# CIVIL AIR QUALITY MONITORING AS AN ALTERNATIVE AND SUPPLEMENT TO THE NATIONAL AIR QUALITY MONITORING NETWORK

by

***Aca V. BOŽILOV[a], Viša M. TASIĆ[b*], Nikola Z. MIŠIĆ[a],***
***Ivan M. LAZOVIĆ[c], Dušan B. TOPALOVIĆ[c],***
***Nenad V. ŽIVKOVIĆ[a], and Nikola S. MIRKOV[c]***

[a]Faculty of Occupational Safety, University of Niš, Niš, Serbia
[b]Mining and Metallurgy Institute, Bor, Serbia
[c]Vinča Institute of Nuclear Sciences, National Institute of the Republic of Serbia,
University of Belgrade, Belgrade, Serbia

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*The European initiatives for citizens' inclusion in the air quality monitoring process have impacted the participants' knowledge, and attitudes towards air pollution and have led to a higher sense of community toward activities and measures against air pollution. In the Republic of Serbia, an experiment with self-made sensor kits "Klimerko – Air to the Citizens" started in 2018. In this paper, we have presented the level of agreement of the particulate matter (PM) readings from selected Klimerko devices to the PM readings of the reference equivalent PM monitors from the National Air Quality Monitoring Network in the cities of Bor and Belgrade. The Klimerko devices that we tested showed excellent stability and reliability during the comparison period. The conclusion of our investigation is that the properly calibrated Klimerko devices could be applied for indicative measurements of PM mass concentrations in the ambient air.*

Key words*: air quality, monitoring, low-cost,*
*particulate matter, PMS7003, sensors*

## Introduction

Exposure to fine particles ($PM_{2.5}$) has been shown to cause cardiovascular and respiratory diseases [1]. This is the main reason why the EU sets the limit values for PM concentrations in the ambient air. Council Directive 2008/50/EC [2] prescribed a daily limit value of 50 $\mu g/m^3$ for $PM_{10}$ concentrations not to be exceeded more than 35 times per calendar year, and an annual limit value of 40 $\mu g/m^3$. Also, the annual mean $PM_{2.5}$ level cannot exceed 20 $\mu g/m^3$ after 2020 [2]. The PM limits and targets for 24 hours and annual means differ from country to country [3]. Gravimetric methods are the basis of European and American reference methods for the determination of $PM_{10}$ and $PM_{2.5}$ concentrations in ambient air. Com-

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[*] Corresponding author, e-mail: visa.tasic@irmbor.co.rs

pared to automatic monitors, gravimetric methods require conditioning and measuring filters, and therefore such methods are time-consuming and expensive [4]. The WHO updated the AQ guidelines in 2021, and for example, the new $PM_{2.5}$ annual mean air quality guideline level has changed to 5 $\mu g/m^3$ [5].

According to the data presented on the Serbian Environmental Protection Agency website [6], in the Republic of Serbia, about 35 air quality monitoring (AQM) stations are capable for real-time monitoring of PM mass concentration ($PM_{10}$ and $PM_{2.5}$) using reference-equivalent GRIMM EDM180 analyzers [7]. The high cost of these analyzers (about 30000 € per unit) is a limiting factor for the expansion of PM monitoring in the national monitoring network. On the other hand, in order to better assess the impact of air pollution on human health, it is necessary to perform continuous real-time AQM in micro-environments where people spend most time [8]. To meet such a need the researchers have started developing low-cost PM monitoring systems with easily available sensors, which have low prices and quick response time.

Therefore, there are two primary areas for the implementation of low-cost PM sensors and systems:

- The application of low-cost PM monitoring systems in the areas with limited or insufficient PM monitoring.
- The application of a large number of low-cost PM monitoring nodes to access the fine-scale variability of PM.

Poor air quality causes an estimated 400000 premature deaths in Europe every year because of the fact that a significant number of population lives in areas where air quality is poor and poses a risk to health [9]. The European initiative for citizens' inclusion in the AQM process has resulted in higher awareness of the citizens to air pollution problem [9]. In the Republic of Serbia, an experiment with self-made sensor kits *Klimerko – Air to the Citizens* started in 2018 [10]. Since then it has been continuously improved in hardware and software terms. The Klimerko device measures: air humidity, air temperature, air pressure, and concentration of $PM_1$, $PM_{2.5}$, and $PM_{10}$. The Klimerko device has not been calibrated, since it was established that the installed low-cost PM sensor PMS7003 [11] is precise enough for civil (indicative) measurement. This has been once confirmed with the installation of four PMS7003 sensors on a vehicle of the Institute of Public Health of Serbia and comparing the data with their professional sensors, as well as by comparing official values obtained by the Serbian Environmental Protection Agency (SEPA) with the values obtained by the Klimerko devices that are located in the close vicinity of the SEPA monitoring stations [10]. At the moment, more than 200 Klimerko devices are deployed on the entire territory of the Republic of Serbia. A good part of them is located on the territory of the city of Belgrade. In this paper, our intention was to compare the PM readings from selected Klimerko devices to the readings of the reference equivalent PM monitors from the National Air Quality Monitoring Network in the cities of Bor, and Belgrade in order to check their usability for indicative measurements of suspended particles in the ambient air.

The characteristics of the PMS7003 sensor, both in the laboratory and in the field conditions, were already investigated in the references [12-15]. The general conclusions are that the correlations of this type of PM sensor and the reference instruments are high. The sensor readings should be corrected because it overestimates PM concentration, depending on the size distribution of particles, meteorological conditions, and PM concentration levels.

## Materials and methods

### *General characteristics of the Klimerko device*

Klimerko is an affordable AQM device that measures PM concentration as well as temperature, relative humidity, and atmospheric pressure [10]. The principle of operation of the Klimerko device is shown in fig. 1.

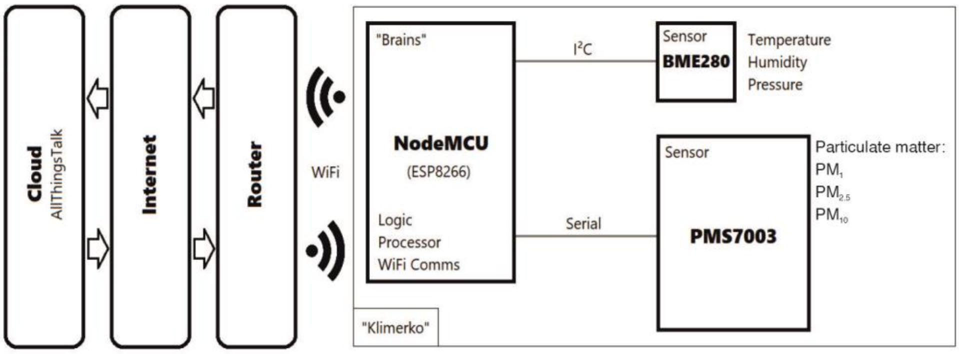

**Figure 1. The principle of operation of the KLIMERKO device [10]**

Klimerko device consists of the NodeMCU (Wireless WIFI Module) [16], plantower PMS7003 air quality sensor [11], and Bosch BME280 temperature/humidity/pressure sensor [17]. It publishes data to All Things Talk Maker Cloud [18] over a local router connected to the Internet, as shown in fig. 1.

### *Sampling locations and measurement campaigns*

The study aims to provide an insight into the characteristics of low-cost PM sensors (Plantower PMS7003) which are built into Klimerko devices, in different outdoor environments in two cities in the Republic of Serbia chosen as representatives for PM pollution originating from industrial sources (Bor) [19], and traffic and local heating sources (Belgrade) [20]. We have selected two Klimerko devices located up to 1 km far from the National Air Quality Monitoring Stations (NAQMS) in the cities of Bor and Belgrade, and compared 1-hour mean PM results obtained by the Klimerko devices and by the GRIMM EDM180 monitors at NAQMS. Selected Klimerko devices are placed on the terraces of residential buildings at a height of 5 m from the ground. The comparison campaigns were conducted in the heating season, from October 19th, 2021 to March 7th, 2022. Also, the aim of our investigation was to explore the applicative value of indicative measurements in civil AQM.

In the city of Bor, the PM readings from Klimerko (44° 04' 11" N, 22° 05' 48" E) were compared with the results of Grimm EDM180 at the NAQMS Town Park (TP) Bor (44° 04' 33" N, 22° 05' 58" E) located about 700 m far from Klimerko, as shown in fig. 2(a). In the city of Belgrade, the PM readings from Klimerko (44° 48' 13" N, 20° 28' 53" E) were compared with the results of Grimm EDM180 at the NAQMS Vračar (44° 47' 49" N, 20° 29' 31" E) located about 900 m far from Klimerko, as shown in fig. 2(b).

### *Data analysis*

Data set were analyzed to assess the overall agreement between PM levels obtained by the Klimerko and Grimm EDM180 PM monitors. Several statistical evaluation measures were used to quantify the differences between the obtained PM concentrations. The 1 hour mean standard deviation (SD), coefficient of variation (CV), accuracy, precision, RMSE, and correlation coefficients, $R^2$, between Grimm EDM180 PM monitors, as reference instruments, and the Klimerko devices have been calculated; these statistics were used in [21]. All analyses were completed using SPSS Statistics 17.0 and Microsoft Office Excel 2010.

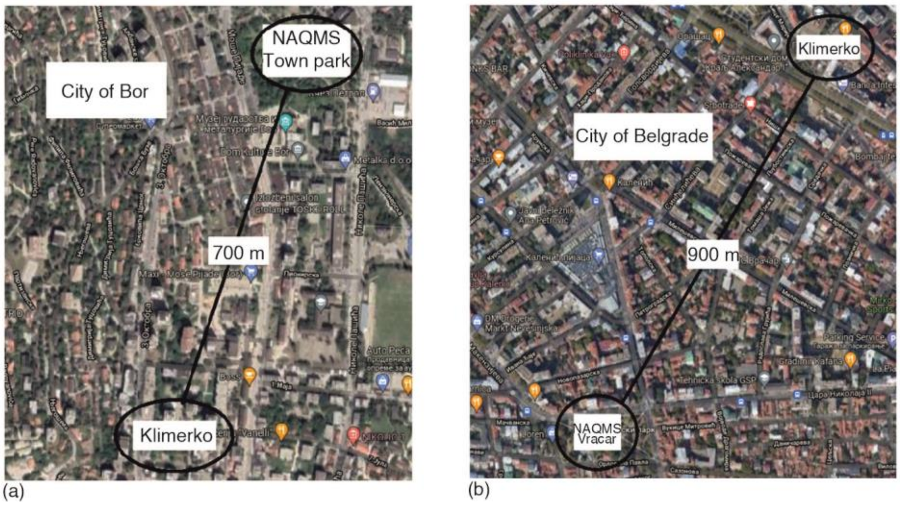

**Figure 2. The distance between the Klimerko and NAQMS; (a) Bor and (b) Belgrade**

Accuracy is the degree of closeness between the measured value obtained by the PM monitor and the reference value. The accuracy for each collocation period was calculated by eq. (1) [21], where *REF* is the mass concentration of the reference instrument (Grimm 180 EDM) and *Unit* is the average PM mass concentration measured by Klimerko during the comparison period:

$$\text{Accuracy}_{\text{campaign}} = 100 - \left| \frac{REF - Unit}{REF} \right| \times 100 \tag{1}$$

The overall accuracy was calculated by averaging accuracies from each collocation period, by:

$$\text{Overall accuracy} = \frac{1}{n} \sum_{i=1}^{n} \text{Accuracy}_{\text{campaign}} \tag{2}$$

The CV, as the measure of the spread of data points around the mean, was calculated using eq. (3), where $\sigma$ is the standard deviation and $\mu$ is the mean of the 1 hour averaged measurements:

$$CV = \frac{\sigma}{\mu} \tag{3}$$

The $R^2$ were calculated between the PM monitors (presented as *Unit*-$R^2$). The RMSE was calculated using eq. (4), where $REF_i$ and $Unit_i$ are the corresponding $i^{\text{th}}$ 1 hour average PM concentrations from a collocation period with $N$ hours. A value of 0 would indicate a perfect agreement between *REF* and the *Unit* [21]. The overall RMSE was calculated by averaging values from each collocation period:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(REF_i - Unit_i\right)^2}{N}} \tag{4}$$

The precision of the two PM monitors was calculated using eq. (5). A precision error of 0% between two units would indicate that units measured identical values [21]:

$$\text{Precision} = \left|\frac{Unit_1 - Unit_2}{\text{Average}\left(Unit_1, Unit_2\right)}\right| \tag{5}$$

## Results and discussion

### *Correction factor calculation*

In order to calibrate PM sensors integrated into the selected Klimerko devices the PM concentration values obtained by Klimerko devices were corrected following the slightly modified method proposed in the reference [22]. The PM results of Klimerko devices were scaled using a specific correction factor as:

$$F = \frac{1}{n}\sum_{i=1}^{n}\frac{G_i}{K_i} \tag{6}$$

where $F$ is the correction factor, $n$ – the number of days, $G_i$ – the 24-hour mean PM concentration for $i^{\text{th}}$ day of measurements obtained by Grimm EDM180, and $K_i$ – the corresponding 24-hour mean PM concentration obtained by Klimerko device for the $i^{\text{th}}$ day of measurements. Each 1 hour PM result obtained by the Klimerko devices was multiplied by this correction factor. The calculated values of correction factor, $F$, are presented in tab. 1.

**Table 1. Summary of the $F$ ±SD**

| Location | $F$ for $PM_{10}$ | $F$ for $PM_{2.5}$ |
|---|---|---|
| Belgrade | 0.54 ±0.13 | 0.61 ±0.12 |
| Bor | 0.72 ±0.16 | 0.64 ±0.08 |

According to data shown in tab. 1, both of the tested Klimerko devices overestimate PM results obtained by the Grimm EDM180 PM monitors ($PM_{10}$ results overestimated 137% in Belgrade and 39% in Bor, $PM_{2.5}$ results overestimated 103% in Belgrade and 56% in Bor). Previous studies on the Plantower PMS5003 low-cost PM sensor (an earlier version of the PMS7003 sensor from the same manufacturer), have established that it overestimates $PM_{2.5}$ values up to 40% in outdoor air [12]. Also, other experimental results have established that most of the light-scattering instruments overestimated $PM_{10}$ and $PM_{2.5}$ levels compared with the reference instruments [4]. These findings point out that the calibration of low-cost PM sensors is needed before their installation, and validation of the PM results is needed prior to their presentation in public in order to provide citizens with more accurate information about PM air pollution.

### *Results of the comparative measurements in the city of Belgrade*

Comparative measurements in the city of Belgrade were performed for 140 days in the heating season, from October 19th, 2021 until March 7th, 2022. Results of the comparative measurements are shown in figs. 3 and 4 (corrected results from the Klimerko device were used). The summary statistics of the PM results are presented in tab. 2.

Despite the fact that the measurement campaign was conducted in the heating season and quite a large distance (900 m) between the PM monitors, values obtained for the determination coefficients ($R^2$ = 0.844 for $PM_{10}$, and $R^2$ = 0.879 for $PM_{2.5}$) indicate strong linear dependence between the results obtained by the Grimm EDM180 and Klimerko (Plantower

7003) PM monitors (corrected results from the Klimerko device were used). The average RH during the measurement campaign was 67.5%, and the average daily temperature was 4.8 °C.

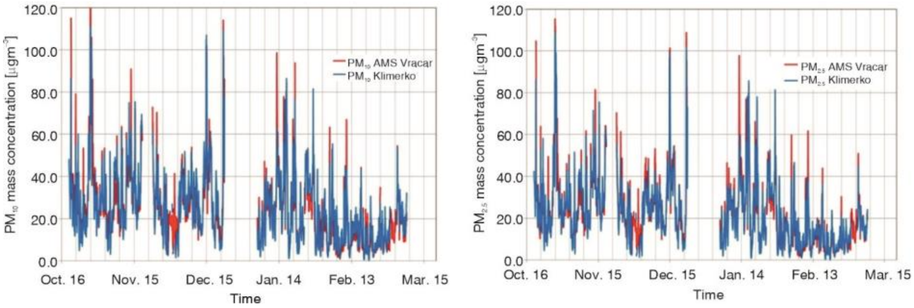

**Figure 3. Line diagram of 1 hour mean PM concentrations in the city of Belgrade**

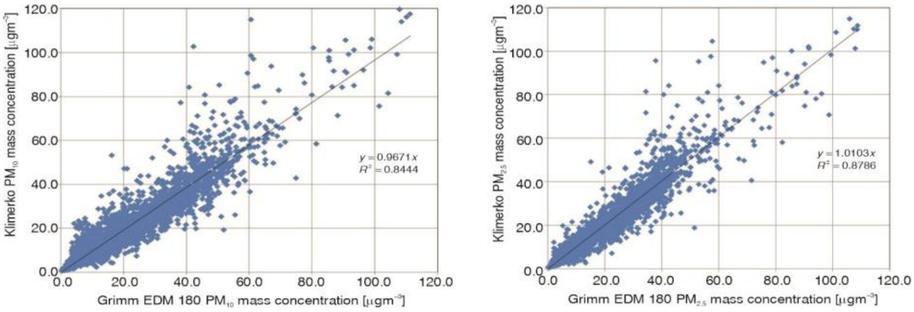

**Figure 4. Scattering plot of 1 hour mean PM concentrations (Grimm EDM180 vs. Klimerko)**

**Table 2. Summary of the mean PM mass concentrations [µgm$^{-3}$], SD, CV, accuracy [%], RMSE, and precision for the measurement campaign conducted in the city of Belgrade**

| Belgrade | PM | Mean | SD | CV | Accuracy | RMSE | P |
|---|---|---|---|---|---|---|---|
| PM monitor | | [µgm$^{-3}$] | [µgm$^{-3}$] | | [%] | [µgm$^{-3}$] | [%] |
| AMS SEPA Vračar Grimm EDM180 | $PM_{10}$ | 18.54 | 14.35 | 0.77 | – | – | – |
| Klimerko Uncorrected | $PM_{10}$ | 43.96 | 29.34 | 0.67 | –37.18 | 26.43 | 81.34 |
| Klimerko Corrected | $PM_{10}$ | 19.90 | 14.08 | 0.71 | 92.44 | 6.87 | 7.27 |
| AMS SEPA Vračar Grimm EDM180 | $PM_{2.5}$ | 17.35 | 14.13 | 0.81 | – | – | – |
| Klimerko Uncorrected | $PM_{2.5}$ | 35.16 | 29.34 | 0.83 | –2.64 | 17.77 | 67.83 |
| Klimerko Corrected | $PM_{2.5}$ | 17.69 | 13.19 | 0.75 | 98.04 | 5.95 | 1.94 |

It should be mentioned that the mean PM levels during the comparison campaign in the heating season in Belgrade were lower than national limits for mean daily $PM_{10}$ (50 µg/m$^3$) and $PM_{2.5}$ (25 µg/m$^3$) levels in the ambient air. The CV values were fairly uniform ranging from 0.67 to 0.83. The accuracy of the corrected PM results from Klimerko was higher than 90%. The RMSE values for corrected PM results were quite similar for both PM fractions. For the whole measurement period, the calculated precision between observed PM monitors (for corrected PM results obtained from the Klimerko device) was below 10% which is the required precision for the ambient regulatory instruments [23].

### *Results of the comparative measurements in the city of Bor*

Comparative measurements in the city of Bor were performed for 77 days in the heating season, from December 20th, 2021 until March 6th, 2022. Results of the comparative measurements are shown in figs. 5 and 6 (corrected results from the Klimerko device were used). The summary statistics of the PM results are presented in tab. 3.

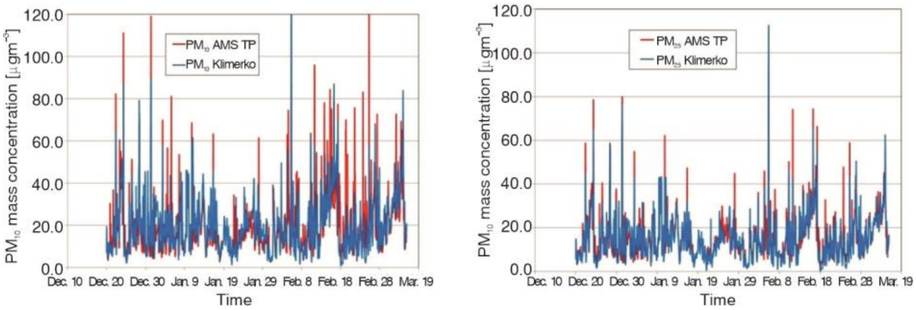

**Figure 5. Line diagram of 1-hour mean PM concentrations in the city of Bor**

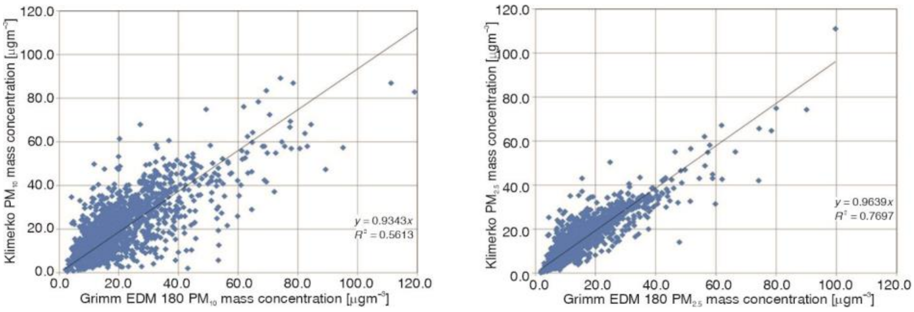

**Figure 6. Scattering plot of 1-hour mean PM concentrations (Grimm EDM180 vs. Klimerko)**

**Table 3. Summary of the mean PM mass concentrations [µgm$^{-3}$], SD, CV,\ accuracy [%], RMSE, and precision for the measurement campaign conducted in the city of Bor**

| Bor | PM | Mean | SD | CV | Accuracy | RMSE | P |
|---|---|---|---|---|---|---|---|
| PM monitor | | [µgm$^{-3}$] | [µgm$^{-3}$] | | [%] | [µgm$^{-3}$] | [%] |
| AMS SEPA TP Bor Grimm EDM180 | PM$_{10}$ | 19.92 | 14.42 | 0.72 | – | – | – |
| Klimerko Uncorrected | PM$_{10}$ | 27.74 | 18.82 | 0.68 | 60.77 | 15.07 | 32.79 |
| Klimerko Corrected | PM$_{10}$ | 19.98 | 13.75 | 0.69 | 98.23 | 9.26 | 1.75 |
| AMS SEPA TP Bor Grimm EDM180 | PM$_{2.5}$ | 15.36 | 10.03 | 0.65 | – | – | – |
| Klimerko Uncorrected | PM$_{2.5}$ | 23.99 | 15.70 | 0.65 | 43.83 | 12.35 | 43.85 |
| Klimerko Corrected | PM$_{2.5}$ | 15.08 | 9.92 | 0.66 | 98.17 | 4.67 | 1.16 |

Despite the fact that the measurement campaign was conducted in the heating season and quite a large distance (700 m) between the PM monitors, values obtained for the determination coefficients ($R^2$ = 0.561 for PM$_{10}$, and $R^2$ = 0.770 for PM$_{2.5}$) indicates moderate and strong linear dependence between the results obtained by the Grimm EDM180 and Klimerko (Plantower 7003) PM monitors (corrected results from the Klimerko device were used). The average RH during the measurement campaign was 78.8%, and the average daily temperature was 2.6 °C.

It should be mentioned that the mean PM levels during the comparison campaign in the heating season in Bor were lower than national limits for mean daily $PM_{10}$ (50 $\mu g/m^3$) and $PM_{2.5}$ (25 $\mu g/m^3$) levels in the ambient air. The CV values were fairly uniform ranging from 0.65 to 0.72. The accuracy of the corrected PM results from Klimerko was higher than 98%.

The RMSE values for corrected PM results were quite similar for both PM fractions. The calculated precision between the corrected PM results from Klimerko was below 10%, which is the required precision for the ambient regulatory instruments [23].

The effect of T and RH on Klimerko PM readings needs to be taken into consideration because the PM mass concentrations measured with any light scattering instrument increase with relative humidity due to the increase of the average particle size associated with condensational growth of its hygroscopic components [4, 12, 24]. In this paper, the Klimerko PM results were not corrected for temperature, $T$, and RH influence because this investigation falls outside the scope of this paper, so that, the influence of $T$ and RH on the Plantower 7003 PM sensor will be the subject of our future paper.

If we compared corrected PM results from Klimerko devices in the city of Belgrade and Bor, presented in tabs. 2 and 3, it is observed that they are of the same order of magnitude for all statistical parameters shown. It is also notable that the results obtained from the PM sensors built into Klimerko devices have to be corrected/calibrated before their public presentation to the citizens.

## Conclusions

In this paper, the measurement results of the PMS7003 sensors, which are installed in the Klimerko device, were compared with the results of the reference-equivalent instruments GRIMM EDM180 from the NAQMS network in the cities of Bor and Belgrade, Republic of Serbia. The PMS7003 sensors showed excellent stability and reliability during the comparison period.

This research shows that the results obtained from the PM sensors built into Klimerko devices should be corrected before their public presentation to the citizens. This should be done, because it is determined that, depending on the microenvironment, the results of measuring PM concentrations using the PMS7003 sensor can exceed the values of PM concentrations obtained by reference-equivalent instruments by more than 50%, which is more than the maximum allowed uncertainty required for indicative measurements.

The conclusion of our investigation is that the properly calibrated Klimerko devices could be successfully applied for indicative measurements of PM mass concentrations in the ambient air.

Tests of the Klimerko devices will be continued with the aim to find the best model for correcting the influence of humidity, temperature, and other meteorological parameters on the measurement results.

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## References

[1] ***, World Health Organization, Outdoor Air Pollution a Leading Environmental Cause of Cancer Deaths, http://www.euro.who.int/en/health-topics/environment-and-health/urban-health/news/news/2013/10/outdoor-air-pollution-a-leading-environmental-cause-of-cancer-deaths, 2020

[2] ***, European Union, Directive 2008/50/EC of the European Parliament and of the council of 21 May 2008 on ambient air quality and cleaner air for Europe. Off. J. Eur. Union L 152, 1e44, https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32008L0050, 2008

[3] Jovasevic-Stojanovic, M., *et al.*, On the Use of Small and Cheaper Sensors and Devices for Indicative Citizen-Based Monitoring of Respirable Particulate Matter, *Environ. Pollut., 206* (2015), Nov., pp. 696-704

[4] Tasić, V., *et al.*, Comparative Assessment of the Real-Time Particle Monitor Against the Reference Gravimetric Method for $PM_{10}$ and $PM_{2.5}$ in the Indoor Air, *Atmospheric Environment, 54* (2012), July, pp. 358-364

[5] ***, World Health Organization, WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and $PM_{10}$), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, World Health Organization, https://apps.who.int/iris/handle/10665/345329. License: CC BY-NC-SA 3.0 IGO, 2021

[6] ***, Serbian Environmental Protection Agency - SEPA, http://www.sepa.gov.rs/, 2022

[7] ***, http://www.mets-oman.biz/METS_3_Grimm_Environmental_EDM180.pdf, 2022

[8] Tasić, V., Using Low-Cost Sensors and Systems for Air Pollution Monitoring, *Proceedings*, 5th International Conference on Electrical Power Renewable Sources, Belgrade, Serbia, 2017, Vol. 1, pp. 11-19

[9] Schaefer T., *et al.*, Citizen-Based Air Quality Monitoring: The Impact on Individual Citizen Scientists and How to Leverage the Benefits to Affect Whole Regions, *Citizen Science: Theory and Practice, 5* (2020), 1, pp. 1-12

[10] ***, Klimerko, https://klimerko.org/faq/, 2022

[11] ***, https://download.kamami.pl/p564008-PMS7003%20series%20data%20manua_English_$V_{2.5}$.pdf, 2022

[12] Wallace, L., *et al.*, Calibration of Low-Cost Purpleair Outdoor Monitors Using an Improved Method of Calculating $PM_{2.5}$, *Atmos Environ, 256* (2021) 118432

[13] Badura, M., *et al.*, Evaluation of Low-Cost Sensors for Ambient $PM_{2.5}$ Monitoring, *J. Sens., 2018* (2018), ID5096540

[14] Jayaratne, R., *et al.*, The Influence of Humidity on the Performance of a Low-Cost Air Particle Mass Sensor and the Effect of Atmospheric Fog, *Atmos. Meas. Tech., 11* (2018), 8, pp. 4883-4890

[15] Kelly, K. E., *et al.*, Ambient and Laboratory Evaluation of a Low-Cost Particulate Matter Sensor, *Environmental Pollution, 221* (2017), Feb., pp. 491-500

[16] ***, http://www.proelectronic.rs/Arduino%20razvojni%20sistemi/17169-NodeMcu%20ESP8266%20CP2102%20V3%20Wireless%20WIFI%20Modul, 2022

[17] ***, https://eu.mouser.com/new/bosch/bosch-bme280/, 2022

[18] ***, https://www.allthingstalk.com/faq/allthingstalk-and-esp8266, 2022

[19] Tasić V., *et al.*, Analysis of Air Pollution Caused by Particle Matter Emission from the Copper Smelter Complex Bor (Serbia), *Chemical Industry & Chemical Engineering Quarterly, 16* (2010), 3, pp. 219-228

[20] Jovanović, M., *et al.*, Comparison of Fine Particulate Matter Level, Chemical Content and Oxidative Potential Derived from Two Dissimilar Urban Environments, *Science of the Total Environment, 708* (2020) 135209

[21] Zamora, M. L., *et al.*, One Year Evaluation of Three Low-Cost $PM_{2.5}$ Monitors, *Atmospheric Environment, 235* (2020) 117615

[22] Ramachandran, G., *et al.*, Characterizing Indoor and Outdoor 15-Minute Average $PM_{2.5}$ Concentrations in Urban Neighborhoods, *Aerosol Sci Technol, 37* (2003), 1, pp. 33-45

[23] ***, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-53, 2022

[24] Liu, H. Y., *et al.*, Performance Assessment of a Low-Cost $PM_{2.5}$ Sensor for a Near Four-Month Period in Oslo, Norway, *Atmosphere, 10* (2019), 2, 41

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