169: Thermal stress maps validation with on-site measurements in a playground

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Abstract

This paper presents a thermal comfort investigation carried out in a well-attended playground in Szeged (Hungary) during summer and autumn of 2011. Thermal conditions of the playground were expressed in terms of physiologically equivalent temperature (PET °C). Firstly, thermal stress maps were created from air temperature, relative humidity, wind velocity and global radiation data. 10-min averages of these parameters were downloaded from the inner city meteorological station of Szeged run by the Hungarian Weather Service. RayMan software were used to model radiation conditions for each grid point (5 m × 5 m) of the playground considering the surrounding buildings and vegetation, and also to calculate PET. Spatial distribution of the derived PET, i.e. thermal stress maps were created by the Surfer 8 software. Secondly, on site measurements were carried out using two micro-bioclimatological stations – they were placed on sunny and shady locations, respectively. The micrometeorological data characterizing the playground were recorded from 10 a.m. to 6 p.m. in every minute at the height of 1.1 m and were used for calculating the PET values also by RayMan. The aim of this study is to analyze the differences between the PET values derived from the modelling procedure (PET-modelled) and from the on-site measurements (PET-measured), i.e. to validate the modelled thermal stress maps and to emphasize the importance of micro-bioclimatological measurements in the outdoor human thermal comfort investigations.

Keywords: thermal comfort, urban playground, physiologically equivalent temperature, validation

1. Introduction

Importance of urban playgrounds in the social life of neighbouring citizens is evident; bringing the children to play is part of the daily routine for many families [1]. As the most frequently attending age-groups (children and the elderly people who often take care of them) are very sensitive against the heat stress [2], the thermal conditions of these public places is an important research topic in the field of urban bioclimatology. Considering the trends of climate change, i.e. the predicted intensification of extreme summer heat in Central Europe the issue becomes even more relevant for Hungarian cities [3].
Application of micro-scale numerical models to simulate the different level of thermal stress in high spatio-temporal resolution on the area of interests can be a valuable tool to create thermal stress maps. These maps may be the initial step to communicate with the decision makers and urban designers about the necessary changes. However, models involve many assumptions and simplifications necessary to keep within reasonable limits the running time of the simulations. Therefore there is a need for adequate on-site measurements reflecting the real micro-bioclimatic conditions to validate the outcomes of the simulation tools [4].
According to the above mentioned reasons a popular playground was selected as study area in the city of Szeged (Hungary) to investigate the difference between measured and simulated thermal conditions.

2. Materials and methods

2.1 Study area

In the frame of a long-term urban bioclimate project in Hungary, a Central European country, several public places are investigated in terms of thermal conditions and human comfort. In the first phase of this project examinations took places in popular squares, parks and playgrounds of Szeged (46°N, 20°E). One of the most modern and well-attended playground of the city is examined from the summer of 2011 (Fig. 1). Its area is about 3300 m^2 where the children could choose among several toys, jungle gyms as well as swings. There are also 20 benches offering seating places for the visitors.

Fig 1. Photograph of the investigated playground

The surface of the area is primarily covered by light-coloured gravel that protects the playing children from greater injuries. Although there are considerable amount of deciduous trees at the edges of the playground (see later on Fig. 3), the largest part is exposed to the direct sunlight during forenoon and in the early afternoon hours.

2.2 Methods

This study introduces an alternative way for creating thermal stress maps based on available meteorological data and modelling procedure by the small-scale radiation- and bioclimate model RayMan [5]. Thermal conditions of the playground were expressed by the Physiologically Equivalent Temperature (PET) index [6], which indicates comfortable conditions around 20°C (Fig. 2).

PHYSIOLOGICAL STRESS LEVEL	PET - CATEGORIES	THERMAL SENSATION
extreme cold	< 4°C	very cold
strong cold	4 - 8°C	cold
moderate cold	8 - 13°C	cool
slight cold	13 - 18°C	slightly cool
no stress	18 - 23°C	neutral,comfortable
slight heat	23 - 29°C	slighty warm
moderate heat	29 - 35°C	warm
strong heat	35 - 45°C	hot
extreme heat	45°C<	very hot

Fig 2. PET ranges for different human thermal sensations and stress levels [7]

10-min averages of air temperature, relative humidity, wind velocity and global radiation (T_a [°C], RH [%], v [m/s] and G [W/m^2] respectively) were obtained from the meteorological station of the Hungarian Weather Service (HWS station) situated in the inner city. The distance between the investigated area and the HWS station is less than 3 km. As the anemometer locates at 26 m a.g.l, v data were reduced to 1.1 m a.g.l. through the equation used by [8]. The G data were modified according to the obstacles (buildings, trees) and the PET values were calculated by the RayMan software on a 5 m × 5 m grid network, using 263 simulation points (Fig. 3). The interpolation of the 'PET-modelled' values and the visualization of the spatial distribution of thermal conditions were carried out by the Surfer 8 software.

In order to validate the results data from on-site measurements were used. In the frame of these measurements T_a, RH, v as well as short- and long wave radiation fluxes were recorded between 10 a.m. and 6 p.m. in every minute at a height of 1.1 m by two mobile micro-bioclimatological stations. One of them was placed in the sun, while the other was in the shade given by trees. PET values calculated from these on-site data are called PET-measured'. Two points from the grid net were selected for the validation according to the location of the mobile stations: points #127 and #103 corresponded to the sunny and to the shaded stations, respectively (Fig. 3).

The measurements were carried out in summer and autumn of 2011 as well as in spring of 2012; altogether 13 days. This paper demonstrates the results of a typical summer day (12th July 2011) and an autumn day (3rd October 2011).

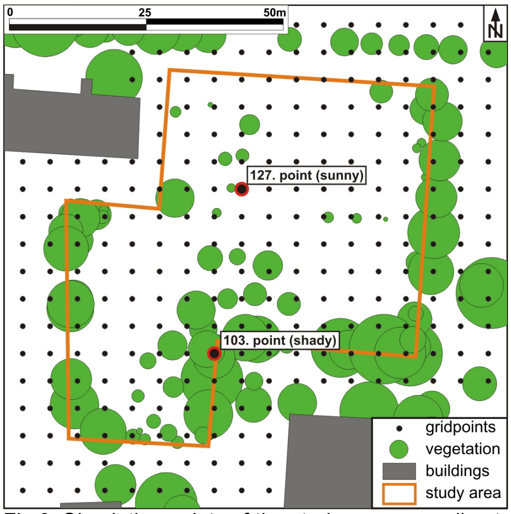

Fig 3. Simulation points of the study area according to the 5m×5m grid network and the locations of the two representative grid points

3. Results and discussion

3.1. Heat stress maps of the selected days

Firstly, the spatial patterns of the modelled PET values are demonstrated in a given period of the selected days. Figs. 4 and 5 reveal that the heat stress maps of the playground at 2 p.m. differ remarkably in the two seasons according to the different input parameters.

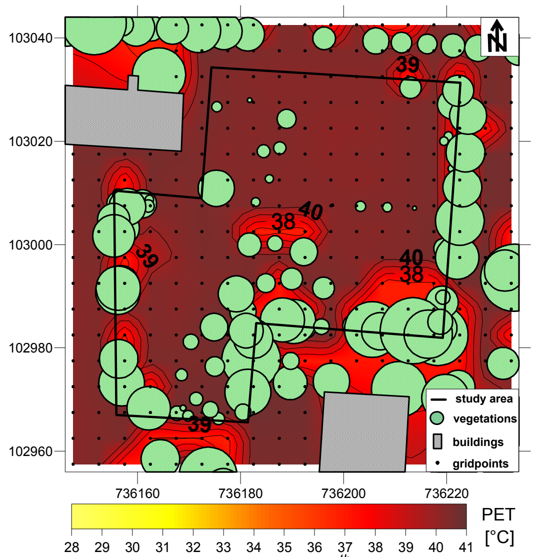

Fig.4. Heat stress map (PET), 12th July 2011, 2 p.m.

On the summer map the PET values are around 40°C on the whole area denoting strong heat stress (hot conditions) for the human organism (Fig. 4). As the northern and middle parts of the playground were exposed to direct solar radiation the PET values here exceeded 41°C. As a consequence of such thermal load several toys and jungle gyms which can be found in these sections are almost unused in summer. Due to the shading effect of the foliage thermal conditions were slightly cooler near to the edges of the playground where denser vegetation is located, as well as close to the single trees. However, PET values were still above 37°C also in these parts of the study area. Fig. 4 shows that the proportion of shaded areas in the playground was relatively small because of the high elevation of the sun in this summer midday period.

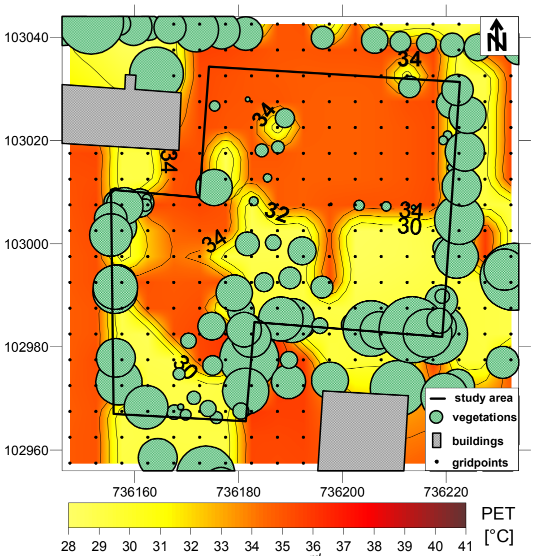

Fig 5. Heat stress map (PET), 3rd October 2011, 2 p.m.

Fig. 5 indicates lower thermal load on the investigated autumn day. PET values varied between 28°C and 35°C corresponding to the slightly warm to warm thermal sensation categories (slight to moderate heat stress). Similar to the summer day the most uncomfortable parts of the area can be found primarily in the north, where practically nothing protects the visitors from the direct radiation. In these places PET values approached 35°C. Due to the lower position of the sun in autumn the vegetation and the nearby buildings shaded greater parts of the playground than in summer. Thereby PET values decreased below 30°C on almost the half of the investigated area.

It is important to note that the 5 m × 5 m resolution did not make it possible to demonstrate the shadowing effect of the trees with smaller foliage. A denser simulation grid net would be more appropriate in this respect, however, taking into account that the PET values need to be modelled separately for all points, the efforts with this procedure would be too much for practical use compared to the benefits.

3.2. Validation

As a second part of the analysis daily curves of the 'PET-modelled' were compared to the 'PET-measured'. Figs. 6 and 7 illustrate the PET values of the sunny and shady locations for the selected summer day and autumn day, respectively. While the measured PET values reflect the rapid changes of the micrometeorological parameters, the modelled curves are much smoother.

The on-site measurements proved that the thermal conditions on the summer day were much more stressful for the human organism than on the autumn day (Figs. 6 and 7). PET values measured in the sun exceeded 40°C during almost the entire investigation period in summer (strong and extreme heat stress), while they remained under 40°C in autumn. In the latter case moderate and strong heat stress occurred almost all day, but after 5 p.m. the PET values dropped into the neutral (no thermal stress) category. This sudden decrease was caused by the low position of the Sun, i.e. from that time there were only shady parts in the playground. Without direct radiation the courses of the PET values in the shady measurement points were more closely to the measured air temperature: the summer day can be characterize with slight to moderate heat stress in the shade (23–32°C PET), while the autumn day with slight cold stress or neutral conditions (14– 23°C PET).

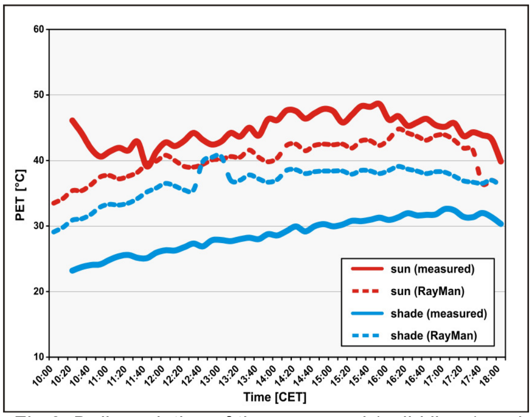

Fig 6. Daily variation of the measured (solid lines) and modelled (dashed lines) PET values, 12th July 2011

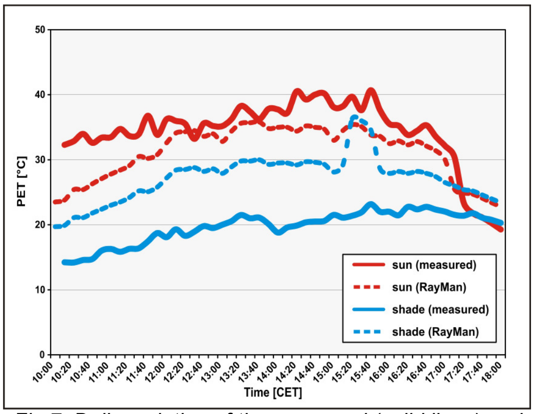

Fig 7. Daily variation of the measured (solid lines) and modelled (dashed lines) PET values, 3rd October 2011

On-site investigations revealed that the sunny measurement point was significantly warmer than the shady point: the mean difference between the two PET curves were approximately 15°C in summer and 14°C in autumn. Contrarily, the differences in the case of the modelled PET values were only about 4°C in both seasons (Figs. 6 and 7).

There is another obvious difference between the modelled and measured curves: the modelled PET values for the shady point suddenly increased at about 1 p.m. in July (Fig. 6) and around half past 3 p.m. in October (Fig. 7) when the two modelled curves (shady and sunny) were almost equal. This is caused by the temporarily increased intensity of solar radiation on the shady grid point. Since the mobile stations were continuously kept in the shade and sun, respectively, during the on-site measurements, the mentioned effect did not appear in the case of the measured curves (Figs. 6 and 7).

Modelled sunny and shady PET curves ran much closer to each other than the measured curves, and their tendencies were also quite similar. This can be explained by the meteorological parameters of the HWS station used as input for the calculation: three of them were the same (T_a, RH and reduced v) and only the radiation conditions were different for the two points according to the RayMan simulation. In fact, micrometeorological parameters can be quite different in spite of the close measurement locations. For example, the mean differences between the two points (sunny-shady) were: ΔT_a 1.5°C and ΔRH 4%. However, the differences between the measured v values were not so consequent and they exceeded sometimes 1 m/s.

The most important findings of the validation procedure are that the modelled PET values were slightly underestimated for the sunny parts of the area and significantly overestimated for the shaded parts (Figs. 6 and 7).

The overestimated PET values in the shade can be explained with the synergetic effect of the followings:

- the measured shady T_a was ca. 0.5°C lower than the HWS T_a;
- the on-site v was usually higher than the reduced HWS v, i.e. the v values measured at 26 m were reduced too low before the calculation of the modelled PET;
- G values measured in the shade were significantly lower than the G values reduced by the obstacles from the HWS G for the shady grid point #103, caused probably by the too high transparency (0.3) of the foliage in the model.

In the case of the slightly underestimated sunny values there are antagonistic effects:

- the measured sunny T_a was ca. 1°C higher than the HWS T_a;
- the air at the sunny point was drier with 3-4% RH than at the HWS station;
- however, the measured v values were also higher in this case;
- the measured G values were sometimes lower, sometimes higher (differences: $\pm$150 W/m^2).

As the modelling procedure simplifies the actually thermal conditions in a great extent (and the modelled values are incorrect especially in the shady parts of the area), it is worth to carry out on-site measurements to estimate correctly the spatio-temporal patterns of thermal conditions.

4. Conclusion

The paper presented a human thermal comfort investigation based on thermal stress maps for a popular playground and the comparison of on-site measured and modelled PET values. According to the PET maps the most unpleasant parts of the playground located in the north and in the middle, where the area were exposed to direct radiation both in summer and autumn. Near to the edges of the playground (especially in the southern parts of the area) PET values were lower due to the shading effects of the dense vegetation.

The heat stress maps provided acceptable information about the shading conditions caused by the artificial and natural obstacles, but the impact of the smaller trees would only be visible if the resolution of the grid would be finer. Beside this, the validation shed light on the certain inaccuracy of the modelling procedure, as the modelled PET values slightly underestimated the real conditions in the sun and overestimated them greatly in the shade. The observed inaccuracy emphasizes the importance of the on-site micro-bioclimatological measurements.

5. Acknoweledgement

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