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The influence of brine graduation towers on biometeorological conditions, on the example of Ciechocinek spa town (Poland)

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Abstract. The paper provides an analysis of the influence of brine graduation towers on biometeorological conditions, on the basis of the example of Ciechocinek – a spa town in Poland. Using the records of air temperature and relative air humidity in the years 2018-2020 at two locations near Graduation Tower 1 and at the reference site near Spa Hospital No. 1 it was demonstrated that the graduation towers caused a mean drop in air temperature of 0.5–0.7°C with maximum differences 7.5°C. The average humidity due to brine evaporation was 3.6–4.6% higher, but maximum differences exceeded 30%. Based on mobile measurements the effects of the graduation tower were found to be limited to its vicinity, where air temperature was lower and humidity higher. The distribution of air temperature and humidity changed depending on wind direction. Cooler and more humid air was carried downwind of the graduation tower. The calculated biometeorological indices showed that neutral, comfortable or refreshing conditions prevailed at the graduation tower and the sensation of heat or thermal stress leading to body overheating was less frequent.

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1. Introduction

Graduation towers are huge structures, usually made of wood and packed with brushwood (typically blackthorn). Originally, they were used to obtain salt by graduating salt brine and evaporating water. The first structure of this kind was erected in Bad Kissingen at the foot of the Alps in 1563 (Piasecki, 2010). In Polish area, the first graduation tower was constructed in Kołobrzeg in 1710 (Zabel, 2008). In 1780, brine graduation towers were built in Łęczyca, in 1782 in Busko Zdrój (Gaweł & Kuczaj, 2012), and in 1836 in Ciechocinek (Nocna, 2016). Today the production of salt using a saltpan is marginal (Kamyk, 2008).

Salt brine is more important for its therapeutic effects (Ciężkowski et al. 2010; Ziemska et al. 2019). Quickly, the saline aerosol found in the air in salt mines, man-made chambers and around graduation towers also began to be used in balneology. Graduation towers are vital in halotherapy. They contributed to the creation of numerous health resorts which use salt therapy (Faracik, 2020a). Renovation and functional adaptation of these facilities is extremely important in the present-day development of salt towns in their post-industrial period (Langer, 2014). Such a phenomenon can be observed, for example, in Ciechocinek, where the primary industrial function has been replaced over time by health resort functions (Matczak, 2019).

In Poland, a revival of therapies using saline inhalations started at the end of the 20th century and continued into the 21st. In 1978, the graduation tower in Konstancin was built. In 2001 the towers in Inowrocław were opened to the public, and a graduation tower was built in Marusza near Grudziądz in 2006, one in Rabka Zdrój in 2008, and one each in Gołdap and Wieliczka in 2014 (Faracik, 2011, 2020a). In many other places new structures of this kind were erected that were often small but that improve the local microclimate (Langer, 2014). As of 2019 there were 89 locations with graduation towers in Poland, and the number looks set to rise (Faracik, 2020b).

Concentrated at more than 1 $mg{\cdot}m^{-3}$ in the air, salt unfolds its therapeutic effects (Stribu et al. 2012). Czajka et al. (2006) demonstrated that the concentration of NaCl per m^3 in the air in the vicinity of a graduation tower (8.8 $mg{\cdot}m^{-3}$) is much higher than it is on the beach of the Baltic Sea (4.7 $mg{\cdot}m^{-3}$). An even higher concentration of salt in the air was found at the Wieliczka salt mine (22.0 $mg{\cdot}m^{-3}$). Near the graduation towers in Inowrocław a substantial increase in the content of calcium and sodium cations was observed in the soil (Krzyżaniak-Sitarz, 2012).

Saline aerosols are inhaled in natural and man-made chambers in salt mines, and in the proximity of graduation towers and other structures (Ponikowska et al. 2009; Zając et al. 2014). Such inhalations support the treatment of respiratory diseases, sinusitis, arterial hypertension, hypothyroidism and vegetative neurotic disorders (Ponikowska & Ferson, 2009). Breathing air with saline aerosol also reduces allergic symptoms, as it contains fewer bacteria (Burkowska-But et al. 2014; Burkowska-But, 2016). Moreover, a number of other substances are found in the air around the towers, such as iodine, whose concentration exceeds that in seaside resorts (Czajka et al. 2006).

Meteorological conditions affect the functioning of the human body (Błażejczyk & Krawczyk, 1991). Graduation towers produce a specific microclimate with higher air humidity and lower air temperature, and an overall physiologically more comfortable climate (Ponikowska et al. 1979; Helbin & Kolarzyk, 2005). This microclimate is used in climatotherapy (Ponikowska & Marciniak, 1988). Ciechocinek, Inowrocław and Konstancin are the most prominent examples of spas which use aerothrerapy (Kuchcik et al., 2013). The most extensive research on the influence of graduation towers on climatic and bioclimatic conditions was carried out in Ciechocinek. Studies were prepared on the basis of field research conducted there (Paszyński, 1957; Kozłowska-Szczęsna, 1965). The microclimate of the bathing area (swimming pool) in the vicinity of the graduation towers (Chełchowski, 1958) and the entire health resort (Gurba, 1959) were examined. On the basis of data from the meteorological station in Ciechocinek, a number of studies in the field of climatology and bioclimatology were created (e.g. Kozłowska-Szczęsna, 1964; Tyczka & Góra, 1978; Marciniak, 1983, 1986; Błażejczyk, 1988; Ponikowska & Marciniak, 1988; Kozłowska-Szczęsna & Błażejczyk, 1999, 2001). The list of the most valuable sources is included in the study by Kozłowska-Szczęsna from 2000. However, the closing down of the meteorological station in Ciechocinek limited the possibilities of conducting further research.

The motivation for researching the influence of graduation towers in Ciechocinek on the microclimate was an observation made by Paszyński (1957). He remarked that "the immediate vicinity of the graduation towers is undoubtedly characterized by specific microclimatic conditions. However, the precise quantification of these phenomena, as well as the determination of the range in which graduation towers in Ciechocinek exert a significant impact on the microclimate, requires more detailed research and the use of specific methods". Nowadays, the introduction of electronic measuring devices offers such opportunities. It is a response to the postulate of Kuchcik (2011) about the need to conduct research on the local differentiation of climatic conditions in health resorts.

The aim of this paper is to analyse the influence of graduation towers on biometeorological conditions in their surrounding area, using the example of Ciechocinek spa town (Central Poland). The spatial range of influence of graduation towers on air temperature and relative air humidity were analysed along with diurnal changes in intensity. The frequency of occurrence of adverse conditions at the towers and beyond their zone of influence was also determined based on biometeorological conditions. The research work was carried out in the years 2018–2020.

2. Research area

The observations comprised the graduation towers in Ciechocinek. The town is one of the largest health resorts in Poland. In 2020, Ciechocinek offered 7,541 beds, including 5,419 in sanatoriums. In 2014 (latest available data), 81,789 people used spa facilities (GUS, 2022). Moreover, Ciechocinek is a spa town frequently visited by tourists; the Schneider index exceeds 1000 tourists per 100 inhabitants (Gonia & Podgórski, 2019).

As early as in the 12th century the existence of saline springs near Ciechocinek was first mentioned. However, it was only in 1824 that – on Stanisław Staszic's initiative – structures for graduating salt brine and a salt works were established. In 1836 the first bathing facility was opened, and soon one of the largest health spa centres in Poland was founded to use natural therapeutic chloride-sodium-iodine-bromine waters at 26–33°C (Krawiec, 2009). Nowadays such diseases and conditions as orthopaedic and traumatic, rheumatic and heart diseases, hypertension, peripheral and upper respiratory diseases, diabetes, obesity and osteoporosis are treated in Ciechocinek. Peloids and climatotherapy are also used, taking advantage of the beneficial, physiologically comfortable climate and saline aerosol formed in the park around the three large graduation towers (Ponikowska & Marciniak, 1988).

The construction of graduation towers using a design by Józef Graf was started in Ciechocinek in 1824. In 1833 the construction of the first two towers (No. 1 and 2) was complete, and in 1859 the third tower was finished. Graduation Towers 1 and 2 are parallel to each other along a north–south axis, whereas Tower 3 marks the northern limit of the area, forming a diamond-shaped area where an outdoor saline swimming pool existed until 2001. The graduation towers of Ciechocinek are robust structures made of oak wood and packed with blackthorn twigs. Graduation Tower No. 1 is 600 m long, No. 2 is 723 m long and No. 3 is 333 m long; they are 10 m wide at the base and 16 m high (Tłoczek, 1958) (Fig. 1).

The towers are used to graduate salt brine pumped from deep intakes (originally using

Fig. 1. Brine graduation towers No. 1 in Ciechocinek
Source: photo M. Kejna

windmills) to the top of the tower, from where it flows freely down through the blackthorn. The brine circulated in the system has a ratio of 43.5–53.4 mg of salt per litre of water (Krawiec, 2009). The water evaporates in the process and the brine reaches a concentration of about 22%. At the same time, air humidity and aerosol content increase around the towers. Around the graduation towers, there is a gravel path. The area surrounding Tower 1 has been turned into a park with a great number of trees, flower beds, ponds and fountains that moderate the biometeorological conditions there.

Ciechocinek is situated within a type IV ('central') bioclimatic Polish region and it is characterized by a weakly stimulus type of bioclimate (Kozłowska-Szczęsna et al., 2002). In the annual cycle over 1971–1990, however, in July there were 9.2% days with hot weather and 7.4% with very hot weather. In June these accounted for 20.9% and 24.2% of days, respectively (Błażejczyk & Kunert, 2011). The bioclimatic conditions of the central region and its therapeutic potential were presented by Kuchcik et al. (2013). In Ciechocinek, there are high values of the perceived temperature, reaching maximum of up to 87°C (Błażejczyk, 2003).

3. Materials and methods

The influence of Graduation Tower No 1 of Ciechocinek on its microclimate was studied in 2018–2020. Two research methods were used: meteorological observations using permanent stations and mobile measurements. Two HOBO data loggers for air temperature and relative humidity registration were installed at 3 m above ground near Tower 1; they were located on the east - GT(E) and west – GT(W) side at a distance of 10 m from the Graduation Tower No 1. The non-standard placement of the recorders was dictated by the safety of the instruments. The highest vertical gradient of air temperature occurs close to the ground surface (Bokwa, 2001), therefore the differences between the 2 and 3 m levels are insignificant. Simultaneous measurements were taken using an automatic weather station in the park near Spa Hospital 1 (SH1), about 1 km from the graduation towers (Fig. 2).

On the basis of hourly measurements taken during the therapeutic seasons (June–September) of 2019 and 2020, differences in air temperature and relative humidity between stations near the graduation tower and SH1 were determined. These differences revealed the influence of the graduation towers on the surrounding microclimate in various weather conditions and at different times of day. Particular attention was paid to the conditions between 8.00 a.m. and 8 p.m. – i.e. when the spa visitors were most active in enjoying the therapeutic effects of the graduation towers.

In the study of the diversity of local bioclimatic conditions, mobile stations should be used (Kuchcik et al., 2013). In Ciechocinek the mobile measurements were carried out in the area of the towers using a Madge Tech RHTemp 101 temperature and humidity data logger placed in a radiation-proof enclosure at 2 m above ground. The other sensor was situated at SH1 in an identical enclosure (Fig. 3). These devices have a fast response time of 60 seconds (see https://www.madgetech.com). At each station, the measurements were taken for at least 2-3 minutes (additionally wind direction and speed

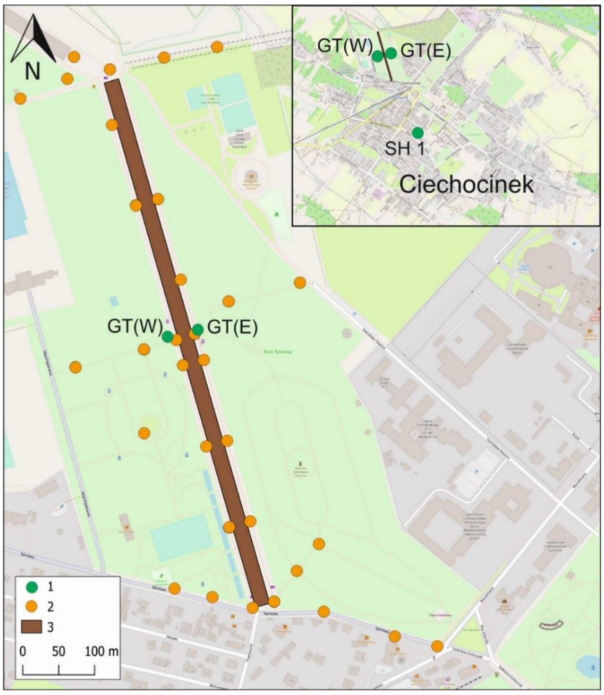

Fig. 2. Location of the measuring sites in Ciechocinek
Explanations: 1 - fixed measurement points: SH1, GT(E), GT(W); 2 - mobile measurement points; 3 - graduation tower No. 1
Source: authors' own elaboration

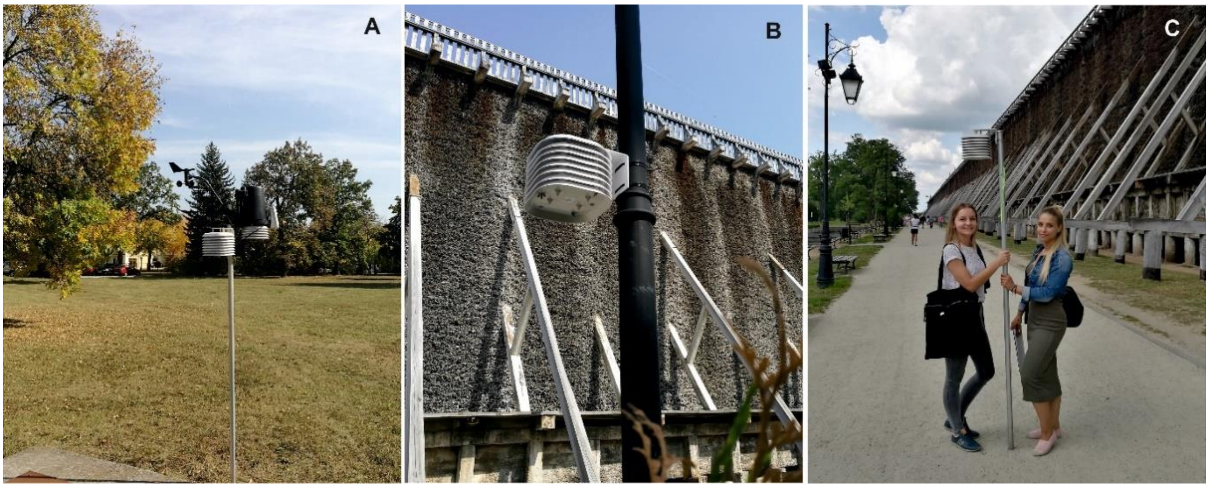

Fig. 3. Measuring sites in Ciechocinek: A – automatic weather station near Spa Hospital No 1 (SH1) B – graduation tower site – GT(W), C – mobile measurements
Source: photo M. Kejna

were measured and cloud cover was assessed). Therefore, the recorded value reflects the thermal conditions and humidity at a given position. The location of the measuring sites is shown in Fig. 2.

Measurements at SH1 and in the area of Tower 1 were synchronised, which enabled the calculation of differences in air temperature and humidity. The observations covered two seasons: 2018 (6 data series) and 2019 (1 data series). The differences provided the basis for developing air temperature and humidity distribution charts for the area of Tower 1. To this end, the inverse distance weighting (IDW) method for interpolation was used in QGIS 3.16. The interpolation weight value P was specified as 2. The use of GIS methods allows for a more detailed analysis of the spatial differentiation of bioclimatic conditions (Kuchcik et al., 2013).
The biometeorological role of the graduation towers was demonstrated on the basis of analysis of indices describing the influence of weather conditions on the human body. For SH1, GT(E) and GT(W) sites, effective temperature (TE) and Humidex were calculated. Due to low wind speeds in the park area of Ciechocinek, a formula for wind of below 0.3 $m \cdot s^{-1}$ was used to calculate TE (Missenard, 1933):

$$TE = t - 0{,}4 \cdot (t - 10{,}0) \cdot (1 - 0{,}01 \cdot RH)$$

where:
TE – effective temperature
t – air temperature
RH – relative air humidity

The nuisance of thermal and humidity conditions in Canada and the United States is determined using the Humidex index (Błażejczyk & Kunert, 2011). It is determined as follows:

$$Humidex = t + 0{,}5555 \cdot (vp - 10)$$

where:
t – air temperature
vp –water vapor pressure calculated from the formula:

$$vp = 6{,}112 \cdot 10\ [7{,}5 \cdot t\ /\ (237{,}7 + t)] \cdot 0{,}01 \cdot RH$$

RH – relative air humidity

As regards the reference site SH1, a greater quantity of data was available, so in order to describe the biometeorological background the following was also determined.

Wind Chill Index (WCI) expressed in $W \cdot m^{-2}$ and calculated using the following formula:

$$WCI = 1{,}162 \cdot [(10{,}45 - v + 10 \cdot v\ 0{,}5) \cdot (33 - t)]$$

where:
WCI – Wind Chill Index
v – wind velocity corrected to a height of 1.2 m above ground

t – air temperature

WCI considers the combined effect of air temperature and wind speed. It was introduced by Siple and Passel in 1945 during bioclimatic research in the Antarctic, but it can also be applied to other climate zones (Błażejczyk & Kunert, 2011). The wind speed was reduced from 2.4 m to 1.2 m above the ground.

Insulation Predicted (Iclp) defines the thermal insulation of clothing required to ensure the heat balance of the body in specific weather conditions. Błażejczyk et al. (2003) applied the Burton and Edholm (1955) formula to determine the total thermal insulation of clothing, and the Fourt and Hollies (1970) formula to determine the thermal insulation characteristics of the surface air layer. Iclp is expressed in clo and determined using the following formula:

$$\mathrm{Iclp} = [0{,}082\cdot[91{,}4 - (1{,}8\cdot t + 32)] / (0{,}01724\cdot M)] - [1 / (0{,}61 + 1{,}9\cdot v\ 0{,}5)]$$

where:

Iclp – Insulation Predicted

Physiological Strain (*PhS*) compares loss of body heat due to convection and evaporation. It is expressed in $W\cdot m^{-2}$ and calculated as follows:

$$\mathrm{PhS} = C/E$$

where:

PhS - Physiological Strain

C – convective heat loss

E – evaporative heat losses

When a body is overheated, perspiration increases and the heat is increasingly driven out of the body through evaporation. When more heat is lost due to convection, cold stress increases.

The above indices were calculated using Bioklima 2.6 (Błażejczyk & Błażejczyk, 2010).

The climate conditions of Ciechocinek were described on the basis of data sourced from the weather station of the Polish Institute of Meteorology and Water Management– for the years 1971–1989 (Kozłowska-Szczęsna, 2002), and for the years 2012–2020 from the weather station of the Provincial Inspectorate of Environmental Protection in Bydgoszcz.

4. Results

4.1. The climate of Ciechocinek

Meteorological observations in Ciechocinek began in 1836. A permanent weather station was not established until 1883, and then observations were carried out only during the therapeutic seasons. Only from 1900 onwards were they carried out continuously. After the break caused by World War I, observations resumed in 1920 and continued until 1939. After World War II, meteorological observations were conducted from 1947 onwards in front of the Spa Administration building, in the Municipal Gardens. The observations were discontinued in 1990 (Kozłowska-Szczęsna, 2002), but resumed in 2012, this time at the Woivodship Inspectorate of Enviromental Protection weather station between the graduation towers. In 2018, topoclimatic observations in Ciechocinek were launched from a reference station was located near Spa Hospital No 1.

The observations from the years 1971–1989 demonstrated that average cloud cover in Ciechocinek at 12 UTC was 70% and total annual sunshine duration reached 1,491.1 hours, including 17.9 days when sunshine was observed for over 8 hours (Table 1).

The mean air temperature was 8.3°C with the lowest mean temperature in January (-1.8°C) and the highest in July (18.3°C). Extreme values of temperature ranged from -30.3°C to 35.5°C. In an average year there were 42.3 hot days (T_{max} >25.0°C), 7.1 very hot days (T_{max} >30.0°C) and 14 very cold days (T_{min} <-10.0°C) (Kozłowska-Szczęsna, 2002). The mean relative humidity of the air at 12 UTC was 67%. The annual precipitation total averaged at 561 mm. During the year there were 153.3 days with precipitation (p ≥0.1 mm). The mean wind speed at 12 UTC was low (3.3 $m\cdot s^{-1}$).

By contrast, the measurements taken in the period 2012–2020 using data from the Woivodship Inspectorate of Environmental Protection weather station showed that solar irradiance amounted to 124.4 $W\cdot m^{-2}$ with a maximum of 242.9 $W\cdot m^{-2}$ in June. The mean air temperature was higher than

Table 1. Mean monthly and annual values of meteorological elements in Ciechocinek in the period 1971-1989

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
C (%)	76	74	64	68	63	66	67	64	69	68	81	82	70
SD (hours)	34.0	60.3	104.8	147	225.7	199.9	210.4	218.6	129.8	94.4	43.5	25.7	1494.1
T_{mean} (ºC)	-1.8	-1.6	3.0	7.5	13.8	16.7	18.3	17.6	13.1	8.4	3.6	0.4	8.3
T_{max} (ºC)	12.3	15	22.3	27.5	33.3	35.5	34.8	33.7	31.1	25.2	15.6	12.6	35.5
T_{min} (ºC)	-30.3	-26.6	-20.1	-5.6	-3.8	0.6	5.6	3.0	-3.2	-6.4	-11.1	-20	-30.3
RH (%)	82	75	65	56	53	58	58	57	64	71	79	83	67
P (mm)	33	24	27	25	52	77	91	64	40	47	40	41	561
WV (ms^{-1})	3.2	3.1	3.9	3.9	3.3	3.3	3.3	2.9	3.1	3.3	3.8	3.3	3.3

Explanations: C - cloudiness at 12 UTC, SD - Sunshine duration, T_{mean} – mean air temperature, T_{max} – maximum of air temperature, T_{min} – minimum of air temperature, RH - relative air humidity at 12 UTC, P – precipitation, WV - wind velocity at 12 UTC
Source: Kozłowska-Szczęsna (2002)

Table 2. Mean monthly and annual values of meteorological elements in Ciechocinek in the period 2012-2020

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nev	Dec	Year
GR (Wm^{-2})	24.4	56.0	104.5	184.5	218.1	242.9	224.0	197.6	131.2	65.2	26.6	17.4	124.4
T_{mean} (ºC)	-0.3	1.1	4.6	9.9	14.8	18.7	20.2	19.9	14.9	9.9	5.7	2.5	10.2
T_{max} (ºC)	11.3	13.4	22.3	33.5	31.8	35.3	37.2	38.3	34.3	23.4	18.3	13.8	38.3
T_{min} (ºC)	-17.9	-22.5	-16.5	-6.3	-0.9	5.0	8.6	7.2	-1.0	-3.7	-7.9	-15.3	-22.5
RH (%)	82.4	77.7	70.3	63.0	66.9	68.5	69.8	69.1	76.3	82.8	87.4	85.3	75.0
AP (hPa)	1011.4	1011.7	1011.0	1011.6	1011.7	1011.0	1010.2	1012.7	1013.8	1013.4	1013.1	1012.9	1012.0
WV (ms^{-1})	1.7	1.6	1.7	1.6	1.2	1.0	0.9	0.9	1.0	1.2	1.5	1.6	1.3

Explanations: GR - Global solar radiation, AP - air pressure (hPa), other explanations as in table 1.
Source: authors' own elaboration according to the data from the Provincial Inspectorate of Environmental Protection in Bydgoszcz

in 1971–1989 and reached as much as 10.2°C. The thermal winter became shorter; a negative mean temperature was recorded only in January (-0.3°C), whereas in July it rose to 20.2°C, which was 1.9°C higher. The mean relative humidity of the air was 75%. The mean atmospheric pressure was 1012.0 hPa, and the average wind speed near the towers did not even exceed 1.3 $m \cdot s^{-1}$ (Table 2).

Considering the continuous increase in air temperature in Poland (Kejna & Rudzki, 2021) in Ciechocinek there is also a growing problem of heatwaves.

4.2. The influence of graduation towers on air temperature

4.2.1. Course of air temperature

Continuous registration of air temperature and relative air humidity was carried out during the therapeutic seasons (June–Sept) in 2019 and 2020 (Fig. 4). In 2019 at SH1 the mean temperature was very high and reached 22.5°C in June and 20.6°C in August. In 2020, the warmest month was August with 19.9°C (Table 3). The highest temperature recorded in 2019 was 36.7°C, and in 2020 it was 32.6°C. In 2019 there were as many as 61 hot days (T_{max} ≥ 25°C), 22 very hot days (T_{max} ≥ 30°C) and 3 extremely hot days (T_{max} ≥ 35°C). In 2020 there were 54 hot and 9 very hot days. That meant substantial heat stress for the human body.

Table 3. Monthly values of air temperature in Ciechocinek (SH1) and air temperature differences between graduation towers No. 1 area (GT(E) and GT(W)) and SH1 in the seasons 2019 and 2020

Stands	Jun19	Jul19	Aug19	Sep19	Jun20	Jul20	Aug20	Sep20
SH1 (mean)	22.5	19.2	20.6	14.2	18.5	18.8	19.9	15.0
SH1 (max)	36.7	32.7	33.3	33.9	30.9	30.6	32.6	29.6
SH1 (min)	8.9	6.9	6.7	3.3	5.7	8.3	9.1	2.1
GT(E)-SH1 (mean)	-1.0	-0.8	-1.1	-0.6	-0.3	-0.8	-0.6	-0.4
GT(E)-SH1 (hourly max)	-7.5	-6.7	-7.6	-5.3	-3.7	-5.8	-6.2	-5.5
GT(W)-SH1 (mean)	-1.0	-0.7	-0.8	-0.1	-0.3	-0.4	-0.9	-0.2
GT(W)-SH1 (hourly max)	-4.9	-5.1	-6.5	-2.7	-5.2	-5.9	-6.3	-6.2

Source: author's own elaboration

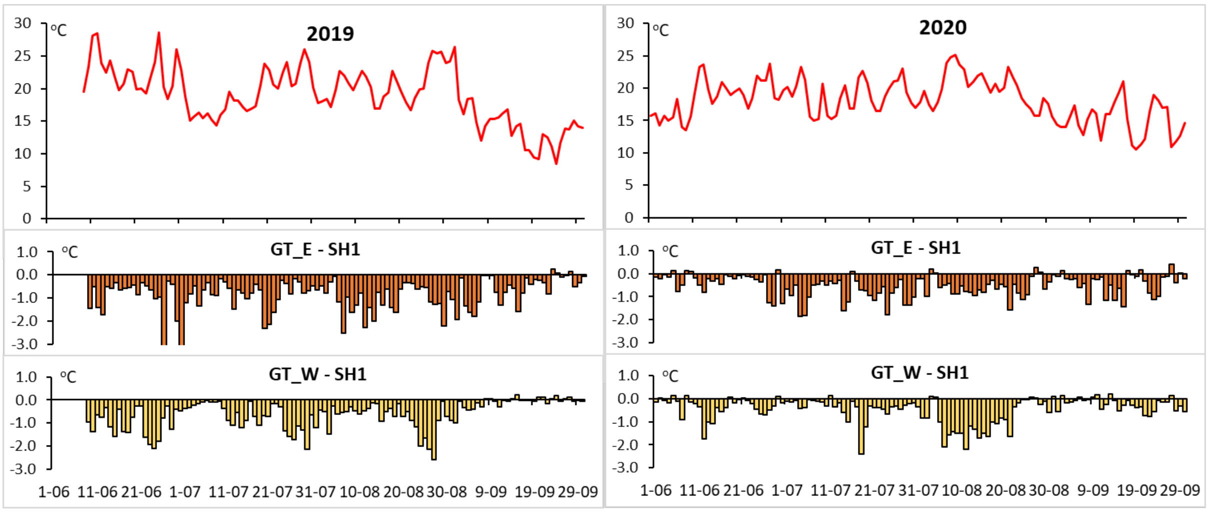

Fig. 4. Course of daily values of air temperature in Ciechocinek (Hospital No. 1 – SH1) and temperature differences between graduation towers No. 1 area: GT_E and GT_W and SH1 in the seasons 2019 and 2020

The air temperature near the relevant graduation tower was lower than at SH1. On average, in the analysed seasons it was 0.7°C colder on the east side GT(E) and 0.5°C colder on the west side GT(W). Maximum differences at individual hours reached 7.5°C at GT(E) and 6.5°C at GT(W). The greatest differences were found for high air temperature values (Fig. 4).

In the diurnal cycle, averaged for the years 2019 and 2020, the lowest temperature at SH1 occurred at 05:00 (13.4°C), whereas at the graduation towers it was at 06:00: 13.7°C – GT(E) and 13.6°C – GT(W) – (Fig. 5).

An analysis of the frequency of occurrence of the differences in air temperature between the tower sites and SH1 during the day (between 08:00 and 20:00) indicated a clear predominance of negative anomalies. On the east side of the tower as many as 91.7% of the hourly situations were characterised

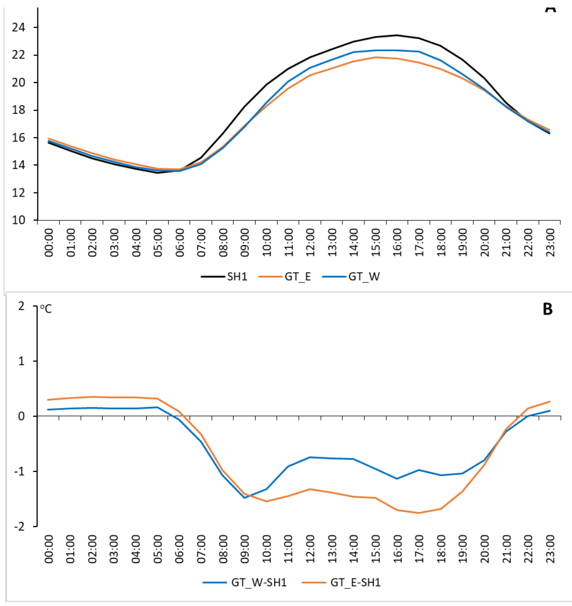

Fig. 5. A - Daily courses of air temperature in Ciechocinek, B - Temperature differences between GT_E/GT_W and SH1 in the seasons 2019 and 2020

by lower temperature – typically within a range of 0.0°C to -0.9°C (30.4%), between -1.0°C and -1.9°C (23.8%) and -2.0°C and -2.9°C (23.6%). Similarly, on the west side, 75.7% hours fell within the three intervals, with a maximum between 0.0°C and -0.9°C (44.4%), and between -1.0°C and -1.9°C (21.4%).

4.2.2. Spatial influence

The influence of the graduation towers on air temperature was analysed on the basis of mobile measurements. Using seven series of observations obtained during the therapeutic seasons of 2018 and 2019 it was found that the temperature of air in the vicinity of the graduation towers was lower. The greatest differences occurred at the northern part of the structure and reached -2.4°C. In the southern part the difference was -1.6°C (Fig. 6).

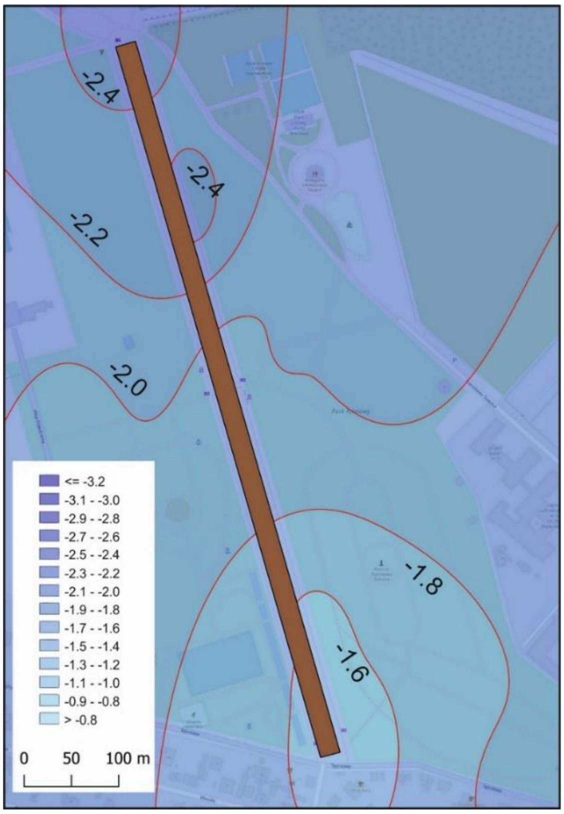

Fig. 6. Distribution of air temperature differences (in oC) in the vicinity of Graduation Tower No 1 in Ciechocinek compared to SH1 based on seven data series from 2018 and 2019.

On individual days, temperature differences followed different patterns, depending on wind direction (Fig. 7). On 17 July 2019, with a westerly (W) wind the greatest differences occurred on the northern and eastern sides of the tower (to -2.4°C). Similarly, on 15 September 2018, with the same wind direction it was colder on the eastern side of the tower (-2.8°C). On the other hand, with a SE wind on 22 September 2018 it was much colder on the western side of the tower. The southerly wind on 30 September 2018 made the northern side of the tower colder (to -2.4°C). The temperature distribution also changes at different times of day; thus, in the morning hours the area to the east of the tower received more sunshine. In the afternoon, the western side is more exposed to the sun and reaches higher temperatures. That is why on 15 August 2018 the eastern side of the tower was markedly colder (the measurements were taken at 16:45–17:26).

4.3. The influence of graduation towers on relative air humidity

4.3.1. Course of relative air humidity

The mean relative humidity of air in the analysed therapeutic seasons of 2019 and 2020 reached 73% at SH1 (Table 4). The course of RH revealed periods with substantial or slight saturation of air with water vapour. The diurnal means at SH1 changed within the range of 49% to 95% (Fig. 8). The relative air humidity near the graduation tower was found to be greater: by 4.6% on average at GT(E) and by 3.6% at GT(W). Maximum differences reached 31.0% and 33.2%, respectively. On the western side of the tower, however, there were days with lower air humidity.

In the diurnal cycle, the highest relative humidity of air was common at night, and in particular in the early hours when the air temperature was lowest: at 06:00 it was 90% at SH1 and 92% at GT(E) and GT(W) – (Fig. 9).

During the day the relative humidity decreased, reaching 56%, 63% and 60% at the respective sites at 16:00. Throughout the whole day a higher humidity of air was observed at the graduation tower, and the greatest differences were found at daytime. At GT(E), the greatest differences occurred at 10:00

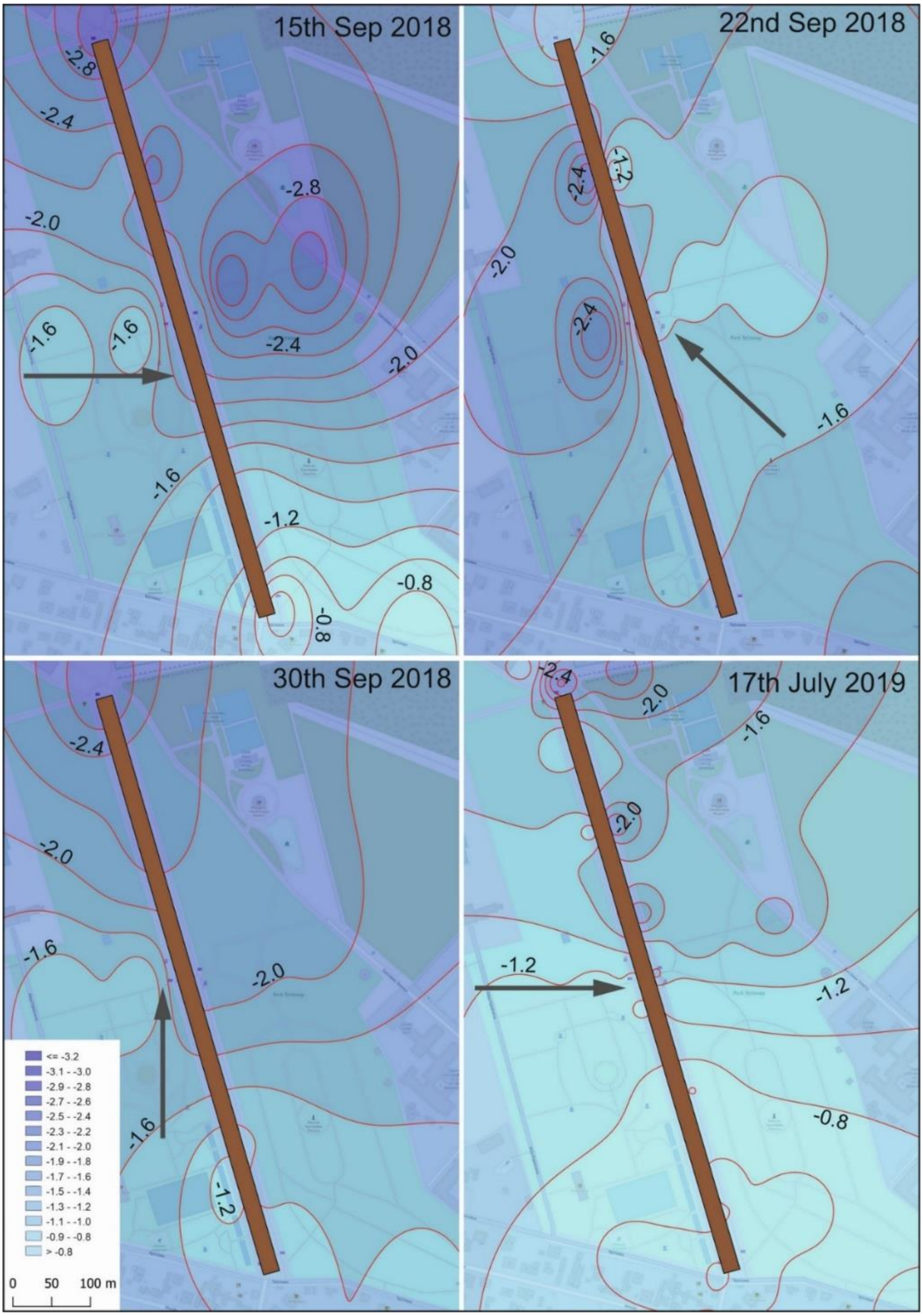

Fig. 7. Distribution of air temperature differences (in °C) in the vicinity of Graduation Tower 1 in Ciechocinek compared to SH1 on selected days of 2018 and 2019. Prevailing wind direction is shown with an arrow

Table 4. Monthly values of relative air humidity in Ciechocinek (SH1) and differences between graduation towers No. 1 area: GT(E) and GT(W) and SH1 in the seasons 2019 and 2020

Stands	Jun19	Jul19	Aug19	Sep19	Jun20	Jul20	Aug20	Sep20	Mean
SH1	65.2	67.8	68.5	79.5	77.8	72.2	74.1	80.8	73.3
GT(E)-SH1 (mean)	3.0	4.5	5.0	5.7	2.6	5.9	3.8	6.1	4.6
GT(E)-SH1 (hourly max)	26.1	31.0	29.0	27.4	19.5	25.2	25.8	33.7	31.0
GT(W)-SH1 (mean)	4.7	3.5	3.6	1.4	3.0	1.9	6.0	4.5	3.6
GT(W)-SH1 (hourly max)	31.8	26.9	31.6	18.5	26.5	33.2	28.9	31.0	33.2

Source: author's own elaboration

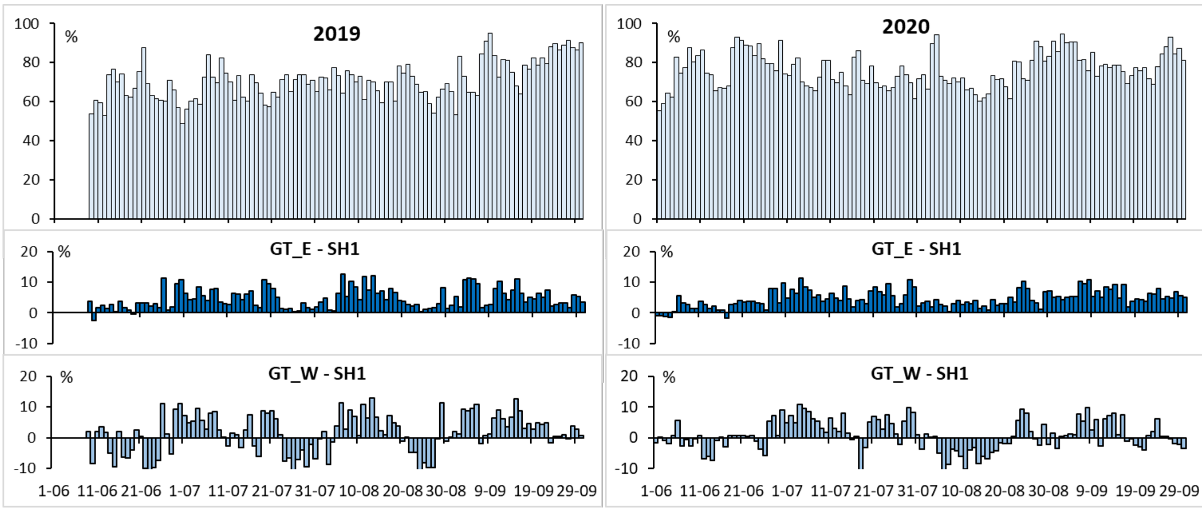

Fig. 8. Course of daily values of relative air humidity in Ciechocinek (Hospital No. 1 – SH1) and differences between graduation towers No. 1 area: GT_E and GT_W and SH1 in the seasons 2019 and 2020

and 17:00 (8%), whereas at GT(W), after an initial increase in the differences at 09:00 (7%), they decreased in the afternoon and rose back to 5% in the evening. Such a clear decrease in the differences of RH in the afternoon indicates that humid air was conveyed away from the area of the towers by convection.

An analysis of the frequency of occurrence of the differences demonstrated an evident influence of the graduation tower on the relative humidity of air. From 08:00 to 20:00, on the eastern side of the tower, GT(E), in as many as 90.8% of the cases the RH was higher, usually by 0–4% (36.2%) and 5–9% (25.3%). On the western side, GT(W), at 73.8% of the hours the air was more humid, and the maximum frequency ranged within 0–4% (34.6%). What is noteworthy is that there was a number of situations in which the air was less humid near the graduation tower (23.3% such situations with less humid). This may be due to the prevailing westerly wind transporting humid air masses to the east of the graduation tower, while drier air flows from the upwind side.

4.3.2. Spatial influence

The influence of the graduation towers is even more evident as regards air humidity. Based on mobile measurements, it was found that mean differences reach 14%, especially at the northern part of the tower. In the southern part the air was less saturated (6–8%) – (Fig. 10).

On individual days the differences in relative humidity were even greater – close to the graduation tower in particular (Fig. 11). On 17 July 2019, with a westerly (W) wind the air was 14% more humid on the eastern side of the tower, but only 2% more on the upwind side. On 15 September 2018 humidity was higher on the eastern side (by 18%); the prevailing wind was westerly and carried

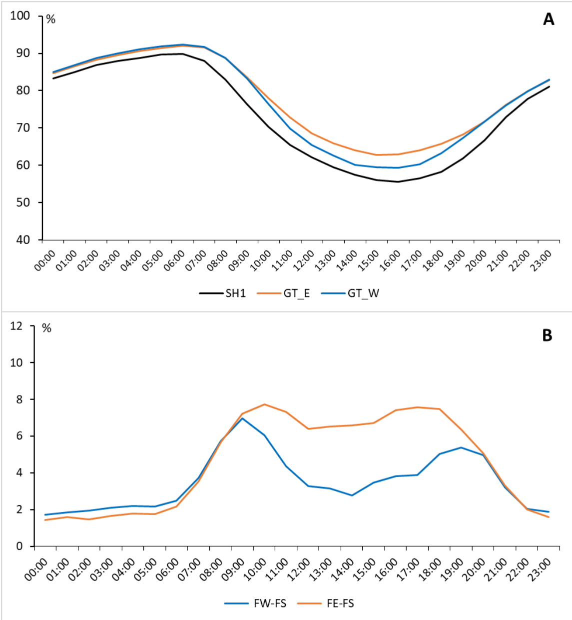

Fig. 9. Daily courses of relative air humidity in Ciechocinek (A) and differences between graduation towers No. 1 area: GT_E and/ GT_W and SH1 (B) in the seasons 2019 and 2020

the air eastwards from above the graduation towers. On the other hand, on 22 September 2018, with a SE wind, the air was more humid on the western side of the tower (by 10%). On 30 September 2018 the southerly wind carried humid air masses from above the graduation towers causing the humidity to rise in the northern part of the tower (by 16%).

4.4. Biometeorological conditions

The biometeorological conditions in Ciechocinek are presented here on the basis of measurements taken at Spa Hospital 1 during two therapeutic seasons (Jun–Sept) of 2019 and 2020, and a detailed analysis covered the period of increased activity of spa visitors, i.e. the hours from 08:00 until 20:00.

A comprehensive view on the influence of air temperature and wind speed is provided by the Wind Chill Index (WCI). Considering the time of year, no values greater than 702.7 W·m^{-2} were observed. Comfortable conditions were the most frequent (55.4%), but there were times of greater heat stress: at 30.5% hours it was too warm, at 9.0% hours it was too hot and extreme heat was observed for a total of 137 hours, i.e. 4.5%. Conditions perceived as cold hardly ever occurred (0.6%) – Table 5.

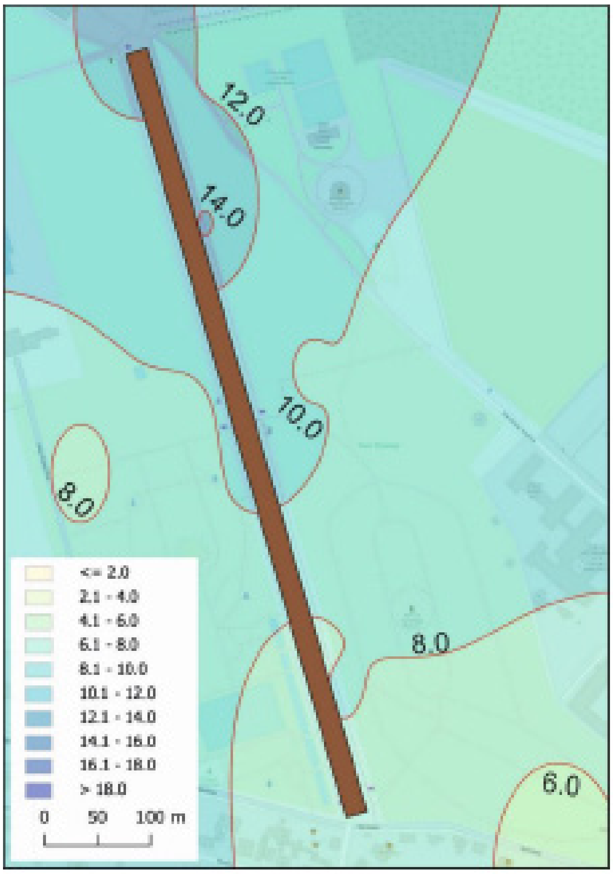

Fig. 10. Distribution of differences in relative air humidity in the vicinity of Graduation Tower 1 in Ciechocinek compared to SH1, based on seven data series from 2018 and 2019

An analysis of Insulation Predicted (Iclp) in Ciechocinek (SH1) shows that the most frequent were very hot days (<0.30 clo): 51.3%, and hot days: 42.9%; neutral conditions were very infrequent (5.7%) – Table 5. This means that only light clothes were worn to ensure a proper heat balance of the body. The maximum value of Iclp reached 1.23 clo, which corresponds to cool weather (Krawczyk, 2003). Yet this kind of condition occurred very rarely.

An analysis of the hourly values of Physiological Strain (PhS) demonstrated that the prevailing conditions in Ciechocinek were thermally neutral (61.2%), in which the thermoregulatory response of the body is moderate (Table 5). Heat stress increased substantially at 30.0% of times, and was of high intensity at 7.2% of them. It was also found that at 1.5% of the hours (47 in total) the cold stress was

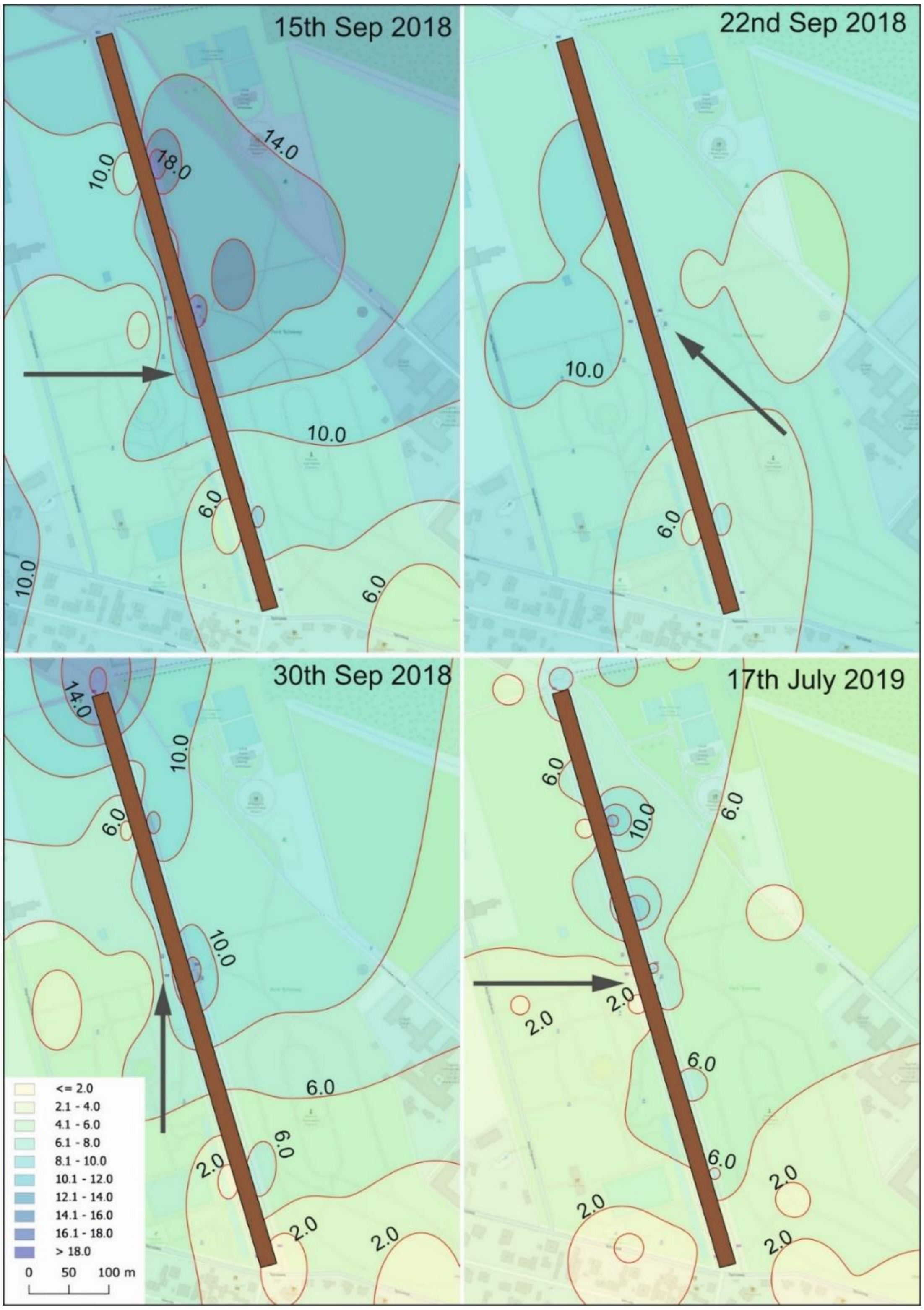

Fig. 11. Distribution of differences in relative air humidity in the vicinity of Graduation Tower 1 in Ciechocinek on selected days of 2018 and 2019. Prevailing wind direction is shown with an arrow

Table 5. The frequency of the thermal feeling (WCI - Wind Chill Index), Insulation Predicted (ICLP) and occurrence of the Physiological Strain (PhS) in Ciechocinek (SH1) between from 8:00 to 20:00 in the period June-September 2019 and 2020

Wind Chill Index (WCI) in $W\cdot m^{-2}$			Insulation Predicted (Iclp) in clo			Physiological Strain (PhS) in $W\cdot m^{-2}$		
Thermal feeling	Range	Freq. (%)	Thermal environment	Range	Freq. (%)	Physiological Strain	Range	Freq. (%)
Extremely hot	< 58,3	4.5	Very warm	≤0.30	51.3	High intensity of heat stress	<0,25	7.2
Hot	58,3–116,3	9.0	Warm	0.31-0.80	42.9	Significant intensity of heat stress	0,25-0,75	30.0
Too warm	116,4–232,6	30.5	Neutral	0.81-1.20	5.7	Thermoneutral conditions	0,76-1,50	61.2
Comfortably	232,7–581,5	55.4	Chilly	1.21-2.00	0.1	Significant intensity of cold stress	1,51-4,00	1.5
Chilly	581,6–930,4	0.6				High levels of cold stress	> 4,00	.
Maximum WCI	702.7		Maksimum ICLP	1.23		Maximum PhS	1.86	

Source: author's own elaboration

considerably intense, with the maximum reaching 1.86 $W\cdot m^{-2}$.

Looking into the above indices, it is evident that in the therapeutic season in Ciechocinek (SH1) comfortable or neutral conditions occur in 55–60% of the analysed time. Very hot conditions with heat stress are frequent, and these require suitable clothing. That is why, in climatotherapy, energy-saving conditions are required in treatment. Such conditions are provided around the graduation towers. The influence of graduation towers on the bioclimate was analysed on the basis of two indices:

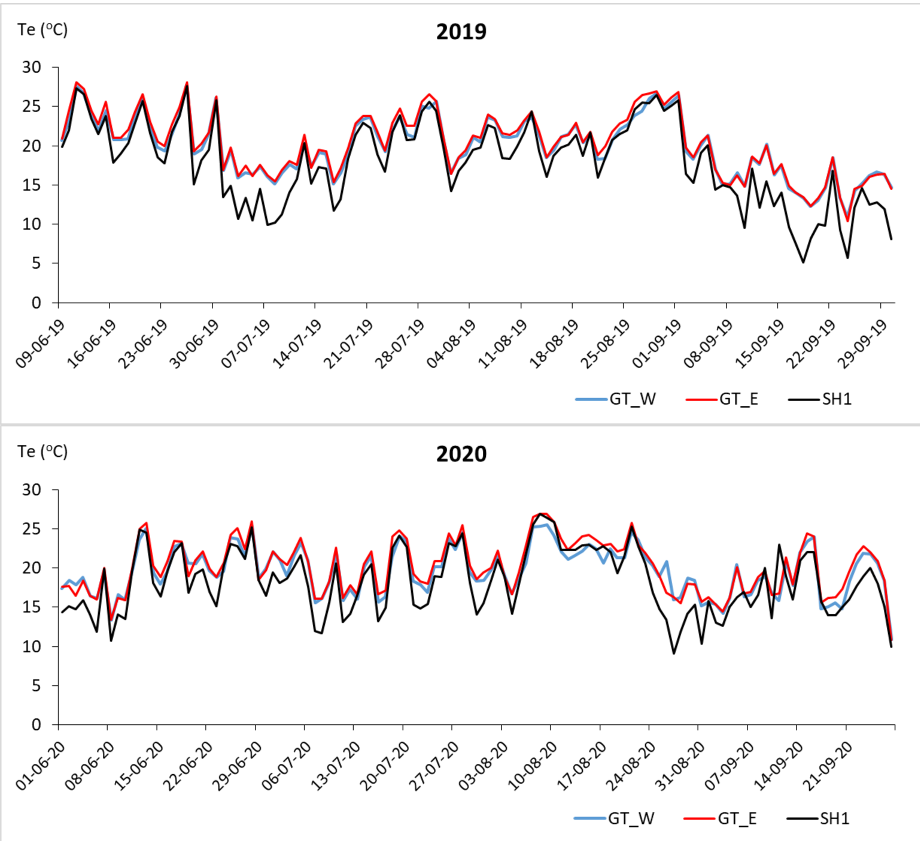

Fig. 12. Course of mean daily values of the Effective Temperature (TE) in Ciechocinek in the period June-September 2019 and 2020

Table 6. Frequency of the Effective Temperature (TE) and Humidex index in Ciechocinek (SH1) and near the graduation tower No. 1 (GT_E and GT_W) from 8:00 to 20:00 in the period June-September 2019 and 2020

Thermal feeling	Effective Temperature (TE)				Humidex index				
	Range	SH1	GT_E	GT_W	Thermal filling	Range	SH1	GT_E	GT_W
Very cold	TE<1°C	0.0	.	.		≤20.0°C	27.2	31.0	29.2
Cold	1°C≤TE<9°C	3.9	0.6	0.9	Lack of discomfort	20.1°C-30°C	51.4	54.2	54.8
Chilly	9°C≤TE<17°C	40.2	28.5	31.7	Slight discomfort	30.1°C - 40.0°C	21.0	14.7	15.9
Refreshing	17°C≤TE<21°C	29.1	35.4	38.1	Great discomfort	40.1°C - 45.0°C	0.4	0.0	0.0
Comfortably	21°C≤TE<23°C	13.2	15.5	16.0	The danger of heat stroke	>45°C	.	.	.
Warm	23°C≤TE<27°C	12.7	18.1	12.6					
Hot	TE≥27,0°C	0.9	1.9	0.7					
Maximum		29.5	29.6	28.5	Maximum		43.4	38.3	40.6

Source: author's own elaboration

Effective Temperature (TE) and Humidex. They consider the combined influence of air temperature and humidity. It was assumed that the effects of wind were negligible and that the person was walking and wearing summer clothes with an Iclp of 1 clo.

In the analysed period in Ciechocinek, TE was substantially variable relative to weather conditions (Fig. 12). The thermal sensation connected with TE was used according to Michajłow (Błażejczyk, 2011, http://rcin.org.pl). An analysis of the hourly values of TE indicated that – compared to SH1 – in the area of the graduation towers the conditions were more revitalising (35.4% at GT[E] and 38.1% at GT[W]) or comfortable (15.5% and 16.0%, respectively) - Table 6.

Humidex, based on the criteria of the Canadian meteorological service (Błażejczyk & Kunert, 2011), shows a greater frequency of comfortable conditions at the graduation towers. At SH1 slight discomfort was observed in 21.0% cases, whereas at Graduation Tower 1 the same conditions applied in 14.7% (GT[E]) and 15.9% (GT[W]) of cases. Also, 12 hours of increased discomfort were recorded at Spa Hospital 1 (Table 6). The maximum values of Humidex reached do 43.4oC, 38.3oC and 40.6oC. respectively. By comparison, in Warsaw, during a hot day, the Humidex reached 35oC. These values are above the warning level and prolonged physical exertion may lead to overheating of the body (Błażejczyk & Kunert, 2011).

5. Summary

Graduation towers are enjoying a revival, and are used not only for brine graduation, but also to ameliorate the climate of urban spaces and spa quarters of towns, in particular. In 1999 in Poland there were 89 graduation towers of various sizes in operation (Faracik, 2020b).

The influence of graduation towers on air temperature mainly consists in the absorption of heat by the evaporation of water. Research (Łabędzki et al. 2012) has shown that in Central Poland (Poznań) the mean reference evapotranspiration determined using the Penman-Monteith method in June–September of 1970–2004 amounted to 382 mm, with a maximum of 116 mm in July. Consequently, water evaporated at a rate of 382 $L·m^{-2}$. Assuming that 2,257 J are required to evaporate 1 L of water, this gives 862.2 kJ of heat per square metre of surface. Evaporation from such a structure as a graduation tower is several times greater, and hence its cooling power is substantial. Another factor is the shade that restricts direct solar radiation. In Ciechocinek, the meridional arrangement of Graduation Tower 1 favours distinctive thermal differences between the eastern side, GT(E), and the western side GT(W) of the structure.

In the two analysed therapeutic seasons (Jun–Sept 2019 and 2020), it was on average 0.5°C cooler on the eastern side of the graduation tower and 0.7°C cooler on the western side than in Hospital No. 1. However, the maximum differences in hourly values reached 7.5°C and 6.5°C, respectively. In the diurnal cycle, the greatest differences occurred at about 8–9 a.m. and 5–6 p.m. At around midday the cooling effect of the graduation tower was found to be slightly weaker. From 8 a.m. until 8 p.m., it was cooler at as many as 91.7% of the hours on the eastern side, but at only 75.7% on the western side. The thermal influence of the tower was limited to its nearest vicinity. It was 2.4°C colder to the north of the tower, but in its southern part the difference was 1.6°C. At the same time, the influence of wind direction is clear, as the wind carried colder air masses away to the downwind side of the graduation tower. Moreover, insolation plays an important part and this depends on the time of day. In the morning hours it was warmer on the eastern side of the tower, but in the afternoon the western side was warmer.

Water evaporation in the process of brine graduation increases the relative humidity of air near the graduation towers by 4.6% on average at GT(E) and 3.6% at GT(W). The greatest differences were observed in the morning and evening hours (8–9%). Around midday, due to convection and turbulence, water vapour and air were quickly conveyed away from the area and the differences decreased to 3–6%. During the day, from 8 a.m. to 8 p.m., on the eastern side of the graduation tower, it was more humid at 90.8% of the times and on the western side at 73.8% of times. Maximum differences in humidity exceeded 30%. The spatial influence of the graduation towers on air humidity is especially evident directly at the tower, where the average difference ranged from 7% (S) to 14% (N). The distribution of more humid and drier air masses changes depending on wind direction. Humidity was higher on the eastern side of the tower.

Referring to the Wind Chill Index, in the therapeutic seasons of 2019 and 2020, at Spa Hospital 1 in Ciechocinek, the prevailing conditions were comfortable (55.4%), but in 30.5% of the hours it was too hot, and even extremely hot (4.5%). According to the Effective Temperature index, it was found that the prevailing conditions near the graduation tower were revitalising (in 35.4% of cases on the eastern side and 38.1% on the western side) or comfortable (15.5% and 16.0%, respectively).

In Inowrocław, the temperature felt in July in 1971-1990 in as many as 45.6% of days reached values defined as hot or very hot (Błażejczyk, 2004). The Insulation Predicted (Iclp) indicates that neutral conditions were in Ciechocinek rare (5.7%), whereas very hot conditions (<0.30 clo) were much more frequent (51.3%). A substantial heat stress load, determined using the Physiological Strain index (PhS), occurred at 30% of the times, whereas its high intensity was found at 7.2% of the times. A positive influence of graduation towers is corroborated by Humidex: comfortable conditions prevail in the vicinity of the tower in Ciechocinek. Kozłowska-Szczęsna et al. (2002) calculated the values of the Heat Stress Index (HSI) for Ciechocinek. Mild and moderate heat stress prevailed in the summer months of 1971-1989. However, there were situations with varying degrees of heat stress, lasting in July for an average of 21.2% of the days.

Considering the ever-increasing air temperature in Poland and elsewhere in the world a weather stress is increasingly frequently encountered – especially in cities (Li & Chan, 2000). The mean air temperature in Central Poland in the years 1961–2018 increased at a rate of 0.4°C·10 yr^{-1} (Kejna & Rudzki, 2021). In cities such as Warsaw there is a great increase in discomfort during the day, which may lead to overheating of the human body (Błażejczyk & Kunert, 2011). Błażejczyk et al. (2003) observed that in the 20th century in Cracow there was a positive trend in the value of Subjective Temperature Index (STI) and a decrease in the predicted insulation of clothing (Iclp). This proves the gradual intensification of heat stress in Poland. However, research conducted in Poland by Baranowska et al. (1986) demonstrated individual thermal sensitivity of humans, depending on the region of the country.

Graduation towers can be effective as part of the treatment of a number of medical conditions (Ponikowska & Ferson, 2009). The concentration of salt in the air near graduation towers is twice as high as at the Baltic Sea (Czajka et al. 2006). The microclimate in the vicinity of graduation towers has characteristics of the maritime climate (Kuchcik et al. 2013).

Moreover, graduation towers mitigate weather conditions: in Ciechocinek it was found that heat stress occurred less often in their vicinity, and even in extremely hot weather comfortable or revitalising conditions are ensured there.

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References

Baranowska, M., Boniecka-Żółcik. H. & Gurba, A. (1986). Weryfikacja skali klimatu odczuwalnego dla Polski. *Przegląd Geofizyczny*, 31(1): 27–40.

Błażejczyk, K. (1988). Zróżnicowanie biotopoklimatyczne Ciechocinka. *Problemy Uzdrowiskowe*, 5/6 (247-248): 49-61.

Błażejczyk, K. (2003). Biothermal features of the climate of Poland. *Przegląd Geograficzny*, 75: 525-543.

Błażejczyk, K. (2004). Bioklimatyczne uwarunkowania rekreacji i turystyki w Polsce. Przegląd Geograficzny, 192, PAN IGiPZ, Warszawa.

Błażejczyk, K. & Błażejczyk, M. (2010) BioKlima 2.6 (Accessed 25 August 2020) http://www.igipz.pan.pl/geoekoklimat/blaz/BioKlima.htm.

Błażejczyk, K. & Krawczyk, B. (1991). The influence of climatic conditions on the heat balance of the human body. *International Journal of Biometeorology*, 35: 103–106.

Błażejczyk, K. & Kunert, A. (2011). Bioklimatyczne uwarunkowania rekreacji i turystyki w Polsce (Bioclimatic principles of recreation and tourism in Poland - in Polish), Warszawa, PAN IGiPZ.

Błażejczyk, K., Twardosz, R. & Kuner, A. (2003). Zmienność warunków biotermicznych w Krakowie w XX wieku na tle wahań cyrkulacji atmosferycznej. In K. Błażejczyk, B. Krawczyk, M. Kuchcik (eds.), Postępy w badaniach klimatycznych i bioklimatycznych, 233–246, Warszawa: Przeglad Geograficzny IGiPZ PAN.

Bokwa, A. (2001). Ekstremalne gradienty temperatury w przygruntowej warstwie powietrza (Extreme thermal gradients in the air layer near the ground - in Polish). *Przegląd Naukowy Wydziału Inżynierii i Kształtowania Środowiska*, 21: 153-159.

Burkowska-But, A. (2016). Tężnie jako czynnik kształtujący mikrobiologiczną jakość powietrza w uzdrowisku. Toruń: Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika.

Burkowska-But, A., Kalwasińska, A. & Swiontek-Brzezinska, M. (2014). The role of open-air inhalatoria in the air quality improvement in spa towns. Int. J. *Occupational Medicine and Environmental Health*, 27(4), 560-570. DOI: http://dx.doi.org/10.2478/s13382-014-0274-8.

Burton, A.C. & Edholm, O.G. (1955). Man in a Cold Environment. London: E. Arnold.

Chełchowski, W. (1958) Wartości ochładzania w ciechocińskim kąpielisku pod tężniami. *Wiad. Uzdrowisk.*, 3(3): 19-25.

Ciężkowski, W., Chowaniec, J., Górecki, W., Krawiec, A., Rajchel, L. & Zuber, A. (2010). Mineral and thermal waters of Poland. *Przegląd Geologiczny*, 58(9/1): 762-773.

Czajka, K., Sziwa, D., Drobnik, M. & Latour, Y. (2006). Porównanie właściwości mikroklimatu i aerozoli w wyrobiskach kopalnianych i naziemnych grotach solnych (The comparison of the microclimate and aerosols properties in the salt mines and the artificial salt chambers - in Polish). *Balneologia Polska*, 48: 176-181.

Faracik, R. (2011). Park Solankowy w Inowrocławiu, Zdjęcia lotnicze. In K. Pyka (Ed.) Atlas fotointerpretacyjny, Tarnów: MGGPAero sp. z o.o.

Faracik, R. (2020a). Dziedzictwo salinarne a współczesna haloterapia w Europie Środkowej (The heritage of a salt mines and contemporary halotherapy in Central Europe - in Polish). In B. Płonka-Syroka B. et al. (Eds) Tradycje i perspektywy rozwoju kultury uzdrowiskowej w Muszynie w kontekście europejskim, 383–398, Wrocław: Oficyna Wyd. Arboretum.

Faracik, R. (2020b). Tężnie w Polsce. Geneza, stan i przyszłość zjawiska (Graduation towers in Poland. Genesis, current state and future of the phenomenon - in Polish). *Przegląd Geograficzny*, 161: 41-59. DOI: https://doi.org/10.4467/20833113PG.20.007.12549.

Fourt, J. & Hollies, N.R.S. (1970). Clothing. Comfort and Function. New York: M. Dekker Inc.

Gaweł, J. & Kuczaj, P. (2012). W cieniu tężni. *Wszechświat*, 113(4–6): 128-131.

GUS (2022) Główny Urząd Statystyczny - https://stat.gov.pl.

Gonia, A. & Podgórski, Z. (2019). Ocena stanu rozwoju funkcji turystycznej gmin województwa kujawsko-pomorskiego (Assessment of tourist function development in communes of the kujawsko-pomorskie voivodeship - in Polish). *Czasopismo Geograficzne*, 90(1): 88-104.

Gurba, A. (1959). O wartościach wielkości ochładzania w Ciechocinku. *Wiad.i Uzdrowiskowe*, 4(1/2): 77-84.

Helbin, J. & Kolarzyk, E. (2005). Wykorzystanie walorów środowiska naturalnego w wspomaganiu leczenia farmakologicznego (Natural environment advantages in pharmacological treatment support - in Polish) . *Problemy Higieny i Epidemiologii*, 86(1): 22-26.

Kamyk, J. (2008). Rynek soli w Polsce – stan obecny i tendencje zmian (Salt market in Poland – current state and tendencies of changes - in Polish). *Gospodarka Surowcami Mineralnymi*, 24(4/4): 143-153.

Kejna, M. & Rudzki, M. (2021). Spatial diversity of air temperature changes in Poland in 1961–2018. *Theoretical and Applied Climatology*, 143: 1361–1379. DOI: https://doi.org/10.1007/s00704-020-03487-8.

Kozłowska-Szczęsna, T. (1964). Porównanie klimatu Ciechocinka i Inowrocławia (Comparison of Ciechocinek and Inowrocław climates - in Polish). *Przegląd Geofizyczny*, 9(17): 249-263.

Kozłowska-Szczęsna, T. (1965). Bioklimat Ciechocinka (The bioclimate of Ciechocinek - in Polish). *Probl. Uzdrowisk.*, 4(26): 1-72.

Kozłowska-Szczęsna, T. (2000). Stan badań klimatu i bioklimatu uzdrowisk polskich. Warszawa: Dokumentacja Geograficzna, PAN.

Kozłowska-Szczęsna, T. & Błażejczyk, K. (1999). Osobliwości warunków bioklimatycznych Ciechocinka - wybrane zagadnienia (Bioclimatic peculiarities of Ciechocinek - selected issues - in Polish). Balneologia Polska, 41(1-2): 126-132.

Kozłowska-Szczęsna, T. & Błażejczyk, K. (2001). Warunki bioklimatyczne Ciechocinka (Bioclimatic conditions in Ciechocinek - in Polish). In: Ciechocinek Dzieje uzdrowiska, 112-140, WTN, Włocławek.

Kozłowska-Szczęsna, T., Błażejczyk, K., Krawczyk. B. & Limanówka, D. (2002). Bioklimat uzdrowisk polskich i możliwości jego wykorzystania w lecznictwie. Warszawa: Monografie PAN IGiPZ.

Krawczyk, B. (2003). Stres ciepła - cecha bioklimatu Polski. Postępy w badaniach klimatycznych i bioklimatycznych (Heat stress - a feature of Polish bioclimate. Advances in climatic and bioclimatic research - in Polish). In K. Błażejczyk, B. Krawczyk, M. Kuchcik M (eds), 283-294, *Przegląd Geograficzny*, PAN IGiPZ, Warszawa.

Krawiec, A. (2009). Wody termalne w uzdrowisku Ciechocinek (Thermal waters in Ciechocinek health resort - in Polish). *Technika Poszukiwań Geologicznych*, 48(2): 73-80.

Krzyżaniak-Sitarz, M. (2012). Influence of graduation towers on average annual cations content in black earths (mollic gleysols) in the Inowroclaw city. *Ecological Chemistry and Engineering A*, 19(6): 573-582. DOI: https://doi.org/10.2428/Ecea.2012.19(06)058.

Kuchcik, M. (2011). O potrzebie prowadzenia badań lokalnego zróżnicowania warunków klimatycznych w uzdrowiskach. *Acta Balneologica*, LIII(2): 144–150.

Kuchcik, M., Błażejczyk, K., Szmyd, J., Milewski, P., Błażejczyk, A. & Baranowski, J. (2013). Potencjał leczniczy klimatu Polski (Healing potential of Polish climate - in Polish). Warszawa: Wyd. Akad. Sedno.

Langer, P. (2014). Salt treatment as an impulse for industrial towns' function change. *Czasopismo Techniczne. Architektura*, 111(4A): 73-86.

Li, P.W. & Chan, S.T. (2000). Application of a weather stress index for alerting the public to stressful weather in Hong Kong. *Meteorological Applications*, 7: 369–375.

Łabędzki, L., Bąk, B. & Kanecka-Geszke, E. (2012.) Wielkość i zmienność ewapotranspiracji wskaźnikowej według Penmana-Monteitha w okresie wegetacyjnym w latach 1970–2004 w wybranych rejonach Polski. (Magnitude and variability of Penman-Monteith reference evapotranspiration in the growing season of 1970–2004 in selected regions of Poland - in Polish). *Woda-Środowisko-Obszary Wiejskie*, 12(38): 159-170.

Marciniak, K. (1983). Klimat. In D. Iwanowska-Jeskie (Ed.) Uzdrowisko Ciechocinek. *Sport i Turystyka Warszawa*: 31-44.

Marciniak, K. (1986). Warunki klimatyczne Ciechocinka. In Uzdrowisko Ciechocinek, 150 lat. *Jantarowe Szlaki*, 29, 1(199): 10-14.

Matczak, A. (2019). Zmiany w strukturze funkcji turystycznej uzdrowisk kujawskich (na podstawie wielkości i struktury bazy noclegowej) (Changes in the tourist function of Kujawy health resorts (based on the capacity and type of accommodation - in Polish). *Turyzm*, 29(1): 57-67. DOI: 10.18778/0867-5856.29.1.06.

Missenard, F.A. (1933). Température effective d'une atmosphere Généralisation température résultante d'un milieu. In Encyclopédie Industrielle et Commerciale, Etude physiologique et technique de la ventilation, *Librerie de l'Enseignement Technique*, 131–185, Paris.

Nocna, A. (2016). Architektura urządzeń lecznictwa uzdrowiskowego w Ciechocinku w świetle użytkowym i historycznym. In: S. Kubiak (red). Ciechocinek i jego znaczenie we współczesnym lecznictwie uzdrowiskowo-rehabilitacyjnym. *Zeszyty Naukowo-Historyczne Towarzystwa Przyjaciół Ciechocinka*, 4, 129–150.

Paszyński, J. (1957). Zróżnicowanie klimatyczne okolic Ciechocinka (The climatic differentiation of the Ciechocinek-region - in Polish). *Przegl. Geofiz.* 2(10): 15-31.

Piasecki, P. (2010). Salinentechnik, In: F. Jaeger (ed.), Enzyklopädie der Neuzeit, Band 11, 542–549, Metzler, Stuttgart/Weimar.

Ponikowska, I. & Ferson, D. (2009) *Nowoczesna medycyna uzdrowiskowa* (Modern health resort medicine - in Polish). Warszawa: Medi Press.

Ponikowska, I., Latour, T., Czerwinskaja, A., Chojnowski, J., Błaszkiewicz, B. & Szmurło, W. (2009). Badania właściwości fizyczno-chemicznych suchego aerozolu solnego w komorze naziemnej (Investigation in physico-chemical proprties of dry salt aerosol in artifical caves - in Polish). *Balneologia Polska*, 60(2): 92–100.

Ponikowska, I. & Marciniak, K. (1988). *Ciechocinek, terenoterapia uzdrowiskowa*. Warszawa-Poznań: PWN.

Ponikowska, I., Marciniak, K. & Graczykowska-Koczorowska, A. (1979). Wykorzystanie mikroklimatu tężniowego w Ciechocinku do leczenia nadczynności tarczycy. *Balneologia Polska*, 24: 603-610.

Siple, P.A. & Passel, C.F. (1945). Measurements of dry atmospheric cooling in subfreezing temperatures. *Proceedings of the American Philosophical Society*, 89: 177–199.

Stribu, C., Stribu, C. & Sandu, I. (2012). Impact assessment of saline aerosols on exercise capacity of athletes. *Procedia - Social and Behavioral Sciences*, 46: 4141–4145.

Tłoczek, I.F. (1958). Tężnie ciechocińskie. *Ochrona Zabytków*, 11(3–4): 212–219.

Tyczka, S. & Góra, T. (1978). Bioklimat Ciechocinka. In: *Bioklimat uzdrowisk polskich*, IMGW i Inst. Bal., 49-70.

Zabel, B. (2008). *Dzieje kołobrzeskich solanek*. Kołobrzeg: Wydawnictwo Reda.

Zając, J., Bojar, I., Helbin, J., Kolarzyk, E. & Owoc, A. (2014). Salt caves as simulation of natural environment and significance of halotherapy. *Ann. Agricultural and Environmental Medicine*, 21(1): 124–127.

Ziemska, J., Szynal, T., Mazańska, M. & Solecka, J. (2019). Natural medicinal resources and their therapeutic applications. *Roczniki Państwowego Zakładu Higieny*, 70(4): 407-413. DOI: https://doi.org/10.32394/rpzh/2019.0093.