Comparative analysis of indoor and outdoor concentration of PM₁₀ particulate matter on example of Cracow City Center

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Abstract

Article concerns the problems of air pollution with PM₁₀ particulate matter in Cracow. An indoor concentration of PM₁₀, along with the outside air pollution, was observed in the period between January and March. Comparative analysis was carried out, especially for the periods with exceptionally high outside concentration of PM₁₀. Both outside and inside concentration results were subjected to analyses on raw and averaged (minute, hourly, daily) data, along with extreme values. The results of investigations showed that for the time periods with extremely high concentration of particulate matter suspended in the air outside, the air quality indoor was also poor. In general, after exceeding the value $250 \mu\text{g}/\text{m}^3$, PM₁₀ concentration inside building was higher than outside, especially during night time. Analysis of the relationship between PM₁₀ concentration and air temperature and wind speed showed higher correlation between PM₁₀ and wind speed; however, the relationship PM₁₀–temperature appeared significant, too.

Keywords PM₁₀ particulate matter · Air quality · Dust pollution

Introduction

Cracow is one of the most polluted cities in terms of air quality, not only in Poland, but also throughout Europe. Particularly noteworthy is a very high concentration of the dust suspended in the air. As it is presented in the reports, issued each year by the Regional Inspectorate for Environmental Protection (WIOŚ) in Cracow, dust emission limits are exceeded for most days during the year. The existing regulations allow for exceedance of these limits ($50 \mu\text{g}/\text{m}^3$) for at most 35 days a year (Dz.U. [Journal of Laws] from 2012, item 1031), whereas in Cracow more than 200 of such days a year can be registered (Table 1, Fig. 1).

High concentrations of dust pollutants in the atmosphere are one of the main environmental factors exerting a detrimental effect on the health of the inhabitants (WHO 2004, 2006), especially in the case of respiratory disease (WHO

2000), cardiovascular problems (Brunekreef and Forsberg 2005), as well as chronic obstructive pulmonary disease (Caiazzo et al. 2013; WHO report 2013).

The dust suspended in the air is a mixture of solid particles and liquid droplets. These molecules contain various components such as sulfur, organic compounds (i.e., polycyclic aromatic hydrocarbons), heavy metals, dioxins and allergens (such as pollen and fungal spores). The most important parameters of air quality are the total suspended particles (TSP) and particles an aerodynamic diameter finer than $10 \mu\text{m}$ (PM₁₀). However, PM₁₀ particles have especially negative influence on humans, because they are inhaled in the upper respiratory system, bronchi and lungs, causing coughing, difficulty in breathing and shortness of breath, especially during physical exertion. They contribute to increase the risk of respiratory infections and exacerbation of symptoms of allergic diseases, i.e., asthma, hay fever and conjunctivitis. Very fine dust fractions (usually finer than $2.5 \mu\text{m}$) can penetrate into the bloodstream, and longer exposure to high dust concentrations can have a significant impact on the course of heart disease (hypertension, heart attack) or even increase the risk of cancer, especially lung disease. The severity of symptoms depends to a large extent on the concentration of dust in the air, the time of exposure and the increased susceptibility of the body. The group,

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Table 1 Number of exceedances of an average 24-h permissible level of the PM₁₀ concentration ($> 50 \mu\text{g}/\text{m}^3$) in Cracow in the period 2007–2017 (measuring station located on Krasieńskiego Av.)

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Number of exceedances	233	263	221	223	200	134	158	188	204	165	132

Fig. 1 Daily concentration of PM 10 particles in Cracow during the years 2007–2017 (Krasieńskiego Av. measuring station)

especially exposed to the negative impact of dust pollution, are children, the elderly and pregnant women (Merklinger-Gruchala and Kapiszewska 2015; van den Hooven et al. 2012).

Regional Inspectorate for Environmental Protection (WIOŚ) in Cracow carries out continuous measurements of air pollution level through several dozens of substances. Measurements of particulate pollutants, including PM₁₀, are performed automatically and manually, while the latter method is the reference for dust measurement. The results of automatic measurements are presented online on the Inspectorate's Web site (<http://monitoring.krakow.pios.gov.pl>).

Permissible standards for air pollution have established separately by Poland, the European Union and WHO, the World Health Organization. In Poland, according to Regulation of the Ministry of Environment (Dz.U. [Journal of Laws] from 2012, item 1031), PM₁₀ fine dust standards are set at three levels for daily mean:

- Acceptable level— $50 \mu\text{g}/\text{m}^3$, exceeded ≤ 35 days/year
- Information level— $200 \mu\text{g}/\text{m}^3$
- Alarm level— $300 \mu\text{g}/\text{m}^3$

Acceptable level for the annual average pollution is $40 \mu\text{g}/\text{m}^3$.

In case of level of information ($200 \mu\text{g}/\text{m}^3$) and alarm level ($300 \mu\text{g}/\text{m}^3$), the following actions (included in a short-term procedure, worked out for Cracow City) are recommended (e.g):

- limitation of the flats airing,
- staying at home,
- limitation of the presence of children in the open space while in school.

The main aim of the paper is to analyze the indoors concentration of PM₁₀ dust particles, especially during the days with the higher pollution (i.e., PM₁₀ concentration outside). The results of investigations presented in the paper showed that in some cases concentration of PM₁₀ dust particles measured indoors can be higher than the respective concentration recorded outdoors at the same time.

Materials and methods

The main research aim of the paper is a comparative analysis of PM₁₀ dust particles pollution level indoors and outdoors in the center area of Cracow City.

Fig. 2 Outdoor (red dot) and indoor (black dot) measuring stations (based on Google Maps)

The outside measuring station was located on Krasieńskiego Avenue, between two street arteries (red dot in Fig. 2) (Bogacki et al. 2016). The station belongs to the Regional Inspectorate for Environmental Protection in Cracow. Measurements inside the building, in turn, were carried out in a room with area of. approx. 15 m², located on the third floor, in the attic. The roof windows in the room were tightly closed. The building has a mechanical ventilation system, operating in exhaust mode, which is a standard equipment in public buildings such offices and schools. The building is located next to Mickiewicza Avenue. Location of the two measuring points is presented in Fig. 2. Both points are located in the main two-way street, located in proximity of the old town of Cracow. The initial analysis of correlation between data collected outdoor in the two points showed a high convergence—the correlation coefficient r equaled 0.9 for the PM10 concentration.

The measurement of the suspended particulate matter PM10 inside the building's room was recorded with using of the Casella Microdust Pro Dust Monitor, which was placed on a tripod at a height of approx. 150 cm. The measurement was performed in a continuous mode (24 h/day); raw data were averaged to 1 min. Measurements have been recorded within the period January 9–March 16, 2017, with some short breaks, resulting from the blackout.

Data from the WIOŚ station (outdoor measuring point) are registered as hourly average data. The meteorological data from the Vaisala WXT520 automatic meteorological station located on the roof of the building located next to

the indoor measuring point were used to analyze the possible influence of selected meteorological factors on the level of PM10 particulate matter concentration.

Results and discussion

As it was said the above, the investigative programme was carried out in the time period January 9–March 13, 2017. An hourly analysis showed that for the days with a relatively lower outside concentration of PM10 (within the range 50–100 µg/m³), the concentration of PM10 inside the building was low and amounted to about 0–20 µg/m³. However, when the outside concentration was higher than 100 µg/m³, the inside concentration increased, too. An average difference between the concentrations inside and outside the building (hourly average) on days with a relatively lower concentration of PM10 (up to 150 µg/m³) amounted to approx. 50 µg/m³ (Fig. 3).

Figure 4 shows the average hourly concentration of PM10 within the analyzed time period. It is noticeable that the concentration of PM10 dust particles inside the building was often higher than the outside one. This situation was observed, especially for the periods with very high outside concentrations of PM10 particulate matters (Fig. 5).

Comparison of average hourly values of PM10 dust particle concentrations measured outside and inside the building for the days with high concentration of PM10 (> 250 µg/m³) showed that the concentration of PM10 inside the building was higher than the concentration

Fig. 3 Average hourly concentration of PM10 particulate matter outdoors and indoors for the days with lower air pollution (March 9–16, 2017)

Fig. 4 Average hourly concentration of PM10 particulate matter outdoors and indoors for the time period January 9–March 16, 2017

Fig. 5 Average hourly concentration of PM10 particulate matter outdoors and indoors for the days with higher air pollution (hatched section = night hours—18:00–6:00; white sections = day hours—6:00–18:00)

Fig. 6 Average minute concentration of PM10 particulate matter indoor for the time period January 17–February 3, 2017

outside. When the outside values of PM10 particles concentrations are higher than $250 \mu\text{g}/\text{m}^3$, the inside PM10 concentration grows rapidly, reaching 400, 500 and even $600 \mu\text{g}/\text{m}^3$. An average minute concentration of PM10 particles, in turn, exceeded even the value of $700 \mu\text{g}/\text{m}^3$ (Fig. 6). The maximum average hourly concentration of PM10 inside the building in the analyzed period was $638 \mu\text{g}/\text{m}^3$ (31 of January, 04:00 AM), while the outside one amounted $354 \mu\text{g}/\text{m}^3$ (31 of January, 03:00 AM). In turn, the maximum average minute PM10 concentration inside the building was as high as $740 \mu\text{g}/\text{m}^3$ (31 of January, 04:34 AM).

In a case when the concentration of PM10 outside begins to decrease, the concentration of analogous dust particles inside the building decreases too; however, this drop is usually delayed by about 1–2 h (Fig. 7).

As it can be seen in the above figures, the rapid increase in PM10 concentration both inside and outside the building begins around 6:00 P.M. and maintains until 3:00 A.M. and even later. Very high concentration of PM10 inside the

building during the night hours is probably linked to the intense traffic in afternoon hours and the coal and wood burning for heating purposes during the evening and night. In order to compare the obtained values of PM10 particles concentrations with the standards determined in the Ministry of Environment regulations, the daily average values were calculated.

Analysis of daily averages confirms the results of analysis obtained for hourly averages. When the concentration of PM10 particles outside the building was within the range $200\text{--}250 \mu\text{g}/\text{m}^3$, the average daily concentration inside the building was lower than the outside one, for approx. $40\text{--}70 \mu\text{g}/\text{m}^3$. In turn, when the outside concentration of PM10 was greater than $250 \mu\text{g}/\text{m}^3$, the concentration inside the building was significantly higher than the outside one. In example, on the 28th of January the daily average concentration of PM10 dust particles amounted to $276.8 \mu\text{g}/\text{m}^3$ and the inside the building $342.0 \mu\text{g}/\text{m}^3$. On 31st of January, in turn, the outside concentration was $287.0 \mu\text{g}/\text{m}^3$ and inside one: $425.4 \mu\text{g}/\text{m}^3$. Therefore, the concentration inside

Fig. 7 Average hourly concentration of PM10 particulate matter outdoors and indoors for the days with higher air pollution in January 2017

Fig. 8 Average daily concentration of PM10 particulate matter outdoors and indoors for the time period January 19–February 3, 2017

Fig. 9 Relationship between concentration of PM10 particulate matter and temperature and average wind speed in the time period January 19–February 1, 2017

the building was higher than the outside one by 65.2 and 138.4 $\mu\text{g}/\text{m}^3$, respectively (Fig. 8). This also means that the alarm level (300 $\mu\text{g}/\text{m}^3$) has been exceeded inside the building, while outside concentration of PM10 was below the alarm level.

The concentration of the suspended particulate matters in Cracow registered outside was compared with the weather conditions (Fig. 9). The following relationships were observed for the days with high PM10 concentrations (January 19–February 1):

(a) the correlation coefficient between the hourly concentration of PM10 and the temperature is negative ($r = -0.4$, significant on the probability level 0.95), which indicates a significant relationship, but rather a moderate (average) correlation,

- (b) the regression function, describing the relationship of PM10 concentration (y) on the temperature (x), has binomial form: $y = 1.2149x^2 + 0.9904x + 151.3$ ($R^2 = 0.1691$),
- (c) the correlation coefficient between the hourly PM10 concentration and the average wind speed $r = -0.5$ (significant on the probability level 0.95), indicates a significant and quite high correlation,
- (d) the regression function describing the PM10 concentration (y) relationship on the average wind speed (x) has the logarithmic form: $y = -100.7\ln(x) + 175.2$ ($R^2 = 0.3133$).

Table 2 Values of correlation coefficients and regression equations for the air temperature and the wind speed

Year	Wind speed versus PM10 concentration	Air temperature versus PM10 concentration
Correlation coefficient	$r = -0.5$	$r = -0.4$
Regression equation	$y = -100.7 \ln(x) + 175.2$	$y = 1.2149x^2 + 0.9904x + 151.3$

Discussion of results

An analysis of hourly concentration of PM10 particulate matters registered for the periods with high outside concentration shows that after exceeding a certain level of pollution, an indoor concentration of PM10 is higher than the outdoor one. It is quite difficult to determine unambiguously the exact level of PM10 concentration outside, above which the concentration of PM10 inside the building begins to exceed the outside concentration. Nevertheless, based on a careful analysis of data presented in Fig. 4, the value around $250 \mu\text{g}/\text{m}^3$ can be accepted as threshold one. The indoor pollution generally decreases slower than the outdoor one, and the data analysis (Fig. 7) shows that when the outside concentration of PM10 begins to decrease, the inside concentration decreases too; however, this drop is usually delayed by about 1–2 h.

The highest levels of PM10 concentration were usually observed during the evening and night hours which is probably linked to both the intense car traffic in afternoon hours and the process of coal and wood burning for heating purposes, especially when it takes part in old and often poorly adjusted domestic furnaces.

An analysis of average daily concentrations confirms the results obtained for the hourly registered measurements. It is worth to mention that when an outside concentration of PM10 was around $250 \mu\text{g}/\text{m}^3$, the pollution registered indoor has exceeded even the alarming level ($300 \mu\text{g}/\text{m}^3$). Considering the fact that highest concentrations of PM10 were registered during the night, it could be considered a ventilation of the indoor room, before the night rest time. The measurement data show that this might not be illogical, especially when the extremely high indoor concentration decreases slower than the outside one.

The concentration of PM10 was also analyzed against the selected weather condition, namely, air temperature and wind speed. The comparison of concentration of PM10 particulate matter shows that as it could be expected, the wind speed influences the level of PM10 concentration more significantly than the temperature. The temperature is usually considered as an indicator of an emission of dust particles coming from domestic furnaces in the following way: the lower the outside air temperature, the more the intense heating of the houses and, as a result, the higher the emission of burning dusts. However, in the case of Cracow City, this kind of emission has the lower impact on the PM10 concentration

than the wind speed. Respective correlation coefficients and regression equations are provided in Table 2.

Conclusion

A high level of the suspended particulate matter concentration and the resulting the air pollution, occurring especially in autumn and winter, concerns not only large urban agglomerations. Recently, it is becoming valid also for smaller cities and towns. The main source of this problem seems to be the low emission from low-efficient household furnaces (dust and harmful gases emission up to 40 m high) fed by the low quality fuels and even garbage. Another important source of dust pollution is the road transport, causing direct and secondary dusting. There are also a number of the other factors, like excessive ill-conceived urban development (restrictions in natural air flow), unfavorable weather conditions (frequent inversions occurring in autumn and winter) and unfavorable geographical location (basin, valley).

The results of investigations presented in the paper showed that high concentration of particulate matter suspended in the air can be a serious threat not only for the people outside buildings, but also for those staying at homes. As it was shown in the above analysis, the concentration of PM10 inside the building may exceed the PM10 concentration outside, especially during the time periods with extremely high values of particulate matter in the air (higher than $250 \mu\text{g}/\text{m}^3$).

An increase in PM10 concentration outside, which caused a rapid increase in PM10 concentration inside the building (PM10 inside > PM10 outside), occurred mainly during the night hours when people generally stay indoors. In the face of the above research results, one should seriously consider proper ventilation of the room.

Analysis of the relationship between PM10 concentration and air temperature and average wind speed showed a significant relationship between PM10 and temperature, but rather a moderate correlation, while PM10 and wind speed showed a significant relationship and a higher correlation.

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References

- Bogacki M, Rzeszutek M, Heba K (2016) Modelowanie dyspersji zanieczyszczeń powietrza w kanionie ulicznym na przykładzie Alei Krasińskiego w Cracowie. *Czasopismo Inżynierii Lądowej, Środowiska i Architektury* 2016, z. 63, nr 2/II, 21–38
- Brunekreef B, Forsberg B (2005) Epidemiological evidence of effect of coarse airborne particles on health. *Eur Respir J* 26:309–318
- Caiazzo F, Ashok A, Waitz IA, Yim SHL, Barrett SRH (2013) Air pollution and early deaths in United States. Part I: quantifying the impact of major sectors in 2005. *Atmos Environ* 79:198–208
- Merklinger-Gruchala A, Kapiszewska M (2015) Association between PM10 air pollution and birth weight after full-term pregnancy in Cracow city 1995–2009—trimester specificity. *Ann Agric Environ Med* 22(2):265–270. <https://doi.org/10.5604/12321966.1152078>
- Regulation of the Minister of Environment of 24 August 2012, On the levels of certain substances in the air (in Polish). *Dz.U. [Journal of Laws]* from 2012, item 1031
- van den Hooven EH et al (2012) Air pollution exposure and markers of placental growth and function: the generation R study. *Environ Health Perspect* 120(12):1753–1759
- WHO (2000) Air quality guidelines for Europe. WHO Regional Publications, European Series No. 91, WHO Regional Office for Europe, Copenhagen
- WHO (2004) Health aspects of air pollution. Results from the WHO project “Systematic review of health aspects of air pollution in Europe”. WHO 2004. Retrieved 8 Oct 2018 from http://www.euro.who.int/__data/assets/pdf_file/0003/74730/E83080.pdf
- WHO (2006) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Retrieved 8 Oct 2018 from http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf
- WHO report (2013) Review of evidence on health aspects of air pollution. REVIHAAP project