A new software tool for SVF calculations using building and tree-crown databases and its possible applications in urban climate studies

Gál T, Unger J
tgal@geo.u-szeged.hu
Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary,
+36 62 343172

Abstract

This paper presents some results related to the development an automatic evaluation method locating the tree-crowns and building roofs, as well as an other method for Sky View Factor (SVF) calculation using tree-crown and building database.

For the software based calculation of the SVF a detailed building and vegetation database is needed. For most of the urban areas some kind of urban building database is available however there is a lack of the detailed information related to the tree-crown data in general. The vegetation and especially the tree-crowns are crucial parts of the urban 3D geometrical configuration and they likely play a major role in regulating long-wave radiation heat loss, therefore a new method for the evaluation of this kind of information could be very useful in urban climate investigations.

The automatic tree-crown and building database generation uses digital photogrammetric methods for tree height measurement and spectral information from aerial photographs. Using the generated tree-crown and building databases we can calculate the SVF pattern of any given urban area from the obtained databases (and from any comparable database). Additionally, this calculation is fast enough and it can be as precise as any vector based calculation method.

Keywords: urban geometry, Sky View Factor, buildings and trees, urban climate, Szeged, Hungary

1. Introduction

It has long been known that the urban areas have climate modification effects from meso (or local) to micro scales depending of the size of the built-up area. The two most important modifications are related to the thermal environment and the airflow conditions, and both of them are primarily connected with the changed geometrical and physical characteristics of the urban surface compared to the original one [1,2].

The thermal modification is often manifested in higher urban temperature (urban heat island − UHI). The largest UHI that is the strongest urban-rural temperature contrast generally appears at night, while in the daytime the difference is moderate or vanish. The main reason of the UHI is the urban-rural difference in the nocturnal cooling processes which are primarily forced by outgoing long wave radiation. In urban areas the 3D geometrical configuration of the surface plays an important role in the restriction of long-wave radiative heat loss, and, as a result, it contributes to intra-urban temperature variations below roof level [e.g. 3,4]. The most appropriate parameter describing the urban geometry is the sky view factor (SVF) [3,5,6]. By definition, SVF is the ratio of the radiation received (or emitted) by a planar surface to the radiation emitted (or received) by the entire hemispheric environment [7]. It is a dimensionless measure between zero and one, representing totally obstructed and free spaces, respectively [8]

There are several solutions for the determination of SVF values in urban environment (see Unger [9] and Chen et al. [10] for brief reviews). One type of them is the computer algorithm which needs a 3D surface database of the study area [e.g. 11,12,+1]. These methods can be grouped on the basis of the used input data (raster or vector). Most of them utilize high resolution raster DSMs (digital surface models containing the terrain and the buildings) for computing patterns of continuous sky view factors. Their advantage is that the roof of buildings can be more easily managed; however, the selection of the resolution of the input data affects significantly the accuracy of the results [12]. Most of the building databases for cities are in vector format, thus for these raster-based methods a vector-raster conversion is needed as a preprocessing. During this conversion data loss can be occurred so the rasterization of the buildings could alter the results of the SVF calculation [13].

There are some examples for vector-based methods as well. Souza et al. [11] developed an algorithm using an Avenue script language of the ESRI ArcView GIS. This script calculates the SVF values more accurately because the buildings are in vector format, thus the locations of the building walls are unequivocal and do not depend on the resolution.

Most of the software based methods do not deal with the vegetation because of the lack of detailed data on it, especially on trees which have 3D extension. However the tree-crowns are important part of the urban 3D geometrical configuration and likely play a major role in regulating long-wave radiation heat loss. Recently there are some development aiming to fill this gap. One example is the SOLWEIG method [14] current version of,15] which applies raster based digital surface model as the representation of the terrain and buildings, and two raster based digital surface models for the tree canopy and trunk zones. The other example is the SkyHelios software [16,17], however it needs very detailed vegetation database which can be obtained via time consuming field measurements.

In our department a new vector based algorithm has been developed for SVF calculation. This is an Avenue script using building database of Szeged (Hungary) in ESRI shapefile format [13] but it can be applied in any other settlement if a similar database is available. The precision of this algorithm has been inspected and it has been compared to other calculation methods with satisfactory results [13,17,18].

The objective of this study is to develop such methods which operate without using any GIS software and the interaction of the user: (i) The one is an automatic evaluation method calculating the shape and elevation of the tree-crowns and building roofs. (ii) The other is a method for SVF calculation using the databases obtained in the previous procedure. This new method is developed in a study area in Szeged (Hungary), however it can be applied in any other study areas if similar data are available. A further objective is to imply the possible applications of the developed methods.

2. Study area

Szeged (46°N, 20°E) is located in the southern part of Hungary in the Great Hungarian Plain at 79 m above sea level (Figure 1). According to Köppen's classification the region of the city belongs to the climatic type Cfb (warm temperate climate with annually uniform precipitation distribution and with warm summer), similarly to the largest part of the country [19]. Its urbanized area is about 40 km^2. In the city core there are mostly four-story buildings that lead to relatively narrow street canyons and several squares and parks offer open spaces. In the other parts of the city there are 1-2-story buildings, and there are several districts where the 5-10-story buildings are dominant with large open spaces. The amount of the vegetation is relatively large, and there are trees in most of the streets, even in the city core. In this investigation we concentrate on a smaller area as an example in order to present the two newly developed methods. This study area (500 x 1000 m) is located in the city core (Figure 1) with an extension of 0.5 km^2. Around it there is a 50 m wide buffer belt where the data on tree crowns are available. This belt is necessary as if there is no information about the trees at the edge of the study area it can alter the obtained results. Within this larger area there are two urban parks and several streets with significant tree cover.

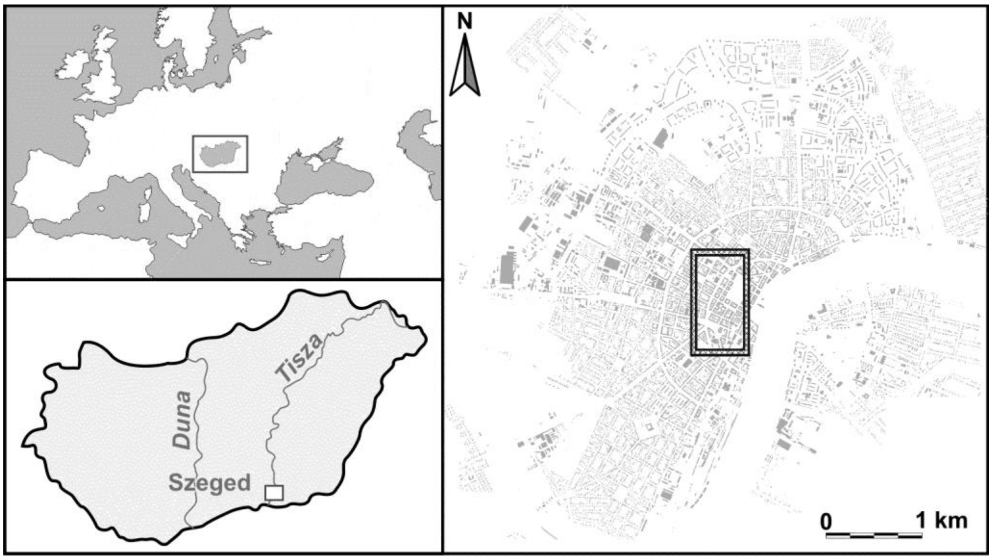

Figure 1 Location of the study area with its buffer belt in Szeged, in Hungary and in Europe.

3. Building and Tree crown databases

Detailed building and tree-crown databases were used as inputs for the SVF calculations in the study area. These databases were calculated with a tree-crown mapping tool (TCM) [20,21]. This standalone automatic software tool was developed in C++ language and it is compatible with Windows and Linux environments. For the mapping of the tree crowns it uses NDVI and elevation information stored in comma-separated text files and the outputs of the software are in two ESRI shapefiles containing the building and tree crown databases [21]. The source of the elevation data can be different: in our case 3D point cloud calculated with photogrammetric method was used however LIDAR measurements are also suitable for this purpose. For the evaluation of the 3D point cloud and calculation of NDVI we used 4-band digital aerial photographs made by the Hungarian Institute of Geodesy, Cartography and Remote Sensing in 2007. The resolution of the photographs is approximately 0.5 m and they have 4 spectral bands (3 visible and 1 near infrared). Due to their spectral and spatial resolution these bands are suitable for calculating high resolution spectral indices (e.g. NDVI), and for height measurements applying photogrammetric methods at the same time. This kind of aerial photographs are commonly used for cartographical issues, thus they can be accessed easily in most of the countries [22].

The obtained building and tree-crown databases contain polygons (bordered by not only straight but curved lines too) representing the parts of the roofs or trees where the elevation values are approximately the same (Figure 2).

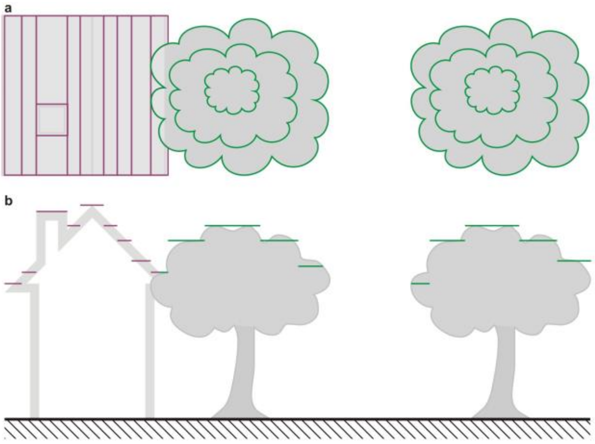

Figure 2 Concept of the building and tree-crown databases (a: footprint, b: side view).

In the study area most of the trees and roofs are localized in a previous study [21]. In the final tree-crown database (Figure 3) there are few places where trees are not identified. In that places the trees have very transparent crowns and under them there are asphalt and tile cover thus the obtained NDVI values are lower than in the case of most of the other trees. The building database contains several polygons within each building footprint, and each polygon represents the nearly equal elevation parts of each roof (Figure 3). Some places – mostly in the very special and complex roofs such as temples – there is minor errors in the derived building database (e.g. in the N-E and S-E part of the study area), but this error is rare. However, it should be noted that in addition to the mentioned small errors of the tree-crown and building database the calculation time is negligible comparing to the manual measurements, and if we intend to represent the vegetated urban surface in a local scale model, the precision of this database is more than appropriate.

Figure 3 Building and tree-crown databases in the study area (with the 50 m wide buffer belt).

4. New vector based method (SVF Mapping Tool) for SVF calculations

4.1. The concept of SVF calculation

The calculation of the SVF is based on a modified form of the equation in Unger [19] and Gál et al. [13], which is originally designed for the calculation using only building data. In order to take into consideration the tree crowns the original equation is modified. The new equation takes into account the effect of different types of objects for the SVF. These objects are: building (B) with the highest elevation angle (β) in a given direction from a given point, tree (T_1) with the highest elevation angle ($\beta + \gamma$) in the same direction and tree (T_2) with the highest zenith angle (δ) of the tree or trees which overlaps the given point where the SVF calculation has taken place (Figure 4).

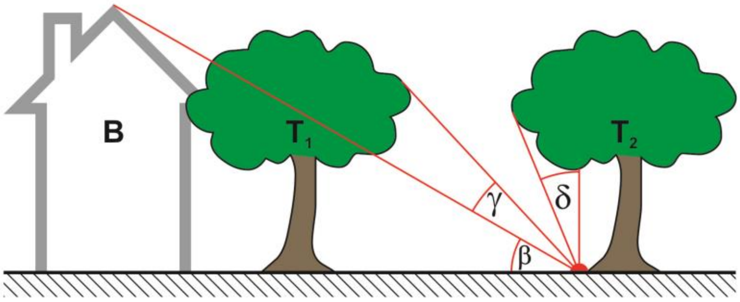

Figure 4 Elevation angles for the different objects in a given direction.

The value of the SVF for a given point is equal to one minus the sum of the view factors (VF) of different objects (B, T_1, T_2) for all of the directions (ω):

$$\mathrm{SVF} = 1 - \left(\int_0^{2\pi} \mathrm{VF}_B \, d\omega + \int_0^{2\pi} \tau \cdot \mathrm{VF}_{T_1} \, d\omega + \int_0^{2\pi} \tau \cdot \mathrm{VF}_{T_2} \, d\omega \right) \tag{1}$$

where τ is the transparency of the tree crowns. This transparency is considered to be constant and it describes the average transparency of the different tree species in the study area.

The calculations of the three different view factors were based on the equation for the calculation of SVF in a regular circle basin given by Oke [2]. For a regular basin, where β is the elevation angle from the centre to the wall, the SVF value is (referring to the basin centre): $\mathrm{SVF}_{basin} = \cos^2\beta$. So the view factor of a basin with the same elevation angle β is $\mathrm{VF}_{basin} = 1 - \cos^2\beta = \sin^2\beta$. Therefore, if we have a regular circular building around the point of interest the view factor of this building is $\mathrm{VF}_B = \sin^2\beta$. Similarly, for the first type of the trees (T_1) the view factor can be calculated using the angle γ with the following equation: $\mathrm{VF}_{T1} = \sin^2(\beta + \gamma) - \sin^2\beta$ (Figure 4). For the second type of trees (T_2) δ is used for calculation: $\mathrm{VF}_{T1} = \sin^2 90° - \sin^2(90° - \delta) = 1 - \sin^2(90° - \delta)$.

In real situations the angular height of the objects are not equal in all direction, therefore the projection of the objects on the hemisphere are not a circle. In this case the 3 angular heights vary as a function of the direction (ω), so the equation 1 is modified:

$$\mathrm{SVF} = 1 - \left(\int_0^{2\pi} \sin^2\beta \, d\omega + \int_0^{2\pi} \tau \cdot \left(\sin^2(\beta + \gamma) - \sin^2\gamma\right) d\omega + \int_0^{2\pi} \tau \cdot \left(1 - \sin^2(90° - \delta)\right) d\omega \right) \tag{2}$$

To develop a computer algorithm the utilization of equation 2 is not appropriate therefore the SVF value of this equation is estimated by using discrete sections of the hemisphere. The width of these sections is defined by the rotation angle α (Figure 5). This angle α determines the resolution of the calculation. If the value α decreases the resolution and precision of the method increase thus the hemisphere will be divided for more and smaller parts, and these smaller parts describe more precisely the real layout of the objects around the point of interest.

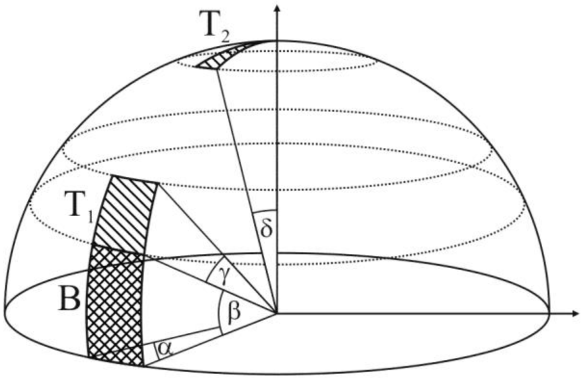

Figure 5 Polygons on the hemisphere corresponding to a building (B) and to the 2 types of tree-crowns (T_1 and T_2).

Using the α angle the equation 2 can be approximated with equation 3, where n is the number of division of the circle (n = 360°/α). For the calculation only the elevation angles (β, γ, δ) (Figures 4, 5) have to be determined for all of the direction using the building and tree-crown database.

$$\mathrm{SVF} = 1 - \left(\sum_{i=1}^{n} \frac{\alpha}{2\pi} \cdot \sin^2 \beta_i + \sum_{i=1}^{n} \tau \cdot \frac{\alpha}{2\pi} \cdot \left(\sin^2 (\beta_i + \gamma_i) - \sin^2 \beta_i \right) + \sum_{i=1}^{n} \tau \cdot \frac{\alpha}{2\pi} \cdot \left(1 - \sin^2 (90^\circ - \delta_i) \right) \right) \qquad (3)$$

4.2. SVF mapping tool – a software for SVF calculation

For the SVF calculation a software tool was developed with the help of the above mentioned method. This new standalone software tool was developed in Java language thus it is compatible with Windows and Linux platforms too, and it does not need any GIS software to operate.

For the calculation detailed building, tree-crown and point databases are necessary. The building and tree-crown data are stored in two polygon type ESRI shapefiles. These polygon shape files contain the building and tree-crown footprints and the elevations of the building-tops or tree-crowns (in m, ASL). These footprints are not identical to the footprint of a single building or tree as these are only parts of a tree or building. Within these parts the elevation of a building or tree is constant (Figure 2). The point database contains the SVF calculation sites and it is in point type ESRI shapefile. This point shape contains the locations of the points where the SVF calculation will take place (x, y coordinates and the elevation). The tree-crowns are only optional input, therefore the calculation is possible only with two inputs (building and point databases) if there are only buildings in a study area or only the building data are available.

The software reads the geometry and attribute information from the input shapefiles and for each SVF calculation points it scans around the point the elements of the building and tree-crown databases with a projection line within a given (user defined) distance. The direction of first scanning line is North and the next one will be rotated clockwise by the (user defined) angle α. The software calculates the highest elevation angles β and γ and the largest zenith angles δ for all of the scanning lines, and it calculates the view factors for the different objects (B, T_1, T_2). In the case of the trees the software applies a user defined constant transparency value (τ) for the calculations.

The accuracy of the algorithm depends on the magnitude of the rotation angle and the scanning distance. Smaller α angles result in more accurate estimation of SVF but require longer computation time. According to the earlier results of a similar method [9] a scanning distance of 200 m and a rotation angle of 1° are appropriate to get satisfying results in the SVF calculations.

The calculation time is significantly lower compared to the earlier developed script [9,13], as in this case the calculation of the SVF for one point takes approximately only 0.6 s in a common PC (core i3 processor and 4 GB memory).

4.3. The transparency of the tree crowns

We carried out field measurements in different parts of Szeged (mostly in urban parks or in streets with significant proportion of tree cover) in order to measure the SVF in several points. The aim of these measurements is to quantify the transparency (τ) of the tree crowns and the effect of the transparency on the SVF value.

For the measurement we used Canon D60 DSLR camera with Sigma 4.5 mm circular fisheye lens. The camera is mounted onto a 10 cm high custom-made tripod, which contains a levelling foot with built in circular level and it can be levelled with geodesic precision (Figure 6, left). In each point one fisheye photo was taken. The exact location of the point (x, y, z coordinates) was determined with a Sokkia Series650RX total station (Figure 6, right).

Figure 6 Equipments for the field measurement.

After the field measurements the SVF values were calculated from the fisheye photos using the BMSky-View software [23] in 383 points. For the estimation of the tree transparency and its effect on the SVF three different SVF values were needed. These values represent the SVF with transparent trees (SVF_{b-t}), with only the buildings (SVF_b), and with nontransparent trees (SVF_{b-nt}), respectively. In each point these three different SVFs was measured several times, in order to minimize the measurement error.

There is a connection between these different SVF values (equation 4). The empirical constant (P_{corr}) represents the effect of the transparency of the tree crowns for the SVF. Using this equation the P_{corr} can be calculated.

$$SVF_{b-nt} = SVF_b + (SVF_{b-t} - SVF_b) \cdot P_{corr} \tag{4}$$

In our case the value of the P_{corr} is calculated with iteration algorithm coded in Fortran language. This algorithm iterates the P_{corr} value and returns with its value when the root mean square error (RMSE) – calculated from the 383 different values by equation 5 – is minimal.

$$RMSE = \sqrt{\frac{1}{383} \cdot \sum_{i=1}^{383} \left(SVF_{b-nt_i} - \left(SVF_{b_i} + \left(SVF_{b-t_i} - SVF_{b_i}\right) \cdot P_{corr}\right)\right)^2} \tag{5}$$

The obtained P_{corr} value using 383 different points are 0.863591 (RMSE = 0.043016), therefore, further we apply this value as the transparency of the tree crowns (τ) in the SVF calculation.

5. Obtained SVF pattern and possible applications

For the SVF calculation a 5 m resolution point grid was laid on the study area containing 20 000 points. The elevations of the points were derived from a DEM covering the area. The points overlapped by buildings were deleted from the point network because the openness of the sky (SVF) in the rooftops has no significant effect on the radiation properties at street level (in the urban canopy layer). The number of the remaining points is 12 889. The total calculation time for all points was about 2 hours and the average calculation time for one point was 0.6 s in a common computer (Core i3 processor, 4 GB RAM).

Figure 7 presents the spatial distribution of the SVF with and without the effect of trees. Comparing the two parts it is obvious that the effect of the vegetation on the SVF is significant. The combined effect of the buildings and vegetation is observable in the obtained SVF pattern (Figure 7B). Different types of the street canyons can be distinguished: for instance, in the street canyons with same width the SVF values are significantly higher if there is no tree-cover (e.g. long street from W-NW to E-SE across the study area in Figure 7B). Furthermore, in the eastern part of the study area there is a large urban park, therefore lower SVF values can be found here (right hand part of Figure 7B), while it is not observable in Figure 7A.

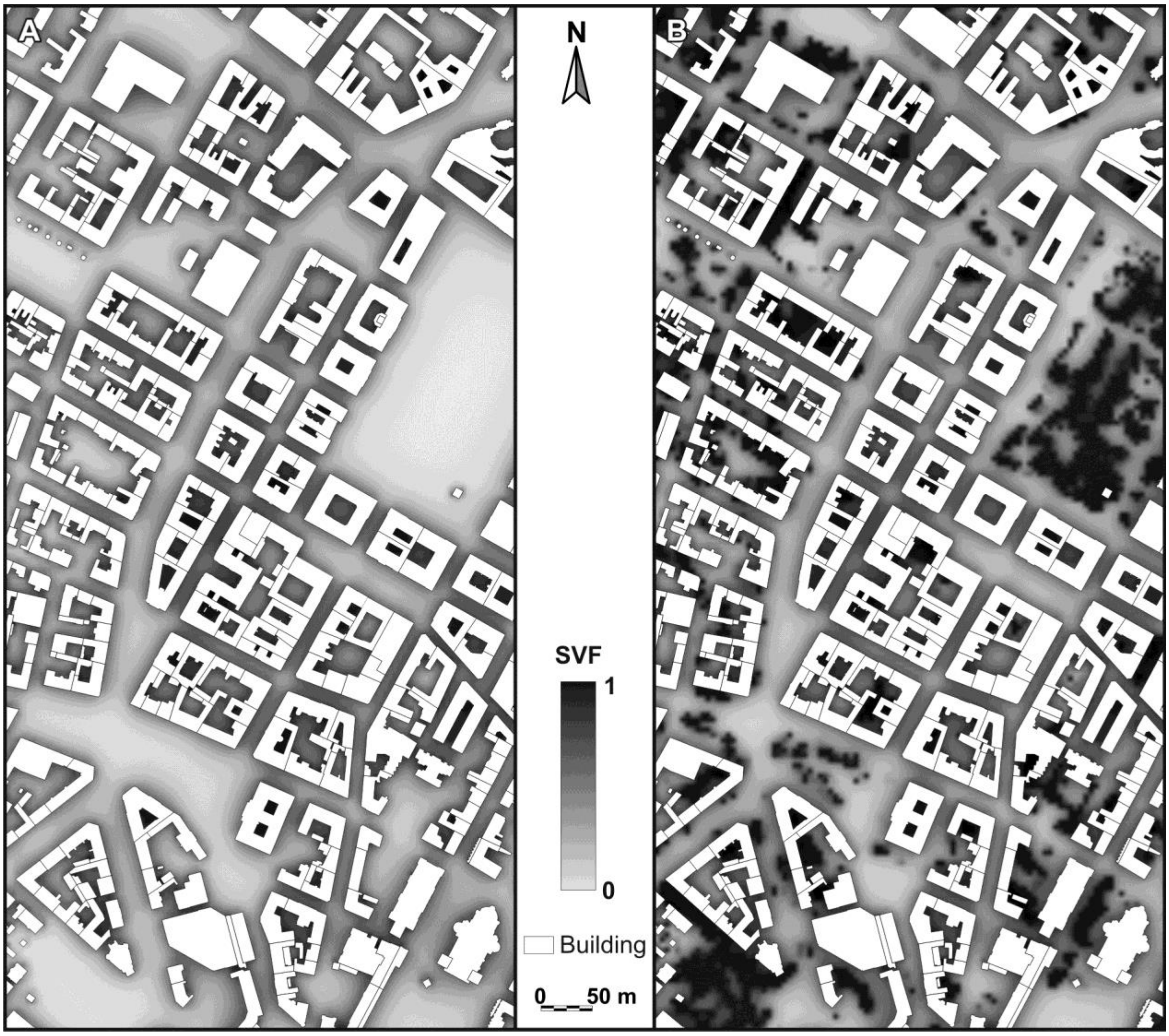

Figure 7 Spatial distribution of the calculated SVF without trees (A) and with trees (B).

To further reveal the effect of the trees on the openness in the study area histograms of the calculated SVF values were prepared. In case of the calculation without trees (Figure 8 A) there are very few low values (SVF < 0.4) and significant amount of values between 0.4 and 1. In case when tree crowns are also involved for the SVF calculations (Figure 8 B) the amount of the high values (SVF > 0.8) decreases. Remarkable that relatively high amount of values occurs between 0.05 and 0.15 which represents the SVF values of the points under tree crowns.

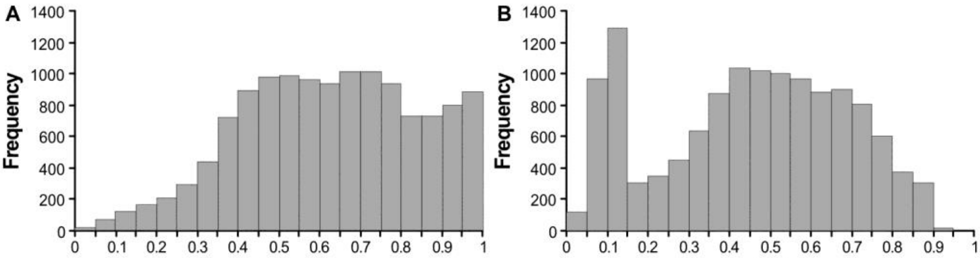

Figure 8 Histograms of the calculated SVF values without trees (A) and with trees (B).

Our results also draw the attention of the significant effect of the tree crowns on the SVF, and because the SVF play a major role in regulating long-wave radiation heat loss, so indirectly on the energy balance of the urban areas. This effect is crucial therefore if we include the urban effect into weather and climate models we should use the SVF patterns calculated using buildings and tree crowns too instead of e.g. the 1 dimensional canyon aspect ratio [24]. These methods and results could also used in studies related to local climate zones [25], because they can be a great help in case of more exact and unequivocal mapping of these zones within urban areas.

6. Conclusions

This paper presented some results related to the development an automatic evaluation method calculating the shape and elevation of the tree-crowns and building roofs, as well as an other method for SVF calculation taking into account the vegetation of the urban surface in addition to the buildings. That is, we can automatically generate tree-crown and building databases if the necessary input data are available. Moreover we can calculate the SVF pattern from the obtained databases (and from any database if that is similar to this input). Additionally, this calculation is fast enough and it can be as precise as any vector based calculation method. The final and verified versions of the software will be available for scientist who are interested in it (http://www2.sci.u-szeged.hu/eghajlattan/).

Acknowledgments

The research was supported by the Hungarian Scientific Research Fund (OTKA PD-100352) and by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. Special thanks are due to M. Kiss (assistant lecturer, Department of Climatology and Landscape Ecology, University of Szeged), Z. Csépe and E. Lelovics (PhD students, University of Szeged), G. Kunfalvi, P. Á. Fábián, J. Kabódi and Z. Laczó (MSc and BSc students, University of Szeged) for their help during the field measurements and data processing.

References

[1] H.E. Landsberg, The urban climate, Academic Press, New York 1981.
[2] T.R. Oke, Boundary layer climates, Routledge, London and New York 1987.
[3] T.R. Oke, Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations, Journal of Climatology 1 (1981) 237–254.
[4] I. Eliasson, Urban nocturnal temperatures, street geometry and land use, Atmospheric Environment 30 (1996) 379–392.
[5] H. Upmanis, D.L. Chen, Influence of geographical factors and meteorological variables on nocturnal urban-park temperature differences - a case study of summer 1995 in Göteborg, Sweden, Climate Research 13 (1999) 125–139.
[6] M. Svensson, Sky view factor analysis – implications for urban air temperature differences, Meteorological Applications 11 (2004) 201–211.
[7] I.D. Watson, G.T. Johnson, Graphical estimation of sky view-factors in urban environments, Journal of Climatology 7 (1987) 193–197.
[8] T.R. Oke, Street design and urban canopy layer climate. Energy and Buildings 11 (1988) 103–113.
[9] J. Unger, Connection between urban heat island and sky view factor approximated by a software tool on a 3D urban database, International Journal of Environment and Pollution 36 (2009) 59–80.
[10] L. Chen, E. Ng, X. An, C. Ren, M. Lee, U. Wang, Z. He, Sky view factor analysis of street canyons and its implications for daytime intra-urban air temperature differentials in high-rise, high-density urban areas of Hong Kong: a GIS-based simulation approach, International Journal of Climatology 32 (2012) 121–136.

[11] L.C.L. Souza, D.S. Rodrigues, J.F.G. Mendes, The 3DSkyView extension: an urban geometry acces tool in a geographical information system, In K. Klysik, T.R. Oke, K. Fortuniak, C.S.B. Grimmond, J. Wibig, Proceed. Fifth Int. Conf. on Urban Climate Vol. 2. University of Lodz, Lodz, Poland, (2003) 413–416.

[12] F. Lindberg, Modelling the urban climate using a local governmental geo-database, Meteorological Applications 14 (2007) 263–273.

[13] T. Gál, F. Lindberg, J. Unger, Computing continuous sky view factor using 3D urban raster and vector databases: comparison and an application for urban climate, Theoretical and Applied Climatology 95 (2009) 111–123.

[14] F. Lindberg, B. Holmer, S. Thorsson, SOLWEIG 1.0 – Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings, International Journal of Biometeorology 52 (2008) 697–713.

[15] F. Lindberg, C.S.B. Grimmond, Continuous sky view factor maps from high resolution urban digital elevation models, Climate Research 42 (2010) 177–183.

[16] A. Matzarakis, O. Matuschek, Sky View Factor as a parameter in applied climatology – Rapid estimation by the SkyHelios Model, Meteorologische Zeitschrift 20 (2010) 39–45.

[17] M. Hämmerle, T. Gál, J. Unger, A. Matzarakis, Comparison of models calculating the sky view factor used for urban climate investigations, Theoretical and Applied Climatology 105 (2011) 521–527.

[18] T. Gál, M. Rzepa, B. Gromek, J. Unger, Comparison between Sky View Factor values computed by two different methods in an urban environment, Acta Climatologica et Chorologica Univ. Szegediensis 40-41 (2007) 17–26.

[19] J. Unger, Comparisons of urban and rural bioclimatological conditions in the case of a Central-European city, International Journal of Biometeorology 43 (1999) 139–144.

[20] P.Á. Fábian, Derivation of tree-crown database using spectral and height information in an urban area (in Hungarian), MSc thesis, University of Szeged, Szeged, Hungary, 2012.

[21] T. Gál, J. Unger, M. Kiss, An automatic method to crate an urban vegetation database using 4 band aerial photographs for Sky View Factor calculation – A case study in Szeged, Hungary, Proceeding of two hundred years of urban meteorology in the heart of Florence: International conference on urban climate and history of Meteorology, (2013).

[22] T. Gál, J. Unger, Surface geometry mapping for SVF calculation in urban areas, Proceeding of 8th Conference on Urban Climate, Dublin, (2012) Paper 168.

[23] M. Rzepa, B. Gromek, Variability of sky view factor in the main street canyon in the center of Łódź, Preprints Sixth Int. Conf. on Urban Climate, Göteborg, Sweden, (2006) 854–857.

[24] V. Masson, A physically based scheme for the urban energy budget in atmospheric models, Boundary-Layer Meteorology, 94 (2000) 357–397.

[25] I.D. Stewart, T.R. Oke, Local Climate Zones for urban temperature studies, Bulletin of the American Meteorological Society 93 (2012) 1879–1900.

[+1] Ratti, C. F. & P. Richens. 1999. Urban texture analysis with image processing techniques. In Proc CAADFutures99. Atalanta, GA.