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Shading effect of Alley Trees and Their Impact on Indoor Comfort

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1. Introduction

The negative effects of climate change on human thermal comfort occur heavily in the anthropogenically modified urban environment. Besides the characteristics of outdoor human thermal comfort the indoor circumstances are also changing in this respect because of the above-mentioned effects. Due to the increased cooling demand of buildings, the phenomena of urban climate have considerable energetic effects as well. The effects of UHI are especially unpleasant in summer, when the heat becomes unbearable for city dwellers. Lately many have decided to install air condition systems in order to create a better indoor comfort. This way of cooling down the indoor areas escalates the heating outdoors and also consumes plenty of energy and money. According to European Union Directive “Energy Performance of Buildings” by 2020 “nearly Zero Energy Building” should be implemented in the national regulation of all EU countries. The tendency of the last decades showed that energy-efficiency in architecture means a well-insulated and airtight building shell, however these features although provide a good indoor thermal comfort in the wintertime, also increase the risk of overheating during the summer. This leads to the more frequent use of air conditioning devices providing a self-generating process from the urban heat island point of view – what’s more it also increases the energy-consumption during the summer season. In order to achieve a high energy performance architects have to make efforts to improve natural ventilation, evaporative cooling and to achieve energy-efficiency. As seen the idea of nearly zero energy building can be put into practice only if the summer cooling demand of buildings can be mitigated at an urban scale.

One of the best solutions for climate sensitive urban design regarding indoor and outdoor thermal comfort and energy-conscious architecture is the application of different types of plants near buildings [1],[2]. The shading effect of tree canopies decrease the solar radiation input. This ameliorates human thermal comfort through the modification of the mean radiant temperature (TMRT), which is one of the most important parameter of thermal sensation. Furthermore, the energy access of walls and windows is decreased as well, modifying the indoor thermal comfort and cooling demand. The near-surface air temperature of shaded places is lower by 0,8-1,7 °C than the ambient air temperature. The TMRT is decreased by a higher extent reaching possibly 15-30 °C [3]. The two main components of evapotranspiration is the direct movement of water from different (soil, water, canopy interception) surfaces (evaporation) and the conversion of water within the leaf to water vapour, released to the atmosphere through the stomata (transpiration). Evapotranspiration has a cooling effect on the leaf and the surrounding microclimate. Evapotranspirative cooling also has an important share in modifying the microclimate near buildings [4]. Urban vegetation, especially trees have several other climate-related ecosystem services. A high number of evaluations, plans and planting guides have been published around the world, with emphasis on the multifunctionality of urban vegetation [5],[6],[7]. In 2013, a Green Infrastructure Strategy was approved in the European Union, the referring communication of the Commission („Green Infrastructure – Enhancing Europe’s Natural Capital”) propose the incorporation of green infrastructure development goals in planning and development processes.

As the energy budget of buildings is a result of many effects of a complicated system, many studies are carried out with measurements on test walls [8]. In planning-oriented studies model applications are widely used to evaluate the effects of tree shading [9],[10],[11]. By using models with suitable parametrisations, different types of tree stands on different locations can be evaluated. If the assessment of a larger number of buildings, the evaluation of the shading effect on a wider scale is targeted, empirical, statistical models are used, with the consideration of as many of the influencing factors as possible [12],[13].

We are short of knowledge about these effects among the climatic circumstances and building characteristics of Central Eastern Europe. Therefore, we present the first results of an integrated analysis of some frequent urban tree species in Hungary, from the point of view of indoor thermal comfort effects of vegetable shading. The targeted model-based evaluations need field-based measurements of the main parameters connected with the shading effect. That is why, in the first part of our study, we present the results of field-based transmissivity measurements in summer, carried out near some real buildings in the downtown area of a Hungarian city.

2. Data and methods

Creating good indoor comfort depends to a great extent on the effectiveness of shading, mitigating the solar access of walls and transparent surfaces. Thus it is an essential issue – regarding the scale of building and plants nearby – to quantify the amount and ratio of the obstructed solar access by the vegetation. In order to be able to make clear the shading effect of often used Hungarian urban trees we made measurements in case of three species. The three species analysed were: Celtis occidentalis, Sophora japonica, and Tilia cordata. All selected trees were in good condition and were typical for their species. In Table 1. some data are to seen about the trees investigated.

	Total height of tree [m]	**Height of tree trunk [m]**	**Radius of canopy [m]**	**Coordinates**	**Orientation of wall behind**
Celtis occidentalis	15.5	2.4	6.55	46.2601°; 20.1405°	130°
Tilia cordata	9.6	2.3	3.65	46.2577°; 20.1448°	130°
Sophora japonica	8.1	2.4	2.85	46.2607°; 20.1604°	100°

Table 1 Measures of the trees

The trees were selected so that their orientation is similar (nearly southwest, with the aim of the longest irradiation that is achievable) and there are no objects to shade the tree during the day (the trees are situated in wide avenues). The distance of the trees and the buildings behind them is identical in the case of Celtis occidentalis and Tilia cordata – measuring 4.5 metres; in the case of Sophora japonica the distance between the wall and the tree is 5.2 m.

Solar irradiance is the most important factor in forming the buildings' microclimate, thus the investigations on the possibilities of natural shading and the measurements of the main parameters describing the effect is one of the main tasks in integral, model-based assessments as well. A simple parameter of the shading performance is transmissivity, which is the ratio of shortwave radiation passing the tree crown to that measured in an unshaded point. This parameter is frequently used in measurement campaigns and model-based human bioclimatological investigations, referring to horizontal surfaces [14]. However, due to the structure of foliage (which is different in the case of different species), the leaf area index, which is in strong connection with transmissivity, have different values measured vertically or horizontally [8].

The measurements were carried out with Kipp&Zonen CNR 1 and 2 pyranometers, in two clear sunny days at every tree species. The instruments were placed at 1 m distance from the wall, at a height of 1,1 m (standard measurement height in human bioclimatological investigations). The measurement design (approximate duration of the measurements, places of instruments) was helped with preliminary modelling of the time course of the shade in Ecotect software, based on size parameters of the trees and on the orientation of the buildings. Transmissivity was calculated from 10 minutes averages of irradiance data.

As described transmissivity data were obtained from field measurements, and were used for further modelling in order to give more general approach of the shading effect of alley trees. Modelling was carried out with Autodesk ECOTECT software. ECOTECT is a sustainable design tool which makes possible a detailed building energy analysis from building to city scale. As ECOTECT is capable for detailed solar simulation too, we found it suitable for our modelling aims.

The main aim of our modelling was to provide more general results about the shading effect of the trees and their impact on the buildings' solar gain. For that we have chosen to carry out measurements on an ideal model, as the modelling results of the real houses near the examined trees couldn't show the tendency of the shading effect clearly. The model consists of a cubic room 12 metres long, 6 metres deep and 4 metres high. A perspective view is seen in Figure VII. In the model materials were used which were similar to the real cases. The wall is a thin brick structure covered with plaster, the windows are single glazed, timber framed. Although researches have shown the importance of using heavy- or light-weight structures [15] we concentrate now on the effect of tree shading. But future studies aim to investigate the dependency of the trees' effect on inner climate on the used structure (heavy-weight, light-weight structures, single-glazed or double-glazed LowE windows).

Trees are approximated as nearly spherical polygons, and the transparency of the canopy material is taken from the pyranometer measurements.

Modelling was carried out for a typical summer day (16th July). Meteorological data were taken from the meteorological station of Szeged (run by the Hungarian Meteorological Service) and imported to ECOTECT.

3. Results

As seen on the *Table 2.* the three investigated trees showed a difference in transmissivity. Besides the evident transmissivity dependence on species, the reason of the difference could be also due to some anomalies in tree condition and dimensions, as the biggest of all studied trees was the Common hackberry (Celtis occidentalis) with thick branches and a rich canopy. Opposite to that the Japanese pagoda (Sophora japonica) was the smallest with a loose foliage, which is also very typical for the species. The best transmissivity values were given by the Common hackberry (Celtis occidentalis), and the Japanese pagoda (Sophora japonica) that showed the worst shading performance. The transmissivity value of the Small-leaved lime (Tilia cordata) showed to be nearer to the Japanese pagoda (Sophora japonica).

Species	τ (%)	σ (%)
Celtis occidentalis	11,3	7,5
Sophora japonica	16,6	7,6
Tilia cordata	12,0	7,6

Table 2. Mean (τ) and standard deviation (σ) of the transmissivity of the studied trees

As *Table 2.* shows, different species have a high variability of transmissivity values. Besides the obvious factors of density of the canopy and the leaf area index, tree condition also influences the transmissivity values of the tree.

As mentioned, further modelling was carried out in ECOTECT. On the base of the created model severe analysis were carried out in order to investigate the trees' effect on indoor and outdoor climate. In this paper we focus on the results of solar analysis, which was carried out for both horizontal and vertical surface (façade). The aim of analysis of solar access on the façade aims primarily to examine how trees – depending on species – mitigate the heating up of building structures. Regarding that mainly solar gain (mainly through transparent structures) is responsible in the risk of summer overheating, one must see the importance of the simulation.

In the below table (Table 3.) the result of the analysis of trees' shading effect on vertical surface is shown. The data are taken from each cell of the analysis grid. Cells are 0.25 x 0.25 m big, the grid covers the whole façade of the model (12 x 4 m). Approximately the 80 per cent of the façade is transparent to be able to show more precisely the shading effect. The horizontal analysis grid is in 1,1m high above the floor level, which is approximately the height of the head of a sitting person. The next two tables show the results of described model runs.

Cumulative value of solar gain on horizontal surface [kWh]				
	Case without tree	*Shadowed by Common hackberry*	*Shadowed by Japanese pagoda*	*Shadowed by Small-leaved lime*
Average	0,74	0,52	0,67	0,60
Minimum	0,46	0,46	0,46	0,46
Maximum	1,99	0,97	1,79	1,74
Rate of reduction in per cent	0%	29%	9%	18%

Table 3. Trees' effect on direct solar gain on horizontal surface (daily values, modelling results from ECOTECT)

Cumulative value of solar gain on vertical surface [kWh]				
	Case without tree	*Shadowed by Common hackberry*	*Shadowed by Japanese pagoda*	*Shadowed by Small-leaved lime*
Average	1,98	0,81	1,60	1,49
Minimum	1,72	0,46	1,18	1,05
Maximum	2,00	1,28	1,92	1,90
Rate of reduction in per cent	0%	60%	19,30%	24,80%

Table 4. Trees' effect on direct solar gain on vertical surface (daily values, modelling results from ECOTECT)

Understanding the results of Table 3. and Table 4. it comes clear, that trees' impact is more effective on vertical surface than on horizontal. But it is also obvious that the effect of tree shading indoors is not less valuable, than outdoors. The solar gain of a shaded façade can be ~20-60 per cent less, and 10-30 per cent less in case of indoors horizontal surface – depending on species, transmissivity and canopy size. Obstructing solar gain on the façade has especially big importance in case of transparent surfaces (windows). As transparent surfaces highly influence the temperature of indoor thermal environment, the shading effect of a tree can mitigate the risk of summer overheating and energy demand too.

After investigating the mitigation of solar gain in case of each species a further step was to find out changes in indoor temperatures. The simplified model could show the tendency that during the day indoor temperatures are lower, but during the night a slight rise is observable.

Figure 1. represents indoor temperatures in two cases:

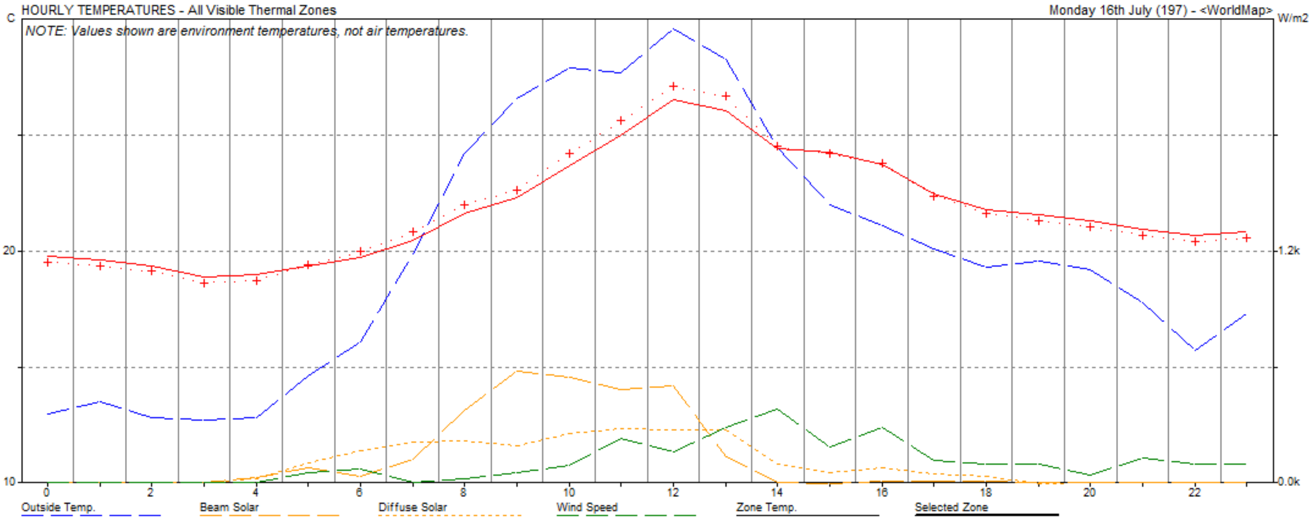

Figure 1. Indoor operating temperatures with (red line) and without (red dotted line) Common hackberry. Blue line represents outdoor temperature.

Modelling has shown, that on a typical summer day Common hackberry had a bigger shading effect, as in this case a mitigation of indoor temperature of 0,6°C was observed. In the case of Small-leaved lime and Japanese pagoda the mitigation of indoor temperature were 0,3 and 0,2°C respectively. These values can vary if other structure is used, but the tendency shows, that the effectiveness of shading depends not only on the transmissivity but also on the diameter of the canopy.

4. Conclusions

Concluding we can state, that our measurements and modelling could prove that the shading effect of trees have a major impact not only on outdoor but also on indoor comfort. The shading efficiency of trees is a species-specific attribute, because of the varying crown structure and leaf density. Our analyses aimed at the quantification of the transmissivity of characteristic individuals of three frequently planted species, and field measurements proved that Common hackberry (Celtis occidentalis) has the bigger potential in shading. The highest transmissivity values (worst shading potential) was observed in case of Sophora species, the two other trees can be characterized with a bit lower transmissivity values, similar to each other.

Modelling has shown that trees can indeed improve indoor comfort. Further modelling is planned in order to give more precise results of shading effect of each species. An important result of our investigation is that with the usage of vegetation a better indoor comfort can be created in summer and this is a non-mechanical way to cool building surfaces.

References

[1] Hunter Block A., Livesley S. J., Williams N. S. G, 2012.. *Responding to the urban heat island: A review of the potential of green infrastructure.* Victorian Centre for Climate Change Adaptation Research, Melbourne, Australia.

[2] Szkordilisz F, 2014. Mitigation of urban heat island by green spaces. *Pollack Periodica,* **9.**, 91-100.

[3] Takács Á., Kiss M., Gulyás Á, 2014. Some aspects of indicator development for mapping micriclimate regulation ecosystem service of urban tree stands. *Acta Climatologica et Chorologica,* **47-48**., 99-108.

[4] Shahidan M. F., Jones P. J., Gwillam J., Salleh E, 2012. An evaluation of outdoor and building environment cooling achieved through combination modification of trees with ground materials. *Building and Environment*, **58**, 245-257.

[5] Rogers K., Jarratt T., Hansford D., 2011. Torbay's Urban Forest – Assessing Urban Forest Effects and Values (online, 2011). Available at: http://www.torbay.gov.uk/tuf.pdf

[6] City and County of San Francisco, 2014. San Francisco Urban Forest Plan.

[7] CNT, 2010. *The Value of Green Infrastructure – A Guide to Recognizing Its Econmic, Environmental and Social Benefits.* Center for Neighborhood Technology, Chicago.

[8] Berry R., Livesley S. J., Aye L., 2013. Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature. *Building and Environment,* **69**, 91-100.

[9] Chagolla M. A., Alvarez G., Simá E., Tovar R., Huelsz G., 2012. Effect of tree shading on the thermal load of a house in a warm climate zone in Mexico. *Proc. of the ASME 2012 International Mechanical Engineering Congress & Exposition IMECE2012,* Houston, Texas, USA, November 9-15, 2012, pp. 761-768.

[10] Simpson J. R., McPherson E. G., 1998. Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento. *Atmospheric Environment,* **32**, 69-74.

[11] Hes D., Dawkins A., Jensen C., Aye L., 2011. A modelling method to assess the effect of tree shading for building performance simulation. *Proc. of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association,* Sydney, Australia, 14-16 November, 2011, pp. 161-168.

[12] Pandit R., Laband D. N., 2010. Energy savings from tree shade. *Ecological Economics,* **69**, 1324-1329.

[13] Donovan G. H., Butry D. T., 2009. The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Buildings,* **41**, 662-668.

[14] Konarska J., Lindberg F., Larsson A., Thorsson S., Holmer B., 2013. Transmissivity of solar radiation through crowns of single urban trees—application for outdoor thermal comfort modelling. *Theoretical and Applied Climatology*, **117**, 363-376.

[15] Szkordilisz F., Heeren N., Habert G., 2014. Energetic and comfort benefits of composite buildings. Learning from vernacular techniques: Section 16, In: *Creating New Resources, Conference Proceedings: Session 16*, World Sustainable Building Conference (WSB14), Barcelona, 2014, Green Building Council - Espana, 2014, pp. 9-15.