Pol. J. Environ. Stud. Vol. 24, No. 1 (2015), 215-226

DOI: *10.15244/pjoes/26116*

Original Research

Variability of Human-Biometeorological Conditions in Gdańsk

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Received: 6 April 2014
Accepted: 8 July 2014

Abstract

This paper concerns the characterization of temporal and spatial variability of thermal and air quality conditions within the area of Gdańsk – a port city The classification of thermo-physiological conditions was done with the use of UTCI (Universal Thermal Climate Index) and the quality of air was determined with the use of CAQI (Common Air Quality Index). The analysis was done on the basis of meteorological and concentration of pollution data from the period of 2005-10 obtained from two automatic stations of the Agency of Regional Air Quality Monitoring in Gdańsk metropolitan area (ARMAAG). It was found that annually two UTCI classes occur most frequently in Gdańsk metropolitan area: *no thermal stress* and *moderate cold stress*, wherein in the center of the city (Wrzeszcz station) *no thermal stress* occurred more frequently and *moderate cold stress* in the southwest region of Gdańsk (Jasień station). Favorable thermal conditions prevail in both regions of the city in the warm half year (April-September): *no thermal stress* constitutes around 65% of hours in the city center and 51% on the outskirts. In the cold half year (October-March) cold stress (UTCI <9ºC) is most frequently recorded in both stations: 95% in Wrzeszcz and 98% in Jasień. The assessment of air quality conducted with the use of CAQI shows that annually the satisfactory quality of air (*very low*, *low*, *medium*) which does not pose a threat to humans occurs on average 96.5% in Gdańsk Wrzeszcz and 98.8% in Gdańsk Jasień. CAQI index classes high and very high corresponding to poor air quality are rarely recorded in Gdańsk metropolitan area: more frequently in the city center (3.5%) than on the outskirts (1.2%), predominantly in the cold half year. It was found that high concentration of PM_{10} was a decisive factor in all cases of recorded poor air quality.

Keywords: thermal index, air quality, urban climate, biometeorology

Introduction

The influence of environmental factors, including weather conditions, on health and well-being of humans is a well-documented fact in the literature on the subject [1-6]. Numerous studies conducted worldwide have verified that thermal stress is related to increased mortality. The results obtained by Błażejczyk and McGregor [7] indicate that each year from 15 to 30% of deaths in Europe can be accounted for by idiosyncratic values of biothermal indices recorded 1-3 days before. A markedly increased threat to health and life, especially in sensitive population groups, is recorded during heat waves [8]. Hübler and others [9] estimated that 80,000 people per year in European Union countries are expected to die from heat-related causes by 2071-2100. According to Kuchcik [10], in the hottest and longest heat waves in Poland the risk of death can increase by 33-37%.

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Increase in air temperature is frequently accompanied by an increase in air pollution levels. In 2003 thousands of Europeans experienced the tragic effects of the synergic influence of heat and smog episodes [11-13]. According to Vatuard et al. [14] and Beniston [15], the summer of 2003 was a prototype of what we have to deal with in the future and could be quite normal by the end of this century.

The ongoing change of climate is an empirical fact manifested by, among others, increased frequency of hot days [16, 17]. Together with the changes in climate, the concentration of pollutants will increase – the tropospheric ozone in particular [18-21]. It is estimated that as a result of climate change, by the year 2050 the mortality rate will have increased by 4.5% due to the increase of ozone levels on hot days in cities [22, 23]. Rising air temperatures associated with climate change will have a significant impact not only on human health but also on economic productivity. Hübler and others [9] predict that in Germany in 2071-2100 the number of deaths caused by heat waves will triple and hospital treatment costs, excluding outpatient treatment will rise six-fold, and work effectiveness during hot weather will cause a decrease in the GDP by 0.1-0.5%.

The possibilities of mitigating and counteracting, at least to some extent, the unfavorable tendencies are connected with, among other things, the reorganization of space and topoclimate amelioration in a city [24]. However, it should be kept in mind that the efficacy of organization and urbanization work depends on detailed identification of the local bioclimatic and air quality conditions. Based on the aforementioned premises, the study focuses on temporal and spatial characteristics of thermal and air quality conditions within the area of Gdańsk metropolitan area (Poland) and makes use of daily meteorological and concentrations of pollutions data obtained from the network of automatic stations of the foundation Agency of Regional Air Quality Monitoring in Gdańsk (ARMAAG) covering the period of 2005-10.

Materials and Methods

Materials

The analysis was conducted using data obtained from automatic measurements of air pollution and the basic meteorological elements from two stations located within the area of Gdańsk in Wrzeszcz (W) and Jasień (J) districts. Fig. 1 present the locations of both stations. The primary data was hourly values of pollution concentration: nitrogen dioxide (NO_2), particulate matter PM_{10}, tropospheric ozone (O_3), carbon monoxide (CO), and sulphur dioxide (SO_2). Meteorological data used in the analysis included hourly values of air temperature, relative air humidity, and wind speed. The study also includes the results of solar radiation measurements essential for calculating UTCI values. However, due to the lack of results of solar radiation measurements for Wrzeszcz and Jasień stations, the analysis makes use of the results obtained from a station in Sopot located approximately 3 km to the northwest of Wrzeszcz (Fig. 1). The analysis covers the period of six years, from 2005 to 2010. The aforementioned data was made accessible by the Agency of Regional Air Quality Monitoring in Gdańsk metropolitan area (ARMAAG). It should be pointed out that measurements are conducted in five points in Gdańsk – the fact that only two of them were selected for the analysis is due to complete meteorological and concentrations of pollution data, which allows for comprehensive analysis.

Methods

The assessment of thermo-physiological conditions was conducted using the UTCI (Universal Thermal Climate Index), which provides information on thermal stress. UTCI was formulated as a result of international cooperation of various research institutions operating within the framework of COST 730, and with the decision of

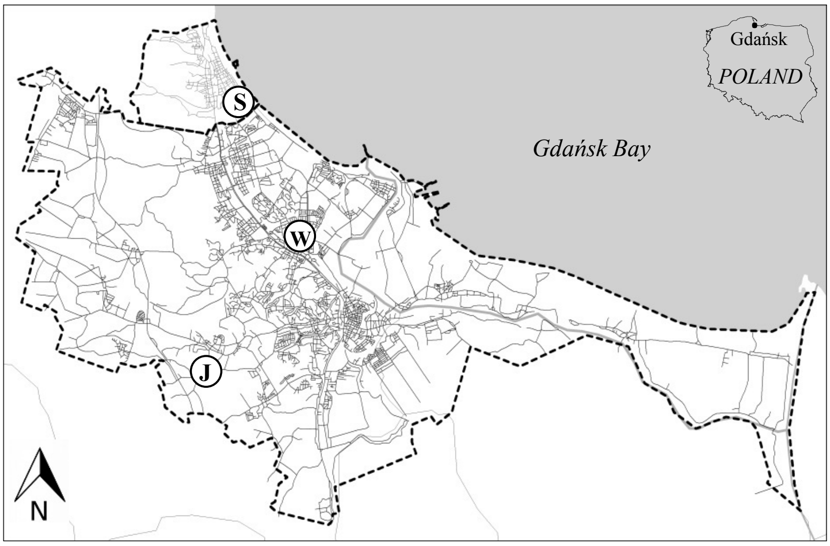

Fig. 1. Location of meteorological and imission stations in Gdańsk and Sopot considered in the study.
S – Sopot, W – Gdańsk Wrzeszcz, J – Gdańsk Jasień

Table 1. UTCI assessment scale of heat stress categories in man according to Błażejczyk et al. [26].

UTCI (ºC)	Stress category
> +46	Extreme heat stress (EHS)
+38 to +46	Very strong heat stress (VSHS)
+32 to +38	Strong heat stress (SHS)
+26 to +32	Moderate heat stress (MHS)
+9 to +26	No thermal stress (NTS)
0 to +9	Slight cold stress (SCS)
-13 to 0	Moderate cold stress (MCS)
-27 to -13	Strong cold stress (SCS)
-40 to -27	Very strong cold stress (VSCS)
< -40	Extreme cold stress (ECS)

the World Meteorological Organization (WMO) it was recommended to be used by the weather service worldwide [25-28].

The index is based on the analysis of human heat balance made with the use of Fiala multi-node model of human heat transfer [29, 30]. Meteorological information (air temperature, water vapor pressure, wind speed, and the so-called mean radiant temperature) and physiological information (metabolic heat production, skin and clothing albedo, emissivity coefficient of body and clothing, evaporation and thermal insulation of clothing), constitute the input data.

The Universal Thermal Climate Index (UTCI) is expressed as an equivalent ambient temperature (°C) of reference environment providing the same physiological response of a reference person as the actual environment. In other words it is assumed that heat transfer between a man and environment depends solely on air temperature, with other meteorological parameters at the constant level. The UTCI assessment scale is based on objective changes of physiological parameters of an organism occurring as a result of environmental conditions regardless of population and acclimation processes. Therefore, the UTCI values presented in Table 1 represent thermal stress of an organism [26]. Daily and hourly UTCI values were calculated using BioKlima ver. 2.6 software (http://www.igipz.pan.pl/Bioklima-zgik.html).

The assessment of air quality was done with the use of the Common Air Quality Index (CAQI). In accordance with air quality standards of the European Union, this form of an index was formulated within the framework of the CITEAIR project for the purpose of comparing air quality in different cities of Europe. Recorded values of CAQI across cities are updated every day on an interactive web service at *www.airqualitynow.eu*. Gdańsk metropolitan area is one of the 11 cities in Poland that regularly send information concerning air quality to the aforementioned web service. The European Environmental Agency (EPA) also uses the CAQI index (*eyeonearth.cloudapp.net*).

Two types of CAQI are specified: urban background index and traffic-related index. The present analysis includes the hourly and daily air quality assessment calculated with use of the urban background index. The urban background index takes into account the three main pollutants (NO_2, PM_{10}, and O_3) and three auxiliary pollutants ($PM_{2.5}$, SO_2, and CO) [31]. $PM_{2.5}$ was not taken into consideration due to the lack of a sufficient amount of data. The CAQI index was calculated only in the situation of complete mandatory pollution. The aforementioned conditions caused total exclusion of Jasień station from calculations in the year 2010 – in that year measurements of ozone concentrations were not conducted in this station. CAQI is calculated according to a grid in Table 2 by linear interpolation between the class borders. The final index is the highest value of the sub-indices for each component. The grid is based on threshold values as they occur in the EU air quality directives, on values used in similar indices.

Table 2. Classes and concentration ranges for pollutants for urban background CAQI index according to Elshout et al. [31].

Pollutant \ Index class grid			Very low 0-25	Low 25-50	Medium 50-75	High 75-100	Very high >100
Mandatory	NO_2		0-50	51-100	101-200	201-400	>400
	PM_{10}	1 hour	0-25	26-50	51-90	91-180	>180
		24 hour	0-15	15-30	30-50	50-100	>100
	O_3		0-60	61-120	121-180	181-240	>240
Auxiliary	$PM_{2.5}$	1 hour	0-15	15-30	30-55	55-110	>110
		24 hour	0-10	10-20	20-30	30-60	>60
	CO		0-5000	5,001-7,500	7,501-10,000	10,001-20,000	>20,000
	SO_2		0-50	51-100	101-300	301-500	>500

NO_2, O_3, SO_2 – hourly value/maximum hourly value (μg·m^{-3})

PM_{10}, $PM_{2.5}$ – hourly value/maximum hourly value or adjusted daily average (μg·m^{-3})

CO – 8 hours moving average/maximum 8 hours moving average (μg·m^{-3})

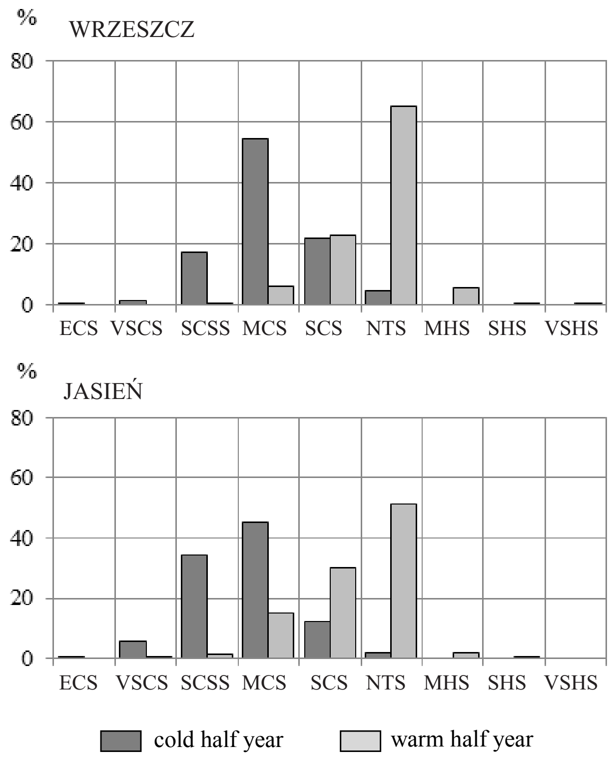

Fig. 2. The frequency of occurrence of hourly of UTCI index according to stress category.

Classes 1-3 mark satisfactory air quality with pollution not posing a threat for humans. Classes 4 and 5 mark bad air quality with pollution concentration posing a health threat particularly to sensitive groups (class 4) or the whole population (class 5).

The relationship between thermo-physiological conditions and air quality was estimated by means of Spearman correlation analysis. Interpretation of statistical significance of the results was based on the criterion α<0.05. Statistica 10 statistical software was used for a calculation.

Results

The analysis of hourly values of UTCI thermal stress index points to distinct variation within the area of Gdańsk metropolitan area. In the central area of the city represented by Wrzeszcz station (W), mean annual value of UTCI amounted to 3.7ºC, whereas in the southwest area of the city – Jasień (J) – it was lower and averaged out at -0.2ºC. The central part of the city is characterized by greater variability of bioclimatic conditions, as indicated by the values of UTCI standard deviation (W – 12.7ºC, J – 10.9ºC). As is shown in Fig. 2, in the warm half year from April to September favorable bioclimatic conditions prevail in Gdańsk, which results in greatest frequency of *no thermal stress* class (on average 65% in Wrzeszcz and 51% in Jasień). The risk of heat stress is slight. During the

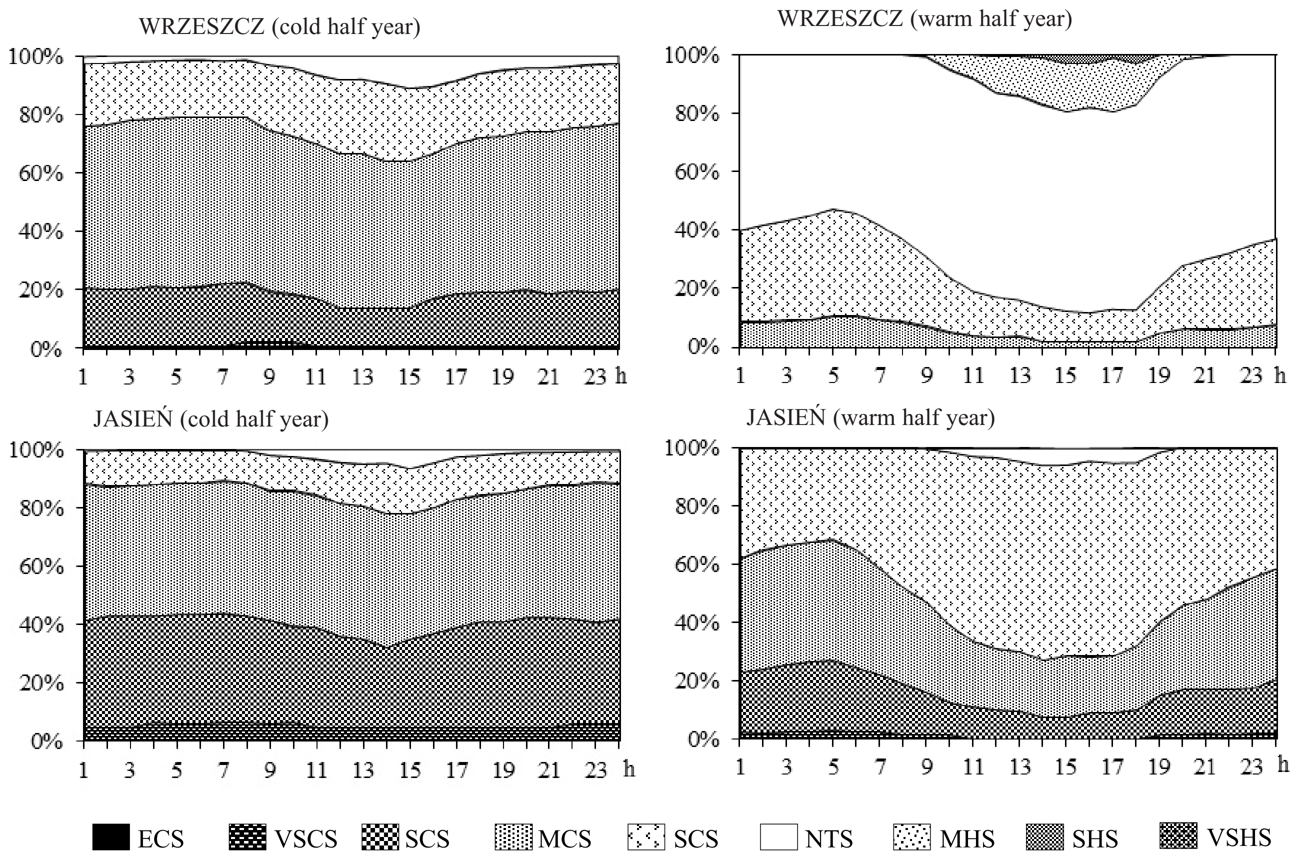

Fig. 3. The frequency of occurrence of UTCI index according to stress category during 24h.

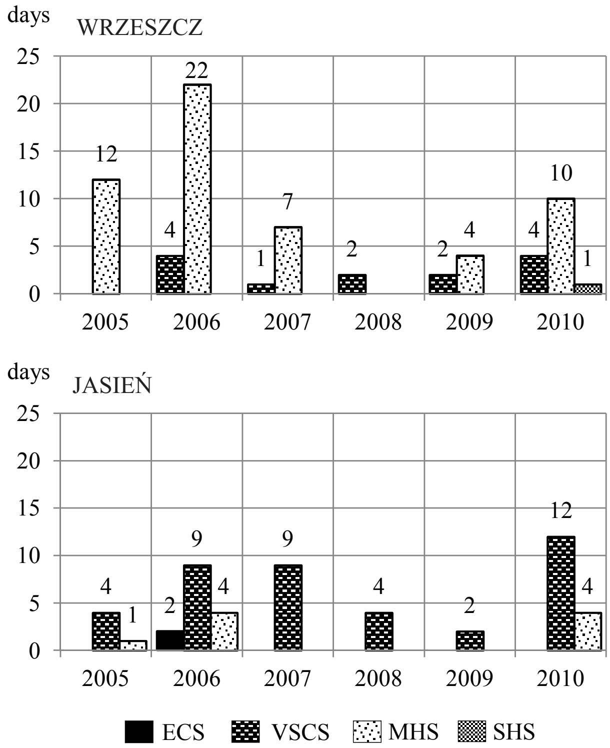

Fig. 4. Number of days with extreme UTCI index values.

analyzed period of six years, the situations with daily UTCI values >26ºC occurred in the city center with a frequency of 6% in the warm period, and over three times less frequently (1.8%) on the outskirts (Fig. 2). As is shown in Fig. 3, thermal stress due to heat can be reported as early during a day as 8-9 a.m. and last to as late as 9 p.m. in the city center (W). Obviously, the greatest probability of high UTCI values occurs in the afternoon – Wrzeszcz 3-5 p.m.: UTCI>26ºC were recorded on average with the frequency of 19%; in Jasień from 2 p.m. to 3 p.m. the values were recorded three times less frequently (6%).

The highest recorded class in the 10-class UTCI thermal stress scale due to "heat" is very strong heat stress. Such onerous conditions occurred only four times during the analyzed period of six years, and were recorded only in the city center (Wrzeszcz) – on the 16th of July 2007 at 4 p.m. and on the 22nd of July 2010 in the three succeeding hours from 3 p.m. to 5 p.m. Climate change scenarios suggest that the heat stress situations mentioned above may become more frequent in the future [16, 19, 32].

In the cold half year (October-March) the favorable bioclimatic conditions (*no thermal stress*) are rarely recorded, with frequency similar to moderate heat stress in the warm half year, and amount to 4.6% in the city center and even less on the outskirts (2%). As shown in Fig. 2, the most prevalent thermal stress class is *moderate cold stress* (W – 54% and J – 45%). In the cold half-year the influence of the city on bioclimatic conditions is even more evident. Most of all this is highlighted by twice as frequent (40%) stress due to cold (UTCI<-13ºC) in Jasień during night-time in comparison to the city center (Figs. 2 and 3).

In the analyzed period, most days with extreme stress due to cold (UTCI <-27ºC) were recorded in 2006 and 2010 and, as shown in Fig. 4, the phenomenon was observed predominantly in Jasień. It is worth mentioning that out of 11 days that fulfil the criteria and which were identified in this station during 2006, seven were recorded in frosty January (two with extreme cold stress), and the remaining four in February. In 2010 days with very strong cold stress were recorded in January (5 days), November (2 days), and December (5 days). The years 2006 and 2010 are characterized by greater (in comparison to other years) number of days with moderate heat stress. Most such days (22) were recorded in the city center in 2006 out of which seventeen were identified in scorching July in a sequence of days between 1-11 and 23-28 July. The heat wave in July 2006 afected other cities as well. For example in Szczecin, the frequency of calls for emergency ambulance service increased by 20.5% in that period [33]. Generally, a pattern can be observed in subsequent years: residents of the center of Gdańsk (W) experience thermal stress due to the excess "heat," whereas resident of the outskirts of Gdańsk (J) experience thermal stress due to the excess "cold."

The quality of the atmospheric environment may have a powerful impact on people's comfort, just to mention the adverse health effects of increased pollution levels. People sensitive to heat waves are, to a great extent, also vulnerable to episodes of air pollution, and when the two environmental conditions occur at the same time the health risk increases markedly. Such situations occur most frequently in the summer period and in cities they are additionally reinforced by the UHI effect [34-36]. Therefore, in order to have a wider picture of the onerous conditions occurring

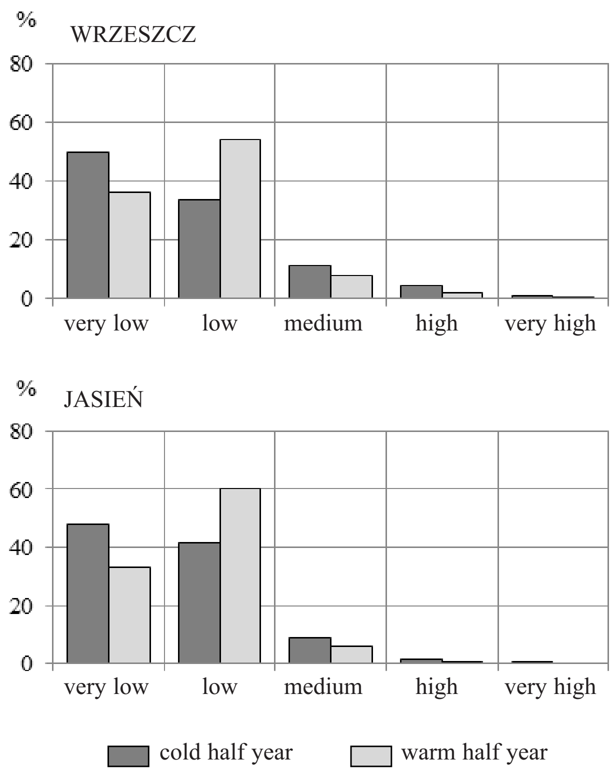

Fig. 5. Frequency of occurrence of air quality class – CAQI.

within the Gdańsk metropolitan area, the second part of the study includes an assessment of air quality made with using the CAQI index.

The analysis shows that in the analyzed period, satisfactory air quality (classes 1-3) that does not pose a threat to humans was observed with the frequency of 96.5% in Gdańsk Wrzeszcz and 98.8% in Gdańsk Jasień. The air quality class prevalent in Gdańsk Jasień station was *low*, with a frequency of 60% of the warm half year (April-September) and 42% in the cold half year (October-March). Comparable frequencies were recorded in Gdańsk Wrzeszcz for the class *very low* (43%) and *low* (44%), with distinct predomination of *very low* in the cold half year and *low* in the warm half year (Fig. 5). The air quality class *medium* was recorded in both stations with greater frequency, 11% of cases in Wrzeszcz and 9% in Jasień. Classes 4 and 5 mark poor air quality, which poses a health threat to sensitive groups (class 4) or the whole population (class 5). The results of the analysis indicate that within the metropolitan area those classes occurred sporadically with frequency range from 1.2% in Jasień to 3.5% in Wrzeszcz, and in each case a high concentration of PM_{10} was a decisive factor. In other regions of Poland the situation is comparable and the air quality (classes high and very high) is poor due to PM_{10} resulting from a high combustion of fossil fuels and a high share of low emissions [37]. As shown in Fig. 5, the worsening air quality is connected with the chilly season of the year. It is worth mentioning that during the period of the warm half year not even one occurrence of very high CAQI index was reported in Jasień.

Fig. 6 presents the frequency of individual air quality classes during a day. In both stations, regardless of the season, the first air quality class (*very low*) was recorded from 5 a.m. to 7 a.m., with the highest frequency of nearly 60%. In the subsequent hours of a day, especially in the warm half year, air quality deteriorated from the first class (*very low*) to the second (*low*). The highest frequency of classes 4 and 5 occurred in the evening hours from 7 p.m. to 1 a.m., a fact that corresponds to the diurnal structure of particulate matter concentration.

The classification of daily air quality shows that in the analyzed period the number of days with poor air quality, only in the city center, was highest in 2005 (Fig. 7). In total, the high and very high classes were identified in 77 days of that year in Wrzeszcz station. The unfavorable air quality conditions were recorded each month, except for July, with the highest daily concentration of PM_{10} (a decisive factor) at 121 $\mu g \cdot m^{-3}$. Even though the number of days classified as belonging to classes 4 and 5 (56 in the center of Gdańsk and 25 on the outskirts – Fig. 7) was lower in 2006 than in the previous year, because of the high concentration of PM_{10} (the highest hourly value 600 $\mu g \cdot m^{-3}$), this year should be considered the most unfavorable in terms of air quality conditions. In January 2006 an explicit deterioration of air quality was caused by severe frosts induced by an extensive high pressure coming from Russia and an increase in the use of heaters that occurred in urban and residential areas. Smog situations in Poland are particularly onerous in agglomeration areas situated in not easily ventilated structural basins and well-developed river valleys in chains of highlands and mountains in southern Poland [37].

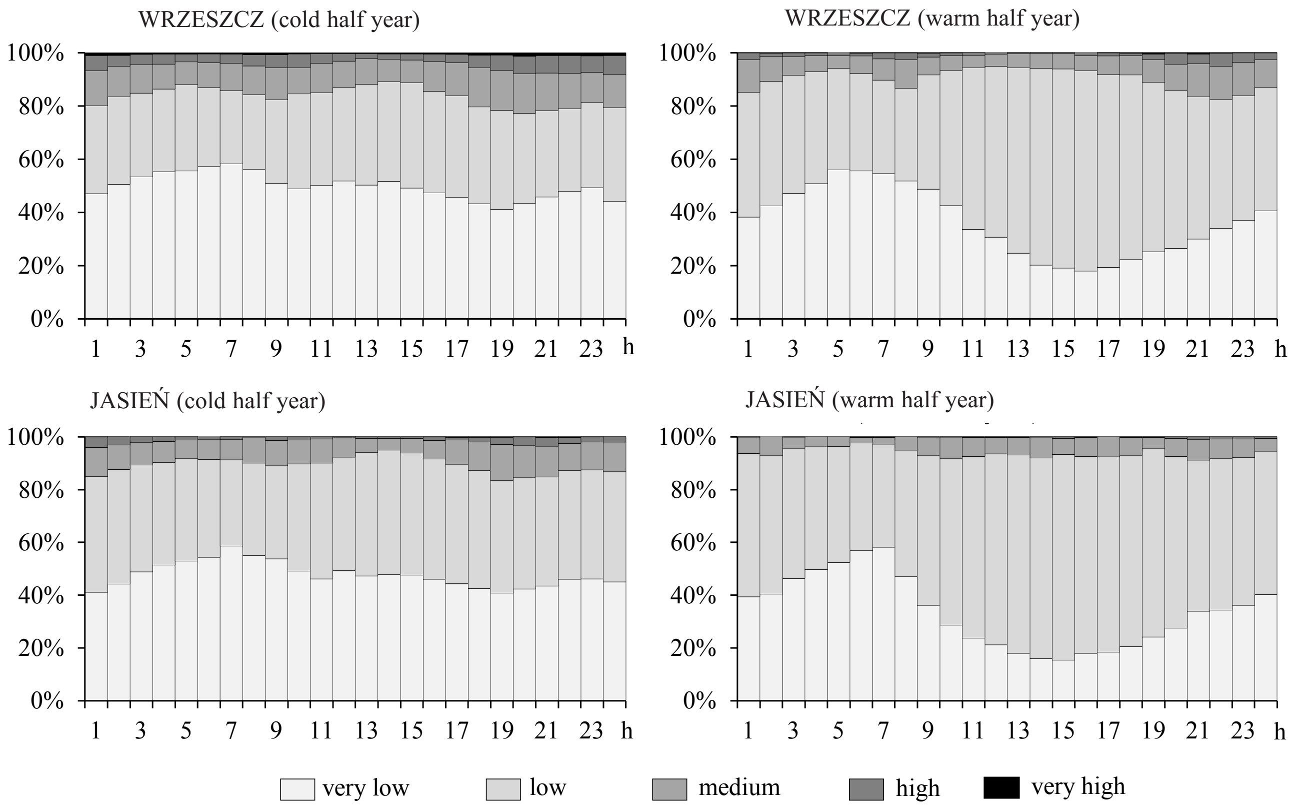

Fig. 6. The frequency of occurrence of CAQI index during 24h.

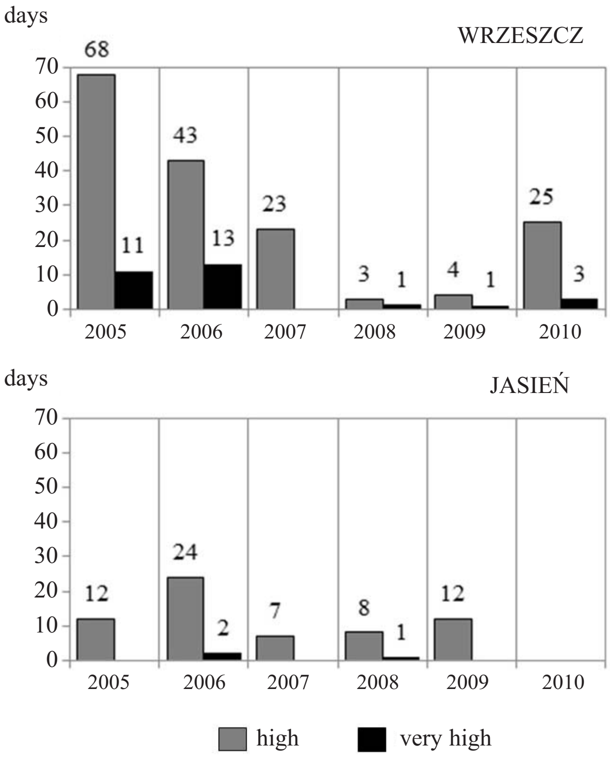

Fig. 7. Number of days with high and very high index CAQI.

However, in January 2006 air quality fell well below standards, especially regarding the 24-hour concentrations of PM_{10} – not only in the areas mentioned above but across the country as well [38]. The highest daily particulate matter concentrations were recorded in the last days of January – in the center of Gdańsk, in Wrzeszcz, the immissions of PM_{10} were up to six times higher than the acceptable 24 h limit (Fig. 8). The unfavourable influence of air quality conditions on the human organism reported at that time was additionally worsened by high thermal stress due to cold, as has been mentioned before (Fig. 8). It is also confirmed by statistical analysis – Spearman correlation coefficient determining the interplay between values of UTCI and CAQI amounted to – 0.38 (at α <0.05). Negative correlation indicates that lower values of UTCI correspond to higher values of the CAQI index.

In order to examine the thermal conditions in the study area when air quality is unfavorable for the majority of the population, the frequency of distribution of the hourly UTCI values was estimated when hourly CAQI was high and very high. Overall, as presented in Fig. 9, bad air quality (classes high and very high) occurred most frequently in bioclimatic conditions with "cold" thermal stress – the relationship was more distinct in Jasień than in Wrzeszcz. In Wrzeszcz, poor air quality was registered in approximately 75% of cases in the conditions of "cold" with similar frequency during slight cold stress (24%), *moderate cold stress* (27%), and strong cold stress (21%). It is worth mentioning that on average every fourth case of bad air quality in the city center was recorded during favorable bioclimatic conditions (*no thermal stress*). In Jasień the frequency was incomparably lower (4.6%). In Jasień poor air quality was mostly concurrent with strong cold stress (43%) and *moderate cold stress* (36%). Situations of discomfort caused by simultaneously occurring poor air quality (CAQI>75) and thermal stress due to heat (UTCI>26ºC) were recorded by far least often. This situation is somewhat obvious as it is the result of rarely occurring UTCI classes marked as heat stress and the rare occurrence of poor air quality in the warm half-year period. In the six-year study period in the center of Gdańsk during moderate heat stress only nine cases of poor air quality were recorded, five in 2006 (four in sweltering July and one on the 1 August). During the course of five years (2005-09) only one such case was reported in Jasień, on 27 July 2009.

The last stage of the research is an attempt to demonstrate, in addition to the co-occurrence described above, the statistical relationship between thermal conditions and air quality. Table 3 shows the values of Spearman correlation coefficient between UTCI index and CAQI, which is used for assessing air quality. The values of correlation coefficients obtained in the analysis were relatively low but met the required level of significance. Positive relationship and simultaneously the highest values of Spearman correlation coefficient were found for CAQI and UTCI class; *no thermal stress* and UTCI values >26ºC. Much lower correla-

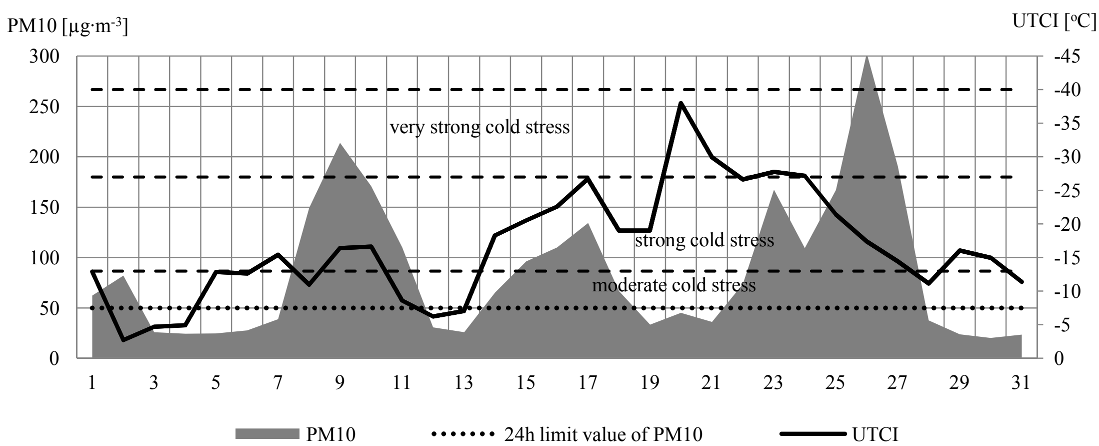

Fig. 8. Mean daily concentrations of PM_{10} on the background values of UTCI index in January 2006 at Gdańsk Wrzeszcz.

Table 3. Spearman correlation coefficients (significant at α < 0.05) for relationship between hourly values of UTCI and CAQI indices.

UTCI (ºC)	Gdańsk Wrzeszcz	Gdańsk Jasień
	CAQI 0-100	CAQI 0-100
> +26	0.21	0.29
+9 to +26	0.21	0.29
< +9	-0.06	-0.02
	CAQI 75-100	CAQI 75-100
+9 to -40	-0.18	-0.18
0 to -40	-0.15	-0.12

tions with the negative direction existed between the UTCI values of "cold" class and values of CAQI index. According to data presented in Table 3, this relationship is stronger in situations of CAQI>75. Slightly stronger statistical relationships between biothermal conditions (expressed as indices ET and UTCI) and selected air pollution was found by Nidzgorska-Lencewicz and Mąkosza [33] in Szczecin. In the hot July 2006 and 2010 the variability of an increased O_3 immission was accounted for by fluctuations of ET index of 55 and 59%, respectively.

Discussion

The conducted analysis shows a characterization of temporal and spatial variability of thermal and air quality conditions within the area of Gdańsk during the period 2005-10.

Gdańsk is located in the lowland zone adjacent to the Baltic sea (the South Baltic Shoreland). Due to its location in the north of Poland and direct influence of the sea, this region is characterized by specific climatic conditions. The features characteristic for this region are land and sea breeze, which have a significant influence on the bioclimatic conditions of the region. Because of industrialization, urbanization, and communication, bioclimatic conditions are subject to ongoing and even greater modification. The intensity of particular stimulus changes over time and space are subject to the size of the city, type of development, land relief, and the extent of green areas within the city. According to regionalization provided by Kozłowska-Szczęsna et al. [39], the Baltic coast is categorized as part of a bioclimatic region subject to strong stimuli.

The assessment of thermal conditions in Gdańsk made with the use of UTCI indicate that *no thermal stress* UTCI class is predominant in the warm half year. According to the results presented by other authors, it is a characteristic bioclimate feature of the lowland part of Poland. On the grounds of UTCI values Lindner [40] points to the fact that in the central part of Poland (Warsaw), from the end of April until the beginning of October at last 60% of analyzed days are characterized by lack of thermal stress. The situation is alike in midwest Poland. The results of a 35-year-long measurement period by Mąkosza [41] indicate that annually in Lubuskie Voivodeship UTCI values ranging from 9 to 26ºC occur more frequently – 36-40%, which is on average from 130-145 days a year. However, in warm months thermo-neutral conditions occur with greatest frequency while in the cold half of the year moderate stress prevails. Additionally, the author identifies a positive trend of days with thermo-neutral conditions and UTCI values >32ºC (heat stress category), and a negative trend for UTCI<-13ºC (cold stress category) in this part of Poland. Interesting results concerning the relationship between UTCI and atmospheric circulation were obtained by Nowosad [42]. On the example of two measuring stations in Poland (Lublin and Lesko) with the use of daily values of zonal and meridional circulation indices (ZI and MI) the following formulas were calculated by Lityński, which characterize the daily large-scale pattern of general circulation valid for Poland. Moreover, it was found that in the period from April to November UTCI was affected more by meridional than zonal circulation. In February, the UTCI was affected more by zonal than meridional circulation.

Even though thermal discomfort due to heat stress is recorded under the climatic conditions of Poland relatively less frequently than cold stress – the results obtained for Gdańsk follow the pattern, the "hot environment" brings about greater danger to human health and in extreme cases to life. This is particularly evident in low latitude countries [5, 11, 35]. According to Kozłowska-Szczęsna et al. [39], in Poland the average increase in mortality due to heat waves was estimated to be 15-22%, depending on the cause of death, whereas the average mortality caused by cold waves, regardless of the cause of death, increases on average by

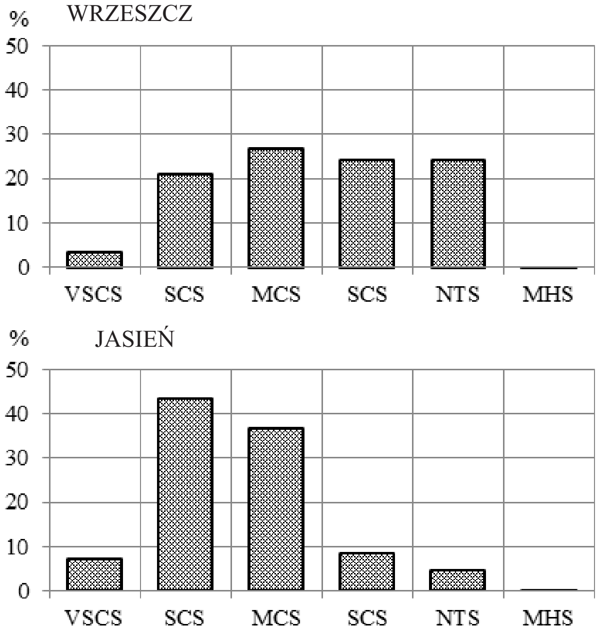

Fig. 9. The frequency of occurrence of individual class UTCI with values high and very high index CAQI.

7.6%. However, it should be taken into account that the figures may increase considerably due not only to the forecasted increase in frequency of heat waves occurrence, but also the fact that the number of people sensitive to weather is growing worldwide [2]. According to NASTOS and Marzarakis [5], in the climatic conditions in Athens a 10ºC decrease in daily maximum and minimum air temperature, its range, PET, and UTCI recorded in the cold period is connected with a 13%, 15%, 2%, and 6%, respectively, increase of the probability of death. However, in the warm half year (April-September) a 10ºC increase in aforementioned values brings about an increase of probability of death by 3%, 1%, 10%, 3%, and 5%.

The conducted analysis shows that frequency of particular UTCI classes in Gdańsk is closely connected with the location of the measuring station – in the center of Gdańsk (W) thermal stress die to excess of "heat" occurs most frequently, whereas in the suburbs of Gdańsk (J) stress due to excess of "cold" is predominant. This fact is widely ascertained in the literature on the subject and results from, among other factors, the thermal privilege of the city center, which is a consequence of UHI [34, 43]. The study by Sikora [44] conducted on the basis of an episode of hot weather of 3-days duration shows that in the city center the conditions of heat stress occur with frequency of 78% – at the same time the frequency in suburban areas is 58%. However, Błażejczyk [45] demonstrated that spatial variability of biothermal conditions in a city is closely connected to the land use regime. The UTCI simulations made for Warsaw show great spatial differentiation of heat stress particularly evident during cool and windy weather as well as at hot, humid, and calm conditions. The city and the forested areas differ greatly in that respect. Forests are significantly warmer than city centers in cool weather, yet during hot weather forests are cooler than city centers or any other type of city landscape.

On the basis of UTCI simulations conducted with the use of GIS for the Ziemia Kłodzka region, Milewski [46], confirms that the most marked differences are to be observed between forests and urbanized areas. The differentiation to UTCI values was defined for several types of weather. The greatest spatial differentiation to values for heat stress was to be observed in sunny, hot, and dry weather in the presence of only gentle winds.

According to research, the UHI effect is responsible not only for unfavorable thermal conditions, but also an increase in concentrations of air pollutants [34, 47, 48]. the aforementioned fact was also found by Czarnecka and Nidzgorska-Lencewicz [36] for Gdańsk. The authors found that in the scorching July of 2010, the intensity of UHI had a statistically significant influence on concentrations of pollutants (NO_2, O_3, CO, PM_{10}, SO_2) and contributed to worsening air quality in the city center. Generally, the strongest effect of UHI intensity on air quality became most evident with the delay of 1-5 hours, depending on the time of day and type of pollution.

Multiannual observations prove that air quality in Europe has improved in recent years. However, increased concentrations of air pollutants and their negative effects are still being recorded particularly in the highly urbanized areas. According to data from 8 EU countries, Dimitriou et al. [49] found that when examining the combined effect of all 5 pollutants (SO_2, CO, NO_2, O_3, PM_{10}), roughly 50-75% of days present risk of increased mortality, whereas in some areas high risk is observed in more than 35% of days. Nowadays, the use of more comprehensive indices instead of absolute values of concentration of pollutants is more common. There are many aggregated air quality indices – the summary of the most important indices and the differences between them was presented by Plaia and Ruggieri [50]. AQI developed by the EPA is the most commonly used and renowned index adapted to meet the standards of air quality [31].

The characterization of variability of air quality in Poland expressed by CAQI can be found in Ośródka et al. [37]. The highest values of CAQI, "very high," which stand for air considered "unhealthy," are recorded in urban areas. This situation is most common in the cold half year during episodes of high concentrations of pollutants in high-pressure weather. High and very high values of common CAQI index are caused by concentrations of PM_{10}. The worst air quality is recorded in the south of Poland, particularly in the area of Kraków agglomeration as well as in the south of Śląskie Voivodeship. PM_{10} is a dominant factor affecting the values of air quality, but concentrations of sulphur dioxide and carbon monoxide also have an effect on air quality. Episodes of increased concentrations of particulate matter are recorded all over Europe [51]. However, in Poland such episodes are to a greater extent than in other parts of Europe connected with municipal emission and fossil fuel combustion [52].

As shown in Fig. 5, generally air quality is satisfactory in Gdańsk (classes 1-3 tend to be dominant), therefore there is limited threat to human life. In the study by Ośródka et al. [37], which takes into consideration density of population, land cover, and meteorological conditions, the region of Tricity (Gdańsk being a part of it) is classified as belonging to a moderate sanitary threat class. The conducted analysis shows that situations of simultaneous occurrence of poor air quality (CAQI>75) with unfavorable thermal conditions are recorded in Gdańsk extremely rarely – in a year with averaged frequency 2.5% in Wrzeszcz and three times less frequently in Jasień (0.75%). However, it is worth mentioning that in both stations poor air quality is recorded almost entirely in "cold" bioclimatic conditions.

In the last stage of the research, Spearman's rank correlation test was applied at 0.05 level of significance to detect the possible relation of UTCI values and CAQI values. The results of the analysis conducted on the basis of all data obtained in the period of 6 years are presented in Table 3. Both in *no thermal stress* conditions (UTCI +9 to +26) as well as thermal conditions of "hot" (UTCI>26) in both stations, significant positive correlation was found, whereas in the "cold" thermal sensations (UTCI<+9) a significant negative correlation was found. Most likely due to the relatively rare occurrence of extreme UTCI values both of "heat" as well as "cold" category and high concentrations of pollutants, results of coefficients of correlation were low. This fact is further validated by the results discussed in the previous section of the present paper – in the extremely chilly January of 2006, in cases of higher values of both indices, the relationship between thermal conditions and air quality is consequently higher – Spearman correlation coefficient in the center of Gdańsk (W) amounted to – 0.38 (at α <0.05). As far as research of this issue is concerned, it is not always possible to explain the obtained results. Theoharatos et al. [35] studied the relationship between thermal sensation (expressed by heat load index) and air quality (expressed by the AQSI stress index) during a heat wave in June and July in 2007 in Athens – the measurements were conducted in 7 stations. The values of obtained coefficients of Spearman correlations changed from -0.78 to 0.19 (p 0.05) for June and from -0.18 to 0.94 (p 0.05) for July, indicating both a positive as well as a negative relationship. The authors explain that the variation of the observed correlations between HL and AQSI24 is probably related to the dependence of AQSI on the concentration levels of O_3, NO_2, and SO_2 that vary inconsistently among the stations.

Conclusion

The results of the research conducted so far indicate that during the year in Poland, cold stress, with various intensity, predominates among thermal stress categories, and thermal discomfort due to heat stress at UTCI>26ºC is recorded far less frequently [33, 40-42]. Additionally, in the coastal zone heat felt by people is eased by the cooling effect of the Baltic sea and wind, as the results obtained in Gdańsk indicate.

The performed analysis shows that according to the UTCI thermal stress scale, a thermal sensation related to "heat" (UTCI>26ºC) is recorded during a year in Gdańsk with a frequency of 3% in the city center (W) and less than 1% in the outskirts (J). Thermal sensations related to "cold" (UTCI<9ºC) are predominant and constitute 62% (W) and 72% (J) in a year. *No thermal stress* class stands for the conditions in which physiological thermoregulation is sufficient to keep thermal comfort – it is observed with the frequency in 35% (W) and 27% (J). Of course favorable thermal conditions strongly prevail in the warm half year (April-September) – *no thermal stress* was recorded in the city center with frequencies of 65% and 51% in the southwest region of the city. In the cold half year (October-March) *no thermal stress* occurred rarely, with frequency of 4.6% in the city center and 2% on the outskirts, and the most frequent *thermal stress* scale was *moderate cold stress* (Wrzeszcz – 54%, Jasień – 45%).

The assessment of air quality with the use of CAQI shows that satisfactory air quality (classes 1-3) that does not pose threat to humans constituted on average 96.5% of cases in Gdańsk Wrzeszcz (2005-10) and 98.8% in Gdańsk Jasień (2005-09). In both stations classes *low* and *very low* (with slight prevalence of the latter) were recorded most frequently, especially in Jasień. The CAQI classes high and very high, which mark poor air quality, were intermittently recorded within the Gdańsk metropolitan area, mostly in the cold half year, and were more frequent in the city center (3.5%) than on the outskirts (1.2%). It was found that all cases of high and very high classes were strongly influenced by high concentrations of PM_{10}. Even though the instances of simultaneous occurrence of unfavourable thermal conditions and poor air quality (CAQI>75) were relatively rarely observed, this relationship was additionally found in statistical analysis.

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