Biothermal Condition Based on the Bioclimatic Index Heat Load

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Abstract: - The human organism is in constant interaction with the thermal environmental conditions. Health effects of the atmospheric conditions in the environment will not rule out a single element of weather, the atmosphere seems rather complex in the action on the organism. In this study bioclimatic method of human heat balance was applied and refers to the possible identification of the certain area with a specific bioclimatic condition from the recreation point of view. The specific identification of bioclimatic condition is proposed by bioclimatic index heat load in man which is result of the human heat balance calculated under the menex model. For this example biothermal comfort condition were analysed for six weather stations in Serbia to present the thermal thresholds in the warmest month of the year. Daily meteorological data were used for month of July in 2011. They are also calculated the annual Heat load values for the year 2011.

Key-Words: - Human heat balance, menex model, heat load in man, biothermal condition, Serbia

1 Introduction

Climate of Serbia has mostly moderate-continental character from steppe climate on the north (Vojvodina region) and east (Negotinska krajina region) to the mountain climate on the flat parts of the Stari Vlah region and highest mountains in southwestern Serbia. The spatial distribution of climate parameters are caused by geographic location, relief and local influence as a result of the distribution of air pressure larger scale, terrain exposure, presence of river systems, vegetation, urbanization etc. Also, there are regional geographical parameters that characterize synoptic situations significant for weather and climate of Serbia. The Alps, the Mediterranean Sea and the Gulf of Genoa, the Pannonian Plain and the valley of Morava, the Carpathians and Rhodopes mountains as well as hills of the mountain valleys and plateaus. The prevailing meridional location of river valleys and plains in the north of the country, allow deep influences of polar air masses to the south.

In this study, biothermal comfort condition were analysed for six weather stations in Serbia to determine possible thermal threshold, proposed by bioclimatic index heat load in man. The precipitation data of six weather stations during July in 2011 was obtained from Meteorological annual of Serbia. The month of July for this study was chosen because of the higher temperature that occurring during the year and thus wants to show biothermal condition during the extreme hot part of the year. The weather stations, from which data were taken, are located in cities (Belgrade, Novi Sad, Nis, Loznica, Vranje) but one of them is located on the mountain resort called Zlatibor. The selected weather stations are chosen for the following reason: three of them (Loznica, Niš and Vranje)[1] have health spa resorts in their

[1] Loznica (121m) is a city located in western Serbia, in theMačva District. It lies on the right bank of the Drina river.
Niš (204m) is the largest city of southern Serbia and the third-largest city in Serbia. It is located in Nis valley, on both sides of the river Nišava, near its confluence with the South Morava river. The central city is located at 194 m above sea level. Niš

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environment, which is important from the point of view of recreation and well being in function of which is analysed bithermal comfort. The health spa resorts are Banja Koviljaca, Niska Banja and Vranjska Banja; Belgrade and Novi Sad[2] are the biggest urban cities in Serbia and they have their own green oasis for convenient recreation and finaly, Zlatibor[3] is affirmed climatic resort, characterized by a cool mountain climate, clean air, long periods of sunshine during the summer and snow cover in winter. Zlatibor plateau is area where the mountains meet the sea air currents, which make this area favourable for healing air, particularly for pulmonary, heart and thyroid diseases.

2 Materials and methods

Biothermal conditions were considered as a response of the human body of the thermal stimuli that shape level of the actual heat load of an organism. To analysis biothermal conditions in Serbia, heat load index (HL) was used. Heat load is one of thermophysiological bioclimatic indices based on human heat balance and it is derived from the MENEX model (Błażejczyk, 2001). The rate and the amount of the heat exchange between man and environment are governed by the fundamental laws of thermodynamics. According to the first law of thermodynamics, heat absorbed by a system can be used by it to produce work or to rise its internal energy.

Heat balance is determined by the net exchange of heat trough: radiation, conduction, convection, evaporation, metabolic heat production and heat storage. According to the MENEX (man environment exchange) model, general equation for human heat balance is:

$$M + R + C + L + E + Res = S$$

where:

S is net heat storage, (Changes in body heat content) and it is function of M is metabolic heat production (both basic metabolic rate and metabolic energy production due to activity and workload), Q is a person's radiation balance, C is heat exchange by convection, E is heat loss by evaporation, Res is heat loss by respiration. If body is in heat balance than heat gain is equal heat loss and body temperature remains stabile (S can be considered equal to zero), (Figure1.). At particular moments, S has positive or negative values. If heat gain exceeds heat loss, body temperature rises and the organism is considered to be in a state of positive heat balance (Positive values of net heat storage indicate accumulation of heat in the body). From the other hand, if heat loss exceeds heat gain, body temperature drops and the organism is in negative balance (negative ones a cooling of the body core). In those imbalances changes in body temperature represent changes in the heat storage.

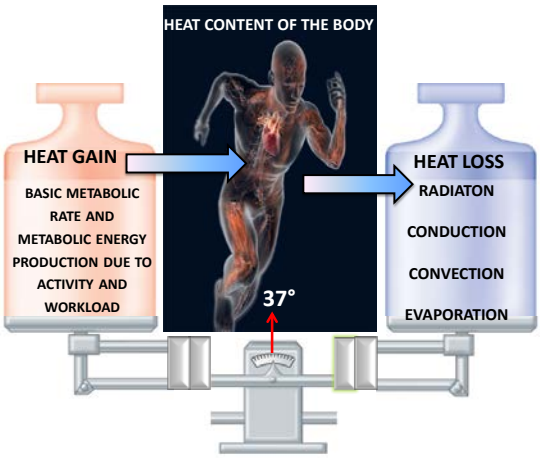

Fig 1. Heat balance of the human body

Heat generated in the body comes from metabolic heat production (M) and solar radiation absorbed by man (R), while heat that go away from an organism to the environment is generated from the heat exchanged by convection (C), long wave emission by radiation (L), heat exchange of latent heat by evaporation (E) and breathing by respiration (Res). All parameters of the heat balance equation are expressed in Wm^{-2}. Atmospheric effects on the body are complex.

Heat load in man HL (dimensionless) describes heat load of central thermoregulation system because of the process of adaptation to an environment. It is evaluated as a combination of the three principal heat fluxes: net heat storage (S), absorbed solar radiation (R) and evaporative heat loss (E). The Heat load index allows determination

District Municipality covers an area of 596.71 km ², where the city of Niš is located at, as well as Niška Banja helth spa resort and 68 suburbs.

Vranje (432m) is located in a valley of Vranje, on the Vranjska river, near its confluence with the South Morava river.

[2] Novi Sad (86m) is a secondary urban centre in the Republic of Serbia. It is located on the left bank of the river Danube, at approximately 86 m above the sea level. It should be noted that the town spreads over the northern foothill region of "Fruška gora" mountain on the right bank of the river Danube, which represents a tourist area.

Belgrade (132m) is the capital and largest city of Serbia. It is located at the confluence of the Sava and Danube rivers, where the Pannonian Plain meets the Balkan Alpes.

[3] Zlatibor (1028m) is a mountain region situated in the western part of Serbia and it is a part of the Dinaric Alps.

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of heat or cold stresses of varying intensity that present different types of biothermal conditions (Table 1.).

Table 1. Observed load by Heat load index values and different types of biothermal condition

HL	observed load	biothermal condition
< 0.250	extreme cold stress	loading
0.250-0.820	great cold stress	strain, hardening
0.821-0.975	slight cold stress	soft
0.976-1.025	thermoneutral	
1.026-1.180	slight warm stress	
1.181-1.750	great hot stress	strain, hardening
>1.750	extreme hot stress	loading

Based on the human heat balance, meteorological and physiological parameters were used to calculate heat load index. Meteorological parameters are temperature of air (^oC), min and max temperature of air, precipitation (mm), cloudness, wind speed (ms^{-2}), relative humidity of air (%), vapour pressure (hPa). Physiological data used for calculation are: metabolic rate ($M=135Wm^{-2}$), skin temperature ($Ts=32^{oC}$), clothing insulation (1clo), albedo of clothing (ac=30 %), skin wittedness (w).

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).

These parameters are estimated using empirical equations and they are considered as a constant value in the model (ISO 8996, ISO/TR 11079).

Heat load index is calculated for the month of July in 2011, using daily meteorological data from the weather stations in Belgrade, Novi Sad, Loznica, NIš, Vranje and Zlatibor and physiological data that are used as a constant values pre-set in the software. (The calculations were made using BioKlima2.6 sotware,http://www.igipz.pan.pl/geoekoklimat/blaz/BioKlima.htm)

3 Results and discussion

According to the men environment heat exchange model, biothermal conditions expressed by heat load index, in July, shows dominant *great hot stress* or *extreme hot stress.* Heat load for less intensive physical movement shows majority of unpleasant days in July. There are 13 days in Belgrade with *extreme hot stress* that causes great loading biothermal conditions. Vranje, Loznica and Niš have 9, 8 and 7 days with *extreme hot stress*, respectively, while in Novi Sad and Zlatibor didn't observed this load. The dominant load observed in July is *great hot stress* and it is present in all mentioned cities, where Belgrade has 13 days, Loznica has 10 days, Niš has 14 days, Novi Sad has 24 days, Vranje has 17 days and Zlatibor has 13 days. The *slight warm stress* load express domination in Zlatibor with 18 days, which is expected to be on the mountain. Loznica has 13 days with *slight warm stress* making it one of the most pleasant cities shown here, except Zlatibor. Niš, Novi Sad, Vranje and Belgrade have at least 4 days with *slight warm stress.*

The given results of the heat load index are presented in the graph 1, so that it simply notes the dominance of Belgrade as the most unfavorable biothermal conditions and Zlatibor as the most favorable biothermal conditions.

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Table 2.The heat load index in Belgrade, Loznica, Niš, Vranje and Zlatibor in July 2011.

day	HL BG	HL Lo	HL Ni	HL NS	HL Vr	HL Zl
1	1.200	1.100	1.061	1.300	1.065	1.062
2	1.000	1.100	1.097	1.400	1.026	1.033
3	1.200	1.100	1.108	1.300	1.040	1.059
4	1.400	1.300	1.252	1.200	1.212	1.065
5	1.300	1.100	1.122	1.100	1.327	1.086
6	1.400	1.400	1.159	1.200	1.184	1.079
7	1.900	1.600	1.377	1.000	1.386	1.213
8	2.700	1.800	1.656	1.100	1.612	1.435
9	2.700	2.100	1.779	1.200	1.881	1.600
10	3.100	1.800	1.922	1.400	1.843	1.569
11	2.300	1.700	1.797	1.400	1.761	1.381
12	2.100	1.600	1.487	1.400	1.655	1.186
13	2.600	1.800	1.729	1.600	1.775	1.413
14	2.900	2.000	1.862	1.500	1.903	1.571
15	2.500	1.800	2.000	1.600	2.006	1.399
16	1.800	1.500	1.585	1.600	1.815	1.114
17	2.100	1.600	1.596	1.600	1.805	1.191
18	2.200	2.000	1.847	1.300	1.681	1.472
19	2.700	2.100	1.890	1.200	2.120	1.709
20	1.200	1.100	1.432	1.200	1.656	1.116
21	1.300	1.100	1.271	1.300	1.498	1.052
22	1.300	1.100	1.207	1.400	1.397	1.069
23	1.300	1.100	1.427	1.500	1.349	1.065
24	1.100	1.100	1.826	1.200	1.545	1.086
25	1.100	1.100	1.216	1.000	1.352	1.093
26	1.100	1.100	1.126	1.100	1.228	1.071
27	1.400	1.200	1.286	1.100	1.426	1.059
28	1.500	1.200	1.802	1.200	1.737	1.228
29	1.100	1.100	1.119	1.300	1.115	1.101
30	1.200	1.300	1.138	1.300	1.108	1.069
31	1.200	1.100	1.323	1.100	1.321	1.112

Above listed heat load values refer to daily values of meteorological data such as air temperature, relative humidity, min and max temperature of air, vapor pressure, cloudiness and wind speed. The figure 2 shows daily values of maximum air temperature and relative humidity whose maximum

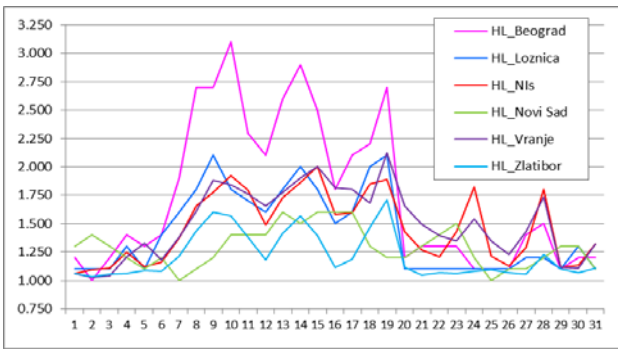

Fig 1. Daily values of the heat load index in July

and minimum values follow the occurrence of maximum and minimum values of heat load index.

It should also be noted significantly higher values of the heat load in Belgrade in comparison to other cities, especially these days with extremely high temperatures. The reason for such high contrast is due to the extremely low values of relative humidity in Belgrade in comparison to other cities (Fig 2, on top). During the month when the heat load was expressed as *extreme heat stress*, in addition to high temperatures over 33°C, relative humidity was significantly low. For example, tenth of July and eleventh of July the temperatures were 37.3°C and 37.8°C while relative humidity was 38% and 35%, respectively. They were also observed several days between 40% and 50% which is pretty low value of relative humidity. It should be noted that in other cities values of the relative humidity was not less then 50%.

The chart with the maximum temperature shows that Belgrade does not stand out significantly from other cities such as it is case with the relative humidity and the heat load (Fig2, at the bottom).

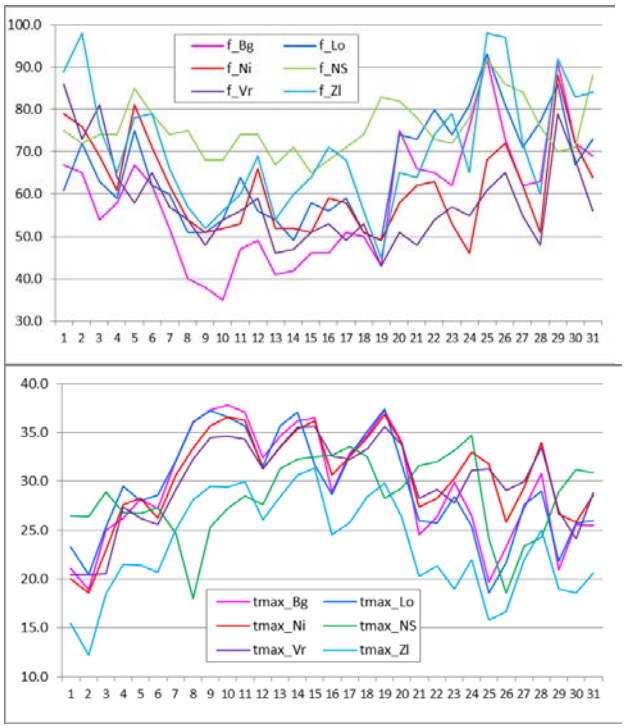

Fig 2. Daily values of the relative humidity (on top) and maximum air temperature (at the bottom)

It is interesting to see the annual heat load values for these cities in 2011 (fig 2). Annual heat load values show *slight warm stress* as ''unfavorable'' value in Loznica and Niš (HL> 1.026) while *thermoneutral* load occurs in other cities as favorable biothermal conditions. It can easily be

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seen that Belgrade has the lowest annual heat load value, compared to the daily values were analyzed in July.

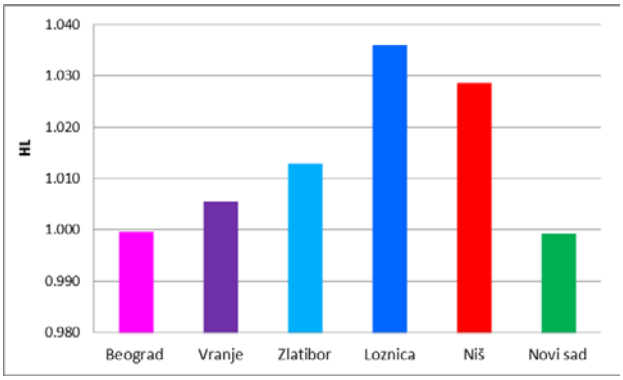

Fig 2. Annual values of the heat load index in 2011

4 Conclusion

In this study bioclimatic index, the heat load in man is used as an indicator of thermal stress and thermal comfort during month of July (2011) in Belgrade, Loznica, Niš, Novi Sad, Vranje and Zlatibor. In the most unfavorable month for bithermal conditions, the results show that Belgrade has dominant load of *extreme heat stress* while Zlatibor has dominant load of *slight warm stress*. Other cities has dominant load of *great hot stress*.

Heat load index include relevant information about climate and actual weather impact on humans. The results listed in this paper show possibility of assessing bioclimatic conditions. Diverse applications are possible for quantification and for identification of specific areas with unfavorable bioclimatic conditions (e.g. effected by heat waves). Specially, it could be helpful for identification of specific areas with favorable bioclimatic conditions (e.g. areas with health resorts, tourism and spa climatology). It is important to know how to cool off the body in hot weather by understanding relationship between thermoregulation and actual weather condition.

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