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Effect of a different degree of anthropogenic transformation on the formation of bioclimatic conditions – Warsaw case study

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Abstract: *Effect of a different degree of anthropogenic transformation on the formation of bioclimatic conditions – Warsaw case study.* The purpose of the work is to evaluate the variability of bioclimatic conditions and their diversity in areas of a different degree of anthropogenic transformation. An important element of the work is to determine frequency of certain biothermal conditions in the analysed areas, strongly exposing the human body to heat and causing thermal stress of a various intensity. The most important meteorological parameter considered in this paper was the air temperature, because out of physical stimuli it is the one which is most intensely perceived, especially when its fluctuations occur at short-time intervals. The research was based on the meteorological data made available by the Voivodship Inspectorate of Environmental Protection (WIOŚ). The data come from automated measurement stations operating as part of air quality monitoring system, located in different districts of Warsaw and outside the city. Each of the stations is marked by individual features resulting from a different degree of anthropogenic transformation of the closest surroundings.

Key words: air temperature, thermal stimuli, urban heat island, Warsaw

INTRODUCTION

An increase in the number of urban populations and the co-related concentration of socio-economic activity in big cities significantly affect the changes occuring in the environment. In consequence, it has some influence on the health and well-being of the human as they are an integral part of the environment. The changes occurring in the local climate of a city as a result of dynamic urbanisation and industrialisation are felt particularly intensively. A different extent of anthropogenic transformation determines formation of specific conditions, having different meteorological parameters, in comparison to the climate of the suburbs. Initial properties of the surface undergo modification, which results in the change of physico-chemical properties of the atmosphere, including radiation, thermal, humidity and circulation properties (Oke 1973; Landsberg 1981; Lewińska 1991; Fortuniak 2003; Gołaszewski et al. 2007; Czarnecka et al. 2011). It is a significant issue from the perspective of human bioclimatology. Therefore, the analysis of local climatic conditions should be a fundamental source of information for the people responsible for spatial planning so that they could take right decisions concerning the location of urbanised, leisure and recreation areas to ensure suitable living conditions for the human (Lewińska 1991). Even if nowadays it is truly essential to properly locate urbanised or leisure areas taking into account

local climate characteristics, this aim is still difficult to achieve.

The purpose of the work is to evaluate the variability of bioclimatic conditions and their diversity in areas of a different degree of anthropogenic transformation. An important element of the work is to determine frequency of certain biothermal conditions in the analysed areas, strongly exposing the human body to heat and causing thermal stress of a various intensity.

MATERIAL AND METHODS

The research was based on the meteorological data made available by the Voivodship Inspectorate of Environmental Protection (WIOŚ). The data come from automated measurement stations operating as part of air quality monitoring system, located in different districts of Warsaw and outside the city. Each of the stations is marked by individual features resulting from a different degree of anthropogenic transformation of the closest surroundings. The data from the following stations were taken into consideration:

Ursynów measurement station is located in the southern part of the capital. The station is situated at a height of 102 m above sea level and represents commercial and residential type of development. The development is sparse and occurs at a relatively long distance from each other, i.e. 150–300 m. The distance from routes with a high volume of traffic is 200 m. It is located on a concrete and grassy surface. Moreover, the location at a comparatively short distance from the Vistula bank and the occurrence of green areas affect the local atmospheric conditions.

Targówek measurement station is located at a height of 85 m above sea level in the northern part of Warsaw within the Bródno hospital. Around it, there is mainly commercial and residential development. From the west it is surrounded by a park and from the east by hospital facilities. The distance from the main traffic route is up to 100 m.

Krucza measurement station represents an urban type of development. It is located at a height of 112 m above sea level. Its development type is defined as commercial and residential one. Around the station there occurs dense multi-family residential development. At a distance of about 80 m there is a road of a traffic intensity of approx. 20,000 vehicles dayly.

Piastów measurement station is located at a height of 99 m above sea level on a concrete and grassy surface. It shows results for residential development in a town with a population below 50,000 people. The development is in the form of single-family houses, individual blocks of flats and school buildings. In the vicinity there is no high traffic congestion.

Legionowo measurement station is located on a grassy surface within the Institute of Meteorology and Water Management (IMGW). It is at a considerable distance from natural terrain obstacles and building development. There occur very good ventilation conditions. It is also characterized by a short distance from the main roads, about 80 m. It represents a suburban type of development. It is located close to the northern borders of the capital so due to a low incidence

of southerly winds, the influence of Warsaw on its climate is relatively low.

The most important meteorological parameter considered in this paper was the air temperature, because out of physical stimuli it is the one which is most intensely perceived, especially when its fluctuations occur at short-time intervals (Mąkosza and Nidzgorska-Lencewicz 2011).

As the basis for calculations, the study used average, hourly air temperature values recorded in summer months (VI, VII, VIII) at the above-mentioned stations in 2008–2011. The selection of summer months was caused by the fact that in the summer with sunny weather, there occur conditions which are particularly conducive to bigger thermal and humidity contrasts of the city in comparison with suburban areas. This results from a very intense influence of different surfaces on the thermal balance of the air layer present directly at the ground in conditions of the highest direct solar radiation (Kopacz-Lembowicz et al. 1984; Fortuniak 2003).

In order to determine the intensity of the urban heat island, the study calculated the differences between air temperature at particular stations in Warsaw and the temperature measured at the suburban station of Legionowo.

Moreover, to examine bioclimatic conditions the study determined the number of characteristic days, calculated the measure of air temperature variability, the measure of the stimulus intensity of the climate and the degree of the stimulus intensity of thermal conditions, according to the method suggested by Kossowska-Cezak (2007).

The characteristic days were determined on the basis of the maximum and the minimum air temperature during the day. The following were distinguished: hot days (max. temperature > 25°C), warm nights (min. temperature > 15°C), very warm nights (min. temperature > 18°C), hot nights (tropical) (min. temperature > 20°C), tropical 24-hour periods (max. temperature > 30°C and min. temperature > 20°C) (Majewski and Cichocka 2012).

From the perspective of biometeorology, another important issue is variability of stimuli, especially of air temperature. The index of temperature variability is determined by the difference between average daily temperatures on a specific day and the previous day. On the basis of that, four groups of changes are determined. They are the following: indifferent changes (a temperature change up to 2°C), perceptible changes (a temperature change of 2.1–4°C), significant changes (a temperature change from 4.1 to 6°C) and sharp changes, having an irritating effect (a temperature change above 6°C) (Kossowska-Cezak 2007).

In order to determine biometeorological conditions also the measure of the stimulus intensity of the climate was determined on the basis of temperature differences on two observation dates, between 7.00 a.m. and 1.00 p.m. and also 1.00 p.m. and 7.00 p.m. Based on thermal differences, five groups of temperature changes were separated. They are the following: imperceptible changes (a temperature change up to 2°C), slightly perceptible changes (a temperature change within a range of 2.1–6°C), moderate changes (a temperature change within a range of 6.1–10°C), substantial

changes (a temperature change from 10.1 to 15°C) and very substantial changes (a temperature change above 15°C) (Kossowska-Cezak 2007).

The index of stimulus intensity of thermal conditions was determined on the basis of the amplitude of daily air temperature, defined by the difference between the maximum and minimum temperature. The calculated amplitudes can be indifferent (a temperature change below 4°C), slightly perceptible (a temperature change within a range of 4–7.9°C), perceptible (a temperature change of 8–11.9°C) and sharp (a temperature change of $\geq$ 12°C) (Kossowska-Cezak 2007).

RESULTS AND DISCUSSION

Urban heat island

Urban heat island is, as it was shown on the basis of author's own calculations, a phenomenon present in Warsaw during the whole summer season. It occurs in the area of each of the analysed meteorological stations with a various frequency. Its intensity depends on the density of development, the height of buildings and the share of green areas. The intensity of the phenomenon decreases with a growing distance from the centre and also accompanying it sparser development. The intensity of the Warsaw urban heat island is the biggest in August. Hourly differences in air temperature between the analysed stations in relation to Legionowo reach the maximum at the Krucza station, with a value of 8.7°C. Graphical presentation of the development and disappearance of the urban heat island during the summer season at different times of day was shown in charts a, b, c, d in Figure 1 with the use of the isopleths of average temperature differences between the stations located in the Warsaw and the Legionowo station located outside the city. The chosen form of visualising the phenomenon perfectly presents microclimatic differences at particular stations. To draw the graphs the study used the programme Surfer-8.

It can be seen in the graphs (Fig. 1) that average thermal contrasts are not big, they amount to about 1°C. The maximum average temperature difference, namely 2.6°C, occurs at the Krucza station in the night hours. Bigger differences of average air temperature values are closely related to the location among dense development, mostly devoid of vegetation. At the station representing the centre, there occurs a significant dependence of the development of the urban heat island on the time of day, particularly in August. More intense development takes place after the sunset, chiefly from 8 p.m., and stays until the morning hours throughout the night. The daily course of the urban heat island and characteristic, bigger temperature differences at night are caused by specificity of buildings which accumulate heat and a type of construction materials used in the city (Gołaszewski et. al. 2007). Big amounts of heat accumulated in concrete walls of the buildings and road surfaces are released at night more slowly than in the areas outside the city. A big role is played by the spatial structure of the centre. From 6 p.m. the thermal contrasts at the Krucza station in relation to Legionowo decrease gradually. Before midday there occurs a phenomenon of negative temperature differences as

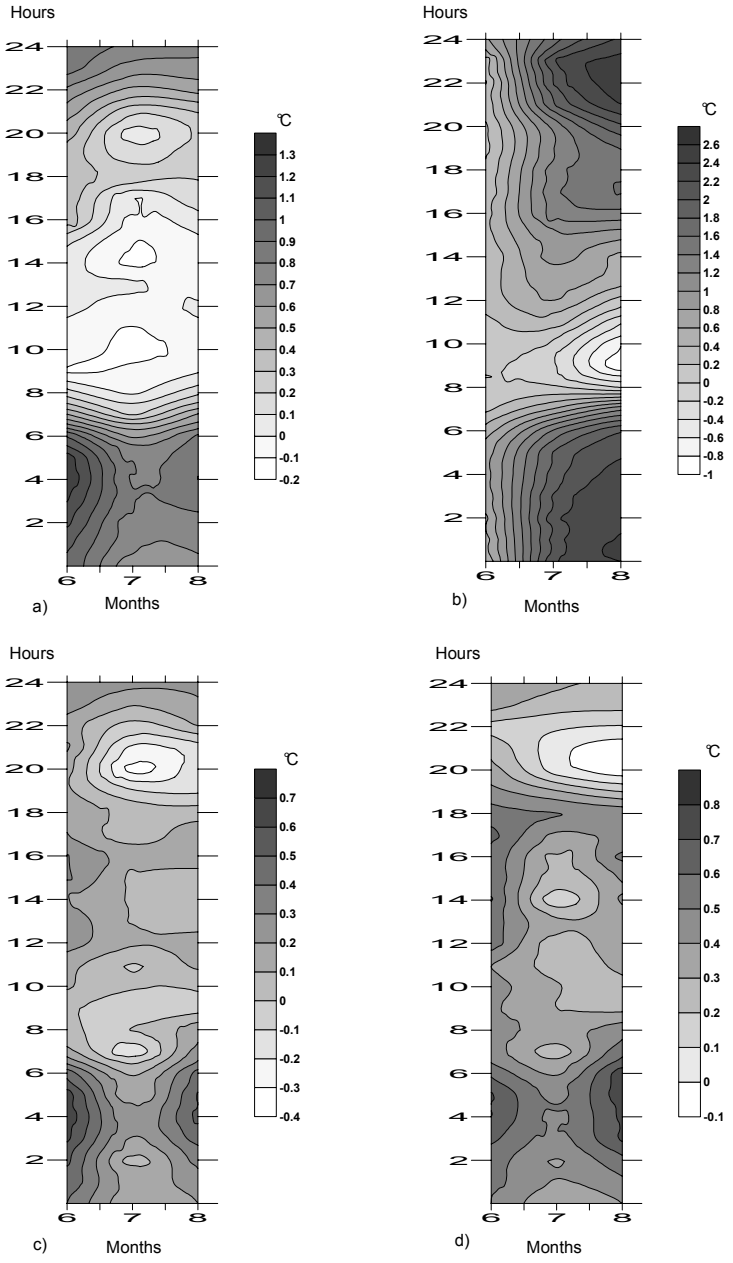

FIGURE 1. The graph presenting the development and disappearance of the urban heat island from VI––VIII 2008–2011 for the analysed measurement stations: a) Ursynów, b) Krucza, c) Piastów, d) Targówek

a result of slower heating of urban air. Tall buildings restrict the access of solar radiation and, thus, the process of air temperature increase is much slower than in open suburban areas, which results in negative contrasts in the centre, reaching a value of –1°C from 8 to 10 a.m. A bigger number of the sources of artificial light, especially near the roads of high traffic, is also conducive to higher intensity of the considered phenomenon. The hours with negative thermal contrasts are characteristic of all the stations, they are evidence to the occurrence of the so-called urban cold island. Depending on the location of the station within the analysed area, the phenomenon occurs with a various intensity and at different hours. For instance, at the Ursynów station negative contrasts occur from 8 a.m. to 9 p.m., mainly in July. It means that at a given time air temperature in Ursynów was lower than in the suburban area. During the day hours it results from the fact that the closest vicinity of the meteorological station is shaded by the buildings. Obviously, it does not prove the thermal advantage of Legionowo in relation to Ursynów. In the case of this station it may also be affected by a high velocity of wind, which mitigates heat perception. In Ursynów the phenomenon of the urban heat island also occurs at night, from 10 p.m. to 6 a.m. However, its intensity is much lower than in the city centre. The maximum intensity value reaches 1.2°C between 3 and 5 a.m. It may prove that the release of thermal energy accumulated during the day is then the most intense. The intensity of the urban heat island in this area of Warsaw is the highest in June and decreases after the end of summer. At the Piastów and the Targówek stations there occurs a certain similarity of the intensity distribution of the urban heat island. At both stations the intensity of the phenomenon is the highest in June, between 1 and 6 a.m. The phenomenon of the urban cold island is characteristic of the night hours, i.e. 8–10 p.m., especially intense in July, in the case of Targówek also in August. In Targówek and Piastów the urban cold island occurs also during the day. However, its presence is variable in particular months and the values of negative differences are slight. In Piastów negative contrasts are much more frequent. This results from a lower degree of development than in Targówek which is currently a dynamically developing region of Warsaw. The highest negative value of the difference at the two stations was recorded in Piastów, i.e. –0.4°C, in July about 8 p.m. In July at this station negative values occurred also from 6 to 12 a.m. In Targówek, due to a stronger influence of urban development negative differences reach only –0.1°C; they are characteristic of the evening, i.e. 8–10 p.m., in July. During the day, the phenomenon of the urban heat island occurs at both stations, but its intensity in relation to the centre is slight.

The frequency distribution of air temperature differences is also an illustration of thermal diversity within the analysed stations. A growing tendency of the share of bigger differences, as can be seen in Table 1, is closely related to increased intensity of development within the stations. According to Table 1, the percentage share of differences above 5°C distinctly dominates at the Krucza station, which represents the most anthropogenically transformed area, at the same time

TABLE 1. Frequency of particular ranges of air temperature differences between the stations in Warsaw and Piastów, and the station in Legionowo

Station	Range of differences [%]						
	< 0°C	0–0.2°C	0.3–0.5°C	0.6–0.8°C	0.9–1.1°C	1.1–5°C	≥ 5°C
Krucza	13.54	4.48	7.00	6.16	11.68	56.10	1.04
Ursynów	31.96	11.74	14.21	9.45	12.59	20.02	0.03
Targówek	24.38	13.86	19.56	11.66	14.42	16.12	0.00
Piastów	41.50	13.98	14.32	7.95	9.14	13.08	0.03

marked by the lowest percentage share of negative differences. The advantage of negative values, as assumed, occurs in the area of the lowest percentage of buildings, in Piastów. The negative values constitute more than 40%.

Characteristic days and nights

The study undertook also the analysis of characteristic days and night, i.e. hot days, warm nights, very warm nights (tropical) and tropical 24-hour periods (Table 2). In the analysed period one can notice a growing tendency of the number of days with a higher minimum air temperature at the Warsaw stations, especially at the Krucza station, where the buildings are conducive to the occurrence of higher air temperatures. Along with a decrease in anthropogenic impact on the shape of space there occurs a decrease in hot days, warm, very warm and hot nights. The most favourable conditions are present in the Legionowo and Piastów. Tropical 24-hour periods happen sporadically. These are single cases, but they occur at all the stations except for Legionowo station. In 2008 tropical 24-hour periods did not take place at all, in 2009 they occurred at three stations (Krucza, Targówek, Piastów), and in 2011 only in Ursynów. Tropical nights occurred at each station, but only in 2009 and 2011. There is a noticeable advantage of tropical 24-hour periods in the city centre where, apart from anthropogenic sources of heat, their occurrence is favoured by a specific spatial structure with dense development and more numerous street canyons. Very warm nights are much less frequent than warm nights. There is a noticeable drop in their share along with a decrease in the density of development. They prevail in the city centre, then their percentage share slowly falls, in the following order: Ursynów, Targówek, Piastów and Legionowo, where they occur from 33 to 59 days less frequently than in the city centre.

Air temperature variability estimation

The human well-being is affected both by excessively high air temperature and its high variability in time. Therefore, air temperature variability was determined on the basis of the difference between the values of average air temperature day to day. Variability of average air temperature during successive days is a valuable bioclimatic index and informs about the dynamics of climate change, which is useful during the evaluation of perceptible conditions in a given area (Kossowska-Cezak 2007).

TABLE 2. Number of characteristic days and nights in particular years and the whole calculation period

Number of characteristic days/nights	Krucza	Ursynów	Targówek	Piastów	Legionowo
VI–VIII 2008–2011					
Hot days, $t_{max} > 25°C$	117	85	96	85	84
Warm nights, $t_{min} > 15°C$	141	105	99	87	82
Very warm nights, $t_{min} > 18$	31	21	13	10	10
Hot nights (tropical), $t_{min} > 20°C$	6	2	3	3	2
Tropical 24-hour periods, $t_{max} > 30°C$ and $t_{min} > 20°C$	1	1	1	1	0
VI–VIII 2008					
Hot days, $t_{max} > 25°C$	42	35	37	35	36
Warm nights, $t_{min} > 15°C$	47	27	25	18	23
Very warm nights, $t_{min} > 18°C$	6	4	1	0	2
Hot nights (tropical), $t_{min} > 20°C$	0	0	0	0	0
Tropical 24-hour periods, $t_{max} > 30°C$ and $t_{min} > 20°C$	0	0	0	0	0
VI–VIII 2009					
Hot days, $t_{max} > 25°C$	39	26	31	27	26
Warm nights, $t_{min} > 15°C$	44	30	31	28	28
Very warm nights, $t_{min} > 18°C$	15	6	4	3	4
Hot nights (tropical), $t_{min} > 20°C$	4	0	2	2	1
Tropical 24-hour periods, $t_{max} > 30°C$ and $t_{min} > 20°C$	1	0	1	1	0
VI–VIII 2011					
Hot days, $t_{max} > 25°C$	36	24	28	23	22
Warm nights, $t_{min} > 15°C$	50	48	43	41	31
Very warm nights, $t_{min} > 18°C$	10	11	8	7	4
Hot nights (tropical), $t_{min} > 20°C$	2	2	1	1	1
Tropical 24-hour periods, $t_{max} > 30°C$ and $t_{min} > 20°C$	0	1	0	0	0

During all the summer months in 2008–2011, in each year two cases of sharp air temperature changes with an irritating effect were recorded. Such an outcome would show that thermal conditions, in terms of a nuisance to the human body, are the same at all the stations. However, the analysis of days with indifferent changes (up to 2°C) shows that at the Krucza station there is the smallest number of them (59.1% of all the analysed days), which means that within this station there occur the least favourable conditions. From the perspective of human sensations it denotes a worryingly small number of days with optimal conditions for the right functioning of the body. The biggest number of

days with indifferent changes occurs in Legionowo (65.8%), then in Targówek (62.6%), Ursynów (61.1%) and Piastów (60.3%). The number of days of perceptible (2.1–4°C) and significant changes (4.1–6°C) is the biggest in the city centre, which confirms the occurrence of unfavourable bioclimatic conditions at this place (Table 3).

TABLE 3. Measure of air temperature variability in VI–VIII 2008–2011

Measure of air temperature variability / changes	Krucza	Ursynów	Targówek	Piastów	Legionowo
Indifferent (< 2°C)	152 / 59.1%	157 / 61.1%	161 / 62.6%	155 / 60.3%	169 / 65.8%
Perceptible (2.1–4°C)	82 / 31.9%	81 / 31.5%	76 / 29.6%	79 / 30.7%	67 / 26.1%
Significant (4.1–6°C)	21 / 8.2%	17 / 6.6%	18 / 7%	21 / 8.2%	19 / 7.4%
Sharp, irritating (> 6°C)	2 / 0.8%	2 / 0.8%	2 / 0.8%	2 / 0.8%	2 / 0.8%
Number of days	257	257	257	257	257

Degree of the stimulus intensity of thermal conditions

The study also made an attempt to evaluate the degree of the stimulus intensity of thermal conditions on the basis of the daily amplitude of air temperature. The results show that, irrespective of a measurement station, the amplitudes perceptible to the body (8–11.9°C) occur with the highest frequency. There is also a big share of days with slightly perceptible amplitudes (4–7.9°C) and sharp amplitudes (≥ 12°C). The fact of the smallest share of days with indifferent amplitudes (< 4°C) at all the stations is worrying (Table 4). Lower daily amplitudes in the city centre may be determined by an additional flow of anthropogenic heat during the whole 24-hour period and by slow heat release by the buildings at night. This conclusion is also confirmed by the occurrence of very high amplitudes at the Legionowo station, having a significantly lower percentage of anthropogenic development. The biggest number of days with sharp amplitudes occur in Targówek. However, from the perspective of the number of days with perceptible amplitudes, which occur less frequently than in Legionowo and days with indifferent and slightly perceptible amplitudes, which prevail in Targówek, it could be stated that biometeorological conditions in Targówek are more conducive to the right functioning of the body. The most favourable conditions in the whole calculation period were characteristic of Ursynów. The share of days with sharp amplitudes is the smallest there, only 18.6 % (less in relation to the other stations by 4.2–10.7%), and with indifferent and slightly perceptible amplitudes is the biggest, 6.5 and 34% respectively (Table 4).

Estimation of the stimulus intensity of the weather

Bioclimatic diversity of particular parts of Warsaw was analysed also in terms of the measure of the stimulus intensity of the climate. This index was determined on the basis of the change in air temperature values in two time ranges, between 7 a.m and 1 p.m., and 1 and 7 p.m.

TABLE 4. Degree of the stimulus intensity of thermal conditions in VI–VIII 2008–2011

Degree of the stimulus intensity of thermal conditions / amplitudes	Krucza	Ursynów	Targówek	Piastów	Legionowo
Indifferent < 4°C	14 / 5.3%	17 / 6.5%	16 / 6.1%	14 / 5.3%	15 / 5.7%
Slightly perceptible 4–7.9°C	80 / 30.4%	90 / 34.%	76 / 28.9%	75 / 28.5%	77 / 29.3%
Perceptible	109 / 41.4%	107 / 40.7%	93 / 35.4%	111 / 42.2%	94 / 35.7%
Sharp ≥ 12.0°C	60 / 22.8%	49 / 18.6%	78 / 29.7%	63 / 24%	77 / 29.3%
Number of days	263	263	263	263	263

As it results from the calculations, the worst bioclimatic conditions in relation to this index within the whole research period occur at the Krucza station. The station is marked by the smallest number of days with air temperature changes, classified as imperceptible to the human body. At the Ursynów, the Targówek and the Piastów stations the number of days with imperceptible temperature changes is similar, and the number of days with substantial changes shows that the worst conditions among the three stations occur in Targówek, and then in Piastów. In spite of a big share of days with substantial changes, the Legionowo station located outside the city is at the same time marked by the biggest share of days with indifferent changes and a big share of slightly perceptible changes. Air temperature changes exceeding 15°C (Table 5) were not recorded at any of the stations.

The measure of the stimulus intensity of the climate, calculated on the basis of air temperature differences between 1 and 7 p.m., shows that air temperature changes at these hours are much milder than between 7 a.m. and 1 p.m. The changes imperceptible to the body prevail and it is the time more conducive to being outside. Changes up to 2°C constitute more than 60% in each case. Like in the case of the previous index, the least favourable conditions occur in the city centre, the most favourable in Piastów and Legionowo. Cases with substantial changes are few; they occur at most two times during the whole calculation period in Ursynów and once at each of the remaining stations (Table 6).

TABLE 5. Measure of the stimulus intensity of the climate in VI–VIII 2008–2012 on the basis of the differences at 7 a.m and 1 p.m.

Measure of the stimulus intensity of the climate / Temperature changes	Krucza	Ursynów	Targówek	Piastów	Legionowo
Imperceptible 0–2°C	23 / 9.3%	24 / 9.7%	24 / 9.7%	24 / 9.7%	25 / 10.1%
Slightly perceptible 2.1–6°C	75 / 30.2%	80 / 32.3%	78 / 31.5%	68 / 27.4%	74 / 29.8%
Moderate 6.1–10.0°C	119 / 48%	121 / 48.8%	107 / 43.1%	125 / 50.4%	113 / 45%
Substantial 10.1–15.0°C	31 / 12.5%	23 / 9.3%	39 / 15.7%	31 / 12.5%	36 / 14.5%
Very substantial > 15.0°C	0	0	0	0	0
Number of days	248	248	248	248	248

TABLE 6. Measure of the stimulus intensity of the climate in VI–VIII 2008–2011 on the basis of temperature differences at 1 and 7 p.m.

Measure of the stimulus intensity of the climate / Temperature change:	Krucza	Ursynów	Targówek	Piastów	Legionowo
Imperceptible 0–2°C	156 / 61.9%	170 / 67.5%	175 / 69.4%	174 / 69%	176 / 69.8%
Slightly perceptible 2.1–6.0°C	88 / 34.9%	74 / 29.4%	69 / 27.4%	70 / 27.8%	68 / 27%
Moderate 6.1–10.0°C	7 / 2.8%	6 / 2.4%	7 / 2.8%	7 / 2.8%	7 / 2.8%
Substantial 10.1–15.0°C	1 / 0.4%	2 / 0.8%	1 / 0.4%	1 / 0.4%	1 / 0.4%
Very substantial > 15.0°C	0	0	0	0	0
Number of days	252	252	252	252	252

CONCLUSIONS

On the basis of the analysis of the intensity of the urban heat island, the number of characteristic days and chosen biometeorological indicators, the following conclusions were made:

- Warsaw is an example of a dynamically developing urban agglomeration in which there occurs a phenomenon of the urban heat island. This phenomenon is present throughout the whole summer period (VI–VIII).
- The intensity of the urban heat island depends on the density of development, the height of buildings and the vegetation cover. The intensity of this phenomenon decreases along with a growing distance from the city centre and, accompanying it, sparser development.
- The differences in the number of characteristic days at particular stations are related with anthropogenic transformation degree and result in nuisance to the human body.
- The intensity of the urban heat island in Warsaw reaches the highest values in August. Average thermal contrasts between the Krucza, the Ursynów, the Targówek, the Piastów stations and the Legionowo station are not high; they reach approximately 1°C. The maximum average air temperature differences occur at the Krucza station at night.
- Hourly values of air temperature differences of ≥ 5°C at particular stations in relation to the Legionowo one occur at the Krucza, the Ursynów and the Piastów stations. These are single cases, the percentage of the differences amounts to 1.04% at the Krucza station and 0.03% at the Ursynów and the Piastów stations. The maximum hourly difference of air temperature in relation to the Legionowo station, i.e. 8.7°C, was recorded in the city centre.
- The values of the analysed biometeorological indicators, i.e. the measure of temperature variability, the degree of the stimulus intensity of thermal conditions, the measure of the stimulus intensity of the climate proved that the least favourable conditions occur at the Krucza station, the station of the highest degree of anthropogenic transformation. Along with a decrease in the percentage of dense-

ly built-up areas and an increase in the share of green and open areas, a negative impact of air temperature on the human body decreases.

- Improvement of bioclimatic conditions in Warsaw may be achieved thanks to activating green areas in the city (the appropriate spatial structure, size of an area, selection of species, green roofs), enforcing ventilation of the city through the creation of the appropriate ventilation corridors, designing water reservoirs in parks, considering in development plans the natural layout of the land, e.g. determined by the river bed of the Vistula compass rose directions, local and regional air circulation, linear arrangement of buildings, locating areas having a different thermal character next to each other. However, all of those actions are still difficult to be sufficiently realized.

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Streszczenie: *Wpływ terenów o różnymi stopniu przekształcenia antropogenicznego na kształtowanie się warunków bioklimatycznych na przykładzie Warszawy.* Celem pracy jest ocena zmienności warunków bioklimatycznych i ich zróżnicowania na terenach o różnym stopniu przekształcenia antropogenicznego. Ważnym elementem pracy jest określenie częstości występowania określonych warunków biotermicznych na analizowanych obszarach, silnie obciążających gorącem organizm człowieka i wywołujących stres ciepła o różnym natężeniu. Elementem meteorologicznym zastosowanym w opracowaniu jest temperatura powietrza, bowiem jest najintensywniej od-

czuwalna spośród bodźców fizycznych, zwłaszcza gdy jej wahania występują w krótkich odstępach czasowych. Dane uwzględnione w opracowaniu pochodzą z automatycznych stacji pomiarowych, działających na ramach monitoringu jakości powietrza i zlokalizowanych w różnych dzielnicach Warszawy oraz poza granicami miasta. Każda ze stacji charakteryzuje się indywidualnymi cechami ze względu na różny stopień przekształcenia antropogenicznego najbliższego otoczenia stacji.

Słowa kluczowe: temperatura powietrza, bodźce termiczne, miejska wyspa ciepła, Warszawa

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