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BIOCLIMATIC INDICES BASED ON THE MENEX MODEL-EXAMPLE ON BANJA LUKA

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Abstract: It has long been known that weather and climate have influence on human health and well-being. The human organism is in constant interaction with the environmental conditions. To access the atmospheric impact on humans, different methods in human bioclimatology are created. Most of them are based on human heat balance. In this paper it has been tried to present several bioclimatic indices based on the human heat balance according to the bioclimatic model menex (man-environment exchange). The aim of this paper is to present bioclimatic conditions in Banja Luka vicinage (Bosnia and Herzegovina) and to explore climate-recreation relationship. In the near vicinity of Banja Luka there are three spa centers that are favorable for recreation. For this analysis average available daily weather data for two extreme months (January and July, 1990) were used as well as the average monthly weather values for the period 1961-1990. The data were taken from Banja Luka weather station. As a result, several thermophisiological bioclimatic indices have been obtained. These are heat load in man, physiological strain, subjective temperature, subjective physiological temperature.

Key words: human heat balance, menex model, termophysiological bioclimatic indices, recreation, Banja Luka (R.S., Bosnia and Herzegovina)

Introduction

Climate is a natural resource for many types of tourism. Since it is represented by meteorological data climate can be measured and evaluated for recreational purposes applying human bioclimatology methods. Climate information provided to tourists and the tourism industry should include not only its general features (mean monthly and annual values of particular climate elements) but also detailed information regarding thermal comfort as well as aesthetic and physical weather factors (*e.g.*, de Freitas, 2003). Major studies on biometeorology for tourism and recreation in Europe have been done from the

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viewpoint of human health (Scott, Jones & McBoyle, 2004; Matzarakis, 2006). Various concepts and methods have been used to show the relationship between climatic characteristics and the human organism. Natural factors such as mineral water, healing mud, healing gases, healing climate (air bath) are important for the treatment of many diseases, recovery after injury or illness, stress, prevention and recreation. Relationships between the atmosphere and humans were analyzed by human heat balance method which is based on the heat exchange between man and environment using menex model created by Błażejczyk (Błażejczyk, 1994, 2001). As a result, several thermophisiological bioclimatic indices have been used.

Materials and methods

Evaluation of bioclimatic conditions implies a set of meteorological factors that affect the human body and cause different adaptive reaction in response to weather conditions. This concept is known as human heat balance and for its application is designed a model that implies heat exchange between man and environment. This model is first published in 1994 under the name *menex* (The Man-ENvironment heat EXchange model). Menex has been updated several times, and the name of the last version is menex_06. According to its author Błażejczyk, menex can be used in various applications: bioclimatic (for recreation and tourism, climatotherapy, human health and urban studies), thermophysiological (work conditions and thermoregulatory system control), spatial design (natural, residential and recreational areas) (Błażejczyk, 1994). As a result of this model series of bioclimatic indices can be extracted: subjective temperature STI, Physiological strain PhS, physiological subjective temperature PST and heat load in man HL. All those indices illustrate connections and a relationship between man and environment. The analyses of the human heat balance based on the model were done in Poland (Błażejczyk, 2001; Błażejczyk, & Matzarakis, 2007; Błażejczyk & Matzarakis,2008).

Thermophysiological bioclimatic indices accurately describe thermal load in humans using several meteorological and physiological parameters. This methodology is based on so-called human heat balance models, which basically start from the heat exchange between man and environment. Models of heat balance between man and environment include all mechanisms of heat exchange, with the aim to maintain thermoregulation in the body. This refers to the metabolic heat production, heat exchange by radiation and convection, heat loss through evaporation and respiration. According to these facts, general equation of heat exchange between man and environment is:

$$\mathbf{M + Q + C + E + Res = S}$$

where:M-metabolic rate, Q-Radiation balance in man (high-frequency radiation, R plus low-frequency radiation of man, L), C-heat transfer by convection, heat loss by breathing E, heat loss by evaporation, S-net heat storage, ie. body heat content changes. All fluxes are expressed in Wm^{-2}.

The above equation is processed on the basis of the input data. The input data are related to the meteorological data (environment) and physiological data (man). Their interaction through the heat exchange equation is shown in figure 1. Meteorological data used for calculation are: air temperature, maximum air temperature, minimum air temperature, relative humidity, cloudiness, wind speed, precipitation, air pressure, sun altitude. General features of the human heat balance around Banja Luka area were assessed on the basis of annual weather data covering the period between 1961 and 1990. Also, available daily weather data in 1990 have been applied for two extreme months, January and July, for 1990, in order to present an example of bioclimatic indices on a daily basis.

The physiological data used for calculation are: metabolic rate, skin temperature, human skin wettedness, albedo of skin, albedo of ground, clothing insulation, velocity of the motion of the man (Figure 1). These parameters are estimated using empirical equations and they are considered as a constant value in the model (International Standard Organization, 1990, 1993). These are the metabolic rate M=135 Wm^{-2}, albedo of skin ac=30%, velocity man of motion v'=1.1 ms^{-1} and clothing insulation (1clo).

The metabolic rate is metabolic energy production include basal metabolism plus metabolic energy produced by physical activity. As a measure of physical activity, metabolic rate is expressed with unit called *"met"*. Met corresponds to heat emission of 58.2 Wm^{-2} from the surface of human body. The average adult's skin surface is 1.8 m^2. According to ISO 8996 for standard applications, metabolic heat is M = 135 Wm^{-2} for the man moving at 1.1ms^{-1} and it is considered as a constant value in the model.

Thermal insulation in clothing is an important parameter of thermal comfort. The insulating properties of clothing are expressed in "*clo*" unit where 1clo equals the thermal insulation required to keep a resting person comfortable at a temperature of 21^{o}C and relative humidity of 50%. Since "*clo*" is not a standard international unit it has the advantage of easily been understand that 1clo is equal to a man dressed in a business suit (shirt, trousers and suit jacket) and it is considered as a constant value in the model. The standard international unit of thermal resistance is $m^{-2}KW^{-2}$ where 1clo corresponds to a 0.155 $m^{-2}KW^{-2}$ (Nishi, 1981. p. 31).

The skin wettedness (w) is an expression of the efficiency of evaporative regulation. The wetted area of the skin is the area of the skin which is covered with sweat. The skin wettedness is a rationally derived physiological index defined as the ratio of the actual sweating rate to the maximum rate of sweating that would occur if the skin were completely wet. It is dimensionless number between 0 and 1 (Nishi, 1981. p. 32).

Net low-frequency radiation of man represents the balance of heat exchange between man Ls and atmosphere La and heat exchange between man Ls and land surface Lg. It is calculated using Stefan–Boltzmann law. Based on available data for cloudiness, the absorbed solar radiation R is estimated using SolAlt model (Blazejczyk, the updated version of man-environment heat exchange model 2005).

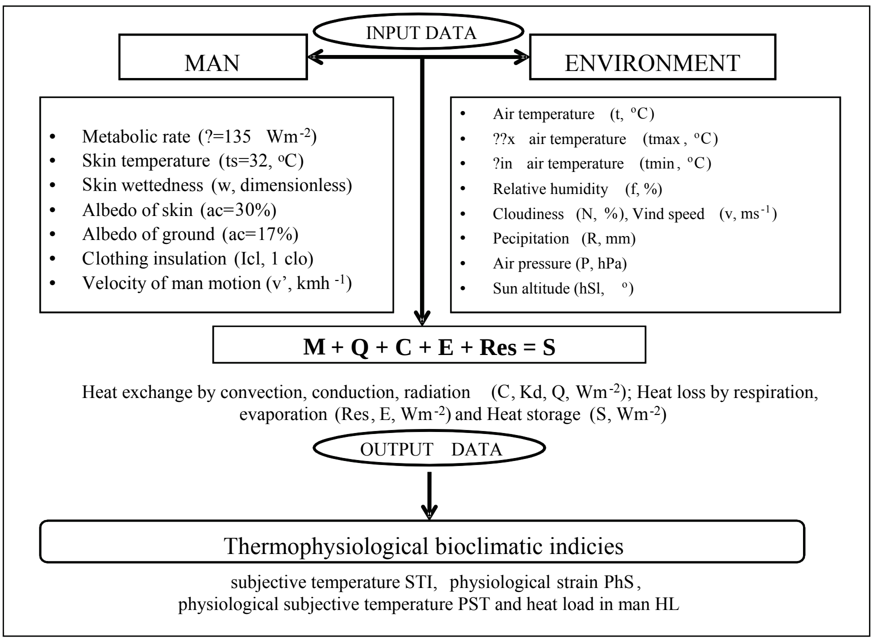

Figure 1. Review of the model methodology used for the analyze

Menex model solves the equation in two steps. In the first step model calculates equation components that occur immediately after contact with the environment.

Temperature receptors activate the physiological response of the organism to keep homeoterme. If weather condition is cooler, the adaptation process does not significantly alter the skin temperature, so the skin receptors register actual temperature of the skin due to the current atmosphere process. In warm conditions, due to intense evaporation of sweat, during the 15-20 minutes there is a cooling of the skin, so the skin receptors register new, lower skin temperature (0,066°C for each $1Wm^{-2}$ of evaporation, Fanger, 1970).

In the second step, the model calculates human heat balance equation taking into account the temperature of the skin resulting from the process of achieving thermoregulation (TsR). In other words, the components of human heat balance equations represent the level of heat exchange between man and the environment after 15-20 minutes the process of the adaptation. As a result, the model gives different bioclimatic indices. Some of them are directly related to the basic physiological characteristics represented by the metabolic energy production. Those are thermophysiological bioclimatic indices: subjective temperature, physiological strain, physiological subjective temperature and heat load in man.

The results that model gives as output data are various indices. Several of them have been analyzed in Banja Luka and they illustrate connections and a relationship between a man and environment. Those are:

Subjective temperature is an index that describes the subjective thermal load in man caused by the external environment before the activation process of adaptation. It is about the thermal load that is formed in a layer of air near the clothes. Thermal influence of the environment is expressed by the mean radiant temperature, while the physiological response of the body is presented by total heat accumulation S.

Physiological subjective temperature is a subjective feeling of the thermal environment by man. Heat sensation in the skin is the result of signals sent to the warm and cold receptors in the skin and nervous system. Thermal influence of the environment is represented by the mean radiant temperature near the skin surface. Current environmental conditions affect the intensity of heat exchange between man and the atmosphere and the basic level of total heat storage (S). Physiological temperature is a subjective level of thermal stimuli that are located near the skin surface after 15-20 minutes of intense process of adaptation. The range of the indices and its comfort values are presented in table 1 and table 2.

Table 1. Temperature range of subjective temperature and subjective physiological temperature and their comfort degree (Błażejczyk, 1994)

Subjective temperature STI (°C)		Physiological subjective temperature (PST) (°C)	
< -38.0	extremely cold	< -36.0	frosty
-18	very cold	-36 – -16.1	very cold
-19.5	cold	-16.0 – 4.0	cold
-22.9	cool	4.1 – 14.0	cool
22.6 - 31.9	comfortable	14.1 – 24.0	comfortable
32.0 - 45.9	warm	24.1 – 34.0	warm
46.0 - 54.9	hot	34.1 – 44.0	hot
55.0 - 69.9	very hot	44.1 – 54.0	very hot
≥ 70.0°C	sweltering	> 54.0	sweltering

Heat load in man describes heat load of central thermoregulation system because of the process of adaptation to an environment. Combination of main heat fluxes were used for calculation: total heat accumulation (S), absorbed solar radiation (R) and evaporative heat loss (E).

Physiological strain is the intensity of the process of adaptation in cold or hot environment. This index depends of the ratio of convective flux and evaporation flux.

Table 2. Temperature range of heat load in man and physiological strain and their comfort degree (Błażejczyk, 1994)

Heat load in man HL (dimensionless)		Physiological strain PhS (dimensionless)		
≤ 0.250	extreme cold stress	< 0.0	extreme hot strain	warm physiological stress that can manifest as: increase in peripheral blood circulation, reduce blood pressure, increased heart rate, excessive sweating and dehydration, major changes in skin temperature
0.251-0.820	great cold stress	0.00 - 0.24	great hot strain	
0.821-0.975	moderate cold stress	0.25 - 0.74	moderate hot strain	
0.976-1.025	thermoneutral	0.75 - 1.50	thermoneutral	mild response of the thermoregulatory system
1.026-1.180	moderate hot load	1.51 - 4.00	moderate cold strain	cold physiological strain, which manifests itself as: reducing the temperature of the skin, reducing the peripheral blood circulation, increase blood pressure, increased thermal insulation in the tissues of the skin and shivering
1.181-1.750	great hot load	4.01 - 8.00	great cold strain	
> 1.751	extreme hot load	> 8.00	extreme cold strain	

Results and discussion

Relationships between the atmosphere and humans were analyzed by human heat balance method which is based on the heat exchange between man and environment. Based on the meteorological data from weather station in Banja Luka, the following results show annual flow of subjective temperature and subjective physiological temperature where maximums are in August (STI_jan=48.3°C and PST_avg=28.5°C) and show *hot* and *warm* bioclimatic types while minimums are in January (STI=23.2°C and PST=-1.2°C) and show *comfortable* and *cold* bioclimatic types. Physiological strain is inverse to the temperatures and has maximum in January (PhS=3.4) and minimum (PhS=1.2). Heat load is almost continual with small exception during, July and August (Figure 2).

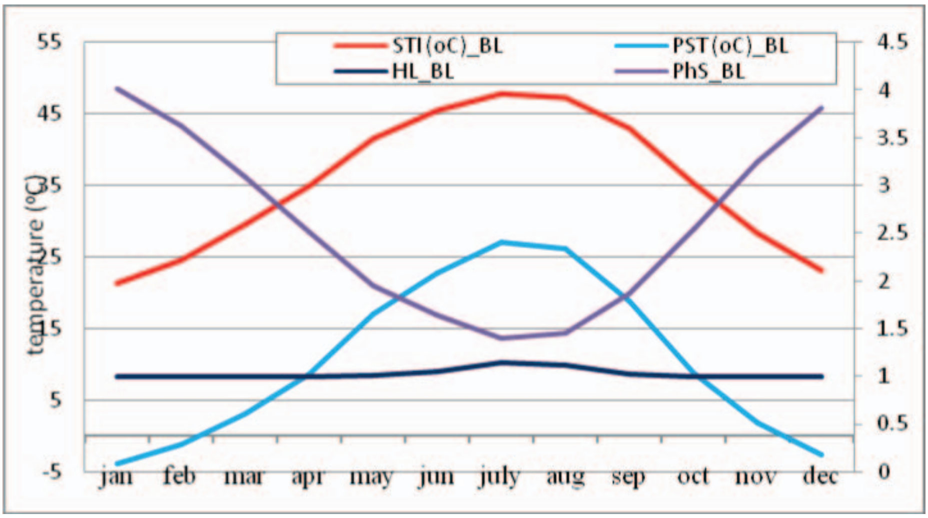

Figure 2. Annual values of thermophysiological indices in Banja Luka (1961-1990)

Daily data in July present real relationships between those indices. Subjective temperature and subjective physiological temperature follow air temperature. If those temperatures are in rise then heat load is in rise as well while physiological strain, which represents intensity of adaptation process, is in decline (Figure 3). Also, if the temperature is suddenly changed than heat load and physiological strain are more expressed. In the cold period, adaptation process will be stronger and physiological strain will rise (Figure 4).

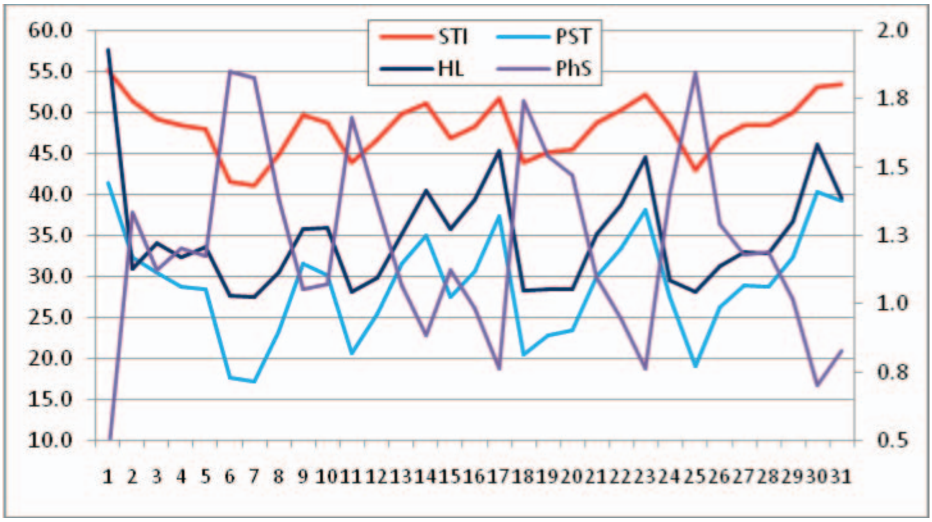

Figure 3. Daily values of thermophysiological indices in Banja Luka, July 1990.

The indices listed in this paper show possibility of assessing bioclimatic conditions in specific area. Banja Luka is an urban area surrounded with diverse landscape favorable for tourism. Diverse applications of this method provide possibility to quantify and identify specific areas with favorable or unfavorable bioclimatic conditions

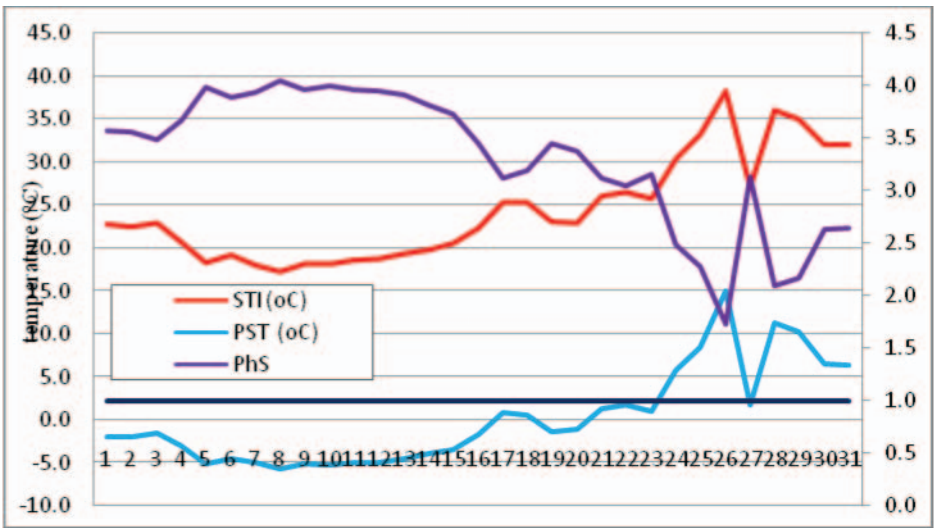

Figure 4. Daily values of thermophysiological indices in Banja Luka, January 1990.

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