Original paper

SCHOOL CHILDREN EXPOSURE TO LOW INDOOR AIR QUALITY IN CLASSROOMS DURING COVID-19 PANDEMIC: RESULTS OF A PILOT STUDY

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SUMMARY

Background: Indoor air quality (IAQ) in classrooms affects children's health and academic performance. The aim of this pilot study was to determine IAQ in elementary schools different in their internal and external characteristics, in settings of COVID-19 epidemics.
Methods: IAQ parameters: fine particulate matter ($PM_{2,5}$) mass concentration, CO_2 concentration, temperature and relative humidity were measured in parallel in four elementary schools/classrooms during October (non-heating season) and four months (including holiday in January) of heating season. IAQ parameters were measured in settings of anti-epidemic restrictions (≤13 students in classroom, frequent ventilation).
Results: During October, except in one school, $PM_{2,5}$ concentrations were below the upper recommended value (25µg/m³), but started rising in all schools in the heating season. The highest concentrations of $PM_{2,5}$ were registered in two schools with closed or shortly opened windows. CO_2 concentrations were mostly in the recommended range (up to 1000ppm) except in the school with constantly closed windows and in three schools in February when concentrations were higher. Except in one, the same school, and in January, both temperature and relative humidity were out of the recommended range (24,0–27,0°C in non-heating; 20,0–24,0°C in heating season; and 45–55%), with temperature mainly above and relative humidity mainly below it in three schools. The largest deviation in temperature and relative humidity were registered in urban schools. Registered differences may be explained by different internal and external characteristics.

Conclusion: Despite anti-epidemic restrictions, most of the measured IAQ parameters were out of the recommended values in heating season. In addition, further deterioration of IAQ could be expected if all students had been presented in the classroom. Finally, to assure a healthy school environment in heating season, further optimisation of both indoor and outdoor conditions is needed in both pandemic and non-pandemic settings.

Keywords: Indoor air quality, classroom, green building certification, health, Covid-19

INTRODUCTION

As people spend 80–90% of their lives indoors, it is very important to ensure high indoor air quality (IAQ). This is particularly important in elementary school classrooms because of the vulnerability of school-aged children to poor air (Burtscher & Schüepp 2012). Indeed, school-aged children absorb significantly more air pollutants than adults because of their two times faster breathing cycle, higher air intake as well as higher metabolic rate per unit of body weight (Nam et al. 2015). IAQ in classrooms, which were mainly shown to be crowded, poorly ventilated and overheated, has been repeatedly shown to significantly affect children's health and academic performance, and also to increase the risk of the development of chronic diseases in adulthood (Oliveira et al. 2019).

IAQ in classrooms is affected both by the concentration of indoor air pollutants (IAPs) such as particulate matters (PMs), carbon dioxide (CO_2), carbon monoxide, volatile organic compounds, nitrogen dioxide, radon, airborne microbes, and also by parameters such as temperature and relative humidity.

PMs found in the European classrooms mainly originate from indoor sources, i.e. school children and their playing activities, classroom furnishings (whiteboards, tables, chairs, etc.), consequences of architectural decadence, use of printers and photocopy machines, air-conditioning, heating systems and human activities such as cooking and cleaning (Destaillats et al. 2008; Morawska 2017; EEA 2017; Oliveira et al. 2019). As widespread complex mixtures of solid and liquid particles suspended in air, PMs vary in origin, composition, shape, and size being classified into ≤10 μm (combined fine and coarse fraction, PM_{10}), ≤2,5 μm (fine fraction including the ultrafine particles, $PM_{2.5}$) and ≤0.1 μm (ultrafine particles fraction) (WHO 2012, Zhang et al. 2015). WHO guidelines set $PM_{2.5}$ limits for indoor air at 25 μg/m^3 for the 8-h period and suggest its indoor concentrations should be as low as possible as it can reach and affect the lowest respiratory tract and even the circulatory system (Kim et al. 2015). Also, a growing evidence on negative health effects following short-term exposure to PMs, their negative effects on cardiorespiratory health and mortality as well as their classification in group I carcinogens (WHO 2016, IARC 2013) put them in the focus of the public health interest.

Concentration of CO_2, a product of human metabolism and respiratory exchange, primarily depends on the number of students in the classroom (Coley & Beisteiner 2002) and was set as a reference for the assessment of IAQ and ventilation control (Persily & Jonge 2017). Indoor CO_2 can also be acquired from outdoor air where concentration reaches around 400 mg/m^3, mainly as a result of fuel combustion from traffic and other human activities. CO_2 limits for safe indoor air are set at 1000 ppm for the 8-h period (ASHRAE 2007), with the higher level considered as both an indicator of unacceptable ventilation as well as with the risk of negative effects on people's perceptions and performance (Fromme et al. 2019).

The wellbeing and respiratory health of school children can also be affected by extreme temperatures and relative humidity (Choo et al. 2015). The recommended temperature range for acceptable IAQ during the heating season is 20,0–24,0°C, while during the non-heating season 24,0–27,0°C (ASHRAE 2007), while recommended relative humidity rate in the classroom is 45–55% (EEA 2017).

Although it is assumed that concentration of IAPs is directly affected by both internal factors such as classroom orientation, classroom ventilation and heating systems and insulation materials, as well as by external factors such as their concentrations outdoors, the vicinity of the road, the farm, or water or sun exposure, the exact data are scarce. Also, the only evidence-based data on IAQ in elementary schools in Bosnia and Herzegovina (BiH) originate from "SEARCH project", an international research on school environment and respiratory health of children that indicated poor IAQ in BiH schools (Csobod et al. 2010). In addition, assessment of IAQ in the settings of COVID-19 epidemic is of additional relevance. Therefore, the aim of this pilot study was to determine IAQ in elementary schools different in their internal and external characteristics potentially affecting IAQ, in the setting of COVID-19 anti-epidemic restrictions.

METHODS

This pilot study was a part of a research of energy efficiency practices in educational institutions of Sarajevo Canton (natural vs artificial construction materials) during the non-heating and heating season. The research was designed and conducted by an interdisciplinary team gathered under the association Green Building Council. It was approved by Cantonal ministry of education.

School selection and characterisation

Out of all schools in Sarajevo Canton, four schools were selected for inclusion in the study. The primary criteria for school selection was different insulation materials presenting a basis for four different scenarios for IAQ assessment.

To identify potential emission sources for IAPs and other factors potentially affecting IAQ, the following data were collected for each school or classroom: number of students in classroom, classroom level, classroom volume, number of m^3/person, flooring, wall covering, material of windows, duration of windows/opening, type of ventilation, classroom orientation, school location (urban/rural), vicinity of the road, classroom orientation to the road, vicinity of the farm or water, sun exposure, type of heating system, type of insulation material, energy efficiency class, etc. School was characterized as being in the vicinity of the road, the farm or water if the distance was equal or less than 50 m. These findings were expressed as school/classroom's characteristics.

IAQ parameters measurements

Following IAQ parameters were measured: $PM_{2,5}$ mass concentration (μg/m^3), CO_2 concentration (ppm), temperature (°C) and relative humidity (%). $PM_{2,5}$ mass concentration was measured by M2000C (Temtop, Elitech, China), CO_2 concentration by HVS-110 (Innen Techsolutions, Zug, Switzerland), and temperature and relative humidity by Testo 174 (Titisee-Neustadt, Germany).

Data collection, analysis and presentation

IAQ parameters were measured and data collected in academic 2020/21, during one month (October) of the non-heating season and four subsequent months (November through February, including winter holiday in January) of the heating season. Parameters were always measured in parallel, i.e. at the end of the third class through subsequent months, or through three school classes in February (six measurements through 100 min-period, i.e. at the beginning and at the end of each of three classes), in the morning shift in four same classrooms, with the same group of students. In February, in addition, outdoor values of all parameters were measured at the end of the third class. Measurements were performed in the settings of Covid-19 anti-epidemic restrictions (≤13 students in the classroom, frequent room ventilation).

RESULTS

School characterization

School/classroom characteristics are presented in Table 1.

IAQ parameters

Median, minimal and maximal values of IAQ parameters measured during the non-heating and the heating season, including holiday period in four schools are shown in Table 2.

$PM_{2,5}$ mass concentrations

Inter-school comparisons through the non-heating, heating season and holiday period (Figure 1a). During October, median $PM_{2,5}$ mass concentrations were mostly below the upper recommended value of 25 μg/m³ for the 8-h period in all schools except in school 4 where concentration was about 4,3 times higher than recommended. In other three schools concentrations however started rising above recommended value with the beginning of the heating season, so through the non-heating season the concentrations in all schools were far higher than acceptable, up to five

Table 1. School/classroom characteristics

	School			
Characteristics	**School 1**	**School 2**	**School 3**	**School 4**
Nr of students in classroom	8	8	9	8
Grade of children	V	III	IV	II, III
Classroom level	first floor	first floor	first floor	ground floor
Classroom volume (m3)	172,2	181,7	180,8	171,3
m3/person	19,7	20,2	18,1	19,0
Flooring	wooden	vinyl floor	laminate floor	vinyl floor
Wall covering	painted	painted	painted	painted
Type of windows	wooden	plastic	plastic	wooden
Duration of windows/opening	third class	second, third class	all three classes	never
Type of ventilation	natural	natural	natural	natural
Classroom orientation	south	south	south	south
School location	urban	rural	urban	rural
Vicinity of the road	yes	yes	yes	yes
Classroom orientation to the road	direct	indirect	indirect	indirect
Vicinity of the farm	no	no	no	yes
Vicinity of water	yes	yes	no	yes
Sun exposure	direct, high	direct, high	direct, high	indirect, medium
Type of heating	public/natural gas	own/natural gas	own/natural gas	own/fuel oil
Type of insulation materials	none	styrofoam	mineral wool	sheep wool and wood
Energy efficiency class*	D	A	A	C

*Regulation on the implementation of Energy Audit and issuance of Energy Certificate; Official gazzet FBiH No 87/18 file:///Users/Aida/Downloads/EPBD%20implementation%20Report_BiH%20(1).pdf

times higher in schools 1 and 4. Even in the holiday period in January, values were still above 25 μg/m^3.

Comparisons through three school classes in February (Figure 1b). All measured $PM_{2.5}$ mass concentrations were higher than recommended one during the observed 100-min period in February in all schools. The concentrations ranged from a minimal increase of 1,8 times higher in school 2 at the beginning of the first

Table 2. Median (M), minimal (min) and maximal (max) values of IAQ parameters measured during the non-heating and the heating season, including holiday period in four schools

	PM2,5 (µg/m³)			CO2 (ppm)			Temperature (°C)			Relative humidity (%)		
Month	M	Min	Max	M	Min	Max	M	Min	Max	M	Min	Max
October	13	6	108	737	705	1443	28	24	30	40	35	58
November	77	61	119	885	421	1080	25	22	26	45	37	55
December	95	65	131	789	752	1003	24	22	27	39	30	56
January	33	30	36	582	425	657	18	15	18	55	54	60
February	92	55	129	1255	953	2826	25	22	26	29	23	49

class, to the maximal one of 6,1 times higher in school 1 at the end of the second class, and even one of 6,3 times higher in school 4 at the end of the first class. As in the earlier parts of the heating season, these two schools constantly registered the highest $PM_{2,5}$ concentrations. The lowest $PM_{2.5}$ concentration was measured in school 2.

CO_2 concentration

Inter-school comparisons through the non-heating, heating season and holiday period (Figure 2a). CO_2 concentrations were mostly in the recommended range (up to 1000 ppm for the 8-h period) in all schools during all months except in school 4 in October (50% higher than recommended) and in three schools in February, with the highest concentration measured again in school 4. A minor increase, up to 40%, was registered in February in schools 2 and 3 (Figure 2a).

Comparisons through three school classes in February (Figure 2b). CO_2 concentration increased during the observed 100-min period in all schools except school 1 where the concentration started decreasing after the first class. The highest values (up to 3,2 times higher than recommended at the beginning of the third class) and all values higher than recommended were recorded in school 4. Although mainly above the recommended level (up to 40% higher than recommended), CO_2 concentration in school 2 was much lower than in school 4. The lowest CO_2 concentration was registered in school 3 where the windows were continuously open. Still, the value measured at the end of the third class was higher than recommended.

Temperature

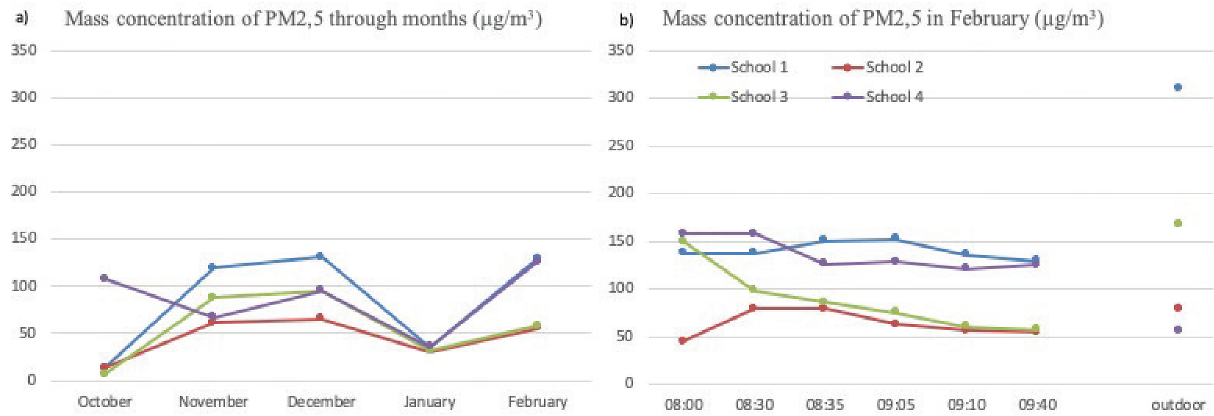
Inter-school comparisons through the non-heating, heating season and holiday period (Figure 3a). Temperature was mostly above the recommended range (24,0–27,0°C in the non-heating; 20,0–24,0°C in the heating season) in all schools through all months except in school 4 and in January (Table 2). The highest temperatures in October were registered in two urban schools (28,8°C in school 1 and 29,5°C in school 3), as well as in the heating season with the highest value of 27°C measured in school 1. The most optimal temperatures in both seasons were registered in school 4.

Comparisons through three school classes in February (Figure 3b). Although at the beginning of the first class in February the temperature was lower than recommended in all schools except school 1, it increased during the first class in all schools. The lowest temperature (12°C) was registered in school 4, but it reached the optimal value by the beginning of the second class. The most optimal temperatures in February were registered in schools 3 and school 4, while in school 1 it was continuously above (up to maximum 28°C) the recommended range.

Relative humidity

Comparisons through the non-heating, heating season and holiday period (Figure 4a). Relative humidity was below the recommended range (45–55%) in all months except January and in all schools except school 4 where the majority of values were in the recommended range and presented always with maxi-

Figure 1. Inter-school comparisons of $PM_{2,5}$ mass concentration a) at the end of the third class through the non-heating, heating season and holiday period in January, b) at the beginning and at the end of each class and outdoor in February, within-day comparison. *Note the difference in the length presented on x axis: class vs break (30 vs 5 min)*



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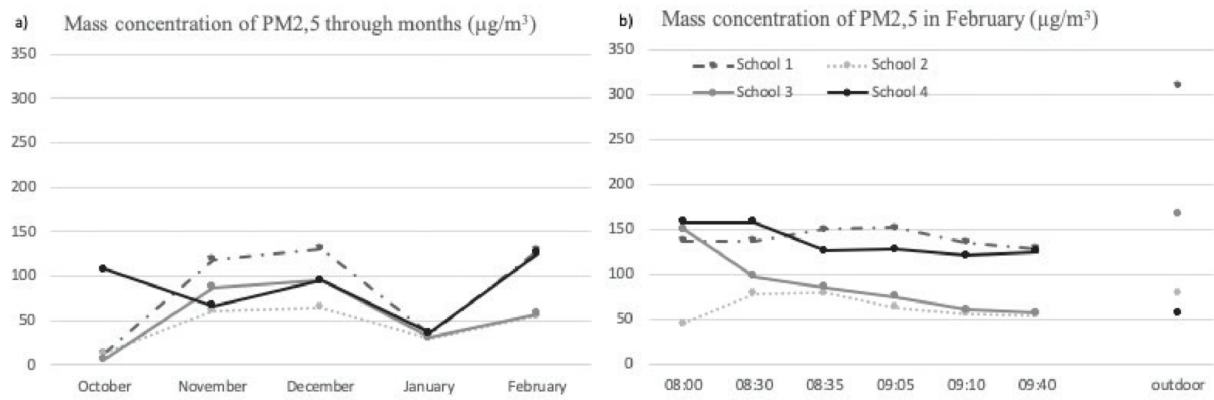


mum value (Table 2). The lowest values, significantly lower than recommended, were mainly measured in school 1.

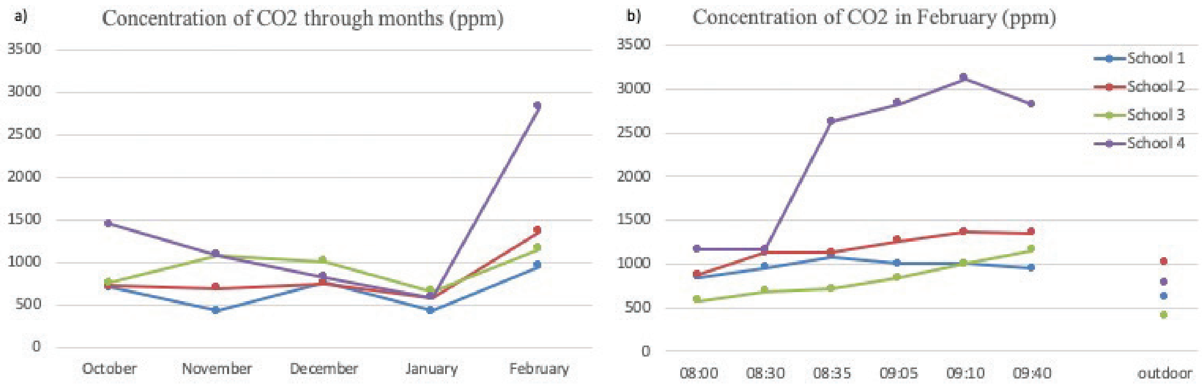
Comparison through three school classes in February (Figure 4b). Values of relative humidity in February were mostly lower than recommended with the minimum of 23% at the end of the third class in school 3. With the exception at the beginning of the first class when the highest value of 65% was measured, relative humidity was continuously maintained within the recommended range only in school 4.

Closed vs open windows comparisons (Figure 1–4b). Intra-school, closed vs open windows comparison was possible in schools 1 and 2. High $PM_{2,5}$ mass concentration, all above the upper recommended value, started decreasing in both schools after the windows were opened.

Although with closed windows CO_2 concentrations were increasing in both schools, they started decreasing after the windows were opened in school 1, but not in the school 2 where the increase continued even after the windows were opened.

Temperature was increasing with closed windows in both schools but started decreasing (28°C to 24°C) after the windows were opened in school 1, but not in the school 2 where the increase continued even after the windows were opened and despite the outdoor temperature of 7–8°C.

Figure 2. Inter-school comparisons of CO_2 concentration a) at the end of the third class through the non-heating, heating season and holiday period in January, b) at the beginning and at the end of each class and outdoor in February, within-day comparison. *Note the difference in the length presented on x axis: class vs break (30 vs 5 min)*



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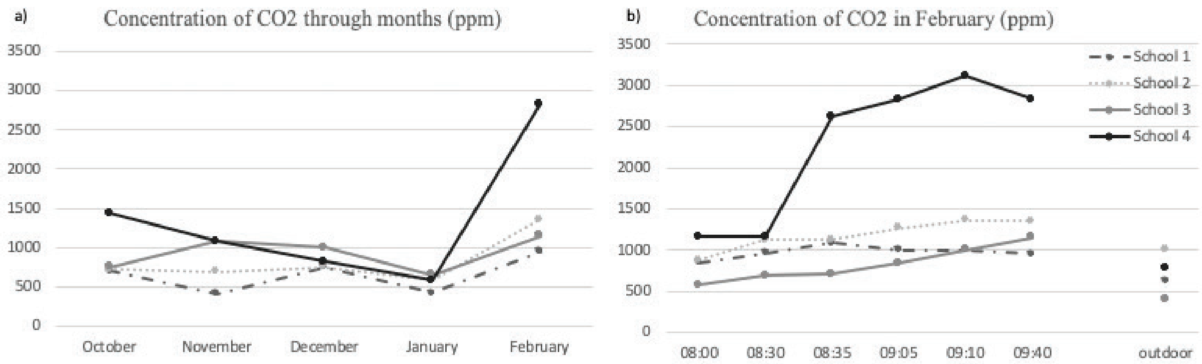


For relative humidity, its decreasing trend related to closed windows, more noticeable in school 2, was continued in the form of slight decrease and then maintenance after the windows were opened in both schools.

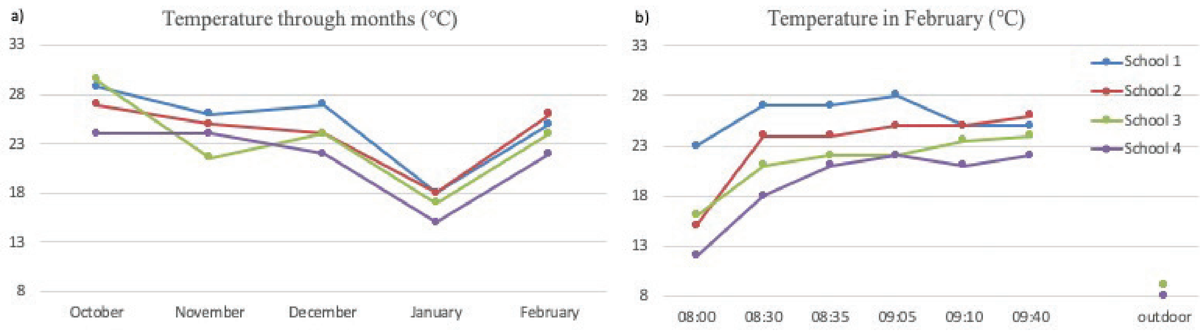
Indoor vs outdoor values comparison (Figure 1-4b, Table 3).

In February, CO_2 concentration and temperature were higher indoors than outdoors in all schools, while $PM_{2,5}$ concentration and relative humidity were lower indoors in all schools except in school 4. Both outdoor $PM_{2,5}$ concentration and relative humidity were higher and CO_2 concentration lower in urban compared to rural schools. The difference between the indoor and outdoor values was the most pronounced for $PM_{2,5}$ concentration.

DISCUSSION

The results of our pilot study showed that, despite anti-epidemic restrictions with frequent ventilation and limited number of students in classrooms, IAQ in classrooms was low, especially during the heating season. The highest concentrations of $PM_{2,5}$ were registered in schools 1 and 4, and the highest concentrations of CO_2 in school 4. However, the most optimal temperature and relative humidity were also registered in school 4, being the most pleasant microenvironment for the students. On the other hand, the largest deviation in temperature, with values mostly above the recommended range, and in relative humidity, with values mostly under the recommended range were registered in urban schools.

Figure 3. Inter-school comparisons of temperature a) at the end of the third class through non-heating, heating season and holiday period in January, b) at the beginning and at the end of each class and outdoor in February, within-day comparison. *Note the difference in the length presented on x axis: class vs break (30 vs 5 min)*



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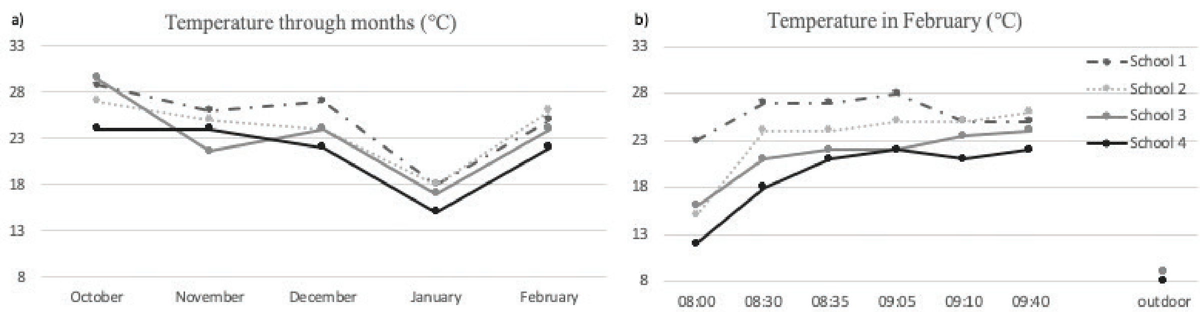
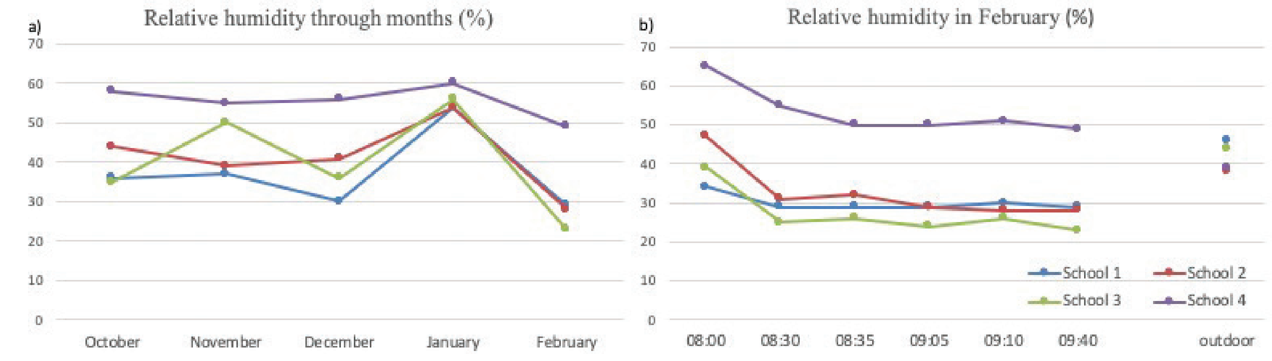


Although indoor $PM_{2.5}$ concentrations in schools are mainly (34%) a combined mixture of organic (skin flakes, cloth fibers, possible condensation of volatile organic compounds) and particles from chalk and building deterioration, PMs can also originate from outdoor sources (road traffic emissions especially if windows and doors face roads with heavy traffic or industry) and penetrate indoors usually by natural ventilation. Regarding the highest $PM_{2,5}$ concentration registered in schools 1 and 4, these schools shared many characteristics. However, as suggested by our intra-school, closed vs open windows comparison of $PM_{2,5}$ concentrations, the ”none windows opening in school 4 or its short duration in school 1” seems to be, next to the number of students in classroom and their activities, a relevant factor that determine high $PM_{2,5}$ concentrations in these two schools. Moreover, $PM_{2,5}$ concentrations in school 4 were even higher indoors than outdoors. In addition, as in school 4 windows were kept closed at all time, its direct orientation to the road and high outdoor $PM_{2,5}$ concentrations did not seem to play a role in high indoor levels of $PM_{2,5}$.

According to “SEARCH project” the highest concentrations of PM_{10} and benzene, and among the highest concentrations of toluene, xylene and NO_2 were measured in BiH schools compared to schools in Albania, Hungary, Italy, Serbia and Slovakia (Csobod et al. 2010). Unlike in our study where $PM_{2,5}$ concentrations declined with natural ventilation, PM_{10} concentrations in SEARCH project were significantly related to frequent window opening, crowdedness and classroom cleaning in the evening. Also, among other factors, heavy traffic and industry in the immediate school neighbourhood were significant determinants of poor IAQ and decreased lung function, while plastic flooring was, besides decreased lung function, also associated with increased prevalence of doctor-diagnosed allergies. The prevalence of children with asth-

Figure 4. Inter-school comparisons of relative humidity a) at the end of the third class through non-heating, heating season and holiday period in January, b) at the beginning and at the end of each class and outdoor in February, within-day comparison. *Note the difference in the length presented on x axis: class vs break (30 vs 5 min)*



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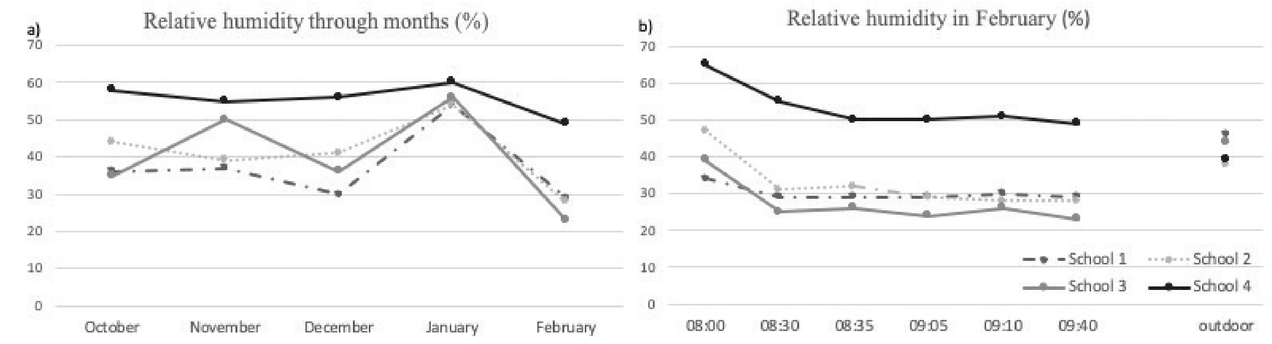

ma, asthma-like symptoms and asthma treatment was higher in BiH compared to the average one for all participating children (Csobod et al. 2010).

SInPHONiE study conducted in 2015 across 23 EU countries, 114 primary schools with 5575 students showed that about 85% of students were exposed to $PM_{2.5}$ and PM_{10} concentrations higher than those considered safe for the prevention of cardio-pulmonary diseases (Annesi-Maesano et al. 2013). Also, a recent review showed that median indoor levels of $PM_{2,5}$ exceeded the defined IAQ guidelines [35,0 (5,14–100,0) µg/m³] in 41 European schools (Oliveira et al. 2019). This range was close to one in our study during the non-heating season [13,0 (6,7–107,7) µg/m³], but both the median and range were lower compared to ones measured in our heating season (November, December and February) [76,9 (61,0–119,1) µg/m³ in November; 95,0 (65,0–131,0) µg/m³ in December; 91,5 (55,0–129,0) µg/m³ in February].

Based on the concentrations of $PM_{2.5}$ reported at European schools, predicted $PM_{2.5}$ short-term health effects on school children were assessed to total of 31 cases of hospital admissions related with respiratory diseases annually (Oliveria et al. 2019), and to a greater use of rescue medication, doctor visits and hospital admissions (Kim et al. 2015; Annesi-Maesano et al. 2013; Brugha & Grigg 2014; Simoni 2010). Also, long-term exposure to $PM_{2,5}$ was directly related with increments of 6–13% in cardiopulmonary mortality (WHO 2012). Furthermore, exposure to $PM_{2,5}$ was responsible for an increase of 20% in human deaths (from 3,5 to 4,2 million deaths till 2015) and is now expected to increase >50% thus reaching 6,6 million deaths in 2050 (Landrigan et al. 2017). Besides health, cognitive development i.e. working memory, attention, learning, school achievement and behaviors are also affected by indoor air pollution in children 7–10 years of age attending schools in high polluted areas (Sunyer et al. 2015).

Table 3. Outdoor values of $PM_{2,5}$ and CO_2 concentrations, temperature and relative humidity measured in February at the end of the third class

	PM2,5 (μg/m³)	CO2 (ppm)	Temperature (°C)	Relative humidity (%)
School 1	311	953	9	46
School 2	79	1356	8	38
School 3	167	1154	9	44
School 4	66	2826	8	39

In Search study, increased levels of CO_2 were significantly associated with classroom level, number of children in the classroom, <2m²/person in the classroom or <6m³/person in the classroom, as well as openable windows <2m² and less frequent window opening. Our results also suggested an effect of classroom level, but unexpectedly, levels of CO_2 were still above the recommended one despite significantly more space per m³/person in the classroom (19,0–20,2 m³/per person) and also did not necessarily decline with windows opening. Moreover, the increase in CO_2 concentration despite the ventilation was registered in schools 2 and 3. High outdoor CO_2 concentrations and/or improper classroom ventilation during heating season generally lead to a serious problem of increase in indoor CO_2 concentration. Furthermore, like with $PM_{2,5}$ concentrations in our study and under the same circumstances, one would expect high CO_2 values in both schools 1 and 4. However, unexpectedly, this was shown only in school 4 while in school 1 high $PM_{2.5}$ concentrations persisted but CO_2 concentrations declined to the lowest ones. This showed that, despite the same "none windows opening in school 4 or its short duration in school 1", the concentrations of $PM_{2,5}$ and CO_2 changed differently suggesting the impact of other factors. Indeed, next to difference in classroom level, also flooring, school location, vicinity of the road or farm, type of heating and fuel, insulation materials, as well as different indoor activities may potentially explain the unexpected dynamics of concentration of $PM_{2.5}$ and CO_2.

CO_2 concentration of above 1000 ppm is related to an increase in absenteeism frequency for approximately 10–20% (Martenies & Batterman 2018). Concentration above 1500 mg/m³ causes unpleasant air and a negative effect on circulatory, cardiovascular and autonomic nervous systems, including psychomotor and cognitive functions (Gilraine 2020; Roth 2020; Polidori 2013; Shendell 2004). The most common first symptoms are fatigue and headache followed by nausea and dizziness, tachycardia, memory disorder and lack of concentration, blurred sight, sweating, restlessness, vomiting, redness of the skin and even panic attacks (De Giuli 2012). Even though the rise of CO_2 over 1500 mg/m³ is followed by an unpleasant smell, students in the classroom do not notice it because the sense of smells gets quickly adapted to new odors (Coley 2007).

Besides PMs and CO_2, extreme temperatures and relative humidity can also cause adverse health effects primarily on the human respiratory system (Choo et al. 2015, Wolkoff 2018). While high relative humidity can cause unpleasant smell and the feeling of suffocation, the low one causes desiccation of mucus membranes in upper airways with coughing, epithelial damage and reduced mucociliary clearance making airways more susceptible to viral infection (Wolkoff 2018). The favorable temperature and relative humidity in school 4 compared to urban school 1 could be possibly explained by the difference in the vicinity of water/river and the level of sun exposure, but also in classroom level, type of heating system and fuel, type of insulation and other indoor materials and activities. Our preliminary results showed the urgent need for better temperature and humidity monitoring in schools.

This was the first study of this kind in elementary schools that took into account different internal and external characteristics when assessing IAQ in classrooms, as well as in the setting of Covid-19 restrictions. However, this study had several limitations. As this was a pilot study with a limited number of schools included and limited IAQ parameters measured, the conclusions cannot be generalised nor the causality can be inferred.

Thus, new larger studies through all seasonal and meteorological conditions in more schools measuring more IAPs, especially those with potential or proven long-term adverse health effects, are needed. Further studies should also include analysis of molecular biomarkers, e.g. DNA damage as a reliable biomarker of exposure to various genotoxins that may help to identify individuals at increased risk of IAQ related long term adverse effect. Also, measures included in Green building certification that may affect IAQ such as air conditioning system, sustainable and efficient heating, natural non-toxic materials for construction and indoor finishing, natural materials for furnishing, safe equipment, cleaning and waste management as well as landscape architecture design making optimal barriers to roads, farms, and other pollution sources should be validated.

Finally, it is of utmost importance for the society to assure that children, and especially the most vulnerable ones, breath clean air. This is crucial for their healthy childhood and growing up and successful academic development. Moreover, on such foundations it is more likely to achieve their later productive life and contribution to the society. With the preventable measures and modern technology, ensuring high indoor and outdoor air quality is not an unattainable challenge.

CONCLUSION

Despite the anti-epidemic restrictions with recommended frequent ventilation and limited number of students in the classroom, measured IAQ parameters in the heating season were mainly out of the recommended values. As students and their activities may also be the sources of $PM_{2.5}$ and CO_2, further deterioration of IAQ could be expected if all students had been present in the classroom. Finally, to assure a healthy school environment in the heating season further optimization of both indoor and outdoor conditions is needed in both pandemic and non-pandemic settings.

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Conflict of interest: None to declare.

Contribution of individual authors:

Aida Kulo: design of the study, study conduct, literature searches and analyses, interpretation of data, manuscript writing, approval of the final version.

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SAŽETAK

Uvod: Kvaliteta unutarnjeg zraka u učionicama utječe na zdravlje i akademske sposobnosti djece. Cilj ove pilot studije je bio odrediti kvalitet unutarnjeg zraka u osnovnim školama različitih unutrašnjih i vanjskih karakteristika u uslovima COVID-19 epidemije.
Metode: Parametri kvalitete unutarnjeg zraka: masena koncentracija fine čestične tvari ($PM_{2,5}$), koncentracija CO_2, temperatura i relativna vlažnost su mjereni simultano u četiri osnovne škole/učionice tijekom oktobra (sezona bez grijanja) i četiri naredna mjeseca (uključujući raspust u januaru) u sezoni grijanja. Mjerenje je vršeno u vrijeme protuepidemijskih restrikcija (≤13 učenika u učionici, često provjetravanje učionice).
Rezultati: Tokom oktobra, osim u jednoj školi, koncentracije $PM_{2,5}$ su bile ispod gornje preporučene granice (25μg/m³), ali su u svim školama počele rasti u periodu grijanja. Najviše koncentracije $PM_{2,5}$ su registrovane u dvije škole, sa zatvorenim i nakratko otvorenim prozorima. Koncentracije CO_2 su uglavnom bile u preporučenom rasponu (do 1000ppm) osim u školi sa konstantno zatvorenim prozorima, i u tri škole u februaru kada su

mjerene više koncentracije. Osim u jednoj istoj školi, i u januaru, i temperatura i relativna vlažnost zraka su bile izvan preporučenog raspona (24,0–27,0°C u sezoni bez grijanja; 20,0–24,0°C u sezoni grijanja; i 45–55%) sa temperaturom uglavnom iznad, a vlažnošću zraka ispod preporučenih vrijednosti u tri škole. Najveće devijacije u temperaturi i relativnoj vlažnosti su zabilježene u školama u urbanoj sredini. Registrovane razlike su najvjerovatnije posljedice različitih unutarnjih i vanjskih karakteristika škola.
Zaključak: Uprkos protuepidemijskim restrikcijama, većina mjerenih parametara su bili van preporučenih vrijednosti u sezoni grijanja. Dodatno opadanje kvalitete unutarnjeg zraka bi se moglo očekivati u prisustvu svih studenata u učionici. Konačno, za stvaranje zdravog školskog okruženja u sezoni grijanja, u pandemijskom ali i u ne-pandemijskom period, potrebna je daljnja optimizacija unutarnjih i vanjskih karakteristika škola.

Ključne riječi: kvalitet unutarnjeg zraka, učionica, certificirana zelena gradnja, zdravlje, COVID-19