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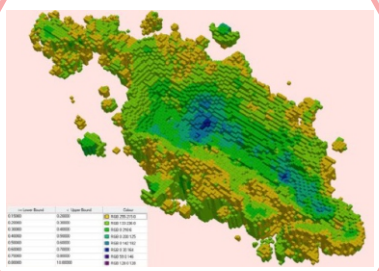

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SUSPENDED PARTICLES CONCENTRATIONS IN THE SECONDARY SCHOOLS IN BOR (SERBIA) IN HEATING SEASON[***]

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Abstract

This paper presents the results of measurements the suspended particles of the PM_{10} and $PM_{2.5}$ fractions in two high schools in Bor (School of Mechanical and Electrical Engineering - MS and Grammar School - GM). The measurements were conducted in two heating seasons for a duration of seven days (five weekdays, and two weekend days). Periods during the weekdays when there were classes and weekend days when there were no classes at school were analyzed separately. The measurement results show that the average concentrations of suspended particles PM_{10} during the class period were 1.7 (GM) and 2.4 (MS) times higher than in the period without classes. The average concentrations of suspended particles $PM_{2.5}$ in both schools during the class period were 1.5 times higher than in the period without classes. In MS the average PM_{10} and $PM_{2.5}$ concentrations during classes were above daily limit values for 3 of 5 working days. In contrast, there was no exceeding of the average daily limit values for concentrations of suspended particles during classes in GM. The results of measurements indicate that more attention should be paid to the way classrooms are cleaned to reduce the possibility of particles resuspension due to the movement of pupils during the teaching period.

Keywords: *classroom, real-time monitoring, particulate matter, air pollution*

1 INTRODUCTION

The most studied and most frequently mentioned environmental pollution is the air pollution. Long-term exposure to the low concentrations of pollutants is a particular problem, which is the most common case [1-3]. The difficulty in study the effects of air pollution on health is the presence of a mixture of pollutants in the air, which is almost always the case making it difficult to single out the individual impacts. EU and national legislation have prescribed the monitoring of two fractions of particles present in the air, particles smaller than 2.5 μm in diameter, and coarse particles that are 2.5-10 μm in diameter [4]. The introduction of limit values for pollutant concentrations in the ambient air, especially those related to the suspended particles, contributes to improving the population health.

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The urban air quality is thought to have a more significant impact on population health than the other environmental factors, and the ambient air pollutants are one of the most significant causes of health problems in general. According to the WHO (World Health Organization), over 4 million deaths occur annually in the world due to the air pollution [5]. Many of the adverse health effects come from the inhalation of increased concentration of particulates from the ambient air. A very important impact on human health has particles with a diameter of less than 2.5 μm. The consequences of a large uptake of these particles into the lungs are usually respiratory infections and, in extreme cases, death. People suffering from asthma, heart or lung disease are most vulnerable to particulate pollution [6 -9].

It is very important to determine the impact of indoor PM concentrations on human health because people spend most of their lives indoors [10]. In the indoor environment, both indoor and outdoor sources contribute to PM levels. The PM in indoor air originates from outdoor infiltration and additional indoor sources such as cooking and heating devices, tobacco smoking, building materials, etc. Indoor air quality in educational buildings is of great importance since children and students spend a large part of their time in classrooms. Unfortunately, there are almost no systematic monitoring programs dealing with the indoor air quality in educational buildings in the Republic of Serbia. This work presents the result of an ongoing study on student's and teacher's exposure to the suspended parti-cles PM_{10} and $PM_{2.5}$ in two secondary schools (School of Mechanical and Electrical Engineering - MS and Grammar School - GM) in Bor, Serbia.

2 METHODOLOGY

Both schools (MS and GM) are located in the Bor town residential area, about 2 km southwest of the copper smelter facilities, as shown in Figure 1. The indoor measurements of suspended particles at each school were conducted at one selected classroom located on the second floor. Both classrooms have a floor space of approximately 60 m^2 and volumes of 240 m^3. The floor is covered with the worn wooden parquet. There is no air conditioning system in the classrooms. The window areas in both classrooms are about 8 m^2. The classrooms are occupied by 15-30 pupils during teaching hours. During the measurements campaign (heating season), the schools were heated regularly using the remote district heating system.

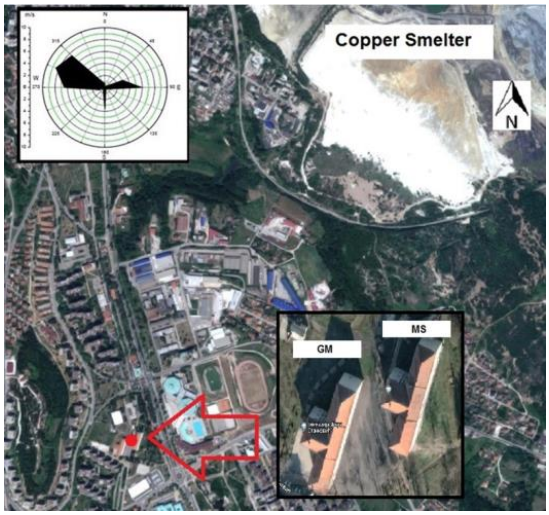

Figure 1 *The position of MS and GM schools on the Bor town map*

The measurements of suspended particulate matter, PM_{10} and $PM_{2.5}$ fractions, were carried out simultaneously in the classroom and outdoor air, for five consecutive working days (Monday - Friday) and two non-working days (Saturday-Sunday). The measurement of indoor PM concentrations was carried out with a Turnkey Osiris real-time PM monitor [11]. The results of measurements were analyzed separately for the teaching hours (PP - pupils present), from 7 AM - 3 PM, and no teaching hours (PA - pupils absent), from 3 PM to 7 AM in the morning of following day. The measurement of outdoor PM concentrations were carried out with a Grimm EDM180 PM monitor at the National Air Quality Monitoring Station (NAQMS) Bor Town Park (TP) (44º04 33"N, 22º05'58"E).

3 RESULTS AND DISCUSSION

The average PM_{10} levels measured in the classrooms at MS and GM are shown in Table 1. According to data shown in Table 1, the average daily concentration of PM_{10} in the classroom at MS was 31.5 μg/m^3. At the same time, the average daily concentration of PM_{10} in the ambient air was 25.5 μg/m^3. Also, the average concentration of PM_{10} in the classroom at MS during the teaching period was 46.2 μg/m^3. This is 1.7 times higher PM_{10} concentration compared with the PM_{10} concentration recorded in the no teaching period (27.2 μg/m^3). In MS the average PM_{10} concentrations during classes were above daily limit values for 3 of 5 working days.

Table 1 *Average PM10 levels and I/O ratios measured in the classrooms at MS and GM (PP - pupils present, PA - pupils absent)*

MS working days						
Date	PM_{10} IN 24h	PM_{10} OUT 24h	PM_{10} IN/OUT 24h	PM_{10} IN PP	PM_{10} IN PA	PM_{10} IN PP/PA
	μg/m^3	μg/m^3		μg/m^3	μg/m^3	
21/01/19	25.6	27.5	0.9	21.6	26.1	0.8
22/01/19	41.8	28.2	1.5	54.2	32.3	1.7
23/01/19	31.5	30.7	1.0	57.8	28.8	2.0
24/01/19	31.2	21.0	1.5	50.3	26.7	1.9
25/01/19	28.9	20.3	1.4	46.9	23.3	2.0
Average	31.5	25.5	1.3	46.2	27.2	1.7
MS weekend days						
27/01/19	5.3	32.5	0.2	6.0	5.5	1.1
28/01/19	11.3	26.3	0.4	12.1	12.7	1.0
Average	8.3	29.4	0.3	9.1	9.1	1.0
GM working days						
Date	PM_{10} IN 24h	PM_{10} OUT 24h	PM_{10} IN/OUT 24h	PM_{10} IN PP	PM_{10} IN PA	PM_{10} IN PP/PA
	μg/m^3	μg/m^3		μg/m^3	μg/m^3	
13/03/23	6.8	22.3	0.3	9.1	4.9	1.9
14/03/23	7.2	36.2	0.2	11.1	5.3	2.1
15/03/23	17.2	28.1	0.6	30.8	11.8	2.6
16/03/23	17.4	11.8	1.5	33.2	13.0	2.6
17/03/23	16.8	12.0	1.4	30.9	13.1	2.4
Average	13.1	22.1	0.8	23.0	9.6	2.3
GM weekend days						
18/03/23	9.4	32.8	0.3	9.7	5.8	1.7
19/03/23	5.1	22.8	0.2	4.5	10.1	0.4
Average	7.3	27.8	0.3	7.1	8.0	1.1

The average PM_{10} levels measured in the classroom at GM was 13.1 μg/m^3. At the same time, the average daily concentration of PM_{10} in the ambient air was 22.1 μg/m^3. Also, the average concentration of PM_{10} in the classroom at GM during the teaching period was 23.0 μg/m^3. This is 2.3 times higher average PM_{10} concentration compared with the PM_{10} concentration recorded in the no teaching period (9.6 μg/m^3).

It can be seen from the presented data that even though in the observed periods, the average daily concentration of PM_{10} in the outdoor air was approximately the same, the average daily concentration of PM_{10} in MS was significantly higher compared to the average daily concentration of PM_{10} in GM. We believe that the different practices of aeration and cleaning, as well as the long presence and large number of students in the classroom in MS compared to the GM, caused such results. This can be confirmed on the basis of changes in PM_{10} concentrations, shown in Figures 2 and 3.

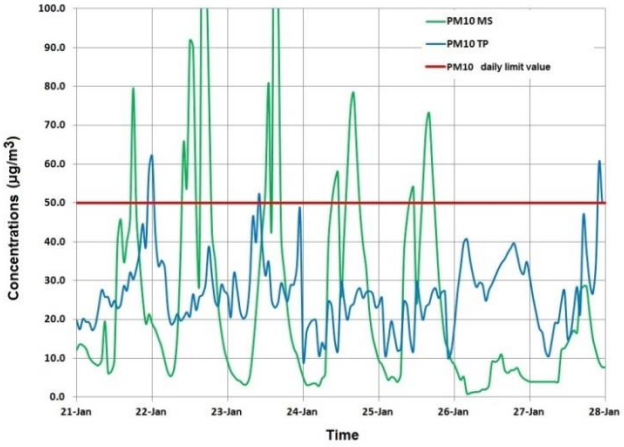

Figure 2 *Line diagram of PM_{10} measured in MS and outdoor air at TP*

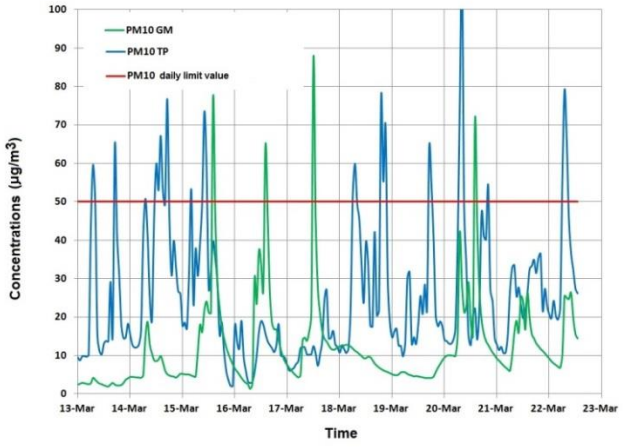

Figure 3 *Line diagram of PM_{10} measured in GM and outdoor air at TP*

The average $PM_{2.5}$ levels, measured in the classroom at MS, are shown in Table 2. According to data shown in Table 2, the average daily concentration of $PM_{2.5}$ in the classroom at MS was 17.6 μg/m^3. At the same time, the average daily concentration of $PM_{2.5}$ in the ambient air was 21.1 μg/m^3. Also, the average concentration of $PM_{2.5}$ in the classroom at MS during the teaching period was 22.1 μg/m^3. This is 1.5 times higher $PM_{2.5}$ concentration compared to the average $PM_{2.5}$ concentration, recorded in the no-teaching period (14.8 μg/m^3). In MS, the average PM_{10} concentrations during classes were above daily limit values for 3 of 5 working days.

Table 2 *Average $PM_{2.5}$ levels and I/O ratios measured in the classrooms at MS and GM (PP - pupils present, PA - pupils absent)*

MS working days						
Date	$PM_{2.5}$ IN 24h	$PM_{2.5}$ OUT 24h	$PM_{2.5}$ IN/OUT 24h	$PM_{2.5}$ IN PP	$PM_{2.5}$ IN PA	$PM_{2.5}$ IN PP/PA
	μg/m^3	μg/m^3		μg/m^3	μg/m^3	
21/01/19	15.5	22.2	0.7	15.5	16.1	1.0
22/01/19	24.5	22.6	1.1	28.7	16.3	1.8
23/01/19	17.2	26.5	0.6	28.5	12.9	2.2
24/01/19	18.8	19.8	1.0	25.3	17.9	1.4
25/01/19	12.0	14.6	0.8	12.7	10.7	1.2
Average	17.6	21.1	0.8	22.1	14.8	1.5
MS weekend days						
27/01/19	5.1	22.3	0.2	4.1	4.2	1.0
28/01/19	8.1	24.7	0.3	5.0	5.7	0.9
Average	6.6	23.5	0.3	4.5	5.0	0.9
GM working days						
Date	$PM_{2.5}$ IN 24h	$PM_{2.5}$ OUT 24h	$PM_{2.5}$ IN/OUT 24h	$PM_{2.5}$ IN PP	$PM_{2.5}$ IN PA	$PM_{2.5}$ IN PP/PA
	μg/m^3	μg/m^3		μg/m^3	μg/m^3	
13/03/23	4.0	12.8	0.3	3.9	3.0	1.3
14/03/23	4.7	19.7	0.2	6.6	3.8	1.7
15/03/23	8.5	18.1	0.5	12.5	6.1	2.0
16/03/23	8.3	8.6	1.0	11.7	7.7	1.5
17/03/23	7.6	9.1	0.8	8.7	9.3	0.9
Average	13.1	22.1	0.6	8.9	6.0	1.5
GM weekend days						
18/03/23	7.8	16.3	0.5	8.1	4.9	1.7
19/03/23	4.1	15.8	0.3	3.7	7.4	0.5
Average	6.0	16.0	0.4	5.9	6.1	1.1

The average $PM_{2.5}$ levels measured in the classroom at GM was 13.1 μg/m^3. At the same time, the average daily concentration of $PM_{2.5}$ in the ambient air was 22.1 μg/m^3. Also, the average concentration of $PM_{2.5}$ in the classroom during the teaching period was 8.9 μg/m^3. This is 1.5 times higher average $PM_{2.5}$ concentration compared with the $PM_{2.5}$ concentration recorded in the no-teaching period (6.0 μg/m^3). Changes in $PM_{2.5}$ concentrations in the observed classrooms are shown in Figures 4 and 5.

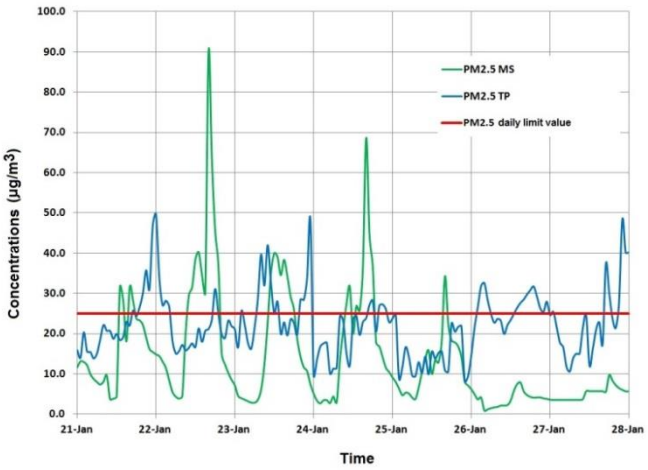

Figure 4 *Line diagram of $PM_{2.5}$ measured in MS and in the outdoor air at TP*

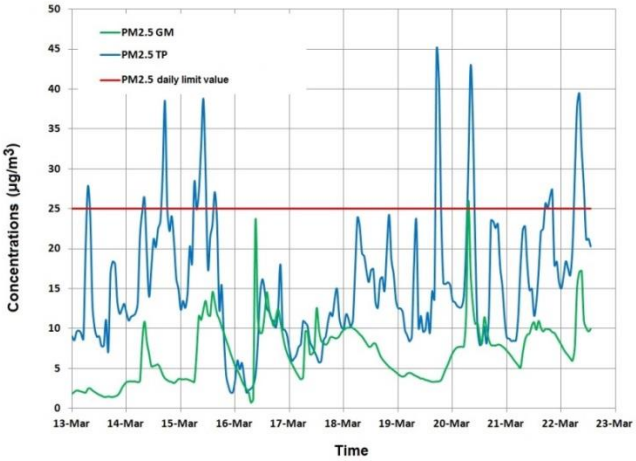

Figure 5 *Line diagram of $PM_{2.5}$ measured in GM and in the outdoor air at TP*

The PM_{10} levels measured in the MS and GM classrooms are comparable with previously reported PM_{10} levels, measured in schools in the Republic of Serbia and EU [12-15]. For example, the average PM_{10} levels in the classrooms in Thessaloniki was 118 µg/m^3, and in the range of 75 - 203 µg/m^3 in the classrooms in Athens [12]. As reported in [13], the PM10 levels measured in schools in Aveiro, Portugal, were 49.2 and 79.8 µg/m^3. The same paper states that the average PM_{10} I/O ratio was 2.4 and 1.84, which is comparable to our results. The average daily PM_{10} level measured in the city of Niš, at the Faculty of Occupational Safety in Nis, was 47.0 µg/m^3, and at the primary school, Vožd Karađorđe in Niš was 54.6 µg/m^3 [14]. Also, the average PM_{10} levels in two primary schools in Bor and Zlot in the heating season were 44.2 µg/m^3 and 49.5 µg/m^3, respectively [15].

4 CONCLUSION

This work presents the results of measurements the mass concentration of PM_{10} and $PM_{2.5}$ in the indoor air of two secondary schools in Bor during the heating period. The measurement results show that the average concentrations of suspended particles PM_{10} during the class period were 1.7 (GM) and 2.4 (MS) times higher than in the period without classes. The average concentrations of suspended particles $PM_{2.5}$ in both schools during the class period were 1.5 times higher than in the period without classes. In MS, the average PM_{10} and $PM_{2.5}$ concentrations during classes were above daily limit values for 3 of 5 working days. Limited ventilation in classrooms during the heating period and resuspension of particles are reasons that caused the high indoor PM concentrations during the teaching period in comparison to the PM concentrations in the no-teaching period. Thus, the appropriate measures should be prescribed to provide better air quality inside the schools, such as different cleaning and ventilation practice. Further study should be continued in the no-heating period to determine whether there are seasonal differences in levels of PM in the classrooms in comparison to the outdoor PM levels.

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