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EFFECT OF METEOROLOGICAL CONDITIONS AND BUILDING LOCATION ON CO_2 CONCENTRATION IN THE UNIVERSITY CAMPUS

WPŁYW WARUNKÓW METEOROLOGICZNYCH I ZABUDOWY NA STĘŻENIA CO_2 NA TERENIE KAMPUSU UCZELNI

Abstract: The quality of atmospheric air and the level of its pollution is inextricably linked with the development of humanity. Its prevalence and the lack of any natural protective barriers causes that it becomes a recipient of increasingly large amounts of different types of pollutants. This is particularly dangerous in the areas where both meteorological conditions and type of building prevent the spread of pollution. By using a portable gas micro-chromatograph it is possible to observe and analyze a seasonal impact of building density on carbon dioxide concentration and the effect of atmospheric conditions on CO_2 level in the air in a specified area.

Keywords: carbon dioxide, building density, meteorological conditions, concentration in the atmosphere

Introduction

The quality of atmospheric air and the level of its pollution is inextricably linked with the development of humanity. In the past, the scale of industrial production and limited industrialized area caused that air pollution occurred only locally. This changed at the time of a global increase of industrial production and demand for energy, intense growth in population density and development of the road system and transportation.

Atmospheric air is an element of the environment and is of particular importance for the existence of life on Earth. At the same time, because it is common and does not have any natural protective barrier the air becomes a recipient of increasingly large quantities of various pollutants. For this reason, the impact of air pollution should be considered not only globally, but also in continental, national and local scale, because even single anomalies can affect the entire state of atmospheric air.

Both atmospheric air and its pollutants are subject to many physicochemical processes which lead to changes in their concentrations. These are the processes analogous to decay of

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radioactive material whose half-life depends on many factors, *eg* insolation, precipitation, or the interaction of pollutants [1].

It is not easy to determine the impact of various pollutants on the human body and/or surrounding environment. For this reason a system for air monitoring and protection is necessary.

In Poland, air quality is controlled within the provincial air quality assessment systems that are supervised by Provincial Environmental Protection Inspectorates. In the Lodz region this is implemented by various measurement networks which are divided according to measurement methodology, *ie* according to the degree of accuracy and frequency of measurements (Fig. 1) [2].

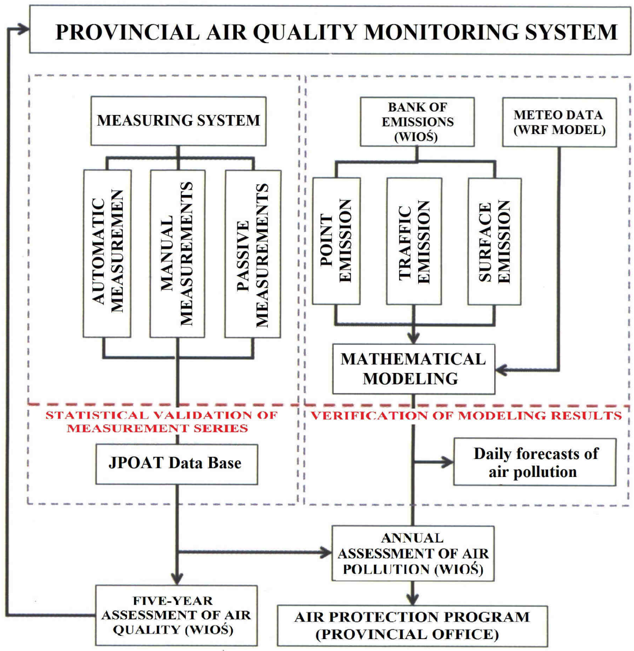

Fig. 1. Organization chart of the provincial air quality monitoring system in Poland [2]

The Lodz measurement system consists of three measurement networks [2]: a network of automatic measurements (continuous), a network of manual measurements (average daily), a network of passive measurements (monthly) (Fig. 1).

The measurement networks provide data for mathematical models which are the basis to prepare annual and five-year documents assessing air quality. If the report contains information that certain permissible pollutant levels in the air are exceeded, then boards of provinces formulate air protection programs which present obligations of local authorities concerning investments and organizational activities to reduce them [2].

Initial, annual and five-year reports assessing air quality are prepared for a specified assessment zone. According to the European Parliament Directive (2008/50/EC) [3] since 2010 these zones are:

- agglomerations with a population of more than 250 thousand,
- towns with a population of over 100 thousand,
- other areas of the province.

Lodz province is divided into two assessment zones: “Lodz agglomeration” and “Lodz zone” (Fig. 2).

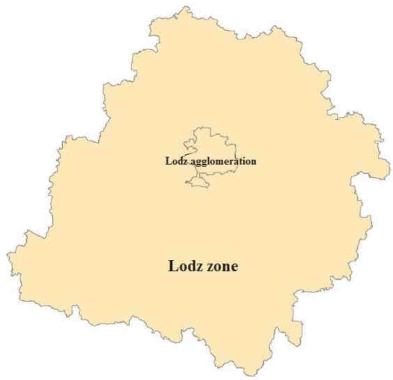

Fig. 2. Air quality assessment zones [2]

The all-Polish environmental law is based on EU environmental legislation. It was implemented before accession in 1999-2001. The main regulation on air protection is based on CAFÉ Directive [3]. Unfortunately, very often we breathe air that does not meet European standards, and the scale of this problem is best illustrated in Figure 3.

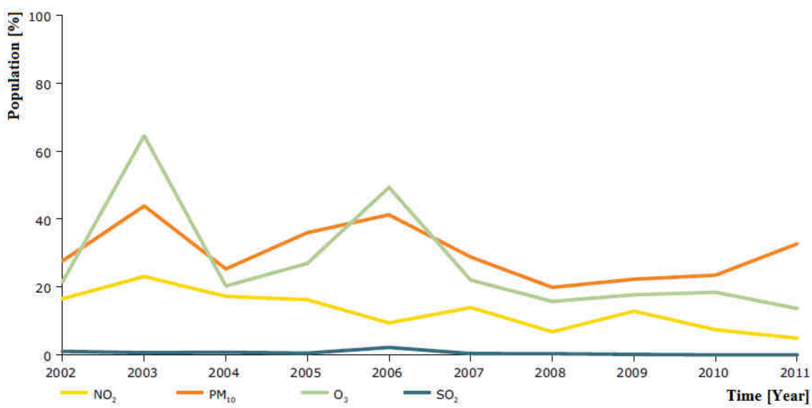

Fig. 3. Percentage of urban population exposed to air pollution exceeding EU air quality standards [4]

The areas of knowledge and science related to air protection have now become key ones for people and natural environment. For this reason, all over the world air pollution measurements, analyzes and calculations are carried out and effects of these actions are reflected, for example, in economy [5-7], ecology [8-10], agriculture [11-13] or medicine [14-16].

Factors affecting the state of air pollution

The state of air pollution is affected by various factors (Fig. 4) which to varying degree and in different time have influence on the environment [1]:

- pollutant emission field,
- meteorological factors determining the transport and chemical transformations of pollutants released into the air,
- topographic factors.

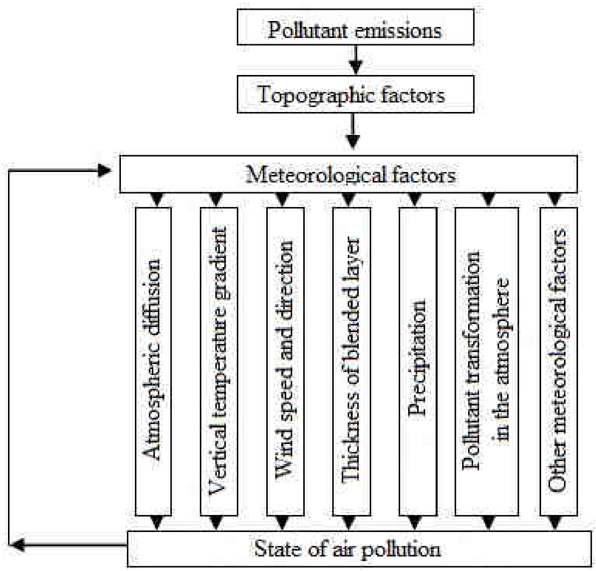

Fig. 4. Factors affecting the state of air pollution [1]

Meteorological factors vary depending on the global and local climate conditions. Changes occur not only in dependence of the season of year but also on the time of day or night and they may have effect not only on the specific area but also on more or less distant regions.

Topographical factors include all sorts of obstacles such as buildings, arterial roads, surface features, wooded areas or water reservoirs.

Characteristics of the tested area

The recent area of the Lodz University of Technology is divided into a northern part, where the buildings are marked with the letters ‘A’ and ‘C’ and the southern part, where the buildings are marked with the letter ‘B’. The entire campus occupies a total of approximately 32 hectares on which there are buildings of various departments, student dormitories and parking lots for students and staff. Various parts of the campus are surrounded by arterial roads with considerable traffic.

Studies on the effect of building density and meteorological conditions on the level of carbon dioxide in the area of the university were conducted for two years (2012 and 2014) in Campus B, *ie* southern part of the Lodz University of Technology which through the M. Klepacz park on the north is adjacent to Ksiadz Harcmistrz Ignacy Skorupka Street, and on other sides is surrounded by Wolczanska Street (on the east), General Walery Wroblewski Street (on the south) and Al. Politechniki (on the west). In addition, on the south west this area is in close vicinity to the urban power plant EC2 (Fig. 5) [17].

Fig. 5. Aerial view of Campus B [18]

The analyzed area covers about 16 hectares of which a large part is occupied by the nineteenth-century palaces and revitalized post-industrial buildings of the former Lodex factory. The complex comprises 19 buildings that belong to the Lodz University of Technology. Significant part of Campus B occupy paved surfaces such as roads and parking lots. The area is characterized by diverse buildings. There are both the regions of compact settlement and predominant biologically active areas [17].

Because while performing test measurements a significant impact of building density on carbon dioxide content in the air was observed, the measuring points were located so as to determine the dependence of building density on carbon dioxide concentration in the air. For this reason Campus B was divided into 4 regions with diversified building density (Fig. 6). A reference area was the area adjacent to the building of the Faculty of Civil Engineering, Architecture and Environmental Engineering (Fig. 7). Next regions were separated from the area of Campus B so as to keep the same reference area. The reference area was 1.5 ha (Fig. 8 refers to region 2, Fig. 9 to region 3, while Fig. 10 to region 4).

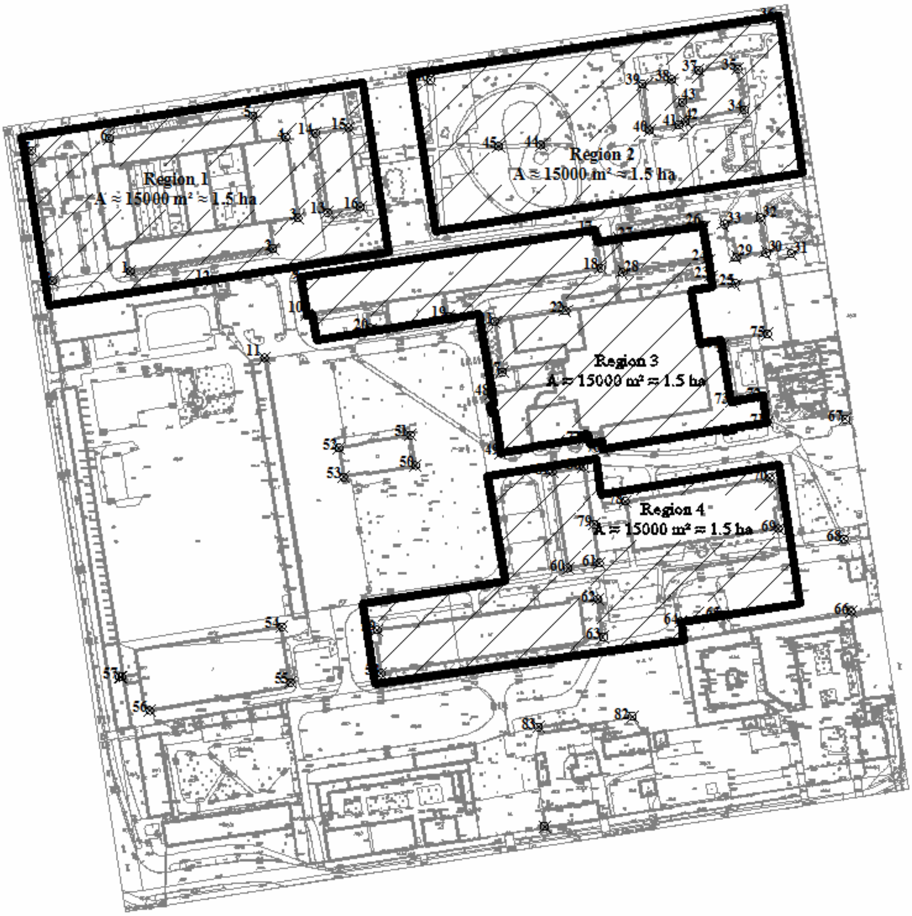

Fig. 6. Location of 4 regions separated from the area of Campus B (measuring points are marked as ⌖)

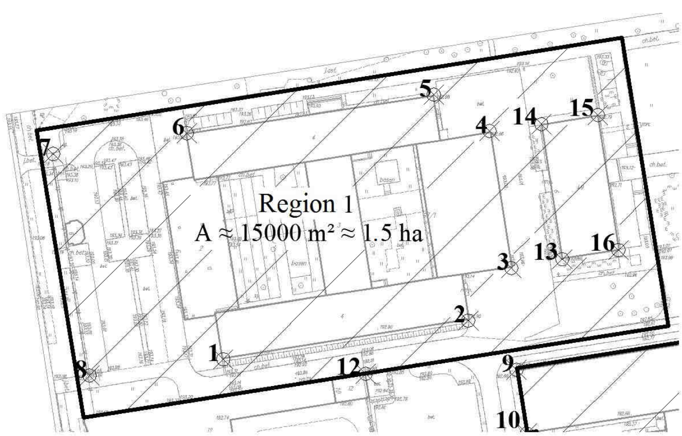

Fig. 7. Location of region 1

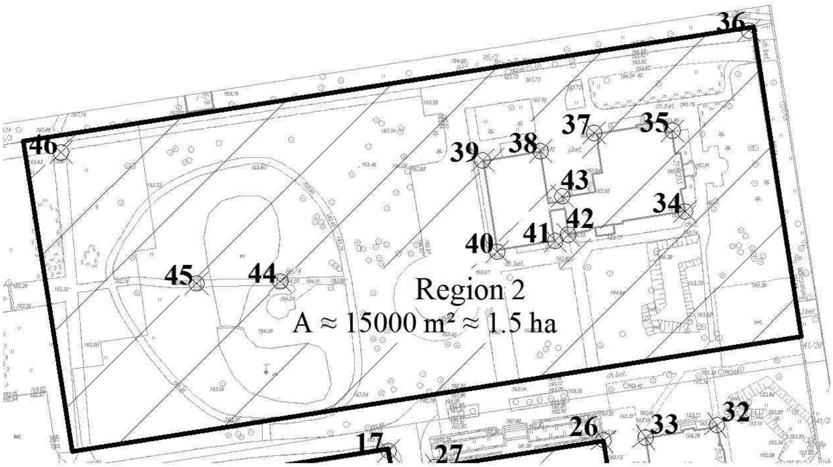

Fig. 8. Location of region 2

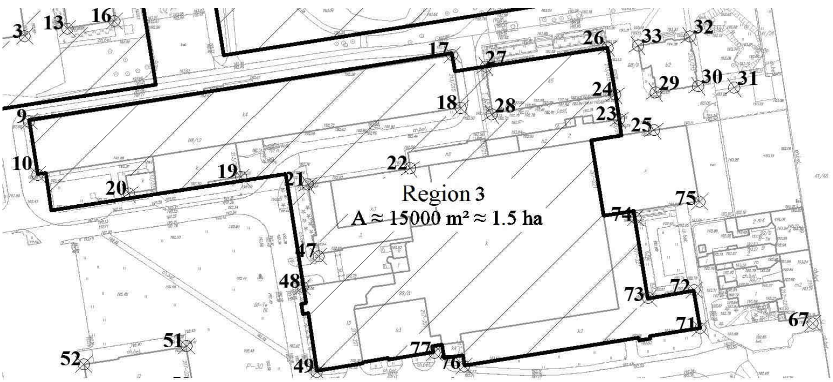

Fig. 9. Location of region 3

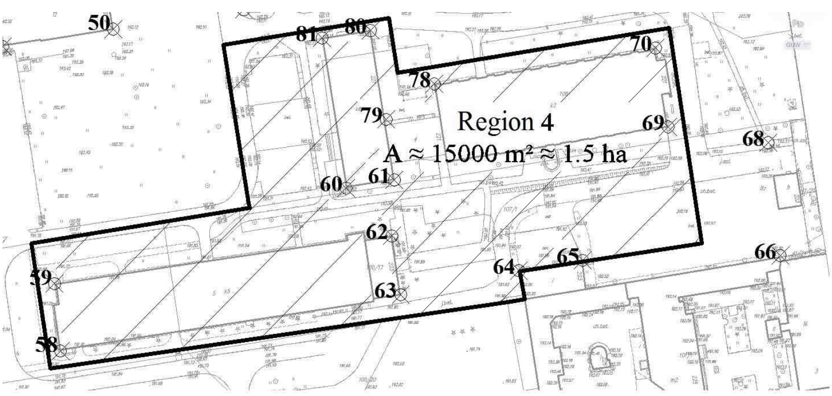

Fig. 10. Location of region 4

Measurement methodology

The concentrations of CO_2 in selected areas were measured using a portable gas micro-chromatograph (Pollution S.p.A.) (Fig. 11). The device is used to analyze gaseous pollutants in field conditions. Owing to two columns that are operating in parallel, it can analyze a broad spectrum of gases during a single measurement. The applied thermal conductivity detector (TCD) enables to analyze samples with a minimum concentration of 500 ppb in a period from 6 to 300 seconds, depending on the type of a tested gas [19].

a) b)

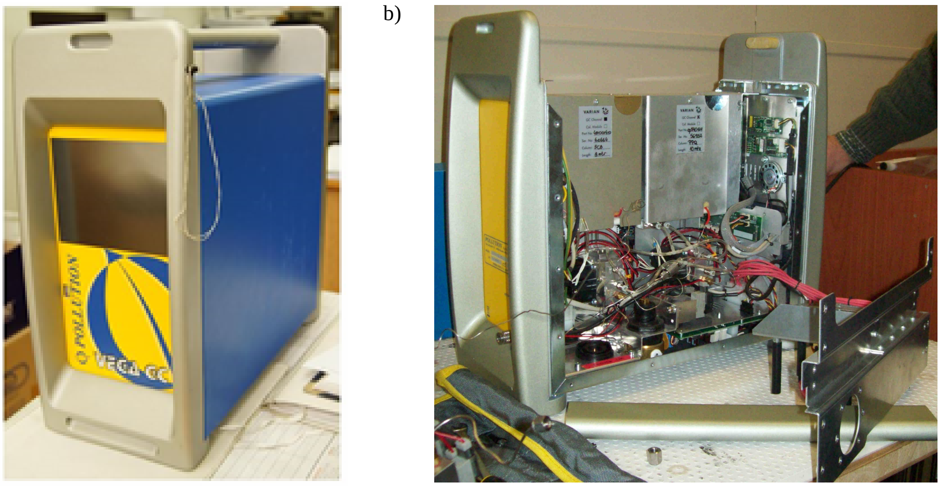

Fig. 11. The image of micro-chromatograph VEGA-GC (a and b)

The carbon dioxide concentrations were measured using a PPQ packed column installed in the VEGA-GC micro-chromatograph (Table 1). Each measurement was performed in an interval of 90 seconds.

Table 1

A measurement column of VEGA-GC micro-chromatograph [20]

Name of column	**Description**	**Exemplary gases**
PPQ	Packed column, an example aplication: hydrocarbons containing carbon particles from C_1 to C_4.	N_2; N_2O; H_2O; CO_2; CH_4; acetylene; ethane; chloroethylene; ethanol; ethylene; propane; hydrogen sulfide and ammonia.

In the measurements a method developed by Cichowicz and Wielgosinski [17] to measure carbon dioxide with the VEGA-GC micro-chromatograph was used. During the measurements the device was directed toward the unbuilt area (toward the pavement). An external device equipped with a GPS receiver was applied. At the beginning of dosing a sample to the device the date, time and GPS coordinates were written on the memory card.

The building area was determined from the geodetic map as the built-up area, *ie* the sum of surfaces of the ground floor of all buildings in the area calculated in the outer contour of walls (with clearances and arcades). The number of storeys of buildings in the analyzed areas was determined and average height of a storey per building was assumed. Owing to this, by multiplying the built-up surface by the number of storeys and average storey height, the volume of the building was obtained. The surface of the area divided by the total volume of buildings in the area allowed us to estimate building density in the area. This value was referred to the arithmetic mean of carbon dioxide concentrations from the measuring points located in the region [17].

Meteorological conditions during the measurements were determined on the basis of data from the meteorological station (Table 2) in the Wladyslaw Reymont Airport in Lodz [21]. As the meteorological station is about 5 km in a straight line from the university campus, the data were used to determine general meteorological conditions for this part of the city.

Table 2

Weather data [21]

Measurement date / Parameter	**20.03.12**	**02.04.12**	**23.04.12**	**25.04.12**	**20.03.14**	**03.04.14**	**24.04.14**	**28.04.14**
Temperature [°C]	9-13	7	9-13	15	11-15	8-19	8-19	13-16
Overcast	light overcast	partly overcast	partly overcast	clear weather	light overcast	clear weather	clear weather	partly overcast
Wind speed [km/h]	22-31	26-30	9-15	13-19	17-33	6-13	17-21	6-17
Wind direction	W	W	SW	SW	W	W	W	SW
Pressure [hPa]	1031.2	1005.1	1008.1	1005.8	1018.5	1005.1	1019.8	1009.1
Relative humidity [%]	53-70	49-53	51-81	44-82	55-72	40-57	46-64	72-94

The level of carbon dioxide on the analyzed area

Figures 12 and 13 show the effect of CO_2 concentration depending on the building density in Campus B. In March 2012 (Fig. 12) there was a slight increase in the mean arithmetic level of carbon dioxide in the air with an increase of building density. In April 2012 no impact of CO_2 concentration in dependence of building density was observed.

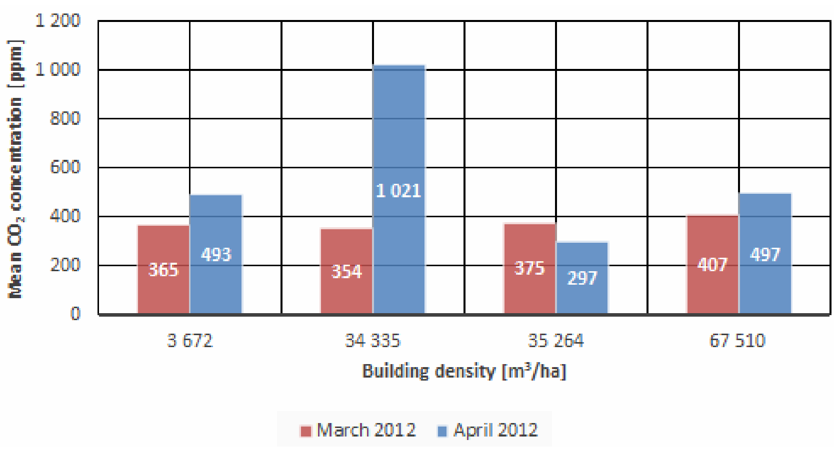

Fig. 12. CO_2 concentration depending on building density in the campus in 2012 (March and April)

In March and April 2014 (Fig. 13) there was a slight increase in the mean arithmetic level of carbon dioxide in the air with an increase of building density. However, this effect is partly distorted.

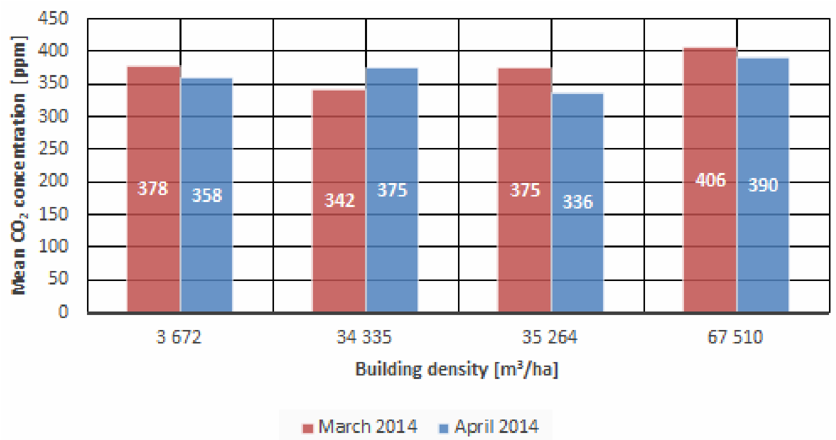

Fig. 13. CO_2 concentration depending on building density in the campus in 2014 (March and April)

Another analysis involved determination of the impact of weather conditions on carbon dioxide concentration in the atmosphere at Campus B of Lodz University of Technology. Results of the measurements were compared with data from Lodz-Lublinek meteorological station. A representative area was the surrounding of the building of the Department of Scientific Publications, at which in 4 outer corners the measuring points were located (pts. 50-53). The area was selected because the building was least protected from the wind (Figs. 14 and 15) and wind speed (Figs. 16 and 17). In 2012 (Figs. 14 and 16) no effect of weather conditions on carbon dioxide concentration was observed. In 2014 such effect could be observed only in dependence of wind speed (Fig. 15).

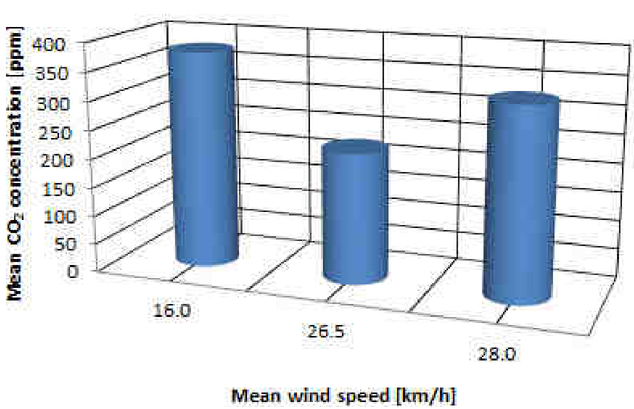

Fig. 14. CO_2 concentration in the campus depending on wind speed (March and April 2012)

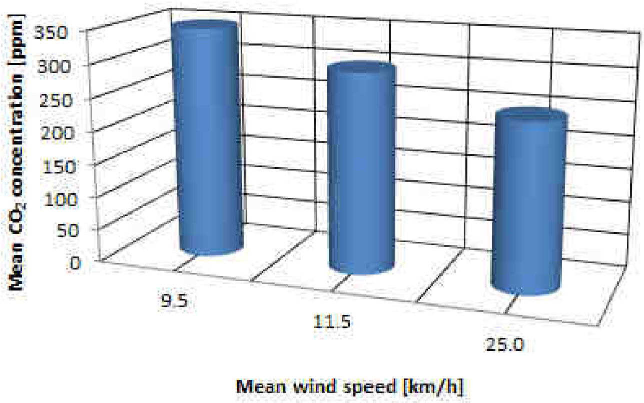

Fig. 15. CO_2 concentration in the campus depending on wind speed (March and April 2014)

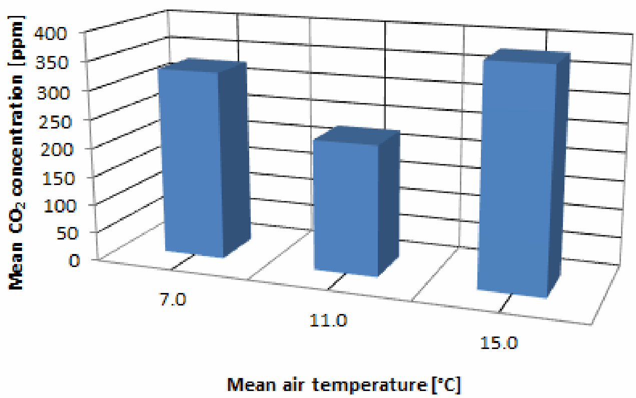

Fig. 16. CO_2 concentration in the campus depending on air temperature (March and April 2012)

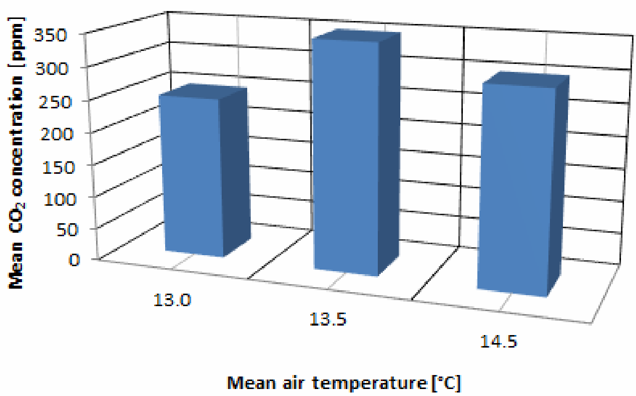

Fig. 17. CO_2 concentration in the campus depending on air temperature (March and April 2014)

Conclusions

Using a portable gas micro-chromatograph precise measurements of carbon dioxide concentration in the atmosphere at a university campus were made. Based on the research it can be assumed that in the analyzed area there are local fluctuations in CO_2 concentrations which can have a negative effect on the users of this area. The impact of carbon dioxide concentration in dependence of building density was also observed. However, the effect of a weather conditions on carbon dioxide concentration in the air was not confirmed.

References

[1] Zannetti P, editor. Air Quality Modeling - Theories, Methodologies, Computational Techniques, and Available Databases and Software. The EnviroComp Institute and the Air & Waste Management Association. 2010.

[2] Raport o stanie środowiska w województwie łódzkim w 2013 r. (Report on the state of the environment in the Lodz region in 2013). Lodz: Regional Environment Protection Inspectorate, 2014. http://www.wios.lodz.pl/Raport_o_stanie_srodowiska_w_wojewodztwie_lodzkim_w_2013_r,12,8.

[3] 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 (CAFÉ) - O.J. of EU 2008;51(152):1-44, 11.06.2008. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=EN.

[4] Air quality in Europe. Copenhagen: EEA Report No. 9/2013, 2013. www.eea.europa.eu/publications/air-quality-in-europe-2013/download.

[5] Shafik N. Economic Development and Environmental Quality: An Econometric Analysis. Oxford Economic Papers. Special Issue on Environ Econom. 1994;46:757-773. Oxford University Press. http://www.jstor.org/stable/2663498.

[6] Taub DR, Miller B, Allen H. Effects of elevated CO_2 on the protein concentration of food crops: a meta-analysis. Global Change Biol. 2008;14;3:565-575. DOI: 10.1111/j.1365-2486.2007.01511.x.

[7] Selden TM, Song D. Environmental quality and development: Is there a Kuznets curve for air pollution emissions? J Environ Econom Manage. 1994;27(2):147-162. DOI: 10.1006/jeem.1994.1031.

[8] Baldocchi DD, Hincks BB, Meyers TP. Measuring biosphere-atmosphere exchanges of biologically related gases with micrometeorological methods. Ecology. 1988;69(5):1331-1340. DOI: 10.2307/1941631.

[9] Lelieveld J, Crutzen PJ, Ramanathan V, Andreae MO, Brenninkmeijer CAM, Campos T, et al. The Indian Ocean experiment: Widespread air pollution from South and Southeast Asia. Science. 2001;291(5506):1031-1036. DOI: 10.1126/science.1057103.

[10] Nowak RS, Ellsworth DS, Smith SD. Functional responses of plants to elevated atmospheric CO_2 - do photosynthetic and productivity data from FACE experiments support early predictions? New Phytologist. 2004;162(2):253-280. DOI: 10.1111/j.1469-8137.2004.01033.x.

[11] Kimball BA. Carbon dioxide and agricultural yield: An assemblage and analysis of 430 prior observations. Agronomy J. 1983;75(5):779-788. DOI: 10.2134/agronj1983.00021962007500050014x.

[12] Erda L, Wei X, Hui J, Yinlong X, Yue L, Liping B, et al. Climate change impacts on crop yield and quality with CO_2 fertilization in China. Phil Trans Royal Soc B. 2005;360:2149-2154. DOI: 10.1098/rstb.2005.1743.

[13] Leakey ADB, Bernacchi CJ, Dohleman FG, Ort DR, Long SP. Will photosynthesis of maize (Zea mays) in the US Corn Belt increase in future [CO_2] rich atmospheres? An analysis of diurnal courses of CO_2 uptake under free-air concentration enrichment (FACE). Global Change Biol. 2004;10:951-962, DOI: 10.1111/j.1365-2486.2004.00767.x.

[14] Almeida SM, Canha N, Silva A, Carmo Freitas M, Pegas P, Alves C, et al. Children exposure to atmospheric particles in indoor of Lisbon primary schools. Atmos Environ. 2011;45(40):7594-7599. DOI: 10.1016/j.atmosenv.2010.11.052.

[15] Peel JL, Tolbert PE, Klein M, Metzger KB, Flanders WD, Todd K, et al. Ambient air pollution and respiratory emergency department visits. Epidemiology. 2005;16(2):164-174. DOI: 10.1097/01.ede.0000152905.42113.db.

[16] Delfino RJ, Staimer N, Gillen D, Tjoa T, Sioutas C, Fung K, et al. Personal and ambient air pollution is associated with increased exhaled nitric oxide in children with asthma. Environ Health Perspectiv. 2006;114(11):1736-1743. http://www.jstor.org/stable/4091805.

[17] Cichowicz R, Wielgosiński G. Effect of urban traffic on the immission of carbon dioxide in the university campus. Ecol Chem Eng S. 2015;22(2):189-200. DOI: 10.1515/eces-2015-0010.
[18] Google Earth version 7.1.2.2041.
[19] Cichowicz R, Sabiniak H, Wielgosiński G. The influence of a ventilation on the level of carbon dioxide in a classroom at a higher university. Ecol Chem Eng S. 2015;22(1):61-71. DOI: 10.1515/eces-2015-0003.
[20] Pollution S.p.A: Catalogue card of micro-chromatograph VEGA GC.
[21] http://freemeteo.com/

WPŁYW WARUNKÓW METEOROLOGICZNYCH I ZABUDOWY NA STĘŻENIA CO_2 NA TERENIE KAMPUSU UCZELNI

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Abstrakt: Jakość powietrza atmosferycznego i poziom jego zanieczyszczenia są nierozłącznie związane z historią rozwoju ludzkości. Powszechność występowania powietrza i brak jakichkolwiek naturalnych barier ochronnych powoduje, że staje się ono odbiorcą coraz to większych ilości różnego rodzaju zanieczyszczeń. Bywa to szczególnie niebezpieczne w obszarach, w których zarówno warunki meteorologiczne, jak i rodzaj zabudowy uniemożliwiają rozprzestrzenianie się zanieczyszczeń. Dzięki zastosowaniu przenośnego mikrochromatografu gazowego można na wydzielonym obszarze lokalnie zaobserwować i spróbować przeanalizować sezonowy wpływ poziomu stężenia ditlenku węgla w zależności od gęstości zabudowy oraz wpływu warunków atmosferycznych na poziom koncentracji CO_2 w powietrzu atmosferycznym.

Słowa kluczowe: ditlenek węgla, gęstość zabudowy, warunki meteorologiczne, stężenia w atmosferze