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ANALYSIS OF THE BIOCLIMATIC CONDITIONS WITHIN DIFFERENT SURFACE STRUCTURES IN A MEDIUM-SIZED CITY (SZEGED, HUNGARY)

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Összefoglalás – A városklíma kutatásokon belül a humán bioklimatológia napjaink egyik legdinamikusabban fejlődő részterülete. Az utóbbi években számos indexet fejlesztettek ki annak számszerűsítésére, hogy mekkora az emberi szervezetet érő hőterhelés különböző környezetben, illetve milyenek az emberi test és a környezete közötti energiaáramlási viszonyok. Jelen vizsgálatunkban egy esettanulmányt mutatunk be Szeged (160 000 lakosú város Magyarország délkeleti határszélén) példáján, melyben egy kis mintaterület bioklimatikus viszonyait elemezzük.
Bioklimatológiai szempontból alapvető fontosságú, hogy a vizsgált test direkt sugárzásnak kitett, vagy árnyékban lévő ponton helyezkedik-e el. Mintaterületünk a város magas beépítettségű belvárosi régiójában található, szűk utcakanyonok jellemzik, 20-30 éves (20-30m magas) útszéli fasorral. A sugárzási viszonyok tehát ezen feltételeknek megfelelően módosulnak. Tanulmányunkban bemutatjuk, hogy hogyan reagálnak a különböző bioklíma indexek-értékek (például a PMV-Predicted Mean Vote és a PET- Physiological Equivalent Temperature) a felszíni struktúra megváltoztatására. Az indexszámításokat RayMan modell segítségével végeztük.

Abstract - Human biometeorological approaches have an important role in applied urban climatology. Several different thermal indices were developed in the last decades to describe human comfort or heat stress of the human body based on the energy fluxes between the body and environment. In this study some results of recent biometeorological investigations in a south-eastern Hungarian city, Szeged (population 160,000) are presented.
From point of view of human biometeorology, the key question is whether the examined body is in the shade or is exposed to direct radiation. Our sample area is in a heavily built-up city centre region with narrow streets and several 20-30 year old (20-30 m tall) trees, so radiation fluxes are determined basically by these factors. This paper shows how the bioclimatic indices, Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET) depend on the situation of radiation at a certain place. It was examined what is the relation between the structure and possible changes of the built-up area and the indices. All the calculations, T_{mrt}, PMV and PET were performed with RayMan model.

Key words: radiation fluxes, thermal comfort, mean radiant temperature, Predicted Mean Vote, Physiological Equivalent Temperature, Szeged, Hungary

INTRODUCTION

One of the environmental stress factors on human being living in the urban area is the effect of partly artificial climate conditions, which are formed mainly by the area's building up.

An important task of the bioclimatological research to evaluate thermo-physiologically the thermal and radiating environment of human beings, because it determines basically the energy balance of the body (*Höppe*, 1993). The physiologically relevant assessment of urban climate, and especially different urban microclimates, requires the use of methods and indices, which combine meteorological elements with personal parameters (*Mayer*, 1993, VDI, 1998). Human comfort issues and quantitative bioclimatological indices generate valuable information for urban planners, helping them to increase the well-being of urban population by planning suitable and healthy environment.

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This study is based on earlier bioclimatic and recent urban climatological studies in a Hungarian city, Szeged. Recent studies show that on annual average an urban heat island intensity of 2.7ºC can be measured in Szeged which can extend up to 6.8ºC at clear, anticyclonal weather conditions (*Sümeghy and Unger,* 2003). It means a significant heat-stress to the human body, especially in summer. In the earlier bioclimatic studies, with the help of suitable indices for the available data set, differences in the annual and diurnal variation of human bioclimatic characteristics between an urban and rural environment were evaluated over a 3-year period (*Unger*, 1999). According to the results, the city favourably modifies the main climatological elements within the general climate of its region; periods likely to be comfortable are therefore found more frequently in the city than in rural areas.

STUDY AREA AND METHODS

Study area

Szeged is located in the south-eastern part of Hungary (46ºN, 20ºE) at 79 m above sea level on a flat plain, with a population of 160,000 (*Fig. 1B*). As *Fig. 1C* shows the city has a boulevard-avenue road system, with several different land-use types from the densely built centre to the detached housing in the suburb regions. *Fig. 1D* – created by the RayMan model – shows the area of investigation (200 x 200 m) in the heavily built-up city centre region with narrow streets and several 20-30 year old (20-30 m tall) deciduous trees.

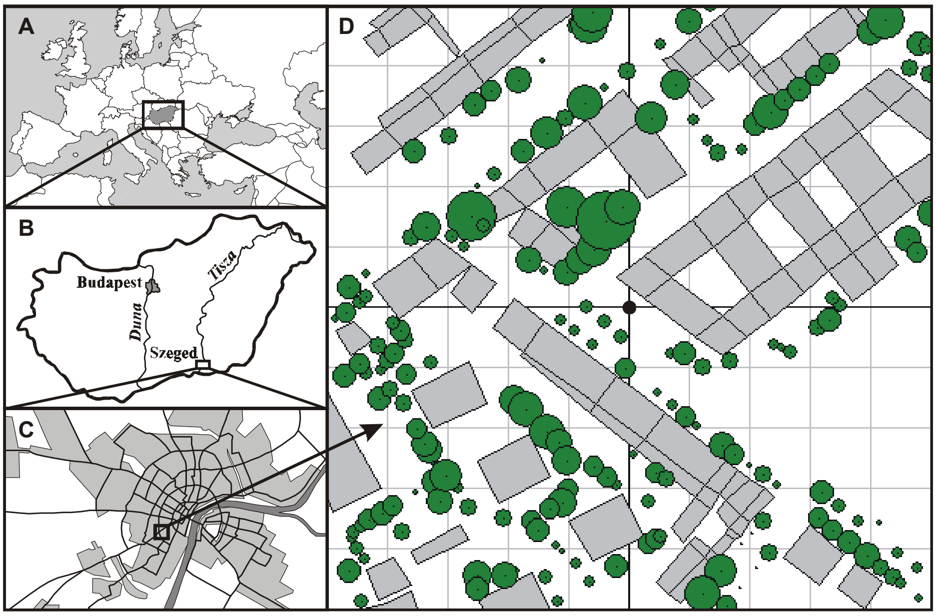


Fig. 1 Geographical location of Hungary in Europe (**A**), of Szeged in Hungary (**B**), the road network of the city (**C**) and the investigation area (**D**) with fixed measurement site in its centre (•) created by the RayMan model. The buildings are marked by light grey and trees by dark grey on the part of **D**.

Parameters and methods

Lots of models were developed to estimate the radiation fluxes, and the energy balance of human body in different environments, including various meteorological parameters, albedo of the surface and solid angle proportion (*Fanger,* 1972*, Gagge et al.,* 1986*, Höppe*, 1999*, Matzarakis et al.*, 2000*, Spagnolo and de Dear*, 2003). The models use complex comfort indices – for example Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET) – to evaluate the thermal stress on the body. Most of the indices are based on mean radiant temperature (T_{mrt}), which is the most important input parameter for the energy balance during sunny weather (*Matzarakis et al.*, 2000). **T_{mrt}** is defined as ”the uniform temperature of a surrounding surface giving of blackbody radiation (emission coefficient ε=1) which results in the same energy gain of a human body as the prevailing radiation fluxes” (*Matzarakis et al.*, 1999).

PMV predicts the mean assessment of the thermal environment for a large sample of human beings by value according to the seven-step ASHRAE comfort scale (in really extrem weather situation PMV can be higher than 3.5, or lower than -3.5) (*Höppe*, 1993 and 1999, *Mayer and Matzarakis*, 1997,).

PET is one of the most popular and useful bioclimate index, because it has a widely known unit (ºC), which makes results easy understandable and comprehensible for urban planners and decision-makers. PET is defined as the air temperature at which the human energy balance for the assumed indoor conditions is balanced by the same skin temperature and sweat rate as the calculated for the actual outdoor conditions (*Mayer and Matzarakis*, 1997).

Table 1 Comparison of PMV (Predicted Mean Vote) and PET (Physiological Equivalent Temperature) ranges for different human sensations and thermal stress level by human beings. (internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo) (*Matzarakis et al.,* 1999)

PMV	**PET (°C)**	**Human sensation**	**Thermal stress level**
		very cold	extreme cold stress
-3.5	4	……………	………………
		cold	strong cold stress
-2.5	8	……………	………………
		cool	moderate cold stress
-1.5	13	……………	……………….
		slightly cool	slight cold stress
-0.5	18	…………….	……………….
		comfortable	no thermal stress
0.5	23	…………….	………………..
		slightly warm	slight heat stress
1.5	29	…………….	………………..
		warm	moderate heat stress
2.5	35	…………….	………………..
		hot	strong heat stress
3.5	41	…………….	………………..
		very hot	extreme heat stress

One of the recently used bioclimatical model is the *RayMan* model, which is well-suited to calculate radiation fluxes because it considers more precisely the effect of a complex urban structure (*Matzarakis,* 2002). Among others a final output of the model is in polar co-ordinates about the area including the sun path of the observation day at the place, with the shadow of buildings, trees, or other obstacles and sky view factor. All our calculations, T_{mrt}, PMV and PET were performed with this model.

A 3-D map of the examined area was made with the help of RayMan model, which gives precise and high resolution data of the surrounding area of the observation point. Meteorological parameters (air temperature, global radiation, wind speed and relative humidity) were logged by a VAISALA-MILOS 500 automatic weather station, which is located at the centre of the investigation area marked with (•) on *Fig. 1D*.

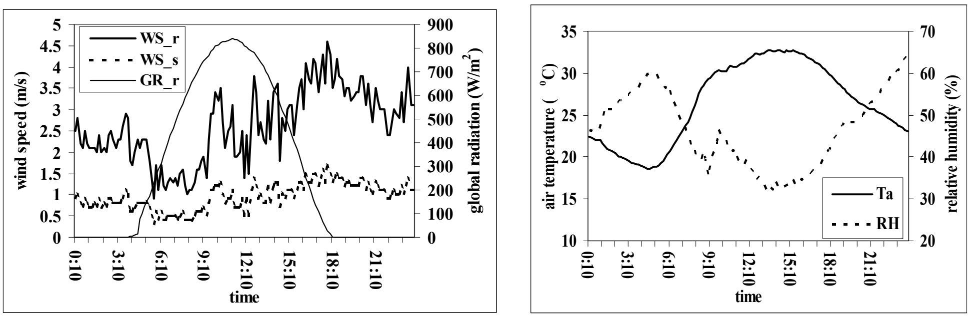


Fig. 2 Diurnal courses of meteorological parameters on 4th August 2000 (WS_r: wind speed on the roof, WS_s: wind speed at the surface, GR_r: global radiation, Ta: air temperature, RH: relative humidity)

Fig 2 shows the diurnal courses of the meteorological parameters, which can characterise the weather conditions of the observed day (4th August 2000). The temperature increased rapidly during the morning hours due to the undisturbed sunshine (global radiation). The maximum temperature was 32.7°C, so that was a hot summer day with – especially at the surface – low wind speed. The minimum air temperature during the night was respectively 19.0 °C.

RESULTS AND DISCUSSION

The bioclimatic situation at the observation point was examined in four cases:

- case **A** (t+b): real situation considering trees and buildings (*Fig. 3A*),
- case **B** (b): hypothetical situation with buildings only (*Fig. 3B*),
- case **C** (t): hypothetical situation with trees only (*Fig. 3C*),
- case **D** (r): without any obstacles like the “roof region” of the buildings (sky view factor = 1).

The calculated obstacle structures in the first three cases are shown in polar co-ordinates, as an output of RayMan (*Fig. 3).* There are notable differences in the radiation conditions between the three situation: on the one hand due to different sky view factors (case **A**: 0.278, case **B**: 0.431, case **C**: 0.560), on the other hand the shading of direct radiation by obstacles.

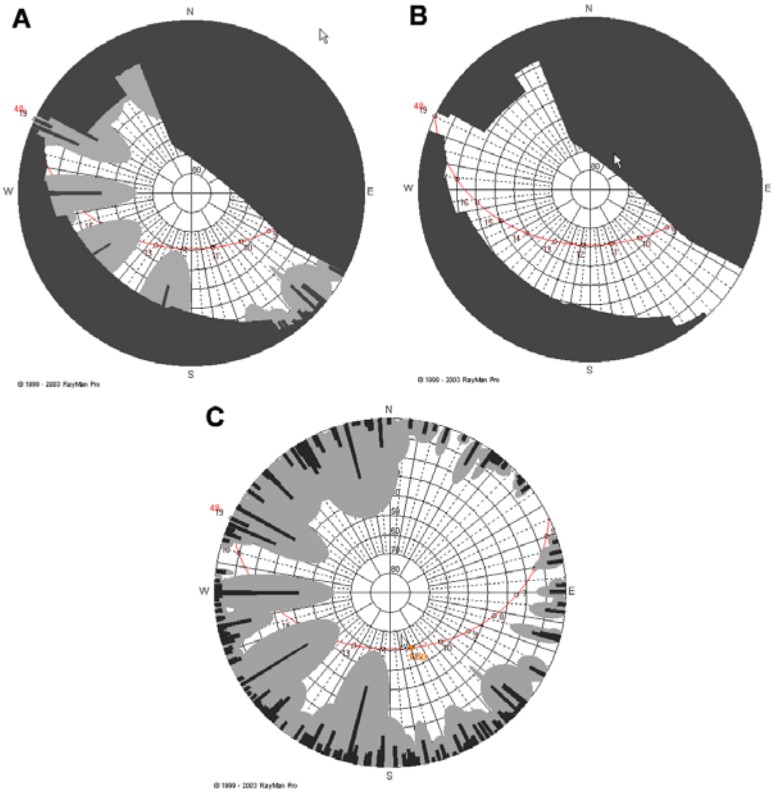


Fig. 3 Output fisheye diagram about the investigation area with buildings and trees (**A**), with only buildings (**B**), with only trees (**C**) and the sun path on 4th August 2000, for the calculation of the sky view factors in RayMan

Estimated T_{mrt} values based on the model are shown on *Fig 4.* Because T_{mrt} values have strong correlation with global radiation values and there was undisturbed sunny day on the day of measurement; significant alterations in the shape of curves caused mainly by the situation when the observation point was shaded or hit by direct radiation. After the sunrise T_{mrt} values increased quickly on the roof (“T_{mrt}_r”) with sky view factor of 1 and in the case of trees only (“T_{mrt}_t”). In the two other cases the increase begins only at 9 am, when the direct radiation hit the hypothetical body. The degree of the observed fast increase is around 30°C. The shapes of the curves are similar at noon because direct radiation hit the body in all cases, but there is a difference in the maximum values. The absolute maximum value is 62.3°C in the case of “T_{mrt}_r”, while at the same time this value exceeds only 59.9°C in the case of “T_{mrt}_t+b” which means real surface structure. This difference is caused by the different projection factor.

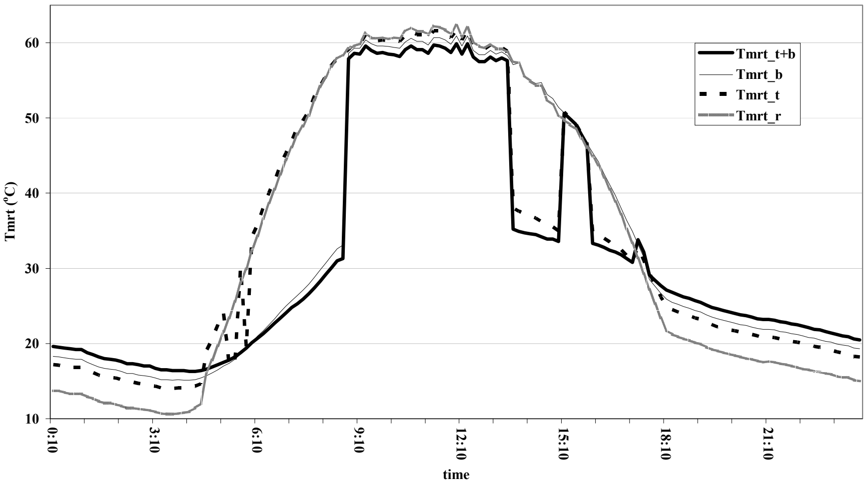
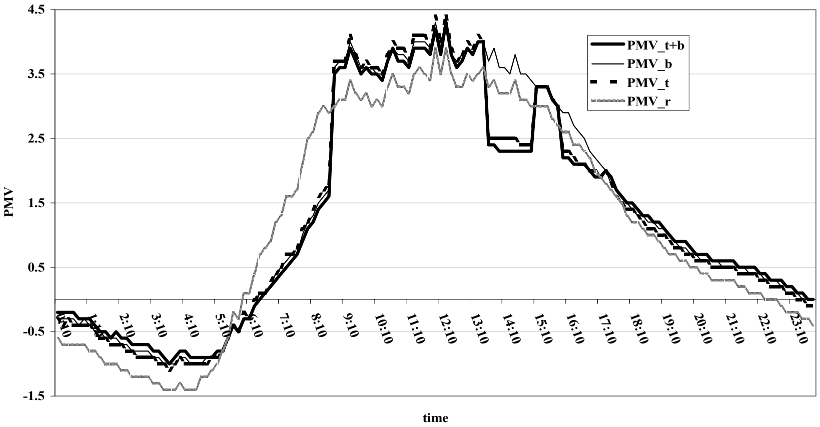


Fig. 4 The mean radiant temperature T_{mrt} computed by RayMan in the three urban structures and on the roof on 4th August 2000

By model calculated PMV and PET values are shown on *Fig. 5A* and *Fig. 5B*, respectively. Heat stress was experienced on the examined day: the highest value of PET was 46.8ºC; and in the case of PMV the scale (based on the ASHRAE scale) was 4.4, which means ”very hot” thermal stress level. The shapes of the courses have almost the same form as T_{mrt}. That was not an unexpected result, because the part of T_{mrt} is primary factor of heat stress. The T_{mrt} values were the highest on the roof between 10 a.m. and 1 p.m., because of the strong, undisturbed direct and diffuse radiation. On the other hand the PMV and PET indices were at this time the lower on the roof. It was caused probably by the higher wind speed on the roof than at the surface (*Fig. 2*).



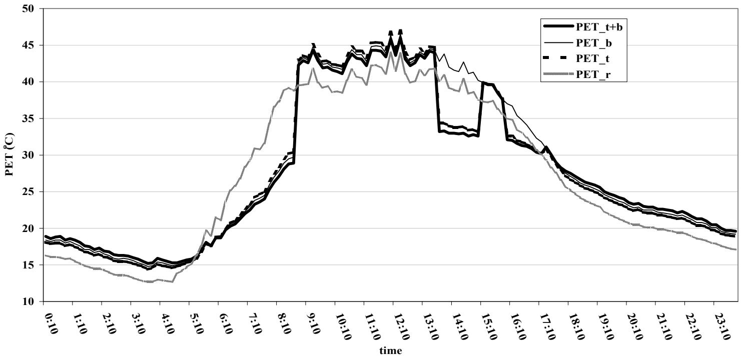


Fig. 5 Predicted Mean Vote PMV and Physiological Equivalent Temperature PET in the three urban structures and on the roof on 4th August 2000

CONCLUSIONS

The following conclusions are reached from the analysis presented:

(i) The presence of natural and artificial obstacles around the human body has impact on the radiation fluxes so on the energy balance of the body.

(ii) Changes in the radiation situation cause changes in thermal comfort perception.

(iii) Disadvantageous bioclimatic conditions can be improved (e.g. planting trees) even in the case of old ”inherited” city structure.

(iv) In the course of planning of new districts in a city bioclimatic conditions must be taken into consideration.

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