

Research article

The thermal perceptions of people in relation to meteorological observations. Case study for the urban agglomeration in Suceava - NE Romania

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Abstract: Background: This study by design, approach, duration and number of respondents is the first of its kind for Suceava and Romania. The first objective of the study was to assess the average level of thermal perceptions of the population in the researched area. **Methods:** The respondents appreciated and wrote the level of comfort/discomfort felt daily, the interdiurnal, interlunar and intertemporal regime of thermal perceptions by reference to the meteorological elements and biometeorological indices was also assessed. The biometeorological survey test was conducted from January 1, 2019 to February 28, 2021, and 9321 valid responses were received (on average 11.8 answers/day-1). **Results:** The overall average of the answers (of -0.55) shows that the respondents perceived the atmosphere of the urban agglomeration as cool, the winters were cold and moderately cold (the answers average = -1.43), whereas the summers were more thermally comfortable than warm (the average of the answers = 0.73). The Pearson correlation coefficients between the averages of the daily answers and the average or extreme values of temperature, respectively of the biometeorological indices, ranged between 0.65 and 0.88. **Conclusions:** The PCA analysis reconfirmed high degrees of correlation between the average responses, the examined meteorological and biometeorological factors.

Keywords: thermal perception; thermal comfort; gradual thermal discomfort.

Introduction

The complex nature of the process's parameters or the weather-climate phenomenon in question, as well as a number of geographical and human-subjective characteristics, influence how the population perceives the weather or climate [1, 2]. Climate change is the most frequently discussed climate-related issue at many spatial scales (global [3], continental for Europe [4], national [2, 5], regional [6], etc.). Studies on urban biometeorology are numerous and varied [7], even in some nations where the area of study was introduced later [8]. A few of them focus on the effects on the health of residents in those places and are connected to the context of climate change and risks [5, 9, 10]. Others generally focus on biometeorological indices and probing subjective biometeorological perceptions by reference to outdoor thermal comfort or discomfort of the target human groups [11-14]. It sometimes proves necessary to quantify or probe temperature sensations in particular metropolitan settings [13,15], public spaces [16,17], or by utilizing new methods [18] and biometeorological context substitutes [19].

Tools for assessing the population's thermal perceptions of different communities have therefore been built on the use of various biometeorological indices or survey techniques. Among more than 100 biometeorological indices used in different studies to identify and analyze the thermal perception of human groups, wider use have thermal sensation votes (TSV), predicted mean vote (PMV), Actual Sensation Vote (ASV) which are also related to their actual interviewing with reference to the perceived thermal state for different time sequences [20, 21, 22].

A number of these indices have proven their limitations over time [23], but they remain viable alternatives for assessing thermal sensations.

More than 120 studies have been conducted recently on the external thermal comfort for Central and Eastern Europe using a variety of methods and indicators [24]. Urban bioclimatology research is scarce in Romania [25], and studies evaluating the perception of biometeorological conditions are nonexistent.

Stehr and Von Storch [26] presented the idea of the "social construction of climate," according to which society might use perceptions of the climate as a permanent instrument to adjust to a changing and fluctuating environment. Regardless of where they live, human communities' views of the weather are shaped by the daily patterns of the weather [27]. We can assume that a community's bioclimatic consciousness will eventually crystallize, making its citizens more able to adapt and behave sustainably to the biometeorological fluctuation that frequently results in discomfort and morbidity/mortality. It has been proven and accepted that people from the same cultural and geographical background develop the same level of tolerance and thermal perceptions [28].

The study's essential components are a result of the severe dearth of thermal perception and biometeorological studies for Romanian cities. These studies are crucial for the proper handling of urban biometeorology issues. The necessity to evaluate a test community's biometeorological culture also gave rise to the study, which has broad applicability to urban areas with temperate climates. A community that shows such a high degree of sensitivity to minor issues related to bioclimatic comfort or discomfort has to be fully recognized for its potential in effectively resolving a number of urgent urban environment issues. The survey's distinctive characteristics include the answers' daily frequency and its lengthy duration (two years and two months), which allowed the biometeorological experiences of the respondents to pass through varied weather conditions, more or less demanding ones) and the high correlation level of the subjective sensory perceptions with the results of the meteorological observations and precise bioclimatic calculations. The study elaborated by Mihăilă [29] in 2022 about the perception of the population of Suceava town and its surroundings by reference to the climatic risk phenomena showed that the population of the urban agglomeration in Suceava is aware about the impact of the climatic risk phenomena and realistically assesses it, but they do not have adapted reactions to them at the moment of their production due to the existing deficiencies in the managerial plan at all the organizational levels of the community.

Study objectives. Starting from this stage conclusion that reflects a high perception level by reference to the meteorological risk phenomena, our study aims the following: *i)* to outline, based on the answers given by the respondents participating in the survey, the defining biometeorological features of the researched territory, and *ii)* to prove by mathematical bases and in a reasonably long period (over two years) the high perception level of the population of Suceva by reference to the complex and variable relationships that are established between it and the weather conditions that are comfortable or marked by discomfort in different degrees, by using the biometeorological survey and the meteorological observations. By considering the signs of the perceptive biometeorological balance, the accomplishment of the two goals will assist the population and decision-makers in identifying a number of their general weather-related vulnerabilities as well as some bi-ometeorological vulnerabilities unique to each month or season of the year. At the same time, the results of the study will be used in urban planning and management of public health problems. It is recommended that the results of the study should be taken

into consideration when preparing adaptation strategies for Suceava and similarly sized cities to the changing regional climate context.

2. Data and methods

2.1. Means and methods

The hourly meteorological data from the Meteorological Station of Suceava belonging to the National Meteorological Administration and from the SV1 / SV2 stations belonging to the National Network of Air Quality Monitoring were processed and transformed into daily data for the period 1st January 2019 and 28th February 2021. The results were average diurnal values of the meteorological elements: air temperature, relative humidity and wind speed. For the maximum and minimum values of the air temperature, we selected the highest and the lowest daily temperature values from one of the three meteorological stations. The biometeorological indices (the thermo-hygrometric index - THI, the wind cooling power index - Pr, of the temperature equivalent to the cooling power of the wind - Tpr and the temperature-humidity index - THI) were calculated with the help of formulas [1 - 4].

The calculation formula of THI [1] was proposed by Kyle in 1994 [30].

$$THI\text{ }^{\circ}\text{C} = T_{dry} - (0.55 - 0.0055 \cdot Rh) \cdot (T_{dry} - 14.5)$$

where:

T_{dry} – the temperature of the air in $^{\circ}\text{C}$ measured on a dry thermometer and Rh – relative humidity (%).

Table 1. The THI threshold values ($^{\circ}\text{C}$) a), the bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c) – according to Mihăilă et al. [31].

a) THI index ($^{\circ}\text{C}$)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
$-20 < \text{THI} \leq -10$	Excessive cold	Bioclimatic discomfort due to overcooling
$-10 < \text{THI} \leq -1.8$	Very cold	
$-1.8 < \text{THI} \leq +13$	Cold	
$+13 < \text{THI} \leq +15$	Cool	
$+15 < \text{THI} \leq +20$	Comfortable	Bioclimatic comfort
$+20 < \text{THI} \leq +26.5$	Warm	Bioclimatic discomfort due to overheating
$+26.5 < \text{THI} \leq +30$	Very hot	
$\text{THI} > 30$	Torrid	

The calculation formula of Pr [2] was proposed by Siple and Passel [32] in 1945 and modified in 1974 by Beçancencot [33].

$$Cp = (12.1452 + 11.62222\sqrt{s} - 1.16222 \cdot s) \cdot 33 - T_{dry} [2]$$

where:

T_{dry} – the temperature of the dry thermometer ($^{\circ}\text{C}$);

s – the speed of the wind (m/s). As an index, Pr has a greater relevance for the cold season of the year, but it was calculated from the need of a comparative analysis that includes all the year for all the days of the period 1st January 2019 and 28th February 2021.

Table 2. The cooling power of the wind ($\text{kcal}/\text{m}^2/\text{h}$) and the significance of the biostress index skin.

Cooling power of the wind (kcal/m ² /h)	Indices of stress skin	Character (significance)	Type of stress
0-149	-2	hypotonic	stress by triggering thermolysis in summer
150-299	-1	hypotonic	stress by triggering thermolysis in summer
300-599	0	relaxing	it does not require thermoregulation
600-899	+1	hypertonic	stress by triggering thermogenesis in winter
900-1199	+2	hypertonic	stress by triggering thermogenesis in winter
1200-1499	+3	hypertonic	stress by triggering thermogenesis in winter
>1500	+4	hypertonic	stress by triggering thermogenesis in winter

The calculation formula of Prt [3] was proposed by Siple and Passel in 1945 and modified in 1974 by Beçancenot (quoted by Escourrou [34] and Teodoreanu [35]).

$$T_{pr} = (33 + (T_{dry} - 33) \times (0.474 + 0.454\sqrt{s_1} - 0.0454s_1)) [3]$$

T_{dry} – the temperature of the air measured by the dry thermometer (°C);

s_1 – the speed of the wind expressed in m/s.

At the recommendation of the World Meteorological Organization, the temperature-humidity index is used as a discomfort index, especially in the warm half of the year (ITU) [31]. For reasons of continuity and reporting/correlation of this index with the average marks of the answers to the biometeorological survey, we calculated this index for all the days of the considered period, according to the formula:

$$ITU = (T_{air} \times 1,8 + 32) - (0,55 - 0,0055 \times Rh) \times [(T_{air} \times 1,8 + 32) - 58] [4]$$

where:

ITU – the temperature – humidity index (units);

T_{air} – the temperature of the air (°C);

Rh – the relative humidity of the air (%).

Table 3. The thresholds of ITU and the comfort intervals, biometeorological alert and severe discomfort related to the latter.

The temperature – humidity index ≤ 65 units indicates the comfort
$66 \leq$ The temperature – humidity index ≥ 79 indicates the alert
The temperature – humidity index ≥ 80 units shows discomfort

December 2018 marked the beginning of the biometeorological survey, which ran until March 2021. It was a component of a broader study, part of which respondents were asked to rate the daily thermal and biometeorological characteristics. The design of the survey was made by dividing Suceava's weather conditions over a year into 9 value classes (from very cold to very hot, passing through the comfort class) according to the detailed quantitative knowledge of the bioclimatic reality of this city. In this investigation, data gathered between January 1, 2019, and February 28, 2021, was considered. The survey was made available on the survey's site. The link through which the survey could be accessed was distributed in the Suceava community, the main distribution vectors being the students of "Stefan cel Mare" University and their families. Only one response per

respondent per day, on any given day throughout this period, was permitted. Some responders provided more responses for multiple for several days, others a smaller number, according to their availability. The fundamental need for each daily response was that the individual respondent should spend some time outside in the open air, experience the atmosphere, and provide their personal opinion regarding their observations of the day's biometeorology. So the respondents filled in the biometeorological questionnaire in front of the computer every day they had the opportunity, ticking one of the 9 thermal options offered (Table 4), the answers being centralized in real time in the survey officer's computer. Since we were in charge of the survey, we suggested that responses be sent in the afternoon or evening of each day, when respondents would have the best perception of the day's temperature and biometeorology. While certain personal information provided by the respondents during the survey day allowed them to be recognized, this information was only used as control data and was never shared with third parties or used for any other reason. Respondents are currently anonymous. Their mediated responses form the statistical basis of this study.

2.2. Data obtained

In this study, we processed time series of meteorological elements (air temperature, atmospheric humidity, wind speed), of bioclimatic indices (the thermo-hygrometric index - THI, the wind cooling power index -Pr, of the temperature equivalent to the cooling power of the wind - Tpr and the temperature-humidity index - ITU). We also processed the answers given by the respondents after they were converted into grades with a value from -4 (the major risk to health or bodily integrity due to meteorological factors at very low temperatures) to +4 (the major risk to health or bodily integrity due to meteorological factors at very high temperatures). As a result, on each day that a survey participant completed it, we, the survey administrators, offered them the choice to select one of nine biometeorological characteristics for that day. The respondent's actual decision to select that option was mostly subjective, and we believe it was influenced by their impressions of the day's temperature and biometeorology (Table 4).

Table 4. The survey authors provided a semi-constructed answer that included a palette with biometeorological characteristics of the days that respondents could check based on their perceptions. The selected option was then converted into a specific grade, with values ranging from -4 to -1 (for days with discomfort to varying degrees due to cooling), 0 for thermally neutral days (with comfort), and +1 to +4 (for days with discomfort to varying degrees due to heating).

The palette with the biometeorological characteristics proposed by the authors of the survey about the days of one year	Note of the characteristic
Major risk to health or bodily integrity due to meteorological factors at very low temperatures	-4
Severe discomfort due to weather factors among low temperatures	-3
Medium discomfort due to meteorological factors among low temperatures	-2
Reduced discomfort due to weather factors among low temperatures	-1
Thermal comfort (17-23 degrees Celsius)	0
Reduced discomfort due to weather factors among high temperatures	1
Medium discomfort due to meteorological factors among high temperatures	2
Severe discomfort due to weather factors among high temperatures	3
Major risk to health or bodily integrity due to meteorological factors at very high temperatures	4

During the period when the biometeorological survey was open for completion and active, we received 9632 answers, of which 311 were invalid, and 9321 answers were validated, 44.8% of the answers were given by men and 55.2% were given by women.

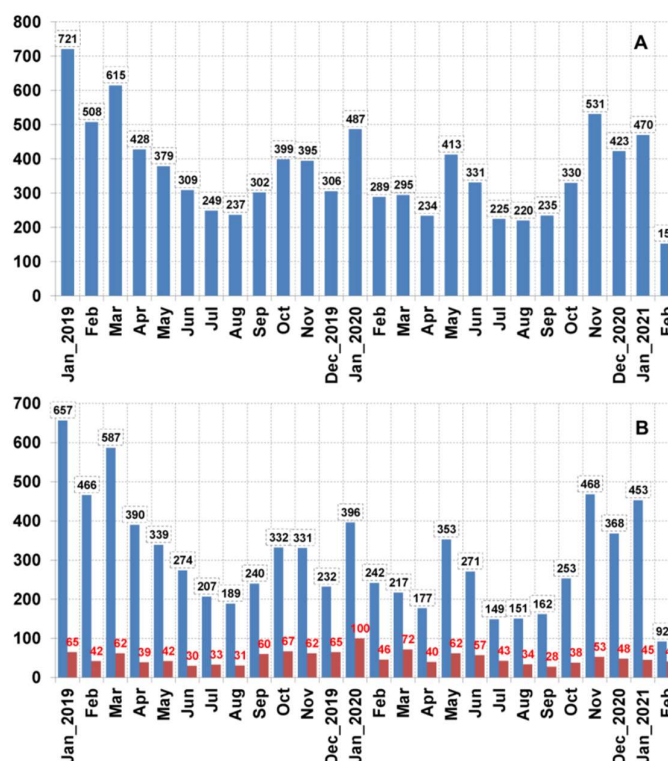


Figure 1. The monthly number of answers to the biometeorological survey from January 2019 to February 2021 - A; the monthly number of answers that were separated by the answers of the respondents who considered themselves healthy and the answers of those who, at the time of the response, were suffering from a certain condition - B.

86.1% of the answers were given by people who considered themselves healthy at the time and 13.9% by people who considered themselves sick. The average age of the respondents was 34.7 years. We recorded an average of 11.8 answers/day and we consider that we were able to give representativeness of the daily averages of the survey marks because we did not have a day in which we recorded less than 5 answers. In total, a cumulative number of 494 respondents participated in this survey during the 790 days when the platform was open. For each month of the analyzed period, the total number of the validated answers and the number of differentially validated answers for healthy / sick persons can be traced in Figure 1 A and 1 B. The statistical analysis is based on a consistent and representative dataset on a daily, monthly and overall basis over the 2 years analysed. The differential analysis of the answers given by healthy persons and by those suffering in certain days of the survey of acute conditions or medically certified as chronically ill, finally allowed us to take into account some important aspects regarding the thermal perceptions of the two categories of people. During the summer holidays of July-September and December (during the winter holidays) the number of answers counted daily was lower (but it did not drop below 5/day).

3. Study area

The study region covers the origin area of the respondents and is divided into two parts: an exterior part made up of neighboring suburban towns and an internal component located in Suceava and its surrounding neighborhoods (Figure 2).

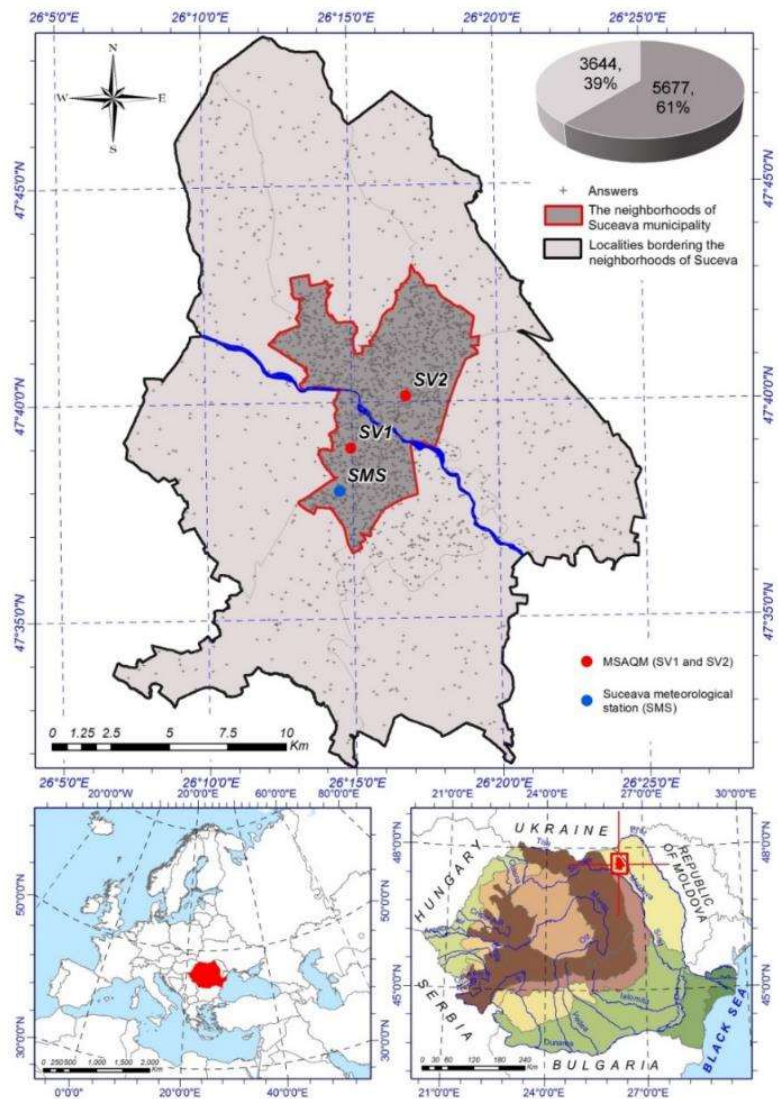


Figure 2. The territorial distribution of the respondents' answers to the survey.

This territory had a total area of 406.9 km², in 2022, according to the data extracted from the TEMPO Online website [37]. There were 186603 inhabitants. Their density was 458.6 people/sq.km (2374.8 / sq.km in the town of Suceava; 180.3 place / sq.km in the towns of the first ring. Since they experienced the weather and climate on a daily basis during the survey period, all of the respondents were aware of the actual conditions in the Suceava metropolitan region. Regarding provenance, 60.9% of the responses were from respondents living in Suceava town's neighborhoods, while 39.1% came from respondents living in the first ring of communities that encircles Suceava on the outside.

4. Results

4.1. The meteorological and biometeorological characteristics of the period 1st January 2019 – 28th February 2021 resulted from measurements and calculations

Certain discrepancies could be observed when comparing the meteorological data from January 1, 2019 to February 28, 2021, with the climate data from 1961 to 2015. The

two years under analysis had 2.5°C more warmth than the 1961–2015 climate average. The two years under analysis were 5–6% drier than the years from 1961 to 2015, based on the relative humidity data. The wind's yearly average speeds exceeded the reference period's average by 0.2 and 0.4 m/s (1961–2015).

4.2. The biometeorological characteristics of the period 1st January 2019– 28th February 2021 resulted from the survey

The analysis covers the months of January 1, 2019–February 28, 2021, which consists of eight winter months and six spring, summer, and fall months. Even a brief examination of the data reveals that a significant portion of the answers recorded from the population of AMSv (68%) indicate that the time / weather was perceived as cold, in different intensity degrees, from low discomfort (41% of responses) to moderate discomfort (18%), high discomfort (9%), and even severe discomfort (9%). Although the averages of the given answers are unclear due to the fact to those indicating different degrees of cooling discomfort. The diurnal time/weather sequences were evaluated as agreeable by 21% of respondents (1954). Only 11% of the answers rated the weather sequences they referred to as warm, marked by low (7%), moderate (3%) or high/severe (1%) discomfort (Figure 3).

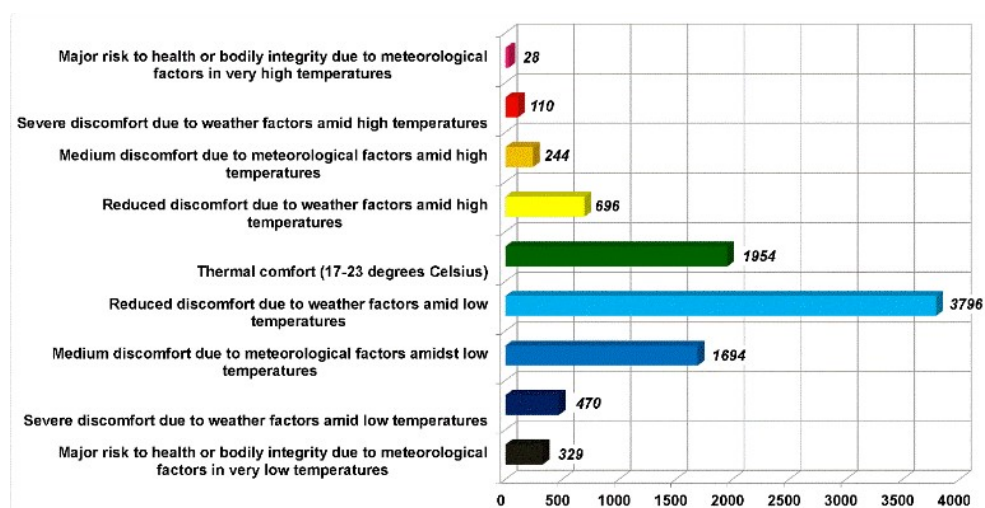


Figure 3. The total number of answers by which the respondents appreciated the relationship between themselves and the air environment for the day they answered the questionnaire, divided into a comfort period and 8 discomfort periods in different degrees (4 discomfort periods due to temperature values assessed by the respondents as low and 4 ranges of discomfort due to temperature values assessed by the respondents as high).

After classifying the responses according to season, we can observe from the boxplot-style diagrams (Figure 4A) that winters were regarded as rather chilly, with pockets of really cold or even freezing days. The autumns were frozen, the springs chilly. According to the responses provided, biometeorological variability was considerable throughout the autumns, but it did not surpass biometeorological variability during the summers, which were moderately warm with pockets of extremely warm days and only inadvertently hot. According to the responses provided by the respondents, the winter months were characterized as chilly, rather cold springs, milder autumns than spring, and those of the summer were distinguished by -1.4 to -1.6 on a monthly average (Figure 4B).

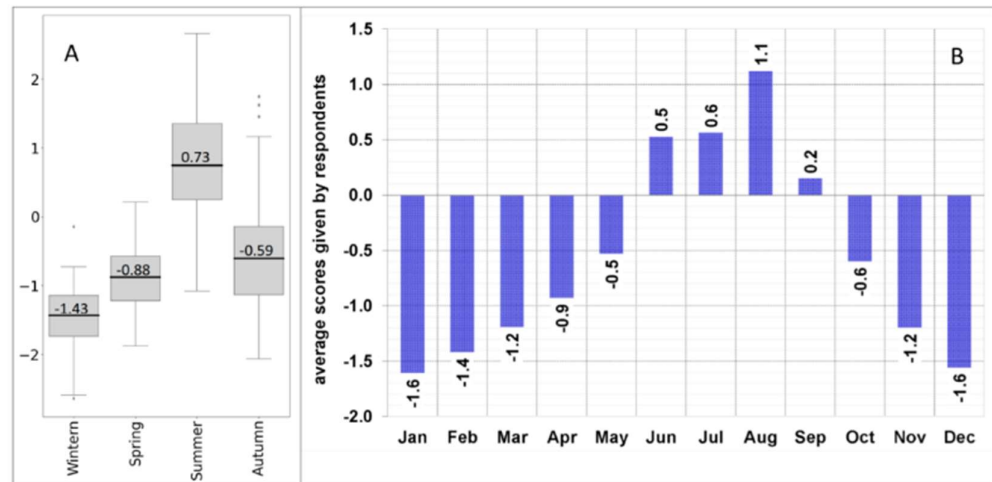


Figure 4A. The boxplot-type diagrams showing for each season the statistics of the averages of the daily answers given by the respondents about their thermal perceptions and that could be selected by the respondents from a scale with 9 qualitative steps (4 related to the cooling discomfort, one to the thermal comfort and 4 related to the heating discomfort, according to those in Table 1); **4B** the annual progress of the monthly averages calculated from the daily grades given to the respondents according to the thermal perceptions in accordance with the 9 qualitative steps in Table 1.

4.3. The analysis of the correlation level between the given answers and the averages of temperature and humidity

For each month of the two years and two months analyzed, by putting the parameters of the air temperature (the average temperature in Figure 5A, the minimum temperature in Figure 5B, the maximum temperature in Figure 5C) in direct temporal relation with the given answers, we can see strong direct correlations between the temperature variables and the averages of their corresponding answers.

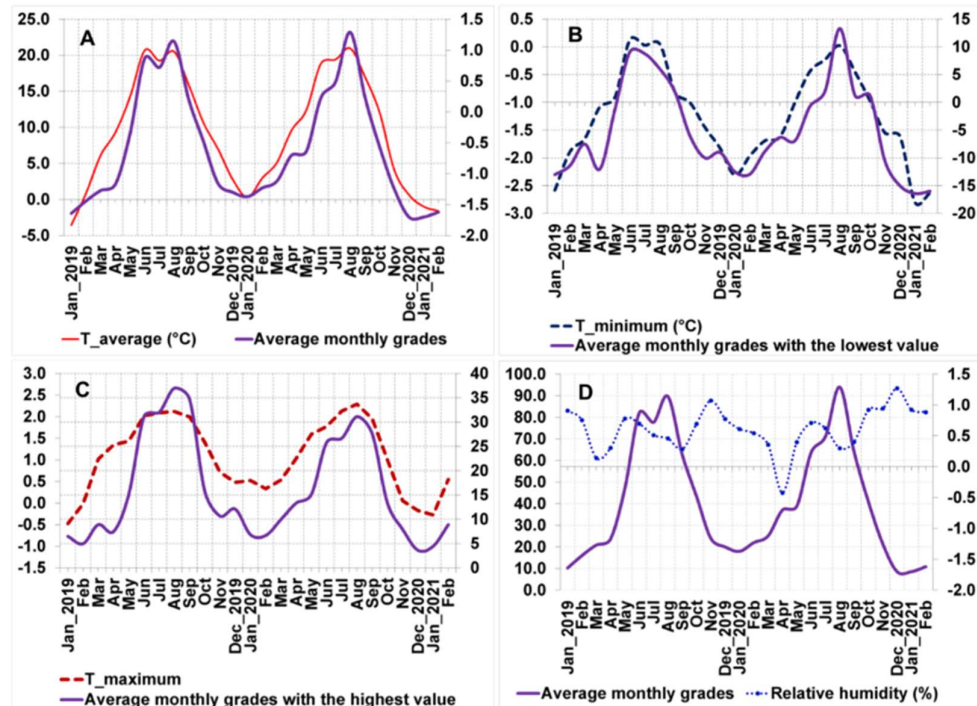


Figure 5. Progress of average values - A, maximum - B, minimum - C of the monthly air temperature, the monthly averages of relative humidity - D compared to the monthly averages of the answers given by the respondents for the period 1st January 2019 – 28th February 2021.

The highest correlation degree occurs between the average and minimum temperature values (Figure 5A and 5B) and the received answers. For all the thermal parameters (averages, minimums, maximums), there is a quasi-synchronism of their intermonthly regime with that of the averages of the given answers. The correlative links are weaker in the case of comfort/discomfort values for monthly thermal maxima. The relative humidity plays only a tangential role that is difficult to prove in the human energy and caloric balance, which is a fact indicated by the inconsistency of the regime of the relative humidity curves and the averages of the received answers (Figure 5D).

Figure 6 illustrates the quasi-synchronicity of the inter-day variability of the air temperature values and the averages of the respondents' responses regarding the degree of comfort or discomfort they felt from the biometeorological questionnaire. This is represented mathematically by the regression equation and the determination coefficient $R^2 = 0.739$ from Figure 7, as well as graphically by the regression line.

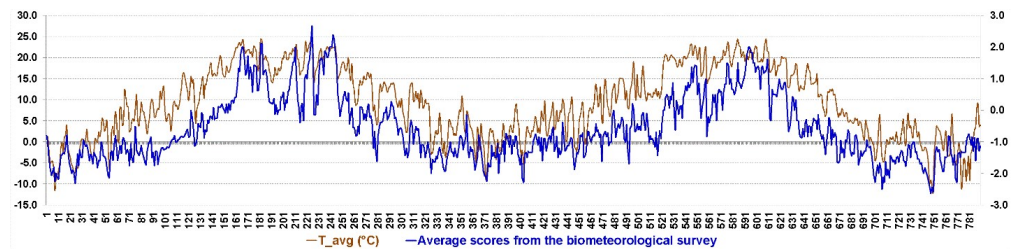


Figure 6. The regime of the daily values of the average air temperature (°C), of the daily averages of the answers given by the respondents for the period 1st January 2019 – 28th February 2021.

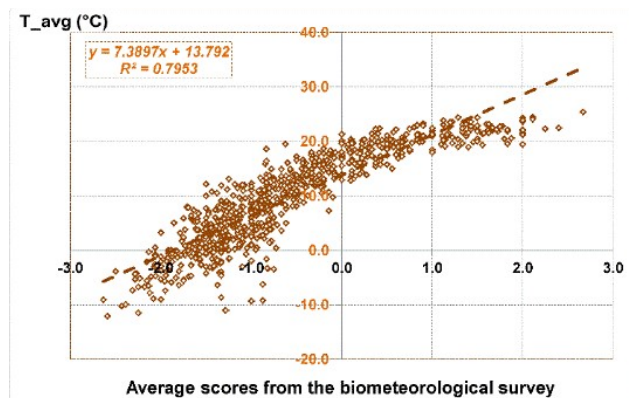


Figure 7. The correlation graph and the regression equation between the daily average values of air temperature in comparison to those of the average marks of the answers given by the respondents for the period 1st January 2019- 28th February 2021.

The statistical and graphical models demonstrate a high correlation between the two variables under analysis, suggesting that human thermal sensations are firmly anchored in the thermo-caloric reality of weather patterns that change day-to-day within the AMSV.

4.4. Analysis of the correlation level between the given answers and the averages of the bioclimatic indices

The monthly correlation between the THI values and the monthly averages of the answers provided is very good and directly proportional. This allows us to understand that the population in AMSV has a high degree of perception regarding the effects of the thermo-hygrometric complex on comfort or graded discomfort, and it is in three distinct month categories: months with comfort (May-June and September-October), months with moderate heat-related discomfort (July-August), and months with moderate to high cooling-related discomfort (November-April). - Figure 8a.

From a valoric perspective, the cooling power of the wind correlates inversely with the monthly averages of the responses provided regarding each respondent's relationship to the level of comfort or discomfort felt in the atmosphere. The more uncomfortable cooling is, the higher this index's value is (particularly in the winter months). At the conclusion of spring, the start of summer, or the start of autumn, thermal comfort is reached when the Pr index reaches average values of 500–600 Wm^{-2} .

When its value is lower (in summer), the discomfort level due to the heat increases - Figure 8B. The monthly averages of the responses correlate directly proportionally and the temperature equivalent to the cooling power of the wind - TPr (Figure 8C) completing the regime patterns identified by the analysis of the other two indices (THI and Pr). Although the ITU, as an index of discomfort, has no real relevance for the months and days from November to March, for reasons related to having a complete graphical model of it for the whole year, the ITU was also calculated for the mentioned months. In the period April-October and especially June-August, the ITU gives relevant results for the chosen bioclimatic analysis and it shows us that the population in AMSV (in accordance with the given answers) suffers from discomfort to a reduced to moderate extent due to the warming of the atmosphere - Figure 8D.

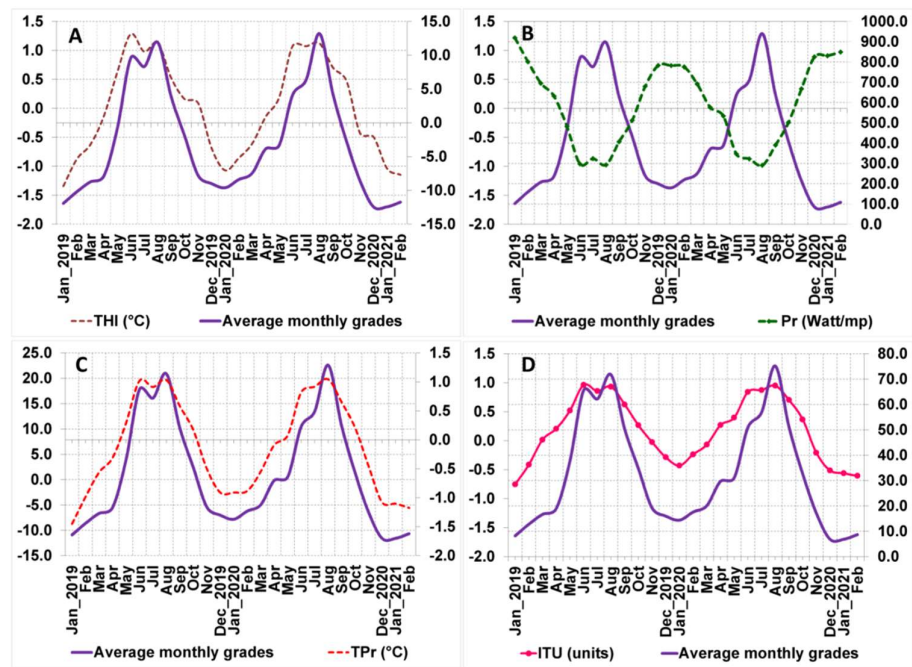


Figure 8 Progress of the monthly average values of THI - A, Pr - B, TPr - C and ITU - D in comparison to the monthly averages of the answers given by respondents for the period 1st January 2019 - 28th February 2021

Strong correlations directly proportional to THI indicators - Figure 9A, TPr - Figure 9C, ITU - Figure 9D, and inverse with Pr - Figure 9B - are revealed at a higher detail level by analyzing the inter-day course of the average answers and the bioclimatic indices (Figures 9A-9D).

The regression models show strong links between diurnal means of responses and bioclimatic indices, their equations and coefficients of determination R^2 (Figure 10A-10D). When comparing the replies to the THI, we found that 47% of them had a positive correlation in value. Sixty percent of the responses for the other indices showed correlation (negative for Pr and positive for ITU).

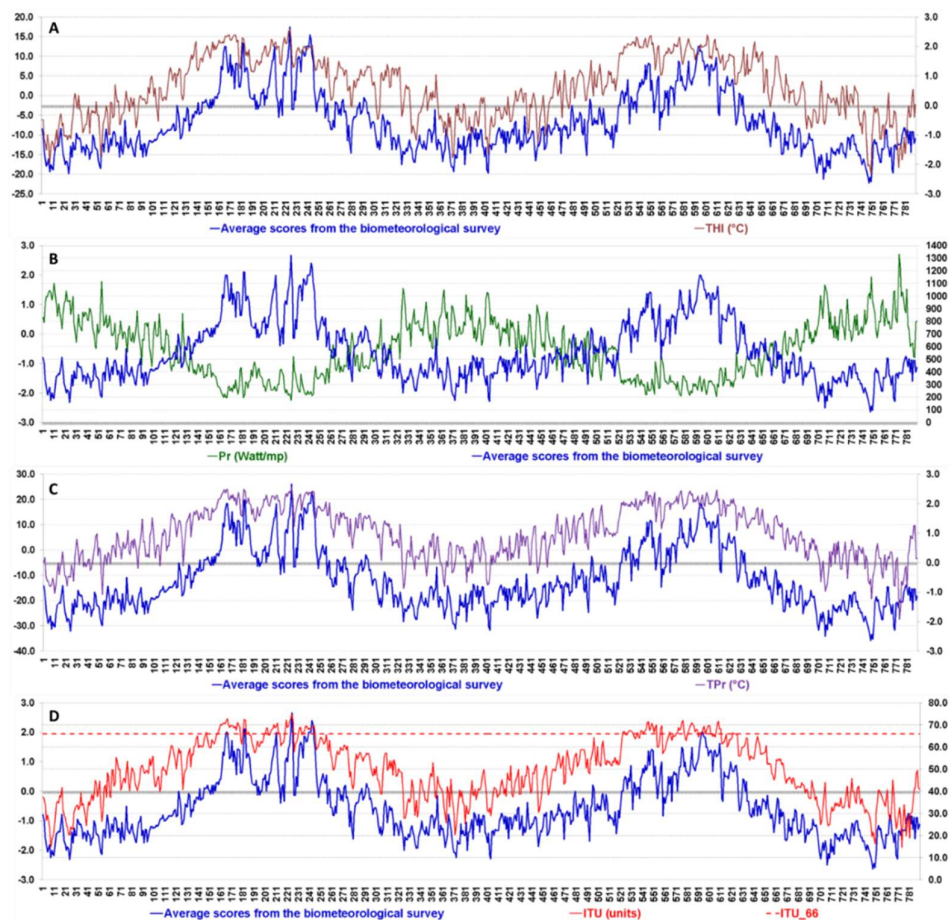


Figure 9. The regime of the daily values of THI (°C) - A, Pr (Watt / mp) - B, Tpr (°C) - C and ITU (units) - D in comparison to the daily averages of the answers given by the respondents for the period 1st January 2019 – 28th February 2021.

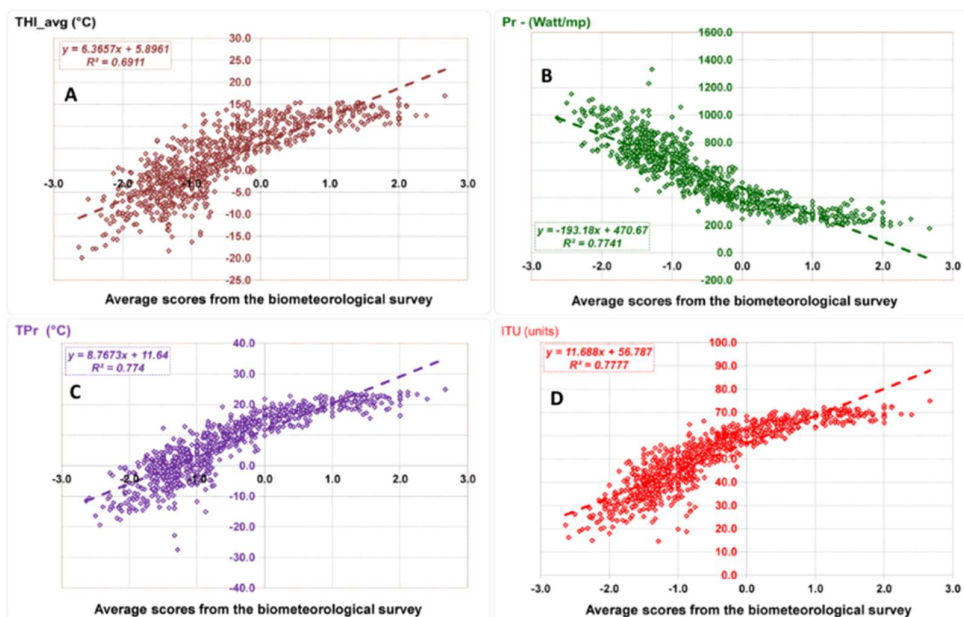


Figure 10. Correlation graphs and regression equations between the daily average values of THI - A, Pr - B, TPr - C and ITU - D in comparison to those of the average scores of the answers given by the respondents for the period 1st January 2019- 28th February 2021.

The significance of the correlations is still high, and the values of the indices decrease slightly (but still significantly) on days when the number of answers was higher, according to an analysis of the Pearson correlation indices between the averages of answers and meteorological elements / bioclimatic indices per day, grouped into three categories based on the number of answers archived in the database (Table 5).

Table 5. Pearson correlation indexes between mean scores of respondents and different meteorological elements and bioclimatic indices reported for the period 1 January 2019 - 28 February 2021

	Number of cases calculated	Average T (°C)	Maximum T (°C)	Minimum T (°C)	Relative humidity (%)	Speed of the wind (m/s)	THI (°C)	Pr (Watt/mp)	TPr (°C)	ITU (units)
Less than 10 respondents /day, but not less than 5	322	0.87	0.80	0.87	-0.09	-0.32	0.83	-0.86	0.86	0.86
between 10 and 20 respondents	389	0.88	0.80	0.86	-0.27	-0.20	0.79	-0.86	0.86	0.87
More than 20 respondents	65	0.77	0.66	0.80	-0.41	0.09	0.65	-0.74	0.74	0.78

Upon conducting a monthly examination of the responses provided by individuals who self-reported as healthy and those who were afflicted with a particular ailment on the day of the questionnaire submission, we observed that the latter group positioned themselves in the area of greater discomfort because they felt the environment was colder than that of the former group (Figure 11). Thus, those who are ill perceive Suceava's weather as being colder than those who are well.

The relationships between diurnal averages of biometeorological survey answers and meteorological variables are grouped and presented briefly in Figure 12.

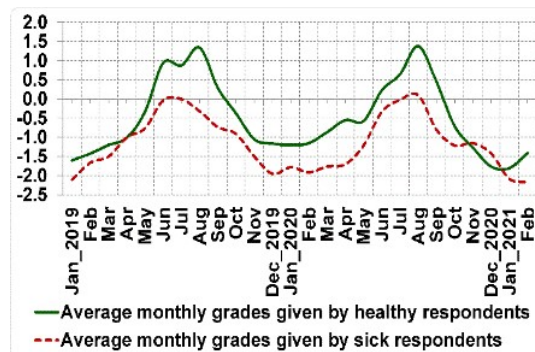


Figure 11. The intermonthly trend of the average answers provided by the respondents who considered themselves healthy, respectively as suffering from certain ailments on the date / day of the answer.

of the survey answers and the indicated meteorological and biometeorological variables. In comparison to the average of the answers to the survey, the wind cooling power (Pr) is positioned in the right quadrant, 180 degrees from it. The position of the average of the answers in relation to Pr indicates inverse proportionality that very strong and highly statistically significant. Relative humidity and wind speed are both located in the right quadrant of the correlation circle; however, their inverse proportionality connections with the average of the responses are weaker and more difficult to fit into an analytical and statistical pattern.

Through the application of principal component analysis (PCA), Figure 12 reveals a number of correlative features. The average of the meteorological survey answers is positioned in the same quadrant (on the left), very close to the thermal variables (average temperature, T_{avg} , minimum temperature, T_{min} , and maximum temperature, T_{max}), as well as the biometeorological variables (THI, TPr, and ITU). This indicates that there are strong, statistically significant relationships between the average

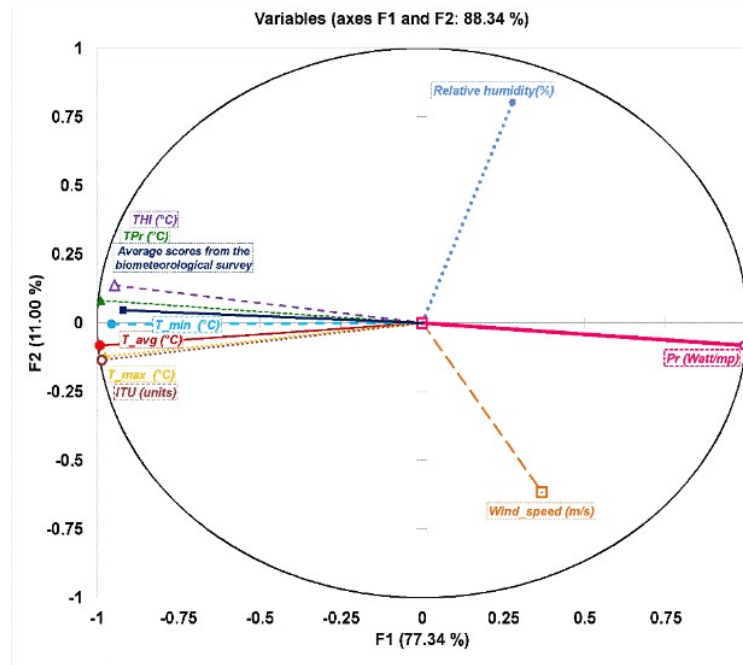


Figure 12. Analysis of the interdependence relationships between the values of the main atmospheric components and the averages of the given answers for the days of the period 1st January 2019 – 28th February 2021 by using Analysis of the Main Component (AMC).

5. Discussions

The thermal perception of the population in AMSv derives from several factors related to the complexity of the relationship established between the human individual and the air environment, as noted by Luo and Zao [1], Cheval [2] when they analyzed the factors influencing perception human related to the climate. The air environment in AMSv has thermal characteristics with a certain dynamics (evolving in the first half of the year, involutive in the second half of the year, both marked by a medium to high variability degree). Although it was a subjective process, the assessment by a perceptive survey of its thermal parameters demonstrated that the population of Suceava's urban agglomeration realistically perceives and assesses the degree of heating or cooling of the atmosphere, just as it did in the previous study on climate risks [31]. The high and statistically significant correlations between the average response and the thermal indicators demonstrate that the respondents accurately felt and assessed the air temperature.

The respondents also perceived correctly and precisely the value level of the biometeorological combinations given by two or more meteorological elements whose values were calculated with the help of the bioclimatic indices: THI (calculated with Kyle's formula [30]), Pr and TPr (calculated by the formulas proposed by Siple and Passel [32], in 1945 and modified in 1974 by Beçancenot [33]), ITU (calculated by the formula proposed by the WMO, [36]). We can remark like Howe [27] that the respondents assessed accurately the daily course of the atmospheric thermalism and that, by the constant repetitive analysis this aspect, they shaped and improved their meteorological perceptions. The biometeorological perception also assessed in other studies by various biometeorological indices with the indication of discomfort or external thermal comfort [11-14] in the case of using THI, TPr, Pr and ITU, for our group of respondents, were marked by a low subjectivity degree.

However, we admit as a limitation of this study that the respondents were somewhat subjective in their assessment of the thermal sensations experienced. Most biometeorological studies are marked by this subjectivity and a certain degree of uncertainty in the respondents' assessment of the thermal valence of the atmosphere [23].

But the compatibility of the given responses with the biometeorological indices calculated from the measurement data is strong and gives robustness to the results obtained.

Even though the external thermal comfort measured by various techniques and indicators has been the focus of numerous studies in the past few years in the region where AMSv is located (Central and Eastern Europe) [20], we believe that our study is the only one of its kind in Romania and that it offers news due to the technique used, the length of time the implementation took, and the explicit results.

6. Conclusions

We conclude from examining the average responses to the biometeorological questionnaire that winters were seen as rather cold, with pockets of extremely cold or even icy days. In winter, the average response was -1.43; in December and January, it was -1.6. The average response for the spring season was -0.88, and the average response for the autumn season was -0.59. The biometeorological variability was high in the autumns, but it was not greater than in the summers, which were mildly warm with pockets of extremely warm days and only sporadically hot (the summer's average of answers was 0.73, but it increased to 1.1 in August). The AMSv bioclimate is generally characterized by mildly chilly discomfort, as indicated by the -0.55 annual average of the replies.

The study provides a mathematical demonstration of the high perception level of the Suceava population regarding the complex and variable relationships established between it and the weather conditions that are either comfortable or marked by discomfort to varying degrees. It does this by using data from the biometeorological survey and meteorological observations over a period of more than two years.

The strong anchoring of the respondents' perceptions (day by day, month by month) in the thermo-caloric and meteorological reality of AMSv is demonstrated by the graphical quasi-synchronism and the high averages of the Pearson correlation coefficients (between 0.65 and 0.88) between the averages of the survey answers and the values of the meteorological elements determined instrumentally, respectively, the values of the biometeorological indices calculated by mathematical formulas. These assertions are supported by the PCA analysis. According to an accurate assessment of the biometeorological reality, the population of the Suceava urban agglomeration is less vulnerable considering the variety of its statements.

The conclusions show unequivocally that urban planning of the Suceava agglomeration in the direction of solving correctly the topoclimatic and microclimatic problems with a reflection on public health (local temperature inversions associated with pollution, urban haze and thermal discomfort, hot spots and cold spots on the thermal map of the city associated with severe thermal discomfort, problems related to local air dynamics or stagnation associated with heating/cooling of the atmosphere, local stagnation or dispersion of noxious gases, lighting problems and solar irradiance inadequate in intensity, etc.). It is recommended that in the future it should include the views of human groups, which are also very useful to include in Suceava's climate change adaptation strategy. Without the consolidated viewpoint of city residents, which has been shown to be in biometeorological agreement with instrumental reality, urban planning and adaptation strategies will not have the weight, acceptance and ownership needed to be successfully implemented.

This study lays the basis for a series of researches that will follow and paves the way for future complex, applied biometeorological and biomedical researches related to the comfort/discomfort of Suceava's population in key points of the city (parks, urban forests, busy intersections and boulevards, residential areas with single or multi-level dwellings, industrial platforms, railway stations, airport, recreational areas, natural or landscaped water areas, etc. including assessments based on indices calculated from measurement data, opinion polls adapted to different synoptic situations, assessments of physical, chemical and biological air quality. These assessments can be used to regionalise the quality of housing and life in Suceava and will be of real help to the population and local authorities.

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