CORVINUS UNIVERSITY OF BUDAPEST
FACULTY OF LANDSCAPE ARCHITECTURE
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OLÁH ANDRÁS BÉLA

THE EFFECT OF THE URBAN BUILT-UP DENSITY AND THE LAND COVER TYPES ON THE RADIATED TEMPERATURE

PhD DISSERTATION BOOKLET

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The applicant has met the requirements of the PhD Regulation of the Corvinus University of Budapest and the thesis has been accepted for the defence process.

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I. Introduction, antecedents, objectives

The antecedents due to which the current research is absolutely timely, are the radical development of our constructed environment and the decreasing quality of the urban environment occurring simultaneously.

The cities of our present days, among them Budapest, are being developed, extended and agglomerated in an extremely high pace. These all eventuate the significant increasing of the virtual size of Budapest (which is much greater than its administrative size), furthermore they lead to remarkable increasing of the ratio of artificial surfaces in this area as well. In the meantime, the recent technical development (high spatial resolution satellite sensors and computers) enables detailed surveying of the correlation between the negative climate effects and the changes of the constructed environment.

The aim of this research is to reveal the connection between the urban surfaces and their thermal behaviour in detail, furthermore to identify those architectural, open space design and urban planning methods, with which the effective mitigation of the urban heat island (UHI) can be achieved and to make proposals on the practical use of these methods. Furthermore another similarly important aim is to identify those methods that increase the urban heat island and to make proposals on how to reduce the use of these methods in the near future.

It is important to note that according to certain forecasts[1] the impacts of global climate change add to the increasing of the intensity, expansion, duration and frequency of these negative urban climate phenomena in a very great number of the cities in the temperate zone, including our homeland.

[1] **IPCC**, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

II. The sources and the method of the research

The primary data sources of this research were the ASTER thermal infrared satellite images.[2] Basically these are the only images that provide sufficiently high spatial resolution (90m) thermal distributions, which enable researching on the urban planning scale.
Altogether 5 satellite image were processed. The reason for this relatively small number is that such images are produced only occasionally, when ordered. During the operation of the sensor 30 satellite images were taken altogether. Unfortunately the major part of these images could not be used due to the full or partial cloud cover appearing on them. One of the used five images was taken in winter, the others in summer and in spring (2-2 pieces).
One of the reasons for this seasonal distribution is that the main purpose was to measure the urban heat island in that specific period, when it causes the most serious problems (i.e. in late spring and in summer). The other reason is that vegetation plays an extremely important role in the distribution of the urban heat island, but only in the vegetation period, thus, it cannot be measured in winter. The analysis of the winter image provides very important data on the thermal impacts of the buildings on the urban environment. The other

[2] ASTER (2001): *ASTER Higher-level Product User Guide,* Version 2.0, Jet Propulsion Laboratory, California Institute of Technology, 80p.

four images were all produced under anticyclonal, sunny and dry weather conditions; consequently they provide quite similar thermal distributions, although the daily temperature values were different. Despite this, the differences in the characteristics of these distributions that occurred in spite of the above were mainly due to the changing land cover.

The meteorological data of the given days in Budapest (source: National Meteorological Service), the regulation plans and the land use plots of Budapest, furthermore the Google Earth Images and orthophotos taken in different years all were further important data sources. Besides the procurement of the digital databases, the on-the-spot examinations of the locations were essential as well in order to clarify issues that could not be answered merely by analysing the remotely sensed data (e.g. were the given surface heated or not? which are the dominant tree species in a the examined forest? etc.).

The essence of the research method was the processing and layering of the above mentioned databases. The thermal infrared images needed to be processed into image sequences, which visibly marked out the isotherms, the cold and hot areas, and furthermore provided information on the exact values of thermal maximums and minimums. These image sequences needed to be layered with the land use plots, the orthophotos taken in the appropriate time and the Google Earth images. The comparing of the processed thermal infrared images with the land cover types made it possible to determine the correlations between the urban surface types and the spatial distribution of the urban temperature.

The primary reason for creating so-called "thermal cross sections" was to analyze the linear thermal distribution, which provided information on the thermal transitions spreading over the borders of the different surfaces. These methods enable the detailed mapping of the effects of the typical urban surfaces on the thermal behaviour of their environment.

At the same time, it is very important to note that it is not possible to examine the entire phenomenon of the urban heat island only by the using this method. This method is the analysis of the ASTER thermal infrared images, which provides information neither on the vertical structure of the urban heat island, nor on its daily alteration, nor on the dependence of this phenomenon on the macrosynoptic situation. However, the correlation and interaction between the different built-up and land use types and the urban heat island can be examined and analyzed in details with this method.

The research confirmed that water surfaces and vegetation covering are virtually those surfaces, which are capable of moderating the urban heat island to the greatest extent. Furthermore, thanks to the relatively good spatial resolution of the used thermal infrared satellite images it was possible to determine that even a single larger-sized building can significantly modify the thermal conditions if its surroundings. At the same time, the quality of the covering is more important than the land use type in this case as well. Another remarkable research result is that tree stands with closed canopy layers have the greatest cooling rate among the urban vegetation types.

III. Theses

1. **The land use plots of the regulation plans usually do not provide sufficient explanation to the development of the structure of the urban heat island, however, the more detailed databases on the constructed environment and the urban surfaces can unequivocally be correlated with the surface temperature distributions.**

   It can be stated based on the different land use regulation plans, orthophotos, Google Earth maps and on-the-spot examinations, that the dependence of the urban heat island on the built-up types cannot be simply explained by the present-day land use plans (which basically set only building and land use possibilities and limits). Nevertheless, the orthophotos and the Google Earth maps enable the clear identification of the thermal effects of the different surface qualities and different vegetation structures.

2. **According to my examinations it can be unequivocally declared that even a single large-sized building (with a ground area over 1 hectare) can have a remarkable impact on the urban surface temperature distribution. In the case of such buildings it is not the land use classification, but the thermal qualities of the surface (facade, roof) material and the building size which were primarily determinant.**

The surveying of the thermal distributions in the surroundings of these kinds of buildings (e.g. Arena Plaza, Papp László Budapest Stadium, Shopping Market No. 1) shows that the extremely hot points (pixels) can be clearly matched with the surveyed buildings. It must be emphasized that comparing them with the neighbouring industrial and transport-infrastructural areas, which were expected to be the hottest points under the given weather conditions, these establishments (institutional buildings) produced far higher temperature values both on the summer and winter dates, moreover on the transitional (spring) dates. The typical covering material of these buildings is glass or metal roofing, which have extremely poor thermal insulating abilities, very low heat capacity; consequently they have an extremely strong heat impact on their surroundings (especially in the case of heated inner spaces).

3. **In the case of similar sized, heated and similarly intensely used buildings even 12°C (!) surface temperature differences can occur, depending mainly on the quality of the surface covering. The surveying of the main building of the Arena Plaza and the connected, similar-sized subterranean garage revealed this significant effect of the surface covering quality and particularly of the biologically active surface/green roof.**

The weather conditions (in this case on any scale) were perfectly identical by the main building of the Plaza and the subterranean garage. Considering the surroundings, and not considering the surface quality, it could have been expected that the surface of the subterranean garage would be warmer due to its proximity to Kerepesi Road and to the rails of Keleti Railway Station, while the main building of the Plaza stood close to the vegetation of the Kerepesi Cemetery. As the subterranean garage is air-conditioned, the difference cannot be explained by the different inner temperature of the buildings, especially not in the latter case of examination done in May (when the heat emission of the service installations was minimal). The only remarkable difference between the two building parts is in their roof surface covering; while one is set up with a green roof, the other has a traditional flat roof with huge glass transom-windows.

4. The different built-up types significantly influence the surface temperature of the urban blocks. When surveying the unbroken row of buildings and the freestanding buildings on the two sides of the Bajza Street, the blocks with unbroken row of buildings proved to be warmer by approx. 3-4°C than those which consist of freestanding buildings.

It is important to note that the land use intensity on the block between Bajza Street and the City Park (with freestanding buildings) is not at all lower than that of the territory between Bajza Street and the Grand Boulevard (with the unbroken row of buildings). These freestanding buildings are relatively big, they cover the major part of their plots, furthermore they are equally high (and have the same building level number) as the unbroken row of buildings on the other side of Bajza Street. Consequently the measured difference can be caused only by the difference in the built-up types and their collateral characteristics (a significantly greater sky view factor, a higher rate of crown canopy covering).

5. Urban water surfaces are the coolest surfaces in the summer period and in transitional seasons, while the same water surfaces are among the warmest surfaces in the wintertime. This remarkable conditioning effect is significant even in the case of relatively small water surfaces; furthermore the lakeside vegetation can also play an outstanding role in increasing this effect.

Urban water surfaces have proved to be the coolest surfaces and among these the role of the River Danube is the most important in Budapest. At the same time it can be stated according to the winter satellite image, that the water surfaces are among the warmest areas in winter (only such point anomalies as the previously mentioned huge buildings and huge artificial surfaces of the airport runways appeared to be warmer than the water surfaces). This heating effect provides a special microclimate on the islands of the Danube, and this fact explains why these should primarily be used as public parks and open spaces. Several statements can be made regarding the correlation between the rate of the cooling effect and the size of the water surfaces. First of all, based on the given satellite images, non such minimal sized water surface can be found, which would not have remarkable cooling effect. The satellite images with 90m spatial resolution have indicated a remarkable (5-8°C) cooling effect even in the case of a 20m narrow water body (along with its waterside vegetation). In the case of the Danube this cooling rate can reach a rate over 10°C. Consequently it can be stated based on the above that even very small water surfaces can remarkably reduce the urban surface temperature in the summer period, thus, in a climatologic aspect their wider usage in the urban environment is recommended. Furthermore the vegetation surfaces surrounding natural water surfaces (lake, rivers, creeks) show a much greater cooling rate than other green stands, consequently the conservation and/or the renewal of these vegetation surfaces is highly recommended from the climatologic point of view.

6. **Surfaces covered by vegetation are the second most effective surface types (after water bodies) in mitigating the urban heat island. Tree stands with closed crown canopy layers and consisting of eurytopic species are the most effective from this point of view. The cooling effect of the vegetation is more complex than in the case of water bodies. It can be stated that the higher the rate of biological activity, the greater the cooling effect.**

Furthermore it can be stated based on the results of my survey that tree stands with closed crown canopy layers have proven to be the coolest vegetation surfaces. According to the survey results regarding the different tree stands, it can be declared that from the aspect of decreasing the urban heat island, those older eurytopic tree species are ideal, which bear urban impacts well, have a great evapotranspiration ability, have a closed crown canopy layer, and which's root zone has already reached the level of the subsoil water. Consequently, it is desirable to achieve the greatest possible crown canopy layer ratio when designing new urban green surface; however, it is also necessary to take into consideration other aspects (e.g. usage) when planning the optimal ratio.

7. **Tree stands protected from external environmental impacts have a greater cooling effect. This can be experienced particularly well at the southern border of the Kerepesi Cemetery, where the most remarkable temperature shift was detected exactly in the line of the bordering wall of the Kerepesi Cemetery.**

   This remarkable surface temperature shift in the case of the Kerepesi Cemetery is on the one hand due to the height and massivity of the fence, and on the other hand to the fact that the tree stand with the most closed crown canopy layer in the Cemetery can be found next to this southern border. These two factors are the cause of the development of such a high cooling rate immediately on the border of the green area.

IV. Utilization

Besides that the hypotheses of the research have proven true it also has been confirmed that the simultaneous usage of different planning methods on different levels (architectural, open space design, urban planning) can lead to the remarkable decrease of the urban heat island. In the following this method structure will be introduced.

Architectural methods:

The urban heat island can be efficiently reduced by the usage of the appropriate architectural tools. These are primarily such kind of solutions, which collaterally reduce the energy consumption of buildings to a high extent. Certain façade/roof materials and building tools can remarkably increase the heat insulating ability of the surface of the given building and significantly increase its total heat capacitance. The installing of evaporating surfaces and the increasing the albedo of buildings are also viable solutions.

The usage of green roofs has the same effect, furthermore in the vegetation period they serve as evapotranspiration surfaces, which have the greatest cooling effect on the building parts receiving the greatest amount of incoming solar energy. The usage of white roofs significantly improves the radiation-reflecting ability of the building, which reduces the rate of heating in the critical summer periods.

Open space planning/design methods:

The rate and intensity of the urban heat island can be remarkably decreased by using appropriate urban space design methods, tools and planning directives. According to the results of my research urban water and green surfaces have the greatest ability in reducing the urban heat island, which surfaces can basically be found in open spaces (excepting green roofs). Besides, usually more than 50% of the total urban area consists typically of open spaces, thus, the appropriate design of these can significantly decrease the urban heat island. Tree stands with closed crown canopy layers and developed stand climate are the most efficient cooing surfaces. According to my examinations the distant effect of such cool surfaces is not significant, thus it is practical to rather design green surfaces covered by water surfaces and closed tree stands with a high rate of closed crown canopy layers and consisting of eurytopic tree species capable of high transpiration. It is also very important to develop urban green networks instead of closed and isolated blocks of urban green areas, which means that the planting and sustaining of linear urban green elements (allées, street tree rows) must be more emphasized.

Urban planning methods

The primary tool for mitigating the urban heat island is the integration of the previously mentioned open space design aspects into the urban planning methods and into the regulation plans and laws, on the one hand by supporting the appropriate architectural and open space planning methods and tools and on the other hand by taking into consideration the climatic aspects in specifically urban planning questions.

The planning aspects and directives can be integrated primarily into the local regulation plans. The purpose of this integration is bifold; on the one hand the usage of the previously mentioned appropriate architectural and open space design methods and tools need to emphasized, and on the other hand those solutions, which eventuate the increase of the urban heat island, need to be rolled back by legal tools.

Climatologic aspects appear in specifically urban planning questions as follows: on the one hand it is worth favouring the freestanding built-up types instead of the usage of unbroken row of buildings.

On the other hand the usage of wider streets have remarkable advantages, as not only do they enable the significant increasing of the sky view factor (which in turn induces the decreasing of the urban heat island according to urban climate researches)[3], but they provide the possibility of "afforesting" the streets more efficiently

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[3] Unger, J. (2010): *A Városi Hősziget Jelenség Néhány Aspektusa (Some Aspects of the Urban Heat Island Phenomenon).* – Thesis for the MTA doctor's degree.

(linear urban elements). Multiplied allées can be planted either entirely on purely public property or partially on private plots as well. This second solution is absolutely in accordance with the directives of open space design tools; consequently it eventuates the creation of a climatologically efficient urban green system. A further aim in the context of the total area of the settlement is to achieve the greatest crown canopy layer covering possible, as this is the most efficient way of decreasing the urban heat island.

V. Publications of the author

Csepely-Knorr L. – Gergely A. – Olah A. B. (2010): The Use of Archive City Plans in Contemporary Urban Planning. *Paper presented at ISUF, 17th Conf. Int. Seminar on Urban Form.* Hamburg, Germany, 20-24. August 2010.

Dobi, Ildikó – Mika János – Olah, András Béla – Lelovics, Enikő – Dezső Zsuzsanna –Pongrácz, Rita – Bartholy, Judit (2009): Cold and hot events in urban environment. *In: ICUC-7, Int. Conf. on Urban Climate*, Yokohama, Japan, 2009. June 29- July 3. http://www.ide.titech.ac.jp/~icuc7/extended_abstracts/index-web.html

Gerzson, L., Oláh, A. B. (2012): A zöld építészet tájépítészeti vonatkozásai, eszközrendszere *4D Tájépítészeti és Kertművészeti folyóirat* Különszám, 245-257 o.

Oláh, A. B. (2010): The correlation between the urban heat island and the different land use types – *In: Fábos International Conference on Landscape and Greenway Planning* 2010, Budapest, Hungary.

Oláh, A. B., (2010): Detected effect of a newly constructed huge building on the heat balance of its surroundings – *In: 9th International Conference on Application of Natural-, Technological and-, Economical Sciences*, Szombathely, Hungary.

Oláh, A. B. (2010): The effects of different vegetation types on the local climate – *In: International Conference in Landscape Ecology*, Brno, Czech Republic.

Oláh, A. B. (2010): The Cold Garden Concept – *In: Non-human in Anthropology International Conference*, Prague, Czech Republic.

Oláh, A. B. (2010): Bioklimatikus városrehabilitáció és városi hőszigetek elkerülése. *Épített örökség és korszerű energiahatékonyság építési kultúra és CO2-kibocsátás Építész szakmai konferencia*, 2010. április 15.

Oláh, A. B. (2010): The Green Building and Sustainability: Sustainable Construction of Ecological Green Living Buildings.*The International Journal of the Constructed Environment*, Volume 1, Issue 1, pp.39-50. Article: Print (Spiral Bound). Article: Electronic (PDF File; 1.285MB).
http://ijv.cgpublisher.com/product/pub.201/prod.15

Oláh A. B. (2010): Innovation beyond the traditional urban transport solution. The advantages of the moving pavement. Scandinavian Urban Transport 2010 Conference. Stockholm, Svédország, Nov. 30-Dec. 1. 2010.

Oláh, A. B. (2011): Zéró szén-dioxid kibocsátású közösségi közlekedés. *Közlekedésbiztonság,* 2011/4, p 74-80.

Oláh, A. B. (2011): The sustainable city. *5th Conference of the International Forum on Urbanism (IFoU).* National University of Singapore, Szingapúr, Feb. 24-26. 2011.

Oláh, A. B. (2011): The ideal building material is transparent, light, is a good heat isolator, just like… *5th Conference of the International Forum on Urbanism (IFoU).*National University of Singapore, Szingapúr, Feb. 24-26. 2011.

Oláh, A. B. (2011): Radically decreasing energy consumption of buildings by using the potential attribute of the gravity field. *5th Conference of the International Forum on Urbanism (IFoU).* National University of Singapore, Szingapúr, Feb. 24-26. 2011.

Olah, A. B. (2011): A mozgójárda kínálta lehetőségek, *Közlekedésbiztonság* 71-75. old., 2011/2, ISSN 2062-6916

Olah, A. B. (2012): The Possibilities of Decreasing the Urban Heat Island, *Applied Ecology and Environmental Research,* Volume 10, Number 2, 2012, p 173-184. ISSN 1589 1623 (Print), ISSN 1785 0037 (Online)

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