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Katarzyna ROZBICKA, Martyna ZAWISTOWSKA
Faculty of Civil and Environmental Engineering, Warsaw University of Life Sciences – SGGW

Long-term changes of weather stimuli based on the example of the southern part of Warsaw – Ursynów

Key words: thermal sensations, thermal stimuli, air temperature, change from day to day, city

Introduction

The whole atmosphere affects the human body. It refers to basic meteorological elements: solar radiation, sunshine, air temperature and humidity, atmospheric pressure, wind, precipitation, but also gas and dust pollutants, noise, odors, air ionization and content of elements (Błażejczyk & Kunert, 2011; Czarnecka, Mąkosza & Nidzgorska-Lencewicz, 2011; Czarnecka, Nidzgorska-Lencewicz & Rawicki, 2017; Tylkowski, 2017). These environmental elements act on the human body continuously and with varying intensity. If the parameters change in a short time, they are called a stimulus that causes positive or negative changes in the human body (Kozłowska-Szczęsna, Krawczyk & Kuchcik, 2004; Mąkosza and Nidzgorska-Lencewicz, 2011; Rozbicka & Rozbicki, 2016a). Air temperature is the most noticeable stimulus for humans, especially when many fluctuations occur in a short time (Dobek & Krzyżewska, 2016; Mąkosza & Nidzgorska-Lencewicz, 2017). Currently, the variability of air temperature and violent weather anomalies are observed. Such changes often cause discomfort and disorder of the body's thermal management.

The heat balance also changes as a result of civilization progress, most noticeable in large cities, due to the occurrence of the so-called urban heat island (UHI). As a result of these changes, the stimuli of air temperature increases, therefore series of tests and analyzes are carried out in this field.

In this article, the southern part of Warsaw – Ursynów was selected for the analysis of stimulus. It is one of the largest and the most dynamically developing district of the City.

Material and method

Daily values of air temperature (average, maximum and minimum) from the weather station Ursynów – SGGW in the years 1961–2016 were used to the analysis. The meteorological station of the Warsaw University of Life Sciences – SGGW, situated in Ursynów (φ = 52° 09' N, λ = 21°02' E, H = 102 m a.s.l.), south of the city centre, is a station around which the area has undergone a very significant transformation. The station was established in 1959 in suburban farmland and this form of land use was maintained until 1970. From 1970 to 2008 however, the immediate vicinity of the station was substantially changed as a result of the extension of the WULS-SGGW campus and the development of the Ursynów residential district. It influenced the thermal, bioclimatic and aerosanitary conditions of the air, which were the subject of research (Majewski, Przewoźniczuk & Kleniewska, 2014; Rozbicka, Majewski & Rozbicki, 2014; Rozbicka & Michalak, 2015; Rozbicki, Kleniewska, Majewski, Rozbicka & Gołaszewski, 2016; Rozbicka & Rozbicki, 2016b, 2018).

The courses of the temperature variations from year to year in individual months were calculated on the basis of average, maximum and minimum values of air temperature and linear trend were determined for them. Then, the frequency of occurrence of thermal sensations was calculated [in %] on the basis of average daily air temperature values for individual years and months according to the Kozłowska-Szczęsna, Błażejczyk and Krawczyk (1997) scale with subsequent modifications by Kossowska-Cezak (2005), Koźminski and Michalska (2011), Mąkosza and Nidzgorska-Lencewicz (2011) – Table 1. The trend equations and determination coefficients were determined of on the basis of the number of days per year for long-time period 1961–2016, for individual sensations and thermal stimuli.

TABLE 1. Scale of thermal sensations based on the average daily values of air temperature according to Kozłowska-Szczęsna et al. (1997) for Kossowska-Cezak (2005)

Air temperature [°C]	Thermal sensations
> 25.0	hot
20.1÷25.0	very warm
15.1÷20.0	warm
10.1÷15.0	cool
0.1÷10.0	slightly cold
–9.9÷0.0	moderately cold
–19.9÷10.0	very cold
≤ –20.0	extremely cold

Thermal stimuli related to day-to-day variability of air temperature have were also determined, where the scale according Bajbakova was used (Kozłowska--Szczęsna et al. 1997) – Table 2. The frequency of occurrence of thermal sensations [in %] for individual years and months was calculated.

TABLE 2. Scale of intensity of thermal stimuli according to Bajbakova, Nevraev and Cubukov (1963) for Kozłowska-Szczęsna et al. (1997) depending on temperature changes from day to day.

Air temperature [°C]	Thermal stimuli
≤ 2.0	neutral
2.1–4.0	perceptible
4.1–6.0	significant
> 6.0	sharp

Results and discussion

Analysis of the thermal conditions Warsaw Ursynów showed that the annual average temperature, the average annual maximum and the average annual minimum in individual years fluctuated in ranges: 6.6–10.7°C, 10.7–14.5°C and 2.3–6.7°C respectively. High variabilities in year to year for all temperatures (average, maximum and minimum) are noticed (Fig. 1). A statistically significant ($\alpha = 0.01$) positive trend of temperature in the analyzed period was found. The highest increase 0.447°C per 10 years characterizes average annual minimum air temperature, while increase 0.38°C per 10 years and 0.314°C per 10 years were found for annual average and average annual maximum, respectively. Similar tendencies were observed in studies for Warsaw by Rozbicki et al. (2016). The obtained results confirm the trends with a fairly high determination coefficient of R^2 equal to 0.49 (correlation coefficient – R is 0.7) for the average annual minimum air temperature, while for the annual average and the average annual maximum temperature R^2 are: 0.40 ($R =$ $= 0.6$) and 0.28 ($R = 0.5$) respectively.

Thermal sensations according to the adopted scale were determined on the base on average daily values of air temperature. Temperature in the range from 0.1 to 10.0, which corresponds to the thermal sensation "slightly cold" occurred most often 36.5% (Fig. 2). The days with this thermal sensation occurred from September to May mainly, with the highest frequency in autumn in November (76.7%) and in spring in March (69.9%) – Figure 3. The literature confirms the highest occurrence of the temperature in this range. Similar results of the research were found for Gorzów Wielkopolski and Zielona Góra (Mąkosza, 2013). Then, "warm" days of the range 15.1–20.0°C and "cool" ones

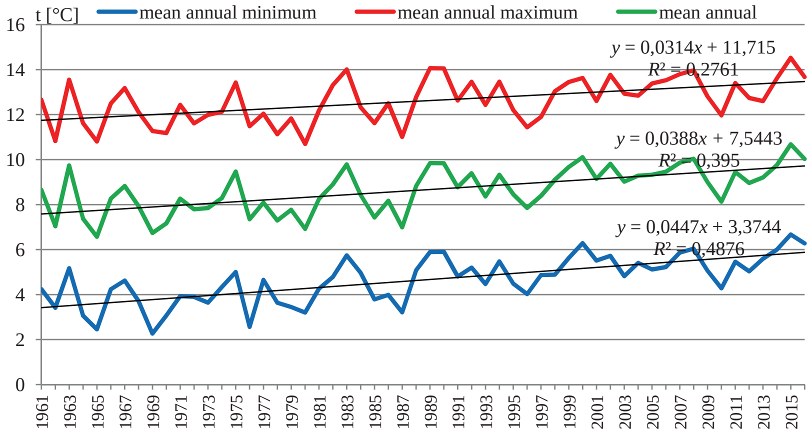

FIGURE 1. Course of mean annual, mean annual maximum and mean annual minimum temperature in Ursynów (1961–2016)

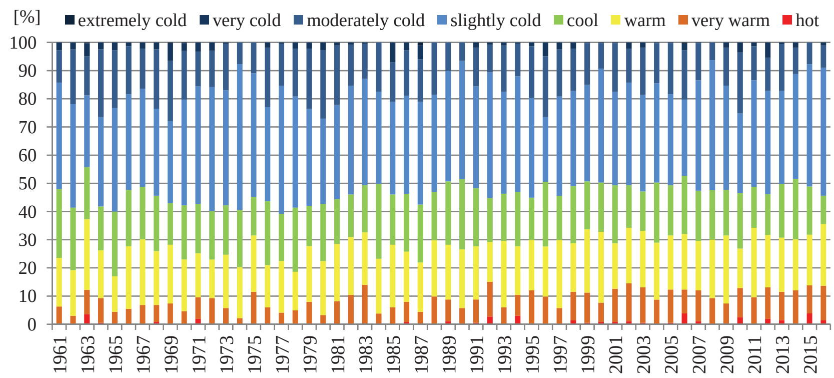

FIGURE 2. The frequency of occurrence of thermal sensations in individual years in Ursynów (1961––2016)

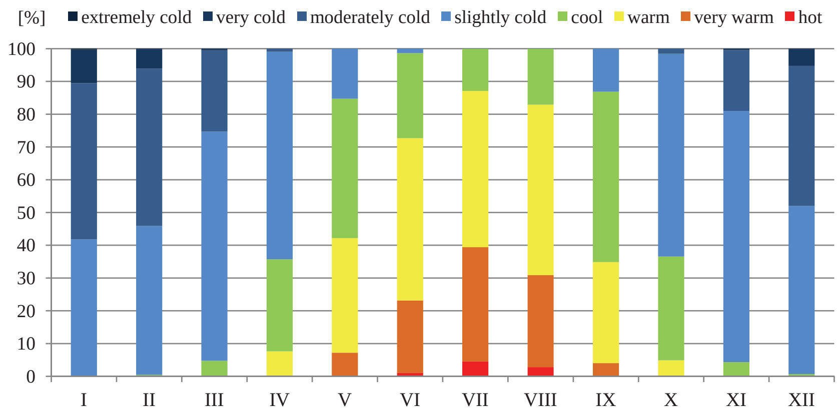

FIGURE 3. The frequency of occurrence of thermal sensations in individual months in Ursynów (1961–2016)

of the range 10.1–15.0°C were with average frequency 19.1 and 18.5% respectively. These thermal sensations can be named as "saving" that have no negative effect on the human body. Extreme thermal sensations occurred very rarely and accounted for a small percentage of days a year: 0.7% of "hot" days ($t > 25°C$), 8.1% of "very warm" days (from 20.1 to 25.0°C), 15.1% of "moderately cold" days (from 0.0 to –9.9°C), 1.8% days "very cold" (from –19.9 to –10.0°C) and 0.05% "extremely cold" days ($t \leq$ –20.0°C). "Very warm" days ($t > 20°C$) occurred mainly in July and August, moderately cool ones ($t \leq 0°C$) from December to February. April and October were months of the most favorable thermal sensations for the human body in the analyzed period were, in which 99% of days with feelings of human benefit so called saving, while in January was the least favorable month in which only 42% of these days.

In the next stage, the intensity of thermal stimuli was determined on the basis of changes in air temperature from day-to-day according to the adopted scale. The analysis results that in the case both of average air temperature, maximum and minimum temperature, the most frequent stimuli are "neutral", regardless of the given year and month. These are stimuli when temperature changes do not exceed 2°C (Fig. 4). Average frequency stimuli "neutral" is 64% in case of daily average temperature, 55% in case of daily maximum and 58% for daily maxi-

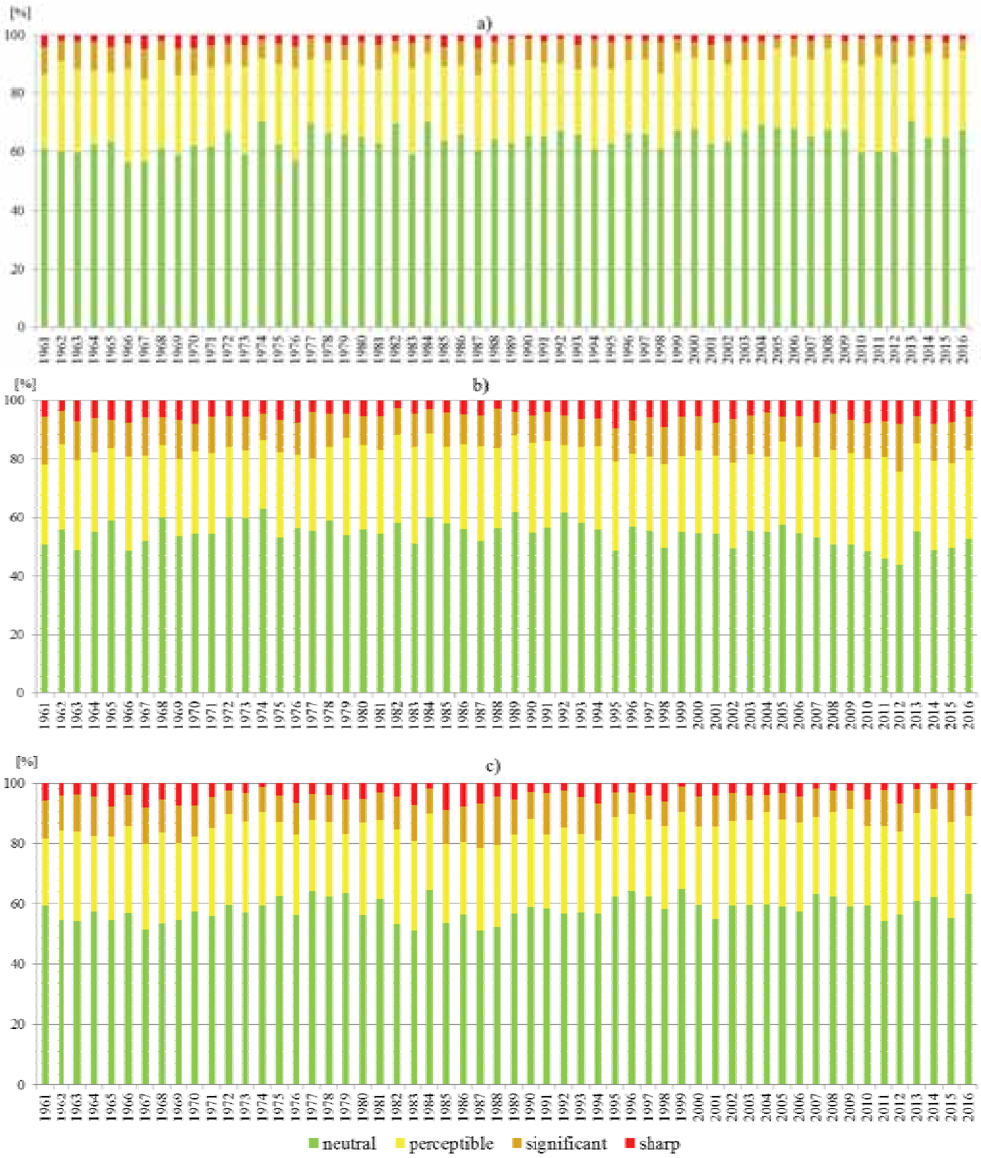

FIGURE 4. The frequency of occurrence of thermal stimuli of mean (a), maximum (b), minimum (c) air temperature in individual years in Ursynów (1961–2016)

mum. Such changes in temperature are neutral for the human body, which means that they do not affect its functioning negatively. Similar results were obtained by Mąkosza (2013) for the Lubuskie Voivodeship. The frequancy of day-to--day changes of air temperature defined as "perceptible" (2.1–4.0°C) was small and amounted to an average of 27% for all air temperature characteristics (average, maximum and minimum). Similar results were obtained by Mąkosza and Nidzgorska-Lencewicz (2011) for Szczecin in north-western Poland, Mąkosza (2013) for Lubuskie Province in western Poland and Panfil, Dragańska and Cymes (2007) for north-eastern Poland. Frequency stimuli "significant", for the range of the temperature changes 4.1–6.0 are 7% in case of daily average temperature, 12% for daily maximum and 10% in case of minimum. The largest percentage of "significant" day-to-day changes in air temperature for the maximum was in the period from April to June, and of the minimum temperature from October to May (Fig. 5). Thermal stimuli referred to as "sharp", i.e. exceeding 6°C, in the case of extreme air temperatures were greater than in the case of average daily air temperature. They amounted to only 2% for average temperature, 6% for maximum one and 4% in case of minimum one. Similar results for extremum temperatures were obtained by Mąkosza and Nidzgorska-Lencewicz (2011) and Mąkosza (2013). The highest frequency of "sharp" temperature changes was observed in the warm period of the year (April and May), and the minimum temperature in the winter months (January and February).

Analyzing the equations of number of days trends (Table 3) for individual thermal sensations, statistically significant ($\alpha = 0.01$) increasing trend was stated for the number of days with the feeling of "very warm" (determination coefficient $R^2 = 0.333$) and "hot" ($R^2 = 0.127$). The decreasing but statistically insignificant trend was stated in case of thermal sensation from „moderately cold" to „extremely cold". However, analyzing thermal stimuli trends, in case of almost all stimuli high significant trend equations were obtained. The equations for thermal stimuli "perceptible" is the only exception In case of thermal stimuli „neutral" increasing trend was stated whereas in case thermal stimuli „significant" ($R^2 = 0.213$) and „sharp" ($R^2 = 0.284$) high significant decreasing trends.

Conclusions

1. In 1961–2016 in Ursynów, the average annual, the average annual maximum and the average annual minimum air temperature in individual years was 8.6°C, 12.6°C and 4.6°C, respectively. For each temperature increasing trend is observed.
2. In the analyzed period thermal sensations that had a positive effect on the human body occured most often (74%). These are the thermal sensations so-called "saving", which includes ones "slightly cold" (0.1––10°C), "cool" (10.1–15.0°C) and "warm" (15.1–20.0°C).
3. April and October were the months of the most favorable thermal sensations, in which occured 99% of ther-

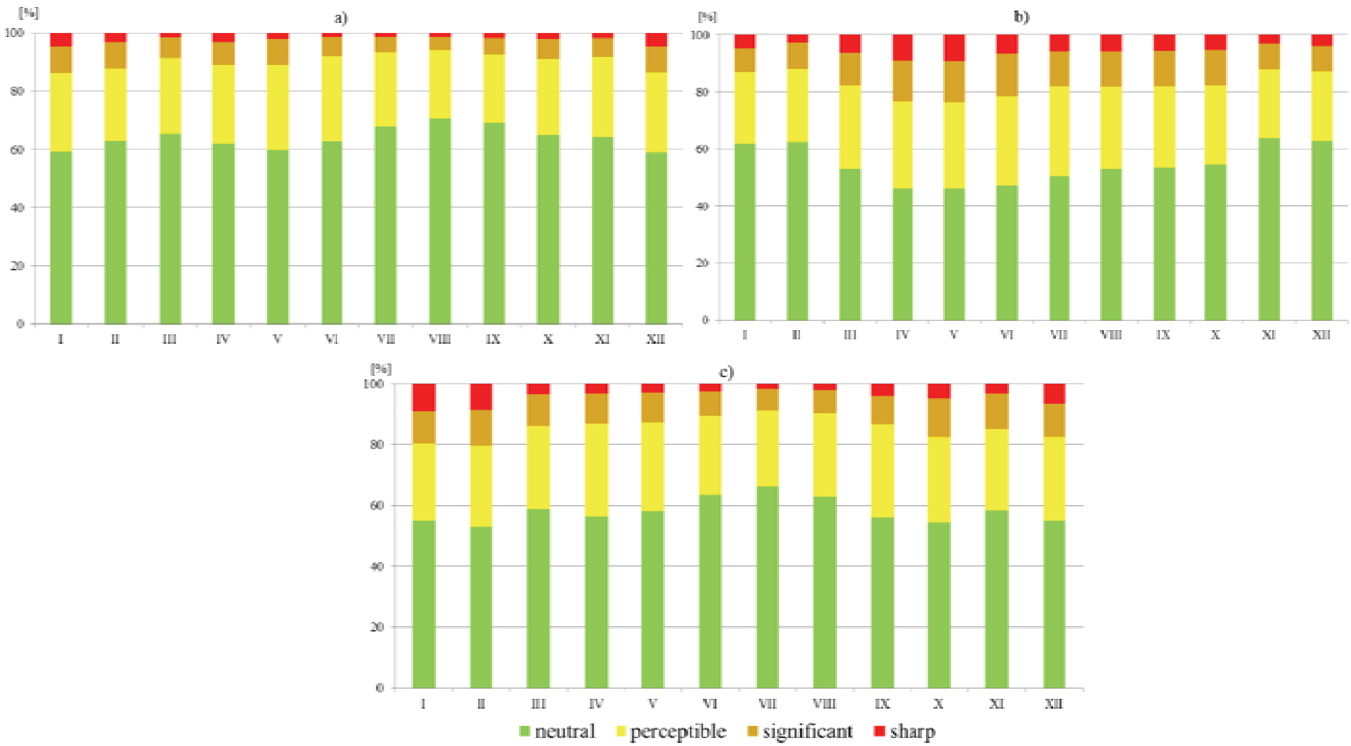

FIGURE 5. The frequency of occurrence of thermal stimuli of mean (a), maximum (b), minimum (c) air temperature in individual months in Ursynów (1961–2016)

TABLE 3. The equations of number of days trends with sensations and thermal stimuli in long-time period 1961–2016 in Ursynów

Specification		Equations	R^2
Thermal sensation	*hot	$y = 0.079x + 0.3909$	0.127
	*very warm	$y = 0.3765x + 18.894$	0.333
	warm	$y = 0.1455x + 65.355$	0.053
	cool	$y = –0.1617x + 71.769$	0.049
	slightly cold	$y = 0.0604x + 131.21$	0.002
	moderately cold	$y = –0.3352x + 64.644$	0.111
	very cold	$y = –0.0845x + 9.0506$	0.053
	extremely cold	$y = –0.0037x + 0.2838$	0.008
Thermal stimuli	*neutral	$y = 0.3553x + 221.89$	0.152
	perceptible	$y = 0.0184x + 95.155$	0.001
	*significant	$y = –0.1756x + 31.147$	0.213
	*sharp	$y = –0.1246xx + 12.392$	0.284

*Level of significance $\alpha = 0.01$.

mal sensations called saving, while January was the least favorable in which occured only 42% of sensations "saving".

4. For each air temperature (average, maximum and minimum), regardless of the year and month, stimuli referred to as neutral, i.e hanges not exceeding 2°C occured most frequently (64% in case of daily average temperature, 55% for maximum and 58% for minimum temperature).
5. Thermal stimuli defined as sharp for changes in temperature greater than 6°C constituted a small incidence (the value of average – 2%, maximum – 6% and minimum – 4%).
6. Based on the analysis of the long-term period trend of the number of days in the year, it can be stated an increase in the number of days with the thermal stress "very warm", which is results from a positive statistically significant trend and also a decrease in number of days with thermal stimuli "sharp".

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Summary

Long-term changes of weather stimuli based on the example of the southern part of Warsaw – Ursynów. The aim of the work is to evaluate thermal sensations based on the average daily temperature of air and to determine thermal stimuli, using interdependent variability of air temperature (average, maximum and minimum). The data from the weather station Ursynów – SGGW was used for the analysis in the period 1961–2016. The analysis showed that with the highest frequency (74%) there are thermal sensations “saving” (“slightly cold”, “cool”, “warm”). In the case of thermal stimuli with the greatest frequency, changes from day to day were described as “neutral”, not exceeding 2°C .

Based on the analysis of the long-term period trend of the number of days in the year, it can be stated an increase in the number of days with the thermal stress “very warm”, which is results from a positive statistically significant trend and also a decrease in number of days with thermal stimuli “sharp”.

Authors’ address:
Katarzyna Rozbicka
(https://orcid.org/0000-0003-2847-3195
Szkoła Główna Gospodarstwa Wiejskiego
w Warszawie
Wydział Budownictwa i Inżynierii Środowiska
Katedra Inżynierii Wodnej
ul. Nowoursynowska 166, 02-787 Warszawa
Poland
e-mail: katarzyna_rozbicka@sggw.pl