ASSESSMENT OF THE UTCI AND HSI BIOMETEOROLOGICAL INDICES FOR CONSTANȚA AND TULCEA

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ABSTRACT – Assessment of The UTCI and HSI Biometeorological Indices for Constanța and Tulcea. The present work aims to make a contribution to raising the level of awareness regarding the influence of environmental factors on the human community, by calculating two biometeorological indices, namely Universal Thermal Climate Index (UTCI) and Heat Stress Index (HSI), which provide quantitative assessments of the thermal stress experienced by human populations in the examined region. Therefore, using the Bioklima software, the two biometeorological indices were calculated based on meteorological parameters recorded at the Constanța and Tulcea meteorological stations during the period from 2016 to 2022. Consequently, the results obtained based on the analysis of the extreme values of the UTCI index, indicate "no thermal stress" as the category of thermal comfort with the highest frequency during the studied years, at both stations. At the same time, the maximum HSI values suggest that the thermal comfort category "slight and moderate heat stress" was the most prevalent during the analyzed period at the Constanța meteorological station, while at Tulcea the most frequent thermal comfort category was "slight cool stress". It is noteworthy that, although these desirable thermal comfort categories were predominant, categories illustrating weather conditions that pose a threat to the health of organisms (particularly humans) were also recorded during the studied years.

Key words: Bioklima, bioclimatic index, climate changes, HSI, thermal comfort, thermal stress, UTCI.

1.INTRODUCTION

Along with the significant increase in the consensus regarding the reality of climate change in the scientific community, the number of studies regarding biometeorological indices has also increased, especially due to the interest in quantifying the vulnerability of human society generated by the direct impact of environmental factors on the human body. Climate change is recognized and supported worldwide by an overwhelming number of individual and intergovernmental studies. An important example in this sense is the Assessment

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Report of the Intergovernmental Panel on Climate Change (IPCC), a document that comprehensively summarizes the state pf scientific knowledge regarding climate change, including its impact and mitigation and adaptation methods (Intergovernmental Panel on Climate Change, 2024)**.** On health, climate change can have a direct impact, related to changes in the frequency of extreme weather phenomena (such as droughts, fires, floods, heat waves and storms), or indirect, created by changes in ecosystems (for example, air pollution or water-borne diseases) (The Lancet Public Health, 2021). For effective public health management, prognostic biometeorological tools that consider the relationships between climate elements and humans are needed (Romaszko, Dragańska, Jalali, Cymes, & Glińska-Lewczuk, 2022). In this context, understanding the effects of very high meteorological parameters values on the human body and the significance of the results from calculations of thermal or thermo-hygrometric stress indices helps to raise awareness of the need to adopt measures, both at an individual level (by hydration, wearing appropriate clothing, avoiding open spaces, etc.), as well as at the institutional level (warning the medical staff in time, limiting working hours outdoors, setting up green spaces to reduce temperatures, etc.) (Croitoru & Sorocovschi, 2012).

Being founded on the above-mentioned aspects, the objective of this paper is to contribute to raising awareness of the need to understand the interdependent relationship between humans and the environment in which they carry out their activities. This will be achieved through the analysis of two of the most used indices found in the specialized literature, respectively Universal Thermal Climate Index (UTCI) and Heat Stress Index (HSI). Thus, the aim is to highlight the vulnerability experienced (and likely will continue to be) by the population in the studied areas from the perspective of identified thermal comfort/discomfort.

2. DATA AND METHODS

2.1. Bibliographic data sources

Both in terms of conceiving the paper itself and the scientific material used, documentation plays a decisive role in the definiteness of applying methods and obtaining the results. Thus, this study is based on articles and books from the fields of meteorology, biometeorology and geography, which collectively form the fundamental source for the theory presented and applied in this paper.

2.2. Meteo-climatic data sources

For the calculation of biometeorological indices, meteorological data recorded at the Constanța and Tulcea weather stations during the years 2016-2022 were used. These cities were considered relevant for the study, as they are located in the geographical and historical region of Dobrogea, which is “the warmest territory in the country” (Cocean & Filip, 2011, p. 213). Constanța is among the warmest cities in Romania, with a continental climate that exhibits extreme tendencies, and an average annual temperature of around 11°C (Ghinea, 2024), while the climate of Tulcea is continental, characterized by cold winters with occasional blizzards, hot summers, large thermal amplitudes, and low precipitation (Consiliul Județean Tulcea, 2024), the average annual temperature oscillating between 10.7°C (in Babadag) and 11.1°C (in Isaccea) (Consiliul Județean Tulcea, 2024). Consequently, highlighting heat stress on organisms becomes facile. The data are acquired from the Meteomanz platform, which provides both weather data obtained from SYNOP and BUFR messages issued by official weather stations, as well as forecast weather data based on GFS and ECMWF global models (Meteomanz, 2024).

2.3. The calculation of the indices

The use of biometeorological and bioclimatic indicators is an important method in biometeorology for establishing relationships between the meteorological processes occurring in the atmosphere and the human body’s reactions to them (Croitoru & Sorocovschi, 2012). They either consider a single weather-climate element (simple), or they can be calculated based on several weather-climate elements (complex) (Croitoru & Sorocovschi, 2012) . Over the last century, more than 160 climate stress indices have been proposed and developed, mainly as a manifestation of the need to quantify the influence of the thermal environment on the human body (de Freitas & Grigorieva, 2015).

2.3.1. Universal Thermal Climate Index

Universal Thermal Climate Index (UTCI) was developed by a commission initiated in 1999, at the level of the International Society of Biometeorology, with support from the European Union within the COST 730 Action (Bröde, et al., 2012), taking into consideration its applicability in any region of the globe (Croitoru & Sorocovschi, 2012). UTCI “is expressed as the equivalent air temperature (°C) of a reference environment that would produce the same human physiological response as in the actual environment” (Petralli, et al., 2020, p. 1).

The objectives for which UTCI was created are the following: “Thermo-physiologically significant across the entire range of heat exchange; applicable for whole-body calculations but also for local skin cooling (frostbite); valid in all climates, seasons, and scales from micro to macro; useful for key applications in human biometeorology, such as in Public Weather Service, Public

Health Service, Precautionary Planning, and Climate Impact Research; represented as a temperature-scale index" (Błażejczyk, et al., 2010, p. 92). The stress categories for UTCI are those in the table below (table1):

Table 1. Thermal stress classes for UTCI

Index value	Stress category
above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress
+9 to 0	Slight cold stress
0 to -13	Moderate cold stress
-13 to -27	Strong cold stress
-27 to -40	Very strong cold stress
below -40	Extreme cold stress

Source: (Błażejczyk, et al., 2010)

2.3.2. Heat Stress Index

Belding and Hatch (1955) developed the Heat Stress Index (HSI) which expresses the evaporation ratio required to maintain the thermal balance of an organism until maximum evaporation under real environmental conditions (Beshir & Ramsey, 1988) . Physiological responses of an organism observed at certain HSI values are those indicated in the table below (table 2):

Table 1. Thermal stress classes for HSI

Index value	Stress category
below 0	Slight cool stress
from 0 to +10	Thermoneutral conditions
From over 10 to 30	Slight and moderate heat stress
From over 30 to 70	Intensive heat stress; health hazard for unacclimated persons
From over 70 to 90	Very intensive heat stress; Water and minerals supply necessary
From over 90 to 100	Maximal heat stress tolerated by young, acclimated persons
above 100	Hazard of an organism overheating

2.4. The BioKlima program and its use

The selected biometeorological indices were calculated using the software BioKlima ver. 2.6 for MS Windows. This program was created by a team led by Prof. Krzysztof Błażejczyk and allows easy calculation of about 60 biometeorological and thermophysiological indices using various methods (Błażejczyk, Climate Research Department, 2023). The software was downloaded as an executable file from the website of the Institute of Geography and Spatial Organization of the Polish Academy of Sciences (Błażejczyk, Climate Research Department, 2023). The application allows the use of input data in .txt format after converting from .xls format.

In order to be able to calculate indices with the BioKlima software, the name of each meteorological parameter must be replaced, in Excel, with the abbreviation accepted by the application. Thus, the word “temperature” was replaced by the letter “t”, “relative humidity” by “f” and “wind speed” by “v”. Moreover, the columns with the other parameters, which were not necessary for the calculation of the indices, were deleted, and the wind speed was transformed from km/h to m/s. Additionally, it was necessary to add a column for the mean radiant temperature or “Mrt”.

Since in Excel the data in the form of decimal numbers were separated by a comma, before inserting the data into Bioklima, to calculate the indices, it was necessary to set a comma as a decimal separator instead of a period in the software, by accessing the “Global loading & saving options” icon in the software.

Further, the data from the Excel file were introduced into Bioklima, in text format, using the “Load into a new table” option. The names of the columns in the software are blue for valid data and names recognized by Bioklima, and red if the entered data or column names were incorrect or not recognized by the software. The text file could not be introduced into BioKlima until the Excel file with the data was closed.

Following, the icon representing the calculation options was utilized to select the targeted indices (UTCI and HSI). After activating the “Calculate” button, the application generated a new window in which there were columns with calculated indexes. The open tab was saved in a known folder, then closed and attached to the worksheet containing meteorological parameters using the “Append to the active table in columns” command.

2.5. The organization of the results

Next, the index values generated by the BioKlima software were centralized in a new Excel file, then transposed into a Pivot Table. In “PivotTable Fields”, the boxes for UTCI, “day”, “month” and “year” have been checked. The

“Sum of year” box was dragged and placed inside the “Columns” box, the “Sum of month” and “Sum of day” boxes were dragged and placed inside the “Rows” box, and the “Sum of UTCI” box was left inside the “Values” box. Also, from “Value Field Settings”, the calculation type has been changed to “Max”, for maximum values. Thus, the table was created with the daily maximum values of the UTCI arranged in (vertical) columns under the (horizontal) row representing the years. Further, in the same file the PivotTable was copied and in the “PivotTable Fields”, in the “Values” box, the “Max of UTCI” was replaced with “Min of UTCI” from “Value Field Settings”, in order to have the minimum values in the second table. This procedure was repeated for the HSI index to make the pivot tables for the maximum and minimum values, the only difference being that instead of the box for UTCI, in the “PivotTable Fields”, the box for HSI was checked.

The data with the maximum and minimum values for both indicators were copied from the pivot tables, in the form of values, into another excel file, leaving a space of three columns between the data copied from different tables. In the column to the left of the day column, the months were numbered. Before each row representing the first day of each month for each year there is the row with the maximum values for that month. This row has been deleted from each month, from each table. The rightmost column in each data set, which represented the all-year high for the day it was next to (Grand Total), was also deleted

To analyze the degree of comfort prevailing in each year, which results from the frequency of values that fall into one of the comfort categories specific to each index, two statistical tables were created for each data set (one each for the maximum and the minimum values of UTCI, respectively of HSI). One of the tables displays the number of days in the year with the maximum/minimum values (of the indicators) that fall into a certain category of comfort and the other indicates the frequency of days in a year, with values that fall into a certain category of comfort, in percentages. To create the first table, the “=” sign was placed in the cell next to the box where the degree of comfort specific to the index for which it was calculated was noted, then the data string corresponding to the year for which it was calculated was selected, and used the “Count if” function, to determine the number of days in a year that fell into a certain category of comfort, depending on the range of values in which they were located.

To create the second table, the values from the first table were divided by the total number of days in that year and then multiplied by 100, obtaining the percentage value. To ascertain the correctness of the calculation, in the lower end of the column for each year, the sum of all the values in that column was calculated, and if the sum is equal to 100, then the calculation is correct, since it is a percentage. In the column to the left of the column for the year 2022, another column was made, which indicates the average values of a comfort category, for each year. The procedure was repeated for each data set (with minimum and maximum values), for data from both stations.

By selecting one by one the tables with the percentage values, representative graphs were created, upon which the statistics were generated to show the degree of comfort (indicated by the indicators) prevailing each year.

3. RESULTS

3.1. UTCI analysis

3.1.1. UTCI maximum values analysis

Following the analysis of the results obtained based on the graphs made using the maximum values, for UTCI (Fig.1), it was found that at the Constanța station, the category indicating the prevailing degree of comfort during the analyzed years is “no thermal stress”, with a frequency average, expressed as a percentage, of 54.7%, throughout the entire period of analysis. This class is followed, in terms of frequency, by “slight cold stress”, with a multiannual average value of 19%, exhibiting significantly smaller variations from one year to another, compared to the “no thermal stress” class. From the field of heat stress, the class with the highest frequency is “moderate heat stress”, with the multiannual average of 18.4%.

Analyzing the graphs made for UTCI, based on the maximum values from the Tulcea station (Fig.2.), the category that indicates the prevailing degree of comfort during the analyzed years is noted as being “no thermal stress” whose frequency varied between 43.1% in 2018 and 50.7% in 2020. In the rest of the years, the values exceeded 44%, the multiannual average being 46.6%. The next class is “slight cold stress”, with the multi-year average of 24.1%. From the field of heat stress, the class with the highest frequency is “moderate heat stress”, with the multiannual average of 16.3%.

3.1.2. UTCI minimum values analysis

It was found, following the analysis of the results obtained from the graphs created using the minimum values, for UTCI, that at the Constanța meteorological station, the category that indicates the prevailing degree of comfort during the analyzed years, is “thermal comfort” (Fig.3.), with the average multiannual of 37.6%. The next class by frequency is “moderate cold stress”, with values between 22.4% in 2018, and 32.9% in 2020, and the average of 27.4%. It is noteworthy that the “strong cold stress” category has a multiyear average frequency of 11.9%, while the “very strong cold stress” category has a multiyear average frequency of 1.5%. In addition, the “extreme cold stress” category is represented, with a multi-year average of 0.4%.

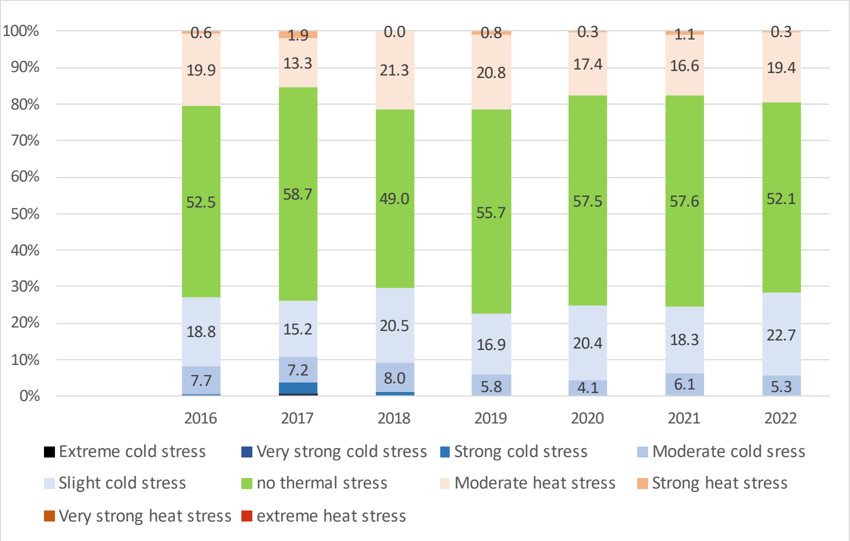

Fig. 1. The frequency of the comfort categories indicated by the UTCI index, based on the maximum values, for Constanta (%)

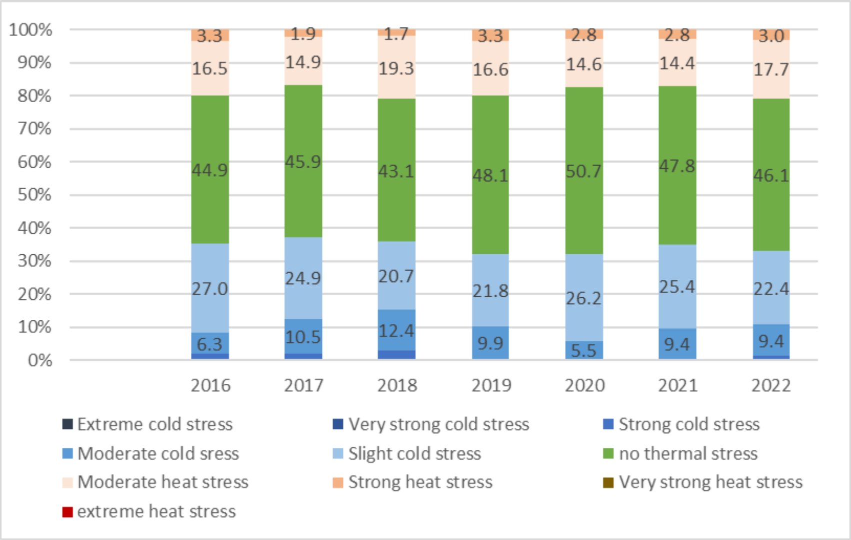

Fig. 2. The frequency of the comfort categories indicated by the UTCI index, based on the maximum values, for Tulcea (%)

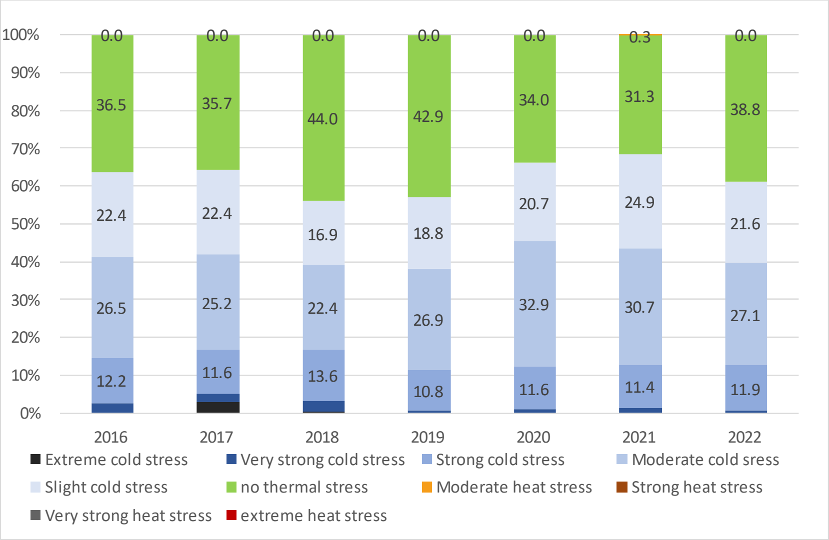

Fig. 3. The frequency of the comfort categories indicated by the UTCI index, based on the minimum values, for Constanța (%)

For the Tulcea meteorological station, the graphs made using the minimum values, for UTCI, indicate the category of thermal comfort that has the highest frequency during the analyzed years, as "no thermal stress" (Fig.4.).

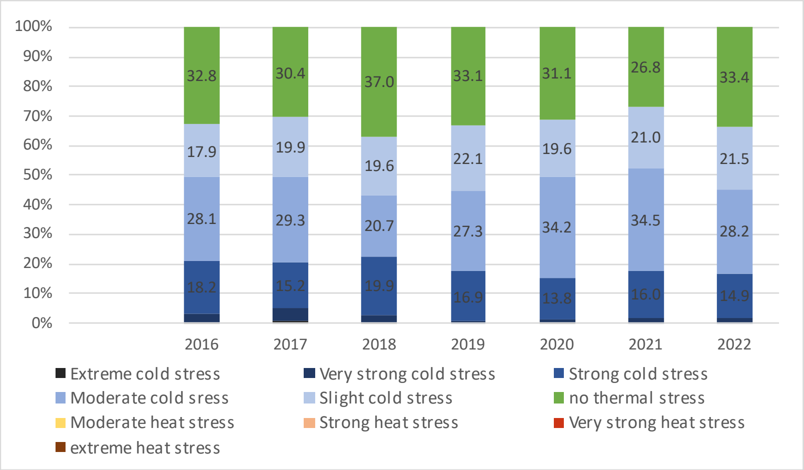

Fig. 4. The frequency of the comfort categories indicated by the UTCI index, based on the minimum values, for Tulcea (%)

According to frequency, the next category that indicates the prevailing degree of comfort is “moderate cold stress”, whose values vary between 20.7% in 2018 and 34.5% in 2021, with the multi-year average of 28.9%. Also worth mentioning are the “slight cold stress” categories, with a multi-year average of 20.2% and “strong cold stress” with an average of 16.4%. Also, the “extreme cold stress” class was recorded in the years: 2016, 2017, 2018 and 2020, the average for this category being 0.2%.

3.2. Analysis of HSI

3.2.1. Analysis of maximum HSI values

Investigating the graphs made using the maximum values, for HSI, it was found that at the Constanța station, the category that indicates the prevailing degree of comfort during the analyzed years, is “slight and moderate heat stress” (Fig.5.), which has a multi-year average of 27.6%. It is worth noting that the “maximum tolerable heat stress” classes are also reached, with 0.3% and “hazard of an organism overheating”, with a multi-year average of 1.1%, with the highest frequency (1.4%) recorded in 2017.

Analyzing the graphs made for the HSI, using the maximum values from the Tulcea station, the category that indicates the prevailing degree of comfort during the analyzed years is noted as “slight cool stress” (Fig.6.) with an average of 31.1%, and values of frequency between 28.4% in 2020 and 34% in 2017. This category is followed by “slight and moderate heat stress”, with values between

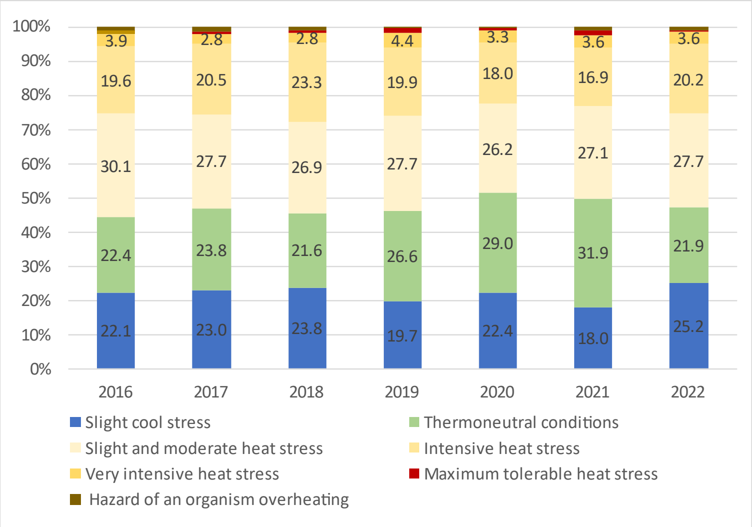

Fig. 5. The frequency of the comfort categories indicated by the HSI index, based on the maximum values, for Constanța (%)

22.9% in 2020 and 27.1% in 2022. The class with the lowest multiannual average is “maximum tolerable heat stress”, with an average of 0.2%.

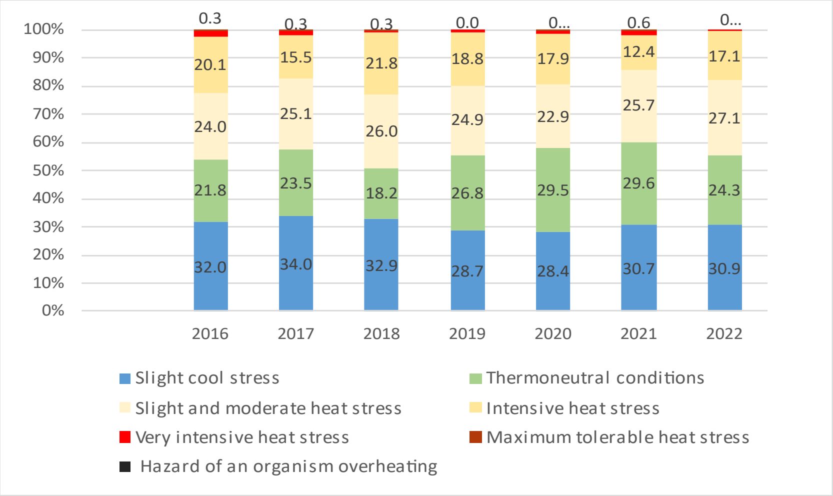

Fig. 6. The frequency of the comfort categories indicated by the HSI index, based on the maximum values, for Tulcea (%)

3.2.2. *Analysis of minimum HSI values*

For the Constanța meteorological station, the class of thermal sensations with the highest frequency during the analyzed years, as indicated by the graph generated based using the minimum HSI values (Fig. 7.), is “slight cool stress” which has a multiannual average of 64.4%. The values of this category range from 59.3% in 2018 to 69.5% in 2021. “Thermoneutral conditions” is the next class by frequency, with the multi-year average of 29.3%. The “slight and moderate heat stress” class is also reached, with an average of 6.4%.

Following the results obtained according to the graphs created using the minimum values for HSI (Fig.8.), it was found that at the Tulcea meteorological station, the category indicating the prevailing degree of comfort during the analyzed years is “slight cool stress”, with a multi-year average. of 70.4%. The frequency of this category of thermal comfort evaluation varied between 65.5% in 2018 and 74.3% in 2021. The next class, in terms of frequency, is that for “thermoneutral conditions”, with an average of 27%. The class with the lowest frequency is “slight and moderate heat stress”, which has a multiannual average of 2.6%, with annual values not exceeding 3.9%.

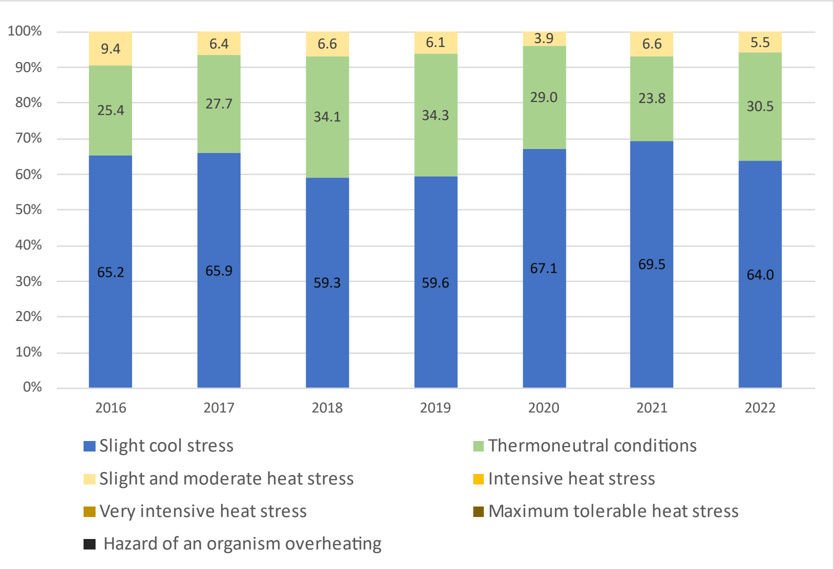

Fig. 7. The frequency of the comfort categories indicated by the HSI index, based on the minimum values, for Constanța (%)

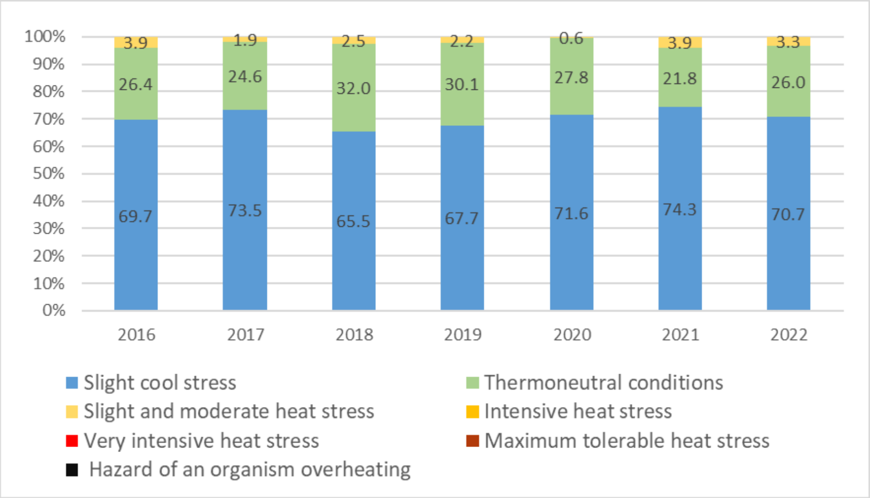

Fig. 8. The frequency of the comfort categories indicated by the HSI index, based on the minimum values, for Tulcea (%)

Assessing the results, it is noted that during the years 2016-2022, both at the Constanța meteorological station and at the Tulcea meteorological station, meteorological parameters were recorded that generated different levels of thermal stress.

DISCUSSION

The observed variations in the frequency and intensity of thermal stress categories between the Constanța and Tulcea stations can be attributed to the climatic and geographical conditions specific to each location. In this sense, the meteorological station in Constanța benefits from a “mitigating influence of the Black Sea” (Cocean & Filip, 2011), which reduces thermal extremes and maintains the humidity relatively constant. At the same time, the meteorological station in Tulcea records greater susceptibility to cooling thermal stress during the cold season and to heating thermal stress in the warm periods, being located further from the coast and influenced by a more temperate continental climate.

A significant limitation of this study is that the analysis is based on meteorological data collected over a period of seven years. Climate analyses generally require longer time frames to identify climate trends (Data, 2024) or long-term changes in heat stress experienced by the population in the study area. However, the study manages to highlight that, in the analyzed area, conditions of extreme stress were reached, such as “extreme cold stress” for UTCI and “maximum tolerable heat stress” and “hazard of an organism overheating” for HSI.

At the same time, the present study serves not only as an assessment of the thermal stress generated by the climatic conditions in the analyzed regions, but also as a foundation for future research. Providing a detailed analysis of heat stress in Constanta and Tulcea over a period of seven years, this study highlights the variability of heat stress under the influence of meteorological factors and the importance of continuous monitoring of these conditions.

The data obtained can be extended both temporally and geographically, following the example of many similar studies that use data over a longer period of time and examine multiple cities with various types of local climate. For example, studies such as “Changes Detected in Five Bioclimatic Indices in Large Romanian Cities over the Period 1961–2016” (Banc, Croitoru, David, & Scripca, 2020) and “Observed Trends in Thermal Stress at European Cities with Different Background Climates” (Founda, Pierros, Katavoutas, & Keramitsoglou, 2019) allow observing the long-term evolution of thermal stress phenomena and evaluating local vulnerability according to regional climatic and socioeconomic conditions. The inclusion of extended time series facilitates a clearer identification of long-term climate trends.

Such an approach can provide a deeper understanding of the impact of climate change on public health (Jian, 2025) and encourage the formulation of more effective policies to manage climate risks.

CONCLUSIONS

The results of calculating the UTCI index using the maximum values, for Constanța and Tulcea, in addition to the "no thermal stress" category, indicate "slight cold stress", which brings a sensation due to which it is necessary to use thicker clothing, and the stress category "moderate heat stress" which leads to abundant sweating. Based on the graph made using the minimum values, it can be stated that, in addition to "no thermal stress", the most frequent comfort categories were "moderate cold stress" and "slight cold stress", which implies the need to adopt the right clothing to avoid both the feeling of cold, as well as that of intense cold accompanied by pain.

The thermal stress conditions indicated by the HSI index are similar at the two stations, but for the maximum values, they are in a different order, meaning the categories with the higher frequency differ. Therefore, the maximum values from the meteorological station display the following categories of thermal stress: "moderate heat stress", closely followed by "thermoneutral conditions" and those of "slight cool stress", and the values from the Tulcea meteorological station indicate the same categories, but in a different order: "slight cool stress" followed by "slight and moderate heat stress", then by "thermoneutral conditions". In the case of minimum values, the order is the same at both stations: the category with the highest values is the one corresponding to "slight cool stress".

Since the analysis is conducted using data recorded over seven years, it is not possible to establish a statistic regarding the representativeness of the degree of comfort for the investigated stations, as well as the evolution of comfort levels over time, as this would require data recorded over a longer period of time. However, the methods used can be applied, evaluating a much larger set of data, over several years, which will be the subject of a larger study in the future if there will be the availability of the necessary data.

In addition, to validate the theoretical aspects, future studies can involve surveying the population, regarding the degree of thermal comfort that people perceive, and the answers can be compared with the results of calculating the indices. Also, the studied area can be extended, in order to carry out a comparative study, using meteorological data from several stations.

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