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THE CALCULATION OF THE PARAMETERS DESCRIBING THE COMPLEX URBAN GEOMETRY AND APLICATION FOR URBAN CLIMATE INVESTIGATION

Theses of (Ph.D.) dissertation

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Introduction, objectives

Studying the altered urban environment is very important because of the high number of the involved inhabitants. The surface cover and the surface geometry differ from the rural surfaces, and the water and energy balances are modified. Urban climate research focuses on these modified local climates. This is a priority topic since the prediction of the possible impacts of global climate change for urban areas is impossible without an in-depth knowledge of the features of urban climate. The two most important modifications of the climate in these areas are the alteration of the thermal environment and the different airflow conditions.

Due to a difference between the rate of the cooling and warming processes in the urban areas and in the surroundings the phenomenon of the *urban heat island* – UHI occurs. The UHI intensity has a marked diurnal variation, and within the urban areas the spatial distribution is heterogeneous. The strongest development of the UHI occurs at night and most of the investigations in the field of urban climate concern this highest intensity. The heat excess of the cities determines human comfort conditions therefore the results of the studies in this topic could aid the urban planning processes.

The main reason for the development of the night-time UHI is the difference in the properties of long-wave radiation. In cities narrow streets and high buildings create deep canyons. This 3D geometrical configuration plays an important role in regulating long-wave radiation heat loss. Due to the fact that only a smaller part of the sky is seen from the surface (because of the horizontal and vertical unevenness of the surface elements), the nocturnal long-wave radiation loss is more restricted here than in rural areas.

Therefore urban geometry is an important factor contributing to intra-urban temperature variations below roof level. The *sky view factor* (*SVF*) is often used to describe urban geometry; however the earlier investigations have sometimes led to inconsistent results.

If the weather conditions are optimal the city generates a mesoscale air flow, the so-called country breeze. For the development of the country breeze the regional winds need to be very weak, so anticyclonal weather conditions are ideal for this flow system. The horizontal temperature (and therefore the pressure) gradient can be sufficient to induce low-level breezes across the urban–rural boundary, which converge in the center from all directions. There is uplift in the center of the city and also a counter-flow in the higher air layer. This is the so-called *urban heat island circulation* (UHIC).

This mesoscale circulation could offer a potential for the improvement of urban air quality. The depth of the inflow in the UHIC system depends on the roughness of the surface. If the city has parts where the roughness is lower than in the other areas and these are interconnected the country breeze can reach the inner parts of the city and it can reduce the accumulated pollution. These are the so-called *ventilation paths*.

There are several types of software for quantifying urban surface geometry (*SVF*, surface roughness), however the development of new methods is always needed. One possible way of exploring urban geometry is the modeling of the surface features using a 3D GIS database. This technique provides the opportunity for the automatic evaluation of the surface parameters without time-consuming field measurements and human-induced errors.

The aims of my study:

1. Develop a method for *SVF* calculation, based on a 3D building database.

2. Compute the *SVF* in the study area in Szeged using my method, after the validation and the comparison with other similar methods.

3. Use the calculated *SVF* values to reveal the relationship between the UHI and the surface geometry applying a new approach.

4. Develop a new method for roughness mapping using morphometric equations and a 3D building database.

5. The existing morphometric equations are only suitable for the mapping of the roughness parameters after the generalization and adaptation for irregular building layout.

6. I plan to develop new parameters in order to describe the airflow-modifying effect of the urban surface and the permeability of the urban canopy layer (UCL).

7. I would like to develop a new method in roder to locate the potential ventilation paths using roughness and my new parameters. I would like to apply this method in my study area in Szeged.

Methods, study area

Study area and the applied data

The study area covers the most urbanized parts of Szeged. This medium-sized city offers ideal conditions for urban climate investigations because it is situated on a plain and there is no large water body nearby. Thus the results of the investigations in this site are suitable for general statements.

For my study I have used the UHI database of Szeged collected within the urban climate research project of the Department of Climatology and Landscape Ecology. This database was collected by mobile measurements along measurement routes during a one-year period (April 2002 – March 2003). After the time correction the UHI values were averaged in all of the grid cells (107). In my investigation I used only the 103 urban grid cells. Moreover I have used the one-hour resolution UHI data referring to the hours after sunset, collected in a representative transect of the study area.

Methods

The 3D building database was prepared using GIS methods. The measurement of the building heights was carried out with photogrammetric methods using the Stereo Analyst module of the ERDAS Imagine. This measurement was based on the local municipality database containing the building footprints and some aerial photographs. Data recording, processing and the final formation of a database were carried out with ArcView GIS software.

My new software methods were implemented using the Avenue script language of the ArcView system. Thus all steps of the investigation were carried out in one GIS system from the creation of the database to the analysis of the results of the calculations. I have used ArcView for the roughness calculation, the calculation of the average values for the grid cells and all the additional calculations as well.

For the validation of my method for *SVF* calculation I have used the BMSky-View software. With this I have calculated the SVF_B values from fish-eye-lens photographs.

I have compared my calculation method with a widely used raster-based algorithm. For this I had to transform the 3D building database to a digital elevation model, which contains the elevation of the natural surface and the buildings. With this Matlab algorithm I have evaluated the SVF in a 2 m resolution grid.

To find the connection between the intra-urban air temperatures and the *SVF* I used a statistical method namely the linear regression analysis.

Summary of the results in theses

1. I have developed a new algorithm for the *SVF* calculation (*Gál et al.* 2005; *Unger et al.* 2006a). It was necessary because the earlier software methods weren't suitable for my research. This ArcView extension was developed using the 3D building database of Szeged (*Balázs et al.* 2005), but it is usable in any other measurement site, if the database contains all the necessary data.

2. I have validated my algorithm for *SVF* calculation. As a first step I have run the algorithm in an idealized building environment, in a basin and in an endless canyon (*Unger et al.* 2006a). For these cases the analytical equations of the *SVF* are known. The differences were negligible. As a second step I have compared *SVF* values calculated with my software with the *SVF* values calculated from fish-eye-lens photographs (*Gál et al.* 2007). The comparison of the photographs and the graphical output of the algorithm proved that the applied building database (without the building rooftops) gives acceptable results. The statistical comparison of the methods showed that there are some differences between the obtained values. These differences are caused mainly by the presence of vegetation around the measurement sites. Apart from the vegetation there is a close connection between the values therefore the vector-based method is appropriate for the *SVF* calculation in an urban environment.

3. I have calculated the spatial distribution of the *SVF* in the study area in Szeged. The calculation was carried out in two ways. Firstly along the temperature measurement routes (*Gál et al.* 2005; *Unger et al.* 2006b) and secondly in a 5 m resolution point network covering the study area (*Unger és Gál* 2007; *Gál et al.* 2008; *Gál et al.* 2009). I have examined the spatial distributions of the *SVF* in the different built-up types of the city. I used these calculated *SVF* values to study and evaluate the relationship between the urban geometry quantified by *SVF* and the intra-urban nocturnal temperature variations using areal means (in the case of the measurement route SVF_{vu} and in the case of the point network SVF_{vt}) in the whole urban area of Szeged.

4. I have made a comparison between my vector-based software and a raster-based algorithm (*Gál et al.* 2009). By using the vector-based method smaller *SVFv* values (e.g. at the points closer to walls than half the pixel resolution) can be included in the calculation of the cell average (SVF_{vt}). Although the raster-based method is significantly faster than the vector-based method, I recommend using my method because of the above-mentioned difference.

5. I have developed a method which is capable of roughness mapping in an entire city (*Gál and Sümeghy* 2007; *Gál et al.* 2008; *Gál and Unger* 2009). This mapping process uses a 3D building database and it is more detailed than the methods applied by most of the earlier investigations. The roughness length (z_0) and zero-plane displacement height (z_d) calculation for irregular building groups is based on the lot area polygons, which can be considered a new approach.

6. I have developed a new parameter for describing the effect of the surface for the airflow within the UCL (*Gál and Sümeghy* 2007; *Gál et al.* 2008; *Gál és Unger* 2008; *Gál and Unger* 2009). This parameter, the so-called porosity of the urban canopy layer quantifies the permeability of the UCL. There are two possible ways to compute this parameter. The first calculation ($P_{h\text{-}const}$) is based on constant UCL height and the second method of porosity computation ($P_{h\text{-}var}$) is based on UCL heights varying by spatial units.

7. I have developed a method for locating the potential ventilation paths. This mapping procedure is based on roughness length (z_0), zero-plane displacement height (z_d) and the porosity of the urban canopy layer ($P_{h\text{-}var}$). The method takes into account the drag effect of the surface for the airflow in the case of the urban heat island circulation.

8. I have validated the roughness calculation method. I have found minor differences between the roughness length (z_0) and the zero-plane displacement height (z_d) values calculated by my method and measured by other authors in cases where the built-up properties of the measurement sites are similar.

9. I have examined the connection between the *SVF* and the UHI intensity in the study area (*Unger et al.* 2006c; *Unger és Gál* 2007; *Gál et al.* 2009). In clarifying the *SVF*–UHI relationship the usefulness of the application of areal means is confirmed and newly proved that the degree of connection is highly improved using areal means of *SVF* to get a more general picture on the geometrical conditions of a wider urban environment. Thus using the SVF_{vt} is a more precise way to describe the effect of urban geometry on the development of the UHI than using the SVF_{vu}. According to the results of my approach, urban surface geometry (described by *SVF*) is a significant determining factor of the air temperature distribution inside the city.

10. I have examined the alteration of the connection between the *SVF* and the UHI intensity during the night. My results prove that the *SVF* plays the most important role in regulating long-wave radiation heat loss and the magnitude of the UHI intensity, but at later night-time hours the importance of the other factors is increasing.

11. I have applied the method for locating the potential ventilation paths in Szeged (*Gál és Unger* 2008; *Gál and Unger* 2009). The located ventilation paths are instrumental for enhancing the efficiency of the country breeze and decreasing the air pollution in the inner parts of the city, especially in a clear and calm weather situation. Based on the results I could give a list of the areas where the city government should keep the advantages of the ventilation paths regarding the human comfort aspects of the urban climate.

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10. ***Gál T**, Sümeghy Z,* 2007: Mapping the roughness parameters in a large urban area for urban climate applications. *Acta Climatologica et Chorologica Univ. Szegediensis 40-41,* 27-36

11. ***Gál T**, Unger J, Benkő D,* 2008: Roughness mapping process in an urban study area. *Klimat Bioklimat Miast*, *Wydawnictwo Uniwersytetu Łódzkiego,* 501-512

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