# Some of the bioclimatic peculiarities of thermal water resorts located in western Romania

**Dumitru MIHĂILĂ[1]*, Andrei-Emil BRICIU[1], Petruţ-Ionel BISTRICEAN[1] and Adriana-Augustina ȘUȘU[2]**
[1] Department of Geography, Ștefan cel Mare University of Suceava, Romania
[2] Secondary School Episcop Doctor Partenie Ciopron, Păltiniș, Botoșani

*Correspondence to: Dumitru Mihăilă. E-mail: dumitrum@atlas.usv.ro.

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**ABSTRACT:** The paper captures some of the spatial differences and similarities, as well as the temporal peculiarities of the bioclimate of the Băile Felix, Moneasa, Geoagiu and Băile Herculane thermal water resorts, which were monitored during field observations between November 2015 and July 2017, within the project PN-II-RU-TE-2014-4-2900. To outline the temporal succession of different bioclimatic conditions in the studied resorts, we were able to calculate the thermohygrometric index (THI) and the DI Arakawa Discomfort Index ($DI_A$) based on temperature and humidity data measured with field iButton sensors. The collected field data allowed us to calculate only these two bioclimatic indices, since they can be obtained using only the air temperature and humidity measured values. In this study, we preferred to use at least two bioclimatic indices, which would allow for a comparison between their bioclimatic values and ratings, rather than to employ a single index without having benchmark data for assessing its values. The values and temporal variability of the indices showed contradictory results for the four thermal water resorts. The annual and diurnal intervals of bioclimatic comfort and discomfort indicated by the two indices are not identical in terms of timing and duration. Taking into account both these findings and the results obtained in a series of previous studies, we consider the THI values more reliable compared to $DI_A$, which visibly contradicts the bioclimatic conditions of the four Romanian tourist resorts. Therefore, based on the data provided by THI only, we highlighted the favorability of these locations for general and health tourism and the high degree to which the bioclimate with sedative characteristics complements and supports the balneary cure and treatment provided in the specialized treatment centers of the respective resorts.

KEY WORDS: bioclimate with sedative characteristics, Băile Felix, Moneasa, Geoagiu, Băile Herculane resorts.

## 1. Introduction

Capturing the most relevant aspects of the bioclimate of four important tourist resorts with treatment bases and with a strong attractiveness for balneoclimatic tourism posed several constraints from the very beginning. The time and resources allocated for research were limited. However, in the absence of quantitative bioclimatic studies based on concrete meteorological observations carried out in the four thermal water resorts (Băile Felix, Moneasa, Geoagiu and Băile Herculane), we considered that our contribution to expanding the knowledge of bioclimatic characteristics in the four locations is welcome and useful.

Consequently, in order to achieve the aim of this study - depicting the peculiarities of the annual and diurnal bioclimate regime in the four resorts - we used the THI index proposed in 1994 by Kyle. This index showed good results and was validated in a series of studies targeting various areas in Romania (Grigore, 2011; Vlăduț, 2011, 2016; Grigore and Săftoiu, 2014; Mihăilă et al., 2016, 2020; Bistricean and Mihăilă, 2017; Bistricean, 2020) and the Republic of Moldova (Mihăilă et al., 2015, 2018).

Several approaches were used to meet the aim of the study, such as: i) capturing the similarities and differences in the regime and values of THI for the four resorts, and ii) validating the results obtained through THI by comparison with other studies and/or with a second bioclimatic index we computed - the $DI_A$. The latter index was also used in a series of studies for Romania by Mihalca and Alexe in 2014 and Vlăduț in 2016 and for the Republic of Moldova by Golovițcaia in 2018. We did not anticipate from the beginning that the two indices may not show congruent results, however, the contradiction in results between THI and $DI_A$ helped us consider the results provided by THI more reliable. The results obtained for $DI_A$ were transposed into the same types of representations as for THI, and are presented as supplementary material.

## 2. Study area

*Băile Felix* resort is located in Crișurilor Plain, at an average altitude of 150 m (153 m a.s.l. in the area of Băile Felix swimming place), northwest of Tășadului Hills, with a NNW opening towards the Vad-Oradea Depression and W towards the Miersigului Plain. To the southwest and south there are the Pădurea Craiului hills. The resort has a turn-applicant bioclimate with sedative characteristics (Fig.1).

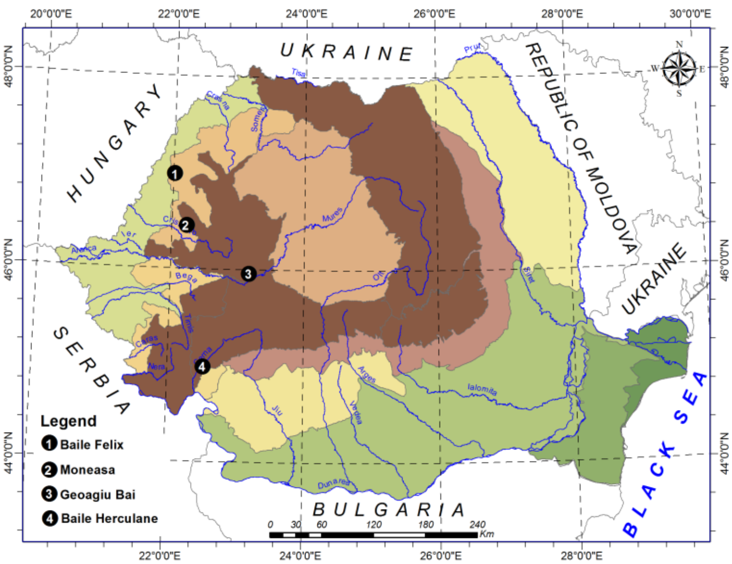


**Figure 1** Location of Băile Felix, Moneasa, Geoagiu and Băile Herculane thermal water resorts in Romania.

*Moneasa* Resort is located on the valley of the Moneasa River (a tributary of the Sebiș River, which is a tributary of the Crișul Alb River), at the south-south-western foot of the Codru Moma Mountains. On both sides of the Moneasa valley, the locality and the homonymous resort span an area of over 4 km length. The width of the valley is between 200 m at the upstream end of the resort and 1 km downstream of the locality. Along the valley that looks like a depression basin, the relief has altitudes of 250-300 m, whereby the surrounding hills, which look like low mountains, are between 500 and 953 m a.s.l. The resort is located altitudinally (the average altitude within the resort is 281 m, the maximum 320 m and the minimum 251 m) at the contact between the climatic belt characteristic of high plains and the belt characteristic of low hills, and has a sedative-indifferent bioclimate (Briciu et al, 2016).

*Geoagiu-Băi* resort is located in the southeastern extremity of the Metaliferi Mountains. To the south of Metaliferi Mountains there is Culoarul Orăștiei corridor. The average altitude of Geoagiu-Băi resort within its perimeter is 349 m a.s.l. The local physical-geographical features (depression basin generally oriented towards the east, surrounded by small hills and hills with average heights of over 450 m on the western side) influence the bioclimate of Geoagiu-Băi resort, which shows distinct peculiarities, both sedative and stimulant (especially during winter).

*Băile Herculane* resort is located on the Cerna River valley. To the west, northwest and north, the resort borders the Cerna Mountains, and to the east and southeast the Mehedinţi Mountains. To the southwest, towards the confluence with Belareca, the Cerna valley widens and takes on the appearance of a wider corridor (Cerna Corridor). The average altitude at which the resort is located is 196 m (inside its perimeter the maximum altitude rises to 225 m and the minimum is 123 m a.s.l.). The difference in elevation between the axis of the Cerna valley and the bordering mountain peaks frequently exceeds 500 m (Briciu et al, 2016). The bioclimate of the resort is sedative with tonic nuances.

## 3. Material and methods

Hourly measurements of air temperature and relative humidity in the four resorts were performed using iButton DS1923-F5# logger sensors (Fig. 2). The resolution of the measurements was 0.0625°C and 0.04% RH.


**Figure 2** iButton for monitoring air temperature and relative humidity.

The measurements were performed between November 2015 and July 2017. Since the measurements performed with iButtons were carried out both in daylight saving time and standard time, all measurements were reported in standard time.

For the calculation of THI we used the calculation formula [1] proposed by Kyle in 1994:

$$THI°C = Tusc - (0.55 - 0.0055 \times UR) \times (Tusc - 14.5) \quad [1]$$

where: Tusc - air temperature in °C measured on a dry-bulb thermometer; UR - relative humidity (%).

For the $DI_A$ calculation we used the calculation formula [2] proposed by Agostini et al. in 2005:

$$DI_A = 0.81\,Td + [0.01 \times R\,(0.99\,Td + 14.3)] + 46.3 \quad [2]$$

where: Td = air temperature (ºC) (dry-bulb temperature); R = relative humidity (%).

Assessment of the bioclimatic effects of these indices for different thresholds and values was performed based on the information from Tabs 1 and 2.

**Table 1** Applicability limits a), THI value thresholds (°C) b), bioclimatic conditions c) and typology of the relationships between bioclimate and the human body d).

a) applicability: the index is calculated regardless of the values of air temperature and relative humidity

| b) THI index (°C) | c) Bioclimatic conditions | d) Levels of bioclimatic comfort / discomfort |
|---|---|---|
| -20 < THI ≤ -10 | Excessive cold | Bioclimatic discomfort caused by cooling |
| -10 < THI ≤ -1.8 | Very cold | |
| -1.8 < THI ≤ +13 | Cold | |
| +13 < THI ≤ +15 | Cool | |
| +15 < THI ≤ +20 | Comfortable | Bioclimatic comfort |
| +20 < THI ≤ +26.5 | Warm | Bioclimatic discomfort caused by warming |
| +26.5 < THI ≤ +30 | Very hot | |
| THI > 30 | Torrid | |

*source: after Kyle (1994), cited by Ionac and Ciulache (2008)*

**Table 2** The scale of applicability of DI Arakawa.

| DI ARAKAWA (units) | Bioclimatic discomfort |
|---|---|
| $DI_A < 55$ | Unbearably cold bioclimate |
| $DI_A = 55\text{-}60$ | Discomfort caused by cooling |
| $DI_A = 60\text{-}75$ | Bioclimatic comfort |
| $DI_A = 75\text{-}80$ | Discomfort caused by warming |
| $DI_A > 80$ | Unbearably hot bioclimate |

*source: after Agostini et al. (2005)*

Since the two indices are calculated based on the values of two meteorological elements (temperature and humidity), they show a high temporal correlation, the corresponding linear regression lines and R2 coefficients indicating unequivocally how well the THI / $DI_A$ data fit with the model derived based on their values - Figs 3, 4, 5 and 6.

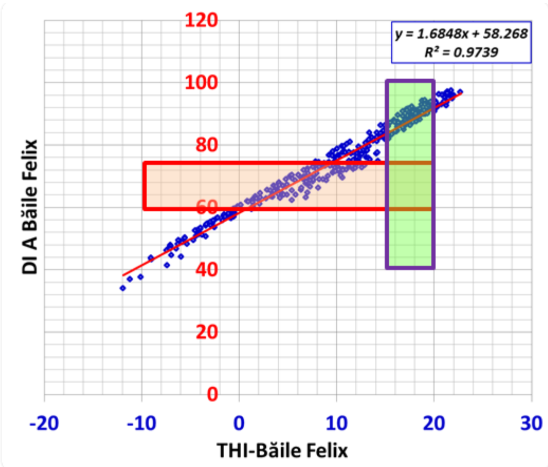


**Figure 3** Statistical relationships between THI (°C) and $DI_A$ (units) for Băile Felix resort.

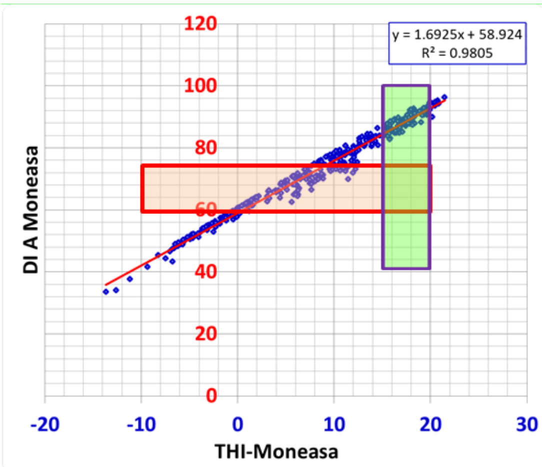


**Figure 4** Statistical relationships between THI (°C) and $DI_A$ (units) for the Moneasa resort.

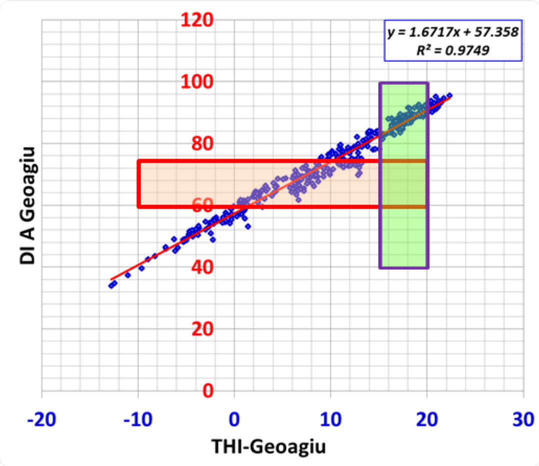


**Figure 5** Statistical relationships between THI (°C) and $DI_A$ (units) for the Geoagiu resort.

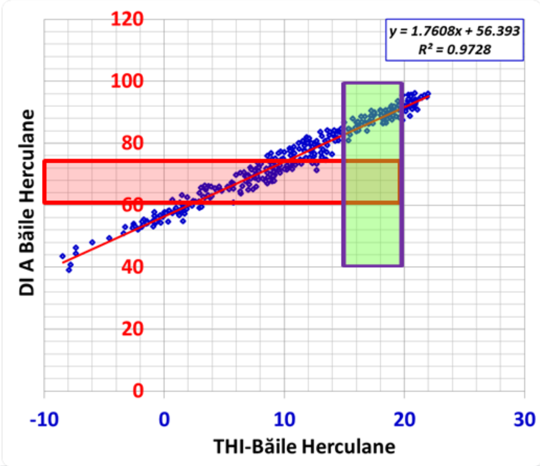


**Figure 6** Statistical relationships between THI (°C) and $DI_A$ (units) for Băile Herculane resort.

In Figs 3-6, the *vertical rectangle* with blue edges and green shade background indicates the bioclimatic comfort range given by the THI values, which is between +15 and + 20°C. This comfort range corresponds to $DI_A$ values in the range of 84 - 92 units, i.e., an unbearably hot bioclimate. The *horizontal rectangle* with red edges and red shade background indicates the bioclimatic comfort range given by the $DI_A$ values, which is between 60 and 75 units and which corresponds to THI values between 0 and 10°C, i.e., specific to a cold bioclimate.

Therefore, for THI values indicating a favorable, comfortable bioclimate we have as correspondents $DI_A$ values that indicate excessively hot conditions, whereby the THI values indicating cold conditions correspond in case of $DI_A$ with a discomfort caused by warming or more often with bioclimatic comfort; similarly, the THI values that indicate cold and very cold conditions correspond in the case of $DI_A$ with conditions of discomfort caused by cooling or with unbearably cold conditions.

Due to these lags and differentiations between the THI and $DI_A$ indices, we included the entire database and representations related to $DI_A$ in the supplementary material attached at the end of this paper.

## 4. Results and discussion

To compute the THI statistical indicators we used 12338 observations and hourly temperature and humidity data for each resort.

### 4.1. The annual regime of THI

The THI monthly values in the studied interval showed that from May to September inclusively, conditions were mostly comfortable or favorable to the well-being of the human body. Activities in the field of outdoor tourism and particularly of spa tourism do not have relevant restrictions from a bioclimatic point of view. Cold conditions prevail in February-April and October-December (with the exception of Moneasa resort) and are characteristic of a medium intensity bioclimatic discomfort caused by the low temperature and high atmospheric humidity that accentuates the feeling of cold. Only January (with very cold weather) shows relevant restrictions for outdoor tourism activities and minor restrictions for spa activities (Tab. 3).

**Table 3** Annual regime of the THI bioclimatic index outlined based on monthly values (November 2015 - July 2017).

| THI(°C) | I | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Băile Felix | -5.6 | 2.7 | 8.1 | 11.7 | 14.4 | 18.7 | 19.3 | 18.4 | 15.5 | 9.1 | 4.6 | -1.4 |
| Moneasa | -5.3 | 2.4 | 7.2 | 10.2 | 13.5 | 17.6 | 18.4 | 17.5 | 14.9 | 8.7 | 4.3 | -2.9 |
| Geoagiu | -4.7 | 3.5 | 8.1 | 11.3 | 14.2 | 18.6 | 19.2 | 18.3 | 15.3 | 9.0 | 3.6 | -1.5 |
| Băile Herculane | -2.0 | 4.6 | 8.9 | 11.8 | 13.7 | 18.2 | 19.4 | 19.4 | 16.2 | 10.4 | 6.4 | 1.6 |

The interdiurnal THI analysis (Figs 7 and 8) for the period November 2015-July 2017 reveals several details.

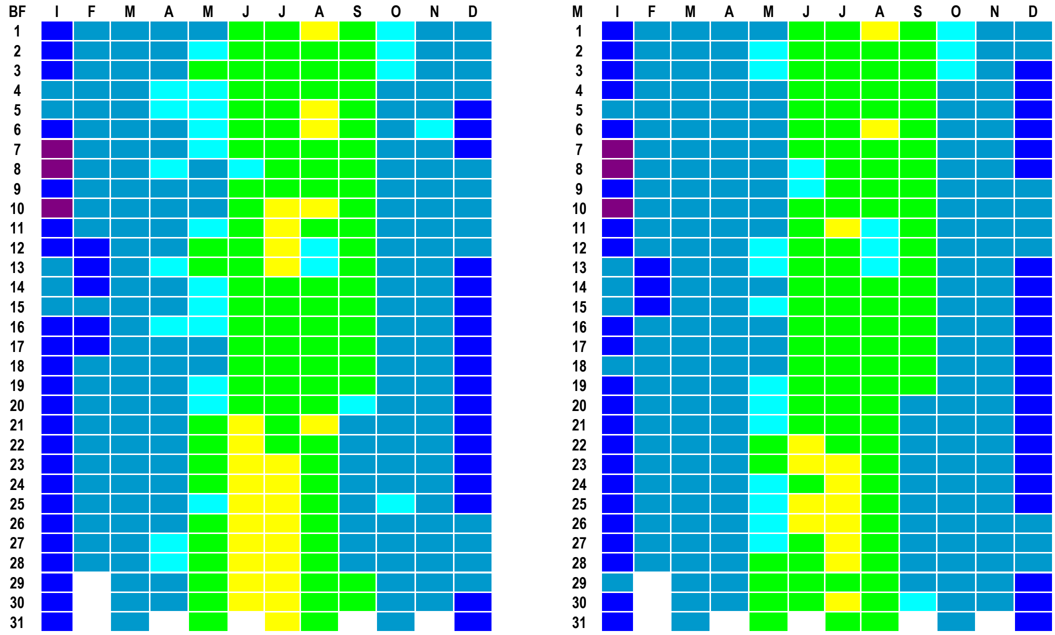


**Figure 7** Interdiurnal succession of bioclimatic conditions at Băile Felix / Moneasa based on THI.

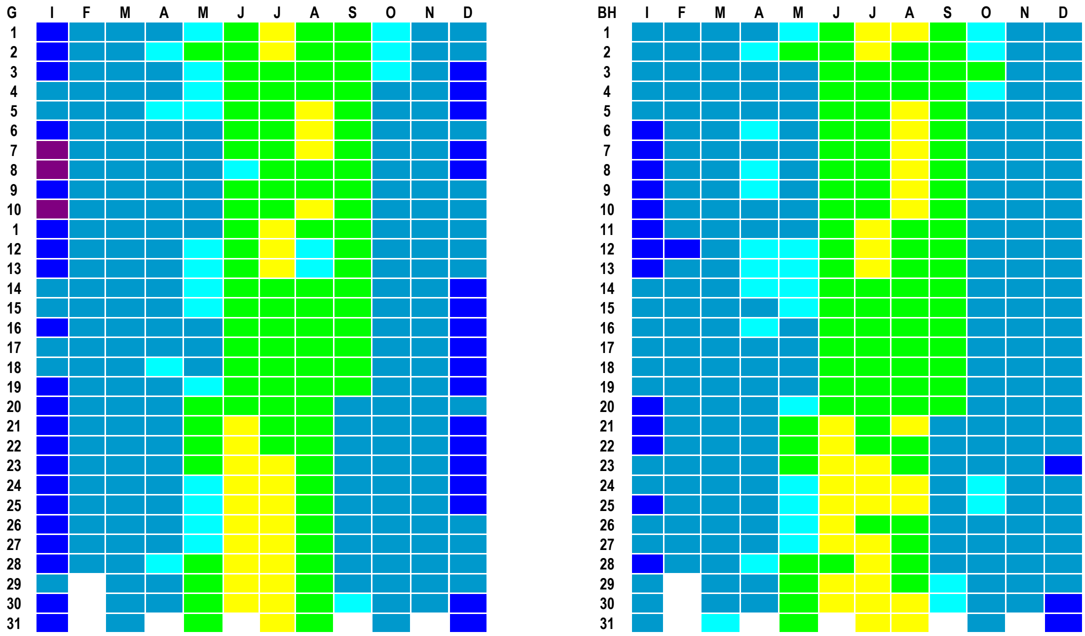


**Figure 8** Interdiurnal succession of bioclimatic conditions at Geoagiu / Băile Herculane based on THI.

Analysis at the interdiurnal level shows that in the summer months warm conditions may prevail during some days and in January excessively cold conditions may prevail. Beyond the small differences between these four resorts, the tourism activities have no significant bioclimatic restrictions from April to October, and the annual interval with bioclimate conditions favorable for tourism can be extended to March and November, respectively. Băile Herculane resort has the most favorable bioclimate of all four resorts analyzed in all months of the year (Tab. 3). This is the only resort for which no days with excessive cold conditions were identified in the winter months (Figs 7 and 8).

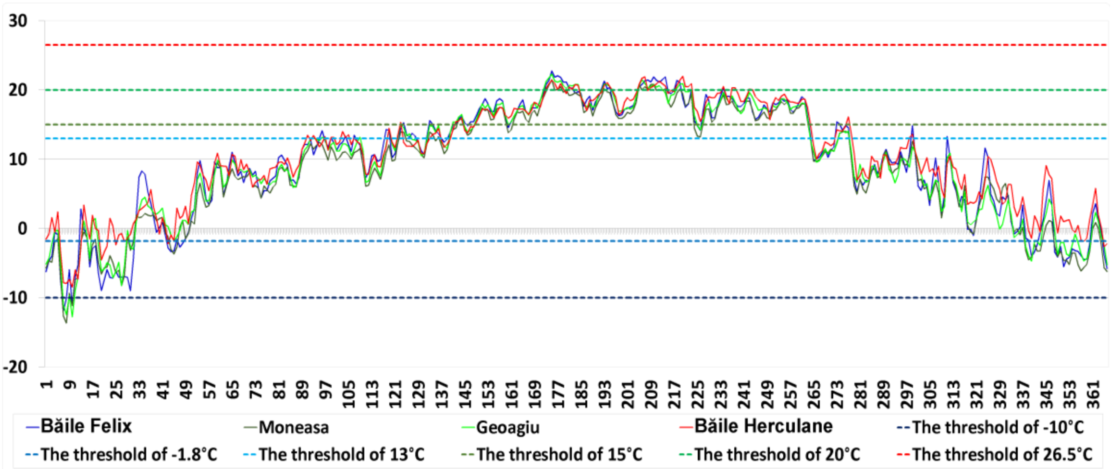


**Figure 9** The annual regime of THI (°C) at Băile Felix, Moneasa, Geoagiu and Băile Herculane, based on daily data from November 2015 to July 2017.

The quasi-synchronous variability of THI in the four resorts is a bioclimatic reality given by dynamic factors and the differentiation in values and deviations of THI are due to local topoclimatic factors that nuance the interdiurnal regime of this index (Fig. 9). The warm season days in a year remain in extenso the most favorable for outdoor tourism activities and the cold season days rarely raise bioclimatic restrictions for health tourism.

## 4.2. The daily regime of THI

The isopleth representations of THI constructed on the basis of data collected in the field campaigns of November 2015-July 2017 show us that in summer, both during the night and the day hours, outdoor tourism and health tourism benefit from very good bioclimatic conditions in all four resorts (Figs 10 and 11). The afternoon summer hours during which hot conditions prevail raise bioclimatic restrictions only for small groups of tourists. During hot weather episodes, outdoor activities are favored such as those on forest shade routes, forest therapy, aeroiono therapy, heliotherapy, aerotherapy and hydrothermal therapy. In April, May and September, the bioclimate is comfortable during the day and cooler during the night. In September, for the entire 24-hour interval, Băile Herculane resort benefits from the most favorable bioclimatic conditions for people and tourists arriving for rest and treatment compared to the other three resorts (Fig. 11). The graphs that show for each season the diurnal regime of THI for the four balneoclimatic resorts reinforce the observations already made.

Summer days show the least bioclimatic constraints, followed by spring, autumn and winter days (Figs 12 and 13).

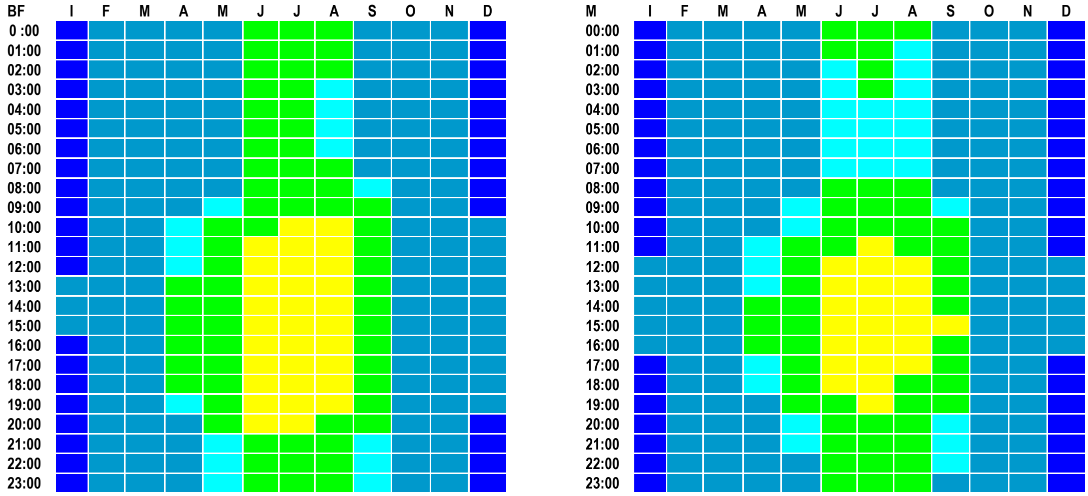


**Figure 10** THI isopleths showing hourly and monthly bioclimatic characteristics at Băile Felix and Moneasa.

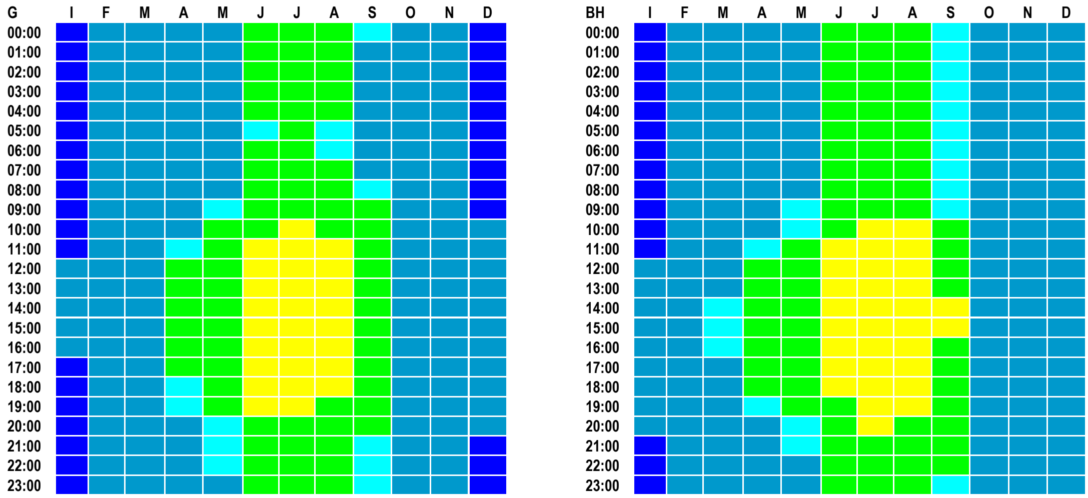


**Figure 11** THI isopleths showing hourly and monthly bioclimatic characteristics at Geoagiu and Băile Herculane.

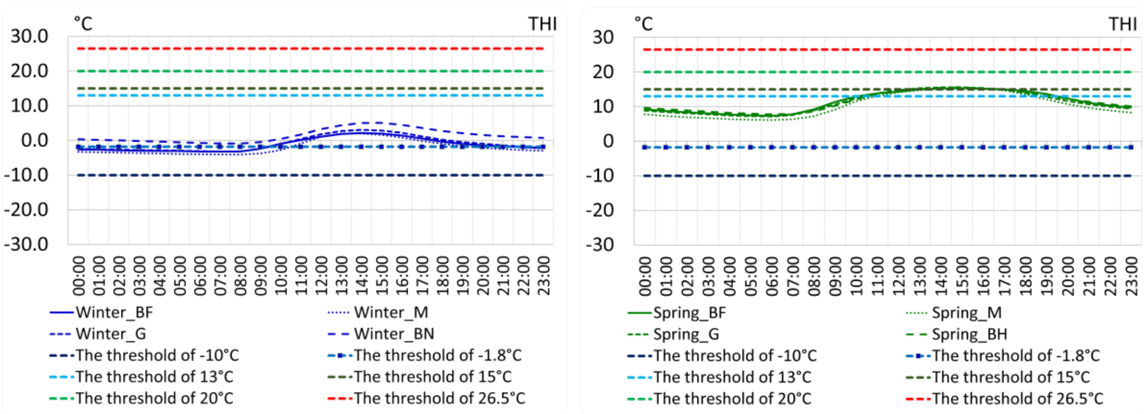


**Figure 12** Daily variability of THI values at Băile Felix, Moneasa, Geoagiu and Băile Herculane during the winter and spring days.

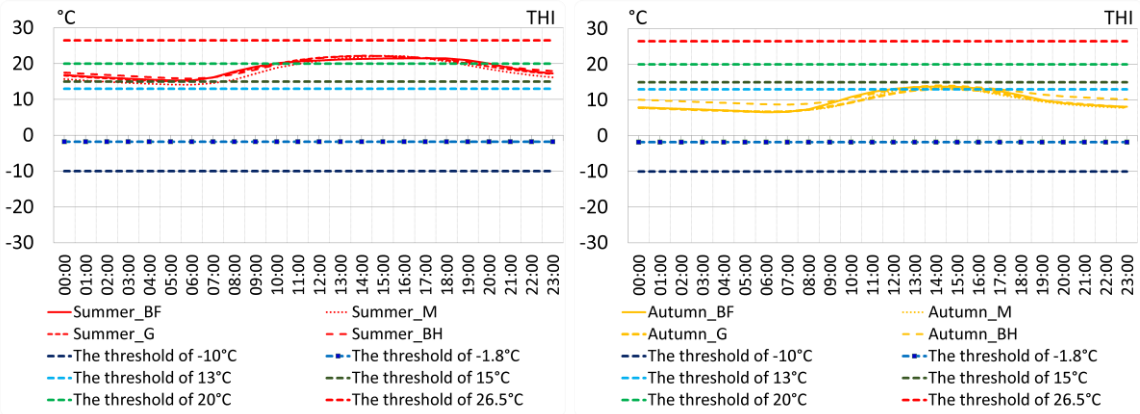


**Figure 13** Daily variability of THI values at Băile Felix, Moneasa, Geoagiu and Băile Herculane during the summer and autumn days.

Intervals with warm conditions may occur during summer afternoons and intervals with cool or cold conditions during the winter night hours. However, on the whole, the basic feature of the bioclimate of these resorts is the favorability for people in general and tourists in particular.

The results obtained by analyzing the regime and distribution of THI values are in agreement with the typology of the bioclimate of these resorts (Teodoreanu and Gaceu, 2013; Silișteanu et al., 2020), but also with the results obtained for areas within the same type of climate (Grigore, 2011; Vlăduț, 2011, 2016; Grigore and Săftoiu, 2014; Mihăilă et al., 2015, 2016, 2018, 2020; Bistricean and Mihăilă, 2017; Bistricean, 2020).

Regarding $DI_A$, the results obtained contradict or somewhat distort the bioclimatic reality of the study area and, therefore, due to the uncertainties, we included the statistics and the representations of $DI_A$ regime only in the supplementary material. Although not explicitly acknowledged, other studies employing $DI_A$ also showed results that are partly questionable. For example, Mihalca and Alexe (2014) used data from four meteorological stations located in Ţara Dornei area. The authors concluded that, in three out of four stations (Cârlibaba, Poiana Stampei and Vatra Dornei, located between 825 and 930 m a.s.l.), the $DI_A$ values (between 60 and 75 units) indicated bioclimatic comfort, whereby at the fourth meteorological station, Rețitiș (2100 m a.s.l.), the DIA values (between 55 and 60 units) indicated discomfort caused by cooling. The conclusions are therefore a projection of a bioclimatic reality that is inaccurate based on the values of this index for at least the first three stations analyzed. Moreover, results obtained by Vlăduț in 2016 in the assessment of the bioclimate of Oltenia Plain raise doubts. Similar doubts arise regarding the conversion of the established bioclimatic reality into a somewhat distorted projection in the case of Golovițcaia's use of $DI_A$ in 2018, when the author analyzed the seasonal variability of $DI_A$ in the Republic of Moldova. The $DI_A$ index yielded results below expectations in terms of spatial differentiations during the same season, but also in terms of the bioclimatic ratings of the seasons.

## 5. Conclusion

Analysis of the statistical and graphic material resulted after processing the THI data for the Băile Felix, Moneasa, Geoagiu and Băile Herculane thermal water resorts enabled us to outline the particularities of the annual and diurnal bioclimate regime in the four top tourist destinations in Romania. The above-mentioned resorts have an indifferent sedative bioclimate (Moneasa, Geoagiu, Băile Herculane) or similar characteristics (Băile Felix). Within a year, the season with the most favorable bioclimate for tourism is summer, when only in the hours before, during or shortly after noon intervals with discomfort caused by warming may occur. The spring and autumn seasons are next with regard to favorability for tourism, with cool daytime and cold night hours, and last there is the winter season which shows several hours with cold conditions at noon, and cold and sometimes excessively cold conditions in the evening, during the night and in the morning. The sedative bioclimate given by the advection of western and Mediterranean air masses, coupled with the foehnal circulation, the generally low altitudes and the geomorphological shelter effect extends the tourist season to almost the entire year. According to THI values, Băile Herculane resort has the most favorable bioclimate for tourism and balneoclimatic tourism. However, the bioclimatic differences between the four resorts are small, as the similarities prevail. These results are consistent with the results already conducted for other balneoclimatic resorts in Romania. Our study marks the need to carefully select the bioclimatic indices to be used in balneoclimatic and bioclimatic studies. This is in order to prevent the risk of drawing forced or even erroneous bioclimatic conclusions, which would contradict the established bioclimatic reality.

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**Supplementary Material** For computing the statistical indicators of $DI_A$, we used 12338 observations and hourly temperature and humidity data for each resort.

**Table 1 SM** Annual regime of the $DI_A$ bioclimatic index based on monthly values (November 2015 - July 2017).

| DI ARAKAWA | I | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Băile Felix | 48.6 | 64.7 | 69.1 | 74.1 | 82.2 | 90.7 | 91.1 | 89.5 | 85.4 | 75.3 | 66.4 | 56.7 |
| Moneasa | 49.8 | 63.4 | 68.5 | 73.4 | 81.3 | 89.5 | 89.2 | 89.4 | 84.9 | 75.6 | 67.0 | 54.8 |
| Geoagiu | 49.0 | 63.7 | 68.0 | 73.0 | 80.9 | 89.1 | 89.3 | 88.8 | 83.8 | 73.8 | 64.9 | 55.7 |
| Băile Herculane | 53.2 | 64.0 | 70.2 | 75.0 | 81.8 | 89.2 | 89.8 | 90.9 | 85.7 | 75.6 | 67.9 | 59.2 |

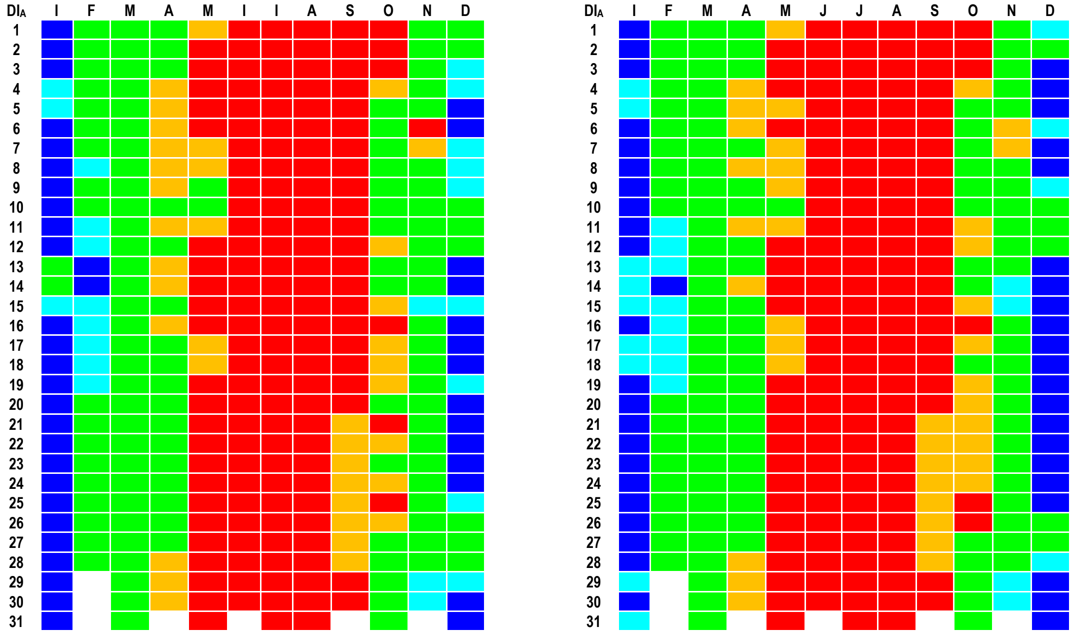


**Figure 1 SM** Interdiurnal succession of bioclimatic conditions at Băile Felix/Moneasa based on $DI_A$.

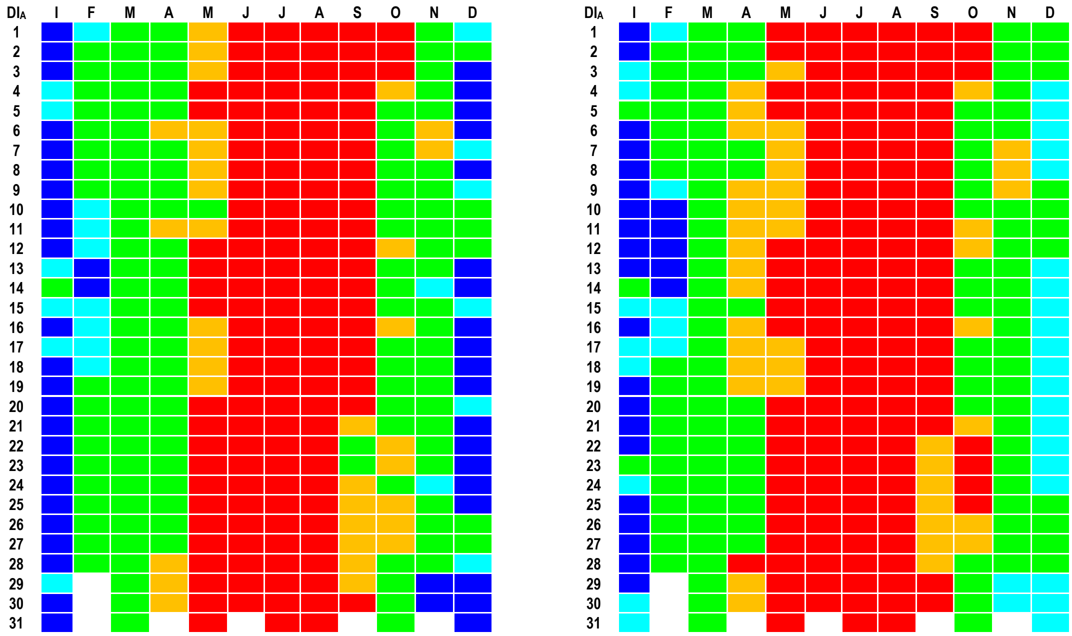


**Figure 2 SM** Interdiurnal succession of bioclimatic conditions at Geoagiu/Băile Herculane based on $DI_A$.

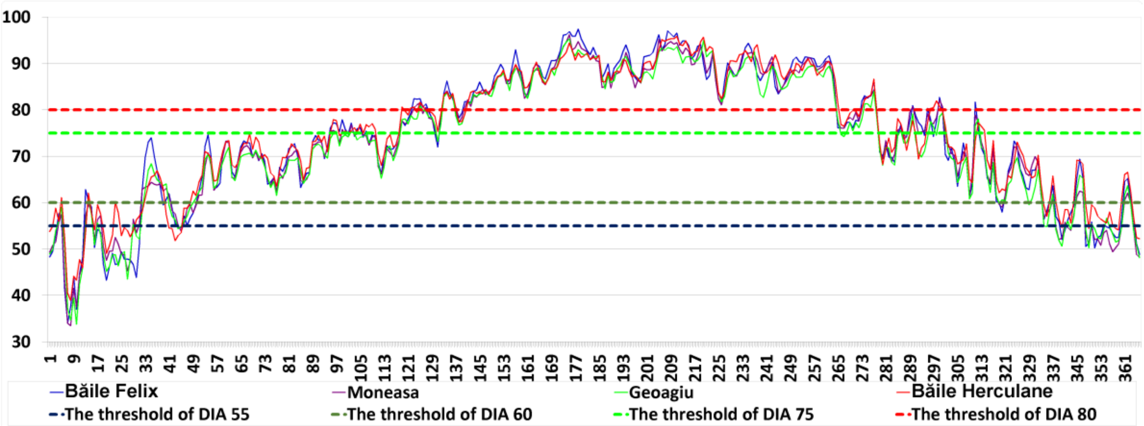


**Figure 3 SM** The annual regime of DIA (units) at Băile Felix, Moneasa, Geoagiu and Băile Herculane, based on daily data from November 2015 to July 2017.

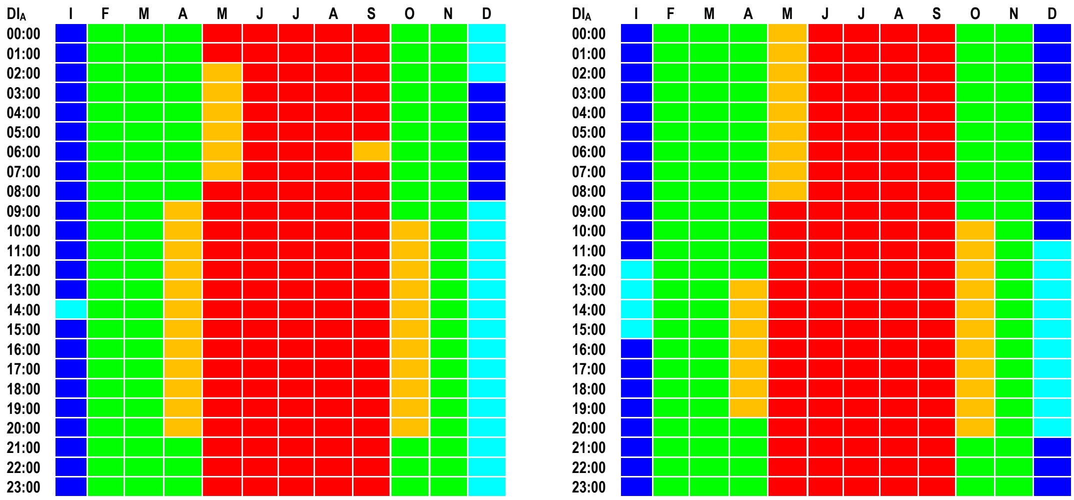


**Figure 4 SM** DIA isopleths showing hourly and monthly bioclimatic characteristics at Băile Felix and Moneasa.

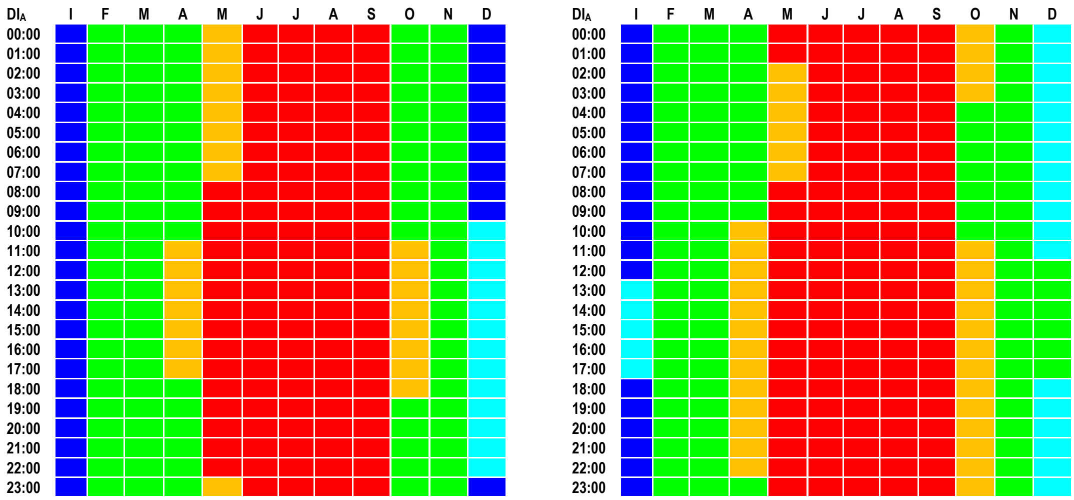


**Figure 5 SM** DIA isopleths showing hourly and monthly bioclimatic characteristics at Geoagiu and Băile Herculane.

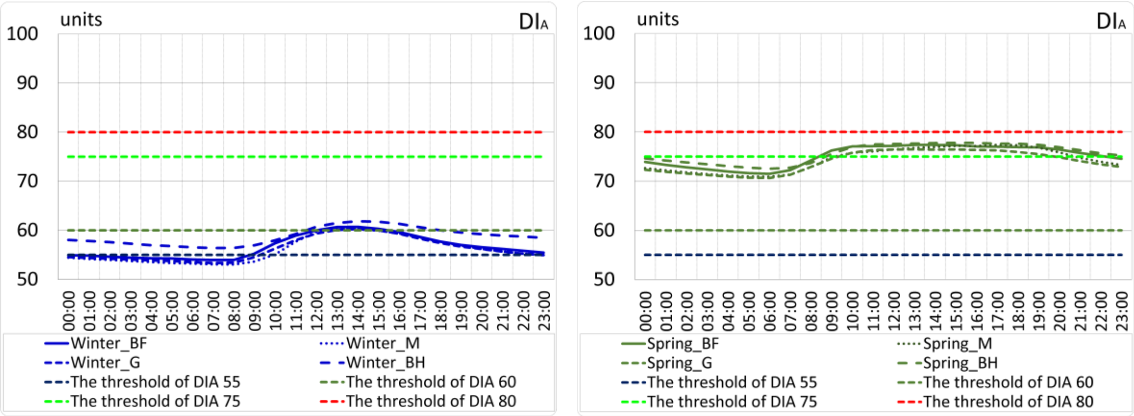


**Figure 6 SM** Daily variability of DIA values at Băile Felix, Moneasa, Geoagiu and Băile Herculane during the winter and spring days.

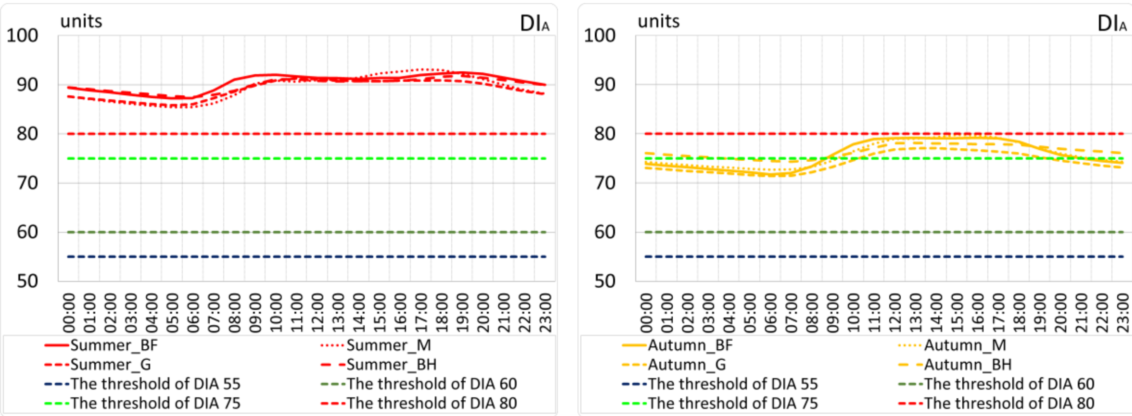


**Figure 7 SM** Daily variability of DIA values at Băile Felix, Moneasa, Geoagiu and Băile Herculane during the summer and autumn days.