DE GRUYTER
OPEN

10.1515/sjph-2017-0031 Zdr Varst 2017; 56(4): 227-235

Matic B, Rakic U, Jovanovic V, Dejanovic S, Djonovic N. Key factors determining indoor air PM_{10} concentrations in naturally ventilated primary schools in Belgrade, Serbia. Zdr Varst 2017; 56(4): 227-235.

KEY FACTORS DETERMINING INDOOR AIR PM_{10} CONCENTRATIONS IN NATURALLY VENTILATED PRIMARY SCHOOLS IN BELGRADE, SERBIA

KLJUČNI DEJAVNIKI, KI VPLIVAJO NA KONCENTRACIJO DELCEV PM_{10} V NOTRANJEM ZRAKU NARAVNO PREZRAČEVANIH OSNOVNIH ŠOL V BEOGRADU V SRBIJI

Branislava MATIC[1*], **Uros RAKIC**[1], **Verica JOVANOVIC**[1], **Snezana DEJANOVIC**[1], **Nela DJONOVIC**[2]

[1]Institute of Public Health of Serbia “Dr Milan Jovanovic Batut”, Environmental Health and School Hygiene Department, Dr Subotica 5, 11000 Belgrade, Serbia
[2]University of Kragujevac, School of Medicine, Institute of Public Health of Kragujevac, Serbia

Received: May 31, 2016
Accepted: Jul 27, 2017

Original scientific article

ABSTRACT

Keywords:
indoor air quality, classrooms, particulate matter, PM_{10}, primary schools, exposure, Serbia

Introduction. Indoor air quality (IAQ) is rated as a serious public health issue. Knowing children are accounted as more vulnerable to environmental health hazards, data are needed on air quality in schools.

Methods. A project was conducted from 2007 until 2009 (SEARCH, School Environment and Respiratory Health of Children), aiming to verify links between IAQ and children’s respiratory health. Study was conducted in ten primary schools on 735 children, in 44 classrooms. Children were randomly selected. Research tools and indicators used for children’s exposure to school environment were indoor and outdoor pollutants, two standardized questionnaires for school and classroom characteristics. In both classroom air and ambient air in front of them we measured, during a 5-day exposure period for continuous 24h measuring: carbon monoxide, carbon dioxide, indoor air temperature, relative humidity, and PM_{10} during classes.

Results. PM_{10} concentrations were significantly most frequent in an interval of ≥80.1µg/m^3, that is, in the interval above 50µg/m^3. Mean PM_{10} value was 82.24±42.43 µg/m^3, ranging from 32.00µg/m^3 to of 197.00µg/m^3.

Conclusion. The increase of outdoor PM_{10} concentration significantly affects the increase of indoor PM_{10}. A statistically significant difference exists for average IAQ PM_{10} concentrations vs. indicators of indoor thermal comfort zone ($p<0.0001$); they are lower in the classrooms with indicators within the comfort zone. Moreover, dominant factors for the increase of PM_{10} are: high occupancy rate in the classroom (<2m^2 of space per child), high relative humidity (>75%), and indoor temperature beyond 23°C, as well as bad ventilation habits (keeping windows shut most of the time).

IZVLEČEK

Ključne besede:
kakovost notranjega zraka, učilnice, trdni delci, PM_{10}, osnovne šole, izpostavljenost, Srbija

Uvod. *Kakovost notranjega zraka (IAQ) predstavlja resen javnozdravstveni problem. Ker so otroci bolj ranljivi za okoljska zdravstvena tveganja, so potrebni podatki o kakovosti zraka v šolah.*

Metode. *Med leti 2007 in 2009 se je izvajal projekt (SEARCH, School environment and respiratory health of children – Šolsko okolje in respiratorno zdravje otrok), katerega namen je bil dokazati povezave med IAQ in respiratornim zdravjem otrok. Raziskava se je izvajala med 735 otroki v 44 učilnicah desetih osnovnih šol. Otroci so bili izbrani naključno. Zunanji in notranji onesnaževalci ter dva standardizirana vprašalnika o značilnostih šol in učilnic so služili kot raziskovalna orodja in kazalniki izpostavljenosti otrok šolskemu okolju. V zraku pred učilnicami in v njih so v 5-dnevnem neprekinjenem obdobju merjenja merili: ogljikov monoksid, ogljikov dioksid, temperaturo notranjega zraka, relativno vlažnost in PM_{10}.*

Rezultati. *Koncentracije PM_{10} so bile pomembneje najpogostejše v intervalu ≥80,1 µg/m^3, torej v intervalu nad 50 µg/m^3. Povprečna vrednost PM_{10} je bila 82,24±42,43 µg/m^3 in je segala od 32,00 µg/m^3 do 197,00 µg/m^3.*

Zaključek. *Povečanje koncentracij PM_{10} v zunanjem zraku pomembno vpliva na povečanje PM_{10} v notranjem zraku. Pojavljajo se statistično pomembne razlike med koncentracijami PM_{10} IAQ glede na kazalnike območja notranjega toplotnega ugodja ($p<0,0001$); nižje so v učilnicah s kazalniki znotraj območja udobja. Poleg tega so glavni vzroki za večje vrednosti PM_{10} sledeči: velika zasedenost učilnice (<2 m^2 prostora na učenca), visoka relativna vlažnost (>75 %) in temperatura notranjega zraka nad 23 ºC, poleg tega pa tudi slabe prezračevalne navade (zaprta okna večino časa).*

***Corresponding author:** Tel: + 381 641 771 746; E-mail: damjanko98@yahoo.com

NIJZ National Institute of Public Health

1 INTRODUCTION

The quality of indoor air of homes, offices, or other public or private dwellings could be accounted as one of the essential determinants of a healthy life and wellbeing of each individual (1). School indoor air quality (IAQ) is expected to have a key role in the assessment of children's personal exposure to air pollution, concerning the fact that they spend at least a third of their time inside school buildings, approximately 7 hours a day (2-5). Children are particularly vulnerable to all types of pollutants, because their breathing and metabolic rates are high. In a school, they have much less floor space than adults working in a typical office. Their breathing zone tends to be closer to pollutant sources, such as a new carpet, and less likely to be well ventilated, as it is below the window level. The immune system of young children is yet immature, and exposure to pollutants can mean allergic reactions or ill health (6).

Poor indoor environment in schools may be attributed to three primary causes: inexistence or inadequate operation and maintenance of ventilation systems, infrequent and unthoroughly cleaned indoor surfaces, and a large number of students in relation to room area and volume, with constant re-suspension of particles from the surface (1). Furthermore, IAQ can be attributed to various phases of the building process, including poor site selection, choice of materials, roof design, poor construction quality, improper installation, or any number or combination of these factors (7). Therefore, it is of utmost importance to provide good IAQ in classrooms, to help minimize these effects (8, 9). Sources of IA (indoor air) pollution could be: furnishings, IT equipment, bio-effluents, and external pollutants, such as nitrogen-dioxide and carbon-monoxide (3, 10-12). In the indoor environment, in which people spend most of their time, both indoor and outdoor sources contribute to PM levels. Indoor PM is affected by ambient concentrations, air exchange rates, penetration factors, as well as deposition and re-suspension mechanisms. In this complex microenvironment, activities such as cleaning, walking, playing, and, particularly, smoking cause the formation of PM in indoor air (13,14).

The main objective of this paper was to study the difference of PM_{10} concentration values, sampled both inside classrooms of ten Belgrade primary schools and in ambient air in front of them, and relate it to different classroom and school characteristics, using SEARCH Project methodology. A specific objective was to study the difference of concentration of the PM_{10} measurements inside and outside the chosen classrooms. In addition, we aimed to correlate a specific quantitative indicator of the thermal comfort zone, as given by the ASHRAE Standards (4), that is, space occupancy (<2m^2 of indoor space per child, not suitable), to the measured values of indoor PM_{10}.

2 METHODOLOGY

2.1 Sampling Site Description

The cross-sectional SEARCH (School Environment and Respiratory Health in Children) study has involved 6 European countries (Albania, Bosnia and Herzegovina, Hungary, Serbia, Slovakia, and Italy). In Serbia, the research was undertaken in the capital city of Belgrade. The project has defined that a sample of 10 schools per country shall be enough to get a clear picture on the level of indoor exposure of children in primary schools. They were chosen (sampled) to be with heterogeneous characteristics. Primarily, schools were grouped by their location, i.e. the level of their exposure to potential sources of air pollution in their vicinity (be it traffic or industrial facility), as suburb schools, schools in broader urban area, and downtown ones, shown in Table 1 (15). As for the vicinity of busy traffic, it can be easily comprehended by consulting the GIS map of their address, together with traffic characterisation (Figure 1). The criterion for the choice of a classroom was its orientation, either towards the street or to the school yard.

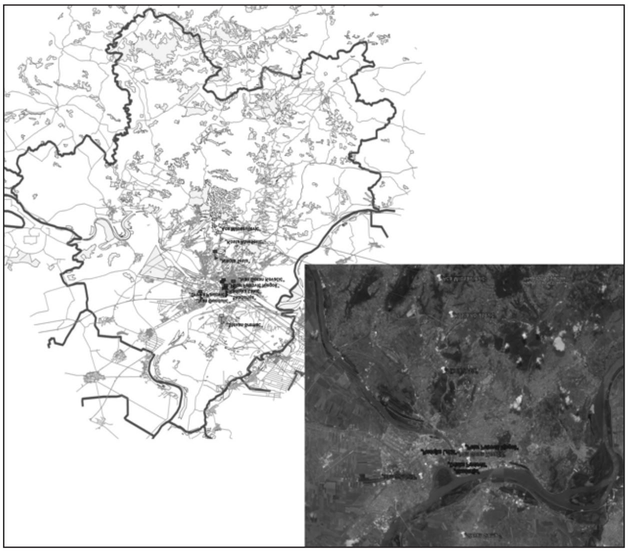

Figure 1. GIS map of 10 schools' geographic distribution on the Belgrade City map

Table 1. Characteristics of sampling sites.

School name	School code	Spatial characteristics of the surroundings	GIS coordinates
“Aca Milosavljevic”	1	Suburb Rušanj village, in the valley downhill the regional highway;	44°41’01,10” N 20°26’20,86” E
“Kosta Abrašević”	2	Suburb Resnik, residential area, trees in between the street and school	44°52’20,13” N 20°27’18,7” E
“Nikola Tesla”	3	Rakovica, suburban municipality, ex-industrial zone, ordinary urban traffic mode	44°42’33,95” N 20°27’06,52” E
“I. G. Kovačić”	4	Broad city centre, isolated from dense traffic, residential area;	44°49’18,19” N 20°24’15,75” E
“Skadarlija”	5	Downtown, high density traffic, backyard towards pedestrian zone, bus stop in front	44°44’30,27” N 20°25’44,89” E
“Stevan Sremac”	6	Borča III, urbanized suburb, with no heavy traffic	44°48’17,27” N 20°29’01,08” E
“Drinka Pavlović”	7	Downtown, close to two busy streets, 1 tunnel	44°48’16,20” N 20°27’43,91” E
”Petar Petrović Njegoš”	8	Downtown, high traffic density	44°48’21,72” N 20°27’21,81” E
“Radojka Lakić”	9	Squeezed between two streets with high density traffic (lots of heavy traffic), downtown, next to the Central Rail Station	44°49’06,12” N 20°27’49,41” E
“Ivan Gundulić”	10	New Belgrade, broader urban zone, frequent traffic	44°48’48,32” N 20°27’54,66” E

2.2 Monitoring Campaign

For both indoor and ambient air PM10 sampling, a portable HAZ-DUST EPAM-5000 particulate monitor (Ambient Portable Direct Reading Aerosol Monitor for Measuring Lung Damaging Airborne Particles) was used. It uses light scattering to measure particle concentration and provide real-time determinations and data recordings of airborne particle concentration in mg/m^3. By the model specification, its accuracy is ±10% to filter gravimetric SAE fine test dust; sensing range: .001-20.0 mg/m^3 or optional .01-200.0 mg/m^3 or 0.1-2000.0 mg/m^3; particle size range is .1-100 µm, and precision ±.003 mg/m^3 (3 µg/m^3) (16). For indoor air monitoring, it was positioned in classrooms, at 1.5 m height, away from the walls, to prevent influence of chipping. The monitor was positioned outside of the school building, in front of the indicated classroom, for ambient air PM$_{10}$ sampling. Monitoring lasted for one whole working week, in both school shifts, while the children were present indoors, only. Monitoring lasted for 4 days during heating season in February 2008, simultaneously with the procedures undertaken in Albania, Bosnia and Herzegovina, and Slovakia. During each of the 4 measuring days, authors would fill in the checklist of the questionnaire for the classrooms, with details on the presence of pupils, and conditions concerning natural ventilation through the windows. Measuring instruments were looked after by the teachers (indoor) and authors who were mostly present in the school to check upon the equipment. The following measurements took place in the chosen classrooms: Combination of diffuse sampling during a 4-day exposure period for formaldehyde (HCHO), nitrogen dioxide (NO2), BTX, and continuous 24h measuring for carbon monoxide (CO), carbon dioxide (CO2) and PM$_{10}$, during school hours. Air temperature and relative humidity were measured as well. Parallel to these IAQ monitoring activities, outdoor air quality was followed for the same specific pollutants, close to school building (selected classroom). Besides air sampling procedures, the study protocol included two standardized questionnaires, namely: for school characteristics (filled in by the school administrator); for classroom characteristics (filled in by the teacher holding classes in it).

2.3 Statistical Methodology

Simple descriptive statistics, such as mean ± standard deviation, was used for continuous variables, IAQ and OAQ PM$_{10}$, the number and % of IAQ interval distributions, by schools and schools’ position, while numbers (percentages) were used for categorical variables. The Kolmogorov-Smirnov test was used to check if IAQ and OAQ PM$_{10}$

had a normal distribution. Quantitative variables were compared using ANOVA F test, and categorical variables were compared using contingency tables and Chi-Square or Kruskal Wallis test. Chi-square test was used to compare IAQ PM_{10} between groups – schools or schools' position. For correlations between variables, we used Pearson Correlation for the linear relationship between two variables, by schools. A P-value less than 0.05 were considered statistically significant.

3 RESULTS

3.1 Geographic Positions of Schools

Table 2 shows comparative values of IAQ PM_{10} and OAQ PM_{10} by groups of schools. Both indoor and outdoor PM_{10} measured values are significantly higher in suburban schools than in those located in the broader urban zone: (for PM_{10} IAQ: K-W test=107.86, $p<0.0001$; PM_{10} OAQ: K-W test=39.43, $p<0.0001$). A similar level of significance appears when correlating values measured in suburban schools, with the values in schools located in the strictly urban zone: (K-W test=93.01; $p<0.0001$), and for PM_{10} OAQ, (K-W test=27.74; $p<0.0001$).

Indoor PM_{10} concentrations are significantly lower in schools located within a broad urban zone, when correlated to ones in a strictly urban zone, i.e.downtown (K-W test=12.943, $p<0.0001$). On the other hand, it does not count in the case of outdoor PM_{10} values (K-W test=2.228, $p=0.135$). PM_{10} IAQ measured values are significantly highest in suburban schools, (K-W test=133.454, $p<0.0001$), together with PM_{10} OAQ, (K-W test=69.86, $p<0.0001$).

Among schools, a statistically significant difference is proved for the distribution of IAQ PM_{10} concentration ($p<0.0001$). School 4 has significantly higher frequency of measured values IAQ PM_{10} in the range lower than 50 g/m^3. On the other hand, schools No. 1, 2, 3 and 8 had highest average values, and in all of them each of measured indoor concentrations was in the interval beyond 50 μg/m^3 (Table 3).

Table 2. IAQ and OAQ PM10 concentration related to school's geographic positions (μg/m^3).

Type of schools by location		No. of exposed children	Mean	SD	95% Cor Mean		Median/ Range	Min	Max
					Lower	Upper			
PM_{10} IAQ	**Suburb schools**	244	109.18	47.66	103.17	115.19	96/164	33	197
	Schools in broader urban area	220	66.08	37.36	61.12	71.05	53/126	32	158
	Downtown	271	71.09	26.90	67.88	74.31	70/79	32	111
	Total	735	82.24	42.43	79.17	85.31	70/165	32	197
PM_{10} QAQ	**Suburb schools**	244	153.90	130.39	137.46	170.34	116/515	34	549
	Schools in broader urban area	220	83.46	55.77	76.05	90.87	55/168	22	190
	Downtown	271	77.30	28.53	73.89	80.72	80/89	30	119
	Total	735	104.57	89.85	98.07	111.08	82/527	22	549

Table 3. Interval distribution IAQ PM10 Concentration >50 or ≤49.9 μg/m^3 by schools

PM_{10} ranges	School 1	School 2	School 3	School 4	School 5	School 6	School 7	School 8	School 9	School 10
≤49.9 μg/m^3	0.0	0.0	0.0	**67.2**	39.7	23.4	32.1	0.0	57.8	37.8
>50 μg/m^3	**100.0**	100.0	100.0	32.8	60.3	76.6	67%	**100.0**	42.2	62.2

The following Table 4 presents indoor PM_{10} mean concentrations (µg/m^3), standard deviation, median and range. The maximum concentration values of PM_{10} (162.12±41.93 µg/m^3) was registered in school No. 2, while a significantly lower concentration value of PM_{10} (44.72±12.48 µg/m^3) was at school 4 ($p<0.001$), and its value is below 50 µg/m^3.

Ambient air mean concentration of PM_{10} (µg/m^3), together with standard deviation, median and range by groups and schools, is given in Table 5. The maximum concentration values of PM_{10} in ambient air (320.82±137.79 µg/m^3) were in front of a suburban school No.2, while significantly lower concentration values of PM_{10} OAQ (38.33±9.65 µg/m^3) were outside school 6, located in the broad urban area, slightly hidden away from frequent traffic flow ($p<0.01$), with a value below 50 µg/m^3. The highest average values of both IAQ PM_{10} and OAQ PM_{10} concentration are accounted to school 2 (suburb schools).

Table 4. IAQ PM_{10} (µg/m^3) concentration by schools.

School Groups	School	PM_{10} (µg/m^3)	IAQ	Ci 95%		Median	Range
		Mean	SD	Lower	Upper		
Suburban	„A.Milosavljevic“	109.16	18.440	105.48	112.84	105.00	46.00
	„K. Abrasevic“	**162.12**	41.926	151.97	172.27	183.00	106.00
	„S. Sremac“	62.47	23.592	57.11	67.82	52.00	63.00
Broad urban area	„Nikola Tesla“	99.70	45.620	89.35	110.06	72.00	107.00
	„I. G. Kovacic“	**44.72**	12.479	41.53	47.92	38.00	30.00
	„I. Gundulic“	50.40	6.224	49.03	51.77	53.00	16.00
Downtown	„Skadarlija“	58.24	18.276	54.12	62.36	70.00	46.00
	„D. Pavlovic“	65.68	26.899	58.26	73.09	51.00	63.00
	„P.P. Njegos“	103.87	8.523	101.92	105.82	110.00	18.00
	„R. Lakic“	52.31	11.222	49.51	55.12	44.00	26.00

Table 5. Outdoor PM^{10} (µg/m^3) concentration by schools.

School Groups	School	PM_{10} (µg/m^3)	OAQ	Ci 95%		Median	Range
		Mean	SD	Lower	Upper		
Suburban	„A.Milosavljevic“	105.84	26.945	100.46	111.21	106.00	78.00
	„K. Abrasevic“	**320.82**	137.797	287.47	354.18	309.00	380.00
	„S. Sremac“	68.27	36.277	60.04	76.51	41.00	85.00
Broad urban area	„Nikola Tesla“	134.00	55.399	121.43	146.57	141.00	135.00
	„I. G. Kovacic“	80.33	35.626	71.20	89.45	75.00	84.00
	„Ivan Gundulic“	**38.33**	9.648	36.21	40.45	42.00	26.00
Downtown	„Skadarlija“	83.64	30.003	76.88	90.41	96.00	87.00
	„D. Pavlovic“	69.85	31.935	61.05	78.65	52.00	83.00
	„P.P. Njegos“	98.00	13.862	94.83	101.17	101.00	46.00
	„R. Lakic“	51.17	3.444	50.31	52.03	51.00	9.00

Descriptive statistical analysis of the data for particulate matter mass concentrations (PM_{10}) measured outdoors and in the classrooms, by schools is given in Table 6. None of the 10 schools satisfies the World Health Organization (WHO) standard for PM_{10} annual average of 20 µg/m^3 (17, 18). However, they meet the National Ambient Air Quality Standards (12) and WHO standards for PM_{10} 24-hour average, which have been set at 150 µg/m^3 and 50 µg/m^3, respectively (19).

Table 7 presents the distribution of the occupancy rate (according to ASHRAE) for each school, in m^2 per present child in the indicated classroom. Values are given as the percentage of children exposed to overcrowdedness (<2m^2/per child), or to convenient spatial conditions (>2m^2/per child). Indicators of crowdedness are the number of children in the classroom (less/more than 20), and space available in the classroom, per one child, of less/more than 2m^2 (4). Statistically significance is proven for the distribution of occupancy rate (m^2/per child), for each school, $\chi2=340.70$, $p<0.0001$.

4 DISCUSSION

As an outcome of our study, when differentiating between OAQ PM10 and IAQ PM10 concentration values in relation to some classroom and school characteristics, we singled out the following moments: the highest average values of IAQ PM10 and OAQ PM10 concentration were measured in the school No. 2 (suburb school), while only in one school measured values IAQ PM10 were below 50 µg/m^3, that is in the school No. 4. The school No. 10, located in New Belgrade, in a broader urban zone with frequent traffic, had PM10 outdoor mean value below 50 µg/m^3, which could be explained with the terrain's topography. New Belgrade is, in geographical means, a flat terrain, with broad boulevards and widely spread buildings, belonging to the geographical entity of the Pannonian plain, enabling the build-up of high ambient air concentrations of traffic-related pollutants. This particular school is located in a residential block, built in the 1960s. School building is encircled by greenery and residential buildings, acting as

Table 6. Correlations between IAQ and OAQ by school (signif.)

School	PM_{10} outdoor median (µg/m^3)	PM_{10} indoor median (µg/m^3)	R	P	N
„A.Milosavljevic“	106.00	105.00	0.799	0.000	99
„K.Abrasevic”	309.00	183.00	0.756	0.000	68
„N.Tesla”	141.00	72.00	0.457	0.000	77
„I.G.Kovacic”	75.00	38.00	0.956	0.000	61
„Skadarlija”	96.00	70.00	0.598	0.000	78
„S.Sremac”	41.00	52.00	0.744	0.000	77
„D.Pavlovic”	52.00	51.00	0.937	0.000	53
„P.P.Njegos”	101.00	110.00	0.725	0.000	76
„R.Lakic”	51.00	44.00	0.160	0.207	65
„I.Gundulic”	42.00	53.00	0.453	0.000	82

Table 7. Child occupancy rate per school distribution (m^2/per child) vs. PM_{10} values (µg/m^3), by schools.

School No.	School name	<2 m^2/child	>2 m^2/child	IAQ PM_{10} mean
1	„A.Milosavljevic“	77.8	22.2	109.16
2	„K.Abrasevic”	/	100	162.12
3	„N.Tesla”	/	100	99.70
4	„I.G.Kovacic”	16.4	83.6	44.72
5	„Skadarlija”	38.6	61.4	58.24
6	„S.Sremac”	/	100	62.47
7	„D.Pavlovic”	/	100	65.68
8	„P.P.Njegos”	47.4	52.6	103.87
9	„R.Lakic”	/	100	52.31
10	„I.Gundulic”	/	100	50.40

a physical barrier to three streets with very busy traffic, of which one is the E-75 highway. It was, moreover, reported by the City of Belgrade Institute of Public Health, that in 2008, a series of days in a row were characterized with SE (south-east) wind ('Košava'), with episodes of wind speed reaching 12m/s, which caused a decrease of concentration of all ambient air pollutants measured by this institution (20).

A statistically significant correlation exists between PM10 indoor and outdoor concentration for each school ($p<0.0001$), except for the school No. 9, 'Radojka Lakic' ($p=0.207$), although it is located in a strictly urban zone, close to the juncture of two streets with very busy traffic. The increase of outdoor PM10 concentration is significantly correlated to the increase of indoor PM10 values (except for the school No. 9).

Considering this school, located close to the heavy traffic and Central rail station, with no statistical significance between indoor and outdoor measurement, we can conclude that, in this case, indoor concentration could be influenced by activities and movements of occupants, allowing re-suspension of previously deposited particles or their delayed deposition or settling. Fromme et al. found an average indoor particulate matter concentration higher than corresponding outdoor level in a German primary school (21). Similar was confirmed in a Belgian survey (22). Oeder et al. detected indoor PM10 concentration even 5-fold higher than outdoor ones in six schools in Munich (23). In addition, the presence of children, together with their movements, could affect indoor PM levels through the interception of personal clouds (primarily comprising of course particles), recorded by sampling devices (1).

In the school No. 1, which is both in the suburb and has all its measured values of IAQ PM10 beyond 50 μg/m^3, with an average PM10 IAQ of 109.16±18.44 μg/m^3, a significantly higher number of children is exposed to classroom indoor environment in a space with less than 2 m^2 per child. Concerning the fact that there is no busy traffic close to the school, high occupancy rate, together with bad ventilation habits and cleaning practice could be the reason for such results. This may be due to large number of students in relation to the room area and volume, whose movements cause re-suspension of settled particles (24).

In the school No. 8, 47.4% of its pupils have less than 2 m^2 per child, while all measured IAQ PM10 were above 50 μg/m^3, in which case the high occupancy rate could be accounted for one of the reasons for it. Some authors have determined that re-suspension is a significant factor affecting indoor particle concentration with suspension rates increasing with the particle size (25).

The school No. 4 is worth mentioning, with only its 16.4% pupils residing in the space with <2 m^2 per child, located in a broad urban zone of the city. IAQ PM10 values were below 50 μg/m^3, with the average PM10 IAQ concentration being the lowest compared to other schools, 44.72±12.48 μg/m^3.

On the contrary, the school No. 3 has 100% PM10 IAQ measurements in space with >2 m^2 per child, located in a broader urban zone, with all measured values of IAQ PM10 beyond 50 μg/m^3. The average indoor PM10 concentration in it is 99.70±45.62 μg/m^3. This school is cleaned mostly with the broom, and combined with the use of chemicals. This cleaning practice, being predominant as a cleaning pattern in this school, obviously facilitates the process of particle re-suspension (24).

As one of the defined elements of the thermal comfort zone, occupancy rate was chosen to be one of the key indicators in this study, together with CO2 indoor concentration, relative humidity, and classroom air temperature. Statistically significant smaller chances exist for formaldehyde indoor concentrations to be below 1.01 mg/m^3 in classrooms with more than 2 m^2 of space per child. For indoor CO2 concentration to increase above 1000 ppm, the number of children in the classroom above 20 ($N>20$) is a statistically significant predictor. Namely, chances for CO2 concentrations to be higher than 1000 ppm are 3.6-fold bigger in classrooms hosting more than 20 children. For indoor (classroom) air temperature within a comfort zone, a statistically significant predictor is classroom crowdedness, i.e. space in square meters per child. In fact, chances for indoor temperature to be within the comfort zone are less likely to occur in classrooms with less than 2 m^2 of space per child (4). For indoor values of relative air humidity, a statistically significant predictor is classroom crowdedness, i.e. space in square meters per child. In other words,, chances for this parameter to be within the comfort zone are close to 18-fold higher in classrooms hosting less than 20 children. Chances for PM10 to be below 50μg/m^3 are smaller, with high statistical significance, in classrooms hosting more than 20 children, having a blackboard, with chalk to write on.

The average indoor PM10 concentrations are lower in the classrooms where indicators of thermal comfort zone are satisfactory. In the school No. 4, the average indoor PM10 concentration is lower in classrooms with achieved standards for indoor comfort zone indicators, with high statistical significance Z - test=6.540, $p<0.0001$, while in the schools No. 5 ($Z=0.105$, $p=0.916$), No. 8 ($Z=1.614$, $p=0.107$) and No. 10 ($Z=0.948$, $p=0.343$) it is lower, but with no such high significance. Significantly highest mean values of IAQ PM10 concentration was measured in the schools 1, 2, 3 and 8, where comfort zone was not achieved ($p<0.001$).

Values of classroom indoor PM10 concentrations, from measurements in similar studies in different countries, during the heating season, are close to the values reported in this study in Serbia: in three schools in Portugal, PM10 average concentrations ranged from 30 to 146 μg/m^3; in a German study implemented in 64 urban and rural schools, it was 105 μg/m^3 (16.3-313.2 μg/m^3), while in HESE study, IAQ was monitored in 21 schools, both urban and rural, with the average PM10 concentration 112 μg/m^3 (91-133 μg/m^3) (1, 10, 26).

In most of the SEARCH1 countries, ambient PM10 concentrations were significantly increased in school zones close to frequent traffic streets, compared to those located further from such sources of air pollution. On the other hand, this difference in the traffic frequency of streets surrounding schools, has not significantly influence IAQ PM10 concentrations measured in classrooms, pointing that key sources of this pollutant are mainly in classrooms themselves (15). In the case of Belgrade study, as a part of the mentioned research, 36.2% of pupils study in classrooms with I/O PM10 ratio beyond 1.0, where the key source of PM10 is within the room; 3.7% is in classrooms with the ratio equal to 1.0., while 60.1% attend classes in rooms with the ratio below 1.0, where the source of a particulate matter is in ambient air, mostly from traffic in the vicinity of school buildings.

Although the city is located close to two coal burning power plants (Obrenovac, Kolubara), traffic is seen as the most powerful source of air pollution. Air back trajectories analysis showed that the prevalence of stagnant or week flow regimes (calm conditions) favours the suspension and accumulation of particles produced locally, resulting at the elevation of suspended particles levels (20, 27).

If we compare the location of Belgrade, on the banks of Sava River, with another region on its banks in Zasavje Region in Slovenia, with PM10 ambient air concentration, we spot some differences. Firstly, it is an issue of topography, as Zasavje is surrounded by steep hilly terrain, while Belgrade spreads in parts of the Pannonian Plain. Secondly, sources of air pollution are different in these two cases. In Zasavje, it is the case of industrial PM10 emissions (36.3μg/m^3), while in SEARCH1 Belgrade study, traffic was attributed as the key source for high PM10 levels (104.7 μg/m^3) (15, 28).

5 CONCLUSIONS

The majority of surveyed children is exposed to high indoor PM10 concentrations (560/735; 76.2%). Maximum PM10 values were measured in suburban schools, away from busy traffic. The increase of outdoor PM10 concentration significantly affects the increase of indoor PM10 values. Concerning an insufficient achievement of standards for indicators of indoor thermal comfort zone, dominant factors for the increase of PM10 are: high occupancy rate in the classrooms (<2 m^2 of space per child), high relative humidity (>75%) and indoor temperature beyond 23°C; bad ventilation habits (keeping windows shut most of the time).

As the authors suggest, measures for the improvement of conditions in classrooms are as follows: schools should be built in places not directly affected by heavy traffic or industry, or any other polluting establishments in the neighbourhood; crowdedness should be avoided in the classrooms; appropriate ventilation regime of the classrooms should be introduced in order to provide good indoor air quality during the whole period of teaching hours, especially in classrooms directed towards crowded streets with presumably high ambient air pollution; in schools being ventilated only through natural means, but located close to traffic-induced air pollution, installing air-conditioning units should be taken into consideration. Cleaning practices should be standardized.

ACKNOWLEDGMENTS

The financial support for the SEARCH project by the Italian Ministry for the Environment, Land and Sea is highly appreciated by the authors.

CONFLICTS OF INTEREST

The authors declare that no conflicts of interest exist.

FUNDING

Italian Ministry for the Environment, Land and Sea.

ETHICAL APPROVAL

In the case of the Republic of Serbia, if there is no direct contact with body fluids, tissues, personal contact concerning individual dignity, through questionnaires, researchers are not required to apply for the permission to research at the Ethical Committee. This study was not implemented on individual subjects, but was concerned only with the positioning of the standardized air quality measuring equipment in the classrooms and outside the same classrooms, for which, the REC project office had direct communication with school directors. Especially, when the moment of the equipment turning on/off was performed while classrooms were empty, with no physical contact with the pupils whatsoever.

REFERENCES

1. Almeida SM, Canha N, Silva A, Freitas MC, Pegas P, Alves C et al. Children exposure to air particulate matter in indoor of Lisbon primary schools. Atmos Environ 2011; 45: 7594-9.
2. Annesi-Maesano I, Hulin M, Lavaud F, Raherison C, Kopferschmitt C, de Blay F et al. Poor air quality in classrooms related to asthma and rhinitis in primary schoolchildren of the French 6 cities study. Thorax 2012; 67: 682-8.
3. Annesi-Maesano I, Moreau D, Cailland D, Lavaud F, Le Moullec Y, Taytard A et al. Residential proximity fine particles related to allergic sensitations and asthma in primary school children. Respir Med. 2007; 101: 1721-9.
4. ASHRAE Standard 55-2004. Thermal environmental conditions for human occupancy. Washington: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004. https://www.ashrae.org/.../20080623_55_2004_a_b_final.pdf
5. Bako-Biro Z, Wargocki P, Weschler CJ, Fanger PO. Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices. Indoor Air 2004; 14: 178-87.
6. Bakó-Biró Z, Clements-Croome DJ, Kochhar N, Awbi HB, Williams MJ. Ventilation rates in schools and pupils´ performance. Building Environm 2012; 48: 215-23.
7. "California Portable Classroom Study Project Executive Summary", Research Triangle Institute International; California Air Resources Board & California Department of Health Services https://www.arb.ca.gov/research/indoor/pcs/pcs-fr/pcs-fr_v3_pes.pdf
8. Chaloulakou A, Mavroidis I. Comparison of indoor and outdoor concentration of CO at a public school: evaluation of an indoor air quality model. Atmos Environ 2002; 36: 1769-81.
9. Estoková A, Stevulová N, Kubincová L. Particulate matter investigation in indoor environment. Global NEST J 2010; 12: 20-6.
10. Fromme H, Twardella D, Dietrich S, Heitmann D, Schierl R, Liebl B et al. Particulate matter in the indoor air of classrooms - exploratory results from Munich and surrounding. Atmos Environ 2007; 41: 854-66.
11. Janssen NAH, Hoek G, Brunekreef B, Harssema H. Mass concentration and elemental composition of PM10 in classrooms. Occup Environ Med 1999; 56: 482-7.
12. Esworthy R. The National Ambient Air Quality Standards (NAAQS) for Particulate Matter (PM): EPA's 2006 Revisions and Associated Issues National Ambient Air Quality Standards (NAAQS). Congressional Research Service; 7-5700 2013: 4 https://fas.org/sgp/crs/misc/RL34762.pdf
13. Pegas PN, Evtyugina MG, Alves CA, Nunes T, Cerqueira M, Franchi M et al. Outdoor/indoor air quality in primary schools in Lisbon: a preliminary study. Química Nova 2010; 33: 1145-9.
14. Seppanen OA, Fisk WJ, Mendell MJ. Association of ventilation rates and CO2 concentrations with health and other response in commercial and institutional buildings. Indoor Air 1999; 9: 226-52.
15. Csobod E, Rudnai P, Vaskovi E. School Environment and Respiratory Health in Children (SEARCH), International research project report within the programme "Indoor air quality in European schools: preventing and reducing respiratory diseases". Available from: http://search.rec.org/search1/doc/SEARCH%20publication_EN_final.pdf
16. Model EPAM-5000 HAZ-DUST (Ambient Portable Direct Reading Aerosol Monitor for Measuring Lung Damaging Airborne Particles). http://www.skcinc.com/catalog/pdf/instructions/SKC%20EPAM-5000%20Instruction%20Manual%20PDF.pdf
17. World Health Organization. Declaration of the Fourth Ministerial Conference on Environment and Health, Budapest, Hungary, 23-25 June 2004, EUR/04/5046267/6: 7-8. http://www.euro.who.int/__data/assets/pdf_file/0008/88577/E83335.pdf
18. World Health Organization, Regional Office for Europe. Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide, Global update, 2005: summary of risk assessment", WHO/SDE/PHE/OEH/06.02. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf
19. World Health Organization, Regional Office for Europe: WHO guidelines for indoor air quality: selected pollutants. 2010. http://jrc.ec.europa.eu/radpar/docview.cfm?docid
20. Kvalitet životne sredine grada Beograda u 2008. godini. Beograd: Sekretarijat za zaštitu životne sredine, Gradski zavod za javno zdravlje, Regionalni centar za životnu sredinu za Centralnu i Istočnu Evropu (REC). http://www.zdravlje.org.rs/publikacije/Zivotna%20sredina%20Bgd%202008.pdf
21. Fromme H, Diemer J, Dietrich S, Cyrys J, Heinrich J, Lang W et al. Chemical and morphological properties of particulate matter (PM10, PM2.5) in school classrooms and outdoor air. Atmos Environ 2008; 42: 6597-605.
22. Stranger M, Potgieter-Vermaak SS, Van Grieken R. Characterization of indoor air quality in primary schools in Antwerp, Belgium. Indoor Air 2008; 18: 454-63.
23. Oeder S, Dietrich S, Weichenmeier I, Schober W, Pusch G, Jörres RA et al. Toxicity and elemental composition of particulate matter from outdoor and indoor air of elementary schools in Munich, Germany. Indoor Air 2012; 22: 148-58.
24. Rovelli S, Cattaneo A, Nuzzi CP, Spinazze A, Piazza S, Carrer P et al. Airborne particulate matter in school classrooms of northern Italy. Int J Environ Res Public Health 2014; 11: 1398-421
25. Thatcher TL, Layton DW. Deposition, resuspension, and penetration of particles within a residence. Atmos Environ 1995; 29: 1487-97.
26. Simoni M, Annesi-Maesano I, Sigsgaard T, Norback D, Wieslander G, Nystad W et al. Relationships between school indoor environment and respiratory health in children of five European countries (HESE study). Eur Respir J 2012; 40(Supp 56): 1370.
27. Tasic M, Rajsic S, Tomasevic M, Mijic Z, Anicic M, Novakovic V et al. Assessment of air quality in an urban area of Belgrade, Serbia, Environmental Technologies, E. Burcu Ozkaraova Gungor (Ed.). 2008. InTech, Available from: http://www.intechopen.com/books/environmental_technologies/assessment_of_air_quality_in_an_urban_area_of_belgrade__serbia
28. Kukec A, Erzen I, Farkas J, Zaletel Kragel L. Impact of air pollution with PM10 on primary health care consultations for respiratory diseases in children in Zasavje, Slovenia: a time-trend study. Zdr Varst 2014; 53: 55-68.