# THERMAL COMFORT WITHIN OLTENIA PLAIN

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**Abstract.** Oltenia Plain, the western of the sector of the Romanian Plain, is characterized by a thermal regime marked by increased temperature during summer, when frequent heat waves occur, while in winter, temperature values may also decrease a lot, even if usually they maintain close to 0°C. In this context, the assessment of thermal comfort is very important, especially for the summer half of the year. Thus, there were calculated four indexes, namely thermohygrometric index (THI), DI ARAKAWA discomfort index (DIa), windchill equivalent temperature (WCET), relative strain index (RSI), in order to emphasize the bioclimatic comfort or discomfort. In spite of obvious similarities, the obtained values also indicate significant differences of the type of bioclimate specific to certain months. Cold stress is characteristic to winter, January in particular, as indicated by THI, DIa and WCET, while heat stress was confirmed by THI and DIa for July, August and, partially, June. RSI indicated bioclimatic comfort for average temperature and vapour pressure values, but when applied on some particular values, registered after 2000, discomfort for both more sensitive and all the people, clearly emerged. Even if the results do not indicate the same months characterized by thermal comfort, taking into account the values, the most balanced months are April, May, October and November. Spatially, it was noticed that cold stress is higher in the northern part of the plain, but there are not important differences in terms of heat stress.

**Keywords:** Oltenia Plain, thermohygrometric index (THI), DI ARAKAWA discomfort index (DIa), windchill equivalent temperature (WCET), relative strain index (RSI).

**Rezumat. Confortul termic în Câmpia Olteniei.** Câmpia Olteniei, care reprezintă sectorul vestic al Câmpiei Române, se caracterizează printr-un regim termic marcat de temperaturi ridicate pe perioada verii, când se produc frecvent şi valuri de căldură, în timp ce iarna, deşi temperaturile se menţin apropiate de pragul de 0°C, acestea pot să scadă destul de mult. În acest context, evaluarea stării de confort termic este foarte importantă, mai ales pentru semestrul cald. Astfel, pentru a reda confortul sau disconfortul termic au fost calculaţi patru indici, indicele termohigrometric (THI), indicele de disconfort DI ARAKAWA (DIa), temperatura echivalentă a puterii de răcire a vântului (WCET), indicele de tensiune relativă (RSI). În ciuda asemănărilor evidente, valorile obţinute indică diferenţe semnificative în ceea ce priveşte tipul de bioclimat specific anumitor luni. Stresul termic indus de expunerea la frig este caracteristic iernii, mai ales lunii ianuarie, fapt confirmat de trei dintre indici – THI, DIa şi WCET, în timp ce stresul cauzat de căldură a fost confirmat de THI şi DIa pentru lunile iulie şi august şi, parţial, pentru iunie. RSI a indicat confort bioclimatic pentru valorile medii multianuale de temperatură şi tensiune a vaporilor de apă, dar disconfortul termic, atât pentru persoane mai sensibile, cât şi pentru întreaga populaţie, a fost în mod clar evidenţiat pentru anumite valori înregistrate la nivel lunar după anul 2000. Chiar dacă rezultatele obţinute nu indică aceleaşi luni ca fiind caracterizate de confort termic, plecând de la valorile medii, lunile cele mai echilibrate sunt aprilie, mai, octombrie şi noiembrie. Din punct de vedere teritorial, s-a constatat că stresul termic indus de expunerea la frig este mai ridicat în partea nordică a câmpiei, dar nu s-au înregistrat diferenţe semnificative în privinţa stresului indus de căldură.

**Cuvinte cheie:** Câmpia Olteniei, indicele termohigrometric (THI), indicele de disconfort DI ARAKAWA (DIa), temperatura echivalentă a puterii de răcire a vântului (WCET), indicele de tensiune relativă (RSI).

## INTRODUCTION

At international level, thermal comfort is defined by ISO 7330-2005 as "that state of mind that expresses satisfaction with the thermal environment" (www.iso.org/obp/ui/#iso:std:iso:7730:en). Taking into account the definition, it is quite difficult to render thermal comfort as it depends on a wide range of factors, both environment-related and person-related factors. Environmental factors refer to air temperature (dry bulb temperature), air velocity, relative humidity, vapour pressure and radiant temperature (the temperature of the surfaces that usually surround a person), each of these factors conditioning the state of thermal comfort or discomfort. Personal factors are related to clothing, metabolic heat, the state of well-being or sickness, age group, etc. LEE & HENSCHEL (1966) defined comfort as thermal neutrality, general satisfaction, no anxiety, while discomfort refers to the sensations of heat and cold perceived by a person at a certain moment, thus being more difficult to globally quantify.

There were developed different biometeorological indexes and various models to render thermal comfort from different points of view, such as its influence on the general health state, work productivity, tourism, etc. Among more complex approaches, there can be mentioned MEMI, Munich Energy Balance Model for Individuals (HÖPPE, 1993), Man-Environment heat Exchange model MENEX_2005 (BLAZEJCZYK, 1994; 2005), Universal Thermal Climate Index – UTCI (initially developed by Commission 6 of the International Society of Biometeorology, http://www.utci.org/isb.php). Besides these models, there are more than 100 simple or complex indices (BLAZEJCZYK et al., 2012). Certain indexes highlight better thermal comfort all over the year (such as thermohygrometric index, DI ARAKAWA discomfort index, Physiological Equivalent Temperature, etc.), while others are more adequate for extreme seasons– summer (Summer Scharlau Index, Relative Strain Index, Summer SIMMER index, Heat index, Predicted Heat Strain, Temperature-Humidity Index, etc.) and winter (Winter Scharlau Index, Wind Chill Index, Windchill Equivalent Temperature, etc.). The purpose of the present study was to assess thermal comfort by using different indexes to emphasize if the obtain results highlight the same state of comfort or discomfort during the year, taking into account that the latest studies (DOBRINESCU et al., 2015) indicate a significant upward trend for certain indexes (THI, WCT).

## MATERIAL AND METHODS

Oltenia Plain represents the western sector of the Romanian Plain, the largest plain unit of the country, located between the Getic Piedmont in the north and the Danube Valley in the south (Fig. 1). This relief unit does not present notable differences in terms of altitude or exposure to certain predominant air masses and thus, the main climatic parameters, such as temperature, humidity, wind speed and direction, relative humidity, vapour pressure, etc. register relatively reduced territorial differences. However, there emerge certain distinct features imposed by location and predominance of influence factors.

The considered bioclimatic indexes – thermohygrometric index (THI), DI ARAKAWA discomfort index (DIa), windchill equivalent temperature (WCET), relative strain index (RSI) were calculated based on mean monthly values of air temperature, vapour pressure, wind speed and relative humidity. These indexes highlight the effects of temperature combined with air humidity or wind speed upon the human organism for both extreme seasons – winter and summer. The data cover a mean period of forty years (1971-2010). The six stations are located in different sectors of Oltenia Plain (Fig. 1, Table 1).

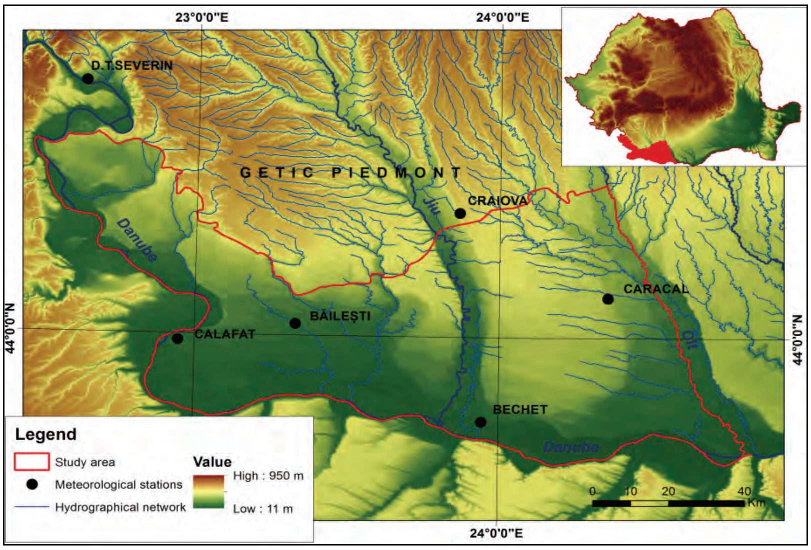



Figure 1. Location of the meteorological stations within Oltenia Plain.
Source: VLĂDUŢ & ONŢEL, 2013.

Table 1. Geographical coordinates of the considered meteorological stations.

| No. | Station | Altitude (m) | Latitude | Longitude |
|---|---|---|---|---|
| **1.** | **Calafat** | 61 | 43°59` | 22°57` |
| **2.** | **Bechet** | 36 | 43°47` | 23°57` |
| **3.** | **Băileşti** | 57 | 44°01` | 23°20` |
| **4.** | **Caracal** | 106 | 44°06` | 24°22` |
| **5.** | **Craiova** | 192 | 44°19` | 23°52` |
| **6.** | **Dr. T. Severin** | 77 | 44°38` | 22°38` |

*Thermohygrometric index (THI) (ºC)* was developed by KYLE (1994). The formula used for the calculation of this index is:

$$THI\ (^{\circ}C) = T_d - (0.55 - 0.0055 \times R)(T_d - 14.5)\text{, where:}$$

$T_d$ = air temperature (ºC) (dry-bulb temperature);

R = relative humidity (%)

The comfort conditions are established according to the temperature perceived by the human body (Table 2). THI is one of the widely used indexes for rendering thermal comfort (UNGER, 1999; EMMANUEL, 2005; GRIGORE, 2013; IONAC & CIULACHE, 2008; TOY et al., 2007; TOY & YILMAZ, 2010).

*DI ARAKAWA discomfort index* (AGOSTINI et al., 2005) renders the combined effect of temperature and relative humidity upon the human body. The advantage of using this index consists in the fact that it emphasizes the discomfort state induced by both high and low temperatures (Table 3). In Romania, the index was applied by MIHALCA & ALEXE (2014) for Dornelor Depression. The formula used for the calculation of the index is:

$$DI_A = 0.81\ T_d + [0.01 \times R\ (0.99\ T_d + 14.3)] + 46.3\text{ where:}$$

$T_d$ = air temperature (ºC) (dry-bulb temperature);

R = relative humidity (%)

Table 2. THI values and the corresponding bioclimate type.

| THI (°C) | Bioclimate type | THI (°C) | Bioclimate type |
|---|---|---|---|
| **THI < – 40** | Hyper-glacial | **13 < THI < 15** | Cool |
| **–40 < THI < –20** | Glacial | **15 < THI < 20** | Comfortable |
| **–20 < THI ≤–10** | Extremely cold | **20 < THI < 26.5** | Hot |
| **–10 < THI ≤–1.8** | Very cold | **26.5 < THI < 30** | Very hot |
| **–1.8 < THI < 13** | Cold | **THI > 30** | Torrid |

Source: KYLE, 1994

Table 3. Bioclimatic discomfort according to DI ARAKAWA index.

| DI ARAKAWA (units) | Bioclimatic discomfort |
|---|---|
| DIA < 55 | Unbearably cold bioclimate |
| DIA = 55-60 | Discomfort caused by cooling |
| DIA = 60-75 | Bioclimatic comfort |
| DIA = 75-80 | Discomfort caused by warming |
| DIA > 80 | Unbearably hot bioclimate |

Source: MIHALCA & ALEXE, 2014

*Windchill equivalent temperature (WCET)* represents the effective temperature air would reach at certain wind speeds. Initially, this index was proposed by SIPLE (1945) and developed by SIPLE & PASSEL (1945). The formula is:

$$T\ pr = [33 + (Td - 33) \times (0.474 + 0.454\sqrt{v} - 0.0454v)]$$, where

Td = air temperature (dry bulb temperature) (°C)
v = wind speed in m/s

The physiological effects, depending on the intensity of the caloric losses experienced by a human body, are rendered in Table 4.

Table 4. Windchill equivalent temperature (WCET) and its physiological effects.

| WCET – T (°C) | Physiological effects |
|---|---|
| Twt > +10 | Comfort |
| +10 ≥ Twt >-1 | Slight discomfort |
| -1 ≥ Twt > -10 | Increased discomfort |
| -10 ≥ Twt >-18 | Very cold |
| -18 ≥ Twt >-29 | Hypocaloric stress |
| -29 ≥ Twt >-50 | Risk of frostbite in case of prolonged exposure |
| Tpr ≤-50 | Risk of instantaneous frostbite |

Source: TEODOREANU & MIHĂILĂ, 2012 apud. IONAC & CIULACHE, 2008

*Relative strain index (RSI)* was developed by SHAPIRO et al. (1982) taking into account a healthy person dressed with business suit at a place not acclimatized to direct heat in order to consider the clothing insulation. This index was calculated according to the formula:

$$RSI = (T_a - 21) / (58 - e) \quad (3)$$, where

$T_a$ = air temperature
e = the water vapour pressure

RSI renders the effects of heat on the human organism, thus, being relevant for the summer months. In Romania, it was calculated for Moldova (IONAC, 2006), Dobrogea (IONAC & CIULACHE, 2007), Parâng Mountains (MERCIU, 2010). The bioclimatic discomfort based on the values of the RSI is rendered in Table 5.

Table 5. The Relative Strain Index- RSI (units).

| Relative Strain Index | Bioclimatic discomfort |
|---|---|
| RSI ≤0.15 | Bioclimatic comfort |
| 0.15 ≤RSI ≤0.25 | Bioclimatic discomfort for more sensitive persons* |
| 0.25 ≤RSI ≤0.35 | Bioclimatic discomfort for all persons |
| 0.35 ≤RSI ≤0.45 | Overheating risk for more than 50% of the population |
| RSI ≥0.45 | Heat-stroke risk for all population |
| * In case of older and sick people, the RSI values equalling to 0.20 actually represent the maximum limit of tolerance, above which heat stroke is evident | |

Source: IONAC, 2006

## RESULTS

Physiologically, the human body permanently adapts to the outdoor conditions aiming at reaching the state of thermal comfort and wellbeing. However, in certain situations, heat or cold impose a higher stress on the human body than usually and thermal adaptation becomes difficult especially for certain age categories, such as children and elderly, or people that have health problems. In order to assess heat or cold stress, there were elaborated certain simple or complex indexes.

According to the *thermohygrometric index (THI)* values, comfort is registered between 15 and 20°C. Any values below 15°C indicate a certain state of discomfort induced by cold, while values above 20°C indicate discomfort produced by heat. The analysed region displays a similar bioclimate type during the year taking into account that there are not notable differences in terms of temperature and relative humidity, the two parameters considered in THI case. Thus, based on the obtained values, it results that there are only two months – May, respectively September characterized by thermal comfort within the entire Oltenia Plain. In June, the bioclimate is considered hot only in the south of the plain, where temperature and relative humidity are higher, while in the other sectors, the bioclimate is comfortable, but close to the hot threshold. The intervals January-April and October-December present a cold bioclimate, even if the values are mainly positive (the only negative values are registered in January) (Table 6).

Table 6. THI values within Oltenia Plain and the bioclimate type.

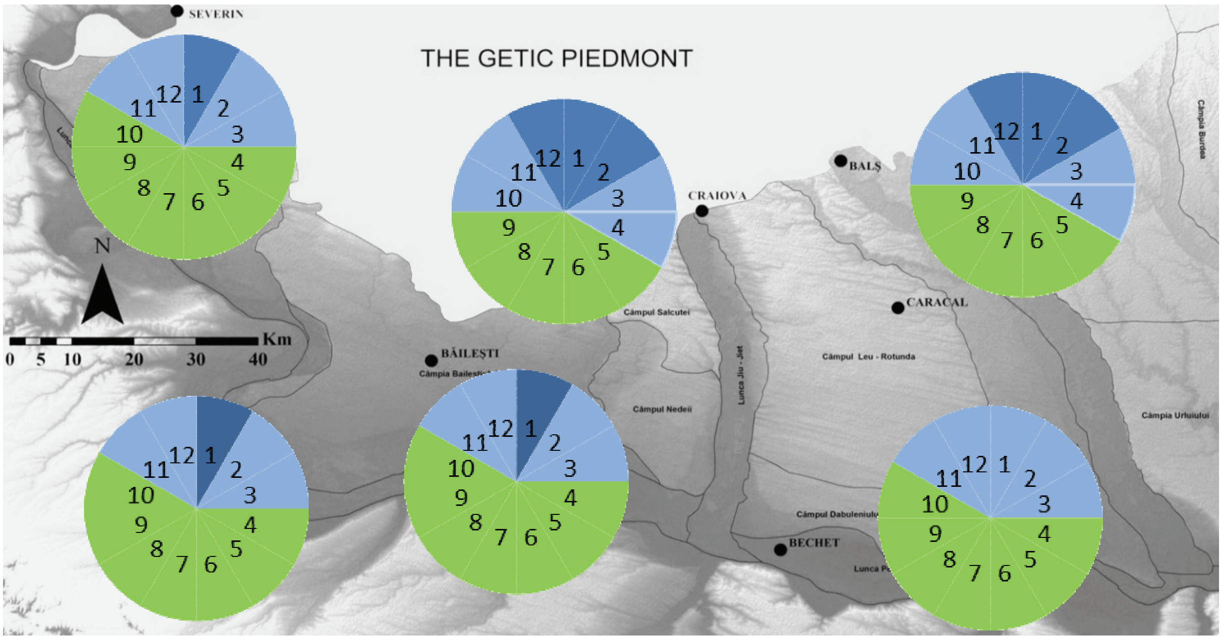
| Station | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D.T. Severin | 1.1 | 3.3 | 7.6 | 12.5 | 16.9 | 19.8 | 21.4 | 21.1 | 17.5 | 12.4 | 7.2 | 2.7 |
| Calafat | 0.7 | 2.7 | 7.3 | 12.6 | 17.2 | 20.1 | 21.7 | 21.3 | 17.5 | 12.2 | 6.7 | 2.1 |
| Bechet | -0.7 | 1.8 | 6.9 | 12.6 | 17.2 | 20.2 | 21.7 | 21.1 | 17.2 | 11.6 | 5.9 | 1.1 |
| Băileşti | -0.4 | 1.9 | 6.9 | 12.4 | 17.2 | 20.0 | 21.5 | 21.0 | 17.1 | 11.6 | 6.0 | 1.1 |
| Caracal | -0.9 | 1.5 | 6.5 | 12.1 | 16.9 | 20.0 | 21.6 | 21.1 | 17.2 | 11.8 | 6.0 | 0.7 |
| Craiova | -0.8 | 1.7 | 6.4 | 11.8 | 16.5 | 19.5 | 21.1 | 20.7 | 16.9 | 11.7 | 6.0 | 0.8 |
| Legend | Cold | | | | Comfort | | | | Hot | | | |

*DI ARAKAWA discomfort index* (DIa) (units) can be used for rendering bioclimatic comfort for the entire year, the values ranging from < 55 units, which means unbearable cold bioclimate to > 80 units which means unbearably hot bioclimate. This index illustrates a higher variation compared to the THI. Thus, discomfort caused by cooling is characteristic to the winter months – December, January and February (except for December in the southwestern extremity, which is characterized by bioclimatic comfort). In fact, February and December are very close the 60 units threshold, displaying value above 59. Thermal comfort is characteristic to spring months – March and April and to November, while October is a month characterized by discomfort caused by warming (Table 7). The interval May – September registers more than 80 units and the bioclimate is unbearably hot, especially in July and August, when the 90 unit threshold is exceeded within the entire plain, except for the southwestern extremity and the central sector.

Table 7. DI ARAKAWA discomfort index values within Oltenia Plain and the bioclimate type.

| Station | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D.T. Severin | 57.3 | 59.6 | 65.8 | 74.0 | 82.0 | 86.5 | 88.7 | 88.3 | 83.5 | 76.2 | 67.6 | 60.0 |
| Calafat | 56.8 | 59.9 | 66.4 | 74.5 | 83.0 | 87.6 | 90.0 | 90.1 | 84.5 | 76.5 | 67.6 | 59.7 |
| Bechet | 56.4 | 59.9 | 66.8 | 75.1 | 83.4 | 88.3 | 90.9 | 90.9 | 85.3 | 76.7 | 67.7 | 59.4 |
| Băileşti | 56.3 | 59.8 | 66.3 | 75.3 | 83.3 | 87.8 | 89.9 | 89.9 | 84.7 | 76.4 | 67.5 | 59.2 |
| Caracal | 56.0 | 59.9 | 66.4 | 75.1 | 83.6 | 88.6 | 90.8 | 90.3 | 84.1 | 76.5 | 68.1 | 59.4 |
| Craiova | 56.2 | 59.7 | 65.5 | 74.1 | 81.9 | 87.2 | 90.0 | 89.5 | 84.2 | 76.1 | 67.5 | 59.0 |
| Legend | Discomfort caused by cooling | | | Bioclimatic comfort | | | Unbearably hot bioclimate | | | Discomfort caused by warming | | |

*Windchill equivalent temperature (WCET)* is a useful index in assessing thermal comfort during the cold season, based on air temperature and wind speed. Values above 10°C indicate comfort, while values below this threshold, different states of discomfort caused by cold exposure. Thus, within the analysed region, comfort characterizes the interval April-October, except for the northern sector, where the first and the last month display a slight discomfort. Increased discomfort is characteristic to January for most of the plain; in December and February, only the northern and northeastern sectors register such values, while in the rest of the region there is a slight discomfort. In March and November, the values oscillate between -0.2°C and 9.5°C, namely the physiological effects indicate a slight discomfort (Fig. 2).




Comfort
Slight discomfort
Increased discomfort

Figure 2. WCET within Oltenia Plain.

*Relative strain index (RSI)* is widely used for rendering the thermal comfort in summer months. Applied on monthly average values of temperature and vapour pressure, RSI emphasized values below 0.15 during the entire year, which means a comfortable bioclimate. Taking into account that after 2000, Oltenia region confronted with increasing temperatures and longer dry periods in summer, RSI was calculated for the months with average temperatures higher than 23°C. Thus, in the last ten years of the analysed period, it resulted that July and August in particular, registered values indicating bioclimatic discomfort for more sensitive persons (0.15 ≤RSI ≤0.25). In June, RSI values maintain within the accepted limits of bioclimatic comfort (RSI≤0.15) in most of the cases, the most exposed area being the southwestern one, where temperatures are usually higher. There should be noticed that in July, in the interval 2000-2004, RSI was higher than 0.15 within the entire plain, except for the central and northern part, while in August, the threshold was exceeded in 2000, 2001, 2003 and 2007 at all the stations. July 2007 registered the highest values indicating a bioclimatic discomfort for all persons (0.25 ≤RSI ≤0.35) (Table 8). This situation was confirmed by previous studies (VLĂDUŢ, 2011). Consequently, in summer, Oltenia Plain has been exposed to a quite increased risk of overheating.

## CONCLUSIONS

The main purpose of the present study was to render certain aspects related to thermal comfort within Oltenia Plain and to compare the type of bioclimate indicated by different indexes.

According to the obtained results, there emerged some common characteristics, but also notable differences. Thus, both THI and DIa, indicate cold stress during all winter months, while heat stress is characteristic to July and August, and only partially to June (in the south of the plain, along the Danube). In case of DIa, heat stress is also registered in May and September, while THI indicates these two months as comfortable months. Bioclimatic comfort is characteristic to March, April, November and we may consider even October (as the values are quite close to 75 units) according to DIa, but the same months present a cold bioclimate according to THI. In order to clarify the differences between these two indexes, there were also used another two indexes, namely WCET and RSI, which better emphasize thermal stress during extreme seasons, winter and summer.

Table 8 Bioclimatic discomfort rendered by RSI.

| | | | |
|---|---|---|---|
| **D.T. Severin** | 0.16/2000; 0.16/2002<br>0.22/2003; 0.18/2007 | 0.18/2000; 0.22/2001<br>0.22/2002; 0.18/2003<br>0.17/2004; **0.26/2007*** | 0.22/2000; 0.24/2001<br>0.23/2003; 0.19/2007 |
| **Calafat** | 0.17/2000; 0.17/2002<br>0.20/2003; 0.21/2007 | 0.22/2000; 0.22/2001<br>0.22/2002; 0.19/2003<br>0.18/2004; **0.28/2007*** | 0.24/2000; 0.23/2001<br>0.23/2003; 0.17/2004<br>0.19/2007 |
| **Bechet** | 0.16/2002; 0.19/2003<br>0.19/2007 | 0.22/2000; 0.23/2001<br>0.22/2002; 0.18/2003<br>0.17/2004; **0.25/2007*** | 0.22/2000; 0.24/2001<br>0.22/2003; 0.17/2007 |

| | | | |
|---|---|---|---|
| **Băileşti** | 0.17/2002; 0.19/2003<br>0.23/2007 | 0.18/2000; 0.20/2001<br>0.18/2003; **0.28/2007*** | 0.19/2000; 0.22/2001<br>0.26/2003; 0.19/2007 |
| **Caracal** | 0.16/2000; 0.19/2003<br>0.19/2007 | 0.21/2000; 0.23/2001<br>0.21/2002; 0.18/2003<br>0.17/2004; **0.28/2007*** | 0.21/2000; 0.24/2001<br>0.22/2003; 0.18/2007 |
| **Craiova** | 0.16/2003; 0.17/2007 | 0.18/2000; 0.19/2001<br>0.19/2002; **0.26/2007*** | 0.21/2000; 0.22/2001<br>0.20/2003; 0.17/2007 |
| *** Bioclimatic discomfort for all persons** | | | |

Thus, cold stress is confirmed for winter months, but only January is characterized by increased discomfort within the entire analysed region, while February and December only in the northern and northeastern sectors, at Craiova and Caracal. In this sector, a slight discomfort is also registered in April and October, which are comfortable months in the other sectors. Heat stress was not confirmed by RSI when applied on monthly average values of temperature and vapour pressure. However, in the last ten years of the analysed interval, there were numerous cases (2000, 2002, 2003), when summer months were characterized by bioclimatic discomfort for sensitive persons or for all the persons (2007), confirming in this way the increased occurrence of heat stress.

Spatially, the results for the used indexes do not indicate notable differences within the analysed region, taking into account that the average monthly values of temperature, air velocity, relative humidity and vapour pressure display close values. However, cold stress or thermal discomfort induced by cooling affects the northern part of the plain more intensely and on longer periods (from December to February compared to January in the rest of the plain). Heat exposure induces discomfort during all the summer months within the entire plain and on longer periods (July and August and partially June). Thus, on the whole, the analysed region is more exposed to heat stress than to cold stress.

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