193 WEATHER AND CLIMATE MODELING POSSIBILITIES USING LOCAL CLIMATE ZONE CONCEPT AND OBSERVATION NETWORK IN SZEGED, HUNGARY

Tamás Gál [*], Nóra Skarbit, Gergely Molnár, András Zénó Gyöngyösi
University of Szeged, Hungary

1. INTRODUCTION

In the field of urban climatology Local Climate Zone (LCZ) classification (Stewart and Oke 2012) is widely accepted as a representation of urban land use. It was designed for the classification of urban measurement sites, but later it was widely used as a basis of urban landform classification and also as a land use input data for urban climate modelling. The application of this system is advantageous because the classification is based on the thermal characteristics of the urban area thus it is an ideal way to represent the effect of the urban surface for the urban heat island (UHI) development. The LCZ categories contain thresholds for the key urban surface parameters (building height, SVF, H/W, etc.), however the climate models needs exact values therefore it is a crucial decision how do we define values for different classes.

The aim of this study is to present the different urban climate modelling initiatives in the case of Szeged, Hungary. In these studies we applied the widely known Weather Research and Forecasting model and MUKLIMO model developed by the German Meteorological Service. In the city data from a 23-element measurement network is available for validation. This monitoring network was deployed to represent the different LCZ classes, therefore it makes the possibility to compare the modelled and observed thermal characteristics of different LCZ classes. Using the different modelling methods and LCZ based observations it is possible to evaluate LCZ based climate modelling concept and also the results may help to find optimal values for urban surface parameters of LCZ classes.

2. STUDY AREA AND MEASUREMENT NETWORK

Szeged (Fig. 1.) is located in the Pannonian Plain. The urbanized area covers about 30 km^2. Tisza River is the axis of the town and the city has a regular avenue-boulevard structure. The climate of Szeged is Cfb (warm temperate climate, no dry season, warm summer) due to the Köppen classification (Kottek et al. 2006) with an annual mean temperature of 10.9°C, sunshine duration of 2049 hours and an annual amount of precipitation of 514 mm. The town is characterized by a densely built core, with openly spaced blocks of flats in the east-northern part and family houses and warehouses on the outskirts. The rural surroundings are mostly croplands (Skarbit et al. 2017).

In this areas numerous surface database are available from previous studies (building database, SVF, albedo, NDVI, etc.) in addition the Local Climate Zones (Stewart and Oke 2012) was also evaluated using different methodologies (WUDAPT method (Bechtel et al, 2016), GIS method (Lelovics et al, 2014).

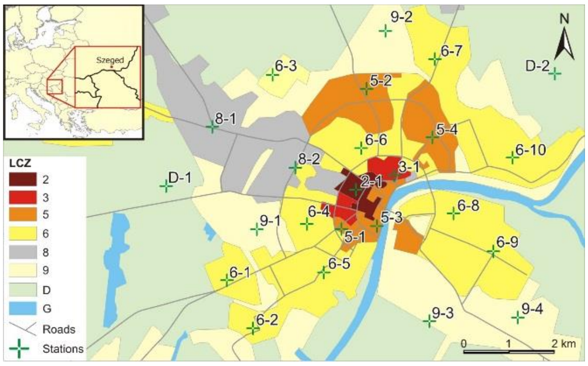

Figure 1. Location and LCZ map of Szeged as well as station locations of the measurement network

In 2014 the so called URBAN-PATH monitoring system was deployed. It contains 24- monitoring stations, it means ~1 station/2 km^2. The station locations are representative of their local climate zones. For details of the measurement network see Skarbit et al. 2017.

3. DATA AND METHODS

4-year air temperature data from June 2014 to May 2018 in 10-min averages were used based on 1-min measurements. To compare temperature modifying effects of different LCZs in Szeged LCZ averages were used. Consequently, in case of LCZ 2 and 3 it means only one station, however in LCZ 6 the average of ten stations was used according to the size of this LCZ class.

In this study, we have aimed to apply the existing LCZ land use database of Lelovics et al. (2014) into the model to test the ability of WRF system in predicting the spatiotemporal change of near-surface air temperature and energy budget components under a 6-day heatwave period characterized by low synoptic forcing.

In case of Weather Research and Forecasting (WRF) model (Skamarock et al, 2008) experiment we aimed to apply the Local Climate Zone system as the land use input data. The simulations were performed using the WRF model version 3.8.1. coupled with the SLUCM of Kusaka et al. (2001) and Kusaka and Kimura (2004). Three one-way nested domains with a grid spacing (and grid points) of 13.5 km (80×75), 4.5 km (121×94), and 1.5 km (105×78) were applied (Molnár et al 2018). Sigma vertical coordinates were prescribed from the surface to 20 hPa. 20 of 44 vertical levels were under 1.5 km in order to give a sufficient representation of the urban boundary layer. The simulation period started on 17 July 2017 (initialized at 12:00 UTC (14:00 LT)) and lasted until 24 July 2017 00:00 UTC (02:00 LT)

---

[*] *Corresponding author address*: Tamás Gál, University of Szeged, Department of Climatology and Landscape Ecology, Egyetem utca 2, 6722 Szeged, Hungary, e-mail: tgal@geo.u-szeged.hu

(Molnár et al 2018). The first 24 hour of the output was considered as spin-up, the rest 132 h was taken into account during the analysis. 3-hour NCEP GFS dataset with a horizontal resolution of 0.25° granted the initial and boundary conditions for the simulations (Molnár et al 2018).

In order to obtain more accurate results we evaluated the urban geometry related parameters of the LCZ classes (Table 1.) in Szeged using numerous GIS datasets (Lelovics et al, 2014).

Table 1. Values of urban geometry-related canopy parameters of LCZ classes applied in the simulations

	Compact midrise	Compact low-rise	Open midrise	Open low-rise	Large low-rise	Sparsely built
Urban fraction	0.90	0.82	0.58	0.66	0.75	0.25
Vegetation fraction	0.10	0.18	0.42	0.34	0.25	0.75
Building height [m]	13.6	7.9	15.4	5.4	6.6	5.0
Road and roof width [m]	5.1	4.3	5.3	3.2	5.5	2.9

WRF uses several thermodynamic-related urban canopy parameters. We evaluated these parameters using a simple sampling method (Molnár et al 2018). Firstly we defined small areas (around 200 m×200 m) in the city for each LCZ class, and secondly we measured the typical ratios of different surface covers and building materials, and finally we estimated the characteristic thermodynamic quantities using engineering reference tables (Wang and Kuo, 2001). The obtained values of these parameters are presented in Table 2.

Table 2. Parameters for land cover properties in WRF model

	Compact midrise	Compact low-rise	Open midrise	Open low-rise	Large low-rise	Sparsely built
Surface albedo of road, roof, walls	0.15	0.14	0.12	0.16	0.16	0.17
Thermal conductivity of road [$Jm^{-1}s^{-1}K^{-1}$]	0.7	0.7	0.7	0.7	0.7	0.7
Thermal conductivity of roof [$Jm^{-1}s^{-1}K^{-1}$]	1.04	1.01	1.2	1.01	1.24	1.01
Thermal conductivity of walls [$Jm^{-1}s^{-1}K^{-1}$]	1.02	1.01	1.1	1.02	1.2	1.01
Heat capacity of road [$Jm^{-3}K^{-1}$]	$1.95\cdot10^6$	$1.98\cdot10^6$	$1.95\cdot10^6$	$1.98\cdot10^6$	$1.94\cdot10^6$	$1.98\cdot10^6$
Heat capacity of roof [$Jm^{-3}K^{-1}$]	$1.97\cdot10^6$	$1.97\cdot10^6$	$1.97\cdot10^6$	$1.97\cdot10^6$	$1.97\cdot10^6$	$1.97\cdot10^6$
Heat capacity of walls [$Jm^{-3}K^{-1}$]	$1.63\cdot10^6$	$1.62\cdot10^6$	$1.72\cdot10^6$	$1.62\cdot10^6$	$1.86\cdot10^6$	$1.61\cdot10^6$
Emissivity of road	0.93	0.93	0.93	0.93	0.93	0.93
Emissivity of roof	0.91	0.92	0.87	0.92	0.86	0.92
Emissivity of walls	0.92	0.93	0.9	0.93	0.87	0.93

In this study we also applied the MUKLIMO_3 model. This non-hydrostatic micro-scale model was developed by the German Meteorological Service (DWD). It solves the Reynolds-averaged Navier–Stokes equations to simulate atmospheric flow fields in presence of buildings (Sievers and Zdunkowski, 1985; Sievers, 1990; Sievers, 1995). The model was prove the possibility of proper urban climate modelling in several occasions (Früh et al, 2011, Buchholz and Kossmann, 2015, Žuvela-Aloise et al, 2016, 2018, Geletič et al, 2016). The model does not include cloud processes, precipitation or anthropogenic heat but it can simulate the daily cycle of temperature, humidity and wind characteristics. The simulations in this study were carried out on a horizontal resolution of 100 m and vertical resolution varying between 10 and 50 m until about 1000 m vertical height (Bokva et al 2018). The boundary conditions are given by a time-varying 1D version of the MUKLIMO_3 model that simulates daily cycle main weather properties at the reference station representative for atmospheric conditions outside of the city. The initial meteorological data were taken from ALARO model and measurements from the reference stations (Bokva et al 2018).

The proper definition of land use parameters are also crucial in this model. For the simulations we applied the following values for the parameters of the model (Table 3.). These values was obtained by GIS calculations in the modelled cities (Bokva et al 2018).

Table 3. Parameters for land cover properties in MUKLIMO_3 model

	Compact midrise	Compact low-rise	Open midrise	Open low-rise	Large low-rise	Sparsely built	Low plants
fraction of built area (γ_b)	0.45	0.45	0.3	0.3	0.4	0.15	0
mean building height (h_b)	16.5	9.2	18.6	6.5	6.8	8.5	0
wall area index (w_b)	3.42	2.4	4.4	2.1	2	2.1	0
fract. of pavement of non-built area (v)	0.7	0.4	0.45	0.4	0.8	0.45	0
fraction of tree cover (σ_t)	0	0	0	0	0	0	0
fract. of low vegetation of remaining surf. (σ_c)	0.9	0.8	0.8	0.7	0.8	0.8	1
tree height (h_t)	0	0	0	0	0	0	0.2
height of the low vegetation (h_c)	0.1	0.1	0.1	0.1	0.1	0.1	0.5

4. RESULTS

The time series of the observed and simulated temperature in different LCZs during the 6 day analysis period (Fig. 2.) illustrates well the performance of the applied WRF model setup. The daily cycle of temperature estimated reasonably well. At daytime the simulated values are slightly higher. At night time the difference between the WRF outputs and the observations are minimal in case of LCZs 2, 5 and 6 and there are major overestimations in case of LCZs 9 and D. Based on these results the most problematic phenomena is the early nocturnal cooling process, thus in rural areas the model cannot follow the intense cooling process, and it cause major underestimation of the urban heat island.

In order to evaluate the performance of the model in case of spatial distribution of the heat island we have plotted the urban heat island intensity (ΔT) for two distinct times (00:00 and 14:00 UTC) (Fig. 2.). These values are 5 day average values. During the calculation of the ΔT the nearest grid to the D-1 monitoring site regarded as a rural basis, in all of the other grid points the value is the difference of the temperature of the given place and the temperature of D-1 grid point.

At night time the urban heat island pattern is clearly visible in case of WRF outputs, however the centre of the UHI was shifted to East (Fig. 3.). The maximum temperature difference are close to the observations and it is about 3°C. At daytime there are no significant temperature difference, thus the model could simulate properly the daily processes.

WRF partly fails to estimate properly the absolute values of the temperature, particularly in the early night time, however it has a clear advantage, namely the system could be applied for operational UHI forecast after some optimization and corrections in the land use datasets.

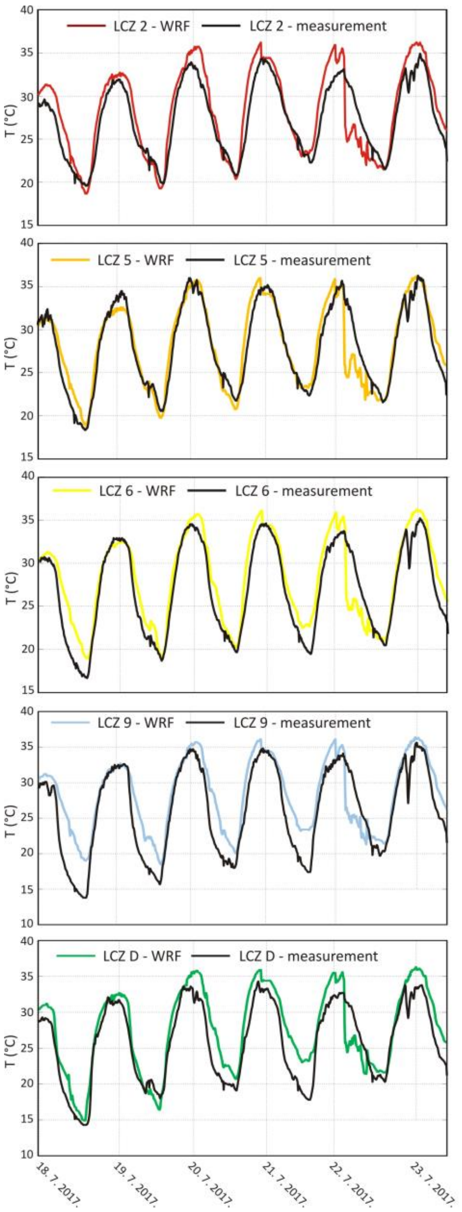

Figure 2. Comparison of observations and WRF prediction of air temperature in a heat wave period (18-23th July 2017) in different LCZs

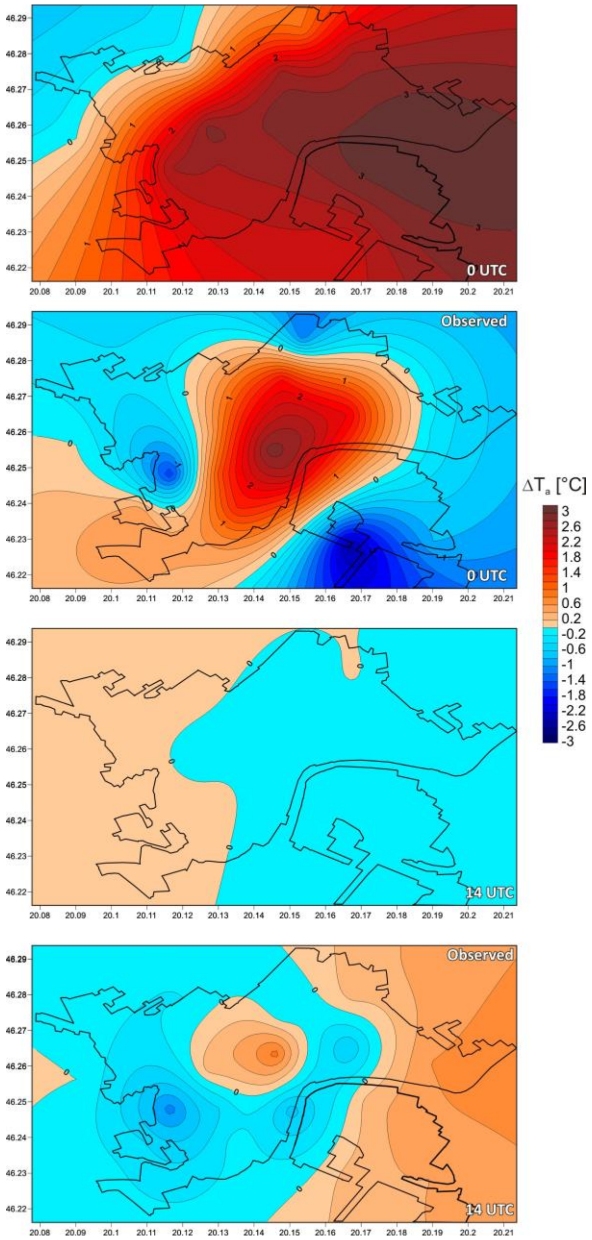

Figure 3. Mean observed and modelled UHI intensity for 18-23th July 2017 at 0 UTC and 14 UTC (2 and 16h in local time)

In case of MUKLIMO we found slightly similar daily temperature circles and differences between observations (Fig. 4.). The night time overestimation of the model is not as obvious as in the case of WRF, in some weather conditions the MUKLIMO results are significantly better. In the other hand the model overestimates the temperature at early daytime (when usually the urban cool island appears).

The estimation of the spatial distribution of the night time UHI is really detailed and accurate (Fig. 5). The maximum value of ΔT estimated properly (it is about 4°C. At daytime the model predict high temperature for the centre of the city, a weak UHI is observable.

This model applies different concept than the WRF. Changing the concept from infinite urban canyon into a porous 3D urban surface is a significant step forward if we evaluate the results and consider the less detailed physical background of the model.

The result shows that the daily cycle of the temperature is captured correctly, the spatial distribution of the nocturnal UHI is correct. In case of daytime the model partly overestimates the temperature.

It is a clear advantage of this model that it can be used for the proper estimation of climate parameters (summer days, tropical nights) based on climate predictions.

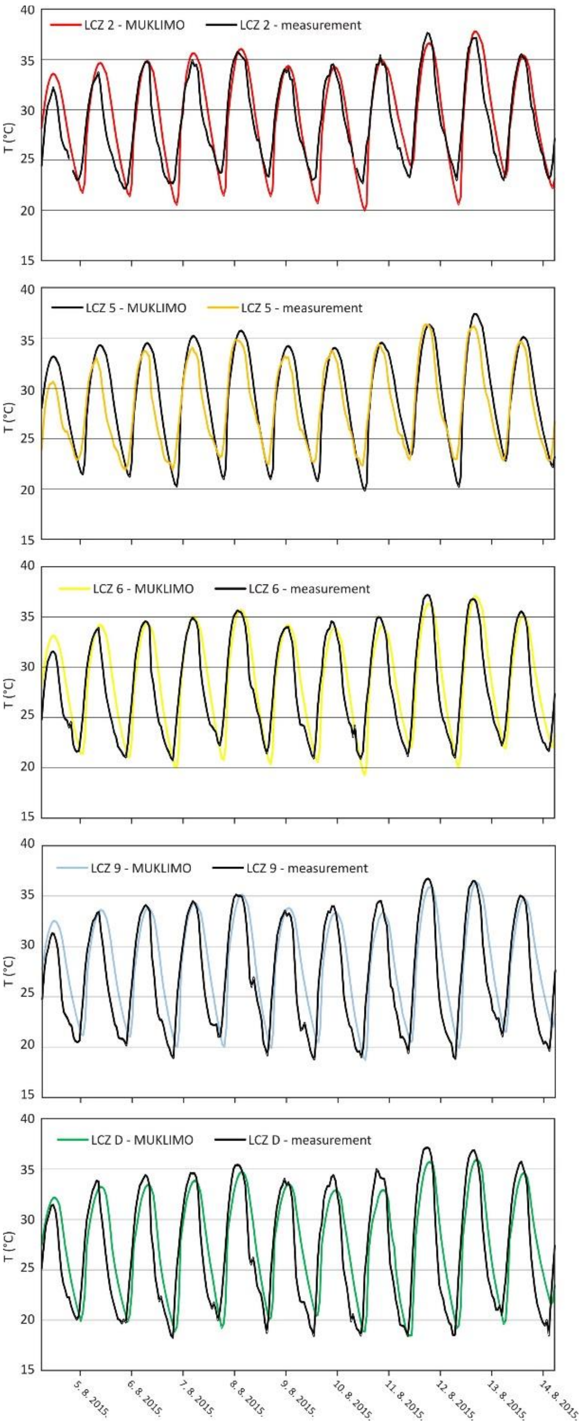

Figure 4. Comparison of observations and MUKLIMO prediction of air temperature in a heat wave period (5-14th August 2015) in different LCZs

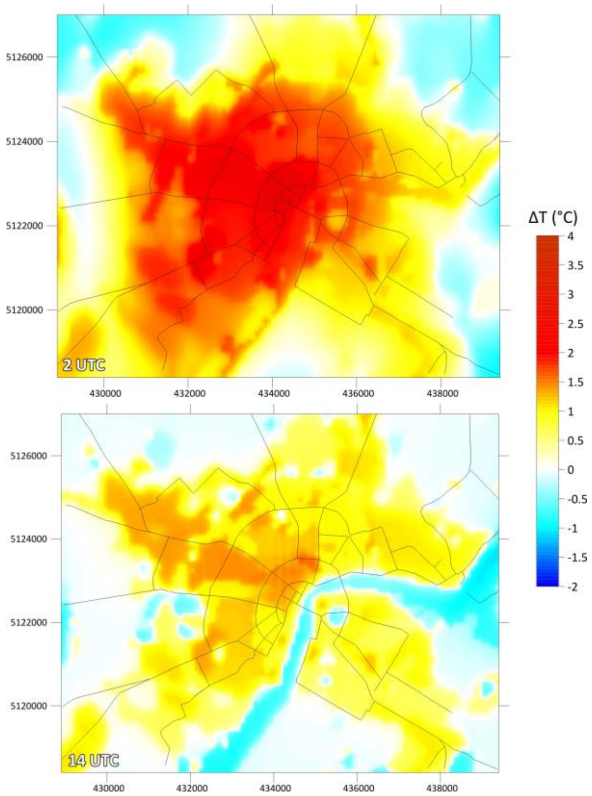

Figure 5. Mean UHI intensity for the modelled period (5-14th August 2015) at 2 UTC and 14 UTC (4 and 16h in local time)

5. CONCLUSION

The results show that both of the applied model is capable to estimate UHI. Our previous results prove the importance of time period near sunset in the role of nocturnal cooling process and the development of UHI. This cooling process could be described properly using the Sky View Factor (Unger et al, 2004, Unger, 2009), unfortunately it is not implemented as an input parameter in models. The use of SVF and a new physical parametrization would be an important step forward in the field of UHI modelling.

ACKNOWLEDGMENT

This work has been supported by OTKA K-111768 and NKFI 120346. The first author was supported by the ÚNKP-17-4 New National Excellence Program of the Ministry of Human Capacities.

REFERENCES

Bechtel, B., See, L., Mills, G., Foley, M. 2016. Classification of Local Climate Zones Using SAR and Multispectral Data in an Arid Environment. IEEE J. Sel. Top. Appl., 9, 3097–3105

Bokwa, A., Geletič, J., Lehnert, M., Žuvela-Aloise, M., Hollósi, B., Gál, T., Skarbit, N., Dobrovolný, P., Hajto, M.J., Kielar, R., Walawender, J.P., Šťastný, P., Holec, J., Ostapowicz, K., Burianová, J., Garaj, M., 2018: Heat load assessment in Central European cities using an urban climate model and observational monitoring data. Energy. Buildings, submitted

Buchholz S., Kossmann, M., 2015: Research Note. Visualisation of summer heat intensity for different settlement types and varying surface fraction partitioning. Landscape Urban Plan., 144, 59-64

Früh, B., Becker, P., Deutschländer, T., Hessel, J.D., Kossmann, M., Mieskes, I., Namyslo, J., Roos, M., Sievers, U., Steigerwald, T., Turau, H., Wienert, U., 2011: Estimation of ClimateChange Impacts on the Urban Heat Load Using an Urban Climate Model and Regional Climate Projections. J. Appl. Meteorol. Clim., 50, 167–184

Geletič, J., Lehnert, M., Dobrovolný, P., 2016: Modelled spatio-temporal variability of air temperature in an urban climate and its validation: a case study of Brno, Czech Republic. Hungarian Geographical Bulletin, 66, 169–180

Kottek. M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006: World Map of the Köppen-Geiger climate classification updated. Meteorol. Z., 15, 259–263

Kusaka, H., Kondo, H., Kikegawa, Y., Kimura, F., 2001: A simple single-layer urban canopy model for atmospheric models: Comparison with multi-layer and slab models, Bound.-Lay. Meteorol., 101, 329–358

Kusaka, H., Kimura, F., 2004: Coupling a Single-Layer Urban Canopy Model with a Simple Atmospheric Model: Impact on Urban Heat Island Simulation for an Idealized Case. J. Meteorol. Soc. Jpn., 82(1), 67–80

Lelovics, E., Unger, J., Gál, T., Gál, C.V., 2014: Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling. Clim. Res., 60, 51-62

Molnár, G., Gyöngyösi, A.Z., Gál, T., 2018: Integration of an LCZ-based classification into WRF to assess the intra-urban temperature pattern under a heatwave period in Szeged, Hungary. Theor. Appl. Climatol., submitted

Sievers, U., Zdunkowski, W., 1985: A numerical simulation scheme for the albedo of city street canyons. Bound.-Lay. Meteorol., 33, 245–257

Sievers, U., 1990: Dreidimensionale Simulationen in Stadtgebieten. Umwelt-meteorologie, Schriftenreihe Band 15: Sitzung des Hauptausschusses II am 7. und 8. Juni in Lahnstein. Kommission Reinhaltung der Luft im VDI und DIN, Düsseldorf. S. 92–105

Sievers, U., 1995: Verallgemeinerung der Stromfunktionsmethode auf drei Dimensionen. Meteorol. Z., 4, 3–15

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., Huang, X.Y., Wang, W., Powers, J.G., 2008: A Description of the Advanced Research WRF Version 3. NCAR Tech. Note NCAR/TN-475+STR

Skarbit, N., Stewart, I. D., Unger, J., Gál, T., 2017: Employing an urban meteorological network to monitor air temperature conditions in the ‘local climate zones’ of Szeged (Hungary). Int. J. Climatol., 37(S1), 582–596

Stewart, I.D., Oke, T.R., 2012. Local Climate Zones for urban temperature studies. B. Am. Meteorol. Soc., 93, 1879–1900

Unger, J., Bottyán, Z., Sümeghy, Z., Gulyás, Á., 2004: Connection between urban heat island and surface parameters: measurements and modeling. Időjárás, 108, 173–194

Unger, J., 2009: Connection between urban heat island and sky view factor approximated by a software tool on a 3D urban database. Int. J. Environ. Pollut., 36, 59–80

Wang, S.K., Kuo, S., 2001: Handbook of Air Conditioning and Refrigeration. 2nd Ed. 1401

Žuvela-Aloise, M., Koch, R., Buchholz, S., Früh, B., 2016: Modelling the potential of green and blue infrastructure to reduce urban heat load in the city of Vienna. Climatic Change, 135, 425–438

Žuvela-Aloise, M., Andre, K., Schwaiger, H., Bird, D.N., Gallaun, H., 2018: Theor. Appl. Climatol., 131, 1005–1018