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Indoor air quality of naturally ventilated Croatian classrooms

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Fig. 1: School areas; Rijeka, AMGS, CETS at Rijeka

ABSTRACT
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.
The present work aims to evaluate the effect of manual airing on indoor air quality in two naturally ventilated Croatian schools. Indoor air quality was studied in terms CO_2, air exchange rate and ventilation rate during the heating and non-heating seasons and compared with outdoor levels.
Closed windows over a prolonged period of time, result in alarmingly high CO_2 concentrations (up to 4000 ppm), and consequently, poor ventilation rates. Longer windows opening periods reduce indoor CO_2 but simultaneously increase the outdoor –generated sub- micron particles.

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, Indicator D1, 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. All measurements were performed in the Andrija Mohorovičić Grammar School (AMGS) and the Civil Engineering and Technical School (CETS) in Rijeka.
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.

EXPERIMENTAL

All measurements were performed in the AMGS and the CETS in Rijeka in the period between Nov. 24th and Dec. 22nd (close windows) and February 12th to March 30th 2018 (open/close windows). The schools are located in the city centre, and it is surrounded by streets with moderate traffic intensity.
All our measurements took place in a specialized physics classrooms which has typical school furniture and hardwood floors. This classroom was typically used by 15–18 year-old students.

Table 1 Characteristics of the classrooms and the number of students (A – floor area, h – height, A(w) – max open windows area, N – number of students).

School	A / m^2	h / m	N(w)	A(w) / m^2	N
AMGS	62.3	4.1	3	4.62	20-26
CETS	64.4	3.9	4	7.28	16-24

RESULTS

The air quality in the AMGS and CETS physics classrooms 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.
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."

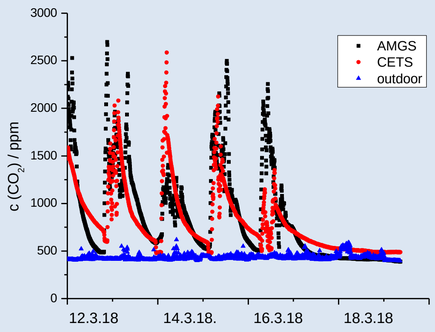

Table 4. CO_2 concentrations for two classrooms, oudoor CO2 increase by traffic intensity

	GSAM			CETS		
	t/ °C	RH/%	CO_2/ppm	t/°C	RH/%	CO_2/ppm
min	16.6	14.8	384	13.2	15.1	379
Q1	19.3	27.1	496	20.1	25.7	511
med	21.1	29.7	704	21.8	34.1	648
Q3	22.8	34.8	1298	23.8	40.8	896
max	25.2	55.5	3270	28.1	70	2586

Table 3. Temperature, relative humidity and CO_2 concentrations for manual airing condition in GSAM and CETS for the sampling period between Feb 12, and Mar 30, 2018

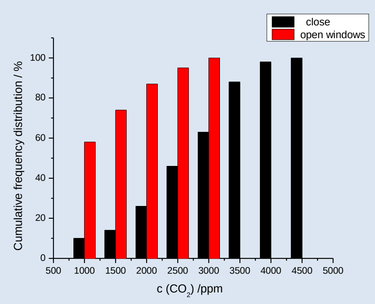

Fig 2. Comparison of two cumulative frequency distributions of indoor CO_2 concentrations associated with open/closed windows for the same number of students in classroom

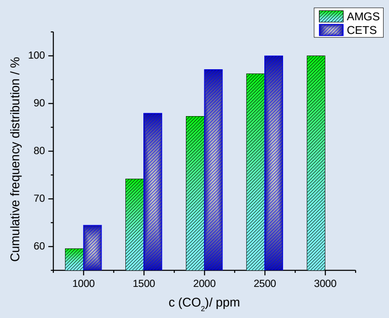

Fig 3. Comparison of two cumulative frequency distributions of indoor CO_2 concentrations associated with the manual ventilation system in the two classrooms

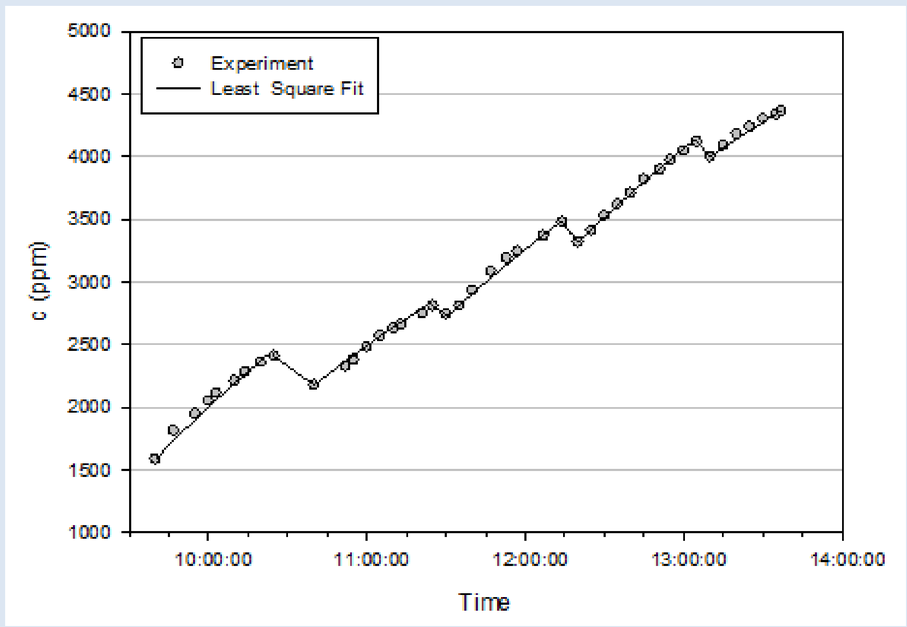

Fig 4. A comparison between **the experimental data** obtained on Dec 11, 2017 and **theoretically** calculated CO_2 concentrations (see Eq.) in closed windows classroom during 5 consecutive physics classes.

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

Where $c(t)$ – CO_2 concentration, N – number of the students, G_p – generation rate per person, V_{air} – volume of a classroom, c_{out} – outdoor CO_2 concentrations, AER – air exchange rate.
Calculated from experimental data:
G_p = 0.31 $Lmin^{-1}$ (typically 0.319 - 0.343 $Lmin^{-1}$ for 15 - 18-year –old students)
C_{out} = (397- 550) ppm, median 428 ppm
AER = 0,18 h^{-1} for unocupied classroom (min)

CONCLUSION

The results of our preliminary measuring are presented in this work. Very high concentrations of CO_2 of over 4,000 ppm were measured in closed windows classrooms. 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.
Detailed CO_2 generation rates, air exchange rates, and ventilation rates are calculated, from the experimentally obtained data. 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 of 5 Ls^{-1} per person according to the EU regulation (EN 15251) and ASHRAE (The American Society of Heating, Refrigeration and Air Conditioning Engineers).

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