INDOOR AIR QUALITY IN A HIGH SCHOOL CLASSROOM IN RIJEKA, CROATIA (SICK CLASSROOMS CAUSED BY RISING CO_2 LEVELS)

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Abstract: *School's indoor air quality (IAQ) is very important as it can affect student's learning abilities and lead to health issues. Therefore, indoor air quality, and in particular the CO_2 concentration, was monitored on a daily basis from mid-November till the end of December 2017, by using several low-cost instruments. The measuring was performed in the physics classroom of a grammar school in Rijeka, Croatia. Detailed CO_2 generation rates, air exchange rates, and ventilation rates are calculated and reported in this work, from the experimentally obtained data. Very high concentrations of over 4.000 ppm were recorded, indicating that ventilation rates are far below 5 Ls^{-1} per person, which is the lowest recommended value of ventilation rate according to the European standard EN 13779. The experimentally obtained data are compared with the theoretical models and a strong correlation are achieved. This is one of the first comprehensive studies of this kind in Croatia; therefore, we hope that it will stimulate interest between health workers, scientists, and school management to implement indoor air quality monitoring practices and perhaps introduce automated ventilation systems in classrooms for the benefit of students' health and their learning abilities.*

Keywords: *indoor air quality, CO_2 concentrations, ventilation rate, EN13779, classroom.*

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1. INTRODUCTION

Indoor air quality in schools has been a public concern for a number of years, as adverse effects of poor air quality have far-reaching effects on children's and students' health. It is estimated that in European countries, primary to high school students receive an average of 7.475 hours (approximately 4.5 hours a day) of instruction in formal classroom settings during the 9 years of compulsory education (OECD 2014). The school's indoor air quality (IAQ) is, therefore, very important, as it can affect students' learning abilities and lead to serious health issues.

The concentration of CO_2 is often used as an indicator of IAQ, especially in high-occupancy spaces such as schools. One of the main reasons is that in recent years, inexpensive and reasonably accurate instruments for measuring CO_2 concentration have become available. On the other hand, CO_2 is an inert gas, and its key emission sources (building occupants, students) are evenly distributed within the classrooms. Typical concentrations of CO_2 in the exhaled air are 4–5%. This is approximately a hundred times higher than the background CO_2 concentration, therefore the classroom concentration will strongly depend on the number of students, their activity, and time spent in the classroom. Factors that will influence a reduction of CO_2 concentration are ventilation rate and size of the classroom. Therefore, without adequate ventilation to remove and dilute CO_2 generated by students, its concentration can quickly increase to very high levels. These may be especially critical for young children, as they inhale higher volumes of air in relation to their body weight and respiratory tract surface area than adults, and their tissues and organs are still actively growing (Selgrade et al. 2008; Ginsberg et al. 2007). This can lead to child–adult differences in delivered doses of the polluted and toxic air. Although CO_2 is not considered to pose serious health risks, it has been demonstrated that elevated concentration levels can have significant impact on students' health and performance, such as lower attention and drowsiness (Mendell & Heath 2005; Bakó-Biró et al. 2011).

From a regulatory point of view, the European regulation EN 13779 provides minimum ventilation rates (VR) values in classrooms as a function of required indoor air quality. According to this regulation, VR has to be at least 20, 12.8, 8, and 5 Ls^{-1} per person (for non-smoking rooms) when high, medium, moderate, and low air quality targets have to be reached, respectively (CEN 2006).

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHARE) recommends that indoor CO_2 concentrations be maintained at or below 1.000 ppm in schools (ASHRAE 2013). Furthermore, the recommended limit averaged over one school shift should be lower than 1.500 ppm (DfES, 2018; Bakó-Biró et al. 2011). The ASHRAE also recommends minimum VRs of 5 Ls^{-1} per person for students of up to 9 years of age (ASHRAE 2013; Goldwin & Batterman 2007).

The conclusion is that adequate ventilation rates need to be guaranteed in order to maintain satisfactory air quality in classrooms. Indoor CO_2 concentrations above 1.000 ppm are generally regarded as indicative of VR, which is unacceptable with respect to air pollution and body odours.

In recent years, the WHO Regional Office for Europe in collaboration with local agencies, initiated a pilot project to measure indoor air quality in several primary schools in Croatia, as well as in other Eastern European countries. Their results are summarised in the Report (WHO 2015), which includes school surveys conducted from 2012 until early 2014 in five European countries: Albania, Croatia, Latvia, Estonia, and Lithuania. According to that report, the highest reported CO_2 concentration measured in primary school classrooms in Croatia was 2.500 ppm.

In another study, measurements of CO_2 concentrations were carried out in two Croatian primary schools during the five working days (March 2014). Daily average values of CO_2 in these two schools were 1.630 ppm for urban, and 2.370 ppm for rural school. (Tasić et al. 2015).

All these studies, along with our results, suggest that alarmingly high CO_2 concentrations and poor IAQ are very common in many schools, especially during the heating season. The situation is critical and requires urgent addressing by school management and responsible government agencies.

2. METHODS

2.1. Sampling site description & measurement period

All measurements were performed in the Andrija Mohorovičić Grammar School (AMGS) in Rijeka in the period between 24 Nov. and 22 Dec. 2017. The school is in the city centre, and it is surrounded by streets with moderate traffic intensity (**Figure 1**).

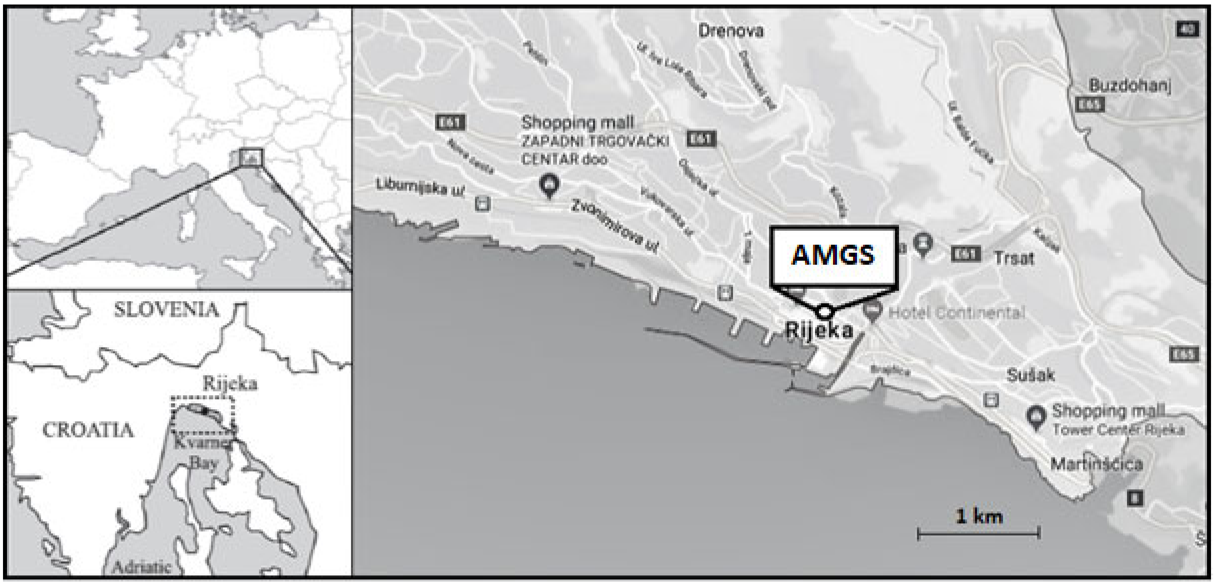

Figure 1. *The location of Andrija Mohorovičić Grammar School (AMGS) in the City of Rijeka, Croatia)*

This is a contemporary building built in 1897, with very solid walls and without an automated ventilation system. The only ventilation was provided in a traditional manner, by occasionally opening windows and doors, and during the winter period, mainly through small imperfections in windows and doors. However, some 15 years ago, the traditional wooden windows were replaced with new ones that allow very little air infiltration. In this way the energy conservation rating of the building was significantly improved. On the other hand, the airtightness of the new windows greatly reduced the ventilation rate of the building. For that reason, our study took place during the winter season, when windows are opened rarely, to reduce fuel consumption used for the central heating system (hot water filled radiators).

All our measurements took place in a specialized physics classroom which has typical school furniture and hardwood floors. This classroom was typically used by 15–18-year-old students (gymnasium grades 1–4). Physical dimensions of the classroom and the number of students is given in **Table 1**.

Table 1. Characteristics of the classroom and the number of students (A – floor area, h – height, N – number of students in the classroom)

SCHOOL	A/m^2	h /m	Vair /m^3	WINDOWS	Open wind. area / m^2	N
AMGS	62.3	4.1	259	3	4.62	22-26

2.2. Instrumentation and measurement

The following three different low-cost instruments were used to measure CO_2 concentration in this work:

1. DT-802 Detector (DT) manufactured by CEM (Shenzhen Everbest Machinery Industry Co.),
2. Green Eye CO_2 meter and data logger (GE) by Tech Grow Co. and
3. CO_2 + CO + RH/T Portable Meter and data logger (CM07) by CO_2Meter Inc.

All the dedicated instruments and loggers for measuring CO_2 concentration are in the range suitable for monitoring air quality in schools or offices, and their characteristics are given in **Table 2**.

Table 2. Characteristics of the instruments (Range ± accuracy)

INSTRUMENTS	CO_2 / ppm	t / °C	RH / %	CO / ppm
DT	(1–9.999) ± 75	(-5–50) ± 1	(0.1–90) ± 5	
GE	(1–10.000) ± 40	(-10–60) ± 0.6	(20–99) ± 5	
CM07	(1–9.999) ± 30	(-10–60) ± 0.9	(20–99) ± 3	(1–1.000) ± 10

All instruments use the non-dispersive infrared CO_2 detection method (NDIR). They were positioned in the classroom at a height of 1.5 m.

3. RESULTS AND DISCUSSION

3.1. Intercomparison of all instruments

To check the validity of our three instruments, simultaneous measurements were performed in the same classroom, with a wide range of CO_2 concentrations (2.200–3.200 ppm).

As evident from **Figure 2,** results from all three instruments are in agreement with each other, as variations from mean values are typically from 5 to 10 ppm, which is less than the instrumental errors specified by the manufacturers. Average values of CO_2 concentrations obtained by these three instruments were used throughout this work.

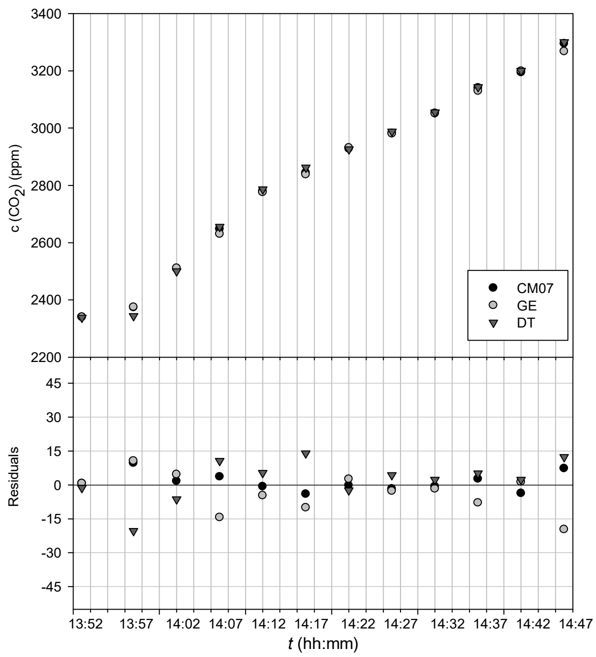

Figure 2. *The CO_2 concentrations measured by our three instruments (accuracy for CO_2; CM07 ± 30 ppm ± 5 % of reading (0-5000 ppm); GE ± 50 ppm; DT ± 8 % (2000 - 9999)) in a wide range of CO_2 concentrations. The lower graph shows residuals from the mean values (in ppm)*

3.2. Outdoor concentrations of CO_2

Outdoor concentrations of CO_2 were measured in the morning and the afternoon hours before the class. The obtained concentrations were found to be within the characteristic range for urban areas i.e. between 410 and 500 ppm (Turnjanin et al. 2014; Bréon et al. 2015).

As evident from **Figure 3**, concentrations obtained in the morning hours were lower, averaging 446 ppm. Afternoon concentrations were somewhat higher, ranging from 435 to 490 ppm. This was expected, due to emissions caused by road traffic, as well as domestic heating (Bréon et al. 2015). As outdoor CO_2 concentrations for year 2017 were not found in the Croatian public reports (Report 2017), the obtained values were compared to the available monthly data from the nearest stations in Hungary (for Nov. and Dec. 2017, 420,56 and 422.35 ppm, respectively) and Germany (for Nov. and Dec. 2017, 411.01 and 412.68 ppm, respectively). These background values were lower than the values measured in Rijeka, as the two stations were located in relatively unpolluted areas: one in the village of Hegyhatsal (station H, Hungary), and the other in the Alpine Region of Hohenpeissenberg (station HPB, Germany) (NOAA 2019).

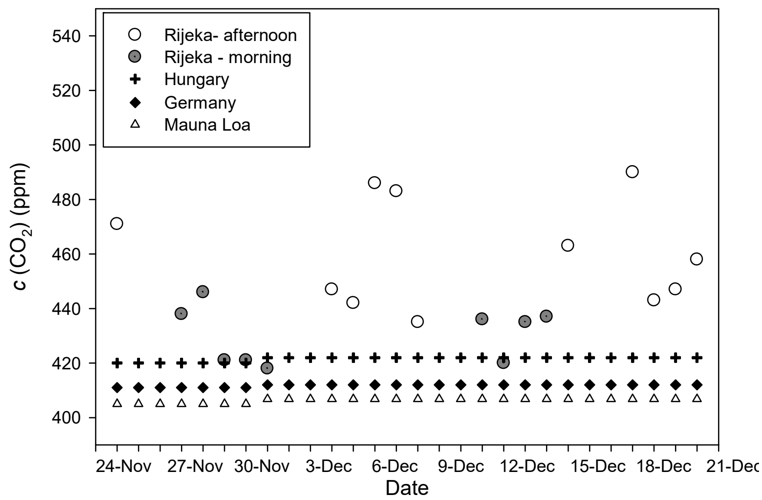

Figure 3. *Outdoor CO_2 concentrations in Rijeka during the morning (grey dots) and the afternoon hours (white dots) from the 24th Nov. to the 22nd Dec. 2017, and CO_2 monthly average concentrations obtained from stations in Hungary, Germany and Mauna Loa*

3.3. Measurement of indoor CO_2 concentrations and temperature

The air quality in the AMGS physics classroom was monitored in the winter period, when the outdoor temperatures were relatively low, ranging from 3 to 12°C. Throughout the sampling campaign, all classrooms were heated with oil-powered central heating radiators. To preserve fuel and to keep temperatures in the classrooms at more comfortable levels, it was common that teachers and student's open windows to ventilate classrooms only occasionally. Therefore, the air quality in classrooms was often poor and temperatures were much higher than recommended. This was one of the major reasons why we embarked on this project, with the aim to objectively assess the air quality in classrooms.

To maintain controlled experimental conditions during the four-week study, it was ensured that the classroom windows were closed the entire teaching period (four to five classes). The classroom was ventilated only during the breaks, when doors were opened for 5 to 10 minutes. However, it must be noted that not opening windows for long periods of time during cold winter days is very common in our schools. Both students and teachers often complain of poor air quality. At the same time, they want to enjoy comfortable room temperatures, and are, therefore, hesitant to open windows. (In our survey, most of the students wrote: "Poor air quality and closed windows in classrooms aren't uncommon in our schools. Teachers usually don't open windows during the class, and only a few will open them during short breaks.").

As expected, the build-up of CO_2 concentrations in the classroom was high, and at the end of the teaching period sometimes exceeding 4.000 ppm. Typical increases of CO_2 concentrations in the physics classroom for one week (Mon. to Fri., afternoon session) are shown in **Figure 4**.

The initial concentration of CO_2 in the classroom was different each day, and it depended on whether the classroom was used by another teacher prior to our measurements. As evident from **Table 3**, the initial concentrations in the morning sessions varied from 437 to 1.373 ppm and from 887 to 1.704 ppm in the afternoon sessions. This is not surprising, as CO_2 concentrations converged to nearly the outdoor levels overnight, while the breaks between morning and afternoon shifts were not long enough to allow for full replacement of air in the classroom. The results of all twenty measurements are shown in **Table 3**.

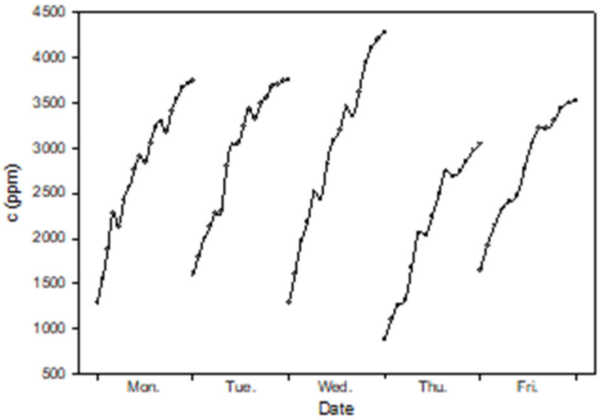

Figure 4. *A typical increase in CO_2 concentrations (in ppm) in the physics classroom during one week of measurements. From the moment when students entered the classroom in the afternoon (at 2 pm), the CO_2 concentration levels increased and reached the peak by the end of the afternoon shift. Occasional sharp drops in the CO_2 concentration were caused by open doors during short breaks.*

Table 3. The results of all the measurements. Data are sorted in ascending order, by the product of the number of physics classes (d*t* in hours), and the average number of students (N) throughout the measurement session. The initial, maximum, and average CO_2 concentrations are given for all days, together with the outdoor and indoor average temperatures (from Nov. 24 to Dec. 22). (M – morning schedule, A – afternoon schedule).

Day	Date	M/A	dt (h)	N	Ndt (h)	c (CO_2) (ppm)				t (°C)	
						d*c*	Initial	Max	Avg.	Outdoor	Indoor avg.
Thu.	30 Nov.	M	1.5	24	36	1305	1559	2864	2071	8	23.5
Thu.	21 Dec.	A	1.5	25	38	1750	1213	2963	2533	4	21.4
Fri.	24 Nov.	A	2.25	20	45	1967	1092	3059	2326	12	23
Fri.	8 Dec.	A	2.25	23	52	1883	1647	3530	2544	11	23.1
Fri.	1 Dec.	M	2.25	24	54	2384	505	2889	2153	8	23.5
Fri.	22 Dec.	A	2.25	24	54	2044	1592	3636	2079	10	23.5
Tue.	19 Dec.	A	2.25	26	59	1660	1704	3364	2630	3	23.8
Thu.	7 Dec.	A	2.25	26	59	2161	887	3048	3161	9	21.7
Thu.	14 Dec.	M	2.25	26	59	2426	437	2863	2955	9	23.3
Mon.	27 Nov.	M	3	23	69	2005	1343	3348	1951	6	23.9
Tue.	5 Dec.	A	3	24	72	2153	1605	3758	2829	6	23.5
Tue.	28 Nov.	M	3	25	75	2918	554	3472	2966	6	25.1
Tue.	12 Dec.	M	3	25	75	1775	1737	3512	2914	12	23.1
Mon.	4 Dec.	A	3	26	78	2455	1295	3750	2450	5	21.5
Mon.	18 Dec.	A	3	26	78	2402	1533	3935	2177	6	22.9
Wed.	29 Nov.	M	3.75	24	90	2530	1028	3558	2984	8	26.3
Wed.	20 Dec.	A	3.75	25	94	2551	1618	4169	2664	5	24.4
Wed.	6 Dec.	A	3.75	26	98	2994	1291	4285	3162	6	24.1
Mon.	11 Dec.	M	3.75	26	98	2781	1586	4367	1691	12	21
Wed.	13 Dec.	M	4.5	25	113	2572	872	3444	2716	7	23.6

Data are sorted in ascending order by the product of average number of students (N) and the number of continuous physics classes (d*t* in hours), with the aim to assess the influence of the product N·d*t* on the overall increase of the CO_2 concentration (d*c*). Due to an obviously low ventilation rate (VR), it is striking to notice that for the entire campaign, the CO_2 concentration built up to a total of over 3.000 ppm, and in several instances even over 4.000 ppm. The column "Avg" contains the average CO_2 concentrations during the entire teaching period. The average values ranged from 1.691 to 3.162 ppm. These concentrations are considerably above the ASHRAE recommended average limit values of 1,500 ppm over one school shift (DfES 2018; Bakó-Biró et al. 2011; ASHRAE 2013). The European standards for Indoor Air Quality are even more restrictive. According to the EN 15251 standard (CEN 2007), indoor air quality is classified into four categories based on the difference between outdoor and indoor CO_2 concentrations (**Table 4**).

Our results show that the IAQ for the entire sampling period was most of the time in the category IV, indicating a very poor IAQ, and a substandard ventilation rate. At the same time, because of a low ventilation rate, the classroom temperature increased to much higher levels than recommended. According to the European standard

EN 15251, an optimal temperature for classrooms is between 21 and 23°C. Our measurements show that in 15 out of 20 days, temperatures were higher than recommended, on several occasions reaching a maximum of 28°C!

Table 4. Four categories of indoor air quality according to the EN 15251. For simplicity, it is assumed that the outdoor CO_2 concentration is constant and equal to 400 ppm.

CATEGORY	c (ppm)
I	$400 < c < 750$
II	$750 < c < 900$
III	$900 < c < 1200$
IV	$c > 1200$

3.4. Theoretical model

Classrooms, such as the one used for measurements presented in this work, are ideal sites for measuring ventilation rates and for testing a simplified theoretical model of CO_2 concentration build-up, as given by **Equation 1**. This equation describes changes in CO_2 concentrations, at rates determined by the number of occupants in a known volume, and the ventilation rate of a confined classroom space. With the assumption that (nearly) ideal conditions are maintained (well mixed air, and no sudden, disruptive CO_2 sources or drains, e.g., opening doors or windows, increased number of occupants or their activity level), **Equation 1** expresses the mass balance of CO_2 entering and leaving the volume at any instant, *t* (Batterman 2017):

$$V\frac{dc(t)}{dt} = Qc_{out} - Q\cdot c(t) + S \qquad (1)$$

This equation describes the rate of CO_2 concentration increase, dc(t)/dt, within the volume of a classroom (V in m^3). Q is the air flow in/out of a classroom (in m^3h^{-1}), which can be used to estimate Ventilation Rate (VR) and/or Air Exchange Rate (AER), c_{out} is outdoor CO_2 concentration, c(t) is indoor CO_2 concentration and S is indoor source of CO_2 concentrations. The indoor source of CO_2 is a function of the number of students in the room, N and the CO_2 generation rate per person, G_p (in $Lmin^{-1}$ per person):

$$S = N\cdot G_p \qquad (2)$$

Air exchange rate, AER (in h^{-1}), is defined as:

$$AER = \frac{Q}{V} \qquad (3)$$

By substituting **Equation 2** for *S* and **Equation 3** for AER into **Equation** 1, the final expression for CO_2 concentration change for the ideal case is obtained:

$$\frac{dc(t)}{dt} = AER\cdot\left(c_{out} - c(t)\right) + \frac{NG_p}{V} \qquad (4)$$

In this equation the first term describes the CO_2 drain rate, and the second term is the CO_2 source. The equation written in this form is suitable for experimentally determining two unknown variables, AER and G_p.

3.5. Air Exchange and Ventilation rates, AER and VR

To estimate an air exchange rate, we use a special case of **Equation 4**, i.e., when S = 0, meaning that there are no occupants in the classroom (N = 0). The **Equation 4** transforms to a simplified form **Equation 5** which can now be used to calculate the AER from the experimental data.

$$\frac{dc}{dt} = AER\cdot\left(c_{out} - c(t)\right) \qquad (5)$$

This is a so-called decay, or step-down method (Sherman 1990; Smith 1988). The measurement period started in the evening hours (after the last class session) and ended in the morning when the indoor and outdoor concentrations of CO_2 were almost equal. Throughout the measurement, windows and doors were kept closed to make sure that the leakage rate was the same as during the class periods.

The CO_2 concentrations experimentally obtained during this measurement demonstrate a typical exponential decrease of CO_2 concentration and are shown in **Figure 5**.

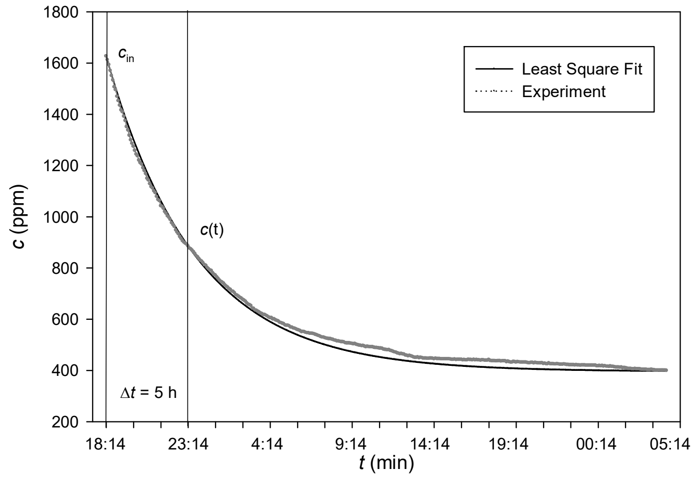

Figure 5. *The CO2 concentrations measured during the night (unoccupied) in the classroom with the closed windows and doors shows a typical, exponential decrease. The smooth line represents the least square fit of the exponential function [Eq. (5)] to the experimental values*

In this case, integration of **Equation 5** will give the following formula for determination of the indoor CO_2 concentration:

$$c(t) = c_{out} + (c_i - c_{out})e^{-AER \cdot t} \qquad (6)$$

where c_i is the initial concentration in ppm. After rearranging, **Equation 6** gives the expression for calculating the AER from the CO_2 decay function:

$$AER = \frac{1}{\Delta t}\ln\left(\frac{c(t) - c_{out}}{c_i - c_{out}}\right) \qquad (7)$$

where c_{out} is approximated with 400 ppm.

The least square fit of the experimental data with this exponential function gave the air exchange rate of 0.18 h^{-1}, for unoccupied classroom with closed windows and doors. Fitting results are shown in Figure 6. The obtained value was much lower than the lowest recommended value of 4 h^{-1} for classrooms by the EN 15251 (CEN 2007).

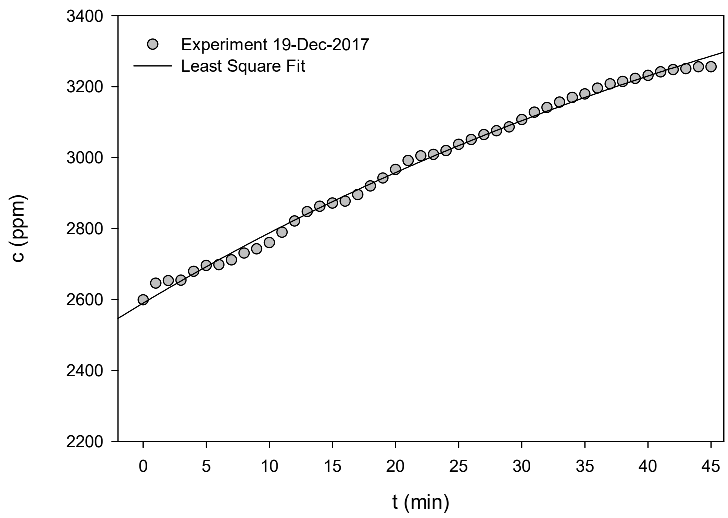

Figure 6. *A comparison between the experimental and best fitted values of CO_2 concentrations by 20 students in closed windows classroom for 19 Dec. 2017*

3.6. Estimation of the CO_2 generation rate

Once the air exchange rate is obtained with closed windows, the least square fit of the experimental data with Eq. (4) gives us a CO_2 generation rate, Gp, which is now the only unknown parameter in **Equation 4**.

For that purpose, CO_2 concentrations were monitored during a 45-minute class, with 20 students occupying the classroom. The measured CO_2 concentrations increased from 2.598 to 3.256 ppm during the class. This concentration increase was a result of the initial concentration, the concentration build-up by 20 students, and the small, but still measurable leak of CO_2 through the gaps in doors and windows.

Experimental data and the obtained fit are shown in **Figure 7**. The obtained fitted value of G_p for this period was 0.31 $Lmin^{-1}$. The obtained value is in the expected range of CO_2 generation for 15 to 18-year-old students in sedentary physical activity level, which is typically between 0.319 and 0.343 $Lmin^{-1}$ (Batterman 2014; Haverinen-Shaughnessy et al. 2011).

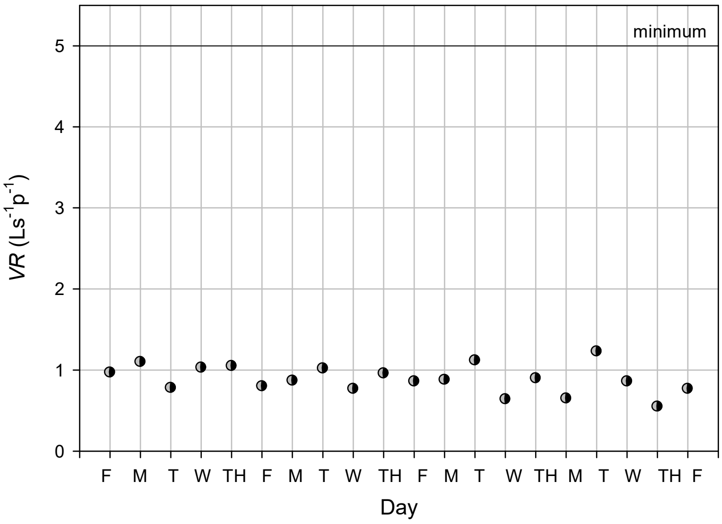

Figure 7. *The calculated ventilation rates for all days were considerably below the ASHARE and EN13779 minimum recommended value*

Air exchange rates in an occupied classroom were defined by means of **Equation 4**. This expression was used to calculate the AER for all days. From the obtained AER, a more commonly used ventilation rate (VR) in $Ls^{-1}p^{-1}$ was calculated with the following expression:

$$VR = \frac{AER \cdot V_{air}}{N} \qquad (8)$$

where V is the volume of air in classroom (**Table 1**) and N is the average number of students (**Table 3**).

The obtained VRs for all days are presented in **Figure 7** (in occupied classroom). As evident from **Figure 7**, ventilation rates varied from 0.56 to 1.23 Ls^{-1} per person. These values are far below the minimum recommended limit value of 5 $Ls^{-1}p^{-1}$ (ASHRAE 2013; CEN 2006).

3.7. Simulation of the entire session

To check the validity of the experimentally obtained CO_2 generation rate G_p and ventilation rate for the closed windows classroom, the data obtained for a typical working day (11 Dec. 2017) during five consecutive physics classes and four breaks (5 to 15 minutes) were used. The experimentally obtained data were compared with the theoretical model for calculating the CO_2 concentration, c(t), as given by **Equation 9**, which was obtained by integrating **Equation 4** into the entire teaching period:

$$c(t) = \frac{N \cdot G_p}{V_{air}} \cdot t + c_{out} + (c_i - c_{out})e^{-AER \cdot t} \qquad (9)$$

By applying the experimentally obtained Gp (0.31 $Lmin^{-1}$) and AER (0.003 min^{-1}) with the exact number of occupants for each class (27, 24, 26, 25 and 25 respectively), to the above equation, a very strong simulation of the experimentally obtained data was achieved (**Figure 8**).

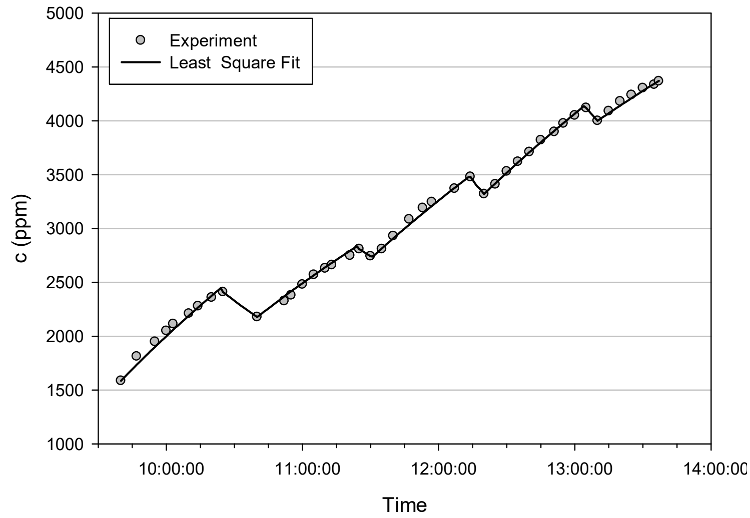

Figure 8. *A comparison between the experimental data obtained on 11 Dec. 2017 and theoretically calculated CO_2 concentrations in closed windows classroom during 5 consecutive physics classes*

During the 5- and 15-minute breaks, when the classroom was empty, **Equation 5** was used to calculate the decay of CO_2 concentrations (the decrease was typically 5 % to 10 %, depending on the length of the break). As evident from **Figure 8**, correlation between the experimentally obtained CO_2 concentrations and simulated values was nearly perfect with R^2 of 0.98. This confirms the validity of the theoretical model used, the experimentally obtained values of CO_2 generation rates, G_p, as well as the ventilation rates for the physics classroom used in this work during the entire teaching session.

4. CONCLUSION

The results of this study show limited ventilation of classrooms during lectures, during the heating season. Very high concentrations of CO_2, of over 4.000 ppm, were measured on several occasions. This is a result of a limited ventilation of classrooms during the heating season, as traditionally, the only ventilation in most of our schools is provided by opening windows. As outdoor temperatures are low during the winter, school's management, teachers, and students are hesitant to open windows and ventilate rooms. Closed windows, over a prolonged period of time, result in a poor ventilation rate, and consequently, in alarmingly high CO_2 concentrations.

Indoor air quality, and in particular the CO_2 concentration, was monitored in the physics classroom on a daily basis from mid-November till the end of December 2017, by using several low-cost instruments. The measuring took place in a grammar school in Rijeka, Croatia.

Detailed CO_2 generation rates, air exchange rates, and ventilation rates were calculated and reported in this work, from the experimentally obtained data. The experimentally obtained data were compared with the theoretical model and a strong correlation was achieved. Ventilation rates were found to be in the range between 0.6 and 1.2 Ls^{-1} per person, which is far below the lowest recommended value of ventilation rate according to the EU regulation of 5 Ls^{-1} per person (EN 15251).

Poor IAQ can have significant impact on students' health and performance. These data may be useful in assessing health effects of student's exposure, in understanding the underlying mechanisms, and in implementing preventive policies in terms of occupied classroom standards. The simplest solutions for reduction of CO_2 concentrations in an occupied classroom are changing the behaviour of teachers, such as having them open the windows at every break between classes, or installing low-cost instruments with an alarm that activates when CO_2 concentrations are above 1.500 ppm. The best technological interventions are an installation of automated ventilation systems in classrooms, which would automatically inject fresh air into the room when CO_2 concentration exceeds 1.000 ppm.

This is the first report of this kind in Croatia; therefore, we hope that many studies by health workers and researchers will follow. Also, we hope that schools' management will introduce the appropriate IAQ monitoring practices and install automated ventilation systems in classrooms for the benefit of student's health and an improvement of their learning abilities.

Acknowledgments*:* The authors thank the school principal Henry Ponte and the students of Andrija Mohorovičić Grammar School in Rijeka.

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