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PARTICULATE MATTER (PM10 AND PM2.5) CONCENTRATIONS IN NATURALLY VENTILATED OFFICES IN BOR, SERBIA

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Abstract. *Monitoring of particulate matter (PM) mass concentrations in indoor air is important for human health risk assessments, since most of the individuals in developed countries spend the majority of their time indoors. The mass concentrations of particulate matter (PM10 and PM2.5 fractions) were measured in several naturally ventilated offices and hallway in the Mining and Metallurgy Institute Bor, Serbia. The measurements are carried out with a portable, direct reading, aerosol monitoring device Turnkey OSIRIS. Several sampling campaigns were conducted in the time interval from 2009 to 2014 in the six selected offices and in a hallway near the main entrance. The average daily mass concentrations of PM in the offices during the summer period (April – September) were 21.9 µg/m3 for PM10 and 8.4 µg/m3 for PM2.5. The average daily mass concentrations of PM in the offices during the winter period (October – March) were 20.3 µg/m3 for PM10 and 10.9 µg/m3 for PM2.5. The indoor air quality seems satisfactory with respect to the both observed fractions of PM. The particle monitor used in the study proved to be practical for PM measurements in the indoor environments, as it is portable and quiet enough not to disturb the occupants in the offices.*

Key words: *monitoring, particulate matter, mass concentration, indoor air pollution*

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1. INTRODUCTION

Particulate matter (PM) is the general term for the mixture of solid particles and liquid droplets in the air. Some particles are large enough to be visible as smoke or soot. Others are so small that they can be detected only with an electron microscope. "Fine" particles (PM2.5 - less than 2.5 micrometers in diameter) result from motor vehicles, coal-burning electric power plants, factories as well as from residential fireplaces and wood stoves. Larger "coarse" particles come largely from windblown dust, vehicles traveling on unpaved roads, and crushing and grinding operations. Some particles are emitted directly from their sources, for example, smokestacks and cars. In other cases, gasses such as sulfur oxides and nitrogen oxides interact with other compounds in the air to form fine particles. High concentrations of suspended particles are sufficient to cause adverse health effects, including increased morbidity or mortality. Air pollution with PM has both acute and chronic effects on human health, affecting a number of different systems and organs [1-5].

Nowadays, special attention has been given to indoor air quality since people spend more than 85 % of their time in indoor microenvironments [6]. Indoor concentration levels may be attributed to indoor and outdoor sources. Indoor sources include particle generation (related to combustion processes, use of spray products and other household articles) and particle resuspension during intense movement and activity. However, except for the different indoor sources, particles of outdoor origin also contribute significantly to the indoor concentration levels [7]. Current EU legislation only regulates PM in ambient air, while there is not specific limit or target values for PM in indoor air at the EU level. However, recently published WHO guidelines for indoor air quality [8] have adopted the same PM guideline values for indoor environments as for ambient air.

Bor town is situated in the eastern part of the Republic of Serbia (Fig. 1). The town has about 40,000 inhabitants. It is a major center for mining and processing of copper and other precious metals. The air pollution is the main environmental problem in the town of Bor area because the emissions from the copper smelters are principally sulfur oxides and particulate matter [9, 10]. Monitoring of particulate matter pollution in ambient air in the town of Bor has been carried out since 2003. These measurements were carried out at the several measuring points in town with the different automatic monitoring devices [11].

The main aim of the present work is to determine mass concentrations of PM10 and PM2.5 in the indoor microenvironment of naturally ventilated offices in a suburban area of Bor town. The PM mass concentrations were monitored by Turnkey OSIRIS automatic particle monitor in several naturally ventilated offices and hallway in the Mining and Metallurgy Institute Bor (MMI), that is situated about 2 km far from Copper Smelter Complex Bor (Fig. 1).With the aim to calculate the PM mass concentrations more accurately, the OSIRIS measurements were calibrated as it was suggested by Ramachandran et al. [12].

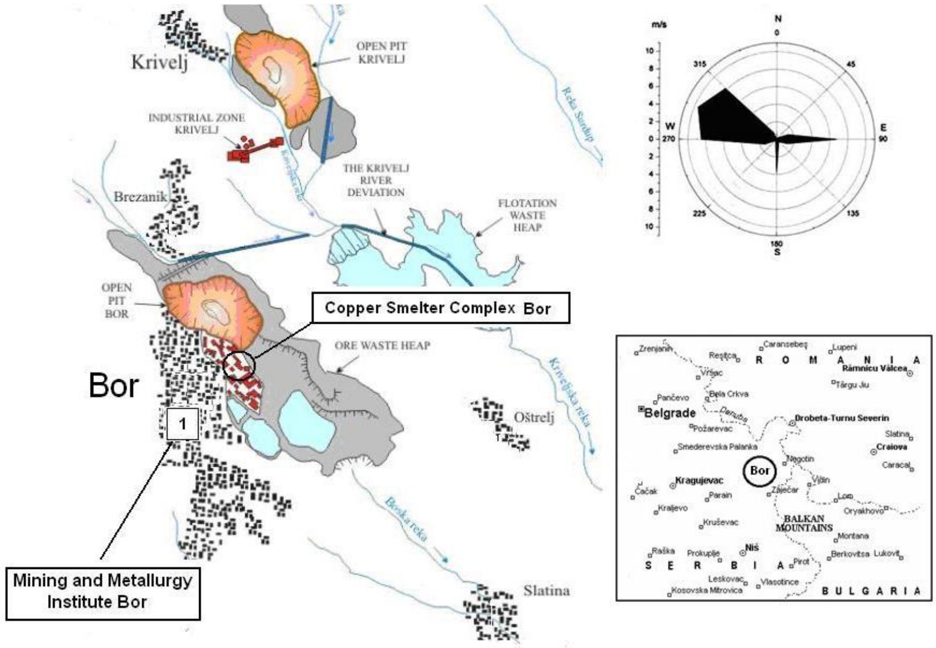

Fig. 1 The location of the sampling site 1 (MMI) on the map of Bor and in the Republic of Serbia together with the wind rose for the measurements period (2009-2014)

2. EXPERIMENTAL SITE AND INSTRUMENTATION

2.1. Instrumentation

Turnkey OSIRIS air particulate monitor gives a continuous and simultaneous indication of TSP, PM_{10}, $PM_{2.5}$ and PM_1 mass fractions. It uses a light scattering (diffraction) technique to determine the concentration of airborne dust in the particle size range from about 0.4 µm to about 20 µm [13]. It is shown that light scattering monitors does not provide really precise measurements but presents high correlations when compared to gravimetric samplers [12,14]

2.2. Data collection

Measurements were performed in the time interval from January 2009 to December 2014 in the several naturally ventilated offices and hallway at the Mining and Metallurgy Institute Bor, Serbia. The real-time aerosol monitor was placed in the center of each office at the breathing height. The measurements were carried out during the winter and summer seasons in duration of 30 days per season per office. There were no more than 3 regular occupants in each office. Smoking was not allowed and the offices were not carpeted. The volume of selected offices varies from 35 to 60 m^3. The window surfaces were approximately 2-3 m^2, and each office has only one door. The windows and doors were usually closed during the winter season. In the summer season, one window was slightly open during the working hours (one shift only, from 7 AM to 3 PM).

2.3 Quality Assurance

At each office during the first week of measurements, a 24-h gravimetric sample was collected concurrently with OSIRIS measurements. The 24-h average concentrations of PM_{10} were obtained from the reference gravimetric method to assess the comparability of results and sampling methods. For comparative measurements gravimetric samplers, Sven/Leckel LVS3 [15] with size-selective inlets for PM_{10} and $PM_{2.5}$ fractions were used. The OSIRIS measurements were then scaled using a specific calibration factor for each sampling site:

$$F = \frac{\sum_{i=1}^{n} \frac{G_i}{O_i}}{n} \tag{1}$$

where F is the calibration factor, G_i is the 24-h average gravimetric concentration for i-th day, O_i is the corresponding 24-h average OSIRIS concentration for i-th day and *n* is the number of days of comparative measurements. The OSIRIS measurements were calibrated with the average aerosol concentration over each 24-h sampling period. Data from the real-time OSIRIS monitor were available as 1-hour averages. For the calculation of the daily averages, minimum 90% of 1-hour averages were required, otherwise the value was considered as the missing. For each 1-hour, the average OSIRIS measurement was multiplied by calibration factor (which ranged between 1.00 and 1.25 for PM_{10} and between 1.5 and 2.92 for $PM_{2.5}$) in order to estimate the gravimetric equivalent 1-hour average PM concentration.

The LVS3 sampler flow rate (2.3 m^3/hour) was calibrated using the certified flow meter several times during the measurement campaign, in the beginning and after one week of measurements.

2.4. Gravimetric analysis

Quartz fiber filters (Whatman QMA 47 mm diameter filters) were used throughout this study for the collection of particulate matter. Pre-conditioning and post-conditioning of filters was undertaken in accordance with the general requirements of EN 12341. Approximately 15% of all gravimetric samples were collected as field blanks. After preconditioning in a clean room, filters were weighing using the Mettler Toledo semi-micro balance (with min. 10 μg mass resolution). PM concentrations were calculated using average (each filter is measured three times) weight of filters. Average change in the field blank weight (2.2 μg) was subtracted from net mass of the sample filters. The detection limit (2.5 $\mu g/m^3$) was calculated as three times the standard deviation in net mass of the field blanks divided by the nominal sample volume.

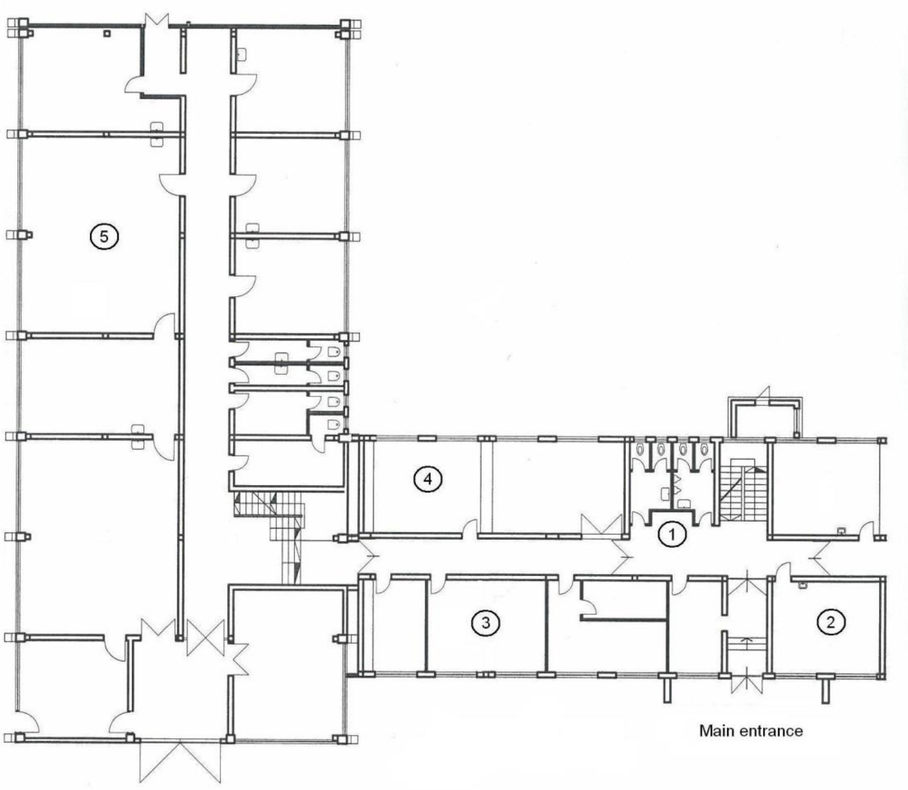

Fig. 2 Part of the MMI building (ground floor) with the sampling locations marked

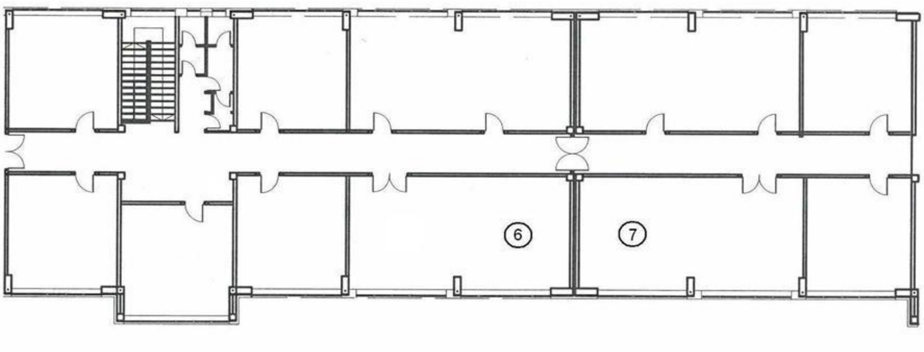

Fig. 3 Part of the MMI building (first floor) with the sampling locations marked

3. RESULTS AND DISCUSSION

The basic statistics of mean daily mass concentrations for PM_{10} and $PM_{2.5}$ are presented in Table 1 for the summer period and in Table 2 for the winter period.

Table 1 Statistics for 24-h mean PM_{10} and $PM_{2.5}$ concentrations for the summer period (SD – standard deviation)

	PM_{10}					$PM_{2.5}$				
Sampling location	Min	Max	Mean	SD	Number of samples	Min	Max	Mean	SD	Number of samples
1	8.0	77.6	26.3	18.4	30	1.8	23.3	7.5	5.7	30
2	4.1	66.8	16.5	10.2	30	1.9	20.8	6.8	3.7	30
3	8.4	43.5	21.2	7.7	30	4.2	24.7	14.0	5.1	30
4	3.4	37.7	15.3	6.7	30	2.3	13.6	6.8	2.7	30
5	10.9	55.1	25.3	14.6	30	2.6	16.7	9.5	4.2	30
6	9.0	98.5	27.2	24.4	30	2.8	24.2	7.8	5.1	30
7	2.6	76.8	21.3	13.7	30	1.2	17.5	6.2	3.6	30

According to Table 1 mean daily mass concentrations of PM_{10} in the offices during the summer periods were in the range from 15.3 to 27.2 $\mu g/m^3$ (in average 21.9 $\mu g/m^3$). Also, mean daily mass concentrations of $PM_{2.5}$ in the offices during the summer periods were in the range from 6.2 to 14.0 $\mu g/m^3$ (in average 8.4 $\mu g/m^3$). The exceedance of the daily limit value of 50 $\mu g/m^3$ for PM_{10} concentration was observed at all sampling locations except location 2 and 3 during the summer period. The fraction of days that exceedance of the daily limit value for PM_{10} concentration was observed ranged between 2-12 % during the summer period. The exceedance of the daily limit value of 25 $\mu g/m^3$ for $PM_{2.5}$ concentration was not observed during the summer period. The daily mean $PM_{2.5}/PM_{10}$ ratio during the summer period ranged between 0.36 – 0.47. These results are in good agreement with the results found in our previous study [11].

Table 2 Statistics for 24-h mean PM_{10} and $PM_{2.5}$ concentrations for the winter period (SD – standard deviation)

	PM_{10}					$PM_{2.5}$				
Sampling location	Min	Max	Mean	SD	Number of samples	Min	Max	Mean	SD	Number of samples
1	13.8	71.0	38.6	33.2	30	6.1	26.1	17.8	16.2	30
2	3.2	29.5	10.1	7.6	30	2.8	9.5	4.2	1.8	30
3	8.2	52.0	18.7	14.3	30	3.3	22.4	7.3	5.7	30
4	3.8	30.9	14.2	7.2	30	1.4	8.2	19.3	4.9	30
5	6.7	48.0	17.7	8.8	30	5.3	16.7	10.1	2.8	30
6	5.4	48.2	22.1	12.6	30	3.8	12.3	8.3	3.3	30
7	3.3	65.7	20.8	16.9	30	2.8	43.9	9.6	13.5	30

According to Table 2, mean daily mass concentrations of PM_{10} in the offices during the winter periods were in the range from 10.1 to 38.6 μg/m^3 (in average 20.3 μg/m^3). Also, mean daily mass concentrations of $PM_{2.5}$ in the offices during the summer periods were in the range from 4.2 to 19.3 μg/m^3 (in average 10.9 μg/m^3). The exceedance of the daily limit value of 50 μg/m^3 for PM_{10} concentration was observed at sampling locations 1, 3 and 7 during the winter period. The fraction of days that exceedance of the daily limit value for PM_{10} concentration was observed ranged between 10-15 % during the winter period. The exceedance of the daily limit value of 25 μg/m^3 for $PM_{2.5}$ concentration was observed at sampling locations 1 and 7 during the winter period. The fraction of days that exceedance of the daily limit value for $PM_{2.5}$ concentration was observed ranged between 10-19 % during the winter period. The daily mean $PM_{2.5}/PM_{10}$ ratio during the winter period ranged between 0.40 – 0.77. These results are in good agreement with the results obtained in our previous study [11].

The results of this study are difficult to compare with the results of other studies, since it was partly not mentioned whether smoking was allowed in the offices. Yet the results obtained in this study are in agreement with the results found in the available literature. For example, in the reference [16] Fromme reported that the median PM_{10} values in non-smoker offices ranged between 30-63 μg/m^3 and the median $PM_{2.5}$ values ranged between 7-51 μg/m^3. Moreover, in the reference [17] Reynolds et al. reported that the levels of PM_{10} in six large office buildings in metropolitan areas in Iowa, Minnesota, and Nebraska were ranged between 14-36 μg/m^3. In the reference [18] an experimental assessment of personal exposure to PM_{10} in 59 office workers was carried out in Dublin, Ireland. The results of the investigation showed that indoor air quality was the overriding determinant of average daily personal exposure as participants in the study spent over 92% of their time indoors. The mean occupational exposure (39 μg/m^3) for the office workers in this study was found to be higher than the overall 24 hour mean personal exposure. The office work exposure played a key role in the day to day personal exposure to PM_{10} of individuals as 30% of every weekday was found to be spent in work by the study subjects [18].

In our research related to PM concentrations in the inner space of residential buildings in the Bor town, the similar results were obtained. For example, in the reference [19] average PM_{10} level measured in an apartment during the winter season was 16.7 µg/m^3. This apartment is located in a residential environment, 300 m west (W) from the MMI. In the reference [20] indoor and outdoor PM_{10} levels measured in 4 apartments located in the different residential areas in Bor were presented. The average PM_{10} level measured in the apartments during the winter period was 26.1 µg/m^3 and 23.2 µg/m^3 in the summer period. According to the reference [11], average PM_{10} level measured in the ambient air in Bor during the winter periods was 39.2 µg/m^3 and 35.0 µg/m^3 in the summer periods. The average $PM_{2.5}$ level measured in Bor during the winter periods was 22.1 µg/m^3 and 19.2 µg/m^3 in the summer periods. The daily mean $PM_{2.5}/PM_{10}$ ratios in the ambient air in Bor were 0.60 during the winter periods and 0.53 in the summer periods.

4. CONCLUSION

The importance of indoor air quality on the overall impacts of air pollution on the health of a typical office worker has been highlighted by the results of this investigation. The extension of indoor air pollution control policy to the monitoring of air quality in the workplace and the enforcement of air quality standards indoors would bring significant improvements in population health. There are no clear seasonal changes in PM levels in the observed workplaces in MMI indoor environments. Daily mean PM_{10} levels observed in all offices in the MMI were beyond the limit during less than 15% of measured days while at the same time indoor $PM_{2.5}$ levels exceeded the limit during 20% of measured days (in the winter period only). No significant difference was found between PM I/O ratios between the summer and winter periods. All these findings point to the absence of significant indoor sources of PM particles in the offices. Therefore, the majority of indoor PM particles originates from outdoor air. To confirm these findings further studies in this area should include a greater number of offices and chemical analysis of collected samples.

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SUSPENDOVANIE ČESTICE (PM10 I PM2.5) U KANCELARIJAMA SA PRIRODNIM PROVETRAVANJEM U BORU, SRBIJA

Većina ljudi provodi najviše vremena unutar stambenih objekata i u prostorijama u kojima rade. Merenje masenih koncentracija suspendovanih čestica (PM) u unutrašnjem prostoru takvih objekata je zbog toga veoma važno sa stanovišta određivanja rizika od izloženosti ovim česticama na zdravlje ljudi. Masene koncentracije suspendovanih čestica frakcije PM10 i PM2.5 merene su u kancelarijama sa prirodnim provetravanjem i u holu Instituta za rudarstvo i metalurgiju u Boru, Srbija. Merenja su vršena prenosnim automatskim analizatorom čestica Turnkey OSIRIS. Nekoliko kampanja merenja je sprovedeno tokom perioda 2009-2014. god. Merenja su vršena u šest odabranih kancelarija, kao i u holu pored glavnog ulaza u Institut. Prosečna vrednost masenih koncentracija suspendovanih čestica frakcije PM10 izmerena u Institutu tokom letnjeg perioda (April – Septembar) iznosila je 21.9 μg/m3, dok je za frakciju PM2.5 u letnjem periodu prosečna vrednost iznosila 8.4 μg/m3. Prosečna vrednost masenih koncentracija suspendovanih čestica frakcije PM10 izmerena u Institutu tokom zimskog perioda (oktobar – mart) iznosila je 20.3 μg/m3, dok je za frakciju PM2.5 u zimskom periodu prosečna vrednost iznosila 10.9 μg/m3. Na osnovu ovih rezultata može se zaključiti da je kvalitet vazduha u unutrašnjem prostoru u pogledu zagađenja suspendovanim česticama u Institutu u periodu kada je merenje vršeno zadovoljavajući za obe posmatrane frakcije suspendovanih čestica. Analizator čestica (OSIRIS) korišćen u toku kampanja merenja suspendovanih čestica u unutašnjem prostoru pokazao se veoma praktičnim, zato što se jednostavno prenosi i postavlja, i zato što je dovoljno tih da ne remeti uobičajene aktivnosti ljudi koji rade u kancelarijama gde su merenja vršena.

Ključne reči*: monitoring, suspendovane čestice, masena koncentracija, zagađenje vazduha u unutrašnjem prostoru.*