Article

PARTICULATE MATTER (PM1, PM2.5, PM10) MONITORING IN INDOOR AND OUTDOOR ENVIRONMENTS AT "AUREL VLAICU" UNIVERSITY OF ARAD, ROMANIA

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Abstract: *The presence of particulate matter, along with other specific air pollutants, significantly contributes to the degradation of air quality outdoors and indoors. High concentrations of PM in indoor educational spaces influence students' health and daily performance. This study presents the results of daily monitoring of PM1, PM2.5, and PM10 concentrations carried out between May 9 and May 15, 2024, at 8:00, 10:00, 12:00, 14:00, and 16:00 in various indoor environments of the M University Complex at "Aurel Vlaicu" University of Arad, including two corridors, two student laboratories, and an auditorium, as well as in the outdoor environment. For indoor environment, the findings indicated relatively low levels of particulate matter, suggesting good air quality for student health with average PM1 concentrations ranged from 2 μg/m³ to 6 μg/m³, PM2.5 from 4 μg/m³ to 11 μg/m³, and PM10 from 5 μg/m³ to 14 μg/m³.*

Keywords: particulate matter, indoor air, outdoor environments, pollutants source, air quality

INTRODUCTION

Air pollution has long been a significant concern, not only due to its environmental impact but also because of its effects on human health. In addition to monitoring outdoor air quality (atmospheric air), indoor air quality (IAQ) requires particular attention, as people spend approximately 70-80% of their time in enclosed spaces, where the potential for exposure to indoor pollutants is high (Kozielska et al., 2020). According to the World Health Organization (WHO), indoor air pollution is the principal cause of Sick Building Syndrome (SBS) associated with pulmonary and respiratory deficiencies (Mansor et al., 2024). In situations involving non-compliant ventilation systems, inadequate room ventilation, and the presence of various indoor pollution sources (e.g., furniture, smoking, carpets, cleaning agents, hygiene products, construction materials, and heating systems), pollutants can accumulate in high concentrations potentially causing adverse effects on human health (Coggins et al., 2024; Tran et al., 2020; Yasmin et al., 2024). Many studies have shown that indoor air pollution can lead to cardiovascular, ocular, olfactory, respiratory, and pulmonary diseases (Abdel-Salam, 2022; Mulia et al., 2020; Sadrizadeh et al., 2022) or even affect the endocrine system by increasing the production of stress hormones, thus affecting the hypothalamic-pituitary-ovarian axis and menstrual function (Giorgis-Allemand et al., 2020; Wronka and Kliś, 2022). Recent studies pay special attention to young people, such as pupils and students, who participate in educational activities (Fang et al., 2023; Kanama et al., 2023; Mulia et al., 2020; Ongwandee et al., 2024; Sadrizadeh et al., 2022). These individuals spend approximately 30% of their day at school and 70% of their time indoors (e.g., classrooms, auditoriums, laboratories, etc.) (Zhu et al., 2021). Young people are more vulnerable to poor IAQ than adults due to their immature organs, lower pulmonary capacity, and higher breathing rates associated with physical activity (Font-Ribera et al., 2022). Poor IAQ can negatively affect their academic performance and daily behavior (Fang et al., 2023; Grineski et al., 2019). Therefore, ensuring a valuable IAQ in educational spaces is of great importance. It is demonstrated that, together with other specific air pollutants (i.e., CO, CO_2, SO_2, NOx, HCOH, VOCs, etc.), particulate matter (PM) stands out for its negative contribution to air quality. These suspended airborne particles can have different sizes, showing different behaviour. The particulate matter resulting from natural sources have diameters between 1μm (PM1) and 10 μm (PM10) and contain dust, sea salts and bioaerosols etc., while those resulting from anthropogenic activities (e.g. fuel combustion, transport, construction, smoking, cooking, agriculture, industry, etc.) vary between 0.1μm (PM0.1) and 2.5 μm (PM2.5) and contain compounds such as sulphates, ammonium nitrates, elemental carbon, metals and heavy metals, organic structures, etc. (Fromme et al., 2008; Mansor et al., 2024; Tang and Pfrang, 2023).

According to Son et al. (Son, 2023), inadequate ventilation is the main factor contributing to high PM levels in enclosed spaces destined for educational activities. In schools, the reliance on natural ventilation facilitates the transport of pollutants from the outdoors into the indoor environment, especially in classrooms (Diapouli et al., 2008; Zhu et al., 2021). Rovelli et al. reported poor IAQ in classrooms in northern Italy due to high concentrations of airborne particulate matter (Rovelli et al., 2014). Recent studies indicate that among the various air pollutants found in classrooms, fine particulate matter with a diameter of 2.5 μm (PM2.5) poses a significant threat to the health of students (Kim et al., 2015; Ongwandee et al., 2024; Sadrizadeh et al., 2022; Son, 2023; Zhu et al., 2021).

Inside classrooms and university auditoriums, high values of PM2.5 and PM10 are caused by various factors such as indoor activities, use of chalk and other teaching materials, deterioration of building materials, emissions of small particles from furniture, heating systems, resuspension (due to the movement of students from one place to another) of material particles deposited in the dust form, air flow from outside, etc. (Dorizas et al., 2014; Elbayoumi et al., 2014; Fromme et al., 2008; Guo et al., 2010). These particles can easily penetrate the respiratory system, favoring the development of pulmonary diseases (Wichmann et al., 2010). They can also favor ocular and olfactory dysfunctions (Sadrizadeh et al., 2022; Son, 2023) or exacerbate the symptoms of atopic dermatitis (Kim et al., 2015).

Monitoring the IAQ and PM values of indoor educational spaces has become necessary to ensure healthy conditions for developing activities.

The purpose of this study is to measure PM1, PM2.5 and PM10 concentrations (μg/m^3) in different indoor and outdoor environment at "Aurel Vlaicu" University of Arad, Romania (University Complex M.) and estimate the air quality in educational spaces.

MATERIALS AND METHODS

PM1, PM2.5, and PM10 concentration measurements were carried out in five indoor locations at the M. University Complex of "Aurel Vlaicu" University of Arad (2 E. Drăgoi Str.) and outside this location. The sampling locations are as follows:

L1- outdoor environment of University Complex M

L2 - building access corridor located on the ground floor with a direct opening to the outside

L3 - 1st floor corridor, ventilation through windows

L4 - Chemistry-Physics laboratory located at 1st floor, with ventilation through windows

L5 - Environmental Protection laboratory, located at 1st floor, with ventilation through windows

L6 - "Dimitrie Cameniță" auditorium located on the ground floor, with a ventilation system in the room's upper part (ceiling).

The particulate matter concentrations were carried out using the professional air analyzer Dienmern DM 106 (Shenzhen Dienmern Testing Technology Co., Ltd., Guangdong, China) with a detection limit of 1 μg/m^3, during the May 9 – May 15, 2024, period, between 8:00-16:00 (sampling times: 8:00, 10:00, 12:00, 14:00, 16:00). The used analyzer had a built-in laser dust counter, dust sensor and time/date indicator, being able to measure PM1, PM2.5, PM10, HCHO, TVOC concentrations, air temperature as well as air humidity. The sample was taken at a height of approximately 1.5 meters above the ground or floor. For each measurement, a time of ~10 min. was allocated in order to stabilize the displayed values. Microsoft Excel was used for the graphic representation.

RESULTS AND DISCUSSIONS

The analysis of the experimental data obtained involved the interpretation of the average PM concentrations from each sampling location at different monitored times. The average concentration values (μg/m^3) for particulate matter PM1, PM2.5, and PM10 in the monitored indoor locations are presented in Fig.1, Fig.2, and Fig.3.

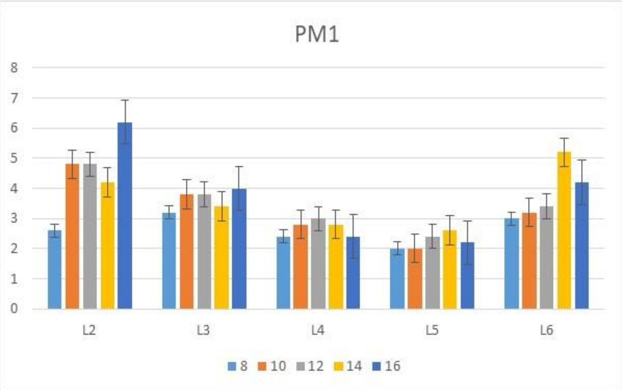

Figure 1. Average values of PM1 concentrations (μg/m^3) in the indoor locations L2, L3, L4, L5, L6 (M. University Complex, "Aurel Vlaicu" University of Arad)

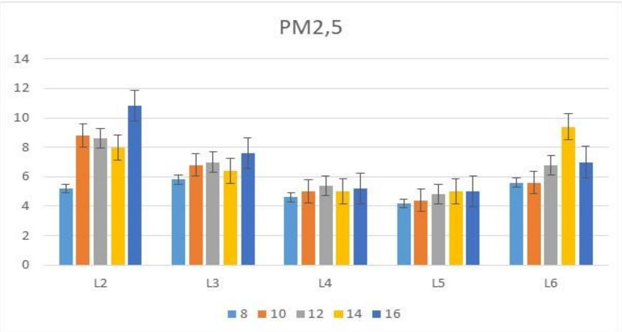

Figure 2. Average values of PM2.5 concentrations (μg/m^3) in the indoor locations L2, L3, L4, L5, L6 M. University Complex, "Aurel Vlaicu" University of Arad)

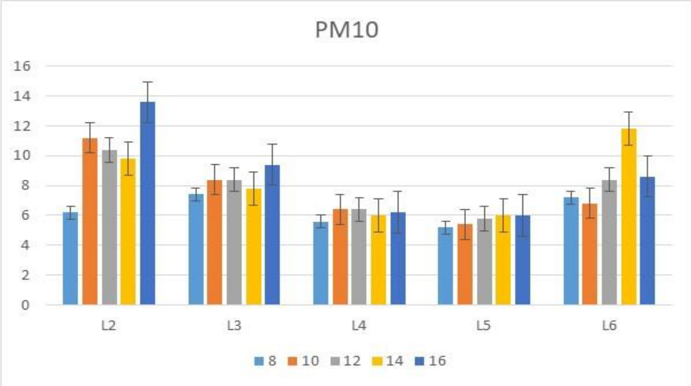

Figure 3. Average values of PM10 concentrations (μg/m^3) in the indoor locations L2, L3, L4, L5, L6 (M. University Complex, "Aurel Vlaicu" University of Arad)

From Fig. 1, Fig. 2, and Fig. 3. it can be seen that the average concentration values (μg/m^3) obtained for 5 days in the monitoring interval time (times: 8:00, 10:00, 12:00, 14:00, 16:00) were the lowest for PM1 and the highest for PM10 with the following sequence:

PM1 <PM2.5<PM10.

The data indicate that the values obtained for all three types of particulate matter (PM1, PM2.5, PM10) remain relatively stable during the 8:00–16:00 time interval in locations L4 and L5. In contrast, this trend is not observed in locations L2 and L3, the two corridors, where particulate matter concentrations show significantly higher fluctuations and elevated values than those recorded in the L4 and L5 laboratories. These variations are primarily attributed to the high foot traffic in these areas and the influence of air currents from outside, which can introduce suspended particles from the external environment. The elevated concentration values in location L2, the main access hall connecting the street to the M. University Complex, can be explained by its daily use by approximately 500–700 people on average.

In location L5, the average PM1 concentrations remained stable throughout the monitored time interval, ranging between 2 μg/m^3 and 3 μg/m^3. A similar pattern was observed for PM2.5, with average concentrations ranging from 4 μg/m^3 up to 5 μg/m^3. Slightly higher but relatively consistent values were recorded for PM10, ranging between 5 μg/m^3 and 6 μg/m^3 in location L5.

The average PM concentration values observed in location L5 can be attributed to a lower number of students (particularly on Fridays and during the morning times of 8:00 to 10:00) as well as to the recent modernization of this laboratory. The laboratory has been equipped with new furniture, and the relatively small number of chemical containers present are stored under appropriate conditions. This difference becomes much more visible when the data from location L5 are compared with those from location L4. Despite being on the same floor and exposed to a similar daily number of students, the average PM1, PM2.5, and PM10 concentrations in L4 were higher than in L5. This is likely attributable to L4 being furnished with older equipment, lacking recent renovations, and improper storage of chemicals.

In location L6 (the "Dimitrie Camenință" auditorium), high average concentrations of the three PM types and significant daily fluctuations were observed. Notably, the highest PM10 value across all monitored locations during the entire period was obtained here: 25 µg/m^3 on May 14, 2024, at 14:00. The elevated PM concentrations in this location can be attributed to the large number of students using the auditorium, the use of teaching materials such as the chalkboard, and the construction materials from the walls and ceiling which tend to accumulate particles indoors in the absence of proper ventilation.

A comparison of the average PM concentrations shown in Fig. 1, Fig. 2, and Fig. 3 reveals that the highest values were recorded in location L2 (ground floor access hall) at 14:00, followed by location L6 ("Dimitrie Camenință" auditorium) at 16:00 for all three types of monitored particles.

Reported data on air quality in classrooms and lecture halls indicate average PM1 values of approximately 2–16 µg/m^3, PM2.5 values of approximately 5–24 µg/m^3 and PM10 values of approximately 20–160 µg/m^3 (Sadrizadeh et al., 2022; Son, 2023; Diapouli et al., 2008; Zhu et al., 2021).

Compared to the findings reported in various scientific studies (Kim et al., 2015; Ongwandee et al., 2024; Sadrizadeh et al., 2022; Son, 2023; Zhu et al., 2021), the average PM1, PM2.5, and PM10 concentrations in the indoor monitored locations at "Aurel Vlaicu" University of Arad are considerably lower. These results indicate excellent air quality and a healthy environment within the educational spaces of the M. University Complex. It is mentioned that globally no mandatory standards exist for PM2.5 and PM10 concentrations in indoor air. However, WHO guidelines are most commonly used to assess indoor air quality. These guidelines establish reference values based on health impacts: for PM2.5, an annual average of 10 µg/m^3 and a maximum of 25 µg/m^3 for 24-hour exposure are recommended, while for PM10, the recommended values are 20 µg/m^3 as an annual average and 50 µg/m^3 for 24-hour exposure (https://www.who.int/publications/i/item/9789240034228).

Fig.4. shows the average values of PM1, PM2.5, and PM10 concentrations obtained during the monitored period for the outdoor environment (L1 location) of the M University Complex.

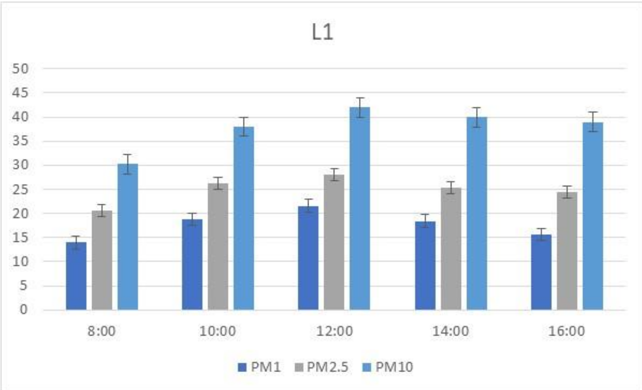

Figure 4. Average PM concentration values (µg/m^3) obtained for the outdoor location L1 (M. University Complex, "Aurel Vlaicu" University of Arad)

From Fig. 4, it can be seen that the average concentrations obtained for PM1, PM2.5, and PM10 in the L1 location from the outdoor environment are considerably higher than those obtained in indoor L2, L3, L4, L5, and L6 (see Fig.1, Fig.2 and Fig.3) as expected. For PM1, the values ranged from 14 µg/m^3 to 21 µg/m^3; for PM2.5, they ranged from 21 µg/m³ to 27 µg/m³; and for PM10, the values varied between 30 µg/m³ and 41 µg/m³. These values do not exceed the limit values allowed by the legislation in force according to which "the concentrations of suspended particles with a diameter of less than 10 microns in the ambient air are evaluated by relating them to the daily limit value, (50 µg/m^3), which must not be exceeded more than 35 times/year and the annual limit value, (45 µg/m^3 for PM10 and 25 µg/m^3 for PM2.5)" (Law no 104/15.06.2011 on the quality of the surrounding air; Directive no. 2008/50/CE of EP). A correlation can be observed between the average concentration values obtained in locations L1 and L2, which supports the hypothesis that the outdoor air quality also influences the air quality in the indoor access hall.

CONCLUSIONS

From May 9 to May 15, 2024, concentrations of PM1, PM2.5, and PM10 were monitored at five indoor locations within the M University Complex at "Aurel Vlaicu" University of Arad, including two corridors, two student laboratories, and one auditorium, at 8:00, 10:00, 12:00, 14:00, and 16:00. The results revealed relatively low levels of particulate matter, indicating good air quality for student health. Average PM1 concentrations ranged from 2 µg/m³ to 6 µg/m³, PM2.5 from 4 µg/m³ to 11 µg/m³, and PM10 from 5 µg/m³ to 14 µg/m³. The indoor particle concentrations were lower than those recorded outdoors.

The indoor particulate matter (PM) concentrations were significantly influenced by the level of foot traffic and the number of students occupying each space, as these factors contribute to the resuspension of dust and particles within the indoor environment. Additionally, several other factors played a notable role in shaping the measured concentrations. The use of various teaching materials during classes often generates fine particulate matter. At the same time, old furniture and outdated equipment may act as sources of particle release over time, especially if poorly maintained. The lack of recent renovations further exacerbates this issue, as aging infrastructure accumulates dust and deterioration, releasing particles into the air. Improper chemical storage, particularly in laboratory or storage spaces, can also contribute to particulate matter levels through chemical reactions or the volatilization of certain compounds. Finally, outdoor air currents entering through open windows, doors, or ventilation systems can introduce suspended particles from the external environment, adding to indoor PM concentrations. These combined factors underscore the complexity of maintaining optimal indoor air quality in educational settings.

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