EVALUATION OF THERMAL CONDITIONS IN JEZIORY (THE WIELKOPOLSKI NATIONAL PARK)

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Abstract. The purpose of this paper is to present selected methods of evaluation of thermal conditions in the Wielkopolski National Park and their initial characterization. The analysis was based on data from the automatic meteorological station in Jeziory measured during the period 2001–2010. The calendar of thermal classes graphically shows the variation in thermal conditions for each month and deviation from the standard adopted for the period concerned (Table 2). A good complement to the calendar seems the graphs of mean daily air temperature for months above and below the standards that enable their connection with the peculiarities of weather occurring in the area of Central Europe (Fig. 1). In addition to complete characterization of thermal conditions, specific number of days according to the average daily temperature ranges (T_{avr}): $t_{avr.} \leq 10°C$, $t_{avr.}$ 10.1–15.0°C, $t_{avr.}$ 15.1–20.0°C, $t_{avr.}$ 20.1–25.0°C, $t_{avr.}$ 25.1–30.0°C and interdiurnal changes of average daily temperature (ΔT_{avr}): $\Delta t_{avr.} \leq 2°C$, $\Delta t_{avr.}$ 2.1–4.0°C, $\Delta t_{avr.}$ 4.1–6.0°C, $\Delta t_{avr.} \geq 6.0°C$ were calculated (Table 3, 4). They were the basis for separating the year into thermal seasons (Table 5, Fig. 2). Ward's method was used giving the best results in the case while both T_{avr} and ΔT_{avr} were taken into consideration. The results obtained allow concluding that different methods of evaluation of thermal conditions applied separately do not give a full picture of thermal conditions of the area. Only a combination of results obtained using the Ward's and calendar methods can give a complete thermal conditions characterization.

Kew words: thermal conditions, the Wielkopolski National Park

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1. Introduction

Thermal conditions largely affect human life and activity, as well as the functioning of fauna and flora. There are also other meteorological elements besides air temperature to evaluate the biothermal conditions. Furthermore, in protected areas they are important from the perspective of tourism.

In many cases, weather as well as gaps in knowledge about the influence of biometeorological conditions on humans makes it difficult to take full advantage of the surrounding environment (Błażejczyk 2011).

Unfavorable thermal conditions are caused by high or low air temperatures, as well as by large temperature variations. Therefore, the parameters used for the purpose of assessing biothermal conditions include the average daily air temperature and its interdiurnal variability (Kozłowska-Szczęsna *et al.* 1997).

This paper sets out to assess thermal conditions and determine thermal seasons on the basis of weather data from Jeziory station. Jeziory is a village located in the Wielkopolski National Park, which – in accordance with the classification of bioclimatic regions of Poland – is situated in the central region, with typical bioclimatic conditions. The region is dominated by mild climate, characteristic for Poland. Relocation within this bioclimate requires little or no adaptation (Kozłowska-Szczęsna *et al.* 1997).

2. Materials and methods

The calculations were made on the basis of data from an automatic weather station situated in a wood clearing being part of the Ecology Station in Jeziory run by Adam Mickiewicz University. The measurements were made by means of Vaisala HMP45D temperature and humidity sensor placed in a radiation shield, 2 meters above ground level. The results of daily air temperature measurements taken at hourly intervals in the years 2001–2010 were used.

In order to determine monthly variability of thermal conditions, the method of Miętus *et al.* (2002) was used. The basis for such classification is a series of empirical quantiles dividing the analyzed set into subsets whose threshold values are strictly related to the range of variability of the analyzed element. As a result, as presented by the authors, the method becomes universal, which is why it can be used for other climatic elements, irrespectively of the density of probability distribution. In the case presented here, the analyzed parameter was the average daily air temperature; therefore, quantile threshold values determine the ranges of perception of thermal conditions based on which the monthly classification was developed. For instance, a given month was considered normal in terms of temperatures if the average daily temperature was between quantile levels of 40.0 to 60.0%. If the temperature was below the quantile level of 5%, the month was considered extremely cold, and if it was above the quantile level of 95%, the month was considered extremely hot. The detailed classification together with threshold

Table 1. Criteria for thermal classification of months in the Wielkopolski National Park (2001–2010).

Quantile levels(%) (thermal character of month)	January	February	March	April	May	June
>95 (extremely warm)	≥6.97	≥7.05	≥9.60	≥14.79	≥19.87	≥22.52
90.01–95 (anomalous warm)	5.69–6.96	5.35–7.04	8.19–9.59	13.43–14.78	18.10–19.86	20.85–22.51
80.01–90 (very warm)	2.28–5.68	3.33–5.34	6.97–8.18	11.82–13.42	16.71–18.09	19.70–20.84
70.01–80 (warm)	1.33–3.27	1.93–3.32	5.87–6.96	11.02–11.81	15.65–16.7	18.84–19.69
60.01–70 (slightly warm)	0.43–1.32	1.04–1.92	4.72–5.86	10.22–11.01	14.53–15.64	17.81–18.83
40.01–60 (normal)	(–2.14)–0.42	(–0.70)–1.03	1.86–4.71	8.05–10.21	13.07–14.52	16.40–17.80
30.01–40 (slightly cool)	(–3.77)–(–2.15)	(–1.61)–(–0.71)	0.70–1.85	7.01–8.05	11.78–13.06	15.33–16.39
20.01–30 (cool)	(–5.64)–(–3.78)	(–2.57)–(–1.62)	(–0.33)–0.69	5.88–7.00	10.88–11.77	14.09–15.32
10.01–20 (very cool)	(–8.95)–(–5.65)	(–4.77)–(–2.58)	(–2.01)–(–0.34)	4.72–5.87	9.60–10.87	12.65–14.08
5.01–10 (anomalous cool)	(–11.49)–(–8.96)	(–6.61)–(–4.78)	(–3.25)–(–2.02)	3.60–4.71	8.53–9.59	11.65–12.64
<5 (extremely cool)	≤(–11.50)	≤(–6.62)	≤(–3.26)	≤3.59	≤8.52	≤11.64

values is presented in Table 1. Thermal assessment of each month in the analyzed period is presented in the form of a calendar. In addition, charts present average daily temperatures in selected months above or below the norm.

Subsequently, thermal conditions were analyzed by means of biometeorological characteristics: average daily temperature (T_{avr}) and interdiurnal average daily temperature changes (ΔT_{avr}). It was assumed that a day with T_{avr} <10°C was cold, 10.1–15.0°C – cool, 15.1–20.0°C – warm, 20.1–25.0°C – very warm, 25.1–30.0°C – annoyingly hot (Kozłowska–Szczęsna *et al.* 1997). In accordance with E.M. Baibakova *et al.* (1963) the relation between ΔT_{avr} and the intensity of thermal stimuli is as follows: ΔT_{avr} <2°C is a neutral stimulus, 2.1–4.0°C – a perceptible stimulus, 4.1–6.0°C – a significant stimulus, and finally >6.0°C – an acute stimulus.

The next step was an attempt at dividing the year into thermal seasons based on T_{avr} and ΔT_{avr} using Ward's method. This taxonomic method allows one to simultaneously consider several elements (features), making it relatively the most precise and unbiased (Chojnicki, Czyż 1973, Parysek 1982).

Ward's method consists of clustering items by the similarity of their features. Such clusters are graphically represented by means of dendrograms. When dendrograms are split at the so-called critical distance, clusters of items with similar features are formed. In this paper, the clustered items form 73 pentads, whose features are average frequencies of days from a given range of T_{avr} and ΔT_{avr} in Jeziory in the years 2001 to 2010.

The critical distance was calculated according to the following formula:

$$D_k = d_{ik} + 2/3Sd$$

where:
D_k – critical distance between items (pentads),
d_{ik} – average distance in a dendrogram,
Sd – standard deviation of distances in dendrogram.

A more detailed description of this method can be found e.g. in Tamulewicz (1982), Bednorz *et al.* (2001), Gabała (2004) and Jarzyna (2004).

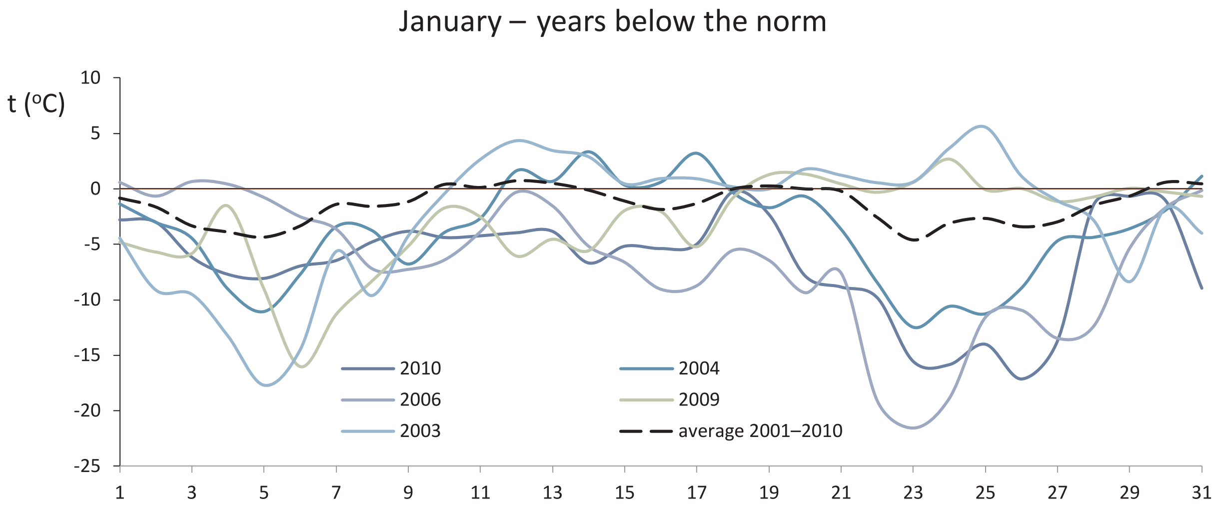
Table 1. cont.

July	August	September	October	November	December
≥25.00	≥23.14	≥18.60	≥14.31	≥9.93	≥6.19
23.81–24.99	21.08–23.13	17.78–18.59	13.29–14.30	9.00–9.82	4.73–6.18
22.08–23.80	20.81–22.07	16.46–17.77	11.98–13.29	7.83–8.99	3.29–4.72
21.25–22.07	20.07–20.80	15.21–16.45	10.79–11.98	6.38–7.82	2.23–3.28
20.26–21.24	19.64–20.06	14.46–15.20	9.61–10.79	5.54–6.37	1.00–2.22
18.32–20.25	18.01–19.63	12.83–14.45	7.62–9.61	3.81–5.53	(–0.41)–0.99
17.46–18.31	17.16–18.00	12.01–12.82	6.06–7.62	2.07–3.80	(–1.62)–(–0.42)
16.66–17.45	15.98–17.15	11.12–12.01	4.95–6.06	0.76–2.06	(–3.53)–(–1.63)
15.64–16.65	15.10–15.97	10.07–11.11	3.62–4.95	(–0.26)–0.75	(–6.49)–(–3.54)
15.05–15.63	14.12–15.09	9.15–10.06	2.66–3.61	(–1.14)–(–0.27)	(–9.54)–(–6.50)
≤15.04	≤14.11	≤9.14	≤2.65	≤(–1.15)	≤(–9.55)

3. Results

Based on the thermal classification of months (Table 1) using the method of Miętus *et al.* (2002), a thermal calendar for the Jeziory weather station was developed. The station represents weather conditions in the Wielkopolski National Park. On the basis of the calendar, one can conclude that in the years 2001–2010 there were no extreme months, i.e. months that were extremely or anomalously hot or cold (Table 2). There were significant month-to-month thermal variations, which is why a uniform change trend in the analyzed period cannot be determined. Months with a smaller deviation were more frequent in transition seasons. Therefore, thermal conditions close to normal are more likely in those periods. Greater monthly thermal variability was observed more clearly in summer and in winter. In the analyzed period, the most frequent were normal months (45 cases) and slightly cool months (27), followed by slightly warm months (17). The greatest number of deviant months occurred in the very cold range (5 cases) and in the very warm range (7). However, the very cold range occurred in winter only, while the very warm one occurred in other seasons as well.

Figure 1 presents the monthly changes of average daily air temperatures in Jeziory in 2001 to 2010 in months above and below the norm.



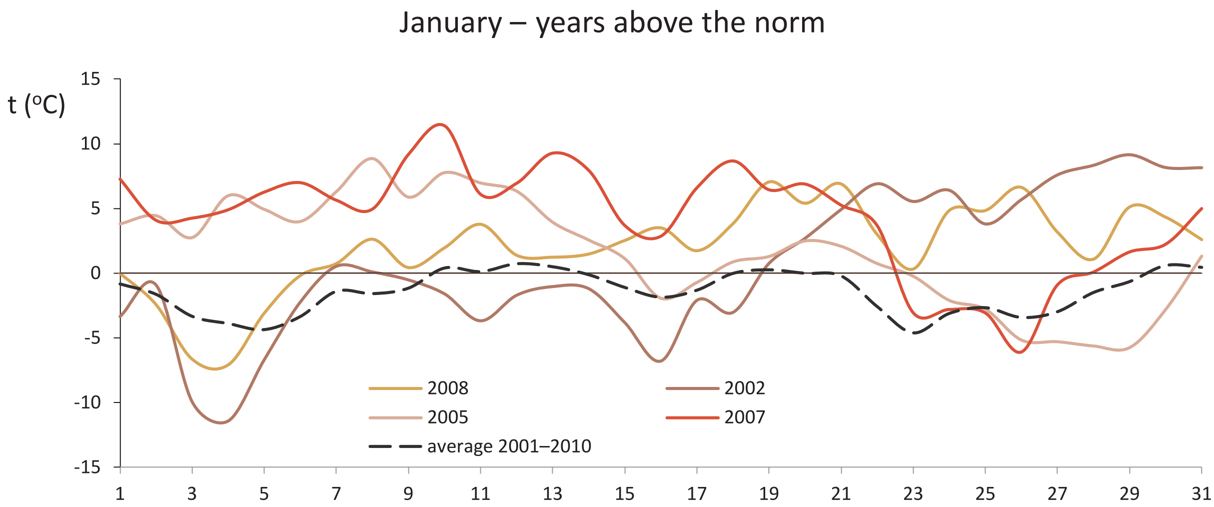
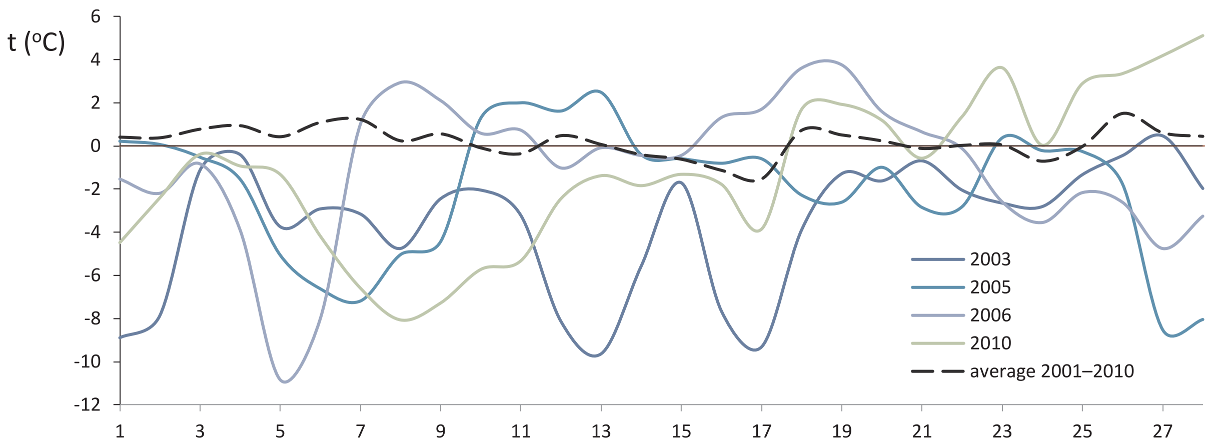
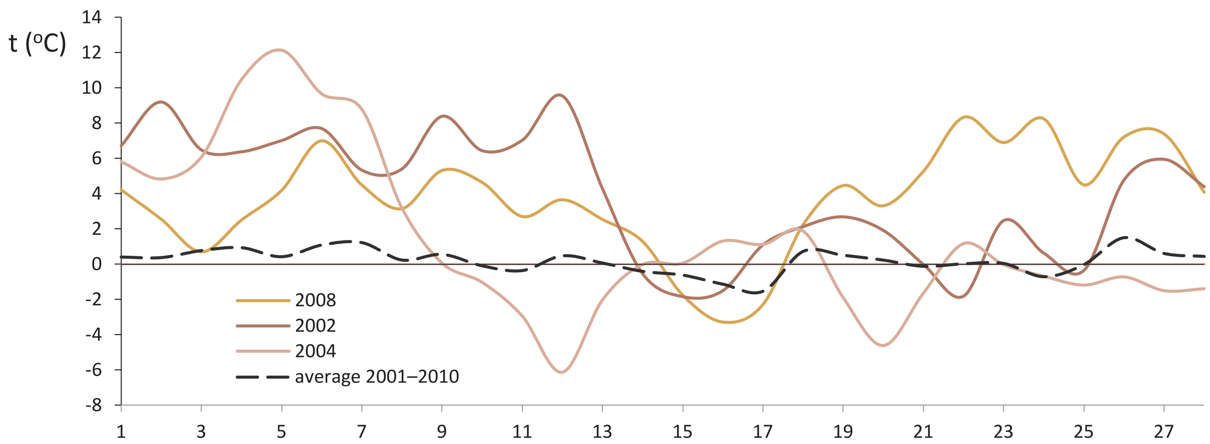


Fig. 1. Average daily air temperature for the months' classes above and below normal thermal conditions designated on the basis of empirical percentiles. Jeziory, the Wielkopolski National Park (2001–2010).

February – years below the norm



February – years above the norm



March – years below the norm

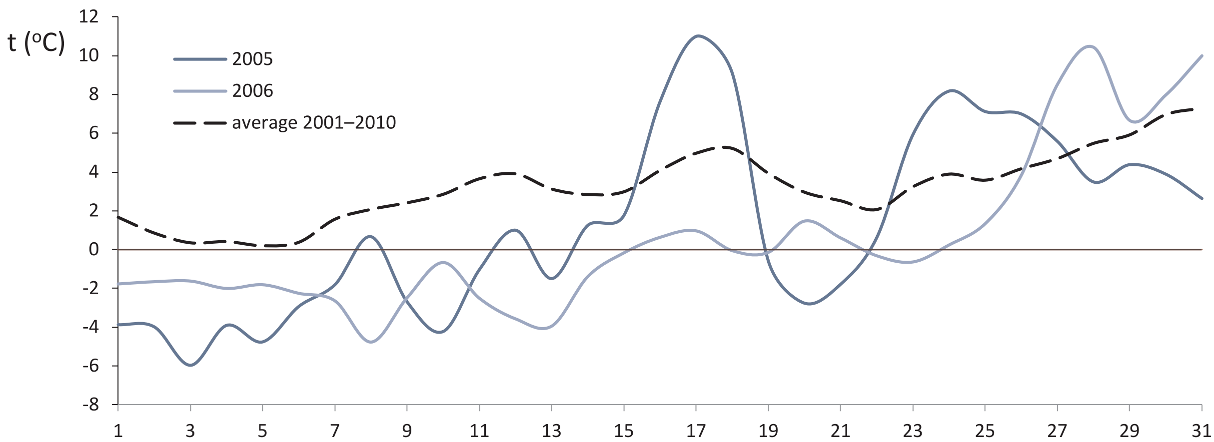


Fig. 1. Cont.

Table 2. The variability of thermal conditions in given months based on the chosen classification in the Wielkopolski National Park (2001–2010).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
I	–0.26	0.60	–2.46	–3.84	1.68	–6.65	4.27	1.97	–3.07	–6.64
II	0.64	3.93	–3.60	1.46	–1.97	–1.01	0.69	3.70	–0.56	–1.23
III	2.31	4.58	2.42	4.22	1.27	0.59	5.94	3.91	3.58	3.51
IV	8.17	8.88	7.95	9.22	8.85	8.81	10.10	7.99	11.47	8.72
V	14.72	17.21	14.80	12.25	13.04	13.47	14.61	13.68	12.90	11.36
VI	14.98	18.64	18.01	15.69	16.26	17.72	18.82	17.45	15.86	16.67
VII	19.70	19.97	18.76	18.15	18.98	23.07	17.76	19.03	19.04	20.42
VIII	18.98	20.28	19.00	19.20	16.63	16.89	17.87	17.84	18.74	20.65
IX	12.26	13.60	14.10	13.84	15.38	15.94	12.79	12.73	14.60	12.12
X	12.30	7.24	5.25	9.81	9.96	10.63	7.80	9.02	7.10	5.84
XI	3.30	3.84	4.83	3.98	2.97	6.33	2.46	5.32	6.12	4.52
XII	–1.63	–3.77	1.38	1.35	0.32	4.42	1.04	0.97	–0.99	–5.72

In January, in years below the thermal norm for that month, temperatures varied from –21.6°C in 2006 to 5.6°C in 2003. The January of 2006 was a very cold month and was the coldest one in the analyzed period, i.e. 2001 to 2010 (Fig. 1A). The shape of the curves indicates two types determining monthly temperatures. The first type (the years 2003 and 2009) denotes a major temperature drop in the middle of the first decade of the month (approx. –17°C), followed by values slightly above the multi-year average and a maximum in the third decade, approx. 3–5°C. In the second type, temperature values until the end of the second decade of January are either below or near the multi-year average and only in the third decade they reach the monthly minimum (the years 2004, 2006, 2010). The other type clearly corresponds to a weather phenomenon regularly appearing in Central Europe, referred to as "the winter invasion" by Flohn (1954, quoted in Woś 1996). The said phenomenon is linked to a macro-scale synoptic situation (development of a continental anticyclone). Anticyclonic circulation was also the reason for a significant air temperature drop in the third decade of 2007, when January was a "very warm" month, being the warmest January in the analyzed period (Fig. 1B).

In February, air temperatures were relatively frequently affected by a cool anticyclone from above North-Eastern Europe, i.e. the so-called late winter (Fig. 1C). It occurs in the period between February 3 and 12, which is also illustrated by temperatures in those years when monthly averages were below the norm. In those years when February had high monthly averages, the daily averages reached as high as 9°C in the beginning of the month and then continued to be well above the mean value nearly all the time (Fig. 1D).

In the middle of March 2005 (being a slightly cold month) there appeared a sudden and strong air temperature rise (with a maximum on March 17 – approximately 17°C), related to the so-called early spring, regularly occurring in this period, caused by anticyclonic circulation (Fig. 1E). On the other hand, the March of 2006 was a "cool" month, with average daily temperatures well below the multi-year average until the middle of the last decade (Fig. 1E).

To ensure a more comprehensive thermal overview, the authors calculated the number of days in a given range of average daily temperatures T_{avr} (Table 3). In the analyzed period, the largest number of days were classified as "cold" (average temperature ≤10°C), amounting to nearly 193 days per year. The year with the largest number of "cold" days was 2010 (210 days), followed by 2008 (197 days) and 2003, 2005 and 2007 (196 days). The lowest number of "cold" days was recorded in 2006 (182 days). The smallest group were "hot" days (average temperature from 25.1 to 30.0°C), with an average of 2 such days per year. The year with the greatest number of such days was 2006 (10 days). In the years 2003 to 2005 and then in 2008 and 2009 there were no "hot" days at all.

By far, there were more "cold" days in the cool part of the year (168 days). Both January and December had 31 such days (Table 4). Other categories, i.e. "cool", "warm" and "very warm" days dominated in the warm part of the year.

Table 3. Number of specific days according to the average daily temperature ranges and the interdiurnal changes of average daily temperature in the Wielkopolski National Park (2001–2010).

Tavr (°C)	thermal sensations	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	I–XII
≤10	cold	183	193	196	184	196	182	196	197	191	210	192.8
10.1–15.0	cool (fresh)	83	49	59	86	69	71	75	66	67	71	69.6
15.1–20.0	warm	75	76	84	72	76	73	60	79	83	46	72.4
20.1–25.0	very warm	23	45	26	23	24	29	32	23	24	35	28.4
25.1–30.0	hot	1	2	0	0	0	10	2	0	0	3	1.8
ΔTavr (°C)	stimuli											
≤2.0	neutral	244	235	243	239	257	256	240	251	241	238	244.4
2.1–4.0	perceptible	90	99	85	101	86	88	97	95	104	96	94.1
4.1–6.0	significant	24	25	32	23	17	14	19	19	15	25	21.3
≥6.1	acute	7	6	5	2	5	7	9	0	5	6	5.2

"Cool" days were the most frequent in September, "warm" days – in August, and "very warm" days – in July.

Subsequently, the authors analyzed interdiurnal average daily temperature changes ΔT_{avr} and calculated the number of days with a given range of perception of these changes by the human body (Table 3). In Jeziory, the most frequent were days with the lowest interdiurnal temperature changes, i.e. "neutral" changes (below 2°C). On average, there were approx. 244 days like that per year. The greatest number of such days was recorded in 2006 (257). Temperature changes between 2.1–4.0°C ("perceptible" changes) occurred on average on 94 days per year. The greatest number of such days was recorded in 2009 (104). Changes classified as "significant" (4.1–6.0°C) occurred on average on 21 days, being the most numerous in 2003 (32 days). The least frequent (5 days on average) were days with "acute" or "annoying" temperature changes (above 6.0°C). The year with the largest number of such days was 2007 (9 days).

"Neutral" days were slightly more common in the warm part of the year (Table 4), being the most frequent in August and the least frequent in January. The same goes for days with "perceptible" changes – they were more frequent in the warm part of the year. They were the most frequent in April and the least frequent in September. "Significant" changes were more common in the cool part of the year, being the most frequent in December and the least frequent in September. "Acute" interdiurnal temperature changes dominated in the cool part of the year.

The division of the year into thermal seasons takes into account days clustered according to the ranges of T_{avr} and ΔT_{avr}, using Ward's method. Three attempts were made, the results of which are presented in Figure 2. In the first attempt, only days with T_{avr} were taken into account (Fig. 2A), which proved unsatisfactory be-

Table 4. Average number of specific days according to the average daily temperature ranges and interdiurnal changes of average daily temperature in months, half-year and year in the Wielkopolski National Park (2001–2010).

Tavr (°C)	thermal sensations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–IX	X–III	I–XII
≤10	cold	30.9	27.8	29.8	17.3	4.3	0.4	0	0	2.8	19.8	28.8	30.9	24.8	168.0	192.8
10.1–15.0	cool (fresh)	0.1	0.2	1.2	11.3	16.5	7.3	1.5	3.0	17.1	10.1	1.2	0.1	56.7	12.9	69.6
15.1–20.0	warm	0	0	0	1.4	8.8	17.3	16.0	18.3	9.5	1.1	0	0	71.3	1.1	72.4
20.1–25.0	very warm	0	0	0	0	1.4	4.8	11.9	9.7	0.6	0	0	0	28.4	0	28.4
25.1–30.0	hot	0	0	0	0	0	0.2	1.6	0	0	0	0	0	1.8	0	1.8
ΔTavr (°C)	stimuli															
≤2.0	neutral	18.2	18.3	21.5	18.9	19.9	20.6	22.0	23.0	22.4	20.1	20.2	19.3	126.8	117.6	244.4
2.1–4.0	perceptible	8.7	6.8	7.5	9.5	8.9	7.9	7.1	7.3	6.5	8.1	7.3	8.5	47.2	46.9	94.1
4.1–6.0	significant	3.0	2.2	1.6	1.3	2.0	1.2	1.5	0.7	1.0	2.4	1.9	2.5	7.7	13.6	21.3
≥6.1	acute	1.1	0.7	0.4	0.3	0.2	0.3	0.4	0	0.1	0.4	0.6	0.7	1.3	3.9	5.2

cause pentads belonging to the same cluster did not form systematic temporal sequences. In the second attempt, only days with ΔT_{avr} were clustered, which yielded good effects, with only one "odd" pentad (Fig. 2B). The best clustering effect was achieved in the third attempt, simultaneously taking into account the number of days with T_{avr} and ΔT_{avr} (Fig. 2C). In this approach all the pentads found themselves in clusters forming uniform sequences. Sequentially arranged pentads read from the dendrogram made it possible to determine the start and end dates as well as the durations of four thermal seasons (Table 5). Season A, continuing for 155 days from November to April, is the coldest and longest season, with the highest numbers of days with acute (annoying) and significant stimuli (a total of approximately 15 days – Table 6). Season B, the shortest one, could be referred to as the colder transition season, includes two periods: from April 1 to 25 and from October 3 to 27. A vast majority of the 50 days in Season B are cool or cold (approx. 48 days), with very rare warm or very warm days. Relatively frequent in Season B are also days with stimuli other than neutral (approx. 20 days). Likewise, Season C (warmer transition season) consists of two periods: April 26 to June 19 and August 29 to October 2 (90 days in total). While this season too is dominated by cool days, warm days are not uncommon (approx. 30 days). Neutral stimuli occur on over 60 days, followed by perceptible stimuli (approx. 24 days) and significant/acute stimuli (approx. 5 days). Finally, the period from June 20 to August 28 is the warmest season, i.e. Season D. It is the most favorable period of the year, dominated by warm (40) and very warm (24) days. Cold and hot days are sporadic (approx. 6 days in total). Also the stimuli related to interdiurnal temperature changes denote very favorable thermal conditions in Season D. On

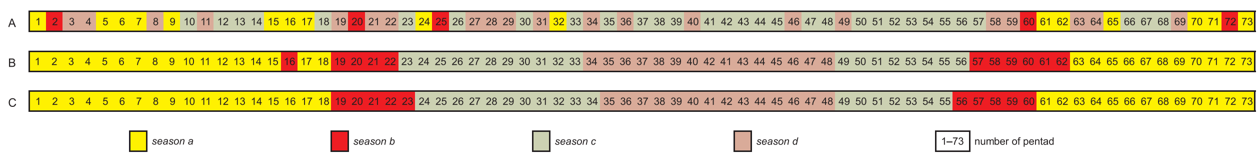


Fig. 2. The result of grouping pentad frequency of days with interdiurnal temperature change ΔTavr (A), specific days Tavr (B) and both a and B. Jeziory, the Wielkopolski National Park (2001–2010).

Table 5. Thermal seasons in Jeziory, the Wielkopolski National Park (2001–2010).

season		the beginning	the end	duration (in days)
A		28 X	31 III	155
B	B1	1 IV	25 IV	25
	B2	3 X	27 X	25
C	C1	26 IV	19 VI	55
	C2	29 VIII	2 X	35
D		20 VI	28 VIII	70

Table 6. Number of days with specific thermal sensation and stimuli in particular thermal seasons in Jeziory, the Wielkopolski National Park (2001–2010).

Tavr (°C)	thermal sensations	A	B	B1	B2	C	C1	C2	D
≤10	cold	151.6	30.7	16.3	14.4	8.8	5.7	3.1	0
10.1–15.0	cool (fresh)	3.3	17.2	8.5	8.7	45.0	25.4	19.6	4.6
15.1–20.0	warm	0.1	1.4	0.2	1.2	31.3	19.9	11.4	40.1
20.1–25.0	very warm	0	0.5	0	0.5	4.8	3.9	0.9	23.6
25.1–30.0	hot	0	0.2	0	0.2	0.1	0.1	0	1.7
ΔTavr (°C)	stimuli								
≤2.0	neutral	100.2	29.7	15.7	14.0	62.0	36.0	26.0	50.8
2.1–4.0	perceptible	39.6	14.7	8.2	6.5	23.2	15.4	7.8	16.0
4.1–6.0	significant	11.6	3.0	0.9	2.1	4.3	3.2	1.1	2.6
≥6.1	acute	3.6	2.6	0.2	2.4	0.5	0.4	0.1	0.6

most days the stimuli are neutral or perceptible (67 days), with significant and acute stimuli being very rare (3 days).

4. Conclusions

Thermal conditions are a key indicator of the comfort of life and determine the tourist potential of a given location. In addition, in the case of the Wielkopolski National Park (located near the major city of Poznań), they determine the possibility of taking advantage of broadly defined recreation by the city's population.

This paper sets out to assess the thermal conditions on the example of a relatively short (10-year) series of data, which is why the results obtained here are treated as a starting point for further analyses. The calendar of thermal classes is a visualization of the monthly variability of thermal conditions and the deviation from norms assumed for the period in question. It seems that average daily air temperature curves in months above and below the norm make a useful supplement for the calendar. The curves also demonstrate recurring weather phenomena taking place in Central Europe.

According to the thermal calendar, in the Wielkopolski National Park there are no anomalously or extremely hot or cold months, with normal months being the most common. Slightly cool and slightly warm months are relatively frequent. Months classified as very cool (5 instances) and very warm (7 instances), largely deviating from the normal conditions, represented as little as 10% of all months.

Important information contained in the thermal conditions calendar was supplemented with information on thermal conditions during the year and thermal seasons, determined on the basis of days with assumed ranges of T_{avr} and ΔT_{avr}. Given the relatively short period of collecting weather data in Jeziory station, the thermal seasons were described in a fairly general manner.

In Jeziory, thermal conditions are usually unfavorable for tourism and recreation. Most of such days are cold (190 days per year on average), cool (70 days) and hot (2 days). The number of favorable days (warm and very warm) is approximately 100. On the other hands, the number of days with significant and acute stimuli (unfavorable for tourism and recreation) is low (25 per year on average).

The prevailing view that only the summer period is favorable for tourism and recreation is evidenced by the numbers of tourist visiting the Wielkopolski National Park in summer. However, as this paper demonstrates, thermally favorable conditions are available in other periods as well. In fact, with the exception of Seasons A and B (October 3 to May 25), cold and characteristic for frequent unfavorable thermal stimuli, the other part of the year (Seasons C and D, May 26 to October 2) provides relatively good thermal conditions for tourism and recreation. In addition, adequate clothing (easily available owing to the development of specialized, breathable fabrics) ensures good thermal conditions even on cool days, thus extending the thermal comfort range and increasing the number of comfort days. Therefore, Season B can also be considered as partially favorable for tourism and recreation.

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