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Case Study of the PM2.5 and PM10 Local Elimination Device – The Impact on Indoor Air Quality

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ABSTRACT

Due to its irritating, allergenic, toxic, pathogenic, and carcinogenic effects, suspended particulate matter (PM) seriously threatens human health. Therefore, it seems obvious to control the level of concentration of PM2.5 and PM10 particles and their reduction in the indoor environment such as homes, workplaces, or public utilities. In the following work, an attempt was made to determine the efficiency of a home air purifier based on the concentration of PM2.5 and PM10 particles at selected measurement points in a teaching room located in the building of the Bialystok University of Technology. The tests were carried out in March and in April 2021, using the DT-96 meter, which measured the concentration of PM2.5 and PM10 in the air. The study included the time and intensity of air purifier operation. In addition, reference was made to the concentration of PM2.5 and PM10 in outdoor air, which was measured at measuring stations in the city of Bialystok. The obtained test results made it possible to assess the initial state of air quality in the test room, as well as to determine the parameters affecting the best efficiency of the air purifier and to notice the dependencies in changes in the concentration of PM2.5 and PM10 between the indoor and outdoor environment.

Keywords: air protection, air purification, particulate matter, PM2.5, PM10.

INTRODUCTION

The suspended particles (PM) present in the air are dangerous pollutants: dioxins, polycyclic aromatic hydrocarbons (PAHs), furans, and heavy metals which are particularly dangerous. Two basic sources of particulate matter emission were classified - natural and anthropogenic. Natural sources include, above all, volcanic eruptions and forest fires, while the main source of anthropogenic dust emissions is: low emission, industry, and transport (Zhang et al., 2015; Leung, 2015; Malec and Borowski, 2016). It has been documented that atmospheric dust is both primary pollution, emitted directly from the source to the atmosphere, and secondary pollution, formed in the atmosphere as a result of chemical reactions, mainly under the influence of solar radiation and precursors (Zhang et al., 2015; Seigneur, 2019).

Particulate matter may differ in structure and chemical composition. In terms of particle size, PM10 (fine), PM2.5 (very fine), PM 1.0 (submicron), and PM0.1 (ultrafine) were distinguished (Vijayan et al., 2016; Hadi et al., 2022). It has been shown that the small size of particles facilitates penetration into the human circulatory and nervous systems, and also affects the length of their stay in the air (hence the term – suspended particles). The (lower particle mass and diameter), the longer the residence time of pollutants, which multiplies the impact of PM2.5 and PM10 particles in the environment (Brunekreef and Holgate, 2002). The basic components of particulate matter coming from direct emission include organic and inorganic carbon matter and elemental carbon – soot, mineral matter, as well as inorganic aerosols (mainly sulfates, nitrates, and ammonium compounds). An important aspect of PM research is the fact that a significant amount of these particles in the air, e.g. as benzo(a)pyrene, lead, cadmium, or nickel, has a serious impact on the deterioration of human health and the quality of suspended atmospheric air (Barret et al., 2012; Violintzis et al., 2009; Liu et al., 2015; Siudek and Ruczyńska, 2021). The particulate matter affects all forms of life on Earth (Zhang et al., 2015; Dwornik, 2019). Many studies have shown the effects of PMs on living organisms in an irritating, pneumoconiogenic, allergenic, toxic, pathogenic, and carcinogenic way. (Zhang et al., 2015, Cao et al., 2011; Leung, 2015; Liu et al., 2015, Frimpong et al., 2023). A review by Hendryx et al. (2019) showed a relationship between air pollution (mainly PM2.5) and the occurrence of chronic obstructive pulmonary disease and other respiratory diseases. The impact of particulate matter is also dangerous for pregnant women, as long-term exposure to fine particulate matter is associated with a 6% higher risk of premature birth. WHO (World Health Organization) reported that in 2005 there were over 800,000 deaths as a result of poor-quality outdoor air, while in 2016, outdoor air pollution caused nearly 4.2 million premature deaths, which shows a drastic increase in the concentration of pollutants and their impact on living organisms (Zhang et al., 2015; Liu et al., 2015). Numerous documentation has shown that the short-term and long-term impact of PM2.5 and PM10 has different effects (Vijayan, 2016). In the case of the first, malaise lasts from 1 hour to several days and is associated with being in a dusty environment. The main symptom is a cough or irritation of the skin and eyes. On the other hand, long-term exposure to particulate matter involves exposure for at least a year, while its effects are often noticeable after many years in the form of serious chronic diseases (Vijayan, 2016; Chen et al., 2020; EEA Report, 2020). The WHO has identified diabetes as a major global health threat. Based on experimental and epidemiological studies, it was found that about 20% of the global burden of type 2 diabetes is related to PM2.5 pollution (Burkat, 2022).

The conducted research on particulate air pollution, as well as the noticeable effects of its occurrence, influenced the development of research in this field and the introduction of acceptable standards for the concentration of PM particles in the air around the world (Zhou et al., 2016). In addition, publicizing the problem constantly increases people's awareness of maintaining good air quality in buildings where they spend the most time during the day. It became necessary to protect the air against particulate matter particles, which in practice resulted in a significant increase in the use of local devices using processes aimed at cleaning the air of particulate pollution (Vijayan et al., 2016). The basic principle of operation of air purifiers used in domestic rooms is based on the use of the filtration process, while larger devices are used, among others, in industry, to reduce PM2.5 and PM10 emissions, they also use absorption, adsorption, and combustion processes (Liu et al., 2015).

The work attempts to determine the effectiveness of a home air purifier based on the concentration of PM2.5 and PM10 particles at selected measurement points in the classroom located in the building of the Białystok University of Technology.

MATERIALS AND METHODS

The area of the PM2.5 and PM10 concentration tests and the assessment of the effectiveness of the air purifier used was the teaching room no. 3/29, located on the second floor of the building of the Bialystok University of Technology. The university is located in the city of Białystok, which is the capital of the Podlaskie Voivodeship, located in the northeastern part of Poland (Jaros, 2011). The room in which the tests were carried out is located at the Faculty of Civil Engineering and Environmental Sciences in the building of the INNO-EKO-TECH Center, commissioned in 2015. About the cardinal directions, the room in which the PM concentration measurements were made is located with the outer wall and windows towards the northwest. This is important in the case of winds, which in the Podlaskie Voivodeship, prevail from the west and southwest, which may favor the blowing of particles 4 pollutions into the room through open windows. Many studies have documented that indoor air quality is greatly influenced by the state of outdoor air quality. Therefore, when carrying out the discussed studies on PM2.5 and PM10 air pollution, both indoor and outdoor environments should be taken into account (Leung, 2015; Department of Urban Planning, 2011). The dimensions of the room were: 6×8.76 m and 3 m high to the suspended ceiling. The room has a total area of 52.56 m^2 and is equipped with mechanical ventilation, a projector, a computer as well as benches, and seats for the lecturer and students. More precise data on ventilation parameters were not obtained from the building administrator. The outside air that flows into the room is not purified.

Measurements of PM2.5 and PM10 concentrations before and after using the air purifier were carried out three times in March and April 2021. During the study on the effectiveness of purification, only the person performing the measurements was present in the room. It was a transitional period, winter and spring. Particulate matter measurements were made in 12 designated points of the classroom (Figure 1), located in the building of the Bialystok University of Technology. Measurements were taken one after the other, point by point, which resulted in a 45-second delay compared to the previous point.

All measurement and control points (twelve in total) are located in the same classroom, but they differ from each other, among others:
- distance between walls and windows,
- location relative to the entrance door,
- location relative to the air purifier.

On each day of the tests, before switching on the air purifier, the concentration of PM2.5 and PM10 was first measured at the measurement and control points to determine the initial concentrations of pollutants in the room. The tests were carried out at a height of 150 cm from the floor, using the DT-96 meter CEM (China). The meter was characterized by the measurement range: PM2.5 - 0 ~ 2000 µg/m^3, PM10: 0 ~ 2000 µg/m^3, resolution 1 µg/m^3. However, the measurement error is 5%. After pressing the START/STOP button, the device measured the concentration of PM2.5 and PM10 in the air for 30 seconds, finally displaying the result on the screen in µg/m^3. After measuring the output concentration of PM2.5 and PM10 at all measurement and control points, the air purifier was turned on. During the measurements, windows and doors were not opened. During the measurements, each day one of the three-stage fan speeds was used: low – 1, medium – 2, or high – 3. The days on which a given run was tested are described in the graphical charts in the results section.

The principle of operation of the air purifier is based on the use of a 3-stage operating mode and an automatic mode that activates the functions of ionization, ventilation, sterilization, humidification, and an odor sensor, regulating the operation of individual functions to improve air quality as soon as possible. The dusty air forced into the purifier initially goes to the cold catalytic filter that

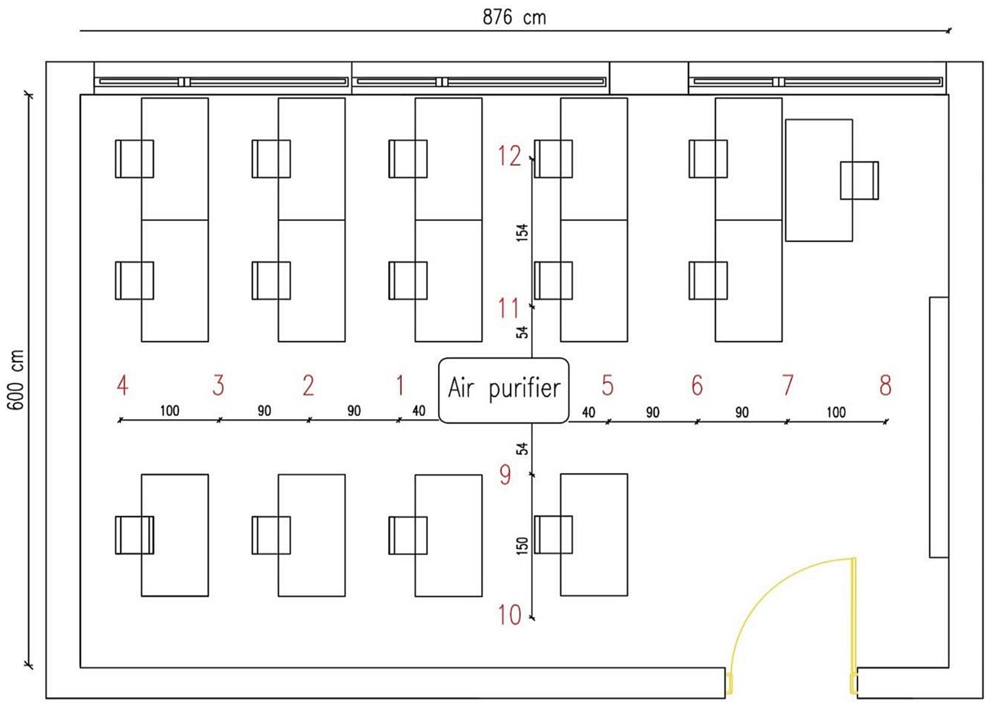

Figure 1. Diagram of the room with the measuring points located

traps large PM particles. Pre-cleaned air passes through a carbon filter that removes unpleasant odors. The third stage is the antibacterial filter, which removes bacteria present in the air. Further, on the HEPA H13 filter with high purification efficiency, almost 100% of PM impurities, bacteria, and fungi remaining after the previous filtration are retained. For the maximum removal of bacteria and fungi, the air purifier uses UV-C light. At the last stage, the supplied air is ionized and clean air is released back into the room. The control panel located at the top of the device shows the degree of air quality in the room by indicating specific colors: green – good, orange – bad, and red – very bad. The purifier is designed for rooms with an area of about 60 m^2. The model and name of the manufacturer of the purifier are not given due to commercial law. The aim is not to promote or negate a specific manufacturer. The smaller the area, the greater the cleaning efficiency. The concentration of PM2.5 and PM10 in a closed, cleaned room was measured with a meter every 30 minutes until the concentration level stabilized. Each measurement series lasted the same time.

In the basic model using the filtration process, before starting to clean the air of PM pollution, the device measures the concentration of PM particles in the room, humidity, and air temperature through sensors. If there are any PM particles detectable by the camera, air purification is started. Due to the type of filters used in air purifiers and the requirements to be met in the room, air protection devices are divided into anti-smog air purifiers, air purifiers with humidification, and air purifiers with the possibility of air ionization (Staszowska, 2020).

RESULTS AND DISCUSSION

Leung (2015), similarly to the study below, took into account the quality of indoor air and correlations between the concentration of pollutants inside buildings and outside. Strong correlations between the quality of indoor air and the outside air flowing through various elements into the buildings have been established. The research showed that the level of pollution with PM2.5 and PM10 particles was often higher indoors than outdoors. Through leaks in the building, particles from car traffic or other external sources flow in, while there is no sufficient air exchange combined with its simultaneous cleaning.

To determine the correlation between the external and internal conditions in the test room, Table 1 presents the average daily concentrations of PM2.5 and PM10 that occurred on the measurement days. The data was collected from two air quality monitoring stations in Białystok. Both measurement points are located in the city center. The first station with a national code - PdBialWaszyn, is located at 16 Washington Street, while the second PdBialWarsza is located at 75A Warszawska Street. Measurements of particulate concentration are carried out continuously, collecting data on hourly and average daily information on the state of air quality.

The average daily concentration of PM2.5 at the PdBialWaszyn station on measurement days ranged from 10.72–35.1 μg/m^3, and at the PdBialWarsza station from 6.3–29.9 μg/m^3. On the other hand, the average daily PM10 concentration was recorded in the monitored period at the PdBialWaszyn station in the range from 9.5 μg/m^3 on April 13, 2021 to 33.0 6.3–29.9 μg/m^3 on March 4, 2021. In turn, at the measuring station in PdBialWarsza in the range from 16.3 to 77.9 6.3–29.9 μg/m^3.

The values of PM10 and PM2.5 concentrations obtained during measurements in the test room are presented in figures divided into PM2.5 and PM10, taking into account the values of dust concentration in each of them depending on the

Table 1. Daily PM2.5 and PM10 concentrations - PdBialWaszyn and PdBialWarsza stations (www.powietrze.gios.gov.pl)

Measuring station	PdBialWaszyn		PdBialWarsza	
Date	PM2.5	PM10	PM2.5	PM10
	[μg/m^3]			
04.03.2021	35.1	33.0	29.2	38.3
11.03.2021	26.0	26.2	29.9	38.9
15.03.2021	14.7	19.3	18.5	18.6
07.04.2021	12.7	15.1	11.5	16.3
13.04.2021	10.7	8.5	6.4	77.9
20.04.2021	16.2	28.1	18.1	38.5

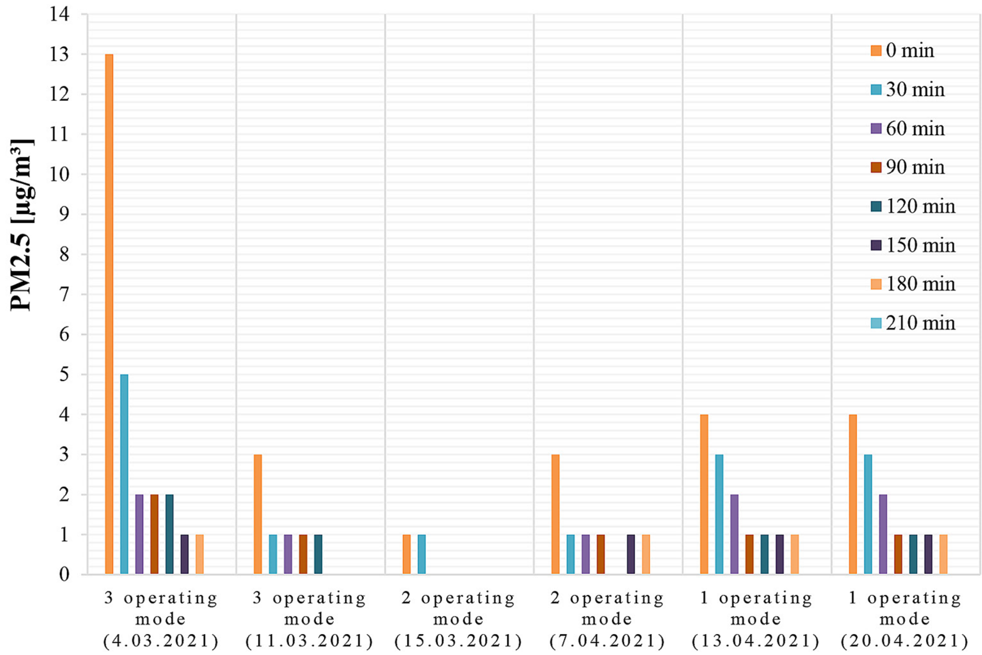

Figure 2. PM2.5 measurement results at point 1

fan speed and air purification time used. Figure 2 shows the selected distribution of PM2.5 concentration at the first measurement and control point, during all measurement days.

Changes in the concentration of PM10 on each measurement day for point 1, using the selected air purifier, were presented similarly. It can be seen that each day the initial concentrations of PM10 were higher than those of PM2.5.

According to the results collected during the operation of the air purifier (Figures 2 and 3), it should be noted that during each intensity of operation of the device, the use of the purifier allowed for to reduction of the concentration of PMs at 1 measurement point. The results for point 1 are presented because, after calculating the efficiency at all points, the maximum efficiency was obtained after the maximum time (Figures 5 and 6). The highest initial concentrations of PM2.5 and PM10 were recorded on March 4 at each measurement and control point, while on all subsequent measurement days, the initial concentrations were much lower. These results are due to the first test day with the use of an air purifier, during

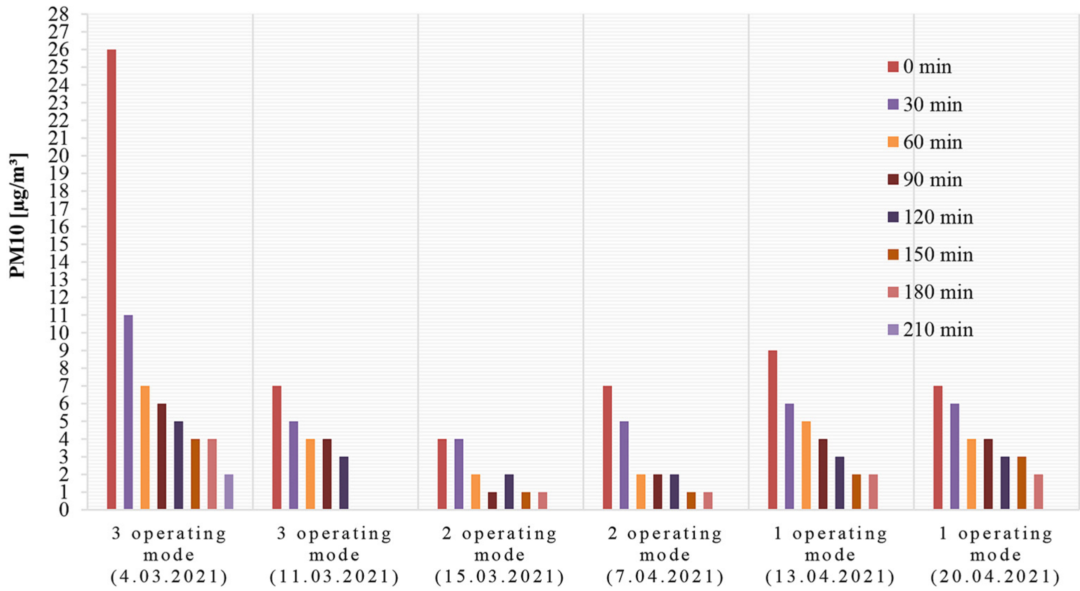

Figure 3. PM10 measurement results in point 1

which all PM2.5 particles and almost 100% of PM10 were removed. As a result, and thanks to good ventilation and negligible impurities coming from the outside, subsequent tests started with much lower values.

It is worth noting the positive correlation between the distribution of PMs concentration levels measured by measuring stations in the city of Białystok and the system of decrease and increase in the concentration of PM2.5 and PM10 in the tested room. It was observed that analogically on the first day, the initial values outside and inside the room showed the highest concentrations, decreasing over the next measurement days. On the last measurement day, the increase in the concentration of particulate matter in the outdoor air and the increased value of the particulate matter in the test room about the falling trend was read again. As in numerous studies already carried out, based on the results obtained, it can be concluded that there is a relationship between the level of concentration of PM2.5 and PM10 and the conditions outdoor (Leung 2015).

In addition, based on the measurements of PM concentration, the efficiency of the purifier was calculated. The purpose of the selected charts was to illustrate the changes in the efficiency of air purification from PM2.5 and PM10 particles over time. Figures 3 and 4 show the efficiency of the air purifier at maximum fan operation at each measurement time, on the first test day. Purification efficiency after a given run was calculated by taking the difference in PM2.5 or PM10 concentration initially measured and after each time the purifier was running by dividing by the initial value.

Figure 4 shows the effectiveness of the PM2.5 air purifier over the entire test period. The highest

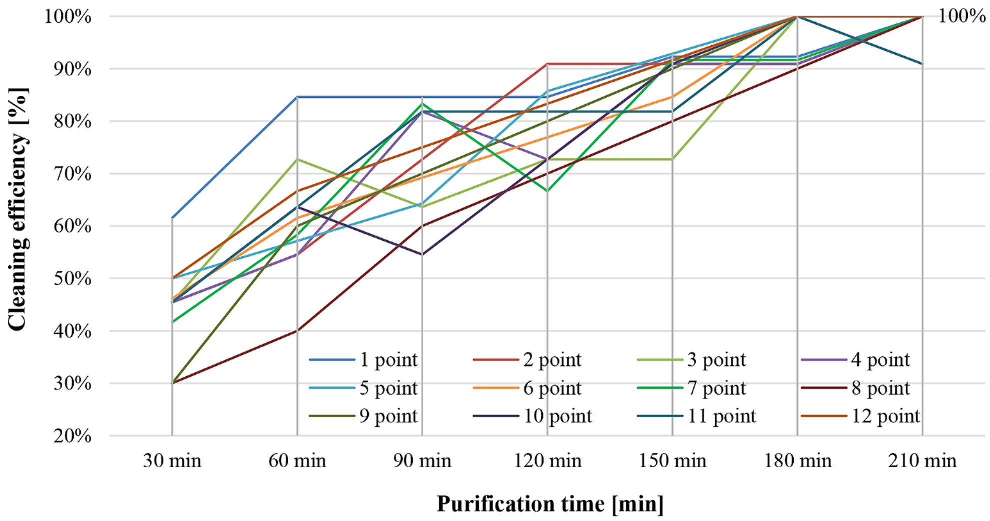

Figure 4. Average air purifier efficiency for PM2.5 (March 4, 2021)

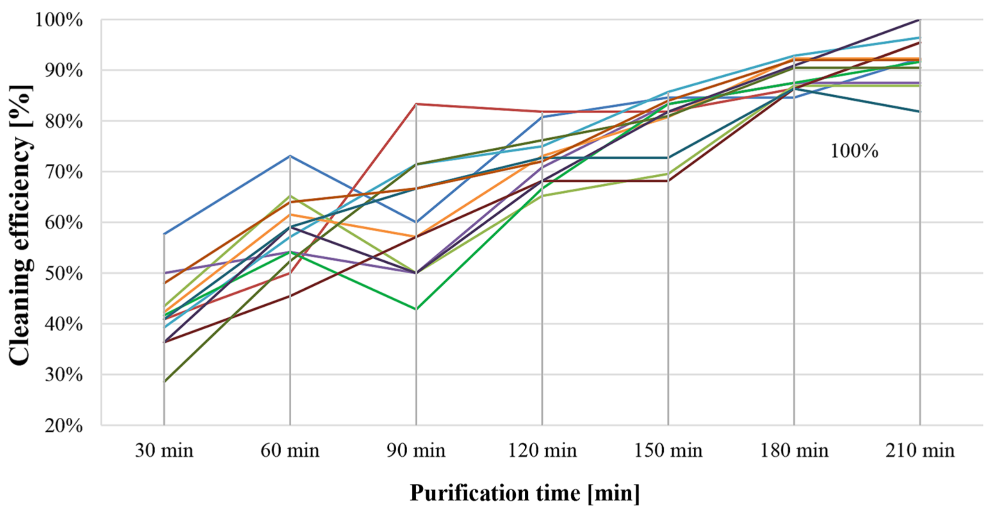

Figure 5. Average air purifier efficiency for PM10 (March 4, 2021)

percentage of PM2.5 removal after the first time measurements occurred in the first – 61.5%, as well as in the fifth and twelfth measurement points, achieving exactly a 50% decrease in PM2.5 concentration within 30 minutes. High efficiency in the above-mentioned points may result from their location in the center of the room, where the air exchange is the best.

Based on Figure 5, which shows the effectiveness of the air purifier from PM10 particles, also throughout the measurement period, it can be seen what effect time has on reducing the concentration of particulate matter suspended in the air. In most points, the PM10 removal effect was satisfactory, on the border of about 90%. The maximum efficiency of PM10 removal in the test room, equal to 100%, was observed in the tenth measurement and control point, while the lowest – in the eleventh point, equal 81.8%.

High dependence on air purification efficiency occurs between the time and the size of the removed PMs (Figures 4 and 5). High-efficiency filters ensure the efficiency of 99% with particles from 0.1 microns. With the increase of time, the efficiency of eliminating PM2.5 and PM10 particles from the air in the test room increases. According to Leung (2015), in previous studies, the efficiency of pollutant removal was also obtained at 60%. In our study, after 210 minutes, the efficiency of removing PM2.5 particles reached 100%, while in the case of PM10 particles, the pollution reduction efficiency was on average 95-99%, indicating a very good efficiency of the device used and its appropriate selection to the requirements of the room. The efficiency of cleaning is also influenced by the intensity of fan operation and the concentration of pollutants. The lower the initial PM concentration and the higher the fan speed, the shorter the elimination time of PM2.5 and PM10 particles.

The conducted research has shown that using air purifiers in the rooms, effectively eliminates and permanently reduces the concentration of PM, thanks to which the exposure of people staying in the room to the negative impact of PM2.5 and PM10 particles is reduced.

CONCLUSIONS

The value of PM2.5 and PM10 concentrations in a room is directly dependent on the concentration of particulate matter outside the building in which the room is located. Based on the tests and graphs, it was found that the air purifier operating time, fan speed, and initial concentration of pollutants had the greatest impact on the effectiveness of PM2.5 and PM10 elimination in the test room. The air purifier used ensured high efficiency in removing PM2.5 and PM10 from the air in the selected test room. The purifier worked most effectively on the 3rd fan speed, and the weakest on the 1st fan speed. This is related to the amount of air filtered by the purifier. After the maximum measurement time set by the authors at 210 minutes, 100% efficiency was achieved in almost every measurement point for each run of the purifier.

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