OCCURRENCE OF HEATWAVES IN SELECTED REGIONS OF POLAND AND GREECE AND THE CHARACTERISTICS OF THEIR BIOMETEOROLOGICAL CONDITIONS

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Abstract: This work aimed to characterise the occurrence of heatwaves and the related bioclimatic conditions in two climate-distinct regions of Europe. This study was based on data of maximum daily air temperature (T_{max}), as well as air temperature and humidity at 12:00 UTC, from two meteorological stations in Poznań (Poland) and Thessaloniki (Greece), spanning the summer seasons (the period from May to September) from 1966 to 2022. A hot day was defined as a day with T_{max} >90th percentile of the station climatology. Heatwaves were defined as sequences of at least three hot days based on the identified hot days. This study revealed a significant variation in thermal conditions over the examined period in both stations. Both stations showed a statistically significant increase in average T_{max}, although changes were more intense in Poznań (0.41°C/10 years). Like T_{max}, the 21st-century seasons also stood out in terms of the number of hot days compared to the analysed multi-decade period. This study showed a statistically significant increase in analysed days at both stations, with changes being more intense in Thessaloniki (3.5 days/10 years). The study revealed a significant variation in biometeorological conditions during heatwaves at both stations. Heatwaves in Poznań were characterised by less burdensome conditions compared to those in Thessaloniki.

Keywords: air temperature, heatwaves, Humidex, Poznań, Thessaloniki, Poland, Greece

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Introduction

For many years, thermal conditions have been the subject of numerous scientific publications in the field of climatology due to the rapidly advancing warming observed on both global and regional scales. According to NOAA (2024), 10 of the warmest years globally since the mid-19th century occurred in the 21st century, all recorded in the last decade (2014–2023). Additionally, since June 2023, each subsequent month has been characterised by the highest temperature anomalies since the mid-19th century.

One of the manifestations of progressive climate warming is the increasingly frequent occurrence of extreme air temperatures, including heatwaves. Among the regions of the world, where a systematic increase in the number and duration of heatwaves is observed, is Europe (Russo et al. 2015, Muthers et al. 2017, Tolika 2019, Tomczyk et al. 2020, Shevchenko et al. 2022, Ballester et al. 2023).

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The occurrence of heatwaves in Poland has been the subject of numerous publications at the national (Porębska, Zdunek 2013, Wibig 2018, 2021, Tomczyk et al. 2019a, Tomczyk, Bednorz 2023), regional (Krzyżewska 2014) and local scale (Krzyżewska 2015, Półrolniczak et al. 2018, 2024). Among the most intense heatwaves, the years 1959, 1963, 1968, 1992, 1994, 2006, 2010 and 2015 are often mentioned (Krzyżewska, Dyer 2018, Wibig 2018, 2021, Tomczyk et al. 2019a, Tomczyk, Bednorz 2023). Research to date indicates that the most bioclimatically burdensome heatwaves in recent decades were observed in 1994 and 2015 (Krzyżewska, Dyer 2018, Krzyżewska et al. 2019, Tomczyk et al. 2020, Tomczyk, Bednorz 2023). These were also the longest heatwaves at most stations in Poland, lasting more than 2 weeks (Tomczyk, Bednorz 2023). One of the consequences of high air temperatures is an increase in the number of deaths (Kuchcik 2017, 2021). Graczyk et al. (2019, 2022) demonstrated an increase in the number of deaths during selected heatwaves in Poland. According to these authors, the total number of additional deaths during the heatwave observed in 1994 in the 10 largest cities in Poland might have exceeded 1070. On the hottest days in the analysed period, the number of deaths in some cities was more than three times higher than the average for the reference period.

Similarly, in Greece, over the last few decades, including 1987, 1988, 1998, 2000, 2007, 2012, 2021, and 2022, several intense heatwaves were identified (Founda, Giannakopoulos 2009, Theoharatos et al. 2010, Zoumakis et al. 2012, Katavoutas, Founda 2019, Founda et al. 2022, Ballester et al. 2023). A significant portion of research on heatwaves has focused on this phenomenon in the context of the urban heat island effect in cities such as Thessaloniki (Keppas et al. 2021) and Athens (Founda et al. 2015, Founda, Santamouris 2017, Katavoutas, Founda 2019, Giannaros et al. 2023). The consequences of such weather conditions include an increase in the number of deaths (Zoumakis et al. 2012, 2013, Kouis et al. 2019) as well as fire hazards (Founda et al. 2022). Parliari et al. (2023) and Papadopoulos et al. (2024) showed that, in the next decades in Thessaloniki, there will be an increase in mortality related to high air temperature, especially among old people. As indicated by Founda et al. (2022), due to the preparedness of authorities and agencies, increased public awareness, and local social acclimatisation, the 2021 heatwave did not result in numerous excessive heat-related deaths, unlike the heatwave observed in July 1987.

As demonstrated above, heatwaves are becoming an increasingly common weather phenomenon, posing a threat to human health (Ballester et al. 2023) and life, as well as various sectors of the economy. Given the rapidly advancing climate warming, it is pertinent to analyse the occurrence of heatwaves in recent decades. Therefore, this study aimed to characterise the occurrence of heatwaves and the bioclimatic conditions during their occurrence in two different regions of Europe from 1966 to 2022.

Data and methods

This study was based on data on maximum daily air temperature (T_{max}), as well as air temperature and humidity at 12:00 UTC, from two stations: Poznań (Poland) and Thessaloniki (Greece), spanning the period from 1966 to 2022 (Fig. 1). Data for the Polish station were obtained from the Institute of Meteorology and Water Management–National Research Institute, while data for the Greek station were sourced from the Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki in Greece.

Poznań is located in western Poland in the region of the Greater Poland Lakeland, which is a large macroregion situated in central Greater Poland and southeastern Kuyavia (Richling et al. 2021). According to the Köppen-Geiger climate classification (Kottek et al. 2006), Poznań falls

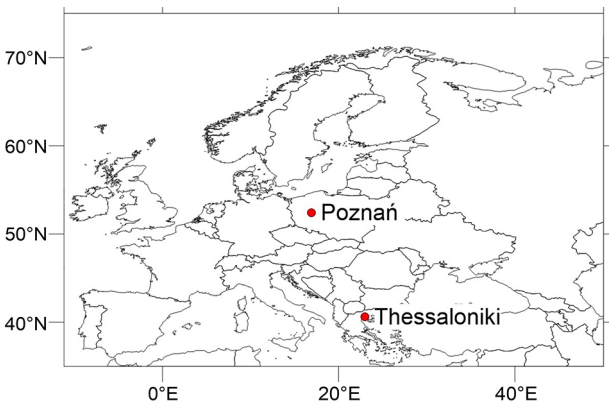

Fig. 1. Location of meteorological stations.

under the Cfb climate type and is characterised as a warm temperate humid climate. Thessaloniki is located in northern Greece, on the Gulf of Thessaloniki (Aegean Sea). It is the second largest city in Greece after Athens. According to the Köppen-Geiger climate classification (Kottek et al. 2006), Thessaloniki is classified under the Cfa climate type and is characterised as a subtropical humid climate.

Based on the acquired data, the average maximum air temperature was calculated for the summer season and each month within the season. Subsequently, changes in T_{max} were examined over the multi-year study period, and their statistical significance was determined at the 0.05 level using the Student's *t*-test. In this study, the summer season was defined as the period from May to September.

Hot days were identified and analysed for all seasons. The direction and statistical significance of changes in the number of hot days were determined (at the 0.05 level) using the non-parametric Mann–Kendall test. A hot day was defined as a day with T_{max} >90th percentile for that specific day. Following this, based on the identified hot days, heatwaves were defined as sequences of at least three consecutive hot days. Similar definitions were used in other studies (Lhotka, Kyselý 2015, Tomczyk, Bednorz 2016). Subsequently, the occurrence of heatwaves was analysed across individual months and decades (the most recent 7-year period), and heatwaves were categorised by their duration.

To characterise biometeorological conditions, Humidex was utilised. This index considers two fundamental meteorological elements: air temperature and relative humidity (RH). It serves as a measure of perceived temperature, especially during hot days (Koźmiński, Michalska 2013). One drawback of this index is its exclusion of factors like solar radiation and wind speed, which can intensify or alleviate human thermal sensation. However, in situations where there is insufficient input data to calculate more advanced indicators, this simplicity of Humidex becomes its advantage. Humidex has found adoption in various global regions, e.g. Europe (Scoccimarro et al. 2017), the Czech Republic (Středová et al. 2015) and Greece (Giannopoulou et al. 2014).

The BioKlima 2.6 program (Błażejczyk, Błażejczyk 2006) was employed to calculate the index. Humidex is reported in °C and categorises thermal discomfort into five levels (Table 1).

The index is calculated based on the following formula:

$$\text{Humidex} = t + 0.5555 \times (\rho - 10),$$

where:
- t – air temperature in °C,
- ρ – vapour pressure of water in hPa.

Humidex calculations used approximations to express vapour pressure of water (ρ, hPa) by RH (RH, %) according to the following formula:

$$\rho = 6112 \times 10[(7.5t) / (237.7 + t)]\ RH / 100$$

where:
- t – air temperature in °C,
- RH – relative humidity in %.

In this part of the study, the Humidex index was calculated for each day which comprised heatwaves over the multi-year period at 12:00 UTC. This hour is commonly used in biometeorological research because it typically coincides with peak human activity during the day. Subsequently, the average Humidex index value was computed for each heatwave, and the thermal discomfort categories were determined based on the index values during heatwaves.

Table 1. Threshold values of Humidex (Koźmiński, Michalska 2013; http://www.rescuedynamics.ca/).

Humidex [°C]	Levels of thermo-humidity discomfort	Heat syndrome
20.0–29.9	Comfort	Fatigue possible with prolonged exposure and/or physical activity
30.0–39.9	Slight discomfort	Heat stroke, heat exhaustion and heat cramps possible with prolonged exposure and/or physical activity
40.0–45.9	Great discomfort	Heat cramps or heat exhaustion likely
46.0–54.9	Dangerous	Heat stroke possible with continued exposure and/or physical activity
≥55.0	Heat stroke imminent	Heat stroke imminent with continued exposure

Results

Maximum air temperature

For the period 1966–2022, the average T_{max} during the summer season was 22.0°C in Poznań and 29.1°C in Thessaloniki. Both stations exhibited considerable interannual variability (Fig. 2, Table 2) (standard deviation of 1.3°C and 1.1°C, respectively). In Poznań, the average T_{max} ranged from 19.3°C in 1980 to 25.2°C in 2018 during the study period. Similarly, in Thessaloniki, these values varied from 26.9°C in 2014 to 31.9°C in 2012. Until the end of the 20th century, both stations predominantly experienced seasons where the average T_{max} was lower than the multi-year average. In Poznań, 71% of seasons until 2000 had negative anomalies, whereas in subsequent years, this dropped to only 18%. In Thessaloniki, the percentage of seasons with negative anomalies was 77% until 2000 and 23% thereafter. The statistically significant research findings revealed an increasing trend in T_{max} during the summer season. In Poznań, this trend amounted to 0.41°C per decade, while in Thessaloniki, it was 0.37°C per decade.

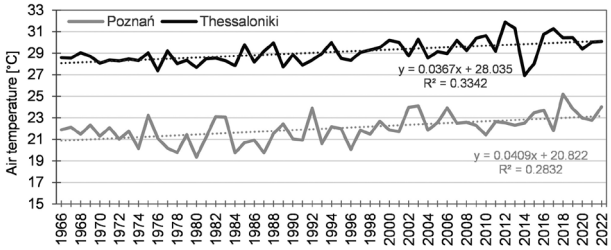

Fig. 2. Course of average T_{max} in the summer seasons in the period 1966–2022 in Poznań (Poland) and Thessaloniki (Greece).

In Poznań, during the summer season, the lowest average monthly T_{max} was recorded in September (19.1°C), while in Thessaloniki, it was recorded in May (24.9°C) (Table 2). As Greece is more prone to drought conditions than Poland due to precipitation deficiencies, the atmospheric cooling procedures delay in time towards the end of the summer, thus resulting in relatively higher temperatures in September in Thessaloniki. On the contrary, in Poznań, the average air temperatures in May and September are quite comparable, indicating that the summer heat stress in Poznań relaxes faster than in Thessaloniki. Conversely, the highest average T_{max} values in both stations were observed in July (24.5°C and 31.9°C, respectively). In Poznań, the lowest average monthly T_{max} during the study period occurred in May 1991 (14.6°C), while the highest occurred in July 2006 (30.7°C). Similarly, in Thessaloniki, the lowest average T_{max} was recorded in May, and the highest average T_{max} was recorded in July, specifically in different years: 1980 (21.8°C) and 2012 (36.0°C). Both stations exhibited a statistically significant increase in average monthly T_{max}, except for changes observed

Table 2. Characteristics of thermal conditions in the summer season in the period 1966–2022.

Month	T_{max}		Lowest average T_{max}		Highest average T_{max}	
	Average	Changes	Value	Year	Value	Year
	[°C]	[°C / Decade]	[°C]	[–]	[°C]	[–]
Poznań						
May	19.5	0.23*	14.6	1991	23.7	2018
June	22.7	0.51	18.9	1984	29.9	2019
July	24.5	0.46	19.9	1979	30.7	2006
August	24.2	0.51	20.4	1987	29.4	2015
September	19.1	0.34	14.7	1996	23.6	2016
Summer	22.0	0.41	19.3	1980	25.2	2018
Thessaloniki						
May	24.9	0.25	21.8	1980	28.1	2013
June	29.5	0.40	26.7	2015	32.6	2012
July	31.9	0.42	29.4	1969	36.0	2012
August	31.7	0.52	28.0	1976	34.9	2012
September	27.6	0.23	24.6	2014	31.1	1994
Summer	29.1	0.37	26.9	2014	31.9	2012

* Statistically insignificant change.

in May in Poznań. The highest increase was observed in June and August in Poznań (0.51°C per decade) and in August in Thessaloniki (0.52°C per decade).

Hot days and heatwaves

The 90th percentile value of T_{max} varied significantly between the analysed stations. In Poznań, it ranged from 20.7°C to 32.4°C, while in Thessaloniki, it ranged from 27.1°C to 36.6°C (Fig. 3). Both stations recorded their highest values around late July and early August. In Poznań, T_{max} >30°C (which corresponds to the 90th percentile) occurred on 26% of days from May to September. On the contrary, in Thessaloniki, such days occurred on 83% of days during the same period.

The average number of hot days was similar in both stations, averaging 13 days. In Poznań, there was one summer season (1980) when no hot days were recorded at all, which coincided with the coolest season observed (Fig. 4). Conversely, in Thessaloniki, such seasons were noted twice, i.e. in 1995 and 2014. The highest number of analysed hot days in Poznań occurred in 2018 (41 days), while in Thessaloniki, it was observed in 2012 (57 days). A clear increase in the frequency of hot days was observed in the 21st century. Until the end of the previous century, Poznań experienced one season with 20 hot days, while Thessaloniki had two seasons with 20 hot days.

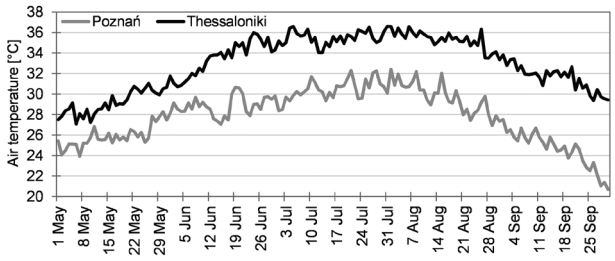

Fig. 3. The 90th percentile value of T_{max} in the summer seasons in the period 1966–2022.

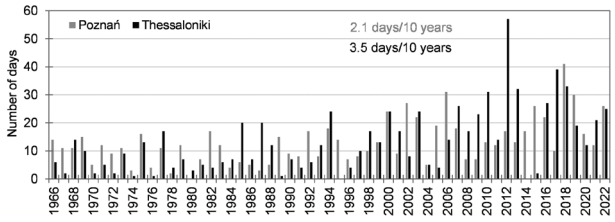

Fig. 4. Number of hot days in the period 1966–2022.

Since the beginning of the current century, the number of seasons with >20 hot days increased to 8 in Poznań and 11 in Thessaloniki. The statistically significant research findings revealed an increasing trend in the number of hot days, which amounted to 2.1 days per decade in Poznań and 3.5 days per decade in Thessaloniki.

During the study period, Poznań experienced 94 heatwaves that lasted for a total of 372 days. In Thessaloniki, 80 heatwaves lasted for a total of 326 days. Both stations exhibited a significant variability in the occurrence of heatwaves during the study period. In Poznań, the fewest heatwaves were observed in the period 1976–1985, with nine occurrences (Fig. 5). In this and the preceding decade (1966–1975), the cumulative duration of heatwaves was 37 days. In Thessaloniki, the fewest heatwaves were recorded in the period 1966–1975, with five occurrences. Similarly to Poznań, the shortest cumulative duration of heatwaves, totalling 20 days, was observed in the first and

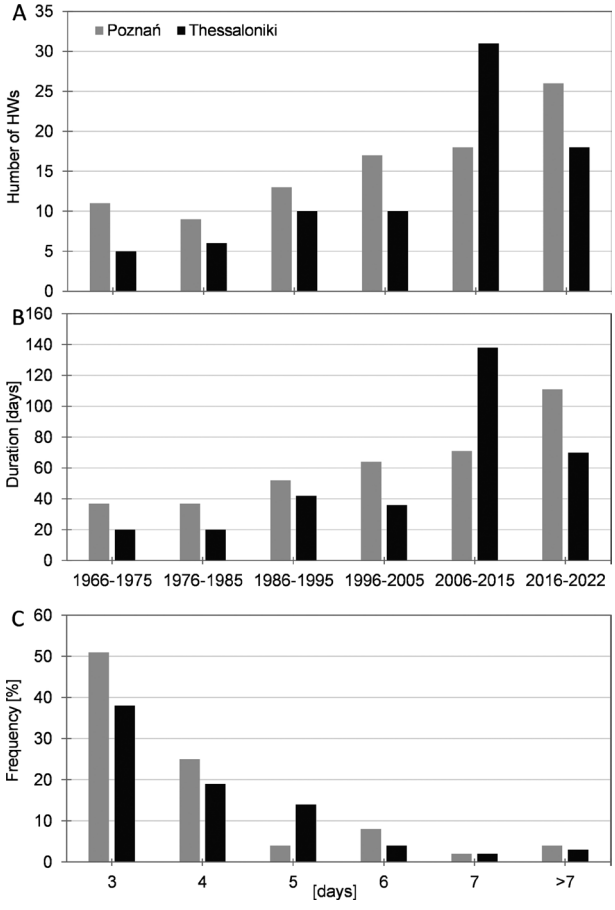

Fig. 5. Number of heatwaves (A), duration (B), and share of heatwaves by duration (C) in the period 1966–2022.

second decades of the analysed period. The highest number of heatwaves and the longest cumulative duration were recorded in Poznań during the last 7 years (2016–2022), with 26 heatwaves lasting for 111 days. A similar situation occurred in Thessaloniki during the years 2006–2015, where 31 heatwaves lasted for 138 days.

In both stations, the most frequently observed heatwaves were the shortest ones, lasting for 3 days (Fig. 5). In Poznań, these constituted 54% of all cases, while in Thessaloniki, they accounted for 48%. The next most common was 4-day heatwaves, comprising 27% and 24%, respectively. Additionally, in Thessaloniki, relatively frequent were 5-day heatwaves, making up 18% of all cases. The longest heatwave in Poznań lasted for 11 days, occurring from 23 July to 2 August 1994. Similarly, a 10-day heatwave was observed for 10 days from 25 May to 3 June 2018. In Thessaloniki, the longest heatwave also lasted for 11 days, recorded from 8 August to 18 August 2010. Furthermore, long heatwaves (lasting for at least 1 week) were also noted in 1987, 2012 and 2017.

In Poznań, the average T_{max} during all heatwaves was 30.3°C, while in Thessaloniki, it was 35.0°C (Table 3). In the first station, the average T_{max} during individual heatwaves ranged from 25.5°C (24–27 September 2006) to 35.5°C (19–21 July 2022). Meanwhile, in the second station, these values varied from 29.1°C (4–7 May 2018) to 40.0°C (22–25 July 2007). T_{max} values of individual days with heatwaves were significantly higher than the average values. In Poznań, the highest T_{max} recorded was 38.0°C on 26 June 2019, while in Thessaloniki it reached 43.3°C on 25 July 2007. During the longest heatwave in Poznań, the average T_{max} was 33.9°C, and in Thessaloniki it was 37.3°C.

In Poznań, the average Humidex value during heatwaves at 12:00 UTC was 30.8°C, while in Thessaloniki, it was 38.7°C (Table 4). In the first station, the average Humidex value for individual heatwaves ranged from 23.4°C (18–20 May 2017) to 38.2°C (15–17 July 2007). Meanwhile, in the second station, the range was broader from 29.1°C (8–10 May 2007) to 47.8°C (5–8 July 1988). The highest Humidex values during the days of heatwaves were 39.8°C (26 June 2019) in Poznań and 53.4°C (23 July 1987) in Thessaloniki. During the longest heatwave in Poznań, the average

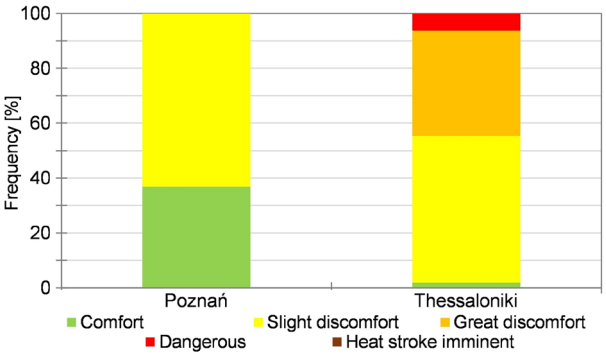

Fig. 6. Frequency of occurrence of particular Humidex values during heatwaves in the period 1966–2022.

Table 3. Characteristics of thermal conditions during heatwaves.

Parameter	Poznań		Thessaloniki	
	Average [°C]	Date	Average [°C]	Date
Average T_{max}	30.3	–	35.0	–
Lowest average T_{max}	25.5	24–27 September 2006	29.1	4–7 May 2018
Highest average T_{max}	35.5	19–21 July 2022	40.0	22–25 July 2007
Highest T_{max}	38.0	26 June 2019	43.3	25 July 2007
Average T_{max} – longest heatwaves	33.9	23 July–2 August 1994	37.3	8–18 August 2010

Table 4. Characteristics of biometeorological conditions during heatwaves.

Parameter	Poznań		Thessaloniki	
	Average [°C]	Date	Average [°C]	Date
Average Humidex	30.8	–	38.7	–
Lowest average Humidex	23.4	18–20 May 2017	29.1	8–10 May 2007
Highest average Humidex	38.2	15–17 July 2007	47.8	5–8 July 1988
Highest Humidex	39.8	26 June 2019	53.4	23 July 1987
Average Humidex – longest heatwaves	35.0	23 July–2 August 1994	43.5	8–18 August 2010

Humidex value was 35.0°C, and in Thessaloniki, it was 43.5°C.

In Poznań, during heatwaves, a slight thermo-humidity discomfort accounted for 61.8% of all days, while comfortable conditions comprised 36.0% (Fig. 6). The remaining 2.2% of days had values below the lower limit of comfort conditions. In Thessaloniki, the biometeorological conditions varied more and were challenging. Most frequently observed were days with slight thermo-humidity discomfort, making up 53.5% of all days. Next were days with significant thermo-humidity discomfort (38.4% of all days), days with dangerous discomfort (6.3% of all days) and days with comfortable conditions (1.9% of all days).

Discussion

This study revealed a significant variation in thermal conditions over the examined period. Both stations showed a statistically significant increase in average T_{max}, although changes were more intense in Poznań. As demonstrated by Ustrnul et al. (2021), the largest changes in maximum air temperature in Poland from 1951 to 2018 were observed in spring and summer, although the changes in summer were slightly smaller (0.40°C/10 years), with the most intense changes occurring in southern Poland. Zoumakis et al. (2012) also observed ongoing summer warming in Thessaloniki. A similar trend was found in Athens, where the rate of change for maximum air temperature was 0.56°C/10 years, although it was lower than the rate for minimum air temperature (Founda et al. 2022). An increase in average T_{max} was noted in each of the analysed months. The weakest changes were recorded in May at both stations, which were not statistically significant in Poznań. Conversely, the most intense warming occurred in August at both stations as well as in June in Poznań.

The progressive warming has led to an increasing frequency of hot days. This study showed a statistically significant increase in the number of analysed days at both stations, with changes being more intense in Thessaloniki. These findings are consistent with previous studies, indicating an increase in the number of heatwaves and their duration in many regions of Europe (Tomczyk et al. 2019b). Using Athens as an example and considering the occurrence of heatwaves from the beginning of the 20th century to 2020, Founda et al. (2022) demonstrated that the most heatwave cases and the longest durations were observed in the last 30 years (1991–2020). In the coming decades, further increases in the number of hot days in Poland are expected (Tomczyk et al. 2022). The most intense changes are forecasted for the central and southern parts of the country, where by the end of the 21st century, an increase of several days compared to the reference period can be expected. A similar situation will develop in southern Europe. It is estimated that by 2050, the frequency of hot days will also increase, and Thessaloniki will experience up to 20 additional consecutive hot days and nearly an extra month of night-time temperatures >20°C, leading to increased discomfort and health problems for the local population (Giannakopoulos et al. 2011).

Comparing the occurrence of hot days and heatwaves at both stations, it can be observed that in Thessaloniki, single instances or 2-day sequences of hot days were more frequent, resulting in a smaller number of heatwaves and shorter durations compared to Poznań. In this station, the highest number of heatwaves and the longest cumulative duration were recorded in the last 7-year period included in the analysis, while in Thessaloniki, this occurred between 2006 and 2015. In both stations, the longest cumulative duration of heatwaves was observed during the hottest seasons, specifically in Poznań in 2018 and Thessaloniki in 2012. In many regions of Central Europe, the year 2018 stood out compared to the last few decades (Twardosz 2019, Tomczyk, Bednorz 2020) and even compared to the period since the second half of the 19th century (Hoy et al. 2020). In that year, positive air temperature anomalies persisted in Poland in January and from April to December, with the highest anomalies occurring in April (Tomczyk, Bednorz 2020). According to Hoy et al. (2020), the year 2012 was notable in many regions of southeastern Europe for the number of hot days and tropical nights compared to the multi-year period. Founda et al. (2022) demonstrated a fivefold increase in the number of heatwaves and heatwave days in Athens after 1990 compared to their average values in the previous period from 1900 to 1990.

During the study period, 3-day heatwaves were the most frequently recorded, followed by

4-day and longer heatwaves. Both in Poznań and Thessaloniki, the longest heatwave lasted for 11 days. In Poznań, this occurred in 1994, and in Thessaloniki, it occurred in 2010. As shown in numerous studies on Poland, the heatwave observed in 1994, along with the heatwave observed in 2015, are considered examples of extreme heatwaves that have occurred in this part of Europe (Krzyżewska, Dyer 2018, Wibig 2018, Tomczyk et al. 2019a, Tomczyk, Bednorz 2023). The heatwave observed in 1994 was recorded over a significant area of Central Europe, including Germany, the Czech Republic and Ukraine (Shevchenko et al. 2014, 2022, Lhotka, Kyselý 2015). The year 2012 significantly deviated from average conditions in Greece, including Athens, where several heatwave episodes were recorded (Founda, Santamouris 2017).

The studies revealed a significant variation in biometeorological conditions during heatwaves in the analysed stations. In Poznań, only days with slight thermo-humidity discomfort and comfortable were recorded. In contrast, in Thessaloniki, days with slight and then significant thermo-humidity discomfort were most frequently noted, along with days with dangerous discomfort and occasional comfortable days. Previous studies have shown that the western and southwestern regions of Poland experienced the most burdensome biometeorological conditions across the country, both in terms of the number of heatwaves (Krzyżewska et al. 2019, Tomczyk, Bednorz 2023) and the frequency of days with heat stress (Krzyżewska et al. 2019, Owczarek 2019, Tomczyk, Owczarek 2020, Tomczyk et al. 2023). Using Poznań as an example, Półrolniczak et al. (2024) demonstrated that biometeorological conditions during heatwaves largely depend on land use. The authors indicated that the most burdensome conditions were recorded in the city centre and in areas with a high proportion of artificial surfaces and a low proportion of natural surfaces, which mitigate thermal conditions.

Conclusions

In the analysed years, a significant variation in thermal conditions was demonstrated in the examined period in both stations. Summer seasons with average Tmax below the long-term average were primarily noted until the end of the 20th century, while from the 21st century, seasons with positive anomalies dominated. In Poznań, the highest anomalies were recorded in 2018, and in Thessaloniki they were recorded in 2012.

The progressive warming has led to an increasing frequency of hot days. Similar to Tmax, the 21st-century seasons also stood out in terms of the number of hot days compared to the analysed multi-decade period.

During the study period, an increase in the number and duration of heatwaves was observed in both Poznań and Thessaloniki. In both stations, heatwaves were least frequent during the first two decades of the analysed period, and most frequently in the 21st century.

The studies revealed a significant variation in biometeorological conditions during heatwaves in the analysed stations. Heatwaves in Poznań were characterised by less burdensome conditions compared to those in Thessaloniki. In both stations, further climate warming will cause deterioration of biometeorological conditions during heatwaves.

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Authors' contribution

AMT: conceptualisation, data curation, formal analysis, investigation, project administration, writing – original draft, writing – review and editing and correspondence with editor. EK: conceptualisation, data curation, writing – original draft and writing – review and editing.

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