# MULTI-ANNUAL VARIATIONS IN THE HEAT LOAD OF POLAND

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Abstract: This study analyses multi-annual variations in biothermal conditions recorded at three weather stations in Kołobrzeg, Poznań and Kraków from 1951 to 2020 at 12:00 UTC based on the Universal Thermal Climate Index (UTCI). The analyses covered the median, lower and upper quartiles and average minimum and maximum UTCIs for respective months. In addition, the study determined the frequency of occurrence of various types of thermal stress in respective months. A significant rise in the annual and monthly trends was observed, while the highest increase was noted in winter and early spring (from January to May).

Keywords: biothermal conditions, multi-annual variations, UTCI, Central Europe, Poland

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## Introduction

Research on climate change in Central Europe points to an increasing trend in air temperature from the mid-19th century (Obrębska-Starklowa 1997, Anders et al. 2009, IPCC 2018). In Poland, since the 1950s, its mean rate of increase has exceeded 0.2°C over 10 years, and changes are the most intense at the end of winter and in early spring (Michalska 2011, Wójcik, Miętus 2014). Studies on the variations in air temperature from 1951 to 2018 carried out in Poland around noon show a regular increase in temperature at that time from 1.99°C to 2.45°C depending on the region (Okoniewska 2019). The recorded increase in air temperature does affect the perception of climatic conditions, and the nature of changes in these conditions around 12:00 UTC is significant as this is the time of day when the level of outdoor activity is the highest. Thus, an average person will most strongly perceive changes occurring at such time.

Currently, the Universal Thermal Climate Index (UTCI) is increasingly used in research concerning biothermal conditions, as it objectively assesses how the human body responds to variations in the perceptible conditions (Bröde et al. 2013). The index is applied in the evaluation of the perceptible climate conditions of entire regions (e.g., Nemeth 2011, Mąkosza 2013, Błażejczyk, Błażejczyk 2014, Bleta et al. 2014, Półrolniczak et al. 2016) and single cities (Chabior 2011, Lindner 2011, Nidzgórska-Lencewicz, Mąkosza 2013, Błażejczyk et al. 2014, Nidzgórska-Lencewicz 2015). As demonstrated by Di Napoli et al. (2018), the UTCI can capture thermal variations in the bioclimate of Europe and identify links between these variations and their impact on human health.

In research on the variations in the biothermal conditions, Owczarek used the UTCI for



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analysing perceptible climate changes in Gdynia from 1951 to 2005 (Owczarek 2007). Before the index was designed, variations in the biothermal conditions of Poland, and specifically of Kraków, were investigated by Błażejczyk et al. (2003) based on the subjective temperature index (STI) and the index of predicted insulation of clothing (Iclp), and their findings relying on studies covering the period from 1901 to 2000 showed perceptible climate trends, with atmospheric circulation playing a leading role.

By contrast, Papiernik (2004) analysed the scale and patterns of perceptible climate change in Łódź in the second half of the 20th century, using, for instance, the Wind Chill Index (WCI) and identified the most and the least favourable decades in the period under review. In turn, Mąkosza and Michalska (2010) applied the STI in their assessment of biothermal conditions in northwestern Poland. An attempt at analysing the variations in biothermal conditions, although on a smaller scale in space and time, was the estimation of biothermal conditions in the summer season in Kołobrzeg in the second half of the 20th century (Bąkowska, Błażejczyk 2007). Okoniewska and Więcław (2013) presented a more comprehensive description of such variations for all of Poland from 1951 to 2000, using the UTCI. The results implying a significant increase in thermal stress until the end of the 20th century indicate the need for further study covering the first 20 years of the 21st century. Significant studies on spatial and temporal variations in the biothermal conditions of Poland from 1951 to 2018 were conducted by Kuchcik et al. (2020), who noted the highest increase in the minimum UTCI and a decrease in cold stress from November to March, in particular in northeastern and eastern Poland and at the foot of the Carpathian Mountains. The study of the long-term variability of biothermal conditions in Poland was undertaken by Kuchcik et al. (2021a) and Błażejczyk, Twardosz (2023).

Since climate change is a major problem of present-day climatology and perceptible climate is undeniably dependent on the progressing rise in temperature, we decided to examine variations in biothermal conditions in Central Europe. To illustrate temporal and spatial variations, the analysis covered cities situated in the north–south transect. Analyses were carried out from 1951 to 2020 at 12:00 UTC to ensure reference of the examined variations to the time when people most often stay outdoors. In particular, the analysis covered existing trends in the index value itself and the frequency of thermal stress of different types.

## Material and methods

Data from weather stations, collected at 12:00 UTC, including air temperature (°C), relative air humidity (%), wind speed ($m \cdot s^{-1}$), cloud cover (oktas converted into%) and information about the weather station's latitude were used for the analysis. Data were obtained from three stations: Kołobrzeg, Poznań and Kraków referred to the years from 1951 to 2020. The data were derived from the database of the Institute of Meteorology and Water Management. Meteorological stations in Kołobrzeg and Kraków changed their locations during the 70 years studied. Homogeneity

Table 1. Thermal stress categories based on the Universal Thermal Climate Index (Błażejczyk et al. 2010).

| UTCI (°C) | Stress category and recommendations for protection |
|---|---|
| > 46.0 | extreme heat stress, periodical cooling and drinking > $0.5\ l \cdot h^{-1}$ necessary, stay without activity |
| 38.1 to 46.0 | very strong heat stress, periodical use of air conditioning or shaded sites and drinking > $0.5\ l \cdot h^{-1}$ necessary, reduce activity |
| 32.1 to 38.0 | strong heat stress, drinking> $0.25\ l \cdot h^{-1}$ necessary, use shade places and reduce activity |
| 26.1 to 32.0 | moderate heat stress, drinking> $0.25\ l \cdot h^{-1}$ necessary |
| 9.1 to 26.0 | no thermal stress, physiological thermoregulation sufficient to keep comfort |
| 0.1 to 9.0 | slight cold stress, use gloves and cap |
| −13.0 to 0.0 | moderate cold stress, increase activity, protect extremities and face against cooling |
| −27.0 to −12.9 | strong cold stress, strongly increase activity, protect face and extremities, use better insulated clothing |
| −40.0 to −26.9 | very strong cold stress, strongly increase activity, protect face and extremities, use better insulated clothing, reduce stay outdoor |
| < -40.0 | extreme cold stress, stay in door or use heavy, wind protected clothing |

of data during the periods of station relocation was tested using Kruskal–Wallis and Student's *t*-tests. The results showed homogeneity in the data, except for wind. Changes in wind speed resulting from the relocation of the anemometer and the location of the station did not affect the continuity of the UTCI. The values of this index are most influenced by air temperature (as proven by, among others, Bröde et al. 2012, Błażejczyk, Twardosz 2023). Based on these data, using BioKlima ver 2.6 software, the UTCI (°C) was calculated and then averaged for respective years and months.

The UTCI (in °C) is defined as the equivalent air temperature at which, in reference conditions, human's vital physiological parameters assume values identical to those of the real environment. It is based on an analysis of the human body's heat balance using the Fiala multi-node heat transfer model (Błażejczyk et al. 2010). It is measured by objective changes in human physiological parameters taking place under the influence of atmospheric conditions. Respective values of this index correspond to different categories of thermal stress (Table 1).

The choice of weather stations was dictated by access to homogeneous data series and an attempt at reflecting variations in biothermal conditions occurring in the north–south transect, on the one hand, to demonstrate changes depending on whether the climate is oceanic or continental and, on the other hand, to examine the variations depending on the distance from the sea (Fig. 1).

Fig. 1. Location of stations in Poland used in the study.

Kołobrzeg represents the Southern Baltic Coastlands (54°10′N, 15°34′E, hs 5 m a.s.l.). It is situated on the Koszalin Coastland (Koszalin Coast mesoregion) (Solon et al. 2018) at the outlet of the Parsęta River to the Baltic Sea and features a mean annual air temperature of 8.1°C. According to the bioclimate-based classification of regions, it is a seaside region most affected by the impact of the Baltic, where the bioclimate is highly stimulating (Kozłowska-Szczęsna et al. 2002). The metering station in Kołobrzeg is located between the city and the health resort, surrounded by low-rise, dense single-family buildings. In 1971, the station was moved, but this did not affect the uniformity of the measurement series.

Poznań is situated in the Poznań Lakeland (52°25′N, 16°55′E, hs 86 m a.s.l.), forming part of the Greater Poland Lakeland with scarcely varied terrain relief (Solon et al. 2018). The mean air temperature in Poznań is 9.0°C. The city is situated in the central bioclimatic region featuring perceptible climate conditions typical of Poland, with a relatively small number of days that are onerous to humans (Kozłowska-Szczęsna et al. 1997). The weather station is located within the Poznań-Ławica airport's premises on the city's western outskirts. The meteorological garden is surrounded by flat grounds free of any natural and artificial obstacles.

Kraków is the main city of the Carpathian Foreland (50°03′N, 19°57′E, hs 220 m a.s.l.), located about 600 km away from the Baltic Sea. The mean annual air temperature is 8.3°C. Kraków is situated in the southeastern bioclimate region – warm and featuring increased intensity of thermal stimuli. The weather station mentioned in this article is located about 2 km away from the city centre on the left-bank alluvial terrace of the Vistula River. The station is immediately surrounded by a park, followed by typical urban buildings built along the streets with heavy motor traffic (Piotrowicz et al. 2011). In the analysed period, there were some changes in the station's surroundings, reflected in the expansion of infrastructure and increased urbanisation around the station. The number of inhabitants of Kraków has also changed and in 1951, it was approximately 355.000, while in 2020, it was 779.966 (BDL 2024). In 1958, the station was moved, which in particular affected the discontinuity of the wind series. However, the analyses performed showed that the change of location did not significantly affect the UTCI index values.

Data readings at 12:00 UTC for the previously mentioned stations were used for calculating the median, lower and upper quartiles and the average minimum and maximum UTCIs for respective months. To illustrate the average thermal stress at noon in the examined cities, the frequency of various types of thermal stress was calculated for respective months. In addition, the multi-annual curves of the previously mentioned statistics with the course of the trend line were shown. Variations in biothermal conditions based on the UTCI were analysed using the linear regression equation. Linear trend values of the index calculated from the equation using the parametric Student's *t*-test were examined for statistical significance of 0.05. Analyses were carried out for the whole year and respective months. To show variations in respective classes of thermal stress, linear regression analysis was also applied, but the number of stress classes was reduced by combining selected stress classes into a single category. As a result, five classes of thermal stress were examined: 1 – extreme, very strong and strong cold stress, 2 – moderate and slight cold stress, 3 – no thermal stress, 4 – moderate heat stress and 5 – strong and very strong heat stress.

## Results

At 12:00 UTC in the analysed stations, the UTCI median ranged from −12.9°C recorded in January in Poznań to 25.3°C in July in Kraków, which implies the average range of variation from moderate cold stress to moderate heat stress. Due to its location on the Baltic Sea, Kołobrzeg featured a small increase in the value of the index in summer, when the average maximum at noon reached 27.8°C in July. However, the decrease was also not big in winter, with an average minimum of −16.3°C in January. Poznań was a station with average biothermal conditions where the annual minimum and maximum values around noon were −22.6°C (January) and 29.9°C (July), respectively. By contrast, Kraków was the warmest station, where the UTCI ranged from −20.9°C in February to 32.7°C in June. The upper quartile values exceeding 20.0°C from May to September, including 26.0°C in July and August, and ranging from −1.2°C in January to 1.2°C in February also testify that Kraków is a station with an increased UTCI. The corresponding values measured in Kołobrzeg were only 21.9°C in summer (August), and ranged from −7.0°C to −4.3°C in winter. In contrast, in Poznań, the highest upper quartile in summer was 22.7°C (July and August), and in winter, it ranged from −9.6°C to −7.0°C (Fig. 2).

The predominant thermal stress at noon from November until March was moderate cold stress. It occurred with a frequency ranging from 49.3% to 67.2% in Kołobrzeg, from 49.4% to 52.9% in Poznań and from 30.6% to 50.0% in Kraków – most often in December. At that time, strong and very strong cold stress appeared more rarely and extreme cold stress was noted sporadically. During the year's cold season, the frequency of conditions featuring no thermal stress was lower than 10%. Such conditions were noted, in particular in Kraków.

The absence of thermal stress at 12:00 UTC was predominant in the warm half of the year – from April until October, whereas most often, in 60.0% up to 80.4% of cases, it was recorded in May and

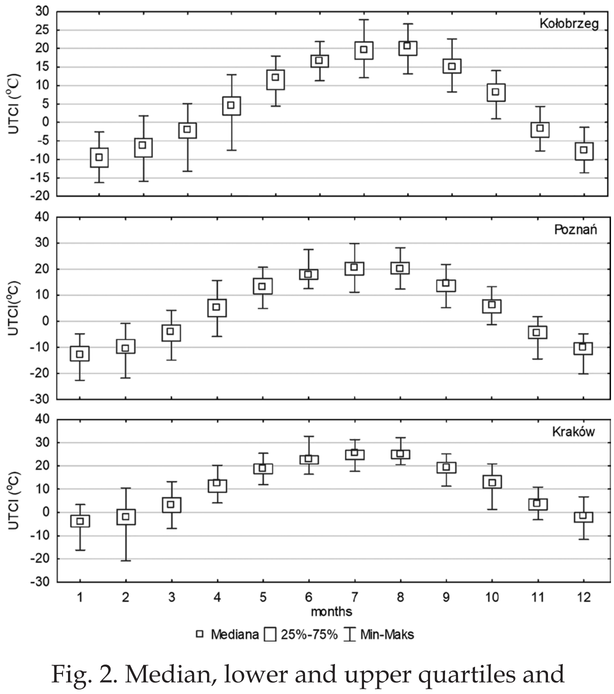


Fig. 2. Median, lower and upper quartiles and average minimum and maximum Universal Thermal Climate Index at 12:00 UTC in Kołobrzeg, Poznań and Kraków (1951–2020).

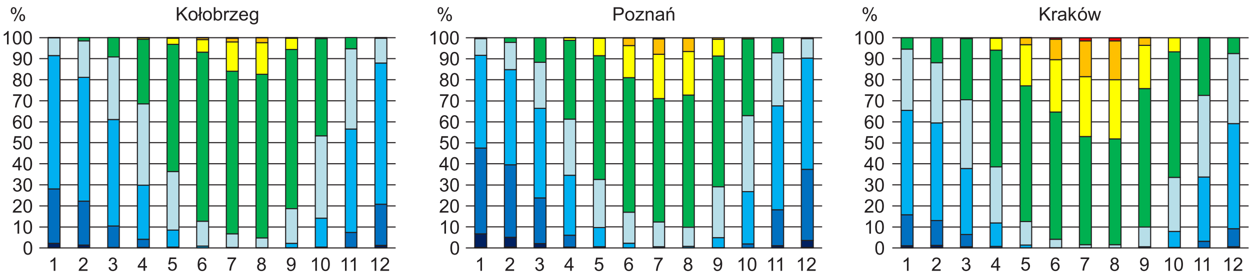


Fig. 3. Frequency of thermal stress based on the Universal Thermal Climate Index at 12:00 UTC in successive months recorded in Kołobrzeg, Poznań and Kraków (1951–2020). Legend: <−40 (extreme cold stress) −40 to −27 (very cold stress) −27 to −13 (strong cold stress)−13.0 to 0.0 (moderate cold stress)0.0 to 9.0 (slight cold stress) 9.0 to 26.0 (no thermal stress) 26.0 to 32.0 (moderate heat stress) 32.0 to 38.0 (strong heat stress) 38.0 to 46.0 (very strong heat stress).

June. In July and August, much more frequently than in other months, moderate, strong and very strong heat stress was observed in exceptional situations. The latter category of thermal stress was recorded notably often in Kraków. By contrast, slight cold stress was reported at that time for Poznań and Kołobrzeg more often than for Kraków (Fig. 3).

The annual and monthly values of UTCI trends around noon imply a significant increase in value. The mean increases from 1951 to 2020 ranged from 4.4°C in Poznań and Kraków (corresponding to 0.6°C in 10 years) to 5.2°C in Kołobrzeg (0.7°C in 10 years). The trends were significant at 0.05. Drastic changes were noted in winter and early spring when the value of trends exceeded 4.0°C (except in January in Kraków), where the maximum of 7.6°C was recorded in April in Poznań and 7.3°C and 7.0°C in March in Kołobrzeg and Kraków, respectively. In summer (July and August), the value of trends was slightly lower but still above zero and statistically significant. At that time, they were from 4.3°C in Kołobrzeg to 5.2°C in Kołobrzeg and Poznań. An insignificant increase in the value of the index was recorded in Poznań and Kraków in September and October and, in addition, in Poznań in June, whereas the lowest increase in Kołobrzeg and Poznań was noted in October and in Kraków in September (Table 2).

Table 2. Annual and monthly values making the multi-annual trend (1951–2020) and 10-year Universal Thermal Climate Index measured at 12:00 UTC in Kołobrzeg, Poznań and Kraków. Values with a statistical significance level of 0.05 are marked in bold type.

| City | Kołobrzeg | | Poznań | | Kraków | |
|---|---|---|---|---|---|---|
| Month | 1951–2020 | per 10 years | 1951–2020 | per 10 years | 1951–2020 | per 10 years |
| 1 | **5.4** | 0.8 | **4.8** | 0.7 | **3.6** | 0.5 |
| 2 | **6.6** | 0.9 | **5.3** | 0.8 | **6.8** | 1.0 |
| 3 | **7.3** | 1.0 | **6.6** | 0.9 | **7.0** | 1.0 |
| 4 | **6.1** | 0.9 | **7.6** | 1.1 | **5.9** | 0.8 |
| 5 | **5.8** | 0.8 | **5.1** | 0.7 | **5.3** | 0.8 |
| 6 | **3.9** | 0.6 | 2.2 | 0.3 | **3.9** | 0.6 |
| 7 | **4.3** | 0.6 | **4.7** | 0.7 | **4.5** | 0.6 |
| 8 | **5.2** | 0.7 | **5.2** | 0.7 | **4.8** | 0.7 |
| 9 | **4.0** | 0.6 | 2.1 | 0.3 | 1.9 | 0.3 |
| 10 | **3.5** | 0.5 | 1.6 | 0.2 | 2.5 | 0.4 |
| 11 | **5.6** | 0.8 | **4.4** | 0.6 | **3.8** | 0.5 |
| 12 | **4.3** | 0.6 | **3.2** | 0.5 | **2.8** | 0.4 |
| year | **5.2** | 0.7 | **4.4** | 0.6 | **4.4** | 0.6 |

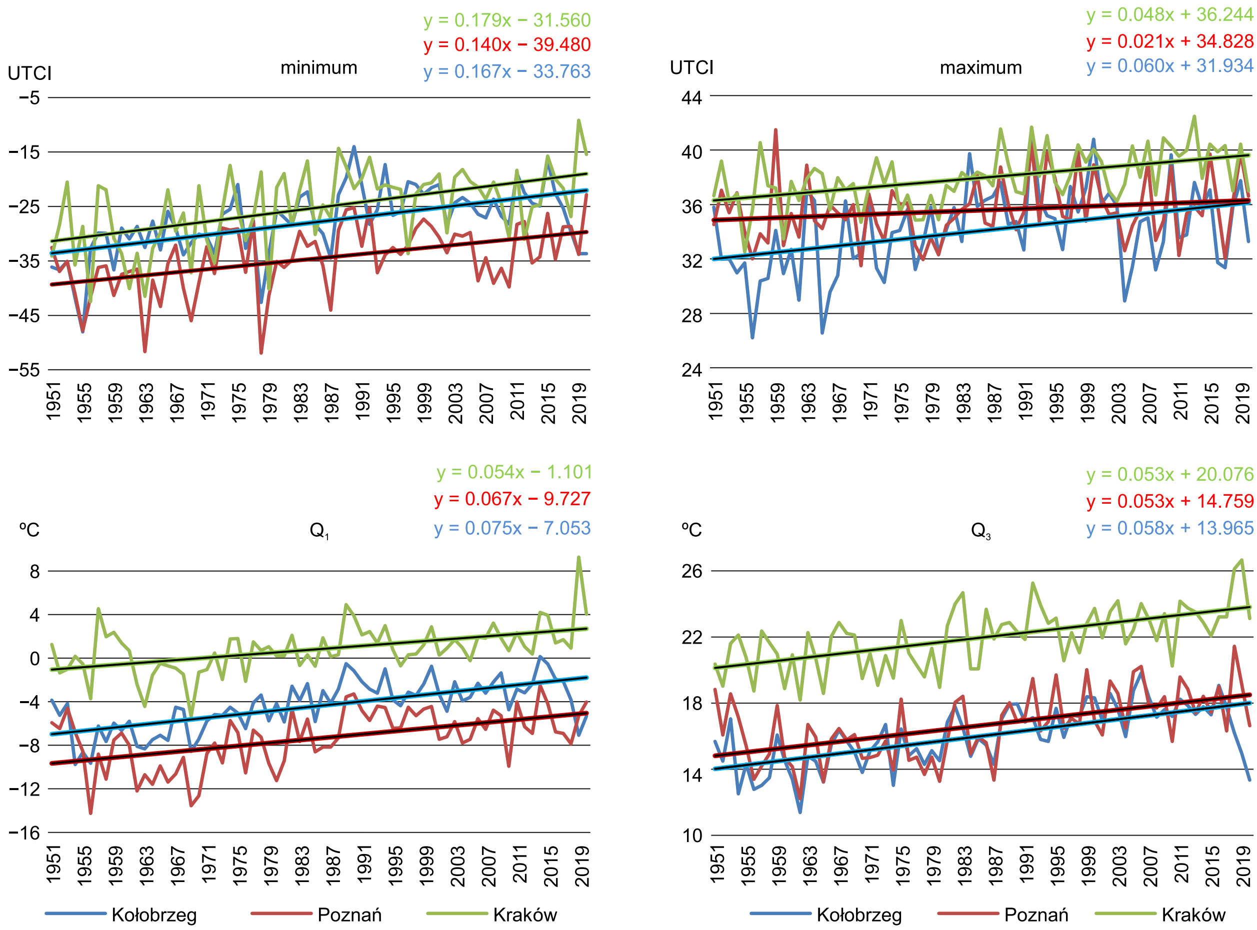


Fig. 4. Multi-annual curve of the minimum and maximum values, lower quartile ($Q_1$) and upper quartile ($Q_3$) and the trend line of the Universal Thermal Climate Index at 12:00 UTC in Kołobrzeg, Poznań and Kraków (1951–2020).

The increase in the UTCI at 12:00 UTC from 1951 to 2020 was corroborated by the analysis of the curves and trend lines of minimum and maximum values and of the lower and upper quartiles of the UTCI (Fig. 4). In particular, the increase in minimum values is well-marked.

Analyses of the frequency of occurrence of respective categories of thermal stress point to a significant reduction in the most extreme thermal stress referring to cold (extreme, strong and very strong cold stress) and a rise in the categories referring to the sensitivity of heat – mostly strong, very strong and moderate heat stress. Extreme sensitivity to cold decreased the most in Poznań and Kołobrzeg, while an increase in the perception of strong and very strong heat stress was most strongly marked in Kraków. Thermoneutral conditions characterised by the absence of heat stress insignificantly increased in Kołobrzeg and Poznań (Fig. 5).

The annual and monthly linear trend values for the analysed categories of thermal stress corroborate the decline in the perception of cold stress, but the decline in cold stress that was statistically significant over most of the months was most clearly marked. The highest decline was noted from January to March, particularly in February in Kołobrzeg, when the value of the trend was −33.4°C. The lowest statistically insignificant decline was observed in October. For moderate heat stress, the biggest increase in Kołobrzeg and Poznań occurred in July and August and in Kraków in June. The values of strong and very strong heat stress trend also went up from June to August, and it reached the maximum amounting to 20.3°C in August in Kraków. In terms of conditions featuring no thermal stress in the summer season (from June to August), a decline in such conditions was most likely because the heat stress frequency increased (Table 3).

Table 3. Annual and monthly linear trend values recorded at 12:00 UTC for the frequency of respective types of thermal stress in Kołobrzeg, Poznań and Kraków (1951–2020). Values with a statistical significance level 0.05 are marked in bold type.

| Month | Extreme, very strong and strong cold stress | Moderate and slight cold stress | No thermal stress | Moderate heat stress | Strong and very strong heat stress |
|---|---|---|---|---|---|
| Kołobrzeg | | | | | |
| 1 | **−30.7** | **30.9** | 2 cases | – | – |
| 2 | **−33.4** | **32.3** | 1.1 | – | – |
| 3 | **−27.0** | **21.9** | 5.2 | – | – |
| 4 | **−8.4** | **−14.5** | **22.3** | 0.4 | 1 case |
| 5 | **−1.1** | **−29.1** | **26.6** | **3.3** | 0.3 |
| 6 | – | **−12.8** | 5.8 | **5.3** | **1.7** |
| 7 | – | **−6.7** | **−11.8** | **15.5** | **2.9** |
| 8 | – | **−11.3** | −7.2 | **14.6** | **3.9** |
| 9 | 3 cases | **−17.4** | **13.7** | 4.4 | −0.4 |
| 10 | −0.6 | **−17.6** | **18.7** | −0.5 | – |
| 11 | **−14.4** | **9.2** | **5.2** | – | – |
| 12 | **−18.3** | **18.7** | −0.4 | – | – |
| year | **−11.1** | 0.1 | **6.5** | **3.6** | **0.8** |
| Poznań | | | | | |
| 1 | **−26.4** | **26.0** | 0.4 | – | – |
| 2 | **−28.8** | **28.3** | 0.4 | – | – |
| 3 | **−29.8** | **24.1** | 5.8 | – | – |
| 4 | **−12.3** | −9.8 | **21.4** | 0.8 | 1 case |
| 5 | **−1.3** | **−19.5** | **16.9** | 3.9 | 0.2 |
| 6 | – | **−9.1** | 5.2 | −1.3 | **5.3** |
| 7 | – | **−12.7** | −1.3 | 8.0 | 6.0 |
| 8 | – | **−14.3** | −4.1 | **13.9** | 4.5 |
| 9 | 1 case | −11.6 | **13.0** | −0.7 | −0.6 |
| 10 | −1.4 | 0.9 | 0.7 | −0.3 | – |
| 11 | **−13.9** | 10.5 | 3.4 | – | – |
| 12 | **−20.9** | **20.9** | 0.0 | – | – |
| year | **−11.2** | 2.7 | **5.1** | **2.1** | **1.3** |
| Kraków | | | | | |
| 1 | **−13.8** | **11.5** | 2.3 | – | – |
| 2 | **−21.9** | **12.5** | 9.5 | – | – |
| 3 | **−17.0** | 3.8 | 13.4 | −0.2 | – |
| 4 | **−1.8** | **−20.1** | **17.6** | 4.0 | 0.4 |
| 5 | – | **−20.1** | 5.2 | **11.4** | 3.5 |
| 6 | – | **−7.9** | −10.6 | 9.0 | **9.5** |
| 7 | – | **−3.9** | **−19.1** | **7.2** | **15.8** |
| 8 | – | **−2.4** | **−22.8** | 4.9 | **20.3** |
| 9 | – | **−7.9** | 2.5 | 6.4 | −1.0 |
| 10 | −0.6 | −5.8 | 0.5 | 6.0 | – |
| 11 | **−4.5** | −7.7 | **12.3** | 1 case | – |
| 12 | **−9.8** | 5.6 | 4.2 | – | – |
| year | **−5.7** | **−3.6** | 1.1 | **4.1** | **4.1** |

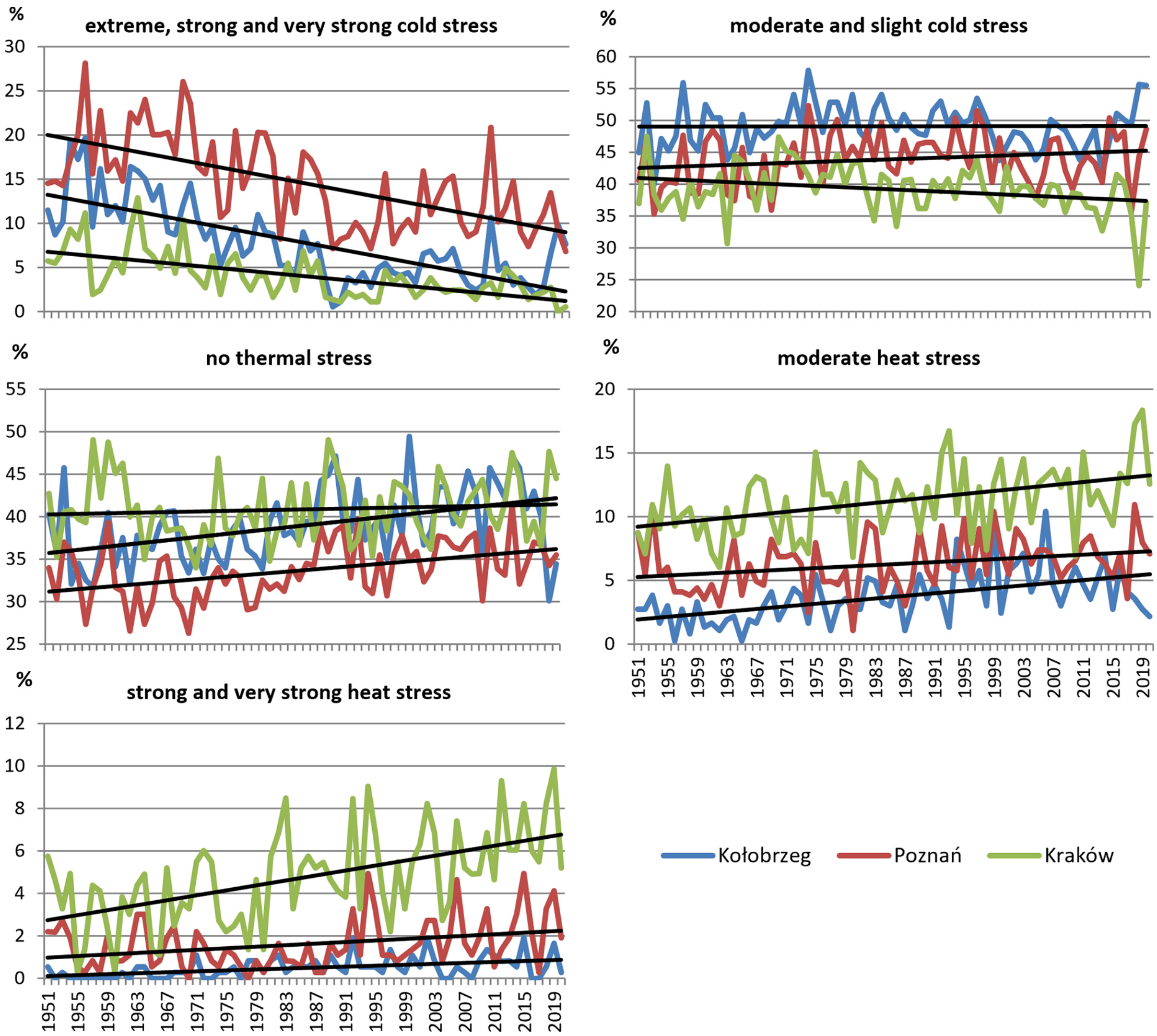


Fig. 5. Multi-annual thermal stress curve at 12:00 UTC including trend line, based on the Universal Thermal Climate Index in Kołobrzeg, Poznań and Kraków (1951–2020).

## Discussion

Variations in thermal stress from 1951 to 2020, on average, ranged from moderate cold stress to moderate heat stress, but the heat stress was definitely stronger in Kraków. The studies found a significant increase in the UTCI at all three stations from 1951 to 2020, which implies an increase in thermal stress intensity. The increase in the intensity of heat stress, especially in the last decades of the 20th century for Kraków, was demonstrated by the authors of the study from 2023 (Błażejczyk, Twardosz 2023), who stated that in Kraków, the annual UTCI values increased by 0.27°/10 years over the entire period. The authors of this article also refer to the work of Kuchcik et al. (2021a) and state that in the period 1951–2018, the trend of UTCI changes ranged from 0.04°C/10 years on the Polish Baltic coast to approximately 0.9°C/10 years in the Kraków area. A similar conclusion was made based on research for the years 1951–2018 at 24 stations selected to represent the entire area of Poland (Kuchcik et al. 2021b), where not only a statistically significant increase in the UTCI value was found in all regions of Poland, but it was also observed that contrasts in range of thermal stresses both for Poland as a whole and for regions have decreased significantly, especially in the north-eastern part of Poland.

In particular, the biggest change was noted in winter and spring when the trend values usually exceeded 4.0°C. Milder bioclimatic conditions in winter were also observed by Błażejczyk and Twardosz (2010, 2023) for a 200-year series in Kraków, Okoniewska and Więcław (2013) examining the second half of the 20th century, and Kożuchowski (2003) analysing the trends for Łódź based on the series from the period 1961 to 2000. Interesting results were obtained by Kuchcik et al. (2021a, b), who analysed changes in bioclimatic conditions in Poland using the UTCI and STI indicators. They found a significant increase in the minimum and average values of the indicators used in the examined period in all areas of Poland, including the mountains. Also, Błażejczyk et al. (2003) examined the conditions in Kraków based on the indicators of perceptible temperature and predicted thermal insulation of clothing and found the existence of trends implying an intensification in thermal stress. I have noted a similar intensification of thermal stress in Kraków, where an upward trend of strong and very strong heat stress was the highest.

Biothermal conditions undoubtedly change due to a rise in air temperature. The recorded changes correlate with the temperature rise trend, in particular in winter and spring, found by many researchers (e.g., Fortuniak et al. 2001, Kożuchowski, Żmudzka 2002, Michalska 2011, Okoniewska 2019), whereas the temperature trends observed in Poland are close to those observed in all Central Europe (Kożuchowski et al. 1994, Niedźwiedź et al. 1994, Trepińska et al. 1997, Kożuchowski, Żmudzka 2002, Anders et al. 2009, Di Napoli et al. 2018, Twardosz et al. 2021, Katavoutas et al. 2022). On average, the UTCI increased by 0.6°C over 10 years in Poznań and Kraków and by 0.7°C in Kołobrzeg. In Kołobrzeg, these values were close to trends observed by Owczarek et al. (2019), which pointed to the warming rate of 0.8˚C over ten years from 1991 to 2015. Rozbicka and Rozbicki (2020), who examined multi-annual variations in bioclimatic conditions and tourism potential, discovered a positive linear trend for the maximum and minimum UTCIs.

The warming of perceptible conditions in successive decades, observed in previous research (Okoniewska, Więcław 2013), was also noted in this study. The observed changes in biothermal conditions are similar to bioclimatic variations in Europe. Analyses carried out by Nastos and Matzarakis (2013) based on data from weather stations at the University of Athens also show an upward trend (of physiologically equivalent temperature, PET), which, in the authors' opinion, implies a deterioration in bioclimatic conditions. Authors of the study for Italy (Matzarakis et al. 2007) also present similar views on the future climate to the extent of perceptible conditions. They forecast that in many areas of Europe and the Mediterranean, climate change will increase the amount of stress caused by bioclimatic conditions, affecting human health and well-being and contributing to changes in tourism patterns. The warming of biothermal conditions in Europe is corroborated by studies conducted in Serbia (Percelj et al. 2021), where the results point to an increase in extreme heat-related biothermal conditions. An analysis of Hungarian cities (Nemeth 2011) pertaining to the period from 1971 to 2000 (at 12:00 and 6:00 PM UTC) revealed a considerable increase in the UTCI in spring and summer, which suggests a slightly different nature of variations than described in this article, where the highest trend was noted in winter and early spring.

The results correspond to the nature of climate change and testify to the deteriorating bioclimatic conditions in Central Europe. The deterioration primarily refers to increased heat stress around noon, as illustrated by the upward trend line of strong and very strong heat stress and the upward trend of the maximum UTCI. My other studies (Okoniewska 2021) showed that bioclimatic conditions in Central Europe have become increasingly similar to those in the south of the continent, and increased thermal stress mostly affects the inhabitants of big cities. Therefore, bioclimatic variations should be studied further, mainly focusing on periods that are particularly onerous and hazardous to human health and those posing a direct threat to human life, such as heat waves. This will make it possible to prepare for future changes and reduce the number of deaths, which, as revealed by numerous studies, increase during heat waves in big cities.

Moreover, it should be noted that noticeable changes in the perceived climate conditions may result not only from general climate changes but also from the ongoing urbanisation and transformation of the infrastructure of the city itself. This problem is very important and worth undertaking more detailed analyses in the future.

## Conclusions

The following conclusions were drawn during studies on variations in biothermal conditions:

- the median value of the UTCI at 12:00 UTC indicates an average range of heat load variability during the study period from 'moderate cold stress' to 'moderate heat stress'; the tested variations mean a change from conditions when it is necessary to increase activity and protect the face against cooling to conditions when it is necessary to replenish water in the amount of $0.25l \cdot h^{-1}$,
- among the analysed weather stations, the one in Kraków showed the most intense perception of heat stress,
- in the study period, in winter, the predominant thermal perception around noon was moderate cold heat, while in summer at that time, thermal comfort with no thermal stress at all prevailed,
- a significant increase was observed in annual and monthly values of the trend of the UTCI ranging from ca. 0.5°C to 1.0°C over 10 years,
- the highest UTCI trends were recorded in winter and early spring,
- the largest decline in the most extreme thermal stress was noted for the perception of cold, with an increase in the perception of heat,
- the elevated UTCI can increase health risks, especially among the elderly, children, individuals with chronic illnesses and those working outdoors; high temperatures combined with humidity can lead to heat strokes, dehydration, overheating and exacerbation of existing conditions,
- an increase in the UTCI may impact communities and the economy, for example, through changes in tourism, agricultural production, energy use (for air conditioning), public health and the need for infrastructure to counteract the effects of heat (e.g. air conditioning and shading),
- an increase in the UTCI may therefore have significant implication for people and society as a whole; therefore, it is important to monitor atmospheric conditions and take actions to protect people's health and comfort in conditions of extreme heat.

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