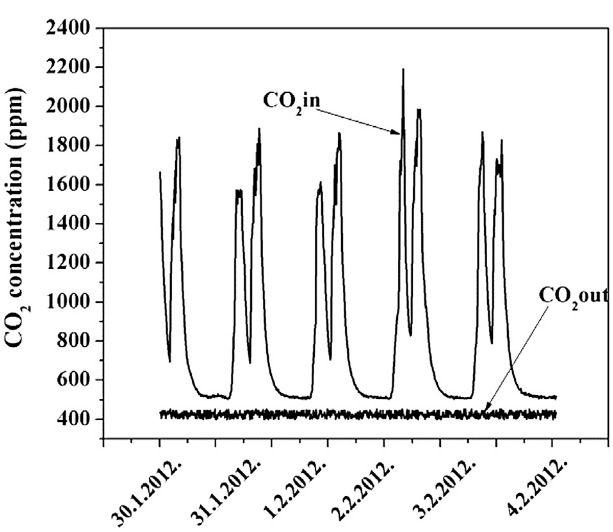

Fig. 2. CO_2 concentration (SCH3, class II, two shifts).

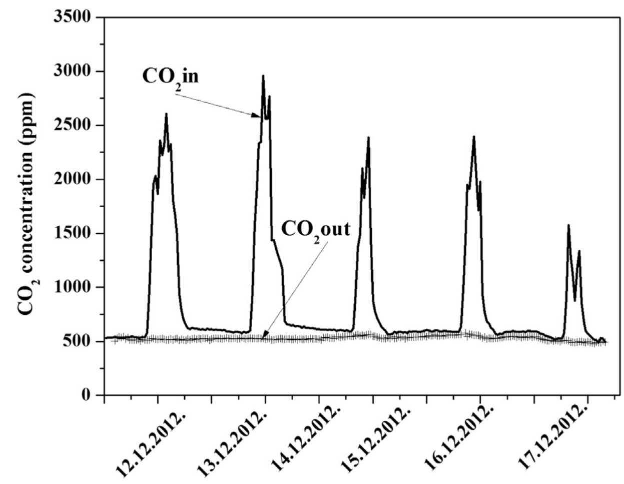

Fig. 3. CO_2 concentration (SCH1, class I, one shift).

Table 1
Concentration of CO_2 in ppm.

School	SCH1	SCH2	SCH3	SCH4	SCH5
	I classroom				
Mean	1727	1242	1182	1150	1167
Min	714	561	472	491	449
Max	2928	2410	1732	2021	2376
	II classroom				
Mean	1628	887	1250	1039	1019
Min	630	536	532	549	420
Max	3045	1606	2190	1775	1604
	III classroom				
Mean	1142	2015	990	1327	1209
Min	535	670	427	601	659
Max	1902	3614	1502	2231	2253

Based on the European standard EN 15251 (Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics) adopted in Serbia, the quality of the indoor air is put into categories on the basis of difference between indoor and outdoor CO_2 concentrations. There are four categories of indoor air quality shown in Table 2.

Fig. 4 shows measuring values of CO_2 concentration during one day in three different classrooms in school No. 3 (SCH3). Table 4 indicates number of pupils which took part in school activities. Beside the number of students in attendance, the level of CO_2 concentration depends on a classroom position in the school building. The outdoor CO_2 concentration was measured only at one place (suitable for setting up the instrument) so the effect of proximity and intensity of traffic could not be fully noticed. The character of curves is the same in all three classrooms. In the classroom No.1 values were lower than expected. In the period from 9:45 to 10:30 there was a reduction in CO_2 concentration from

Table 2
Recommended CO_2 concentrations above outdoor concentration.

Category	Corresponding CO_2 (ppm)
I	350
II	500
III	800
IV	>800

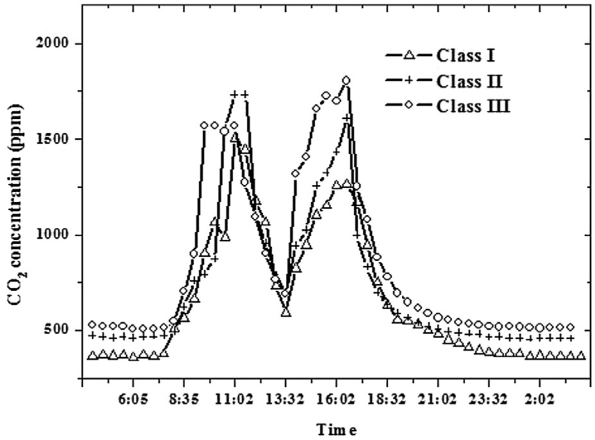

Fig. 4. CO_2 concentration in three classrooms in school SCH3.

1134 ppm to 987 ppm, probably due to temporary absence of children or/and slightly opened classroom windows. Comparing the results from the first and second shift, similar character of graphs could be noticed. The difference in CO_2 concentration intensity among two shifts originates from different students' number of morning and afternoon shift in the same classroom.

Table 3 shows categories of the classrooms' indoor air quality determined from Table 2, difference between average indoor (Table 1) and outdoor CO_2 concentrations. According to Serbian standards, II category is recommended for school buildings and Table 3 shows mostly III and IV category of the air quality.

Values of outdoor CO_2 concentrations show the influence of the dominant heating modes and traffic in the vicinity of schools. SCH3 was located in the center of the Bor town where district heating covers about 60% of the buildings. Despite intense traffic and developed industry, the outdoor CO_2 concentration in Bor was at the same level as in the environment of school SCH5, which was located in the suburb of Zaječar town with reduced transport but with dominant individual heating mode using wood and coal as a fuel. SCH4 was situated in the city of Belgrade, near to the river, protected from traffic by buildings and trees. Values of the outdoor CO_2 concentration were relatively low.

The aim of this paper is calculation of the average AER (air exchange rates) for each classroom in all chosen schools based on attenuation of CO_2 concentration (decay method). This calculation has been performed using equation (4) and measurement data for the unoccupied period (3 h lasting time) in selected classrooms. Fig. 5 shows attenuation of the indoor CO_2 concentration from the time when pupils left the classroom.

Table 3
Classrooms air quality categories.

School	SCH1	SCH2	SCH3	SCH4	SCH5
Out. CO_2 (ppm)	522	460	424	408	420
	I classroom				
Mean	1727	1242	1182	1150	1167
Diff.	1205	782	758	742	747
Category	IV	III	III	III	III
	II classroom				
Mean	1628	887	1250	1039	1019
Diff.	1106	427	826	631	599
Category	IV	II	IV	III	III
	III classroom				
Mean	1142	2015	990	1327	1209
Diff.	620	1555	566	919	789
Category	III	IV	III	IV	III

Volume of the observed classrooms, average numbers of occupants (only for the first shift) for the period taken into consideration, calculated value of AER and ventilation rate are presented in Table 4. Air exchange rate values are in the range of $0.475 \div 1.451$ h^{-1} for all schools. School No. 4 (SCH4) placed in Belgrade (windows partly replaced) has the lowest values of AER ($0.47 \div 0.66$ h^{-1}) and the highest values of AER ($1.32 \div 1.45$ h^{-1}) are calculated for the village school (SCH1) without any envelope renovation. Anyway, those values are very small in comparison with recommended values for school classrooms from $4 \div 10$ h^{-1} [17].

Consequently, ventilation rates are also small from $0.826 \div 4.146$ l/s per person. Taking into account the number of students in attendance, it can be noticed that ventilation rate values can vary considerably in the same school with similar patterns of window opening. For example: SCH2 in the classroom I (volume 182 m^3, 29 pupils, VR 0.826) and in the classroom II (volume 205 m^3, 18 pupils, VR 3.208). In order to establish IAQ in schools, there is a need for more detailed studies of each school. It is necessary to analyze in details the situation in every classroom, taking into account the number of students and the type of their activities together with condition of the building envelope.

5. Discussion

School buildings under consideration have poor energy performance. They are all age of about 40 with necessity of complete building envelope reconstruction (walls' insulation and windows' replacement). In all schools, average value of CO_2 concentration exceeds acceptable 1000 ppm, and a maximum value of 1500 ppm, which indicates the need for classroom ventilation improvement. Even if there are mechanical ventilation systems, students' and teachers' habits to open and close windows have a great impact on ventilation as it shown in Ref. [18]. During the heating season, windows are opened less frequently than necessary, and sometimes they're not open at all in buildings with poor thermal envelope. This is related to thermal comfort, which has a higher priority than the air quality. Improving the energy performance of the building envelope would allow, not only increase in energy efficiency, but more frequent opening of windows to reduce CO_2 concentration without compromising thermal comfort in classrooms.

One of suitable solutions to reduce CO_2 concentration is trickle ventilation and goes along with windows replacement. The

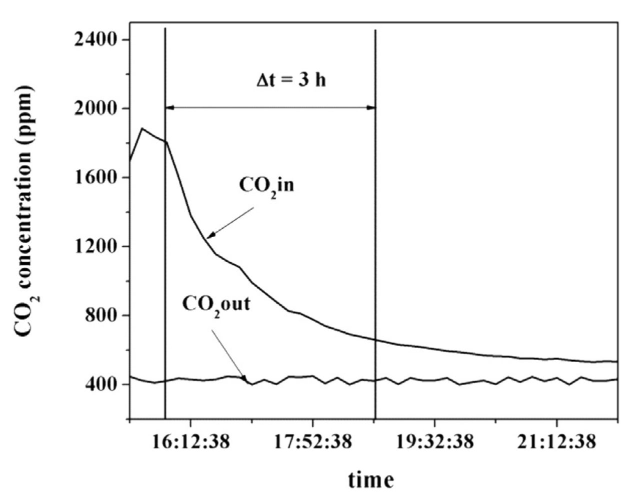

Fig. 5. CO_2 concentration decay in unoccupied period.

Table 4
Calculated values of AER and Ventilation rate in schools.

School	SCH1	SCH2	SCH3	SCH4	SCH5
	I classroom				
Volume (m^3)	216	182	210	288	204
Number of pupils	25	29	20	24	22
AER (1/h)	1.057	0.474	1.142	0.475	0.92
Ventilation rate (l/s per person)	2.537	0.826	3.331	1.583	2.37
	II classroom				
Volume (m^3)	216	205	210	272	204
Number of pupils	22	18	28	28	20
AER (1/h)	1.322	1.014	1.218	0.66	0.584
Ventilation rate (l/s per person)	3.605	3.208	2.538	1.781	1.655
	III classroom				
Volume (m^3)	216	195	210	288	204
Number of pupils	21	31	16	21	19
AER (1/h)	1.451	0.795	0.886	0.64	0.721
Ventilation rate (l/s per person)	4.146	1.389	3.23	2.438	2.15

simplest and cheapest solution is to change behavior introducing an obligation for teachers at every break between classes (from 5 to 20 min) to open windows and increase air exchange in the classroom. Also effective solution is the installation of the sensor with an alarm to be activated at the CO_2 concentrations above 1500 ppm. Due to the high value of the CO_2 concentration, in all schools taken into consideration, the best is to install mechanical ventilation, which would automatically inject fresh air in the classrooms when CO_2 concentration exceeds 1000 ppm.

The highest values of outdoor CO_2 concentration were measured in the surroundings of a village school SCH1. This school was heated by individual heating plant placed in the school building and using coal as a fuel. Nearby houses mostly use coal for heating too, so the initial concentration of CO_2 (before children enter the classroom) is quite high (535–714) ppm. In this school, the highest CO_2 concentrations were measured (1902–3045) ppm. Among all these 5 schools, SCH1 is the only one located in a rural environment with a great production of wheat and maize and consequently large amount of biomass which is now burnt in the fields in order to remove. So it would be very good for local community, and very cost-effective, to replace coal boiler with one using biomass as a fuel. This would significantly reduce the cost of school heating, and also a CO_2 emission in this area. SCH2, SCH3 and SCH4 are connected to district heating system and reduction of CO_2 emission is possible by increasing energy efficiency, i.e. building envelope improvement.

The school SCH2 has obvious influence of the number of students in attendance (Table 4). The average CO_2 concentration in the classroom III (in which 31 students were present) was 2015 ppm and 3614 ppm maximum. In comparison to the classroom I (with the similar ratio of m^3/pupil), the difference in the opening window frequency. This points to solution effectiveness introduced with purge ventilation obligation. The SCH5 have individual heating plant using coal as a fuel. Except building envelope improvement, recommendation is to connect this school to district heating system already available in the Zaječar town. The SCH3 and SCH4 have flat roofs and good potential to install solar thermal collectors to substitute part of energy obtained from district heating system. From one side, all recommended actions will lead to better energy efficiency, and, from the other side to CO_2 reduction in the schools' vicinity.

The issue of air pollution in cities is becoming lately very important in developing world as a result of rapidly expanding mobile population. Generally speaking, indoor air quality has strong dependence of outdoor air quality especially in urban areas with large amount of cars, busses and transportation vehicles. In many developing countries energy consumption from the transport sector has not been investigated in details and consequently the harmful emissions intensities and GHGs produced from the exhaust pipes of these vehicles [19]. Therefore, recent research in this area shows necessity of Driving Cycle establishment in urban areas (characteristics varies from one city to another) in order to understand and reduce vehicle emissions [20,21]. Also, good passenger road transport scenarios, with better mobility and quality of life in the region, based on modal shift from private car trips to a Bus Rapid Transport system can help in achieving lower emissions. Increasing fuel efficiencies and introducing new technologies for vehicle emission controls (vehicles with increased engine efficiency, reduced air resistance, with lightweight design etc.) is important too, beside standardized driving technique, unobstructed traffic conditions, cruising at an optimum speed for the vehicle and the reduction of cold starts [19,22].

6. Conclusion

There is a constant tendency in the world building industry to reduce energy consumption in buildings. All measures taken for energy savings, no matter whether they were undertaken by new or reconstructed buildings, were leading to a reduction of air exchange rates in buildings and consequently affecting the quality of indoor air. Regarding to schools, air quality becomes much important indicator because it affects children's health and their learning ability. Among all methods for determining air exchange rates, there is a way to calculate it based on measured values of indoor and outdoor CO_2 concentrations.

This study was conducted during the heating season in five primary naturally ventilated schools in Serbia situated in rural and urban areas. Measurements of indoor CO_2 concentration are performed in classrooms occupied by children age from 7 to 10.

According to standard EN 15251, preferred values of the ventilation rates for schools are (4 ÷ 10) l/h/person, while values obtained by the measurements are (0.8 ÷ 4.1) l/h/person indicating very poor ventilation. This was confirmed by the measured indoor CO_2 concentrations, which values exceed 1000 ppm over 50% of the time during children are in the classroom. Toward the end of the shift, CO_2 concentration reaches a maximum value, of about 3600 ppm. According to standard EN 15251, the indoor air quality is low and mostly belongs to the III and IV category.

This research has shown that areas with a higher number of households connected to district heating system (Bor and Belgrade), have lower values of the outdoor CO_2 concentration, influencing the indoor air quality in schools.

The main reason of high indoor CO_2 concentration and low indoor air quality is in insufficient ventilation of the classrooms. Temporary solution could be an adoption of recommendations about opening windows in classrooms during breaks with extended periods of time and frequency of opening in order to lower the initial CO_2 concentration at the beginning of each class.

Those results also indicate the need of serious approach to carbon dioxide concentration in schools and studies designed to investigate correlation between CO_2 concentration and age of the pupils, their activities and behavior during their stay in school, and also necessity of developing the management strategy for the ventilation control.

Acknowledgments

This work was carried out within the framework of research projects: (1) FP7-ENV-2010: PURGE-Public health impacts in urban environments of greenhouse gas emissions reduction strategies, Project number: 265325, financed by the EC; (2) Improving the energy performance and the indoor air quality of educational institution buildings in Serbia with the impact on health, Project number: III42008, financed by the Ministry of Education, Science and Technological Development of Serbia. (January 2011–December 2014).

References

[1] Seppänen OA, Fisk WJ, Mendell MJ. Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institutional buildings. Indoor Air 1999;9(4):226–52.
[2] Shendell DG, Prill R, Fisk WJ, Apte MG, Blake D, Faulkner D. Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho. Indoor Air 2004;14(5):333–41.
[3] Daisey JM, Angell WJ, Apte MG. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air 2003;13(1):53–64.
[4] Apte MG, Fisk WJ, Daisey JM. Associations between indoor CO_2 concentrations and sick building syndrome symptoms in U.S. Office buildings: an analysis of the 1994–1996 BASE study data. Indoor Air 2000;10(4):246–57.
[5] Bluyssen PM, De Oliveira Fernandes E, Groes L, Clausen G, Fanger PO, Valbjørn O, et al. European indoor air quality audit project in 56 office buildings. Indoor Air 1996;6(4):221–38.
[6] Kusiak A, Li M. Optimal decision making in ventilation control. Energy 2009;34(11):1835–45.
[7] Wang Y, Zhao F-Y, Kuckelkorn J, Liu D, Liu L-Q, Pan X-C. Cooling energy efficiency and classroom air environment of a school building operated by the heat recovery air conditioning unit. Energy 2014;64(0):991–1001.
[8] Kusiak A, Tang F, Xu G. Multi-objective optimization of HVAC system with an evolutionary computation algorithm. Energy 2011;36(5):2440–9.
[9] Xamán J, Ortiz A, Álvarez G, Chávez Y. Effect of a contaminant source (CO_2) on the air quality in a ventilated room. Energy 2011;36(5):3302–18.
[10] ASHRAE. Ventilation for acceptable indoor air quality. ASHRAE Standard 62–1999. American Society of Heating, Refrigeration and Air conditioning Engineers; 1999.
[11] ISO 7730:1994–Moderate thermal environments – determination of the PMV and PPD indices and specification of the conditions for thermal comfort. 1994.
[12] Kamaruzzaman SN, Razak RA. Measuring indoor air quality performance in Malaysian goverment kindergarten. J Build Perform 2011;2(1):70–9.
[13] Prill R, Blake D, Hales D. School indoor air quality assessment and program impementation. Washington State University; 2012.
[14] You Y, Bai Z, Jia C, Hu X, Ran W, Zhang J, et al. Ventilation conditions and the related symptoms in selected indoor environments in a University. In: The 6th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings IAQVEC; 2007. Sendai, Japan.
[15] Santamouris M, Synnefa A, Asssimakopoulos M, Livada I, Pavlou K, Papaglastra M, et al. Experimental investigation of the air flow and indoor carbon dioxide concentration in classrooms with intermittent natural ventilation. Energy Build 2008;40(10):1833–43.
[16] You Y, Bai Z, Jia C, Wan Z, Ran W, Zhang J. Measuring air exchanges rates using continuous CO_2 sensors. In: 9th REHVA World Congress Clima 2007 "Well-Being Indoors"; 2007. Helsinki, Finland.
[17] EN 15251-indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. CEN European Committee for Standardization; 2007.
[18] Gao J, Wargocki P, Wang Y. Ventilation system type, classroom environmental quality and pupils' perceptions and symptoms. Build Environ 2014;75(0):46–57.
[19] Achour H, Marashly A, Olabi A-G. Assessing energy consumption of the transport sector in Aleppo, SYRIA. J Sustain Manuf Renew Energy 2012;1(3–4):87–102.
[20] Achour H, Olabi AG. Monitoring on road vehicle emissions and its impact on air quality. In: The 6th Internationl Conference on Sustainable Energy & Environmental Protection SEEP 2013; 2013. Maribor, Slovenia.
[21] Achour H, Carton JG, Olabi AG. Estimating vehicle emissions from road transport, case study: Dublin City. Appl Energy 2011;88(5):1957–64.
[22] Chavez-Baeza C, Sheinbaum-Pardo C. Sustainable passenger road transport scenarios to reduce fuel consumption, air pollutants and GHG (greenhouse gas) emissions in the Mexico City Metropolitan Area. Energy 2014;66(0):624–34.