The correlation between the urban heat island and the different land use types

András Béla Oláh, Ildiko Dobi, Janos Mika,
Eniko Lelovics, Zsuzsanna Dezső, Rita Pongrácz, Judith Bartholy,
Corvinus University, Department of Garden and Open Space Design,
Hungarian Meteorological Service,
Eotvos Lorand University, Department of Meteorology Name of University,

Introduction: In the following study the local climate modifying impact of the man modified environment is to be discussed in detail. Such studies have come in demand nowadays, since the meteorological forecasts have just recently become detailed and accurate enough for this purpose. Furthermore the number and extension of huge sized artificial areas has also radically increased.

The appearance of these highly diversified artificial surfaces to such an extent can modulate the local climate so significantly that it can not be neglected. However, at the same time this extreme diversity of the surfaces and materials makes it very hard to analyse the impacts made on the urban climate, and it eventuates a very complex climate system. This makes forecasting very difficult. In this study the Urban Heat Island (UHI) will be discussed as a case study. The examined area of this study is an inner district of Budapest. The phenomena of the UHI has been well known for about 200 years, but nowadays its impact can be so great in huge cities that it is high time to discuss it as fully as possible.

There are many purposes of such studies, and there are basically two groups of these. In the first case the improved meteorological forecast is the purpose. This means that a so called ‘urban’ factor is also calculated on, which factor can be added to the value of the ordinary meteorological forecast. This can be very important especially when extreme weather occurs, for example when forecasting extreme heatwaves in cities. The other momentous purpose is providing feedback. This means that by understanding the artificial factors causing the UHI, a method can be provided for urban planning in order to decrease this phenomenon as much as possible.

Background/literature review : Nowadays great attention is payed to urban climate researches in meteorology (Unger, Pongracz, 2008.), (Alcoforado et al., 2009.). Yet the greatest difficulty is caused by the difference of the scale: the scale of meteorology is of a countrywide size, while the scale of urban planning is the size of an urban block. By these days the level of technology that has been reached provides the possibility of connecting the two scales. Earlier the strength of satellite acquisition had already been experienced many times. A great advantage of this is that it is possible to simultaneously gain information from the whole territory of the city. Such quantity of data could only be acquired by deploying a very dense and very expensive meteorological measure network. The development of the satellites (NASA, 1999.) and the more and more fine spatial resolution of infrared satellite images makes it possible to take such detailed infrared photos which provide information not only on different land use types but even on the impacts of great buildings. In the case of such studies it is indispensable to be aware of the land use, the urban fabric, the local plan and the ortophoto of the examined area as well. In some special cases to case examination on the spot is also indispensable.

Goals and objectives: With the help of such studies accurate information on the effects of the different land uses on the UHI phenomena may be gained. There is also a possibility to accurately define which kind of land use strengthens the UHI and which kind weakens it. The integration of such kind of examinations into the system of environmental effect studies or into the procedures of the building permission provides a very useful tool in sustainable urban development which prevents the rate of the UHI from further increasing (or minimising this rate).

Useful information suitable for modifying the urban climate to a better state may be gained during the measurement of the existing state of a given area by finding and analysing those phenomena which differ from the anticipation. Moreover those architectural solutions can also be singled out which keep playing an important role in the UHI. Our final purpose is to recognise as detailed as possible the effects of the natural and artificial elements on the urban climate and to integrate this knowledge into our plans and methods to make our cities sustainable.

Method(s): Our purpose during the study was to perform a most detailed examination of the UHI. The main regard when selecting the examination area was to find an area, which contained a lot of different kinds of land use types. Thus the the 8th District of Budapest and its environment was chosen. Almost all kinds of land use types can be found in this area except for the hilly types. At the same time momentous building processes were carried out here in the last decade. Thus not only can we get information on the spatial distribution and the seasonal changing of the UHI but also on the effect which comes with the changes of land use.

We have obtained the necessary data from several sources. The temperature data were the first and the most important of them. We procured thermal infrared pictures from the satellite image database of the NASA (https://lpdaac.usgs.gov). These were shot by the Aster sensor of the satellite Terra. The spatial resolution of this sensor is 90 m (1 pixel equals 90 * 90 m). This resolution is fairly good and enables us to examine even the effect of an urban block (its size is approx. the size of one pixel of the Aster image). It is important to note that these temperature data are not the conventional temperature data (measured in 2 m high, in shadow). These are so called thermal surface kinetic temperature data. There are statistical methods to provide the correlation of these two kinds of temperatures. We can say that from our point of view these differences are not significant (Dobi et al., 2009), and when considering the human sensing of heat it can be discussed which kind of temperature is more determining. The next significant source is the actual part of the Metropolitan Regulation Framework Plan (http://terkep.budapest.hu/website/fszkt).

In this the land use types and the maximal rate of the building in are featured. By comparing this plan with the satellite images we can draw qualitative inferences about the correlation of the land use and the UHI. However, the regulation plans do not always provide enough information about the site. The quality of the green areas are very important, and also the different types of pavement and covering, but these do not appear in the regulation plans. That is what made it necessary to use the Google Map (http://maps.google.com), thus we can provide a qualitative analysis even in those special cases when the correlation is not understandable only from the regulation plan itself.

We completed the study using these three image databases. The first step of the procedure was the processing of the satellite image datas. The heat recordings were converted into a picture sequence. All of these pictures contain bright and shady areas and they can be attributed with a temperature value, a so called given limit temperature. The shady areas are colder and the bright areas are warmer than this limit temperature. This given limit temperature was increased with 1 ^{0}C on all pictures in such sequences. This means that the size of the shaded area would be increasing and the size of the bright area would be decreasing. In this method it is very beneficial that the kinetic temperature of an arbitrary point of the examined area can be exactly shown and the very cold and very hot points become very clearly visible. All pictures from these sequences are jointed onto the land use (regulation) map and the Google map. In this way we gained so called composite pictures which consist of multiple layers. With the help of these composite pictures a very detailed quantitative discussing can be obtained referring to the connection of the built-in types, the land use and the UHI. Using such composite pictures instead of the well-known fake-coloured infrared images, not only the hot and cold point and their shapes can be clearly detectable, but the exact values of them also.

Results: Four satellite images were analysed, one of them was made in summer (6th July 2001), two of them in spring (4th May 2002 and 6th May 2008) and one in winter (2nd February 2003).

The summer case (6th July 2001): this was a sunny and dry day. The average surface temperature was 38^{0}C in the examined area, the minimum was 13^{0}C and the maximum was 53^{0}C. The coldest point (13^{0}C) occurred due to a small cloud, so there was not any useful information about this small area (Rákóczi Square) from this satellite image. The line of the Danube River appeared at 19^{0}C. The first cold point on the land appeared at 24^{0}C and this was an inner area of the Kerepesi Cemetery. The oldest trees of the Cemetery stand in this area. By 26 ^{0}C appears the coldest point of the City Park by the northern border of the examined area. The smaller parks, the coldest points of public gardens and the lake of the Orczy-Garden become clearly visible at 27^{0}C. The boundaries of these green areas become clearly noticeable between 27 and 33^{0}C. Not only do the green areas become visible between 33 and 38^{0}C but the thermal difference between the different types of residence areas appears as well. The surface temperature is significantly higher in the case of densely built-up areas (unbroken rows of 6-8 storey buildings) than in the garden cities. Another interesting phenomenon can be recognised at 38^0C. There are significant differences between the surface temperature of the inner yards of the densely built-in areas. The systematically colder inner yards are afforested and the hotter ones are usually paved. The housing estates, the garden cities and the green areas are all colder than 43^0C. Those areas where the surface temperature is between 44^0C and 53^0C are typically the territories of factories, other industrial areas and the sites of railway stations and railroads.

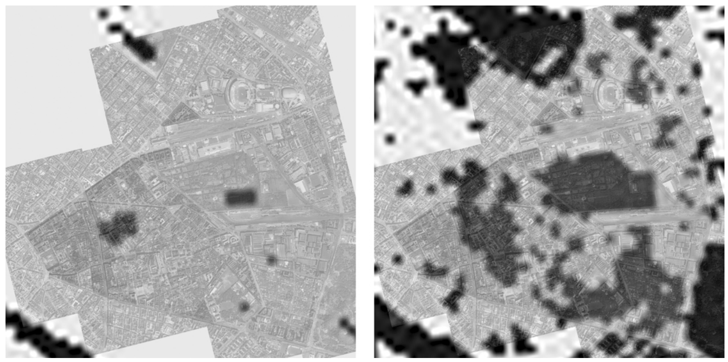

Figure 1. Composite pictures with the given limit temperature 27^0C and 38^0C by the summer case

The earlier spring case (4th May 2002): This was also a bright day with an average surface temperature of $35{,}5^0$C; the minimum was 15^0C and the maximum was 44^0C. Between 15 ^{0}C and 24 ^{0}C only the line of the River Danube is visible. The bridges of the Danube were clearly noticeable at 18^0C. The first cold point in this case appears in the City Park at 25^0C. The lake of the Orczy-Garden and the coldest points of the Népliget (People's Groove) appear at 26^0C. The coldest point of the Kerepesi Cemetery only appears at 27^0C. The situation is very similar to the summer case between 27 and 34 ^{0}C. The Köztársaság Square is clearly visible at 33^0C. This square consists of two parts. The greater part is a park and a theatre and its surrounding pavement stands on the smaller part. When examining the site on the spot we noticed that the roof of the theatre is covered with zinc. The cold L-shaped zone and the hot square of the theatre is very clearly visible. Between 35 ^{0}C and 44 ^{0}C the situation is also very similar to the summer case. The main block of the Corvinus University on the bank of the River Danube is very interesting. Here is no industrial activity, however the inner yards of the building are covered with glass roofs. This building is noticeable even at the limit temperature of 41 ^{0}C similarly to the hottest industrial zones.

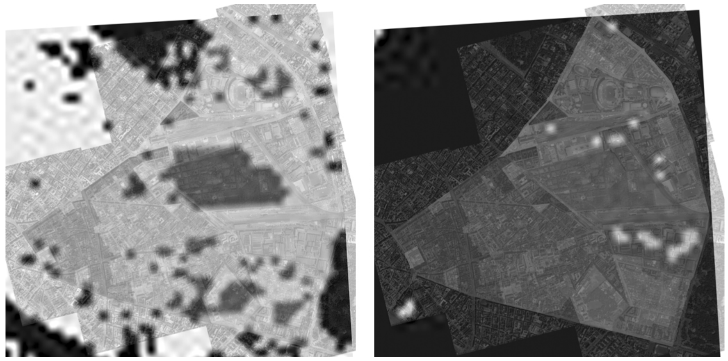

Figure 2. Composite pictures with the given limit temperature
33^{0}C and 41^{0}C by earlier spring case

The winter case (2nd February 2003): On this bright day the average surface temperature was -1 ^{0}C; the minimum was -6 ^{0}C and the maximum was 5 ^{0}C. The coldest point was a railway overpass outside the examined area in the direction of the outer zone of the city. Between -6 ^{0}C and -3 ^{0}C the parks and the greater opened areas appeared as cold zones. The boundaries and green areas become clearly visible at -3^{0}C. Between -2^{0}C and -1^{0}C the garden cities appear colder and the inner densely build in zones appear warmer. The surface of the River Danube becomes clearly visible between 0^{0}C and 2^{0}C. Only a few hot points can be noticed at 2^{0}C. When comparing them with the Google map and the land use plan we can say that it is not the land use but rather the material of the roofs which is determining in these cases. As we have seen earlier the metal and glass covered buildings heat their environment the most.

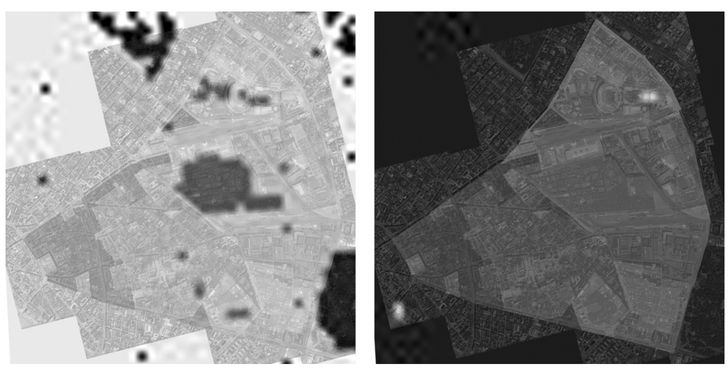

Figure 3. Composite pictures with the given limit temperature
-3^{0}C and 2^{0}C by the winter case

The second spring case (6th May 2008): The reason we are processing this satellite image is to study the changes of the UHI which happened due to the changes of the urban structure. The time interval between the two spring cases is 6 years. During this period very remarkable building processes went under on the examined area. On this bright day the average surface temperature was 31,8^{0}C; the minimum was 16^{0}C and the maximum was 46^0C. Between 16^0C and 23^0C only the River Danube appears, the first cold points appear on the land in the inner zones of the City Park and the Népliget (People's Groove) at 24^0C. The lake of the Orczy-Garden and the coldest part of the inner zone of the Kerepesi Cemetery appear at 25^0C. The boundaries of the afforested zones become noticeable and the smaller afforested areas like the Köztársaság Square appear at 27^0C. The smaller afforested areas, the green surfaces of the living zones and the boundaries of the greater public parks appear between 27 ^{0}C and 31 ^{0}C. The shape of the northern boundary of the Kerepesi Cemetery differs from its form in the previous spring. A cool stripe appears in this zone between the Cemetery and the railway station at 33^0C. However there is a very hot area between this cool stripe and the Cemetery, which area is also visible at 40^0C while the hottest point of the railway station is only 38^0C warm. The hottest point is in an industrial zone near the Népliget (People's Grove). It is very interesting that the coldest point is in the Népliget (People's Grove) (except for the Danube), relatively close to the hottest zone. It is thus conceivable how great the impact of the UHI would have been, should have the area of the Népliget (People's Grove) been used as an industrial zone according to some plans made at the end of the XIX. Century (Csepely-Knorr, 2010).

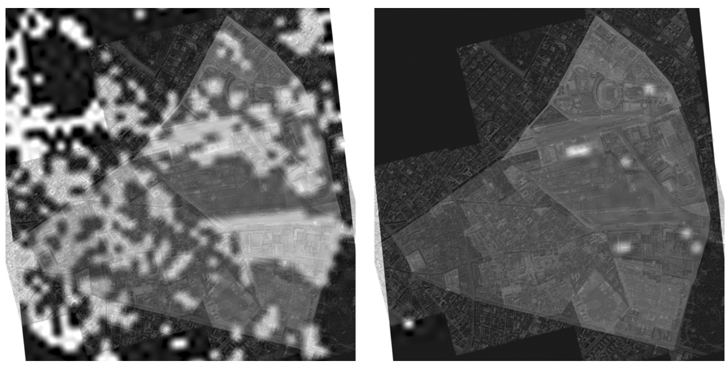

Figure 4. Composite pictures with the given limit temperature 33^0C and 40^0C by the later spring case

Discussion and conclusion: we have come to the following observations: The multi-levelled vegetation with closed canopy layers are the coldest; the densely built-in areas with 6-8 storey buildings, the industrial zones and the railway stations are the hottest. The water surfaces, especially the Danube River, are very cold in summer and very warm in winter. In the case of closed inner yards we can say that those covered with plants can be even 5^0C colder than those which are paved or simply without planting. In those cases when the green areas are separated from the neighbouring (living or other) zones, the temperature is lower in the green area, especially near to the boundary, however the conditioning impact of the green surfaces does not prevail in the neighbouring zones. This situation occurs among the southern border of the Kerepesi Cemetery (**Fig. 2**, **Fig. 4**). The opened grassy areas are significantly hotter than the afforested zones. The residential areas can be separated according to the following: the garden cities and those housing estates which contain green surfaces covered with multi-levelled vegetation are significantly colder than the densely built-in areas. Comparing the spring and summer cases we can see that the colder points are usually not in the same locations. The difference between the spring and the summer is due to the different aspects and the different state of the vegetation. The difference between the two spring cases is due to the six year difference which has eventuated changes in the structure of the vegetation.

The analysis of the local anomalies: In the first spring case (4th May 2002) that part of the Köztársaság Square covered in green can be clearly visible at 33^{0}C (**Fig. 2**). The closed canopy layer of the trees are also dominant here. In the spring cases certain very hot points appeared. In line with our expectations they appeared in the inner zones of industrial areas and railway stations, but some of them appeared in other areas as well. The surface temperature value was extraordinarily high at the new Coliseum and the greater metal or glass covered buildings (**Fig. 2**). This means it would be useful to have these building parameters regulated in the Building Regulation. In the winter case one of the conclusions has come to the same results as in the other cases: the outer garden cities and housing estates are colder, the inner densely built-in zones are warmer. It is interesting that those industrial zones which were not heated (depositories for example) were also colder. The great buildings (Coliseum, the main building of the Corvinus University) which have been covered with metal or glass and had been heated showed extremely high surface temperature values (**Fig. 3**). They were even hotter than the railway stations and industrial zones.

The second spring case (6th May 2008) is very interesting because in the former six-year-period a huge building (covering many hectares) with a significant thermal impact was erected. This is the Arena Plaza between the Kerepesi Cemetery and the Keleti railway station (Szilagyi, 2009.). The average surface temperature value was different from the former spring case, in the earlier occasion the average value was lower by 3,7 ^{0}C, thus the pictures belonging to the same given limit temperature can not simply be connected with each other, but the different shapes of the boundaries of the bright and shady areas show the differences very well. The change becomes clearly visible at higher temperature values (over 30^{0}C). In the earlier case (4th May 2002) the area of the Kerepesi Cemetery was clearly cold and the there was a balanced, monotonous temperature transition towards the railway station where was the highest temperature value. However in the latter case (6th May 2008) the northern boundary of the area of the Kerepesi Cemetery is not so clear and also its shape differs from the other case. Some places are hotter than the others despite the fact that they are equally covered with old trees and similar temperature values belonged to them according to the earlier case. The following anomaly appears in the higher temperature values: the transition towards the railway station is not monotonous any more, there is a relatively cold stripe between the building of the Arena Plaza and the railway station (**Fig. 4**). Considering the Google Map we have observed that this relatively colder stripe is the huge rooftop garden of the Arena Plaza which lays between the building and the railway station. Considering the highest given limit temperature values the following results occurred: the hottest point is not in the area of the railway station any more, but it is the building of the Arena Plaza which is 2^0C hotter than the hottest point of the railway station (**Fig. 4**). The roof of the Plaza is flat and partly covered with huge glass transom-windows. This means that such great metal or glass covered buildings have a significantly negative thermal impact on their environment. The unlucky placement of such buildings can extremely deteriorate the positive impacts of the existing urban green system. It is clearly visible that the rooftop garden has positive impacts, however these are much less than the afforested zones of the parks. With the help of these results there can be made such urban open space and regulation plans which can really make better the quality of the urban environment.

References

[1] Unger, J. And R. Pongracz, 2008. *Urban Climate Research in Hungary*, International Association for Urban Climate, Issue No. 28, 17-20.

[2] Alcoforado M., H. Andrade, A. Lopes, J. Vasconcellos, 2009: *Application of climate guidelines to urban planningThe example of Lisbon (Portugal).* Landscape and Urban Planning 90, 56-65.

[3] NASA, 1999: *Science writers' guide to Terra.* NASA Earth Observing System Project Science Office, Greenbelt, MD

[4] https://lpdaac.usgs.gov/lpdaac/products/aster_products_table/on_demand/surface_radiance_tir/v1/ast_09t

[5] Dobi, I., Mika J., Olah, A. B., Lelovics E., Dezso, Zs., Pongracz, R. and Bartholy, J., 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

[6] http://terkep.budapest.hu/website/fszkt/viewer.htm

[7] http://maps.google.com/

[8] Csepely-Knorr, L. 2010: *Public Parks in Budapest at the turn of the 19th Century*. In: Lippay- Ormos- Vas Conference full paper book. In Press.

[9] Szilágyi, K. 2009: *Urban Green System in the context of Urban Planning and Development (Zöldfelületi rendszer a városfejlesztés és várostervezés kontextusában),* In: MM XC. Studies and Essays of the Scientific Conference of Landscape Architecture in honour of the 90 years old Mihály Mőcsényi (Tanulmányok és esszék a 90 éves Mőcsényi Mihály tiszteletére Magyar Tudományos Akadémia Dísztermében rendezett tájépítészeti konferencia kötete), Budapest, 2009. p. 217-227