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INFLUENCE OF ROAD TRAFFIC ON INDOOR AIR QUALITY

WPŁYW RUCHU DROGOWEGO NA JAKOŚĆ POWIETRZA WEWNĘTRZNEGO

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Abstract

The quality of air that people breathe has become a very important parameter of quality of life. Pollution contributes to numerous diseases, problems with the absorption of knowledge, and also reduces work efficiency. The article attempts to find the relationship between road traffic and indoor air quality. The parameter used to assess air pollution was particulate matter (smog). The research was carried out in three localisations with different traffic volumes, in three places for each localisation, in the summer, autumn, and winter periods. It was found that in areas with heavy road traffic, this traffic causes an inflow of pollutants into the rooms. In low – traffic localisations, sources other than road traffic have a greater impact on the indoor air quality, especially in the cool periods (autumn, and winter).

Keywords: particulate matter PM2.5, PM10; Indoor Air Quality; road traffic

Streszczenie

Jakość powietrza, jakim oddycha człowiek, stała się bardzo istotnym parametrem jakości życia. Zanieczyszczenia przyczyniają się do licznych zachorowań, problemów z przyswajaniem wiedzy, a także obniżają wydajność pracy. W artykule podjęto próbę odnalezienia zależności pomiędzy natężeniem ruchu drogowego i jakością powietrza wewnętrznego. Parametrem, który wykorzystano do oceny zanieczyszczenia powietrza, był pył zawieszony (smog). Badania przeprowadzono w trzech lokalizacjach o różnym natężeniu ruchu, w trzech miejscach dla każdej lokalizacji, w okresach lato, jesień i zima. Stwierdzono, że w lokalizacji o dużym natężeniu ruchu pojazdów ruch ten powoduje napływ zanieczyszczeń do pomieszczeń. W lokalizacjach o małym natężeniu ruchu większy wpływ na jakość powietrza wewnętrznego mają inne niż ruch drogowy źródła, szczególnie w okresach chłodnych (jesień, zima).

Słowa kluczowe: pyły zawieszone PM2.5, PM10; jakość powietrza wewnętrznego; ruch drogowy

1. INTRODUCTION

The quality of the air that people breathe, especially in the centre of crowded cities, has become an extremely important parameter of the quality of human life [1]. Air pollution is a major contributor to noncommunicable diseases around the world [2]. Evidence collected by scientists shows the damaging effects of pollutants on the respiratory and cardiovascular systems [3], and epidemiological and toxicological studies also indicate negative effects on the central nervous system [4-11]. In particular, traffic-related pollutants, including carbon monoxide,

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nitric oxide, and particulate matter less than 2.5 µm in diameter, have been associated with a number of adverse neurodevelopmental effects in children (eg. autism spectrum disorders) and neurodegenerative disorders in adults (eg. Alzheimers disease) [12-14].

Breathing polluted air is associated with more frequent hospitalizations [15], and exhaust gases, semi-volatile, and gaseous pollutants containing organic compounds present in the air are mutagenic and cause genetic damage [16]. In addition, air pollutants can cross the placental barrier and directly affect the embryo and the foetus [17, 18]. Several studies have shown that city dwellers spend almost 90% of their time indoors [19]. If the air we breathe for such a long period of time is of poor quality, it has a significant impact on our health and well-being. It should be noted that due to the lack of immediate health effects, the problem of indoor air pollution is underestimated. This is an extremely dangerous activity. We live in a time when, in the name of modernity, huge amounts of harmful substances are released into the atmosphere. Hardly anyone is aware of the scale of this problem. The industries, transportation, and electricity production sectors emit millions of tons of pollutants. The effects of these emissions often spread over time. There is a widespread belief in society that closed windows or doors effectively isolate us from air pollutants outside. However, it should be remembered that they are never perfectly tight and that the contaminants that enter can even be 10 µm or less. Furthermore, it has been shown that the level of indoor pollution can be up to 10 times higher than the level of outdoor pollution [20]. These indoor pollutants that can contribute to the so-called sick building syndrome, SBS, cause several respiratory and cardiovascular diseases, and reduce work efficiency. US data estimate that SBS-related health problems generate $ 57 billion in losses annually [21]. The WHO (World Health Organization) [22] also reports that 3.8 million deaths worldwide in 2016 were caused by air pollution. In contrast, particulate matters PM2.5 is responsible for approximately 4.5 million of these deaths [23]. In the UK alone, around 40.000 premature deaths are caused by air pollution each year, about half of which are related to pollution from transport [24]. In Poland, PM 2.5 particulate matter is also responsible for 82% of the burden of diseases resulting from exposure to indoor air pollution [25].

The WHO regularly publishes guidelines to improve them as much as possible, and government institutions are taking steps in the right direction, trying to reduce the amount of harmful substances emitted into the atmosphere. Despite this, millions of people around the world are chronically exposed to air pollutants in concentrations well above legal safety standards [26]. The concentrations of particulate matter currently recommended by the WHO are 5 $\mu g/m^3$ for PM2.5 and 15 $\mu g/m^3$ for PM10 per year, 15 $\mu g/m^3$ for PM2.5 and 45 $\mu g/m^3$ for PM10 per day.

Indoor air pollution most often comes from the external environment. They penetrate the inside through leaks in window openings, doors, and through ventilation [27]. Particularly important from the point of view of the amount of incoming pollutants is the type of ventilation system. Mechanical air exchange systems are equipped with filters that are not present in natural ventilation. In the case of natural ventilation, only systems that inform about the need to close windows [28] due to the high pollution of the outdoor air can help reduce the flow of pollutants into the rooms. The main ones are carbon oxides (CO, CO_2), nitrogen oxides (NO_x), polycyclic aromatic hydrocarbons (PAHs), ozone (O_3), and PM (particulate matter). The dominant component of air pollution in cities and suburban areas is dust pollution, among which we distinguish particulate matter with an aerodynamic diameter: 2.5 to 10 µm (PM 10), fine particles below 2.5 µm (PM 2.5) and ultrafine particles less than 0.1 µm [29]. Furthermore, it is important that dust (especially PM 2.5) can stay in the air for a long time, can be transported over hundreds of kilometres, and can penetrate inside buildings [30].

The source of particulate matter is mainly industry [31], but, as Merzkisz [32] reports, particulate matter also arises in transport as a result of wear of the vehicle's consumables, such as the braking system, and tires, and are products of incomplete combustion of fuels, in the combustion chamber. In addition, the research by Xiong et al. [33] proved the impact of vehicle traffic on the increase in PM 2.5 concentration in the air. They observed a reduction in pollution during mobility limitation during the SARS Cov2 pandemic. Particulate matter emitted during the combustion process increases in mass as the temperature of the exhaust gas decreases. The main reason for this phenomenon is the fact that soot, which is the main component of exhaust gas solids, has strong absorption properties. Models describing the process of soot formation in the cylinders of internal combustion engines describe the dehydrogenation of hydrocarbons followed by their decomposition into ethyne. Subsequent processes include polymerization, cyclization, and coagulation of polymers, which consequently lead to the formation of a porous carbon black structure. The course of PM formation is shown in Figure 1. The harmfulness of these particles is mainly related to the heavy organic substances and heavy metals absorbed in the soot particles. It is worth remembering that the smaller the molecule, the more dangerous it is to human health. The smallest ones can penetrate deep into the human blood system and its internal organs.

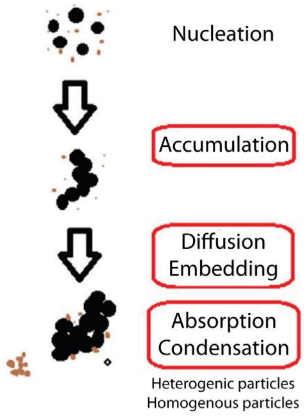

Fig. 1. Formation of particulate matter in vehicle exhaust gas

The correct assessment of indoor air quality should begin with recognition and characterization of the source of pollutant emission [34]. This research work attempts to check whether indoor air quality is related to road traffic volume in the area and which place in the apartment is most exposed to possible pollution. Air quality was assessed on the basis of the amount of particulate matter in the air. The study was carried out at three localisations that differ in terms of road traffic intensity in their vicinity.

2. MATERIALS AND METHODS

In order for the study to show differences in air quality depending on the volume of vehicle traffic, the localisations of the research were selected in such a way that the differences in traffic intensity were obvious and noticeable. For this purpose, 3 sites were selected in Kielce, Poland (Table 1).

The concentration of particulate matter was measured with meters (Table 2), located outside the building (P I), in a room facing the road – 10 m from the road (P II) and in the room located on the other side of the building – 100 m from the road (P III). The concentration of PM1, PM2.5, PM10 particulate matter, the temperature of the air, and the relative humidity of the air were measured. The measurement was carried out around the clock with a time step of 15 minutes.

The buildings analysed are single-family houses equipped with natural ventilation. The building in the L1 location was equipped with a district heating system, the buildings in the L2 and L3 locations were equipped with wood-fired fireplaces with a closed combustion chamber. The users of all facilities opened their windows in the summer, whereas in autumn and winter they opened them for several minutes in the morning and evening to ventilate the rooms. In L1, users stayed mainly in the morning and afternoon hours; in L2 and L3, they stayed constantly. The dust was not removed during the tests.

The content of particulate matter was measured on the basis of laser light scattering technology, air temperature with a silicon bandgap sensor, and relative air humidity with a capacitive sensor. Research was carried out in three series of measurements in three different seasons of the year: summer, autumn, and winter.

Table 1. Localisation of research objects

Localisation	Geographical coordinates	Road traffic	Building
L 1	50°52'2.38"N, 20°39'38.141"E	heavy	low, compact, urban
L 2	50°51'45.305"N, 20°39'37.204"E	moderate	low, compact, outskirts of the city
L 3	50°51'55.8"N, 20°49'25.907"E	low	low, low density, countryside

Table 2. Characteristics of the particulate matter concentration meters

Parameter	Measurement range	Accuracy	Resolution of Indications
Concentration of particulate matter	0 – 500 mg/m^3	± 10 mg/m^3 for 0 – 99 mg/m^3 ± 10% for 100 – 500 mg/m^3	1 mg/m^3
Temperature	-40 – 100°C	± 0.5°C for -20 – 80°C	0.01°C
Relative humidity	0 – 100%	± 3% for -20 – 80%	1%

3. RESULTS AND DISCUSSION

3.1. Experimental Studies

The data obtained allowed the development of diagrams showing the course of changes in dust concentration over time, depending on the localisation and for different localisations of the meters within the analysed building. In Figures 2-10 the measurement accuracy (10 μg·m^{-3}) is marked. The concentrations of particulate matter recorded during the tests often reached values below the accuracy of the measurement.

L 1 (Fig. 2) is a building on the road with the highest traffic. It is an exit road from Kielce to Lublin, characterized by particularly increased traffic at night until 9:00 and in the afternoon. The course of changes in the concentration of particulate matter in the outside air is significantly higher at night and in the afternoon. The concentration of particulate matter in the room near the road is higher than the concentration of particulate matter in the room located away from the road. This clearly shows the impact of road traffic on the condition of the internal air.

L 2 (Fig. 3) is characterized by moderate traffic intensity with visible intensity in the morning (6:30-9:00) and afternoon (14:30-18:00) hours. This is reflected in the concentration of particulate matter in those hours. At ‘P I’ there is a clear increase in the concentration of particulate matter in the morning, evening, and night, and the lowest concentration is visible during the day. Greater concentrations can be seen inside the room facing the street than in the room located away from the road. This also means that the influx of pollutants from the road into the interior has a greater impact on indoor air quality.

In L 3 (Fig. 4), due to low road traffic, no effect of vehicle traffic on the concentration of particulate matter in the air during the summer was observed. There was no tendency to change the concentration

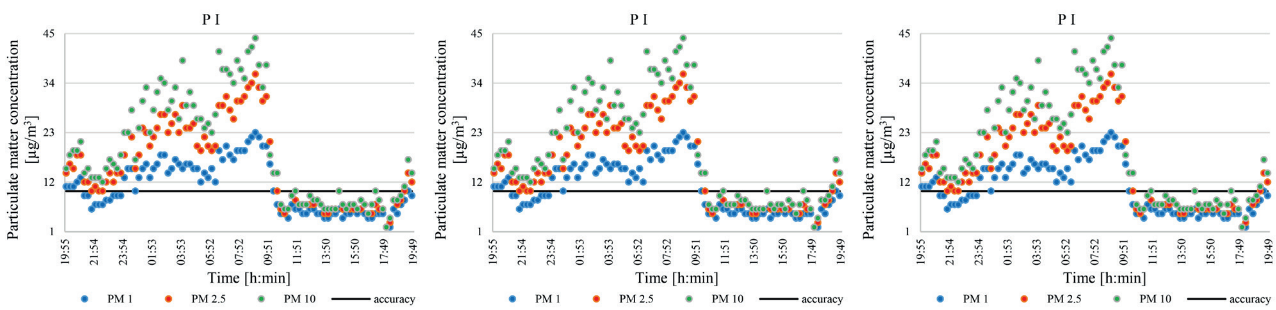

Fig. 2. Changes in particulate matter concentration for L 1. Season – summer

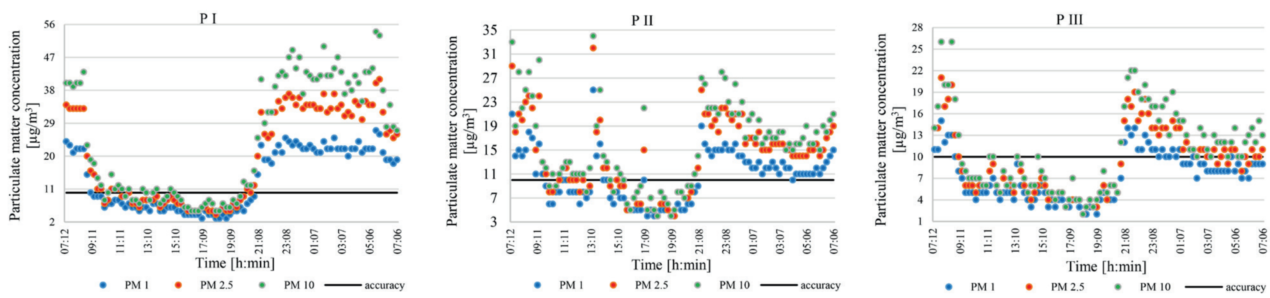

Fig. 3. Changes in particulate matter concentration for L 2. Season – summer

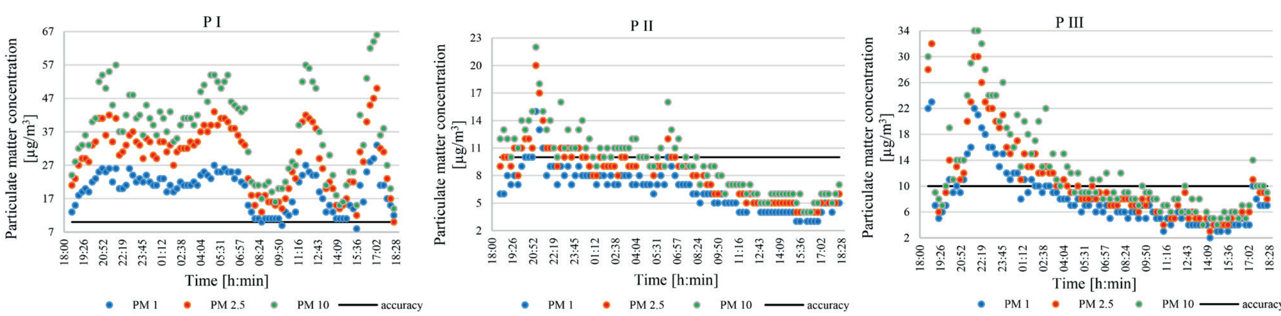

Fig. 4. Changes in particulate matter concentration for L 3. Season – summer

of particulate matter outside the building depending on the time of day. In the rooms within the building, increased concentrations were observed in the evening hours. This is related to the increase in heat production for the purpose of preparing domestic hot water for bathing. This is also evidenced by a higher concentration of particulate matter in 'P III' than in 'P II', i.e. in a room located away from the road and close to other residential buildings. During the night and during the day, the concentration was lower. At the same time, the highest concentration of particulate matter was found outside the building, which means that the main source of pollution is the surroundings of the building.

In the autumn period, at L 1 (Fig. 5), the concentrations of particulate matter outside the building were the highest, and, similarly to the summer period, in the room located away from the road, they were the lowest.

In the autumn period, for L 2 (Fig. 6) outside, the daily differences in the concentrations of particulate matter are smaller than in summer. The beginning of the heating season is of significant importance for the equalization of the concentration of particulate matter throughout the day. It means a significant influence of the particulate matter from the furnaces. In this case, the concentration of particulate matter in the room located away from the road was also the lowest.

In autumn, at L 3 (Fig. 7), the highest concentrations of particulate matter were observed outside the building, and, similarly to summer, the concentration of particulate matter increased in the afternoon and evening hours. Particulate matter concentrations in the indoor air reached higher values in a room located away from the road, confirming the low impact of road traffic in a low-traffic localisation.

In winter, at L 1 (Fig. 8), the highest concentrations of particulate matter were recorded outside in the

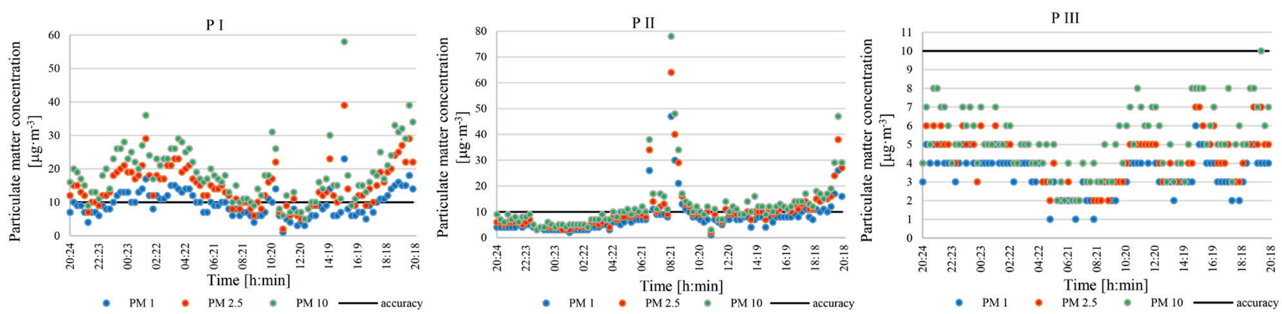

Fig. 5. Changes in particulate matter concentration for L 1. Season – autumn

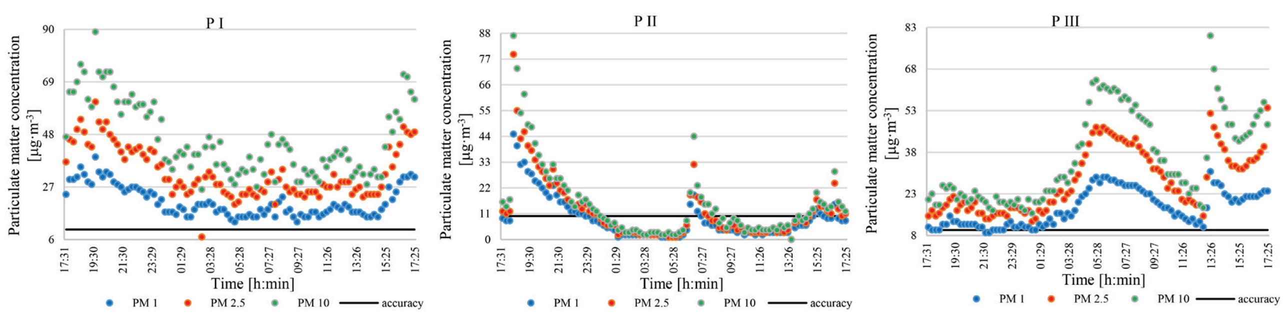

Fig. 6. Changes in particulate matter concentration for L 2. Season – autumn

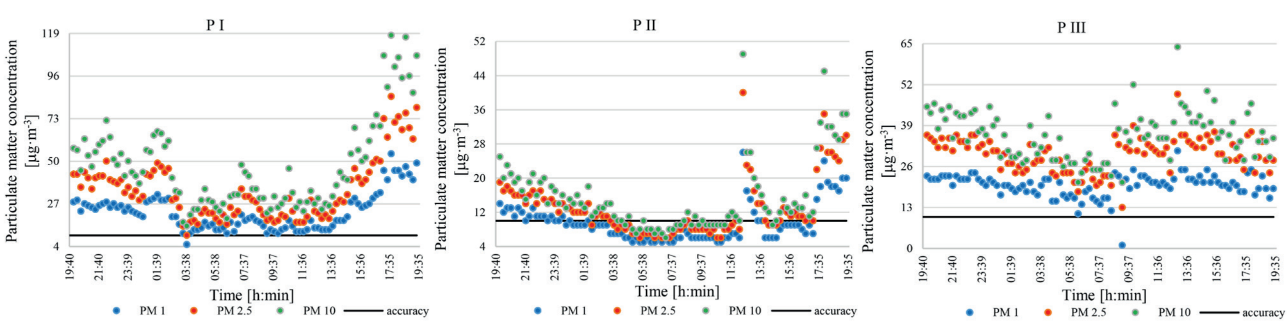

Fig. 7. Changes in particulate matter concentration for L 3. Season – autumn

evening and night hours. In the room located away from the road, the concentrations of particulate matter in the indoor air were higher than in the room near the road, which means that the particulate matter coming from outside also has a source other than transport. Taking into account the ongoing heating period, this was particulate matter from the furnaces. This room also does not exhibit diurnal variability similar to the outdoor concentration of particulate matter. In turn, the course of changes in the concentration of particulate matter in the room near the road is similar to the variability in the outside air.

In the winter period, at L 2 (Fig. 9), the highest outdoor concentrations of particulate matter were recorded with a visible difference in concentrations for night and day hours. As in the autumn period, the difference in the concentration of particulate matter at different times of the day is smaller than in summer. The diurnal differences are more pronounced in the room facing the road (P II). The lowest concentrations occurred in the room on the other side of the building (P III).

In winter, at L 3 (Fig. 10), the daily difference in the concentrations of particulate matter is visible. Lower concentration values appear during daylight hours. In this case, the highest concentration of particulate matter values were also found outside the building (P I) and the lowest in the room on the other side of the building (P III). The diurnal variability is also visible at P III, where higher concentrations of particulate matter occur between 10 pm and 6 am.

3.2. Statistical Analysis

Figures 11 to 13 present the box plots, which show the distribution of *the concentration of particulate matter (pm 2.5 and PM 10)* characteristic in groups

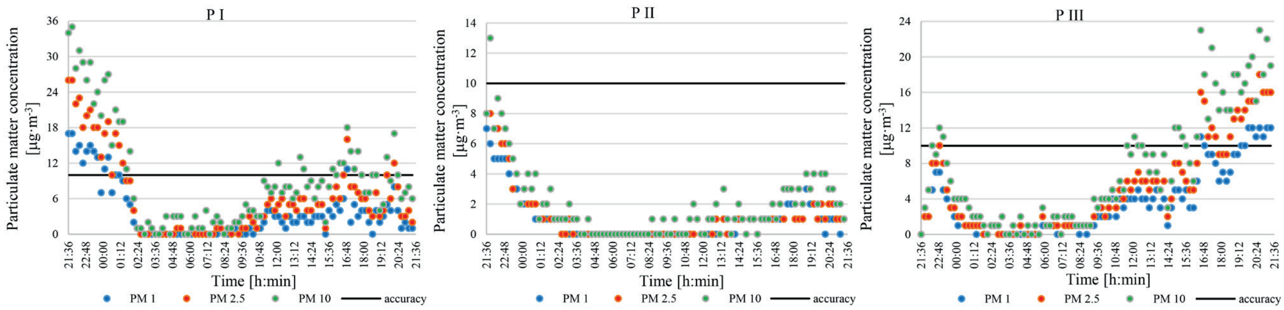

Fig. 8. Changes in particulate matter concentration for L 1. Season – winter

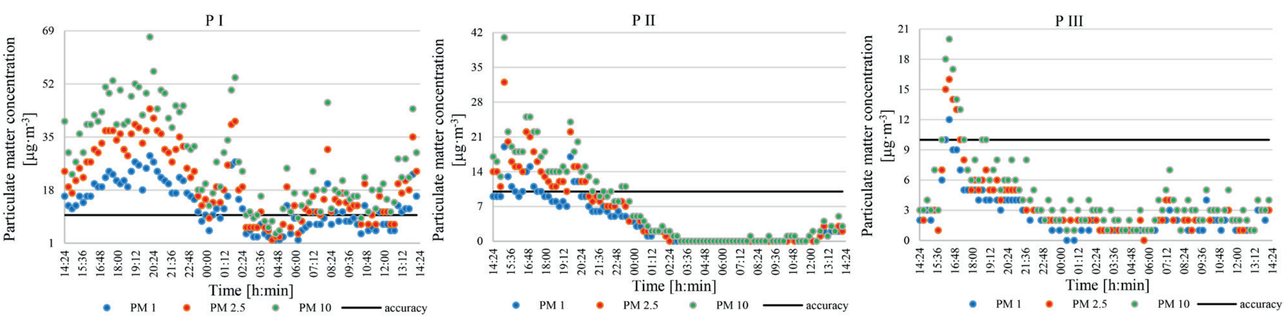

Fig. 9. Changes in particulate matter concentration for L 2. Season – winter

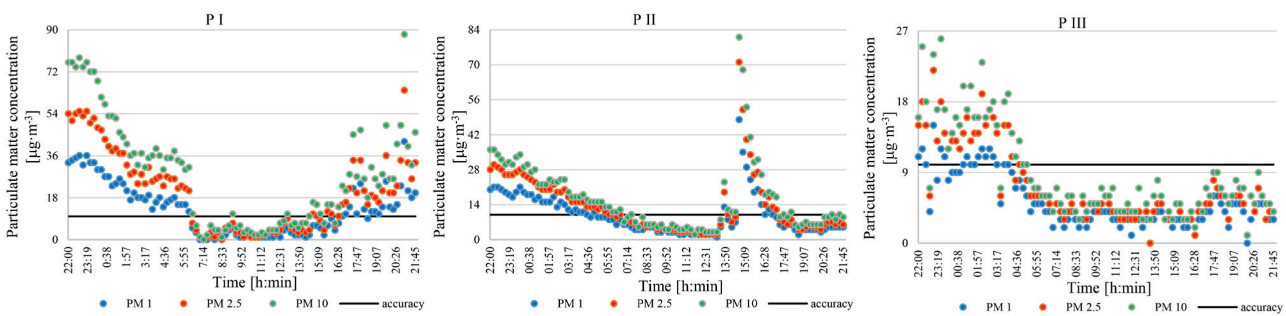

Fig. 10. Changes in particulate matter concentration for L 3. Season – winter

determined by *localisation* characteristic. The single box plot presents: the smallest value, the lower quartile, the median, the upper quartile, and the largest value of the examined characteristic, as well as the mean value using the marker. The difference between the upper and the lower quartiles, called the interquartile range, indicates how long the range covering half the centrally located values of the examined characteristic is.

Figure 11 shows that the lowest average value of the concentration of PM 2.5 particulate matter outside the building can be expected in summer, autumn, and winter for L 1. Furthermore, in the cooler period (autumn and winter), the average values of the PM 2.5 particulate matter concentration are similar. This means that fuel combustion is more important than road traffic for air quality.

In the case of the concentration of PM 10 particulate matter, as for the concentration of PM 2.5 particulate matter, the lowest average value outside the building in summer, autumn, and winter can be expected for L 1. Furthermore, in the cooler period (autumn and winter), the average values of the PM 10 particulate matter concentrations are similar to each other. This means that fuel combustion is more important than road traffic for air quality.

According to Figure 13, in the localisation with the highest road traffic, the concentration of PM 2.5 particulate matter is the lowest at all three measurement points, which confirms that the amount of PM 2.5 particulate matter in the air is mostly affected by fuel combustion, and not by road traffic itself. At the same time, in localisations where fuels are not burned and traffic is heavy, the presence of

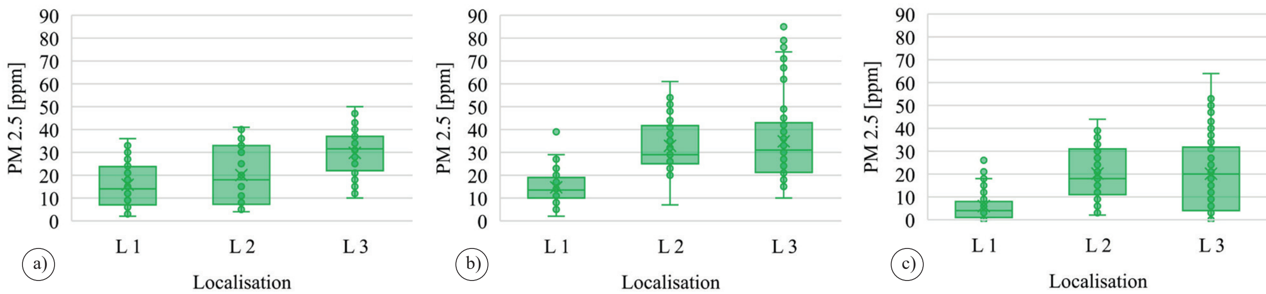

Fig. 11. Box plots of the concentration of PM 2.5 particulate matter outside the building: (a) Summer, (b) Autumn, and (c) Winter

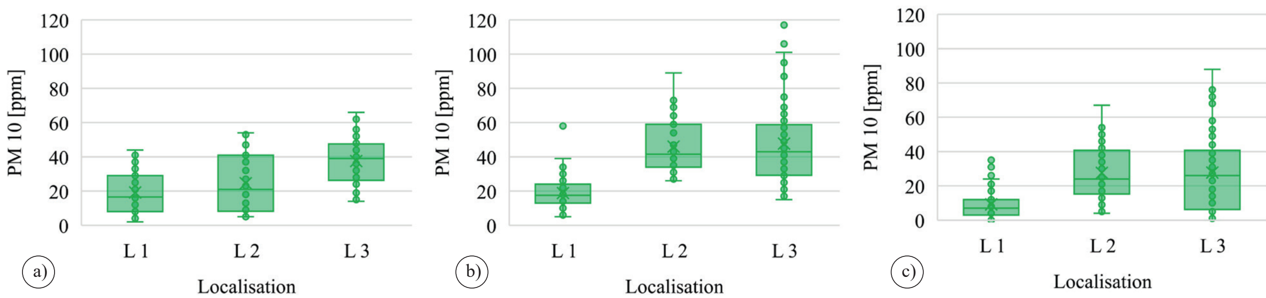

Fig. 12. Box plots of the concentration of PM 10 particulate matter outside the building: (a) Summer, (b) Autumn, and (c) Winter

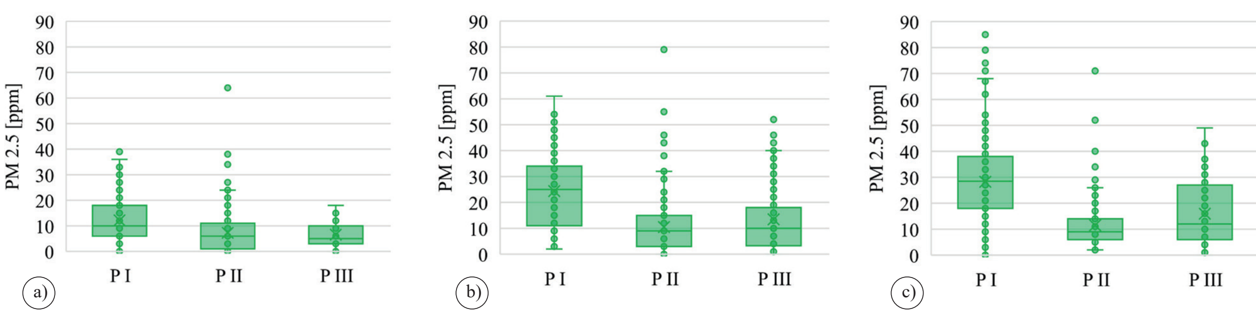

Fig. 13. Box plots of the concentration of PM 2.5 particulate matter outside the building: (a) L 1, (b) L 2, and (c) L 3

indoor particulate matter was recorded, and therefore road traffic is a source of indoor air particulate matter in areas with heavy traffic. L 2 and L 3 show higher concentrations of particulate matter in indoor air. At L 3, the concentration of particulate matter in the room located away from the road is highest, which means that the road with the lowest traffic has little effect on indoor air quality.

3.3. Discussion

The results of the conducted tests do not indicate a clear increase in the concentration of particulate matter in the morning and afternoon hours, i.e. those with increased road traffic. There is a tendency to increase concentrations of particulate matter in the afternoon and night and a relatively stable level during the day. An important factor here is movement, which during the hours of our activity causes, e.g. a more frequent exchange of air in the rooms. Also, especially in summer, open windows facilitate faster air exchange. This means that pollutants enter the room as quickly as they are removed from it, for example, due to the air flow caused by passing cars. In the afternoon and at night, when this movement is very limited, harmful substances stay in the air longer, maintaining this concentration for a relatively long time. The second factor is heating, where heat is produced by burning solid fuels, such as coal or wood, or liquid fuels, such as gas and fuel oil. Fuel combustion releases the products of incomplete combustion into the atmosphere, that is, solid particles that create smog. The figures show the dependence of the increase in particulate matter concentration in the afternoon and their maintenance at a high level for a longer period of time.

In the literature, you can find various research works on the subject of the dependence of air quality on the intensity of vehicle traffic in the environment. An example may be the article by Badyda, Majewski [35], who attempted to check the relationship between vehicle traffic and air pollution near traffic roads, taking into account weather conditions. Their 168-hour study showed a relationship between air quality and traffic in the area. For this purpose, they monitored the number of cars passing at different times of the day, broken down into passenger cars, trucks, and buses, measured the level of carbon monoxide, nitrogen oxides, benzene, ethylbenzene, toluene, xylene, sulphur dioxide, and PM10 particulate matter, and recorded the prevailing meteorological conditions such as air temperature and humidity. The results of their research are unequivocal. During the peak traffic period, along with the increase in traffic, the amount of pollutants in the air increases. This is especially visible between 8:00 am and 9:00 am and 4:00 pm and 6:00 pm on working days. However, it should be mentioned that the intensity of traffic in the afternoon does not usually coincide with the increase in pollution. This intensification occurs about 5 hours later. This is precisely related to the meteorological conditions at the measurement site. The authors indicate that in addition to the intensity of traffic itself, the measurement results are significantly influenced by variables such as wind speed, air temperature, solar radiation intensity, precipitation height, and relative humidity of the air. Depending on the season, the above – mentioned variables affect air quality to a different extent.

Another example in the literature dealing with the same topic is the article by Gliniak et al. [36], in which the authors attempted to investigate the relationship between vehicle traffic and air pollution in the form of PM 10 and PM 2.5 particulate matter. The study was carried out from March to July 2013 on different days of the week, from 12:00 p.m. to 3:00 p.m. and from 10:00 p.m. to 1:00 p.m. The results of their tests do not show any relationship between the intensity of road traffic and the amount of particulate matter in the air. The increase in the number of vehicles passing near the measurement point did not increase the concentration of particulate matter. Such results indicate that in Krakow, the share of road traffic in the emission of air particulate matter pollutants is negligible and comes from completely different sources.

The Pearson correlation analysis conducted for the concentration of outdoor particulate matter (Table 3) showed that in the summer the correlations of the L 1 and L 2 localisations are stronger than the correlations of the L 1 and L 3 localisations, in the autumn the correlations for both variants of localisations are moderate, and for the winter period, there is a stronger correlation between the L 1 and L 3 localisations than between L 1 and L 2. In summer, the only source of particulate matter outdoors is vehicle traffic; hence, the weaker correlation between the localisation with the smallest and largest vehicle traffic. The correlation analysis also confirms the large impact of fuel combustion on the concentration of particulate matter in the outdoor air in places with little traffic and solid fuel heat sources.

Table 3. Pearson's correlation between localisations for each period

Summer	L 1 / L 2	L 1 / L 3
	0.7	0.2
Autumn	L 1 / L 2	L 1 / L 3
	0.5	0.5
Winter	L 1 / L 2	L 1 / L 3
	0.4	0.6

To clearly determine the impact of vehicle traffic on indoor air quality, a Pearson's correlation analysis was performed between the measurement points for each localisation (Table 4). The winter period was selected as the most authoritative period, as the windows in each of the buildings were closed most of the time. There is a stronger correlation between P I/P II in localisations with more traffic. In L 3, a stronger correlation occurred for P I/P III, confirming the greater influence of fuel combustion on the concentration of particulate matter.

Table 4. Pearson's correlation between measurement points for each localisations

	Winter	
	P I/P II	P I/P III
L 1	0.8	0.3
L 2	0.7	0.6
L 3	0.4	0.7

Taking into account the current WHO recommendations for the concentration of suspended particulate matter during the day, it is worth noting that in all localisations the concentration of PM 2.5 particulate matter exceeded the recommended value. In L 1, in winter, the concentrations of PM 2.5 were exceeded at night, i.e. during the period of increased vehicle traffic. In L 2 and L 3, temporary exceedances of PM 10 concentrations were also observed.

The research carried out for the purposes of the article and the analysis of the literature show that it is necessary to conduct further research, extended to the monitoring of a larger number of parameters, in order to unequivocally determine the impact of road traffic on air quality. In this case, it would be important to take into account the type of engine in the vehicles to determine whether the fuel combustion of the engines or the wear of roads and tires has a significant impact.

3.4. Limitations of the study

The findings of this study must be seen in light of some limitations. Meters detect the presence of particulate matter in the air, but do not allow us to determine the source of air pollution, which may be vehicle traffic, fuel combustion, and other activities in households. To overcome this limitation, more research is needed with a greater variety of building localisations, and this study is a good introduction for further analyses.

4. CONCLUSIONS

The conducted analysis showed that:

1. In localisations with heavy vehicle traffic, the concentration of particulate matter in the air is lower in rooms located away from the road, regardless of the season. For the period of autumn and winter there is a percentage difference of 53-84% in the summer period 2%.
2. Indoor air quality depends on the intensity of road traffic.
3. In a localisation with low traffic, fuel combustion for heat production has a greater impact on the concentration of particulate matter, than road traffic.
4. Further analysis is necessary to assess the significance of the share of road traffic as a source of particle matter pollution, taking into account other sources (mainly fuel combustion) and the parameters of the outside air and the floor of the building. It is also important to take into account the direction of the wind, which can cause differences in the inflow of pollutants into the interior from different sides of the building.

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