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THE IMPORTANCE OF UNDERSTANDING THE IMPACT OF APPARENT TEMPERATURE ON HUMANS

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Abstract

Human bioclimatology studies the impact of climate on humans and vice versa. The subjective feeling of temperature (apparent temperature) seems to be warmer during the day in summer and colder in winter than the data of official measurements show. To analyze these parameters, data from two main climatological stations, Belgrade and Kopaonik, were analyzed during the ten-year observation period (2011-2020). Indices were utilized to evaluate the effect of heat and cold on the human body in various environmental conditions: Heat Index (HI) and Wind Chill Index (WCI). During the analyzed period, the highest air temperature occurred at 2 PM in August 2012 in Belgrade, reaching 39.6°C, while the maximum daily relative humidity was 44%. Due to the Heat Index value, it felt like 48°C. This significantly increased the risk of heatstroke, muscle cramps, or exhaustion. During the analyzed period, the minimum air temperature of -24.8°C was recorded at 2 PM in January 2017 on Kopaonik, with a wind speed of 15 m/s. According to the Wind Chill Index, the apparent temperature was -35°C, which posed a risk of frostbite within 10-30 minutes on exposed areas of the body, such as the face and hands, as well as a risk of hypothermia.

Key words: *Heat Index, Wind Chill Index, human health.*

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Introduction

The climate and its changes on Earth have consistently influenced humanity. Scientific disciplines and research methods in meteorology and climatology, which examine the impact of climate on humans, are referred to differently: clinical climatology, medical climatology, biometeorology, and bioclimatology [1]. Bioclimatology studies the impact of climate on all living beings, while human bioclimatology examines the impact of climate on humans and vice versa. The complex relationship and combined influence of meteorological elements (air temperature, air humidity, insolation, wind, precipitation) on the human body is studied [2].

Subjective feeling of temperature and its definition

Also, it is generally known that there is a so-called subjective feeling of temperature (apparent temperature) which reflects our actual experience of temperature. This means that we often perceive it to be warmer in the summer and colder in the winter than the official measurements indicate. These official measurements, known as objective or actual temperature, are taken in a meteorological shelter at a height of 2 m. The subjective feeling of temperature was defined in the late 70s and 80s of the last century. The apparent temperature sensation index is a mathematical model involving an adult walking in the shade [3].
During the summer of 2025, characteristic phenomena related to the external temperature were observed [4]:

- Belgrade, 7/July/2025, 2 p.m., sunny: +37°C; air humidity 25%; subjective opinion +37°C;
- Belgrade, 9/July/2025, 7 p.m., after rain: +15°C; air humidity 92%; subjective opinion +13°C;
- Belgrade, 7/August/2025, 9 a.m. +19°C; air humidity 62%; subjective opinion +25°C;
- Belgrade, 18/August/2025, 9 a.m., rainy: +20°C, air humidity 81%; subjective opinion +24°C;
- Niš, 21/July/2025, 1 p.m., clear weather: +37°C; air humidity 24%; subjective opinion +36°C.

The subjective feeling of air temperature (SFT) is influenced by several factors, in addition to the actual measured temperature. These factors include air humidity (the amount of water vapor in the atmosphere), wind speed, and solar radiation. These parameters are also used for its calculation. Other climatic parameters participate in the calculation (SFT) with only 1.5%, so they are ignored for the sake of simplicity of the calculation. In winter, the air temperature is low while the relative humidity is high. In summer, the temperature is high, and the relative humidity is low. It is known that when the humidity is high, water evaporates more slowly, and when it is low, it evaporates faster. Therefore, when the humidity is high, the sweat on our bodies cannot evaporate easily, making it difficult for the body to cool down. This makes us feel that we are warmer than the actual temperature shows, and we feel hot. The impact of air humidity is more significant during the warm months than in the cold

months, particularly when temperatures exceed 27°C and humidity levels are above 40%. This situation is common in the warmer part of the year. Therefore, high temperatures in combination with higher air humidity affect the subjective feeling so that it seems to be much hotter than the thermometer shows, as well as the appearance of a feeling of humidity. The wind contributes to the evaporation of moisture from the human body, so in the summer it reduces the feeling of heat and makes the feeling more favorable, and in the winter, at low temperatures, it increases the feeling of cold, i.e., the feeling is created that the temperature is much lower than it objectively is. The influence of wind on SFT is especially pronounced when the temperature is below 10°C - the subjective feeling is that it is much lower than it is objectively, and during the summer, it contributes to the feeling of cooling, because it removes heat from the body's skin. However, in hot weather, when the outside temperature is higher than the human body temperature (36.6°C), the wind worsens SFT instead of refreshing it, i.e., increases the feeling of warmth. Direct exposure to the Sun also contributes to us being warmer than the thermometer shows, because the human body is directly heated [5]. The temperature sensation index is a mathematical model related to a person walking in the shade [3, 6-8]. Apparent temperature measures how hot it feels to the human body, considering both air temperature and humidity [9-11].

Statements about the subjective sensation of temperature are available on the website of the Republic Hydrometeorological Institute of Serbia (RHMZ). There is an explanation that this sensation relates to how hot one feels during prolonged exposure to extremely hot and humid weather in the warmer months. Similarly, it describes the feeling of cold during exposure to extremely low temperatures and wind speeds in the colder months [12].

Based on the above facts regarding how weather affects human health, the term Meteoropathy was introduced, which represents difficulties associated with changing meteorological factors. Meteoropathy symptoms usually appear a day or two before the weather changes and a few days after. The most sensitive individuals are meteoropaths, who frequently experience complaints or worsening of their underlying conditions linked to specific weather changes. The most common are: fatigue, mood changes, reduced concentration, sleep disorders, and headaches, rheumatic pains, pain in the area of old injuries and scars, fainting, dizziness, as well as palpitations, and increased blood pressure may also occur [13].

Bioclimatic indices and models for expressing the subjective feeling of temperature

Numerous studies on people's subjective feelings regarding different combinations of temperature, air humidity, and wind speed have led to the development of various indices and models describing thermal feeling. Different definitions of the heat index can be found in literary sources, but essentially, it is about how the human body perceives the outside air temperature [14].

The first models that describe the heat energy balance between the human body and the environment in more detail were used in the 1970s and 1980s. The models define numerous bioclimatic indices for heat stress and heat load, which are the main subject of modern human studies. Today, there are more than a hundred indices that assess

the impact of heat and cold on the human body in different environmental conditions [15].

The specified Apparent temperature (AT) is an index that basically represents and shows the adjustment of the temperature to the given relative air humidity. If the air humidity is higher than the reference, then the AT will be higher than the air temperature, and vice versa. Later, the formula was extended to include the effect of wind [11]. Numerous research results have shown that bioclimatic indices give a better picture of thermal conditions than meteorological elements alone. The bioclimatic index UTCI (Universal Thermal Climate Index), whose purpose is to evaluate the degree of thermal stress of the human body, and which was often used, is particularly significant. It was also used in research in Serbia to identify biothermal heat hazard [16].

The Heat Index (HI) is commonly used to assess the subjective feeling of temperature during the summer. It combines the actual air temperature with the relative humidity to determine the apparent temperature. In the winter, the Wind Chill Index (WCI) is used to evaluate how external wind affects the perceived temperature on exposed skin in cold conditions [17].

Study of climate and climate-vegetation characteristics of Serbia

Due to the increased need and importance of knowing the climate and bioclimate, the occurrence of extremely high and low temperatures in Serbia, numerous studies were conducted, including bioclimatic and climate-vegetation characteristics [18]: seasonal analysis of cold and heat waves in Serbia during the period 1949-2012 [19]; climate characteristics of a hilly-mountainous area in eastern Serbia [20]; climate-Vegetation characteristics of the Kopaonik mountain in Serbia [21]; the role and importance of meteorology in forestry [22]; multi-criteria analysis of comparative climatic characteristics of certain forest areas in Serbia [23]; climate change in Serbia and its impact on forest ecosystems [24]; effects of extremely high temperatures on some growth parameters of sessile oak (Quercus petraea/Matt./Liebl.) seedlings in northeastern Serbia [25]; climatic charsteristics of the beech forests (*Fagetum moesiacae montanum*) belt in northeast Serbia [26].

Studies of the importance of climatic characteristics of Serbia in the function of ecotourism and health tourism were also carried out: Climate and vegetation characteristics of the Kopaonik mountain and ecotourism [27]; Study of the bioclimatic picture of Western Serbia in the function of tourism [11]; Climate characteristics and Vegetation in the area of Lukovska Banja in the function of Health tourism development [28].

The importance of knowing the current climate changes

In the context of the importance of air humidity for humans, the most comfortable humidity is 40% - 60%. Air is considered dry if the relative humidity is between 30% and 50%, and humid if it is between 70% and 90% [5]. Humidity levels based on

outside temperatures indicate the level of relative humidity at which you would feel comfortable:

- External temperature over 30°C, humidity level should not exceed 50%,
- External temperature over 20°C, humidity level should not exceed 40%,
- External temperature between 10°C and 20°C, internal humidity level should not exceed 35%,
- External temperature between 0°C and 10°C, internal humidity level should not exceed 30%.

Sudden climate changes - changes in rain and sun, sudden cooling and warming, high air humidity, and changes in atmospheric pressure can lead to certain health problems. Medical workers state that pain in the bones, muscles, and joints, rapid heart rate, suffocation, dizziness, fatigue, and weakness are the most common symptoms, so they advise that it is necessary to take care. Sudden climate changes, oscillations in temperature often by 20 or more degrees, as well as large changes in atmospheric pressure, affect the blood flow the most. The drop in temperature acts to constrict the blood vessels, which increases blood pressure with related health consequences. High air pressure and higher air humidity affect the blood vessels of the brain and can be the cause of a stroke. High temperatures affect the expansion of blood vessels, increasing sweating, blood pressure values are lower. Warm and humid weather is particularly unfavorable for lung patients [29].

Materials and methods

For the specified parameters referenced in the literature, there are tabular representations available for reading apparent temperature, as well as suitable formulas for calculations based on objective temperature, air humidity, or wind strength [15]. These resources can also be found on relevant websites.

The calculations for this paper were based on climate data from the standard measurement period of 2011-2020. Data from the meteorological station in Belgrade were used for the calculation of the Heat Index, and data from the meteorological station on Kopaonik Mountain were used for the Cooling Index. During the summer months of 2025, the Republic Hydrometeorological Service of Serbia provided comparative data on its website. This data is updated daily for specific dates and times at various meteorological stations across Serbia. It includes basic values and subjective temperature sensations [12].

Formulas for calculating the subjective feeling of temperature

Calculation of the heat index (HI)

There are several formulas for calculating the subjective feeling of temperature - the Heat Index (Heat Index - HI). The formula for calculating the Heat Index in °C based on the measured air temperature (T) and relative air humidity (RH) is [17]:

$$HI = -8{,}784695 + (1{,}61139411 \times T) + (2{,}338549 \times RH) - (0{,}14611605 \times T \times RH) - (1{,}2308094 \times 10^{-2} \times T^2) - (1{,}6424828 \times 10^{-2} \times RH^2) + (2{,}211732 \times 10^{-3} \times T^2 \times RH) + (7{,}2546 \times 10^{-4} \times T \times RH^2) - (3{,}582 \times 10^{-6} \times T^2 \times RH^2) \quad (1)$$

A similar formula is from the website [9] without citing the author of the formula, and an example is given: if the air temperature is 30°C and the relative humidity is 70%, the subjective feeling of temperature would be 36°C.
The Republic Hydrometeorological Service of Serbia provides daily updates on its website [12], specifically for individual meteorological stations such as Belgrade (2025). The data includes various meteorological parameters, such as the temperature, humidity, and wind speed, as well as the subjective feeling of temperature. Additionally, the sky's cloudiness and the likelihood of precipitation are indicated. However, the website does not provide the formula used to calculate the heat index.
A special formula for calculating the heat index is also listed on the website [30], and different categories are given that are considered moderate, severe, or very severe stress.
The website [10] also provides a formula for calculating the Heat Index, with the note that this is an assumed (ideal) model, and that in real conditions, there are many deviations:

$$HI = T + 5/9 \times ((6{,}12 \times 10^{(7{,}5 \times T)/237{,}7+T)} \times RH/100) - 10) \quad (2)$$

HI - expressed in °C; T – air temperature (°C); RH - relative humidity (%), with a note that the formula makes sense only for temperatures above 26°C and air humidity above 40%.
Basically, the apparent temperature is an index that represents the adjustment of temperature to a specific relative humidity [3, 11].
A special formula for calculating the heat index based on temperature (T) and humidity (RH) is also listed on the website [32]:

$$HI = 0.8 \times T + RH \times (T-14.4) + 46.4) \quad (3)$$

It is used in practice to assess heat stress for humans and animals, and different ranges are given, defined realistically: moderate (72 - 79 HI), severe (80 - 89 HI), very severe (90 and above HI).

Calculation of the wind chill index (WCI)

The formula used to calculate the Wind chill index (WCI) can be found on the specified website [33].

$$\boldsymbol{WCT} = 13.12 + 0.6215 \times T - 11.37 - V^{0,16} + 0.3965 \times T \times V^{0,16} \quad (4)$$

T – air temperature (°C), V - wind speed at a height of 10 meters (standard measurement height), expressed in km/h.

The cooling index is defined only for temperatures at or below 10°C and wind speeds above 4.8 km/h. With the formula, the results of the model can be approximated (to within one °C).

Research results and discussions

Calculation of heat index (HI)

For the relevant parameters, the literature provides tabular displays for reading apparent temperature, along with corresponding formulas for calculation based on objectively measured temperature and air humidity. These resources can also be found on specified relevant websites. While air humidity has the most significant influence, direct exposure to sunlight also plays an important role.
Appropriate calculations for the needs of this paper were made based on climate data of the standard measurement period in the ten years (2011-2020). For the calculation of the Heat Index, data from the meteorological station Belgrade was used, and for the Cooling Index, from the meteorological station Kopaonik. The value of the subjective feeling of temperature significantly depends on the current humidity of the air. The value of the heat index data from the table is shown: Heat index - subjective feeling of temperature [17], for slightly above the limits for humans, the most comfortable air humidity is (65%):

- if the real temperature is below 30°C, the subjective feeling is that the temperature is up to 3°C higher,
- if the real temperature is above 30°C, which means that it is a tropical temperature (31-35°C), the subjective feeling of temperature is that it is higher by 6-10°C.

Table 1: Heat index - subjective feeling of temperature [17],
possible consequences for human health

Category	Heat index	Possible heat disorders in people at increased risk
Extreme danger	54°C or more	Heatstroke; Sunstroke
Danger	41°C - 54°C	Sunstroke; Muscle cramps; Heat exhaustion; Heat stroke with prolonged exposure and physical activity
Extreme precaution	32°C - 41°C	Sunstroke; Muscle cramps; Heat exhaustion from prolonged exposure and physical activity
Precaution	27°C - 32°C	Possible fatigue with prolonged exposure and physical activity

As stated in the work method, formula 1 [17] was used to calculate the Heat Index in Belgrade. Based on the standard multi-year period of climate data measurement in the last ten-year period (2011-2020), the maximum real air temperature in the hottest part of the day (24 h) in August 2012 was 39.9°C, and the maximum daily relative humidity was 44%. Based on those heat index values using a separate table [17], the subjective feeling of temperature is that it was around 48°C. Based on that heat value, disorders

of the influence of heat were possible - in humans, there was a danger with an increased risk of sunstroke, muscle spasms, heat exhaustion, and heat stroke during prolonged exposure and physical activity (Table 1). At the same time, when in that period in 2014 the maximum air humidity was 58% and the real air temperature was 34.8°C, the subjective feeling of temperature was around 44°C. Based on this, heat disorders were possible, and in humans, there was a danger with an increased stated risk.

Table 2: Heat index - possible consequences for human health based on formula 2 specified in the work method, using climate data for Belgrade in the analyzed period 2011-2020 for the three warmest and coldest years in that period.

Year	Air temperature °C	Relative humidity %	Apparent temperature °C [17]	Apparent temperature Formula for Heat Index
2012 Warmest	39.9	50	54.4	52.2
2017 Warm	39.8	52	55.6	55.3
2013 Warm	39.1	55	55.3	55.0
2018 Coldest	34.7	56	42.4	46.3

Since the apparent temperatures were more than 54° C during the mentioned period, there was a possibility of heatstroke or sunstroke, and extreme caution was required.

Examples for Belgrade based on data from the Republic Hydrometeorological Service of Serbia for the period June-August 2025 from website [12]:

- 18/June/2025, 9 a.m., sunny: 24°C; air humidity 60%; subjective feeling 26°C;
- 20/June/2025, 9 p.m., 21°C; air humidity 41%; subjective feeling 24°C;
- 26/June/2025, 11 a.m., 33°C; air humidity 40%; subjective feeling 35°C;
- 01/July/2025, 2 p.m., sunny: 31°C; air humidity 22%; subjective feeling 31°C;
- 03/July/2025, 2 p.m., 37°C; air humidity 18%; subjective feeling 37°C;
- 07/July/2025, 2 p.m., 37°C; air humidity 25%; subjective feeling 37°C;
- 09/July/2025, 7 p.m., after rain: 15°C; air humidity 92%; subjective feeling 13°C;
- 19/July/2025, 7 p.m., cloudy: 24°C; air humidity 63%; subjective feeling 26°C;
- 15/August 2025, 2 p.m., windy: 35°C; air humidity 21%; subjective feeling 35°C;

Since the heat index, that is, the subjective feeling of temperature in the hottest period, was 37°C, the heat index indicates that extreme caution was needed in that period because there was a possibility of sunstroke, muscle spasms, fat exhaustion with prolonged exposure to the Sun and physical activity (Table 1).
In the rest of the period, that is, when the subjective feeling of temperature in the hottest period was below 32°C, caution was needed due to possible fatigue during prolonged exposure to the sun or physical activity.

Calculation of wind chill index (WCI)

Wind chill index (WCI) shows the effect of wind and external temperature on the exposed part of the skin in a cold environment. WCT defines the environment in

conditions of low temperatures and increased influence of wind [17]. This index was until recently used by the US Weather Service as a significant indicator of cold weather. As stated in the work method, it is calculated using formula no. 4.

Based on the standard multi-year period of measurement in the last ten-year period (2011-2020), in the winter period on Kopaonik, the coldest year was 2017, with the air temperature in January, when the real air temperature of -24.8°C was measured at 2 pm, and the wind speed was 15 m/sec (Table 4). Using the specified appropriate formula no. 4, it was determined that at that increased wind speed, the apparent temperature was -35°C (Wind chill index - WCI). Based on that temperature value in the corresponding table 3, it was stated that there was a risk of frostbite in 10-30 min on exposed parts of the body - face and extremities, risk of hypothermia if staying outside without adequate protective clothing and shelter from wind and low temperature.

From a separate table for the Cooling Index [33], the following data for the measured wind speed of 10 km/h (36 m/sec), the highest recorded on Kopaonik, are given:

- at an air temperature of -1°C to -5°C, the apparent temperature will be from -2°C to -9°C,
- at an air temperature of –6°C to –10°C, the apparent temperature will be from –10°C to –15°C,
- at an air temperature of –11°C to –15°C, the apparent temperature will be from –16°C to –21°C,
- at an air temperature of –16°C to –20°C, the apparent temperature will be from –22°C to –27°C,
- at an air temperature of –21°C to –25°C, the apparent temperature will be from –28°C to –33°C.

The cold index is an indicator of the harshness of the weather. The human body reacts to lowering the temperature and increased cooling can lead to freezing (Table 3). Given that the cooling index represents the feeling of coldness on the skin of a person, the following table was created based on this formula.

Based on the data in table 4, the corresponding data in the analyzed period 2011-2020 are presented, for the three coldest and one warmest year in that period.

Table 3: Cold index - subjective feeling at the indicated temperatures

Index °C	Possible heat disorders in people at increased risk
4 to 6	Unpleasant feeling
-7 to -17	A very unpleasant feeling
-18 to -28	Possible frostbite. Exposed skin can freeze in 5 minutes. Avoid outdoor activities
-29 to -56	Frostbite possible. Exposed skin can freeze in 1 minute. Outdoor activities dangerous.
below -56	Freezing for sure. Exposed skin can freeze in 30 seconds.

Table 4: Wind chill index (WCI) in the period 2011-2020

Year	Air temperature °C	Wind speed m/sec	Apparent temperature °C [17] for WCI	Apparent temperature

				Same formula for WCI
2017 Coldest	- 24.8	15	- 35.0°C	- 35.0°C
2012 Cold	- 23.6	7	- 29.8°C	- 29.8°C
2018 Cold	- 20.6	19	- 31.0°C	- 31.0°C
2020 Warmest	- 13.3	19	- 23.1°C	- 23.1°C

Based on the apparent temperature data in Table 4, frostbite was possible in such conditions - exposed skin can freeze in 5 minutes, and it is recommended to avoid outdoor activities (Table 3), i.e., frostbite is possible, skin can freeze in 1 minute, and outdoor activities are dangerous.

Conclusion

The subjective feeling of temperature, also known as apparent temperature, refers to how warm or cold it feels to us, which can differ from official measurements. These official measurements, or objective temperature, are based on the actual temperature along with factors such as air humidity, precipitation, and wind. As a result, we may perceive it as feeling warmer during the day and colder in the winter than what the measured data indicates. To analyze these parameters, data from two main climatological stations, Belgrade and Kopaonik, were analyzed during the ten-year observation period (2011-2020). Indices were utilized to evaluate the effect of heat and cold on the human body in various environmental conditions.
For the appropriate specified parameters, tabular representations for reading the apparent temperature in literature sources are provided, as well as appropriate formulas for calculation, based on objectively measured temperature and air humidity or wind strength, which can also be found on certain appropriate websites.
Based on the above facts and how the weather affects people's health, the symptoms of meteoropathy, which represent difficulties associated with the change in meteorological factors, which usually appear a day or two before the change of weather and a couple of days, are presented.

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