ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 46, 2012, 107-114

ASSESSMENT OF THE BIOCLIMATIC CONDITIONS OF A POPULAR PLAYGROUND BY THE MICROCLIMATE MODEL ENVI-MET

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Summary: The paper introduces a thermal comfort examination carried out in a well-attended playground located in the city centre of Szeged (Hungary). The aim of this study is to find the optimal land cover and vegetation options of the study area by means of numerical simulations. For this evaluation the modelled micro- and bioclimatological conditions of a typical summer day (12th July 2011) were analyzed. The thermal and radiation environments of the playground were quantified by one of the most popular bioclimatological comfort index Predicted Mean Vote (PMV) and the Mean Radiant Temperature (T_{mrt}). The simulations of the investigated parameters were performed by the microclimate model ENVI-met. The obtained results proved that the modelled area provided a variety of thermal conditions for the visitors due primarily to the different land covers. Moreover this paper emphasizes the important effect of the vegetation on the human thermal sensation.

Key words: thermal comfort, Predicted Mean Vote (PMV), Mean Radiant Temperature (T_{mrt}), ENVI-met, land cover

1. INTRODUCTION

The climatological and bioclimatological conditions are modified in urban environment compared to the rural areas (Unger 1999), and even inside a city in micro-scale these conditions are changing rapidly following the urban surface characteristics. The setup of the urban surface characteristics is related with the work of planners, architects and urban planners therefore they have an influence on the local and micro-scale climate conditions. Urban planning in general and within it the planning of urban green spaces is a very complex process and it has several climatological aspects. The final shape of an urban park is defined by the aspects of the architecture but this final setup determines the microclimate of that area and finally the thermal comfort of the visitors. As a result of the thermal comfort conditions the visitors or users of the urban park may alter their opinion about it. If the park is perfect from an architectural point of view, but heat stress frequently occurs there, the visitors will avoid the area.

In the last decades there were numerous researches in the topic of microclimate and thermal comfort, therefore now several methods and software are available to predict the microclimate conditions of an urban park when it is only in the planning stage, or before the construction starts (e.g. Lehme and Bruse 2003, Gulyás et al. 2006, Chow et al. 2011, Fröhlich and Matzarakis 2012). This study is an example for this type of micro-scale modelling, which can give useful information for the architects to make sure that the constructed open space or park has in the end the optimal or best setup in several aspects.

2. MATERIAL AND METHODS

2.1. Description of the study area

The present human thermal comfort examinations took place in the centre of Szeged, located in the south-eastern part of a Central-European state, Hungary (46°N, 20°E). The investigated approximately 3300 m^2 large area is one of the most modern and well-attended playgrounds in the city. In this open the space children can choose among several toys, jungle gyms as well as swings, and 20 benches offer seating for the visitors. In the eastern part of the playground a cottage is situated where the children can play even in bad weather (Fig. 1).

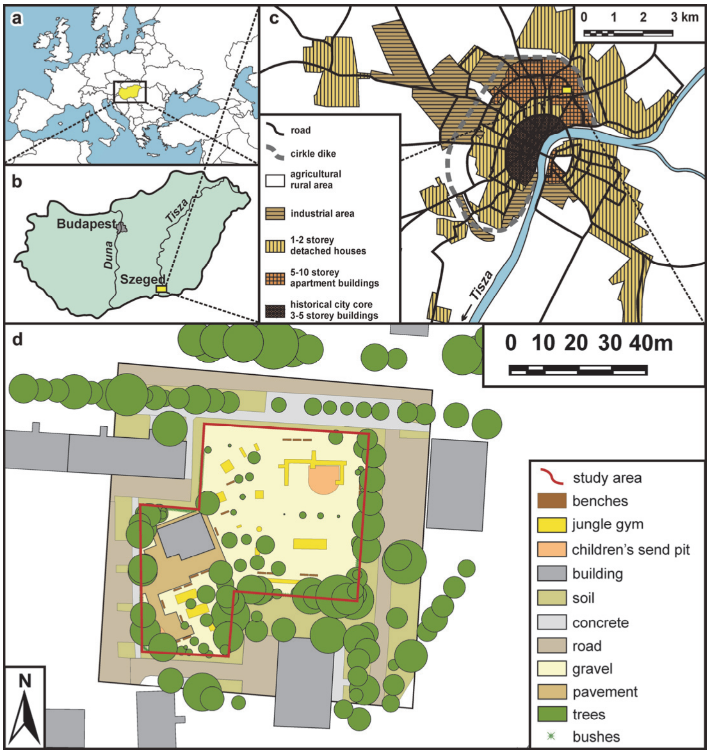

Fig. 1 Geographical location of Hungary (a) and Szeged (b);
Detailed maps of Szeged (c) and the investigated playground (d)

The surface of the area is primarily covered by light-coloured paving stone that protects the playing children from greater injuries. Other land cover can only be found in the following parts of the playground: the children's sand pits are filled with sand, and the immediate vicinity of the cottage and the southeast corner of the playground are paved. The amount of vegetation is considerable (primarily deciduous trees), however, they are mainly located at the boundaries of the study area. Therefore during forenoon and in the early afternoon hours a large part of the playground is exposed to the sunlight (Fig. 2).

Fig. 2 Photographs of the investigated playground

2.2. Methods

The present study applies the ENVI-met model in order to compare the effects of different land covers and designs on the micro- and human comfort conditions. ENVI-met is a three-dimensional non-hydrostatic climate model which is able to model the interactions in the surfaces-atmosphere-vegetation system with relatively high temporal (10 min) and spatial (0.5-10 m) resolution (Bruse and Fleer 1998). The simulation required two groups of input data: the configuration file (.cf) contains the basic settings and the necessary meteorological parameters of the simulation while the area input file (.in) includes the morphological elements (buildings, plants, land covers etc.) of the investigated area.

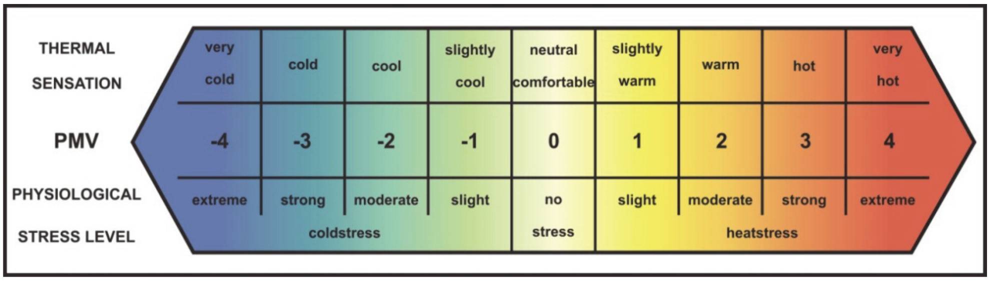

Fig. 3 PMV scale for various thermal sensation and stress levels (according to Mayer 1993)

The micro-bioclimatological environment of the study area was quantified by two thermal indices besides air temperature: Mean Radiant Temperature (T_{mrt}) describes the radiation environment of an area, while Predicted Mean Vote (PMV) quantifies the thermal sensation of the people. T_{mrt} is defined as the uniform temperature of a surrounding surface giving off black body radiation (emission coefficient, $\varepsilon = 1$) which results in the same energy gain of a human body as the prevailing radiation fluxes (Höppe 1992). The other index PMV predicts the mean assessment of the thermal environment for a large sample of human beings by values according to the originally seven-point (from -3 to +3) ASHRAE comfort scale. This comfort scale at around 0 is characterized as comfortable, higher and lower values indicate increasing probability of thermal discomfort as well as stress due to heat and cold conditions, respectively. In (extreme) real weather conditions, PMV can be higher than +3 or lower than -3 (Mayer and Höppe 1987, Mayer 1993) (Fig. 3)

Table 1 The basic input parameters of the simulation

Parameter	Input value
Temperature (K)	296
Relative humidity in 2 m (%)	58
Wind speed in 10 m (m/s)	3.4
Wind direction (°)	325
Spec. humidity in 2500 m (g/kg)	7
Roughness	0.1
Total simulation time (h)	18
Start simulation	00:00:00

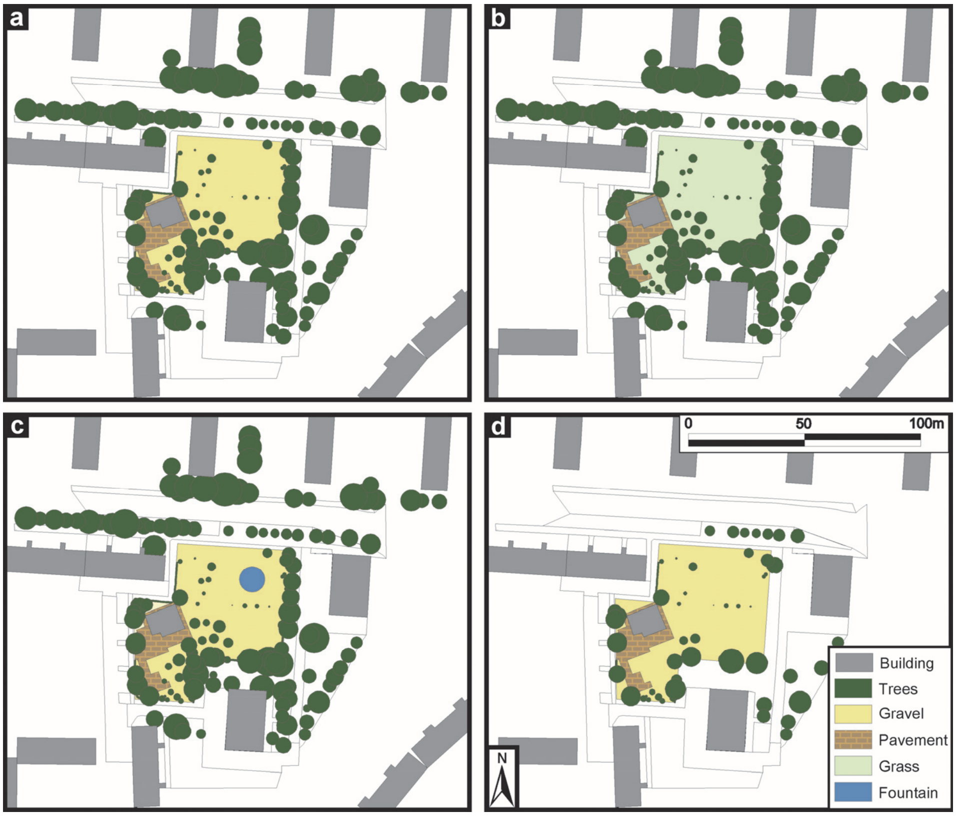

Fig. 4 The schematic pictures of the four simulation scenarios

The simulation was run on a typical hot, cloudless summer day (12th July 2011), because the differences in the thermal and microclimatic environment can clearly be observed at this time. As parameters of the modelling procedure, 18 hours (from 12 a.m. to 6 p.m.) of total simulation time and a spatial resolution of 1.5 m were adjusted in ENVI-met. The simulation results were related to the bioclimatological reference height of

1.1m. Table 1 shows the basic settings of the simulation and the necessary meteorological data obtained from the meteorological station of the Hungarian Meteorological Service situated in the city centre of Szeged (Unger and Gál 2011).

Four simulation scenarios were created in ENVI-met to find the optimal land covers and design for the studied playground. *Scenario 1* contains the base area without any modification (Fig. 4a). In *scenario 2* grassy land cover was employed instead of gravel (Fig. 4b). In case of the *scenario 3* a little fountain (lake) was virtually built in the north-eastern part of the playground, but the original land covers were retained (Fig. 4c). Finally, in *scenario 4* a part of the vegetation was removed (Fig. 4d). This paper demonstrates the results of these modifications at a selected time (11 a.m.) on the investigated simulation day, when the differences of the microclimatic conditions can be easier observed.

3. RESULTS AND DISCUSSION

3.1. Thermal and radiation characteristics of the base area without modification

In the first part of the analysis, the results of scenario 1 were examined. Fig. 5a shows that the spatial patterns of the simulated air temperature were relatively homogeneous, differences were not larger than a few tenths of degree Celsius all over the area. Higher values (about 24°C) occurred in the northern areas. In the eastern and southern parts, where the vegetation is significant, the temperature was slightly cooler (23.4–23.6°C).

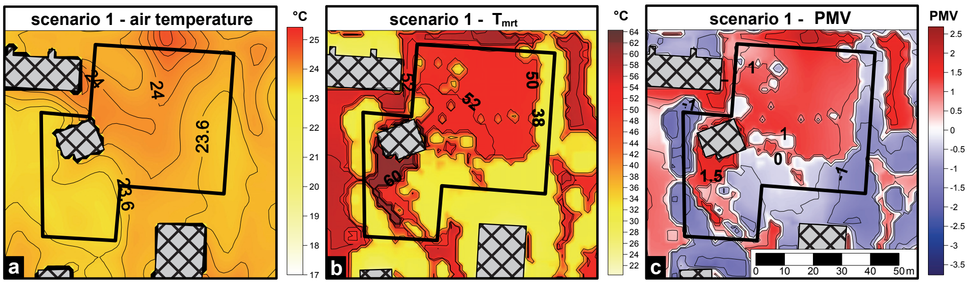

Fig. 5 The thermal features of the modelled area without modification (scenario 1)

However, the maps of T_{mrt} and PMV (Figs. 5b and 5c) representing the spatial distribution of the radiation environment and thermal sensation were much more diverse, proving the complexity of these bioclimatological indices compared to air temperature. At the same time, these maps illustrate the effects of the different land cover and vegetation types on the human thermal sensation. The spatial distributions of T_{mrt} and PMV values were analogous, which supported the fact that the radiation factor plays a very important role in human thermal sensation at this time of the year.

Duo to the strong direct radiation in this period as well as the significant reflected radiation from the surface of the pavement, the highest T_{mrt} values (60°C) occurred in the vicinity of the cottage. In the middle parts of the area T_{mrt} values slightly decreased (50–52°C), however significant drop in the values can only be found in the shade of the trees

(38°C). The heat stress map (PMV map) illustrates that the most unpleasant part (PMV = 1.5, slightly warm – warm thermal sensation) of the playground is situated on the pavement due to the above mentioned increased radiation. However, under the trees where both the incoming and reflected radiation fluxes were minimal at this time, the thermal conditions were more comfortable and the values approached to PMV = 0 (neutral thermal sensation) and the PMV = -1 (slightly cool thermal sensation).

3.2. The effects of the area modification on the thermal conditions

In order to compare the scenarios, difference maps were created. In these maps the modelled values of the base case (area without modification, Fig. 5) were subtracted from the corresponding values of the given scenario (scenarios 2-4), thereby the effects of the modification can be more easily observed.

According to Fig. 6a, the air temperature slightly increased in scenario 2 (grassy surface instead of gravel), which can be explained by the different water-holding capacity of the gravel and the grass. However, this difference did not exceed 0.15°C anywhere, consequently the influence of the modifications in scenario 2 were practically negligible.

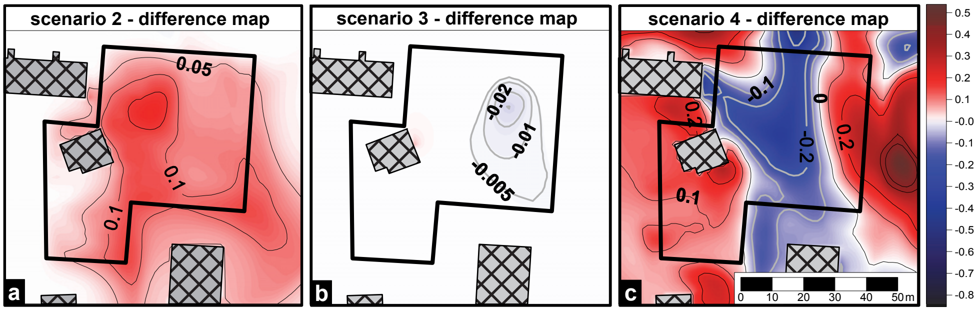

Fig. 6 Difference maps of the modelled air temperature (°C) at different scenarios (black and grey isotherms mark the positive and negative changes, respectively)

A similar tendency can be observed in the case of scenario 3 (simulation with fountain): although the air temperature decreased in the vicinity of the fountain, its cooling effect was negligible (Fig. 6b). This can be caused by the fact that the simulation applies simplifications: the fountain was visualized as a small water surface causing reduced cooling effect compared to a sprayed mass of water. Besides this the present version of ENVI-met may not be able to render such fine adjustments as employed in scenarios 2 and 3. On the map of scenario 4 (simulation with reduced vegetation), the values of difference varied between -0.2 and 0.2°C (Fig. 6c). Positive differences, i.e. increase of air temperature mainly occurs at the boundary of the study area, where some parts of the vegetation were removed. In the north-western part of the simulation area a large group of trees was removed (Fig 4d), which gave way to the prevailing northwesterly wind (Table 1). The incoming wind cooled down the environment, therefore the temperature in the middle part of the area slightly decreased.

As illustrated in Fig. 7, the variation in the thermal radiation conditions was hardly significant on the first two difference maps (scenario 2 and 3). In the case of scenario 2 the deviations of the T_{mrt} values not even achieved 1°C (Fig. 7a). In scenario 3 the effect of the fountain was limited and expanded only to the area of the water surface (Fig. 7b). However, the map of scenario 4 highlighted that the modification of the vegetation caused significant changes in the radiation environment (Fig. 7c). The dark patches on the map indicate places of removed vegetation, where the increase of T_{mrt} values exceeded even 20°C due to the strong incoming radiation.

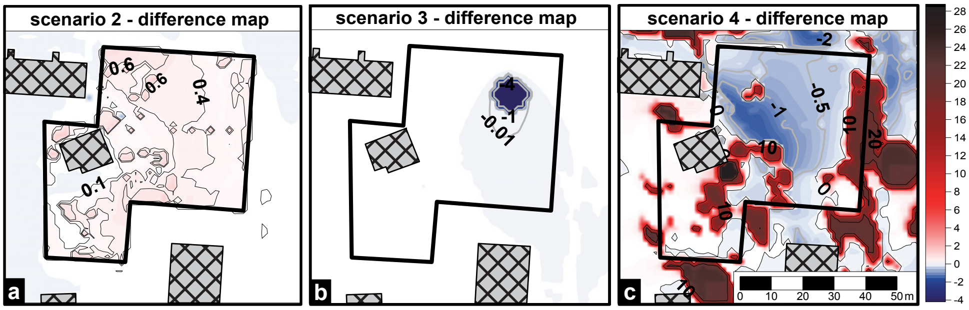

Fig. 7 Difference maps of the modelled T_{mrt} (°C) at different scenarios

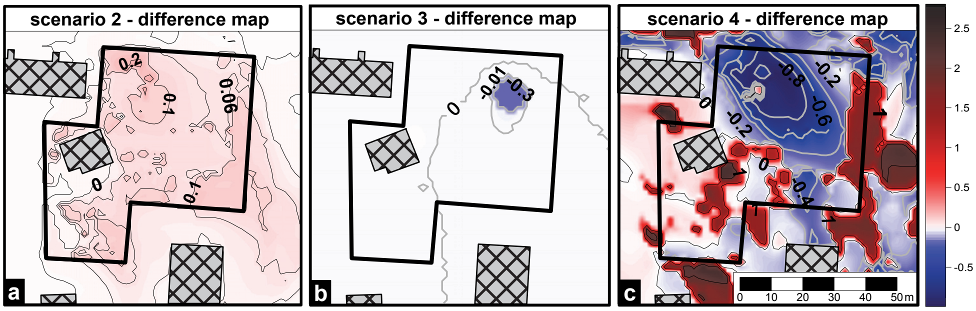

Fig. 8 Difference maps of the modelled PMV at different scenarios

Although the air temperature and T_{mrt} values are important indicators of thermal comfort, PMV can predict and quantify how people sense the thermal conditions of a given area. Therefore the analysis of the spatial patterns of the PMV values is explicitly pronounced in the investigated scenarios. Fig. 8 shows the difference maps of the modelled PMV values. According to our simulation results, scenarios 2 and 3 caused negligible changes in the thermal environment (Figs. 8a and 8b). The slight increase of PMV values (0.06 – 0.2 PMV) in scenario 2 and the reduction of that (-0.01 – -0.3 PMV) in the vicinity of the fountain (scenario 3) are almost imperceptible to humans. However the difference map of scenario 4 shed light on the important role of vegetation in thermal comfort (Fig. 8c). Namely, the removal of trees from certain parts of the playground caused an increase of as much as 1 PMV, so these areas shifted into another, warmer thermal sensation category (slightly warm instead of neutral). In the middle part of the playground, slightly cooler PMV values (-0.2 – -0.8) can be found due to the above mentioned north-western wind. Consequently, in some cases the appropriate position of the trees may contribute to the ventilation of the area providing more comfortable environment in otherwise stressful conditions.

4. CONCLUSIONS

Some preliminary results of a thermal comfort investigation based on the simulation of micro- and bioclimatological conditions were presented discussing the effect of different land covers on the thermal comfort sensation. The effects of four simulation scenarios were compared by the simulations of ENVI-met, where the thermal environment was characterized by bioclimatic indices T_{mrt} and PMV besides air temperature.

The results of the examination show that a grassy land cover (scenario 2) and a virtual fountain (scenario 3) caused only slight variations in the thermal condition. Contrary to the expected results, the influence of the surface cover modifications of these two scenarios was not significant according to the obtained maps. This can probably be explained by the fact that it is difficult to treat these minor changes in the model area using the present version of the simulation. However, the outcome of scenario 4 revealed the importance of the effect of the vegetation on the thermal sensation. The reduction of the number of trees increased the thermal load in the playground, but at the same time an increased ventilation occurred on the area by the prevailing wind.

The aim of this study was to emphasize the importance of the modelling procedure in the process of urban planning and to give a hand in the development of a comfortable urban environment.

Acknowledgements: The study was supported by the European Union and co-funded by the European Social Fund (TÁMOP-4.2.2/B-10/1-2010-0012) and the Hungarian Scientific Research Fund (OTKA PD-100352). The authors' special thanks are due to János Unger for his comments and suggestions at the preparation stage of the manuscript and to Eszter Tanács for the language revision of the manuscript.

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