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SELECTION OF REPRESENTATIVE SITES FOR AN URBAN TEMPERATURE MONITORING NETWORK IN NOVI SAD (SERBIA)

• Micrometeorology study •

Urban-Path

Novi Sad, 2013

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Good neighbours creating common future

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BACKGROUND OF URBAN HEAT ISLAND PHENOMENON

Introduction

In the second half of XXth century urbanization reached significant level and because of this half of world population is under negative influence of urban environment, such as: pollution, noise, stress as a consequence of life style, modified parameters of urban climate, etc. (Unger et al, 2011a). As urban areas develop, artificial objects replace open land and vegetation. Among the parameters of the urban atmosphere the near-surface (1.5-2 metres above ground level or screen-height) air temperature shows the most obvious modification compared to the rural area (Oke, 1987). This urban warming is commonly referred to as the *urban heat island*[1] (UHI) and its magnitude is the UHI intensity (ΔT_{u-r}). This is a phenomenon where urban regions experience warmer temperatures than their rural surroundings. They are called urban heat islands because the warmer air in the city is surrounded with colder air (similar to island surrounded with water). The annual mean air temperature of a city with one million or more people can be 1 to 3°C warmer than its surroundings (Oke, 1997) and on a clear, calm night, this temperature difference can be as much as 12°C (Oke, 1987).

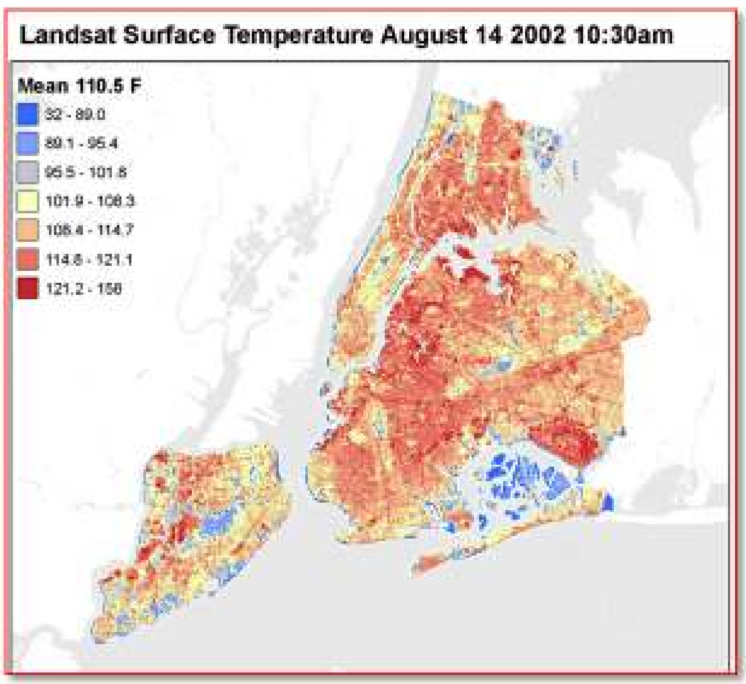


Figure 1. A thermal satellite image of New York City captured by NASA's Landsat satellite on August 14, 2002 at 10:30 a.m. shows the locations of the warmest air temperatures as seen in red. The blue indicates areas with cooler air temperatures. Source: http://www.nasa.gov/centers/goddard/news/topstory/2005/nyc_heatisland_prt.htm

There are two main types of urban heat islands: surface and atmospheric. They differ in ways of their creation, measurement techniques, impacts and mitigation strategies. *Surface*

[1] "Urban heat island," a term first coined in the 1940s (Balchin and Pye, 1947), refers to the atmospheric warmth of a city compared to its countryside.

urban heat islands (SUHI) are present during day and night. They are the most intense during the day when solar heating is strong and in summer when more radiation energy from the sun is available. Common way of acquiring data about temperature characteristics of the surface area in the city is with remote sensing which provides thermal images (Figure 1).

Warmer air in cities compared to its surrounding creates *atmospheric urban heat island*(AUHI). It is divided into two different types: canopy layer and boundary layer urban heat islands (Figure 2). *Canopy layer urban heat islands* (CLUHI) forms in the lowest part of the atmosphere from ground to the tops of trees and roofs. They are the most intense after sun goes down, during night and predawn, because of the energy released from the urban infrastructure. During the day the CLUHI intensity is typically fairly weak or sometimes negative (*urban cool island*) in some parts of the city where is extensive shading by tall buildings or other structures present and/or because of a lag in warming due to storage of heat by building materials (Voogt, 2004). Many scientific works are dealing with CLUHI because this part of atmosphere influences people the most. *Boundary layer urban heat island* (BLUHI) begins at treetops and rooftops to the height where the city influence to the atmosphere stops (no more than 1.5 km from the surface) (Oke, 1982). BLUHI is generally positive both day and night but much smaller in magnitude than CLUHI or SUHI. The BLUHI tends to maintain more constant heat island intensity both day and night (~1.5° to 2°C) (Voogt, 2004). Atmospheric urban heat islands are usually measured on fixed weather stations or with mobile measurements on traverses. Typical depiction of atmospheric urban heat islands is isotherm map (Figure 3) and temperature graph.

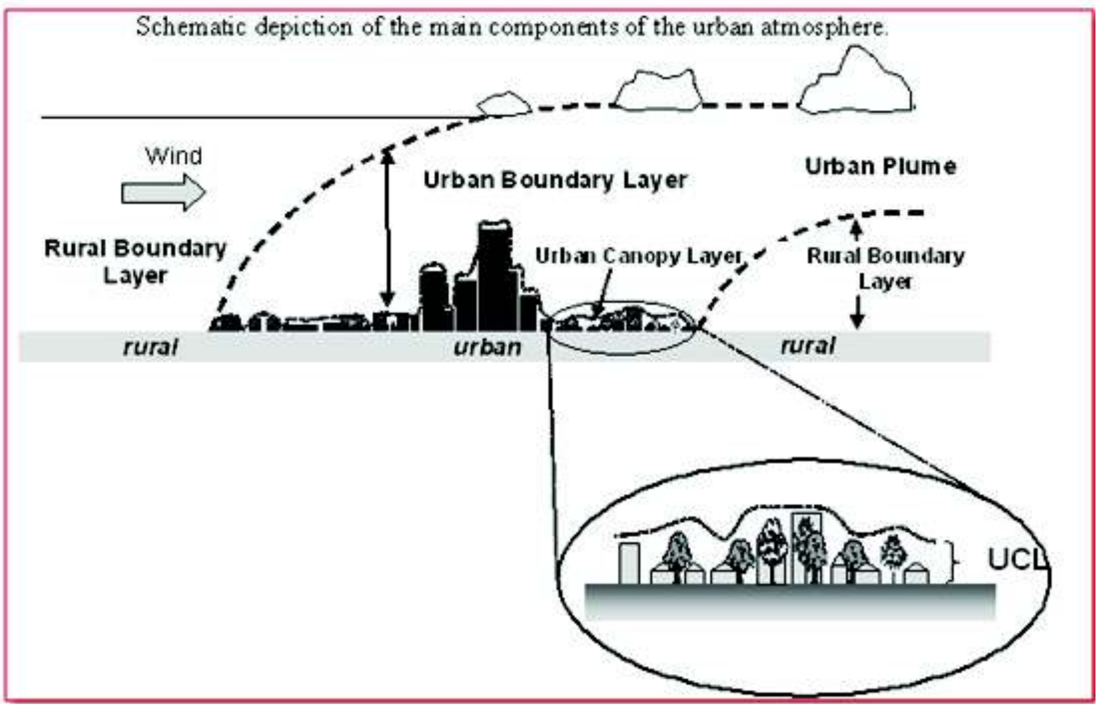


Figure 2. Schematic depiction of the main components of the urban atmosphere (Voogt, 2004)

Surface and air temperatures are related, e.g. over cooler surfaces like city parks, lakes and rivers air is also colder. Buildings, industrial facilities and roads have higher surface temperatures that contribute to the higher air temperatures over these structures (Figure 4). Due to mixing of air in the atmosphere these relationships are not constant and change with different seasons, weather conditions, sun intensity and ground cover.

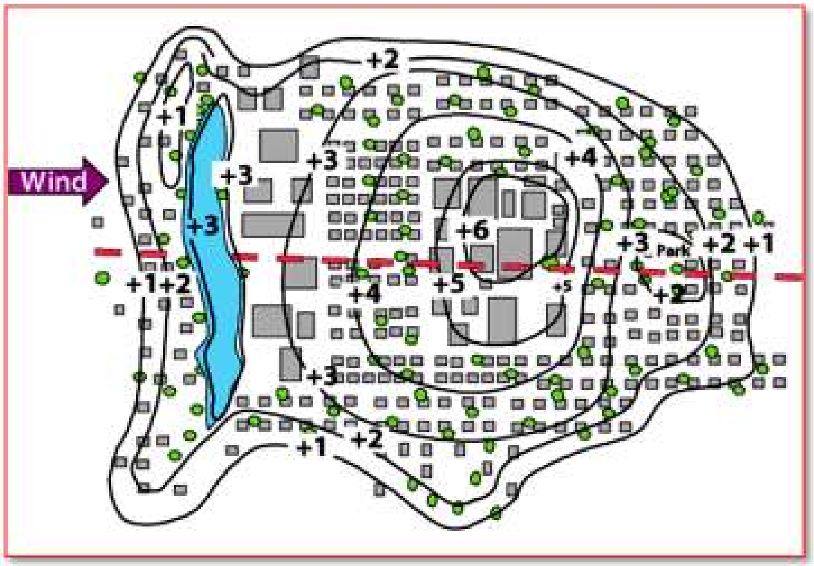


Figure 3. Conceptual Isotherm Map Depicting an Atmospheric Nighttime Urban Heat Island. Red lines indicate traverse route (Voogt, 2000)

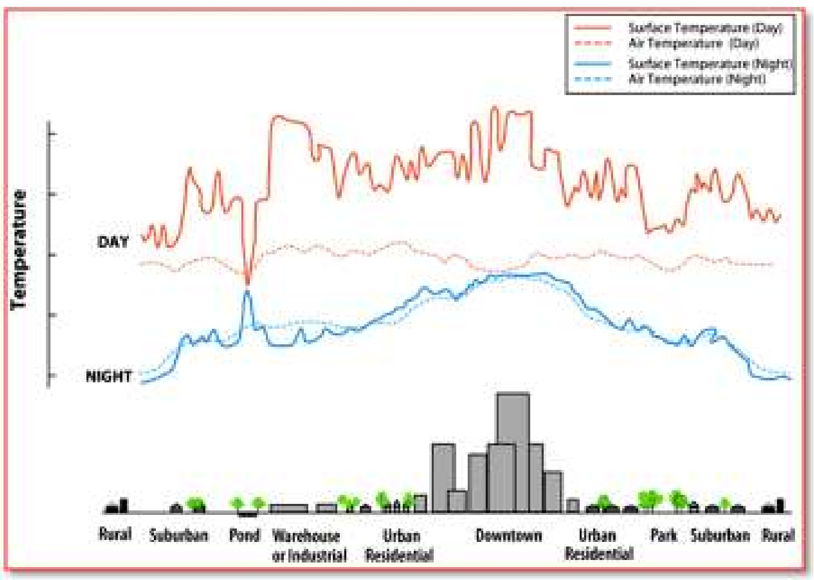


Figure 4. Variations of Surface and Atmospheric temperatures during day and night (Voogt, 2000)

Causes of Urban Heat Island

Main causes for creation of urban heat islands are:

1. Reduced vegetation in cities,
2. Properties of urban materials,
3. Urban geometry,
4. Anthropogenic heat emissions,
5. Specific weather situations and
6. Geographical locations of cities (EPA, 2008)

Reduced vegetation in cities provides less shade due to which urban infrastructure receives and stores more Sun's energy. Consequences of this are higher surface temperatures and air temperature rise above them after this energy is released from the surface. One more consequence of scarce vegetation in cities is less water vapor released to the air. Because of this the need for latent heat used for transpiration is lower and more energy is available for temperature rise.

Important properties of *urban materials* that contribute to the creation of urban heat island are: solar reflectance (albedo), heat capacity and thermal emissivity. Solar reflectance or albedo is a property of material that shows how much (in percentage) of Sun's energy is being reflected by the surface. Darker surfaces reflect less energythan lighter ones because they have lower albedo values. Important property of materials is their heat capacity which is a measure of the amount of energy that can be stored in them. Materials often used in cities, like stone and steel, have higher values of heat capacity compared to soils, vegetation and sands in rural surroundings of the city. As a result, much more energy is stored in city. This energy, once it is released, contributes to the air temperature rise in the cities. Downtown metropolitan areas can absorb and store twice the amount of heat compared to their rural surroundings during the daytime (Christen and Vogt, 2004). Thermal emittance represents the ability of materials to emit long-wave (infrared) radiation. Most construction materials in cities, except metals, have high thermal emittance values which contribute to materials cooling and air temperature rise (Figure 5).

Under the term *"urban geometry"* are considered dimensions of buildings (height and width) and spacing between them in cities. These characteristics influence wind flow, energy absorption and release in cities, especially during night. As a result of a small spacing between buildings they cannot easily emit stored energy while reflected energy from the surface is often reabsorbed and reemitted by the building walls. This further decreases overall albedo of the cities (surface albedo plus building geometry albedo) and increases the air temperatures (Sailor and Fan, 2002). Researchers are often interested in two aspects of urban geometry: urban canyons and sky view factor. *Urban canyons* are artificial "canyons" in cities where its bottom is represented by streets and its sides by building walls. They are called canyons because they are narrow and deep. These structures have dual influence on the creation of urban heat island. During the day buildings provide shade for the surface thus lowering its temperature and air temperature above it. During night stored energy is being released from surface, than reabsorbed and reemitted from building walls which slowdown energy escape from canyon and increases its temperature. The most common parameter used to describe the urban geometry is the *sky view factor* (SVF) (Oke, 1981; Upmanis and Chen, 1999; Svensson, 2004). 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 (Watson and Johnson, 1987). It is a dimensionless measure between zero and one, representing totally obstructed and free spaces, respectively (Oke, 1988). For example, parking lots and open areas with few obstructions have large sky view factor value (closer to 1), while urban canyons have low sky view factor value (closer to zero).Because of these characteristics, urban geometry is an important factor contributing to intra-urban temperature variations below roof level (Oke, 1981; Eliasson, 1996).

Anthropogenic heat emissions refer to energy released in the air as a consequence of human activities (transportation, industrial activity, heating and cooling of buildings and running appliances, etc). This extra energy contributes to the urban heat island formation, especially during winter when demands for energy is high due to necessary heating of buildings.

*Weather condition s*influence creation and intensity of urban heat islands, especially important are cloud cover and wind speed. If the sky is clear daytime temperatures are higher due to more radiation received, while no wind or slow wind speed decrease atmospheric mixing and provide bigger thermal differences between city and its surroundings.

Geographical location of the city is another important cause for formation of urban heat islands. Water bodies and mountains can influence thermal differences and wind patterns on city territory. Rivers and lakes can reduce air temperature values in cities while mountains near city can slowdown/block winds or create winds that go over city territory.

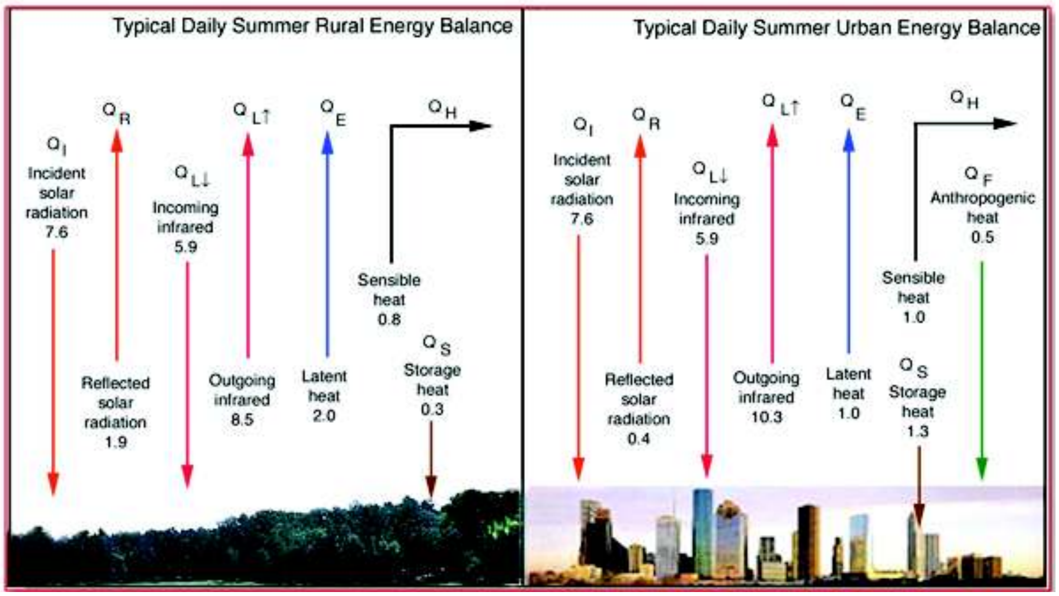


Figure 5. Energy balance differences between rural and urban area in summer in kWh/m2/day. Source: httphttp://www.ruf.rice.edu/~sass/Policy%20Stuff/Figure%203%20Sym%20.jpg

Consequences of Urban Heat Island

Urban climate is a phenomenon that is present on a relatively small area but affects many people living in cities. Excess heat present in cities determinates the sensation of (thermal) comfort, health and performance of inhabitants and affects all of their daily or leisure activities. UHI formation has positive and negative consequences on urban environment and city dwellers. Unfortunately, negative consequences are more numerous and include:

1. Increased energy consumption,
2. Elevated emissions of air pollutants and greenhouse gases,
3. Compromised human health and comfort and
4. Impaired water quality (EPA, 2008).

Energy consumption in cities is very big during summer when a lot of energy is used for cooling. This demand for energy used for cooling can burden the electrical system, especially during heat waves when high air temperatures (over 30°C) are present in city for a few days or even weeks.

Power plants, transportation and industry are main sources of *pollutants* released in air over city. Due to combustion of fossil flues (coal and petroleum products) in plants and cars, pollutants like sulfur dioxide (SO_2), carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO)and mercury (Hg) are released in air. These gasses act like a “blanket” that traps long-wave radiation over cities which leads to air temperature rise (so-called “greenhouse effect”). Air pollutants have negative influence on human health and comfort and can produce environmental problems such as smog and acid rain. With air temperature rise in city the amount of created near surface ozone (O_3) is higher leading to negative influences on human health, especially their respiratory system.

Elevated temperatures and air pollution affect *health and comfort of city dwellers*. This is manifested by general discomfort of population and affects their heat thermal conditions (heat cramps and exhaustion, non-fatal heat stroke and heat-related mortality) and respiratory difficulties. For example, the Centers for Disease Control in USA estimated that from 1979 to 1999, excessive heat exposure contributed to more than 8,000 premature deaths in this country (CDC, 2004). This figure exceeds the number of mortalities resulting from hurricanes, lightning, tornadoes, floods, and earthquakes combined (EPA, 2008). Especially vulnerable to these conditions are children, older adults, and those with existing health conditions. These negative impacts are even more intense during heat waves occurrence when city dwellers are under additional pressure. The lack of nighttime relief in air temperatures is strongly correlated with increased mortality during heat waves. Some studies suggest that these oppressive nighttime temperatures may be more significant than high maximum daytime temperatures (Kalkstein, 1991).

Water quality in city is affected mainly by SUHI (thermal pollution). When stormwater reaches hot roofs and pavements this excess heat is transferred to stormwater. Once this water reaches river or lake it can rapidly change its temperature which produce negative effects and thermal stress to some life forms of aquatic life. Field measurements from one study showed that runoff water from urban areas was about 11-17°C hotter than runoff water from a nearby rural area on summer days when pavement temperatures at midday were 11-19°C above air temperature (Roa-Espinosa et al., 2003).

Important positive consequence of urban heat islands is *prolongation of plant growing-season* in cities. Unfortunately, cities are not places where this benefit is used in a greater deal (opposite to rural places).

Climate Change, Global Warming and Urban Heat Island

Urban areas have been identified as one of the key elements in global climate change (UN-HABITAT, 2011; Rosenzweig et al. 2011). As a major contributor of greenhouse gas emissions related to energy consumption in households, industry and mobility, they have a crucial role in addressing global mitigation strategies (Stern, 2007; IEA, 2008). Future climate projections indicate further rise in global surface temperatures by the end of the 21st century (IPCC, 2007) and high probability of more frequent and severe heat waves in Europe (Schär et al., 2004; Fischer and Schär, 2010). Due to the high population concentration and their crucial role in economic and social stability, the cities are extremely vulnerable to natural disasters and impacts of climate change. Storms, sea level rise, floods and droughts count among serious threats for urban areas beside the heat load risks. However, these hazards are not directly caused by processes on a local scale, compared to the UHI effect.

Climate change refers to any significant change in values of climate elements (temperature, precipitation, wind, etc.) which leads to changes in frequency and intensity of climate processes (for example, extreme weather events) lasting for an extended period (decades or longer). Main causes of these changes are natural (changes in Earth's orbit, volcanoes, Sun's intensity, etc.) and anthropogenic factors (greenhouse gases, deforestation, urbanization, etc.).

Global warming represents temperature increase of the atmosphere near the Earth's surface and it represents just one part of climate change, along with changes in precipitation, sea level, extreme events frequency and intensity, etc. It often refers to the warming as a result of increased emissions of greenhouse gases from human activities (Hansen et al., 1988; Karl et al, 1991).

The causes and consequences of climate change, global warming and UHIs are often similar. Urban heat islands are examples of local climate change and local warming. It is local because of its spatial characteristics while the climate is changed due to warming connected with the urbanization processes and human activities occurring on city territory. UHIs and global climate change can both increase energy demand, air pollution, greenhouse gas emissions and plant growing-seasons.

Meteorological data from many cities are used for climate change analysis on global level. Results show increase of air temperature on global level, but the problem occurs in the fact that these results are in one way "corrupted" because they do not consider the contribution of UHI effect on recorded air temperature rise.

Climate change over the next few decades and beyond is likely to have a major impact on the climate of many cities, including Novi Sad, and potentially could affect both the frequency of occurrence and magnitude of extreme UHI events. In order to acquire better conditions for living in cities in the future, necessary measures should be taken. Many strategies addressing the mitigation of UHI effects can be helpful in addressing climate change on global level.

Strategies for Urban Heat Island Mitigation

Urbanization causes significant modifications in land use generating specific local climate conditions. Sustainable urban planning and climate risk assessment require accurate climatic information on a local scale. Complex interaction between the urban fabric and the climate system needs to be considered in the process of design and implementation of mitigation and adaptation policies.

Community interest and concern regarding urban heat island has increased in the last few decades. This increased attention to urban environment and health issues has helped to advance the development of heat island reduction strategies. These strategies can be divided into voluntary and policy strategies. Local authorities implement one of them or their combination.

Voluntary strategies consists of:
1. Demonstration projects,
2. Incentive programs,
3. Urban forestry programs,
4. Weatherization,
5. Outreach and education and
6. Awards (EPA, 2008).

Local authorities, faculties and public institutions can develop and implement projects that demonstrate one or more strategies for urban heat island mitigation. For example, City of Chicago installed a green roof on its city hall (Figure 6). This has helped to raise the visibility of green roofs and to increase public understanding of their benefits with proper education.

Incentives are very efficient way for acquiring individual actions for urban heat island reduction. Governments, utilities and other organizations can include below-market loans, tax breaks, product rebates, grants and giveaways to encourage people in supplementing urban heat island mitigation strategies (EPA, 2008). Authorities of cities like Chicago, Baltimore, Sacramento, Houston, Austin, etc. gave grants to people, coupons and rebates for purchasing and installation of green roofs, cool roofs, cool pavements and trees.

Figure 6. Green roof of Chicago city hall. Source: http://blog.buzzbuzzhome.com/wp-content/uploads/2013/07/Chicago-City-Hall-green-roof.jpg

Urban forestry or tree planting strategies consider many benefits of trees like air temperature reduction, shade, stormwater runoff reduction, air quality improvement, etc. and encourage people to plant trees. Many cities and counties in USA gave free trees to people and have educated them in their maintenance.

Weatherization usually involves making homes of qualifying residents, generally low-income families, more energy efficient at no cost to the residents (EPA, 2008).

Outreach and education programs are very important for spreading the knowledge about UHI effects and its mitigation strategies. They can address wide range of population from elementary students to pensioners.

Governments, community groups and corporations have rewarded exemplary work as a way to highlight innovation and promote solutions to mitigate heat islands across the public and private sectors (EPA, 2008).

Local and state government can conduct *policy strategies* that include:

1. Procurement,
2. Resolutions,
3. Tree and landscape ordinances,
4. Comprehensive plans and design guidelines,
5. Zoning codes,
6. Green building standards,
7. Building codes and
8. Air quality standards (EPA, 2008).

Number of cities in the USA with support of the local authorities started to procure cool roofs for municipal buildings and permeable pavement cover instead of impermeable.

A resolution is a document stating a group's awareness and interest in an effort, such as a heat island mitigation project (EPA, 2008). Resolutions are generally discussed and made by local authorities.

Many local governments have enacted tree and landscape ordinances, which can ensure public safety, protect trees or views and provide shade. Three types of ordinances, in particular, are most useful from a heat island perspective: tree protection, street trees, and parking lot shade (EPA, 2008).

Comprehensive plans and design guidelines consist of policies, goals and objectives that should be fulfilled in order to reduce UHI negative effects. They are usually long-term and have broad scope.

For implementation of comprehensive plans objectives and goals, zoning codes are used. They regulate functions of an area, like buildings height and width, population density, parking shade, etc.

Green building standards are implemented by many local authorities. They especially address human health and comfort through implementation of different building requirements, like green roofs, green walls, cool roofs, etc.

Building codes are regulations adopted by local and state governments that establish standards for construction, modification and repair of buildings and other structures. An energy code is a part of the building code that relates to the energy usage and conservation requirements and standards (EPA, 2008).

Many local authorities are concerned with air quality in their city. Because of that they develop different strategies for reduction of air pollution, especially near surface ozone formation. Main solutions that they choose for dealing with this problem are urban forestry, green roofs and emission control strategies.

Mitigation strategies for UHI reduction that are usually implemented are: green roofs, cool roofs and cool pavement installation, planting of trees and vegetation and heat wave detection and preparedness plans.

URBAN HEAT ISLAND INVESTIGATION

The preoccupation of researchers for many decades was to measure the heat island effect through simple comparisons of "urban" and "rural" air temperatures. The conventional approach is to gather temperatures at screen height for two or more fixed sites and/or from mobile temperature surveys. Sites are classified as either urban or rural, and their temperature differences are taken to indicate the heat island magnitude (Stewart and Oke, 2012). But this approach created many difficulties because the term "urban" has no single, objective meaning as the areas around the measuring sites could be very different depending on the investigated cities (e.g. park, college ground, street canyon, housing estate, etc.) (Unger et al., 2013).

To diminish this deficiency, Stewart and Oke (2012) developed a climate-based classification system for describing the local physical conditions around the temperature measuring field sites universally and relative easily based on the earlier studies from the last decades (e.g. Auer, 1978; Ellefsen, 1991; Oke, 2004; Stewart and Oke, 2009), as well as a thorough review on the empirical heat island literature and world-wide surveys of the measurement sites with their surroundings (Unger et al., 2013). The elements of this system are the "local climate zones" (LCZ) and they are presented shortly in Table 1.

Because of the complexity of the urban terrain the monitoring of the representative intra-urban thermal features is a difficult task (Oke, 2004). The locations of the sites of an urban station network within the city and thus the question about its appropriate configuration raises an essential problem. This problem is related to the relationship between the intra-urban built and land cover LCZ types and the locations of the network sites. Two situations arise:

(1) In the case of an already existing network (e.g. Schroeder et al., 2010) it may be required to characterize the relatively wider environment around the measuring sites, namely what type of urban area (LCZ) surrounds a given station and whether it can be clearly determined. In other words, how representative is the location of a station regarding a specific, clearly defined LCZ type in an urban environment?

(2) In the case of a planned station network (e.g. Unger et al. 2011a) the most important questions are what built and land cover LCZ types can be distinguished in a given urban area, how precisely they can be delimited, how many they are and whether their extension is large enough to install a station somewhere in the middle of the area (representing the thermal conditions of this LCZ) while of course taking care to minimize the microclimatic effects of the immediate environment (Unger et al., 2013).

Table 1. Names and designation of the LCZ types (after Stewart and Oke, 2012)

Built types	Land cover types	Variable land cover properties
LCZ 1 – Compact high-rise	LCZ A – Dense trees	b – bare trees
LCZ 2 – Compact midrise	LCZ B – Scattered trees	s – snow cover
LCZ 3 – Compact low-rise	LCZ C – Bush, scrub	d – dry ground
LCZ 4 – Open high-rise	LCZ D – Low plants	w – wet ground
LCZ 5 – Open midrise	LCZ E – Bare rock / paved	
LCZ 6 – Open low-rise	LCZ F – Bare soil / sand	
LCZ 7 – Lightweight low-rise	LCZ G – Water	
LCZ 8 – Large low-rise		
LCZ 9 – Sparsely built		
LCZ 10 – Heavy industry		

Table 2. Zone properties of LCZ system (after Stewart and Oke, 2012)

	Type of properties	
	Geometric, surface cover	Thermal, radiative, metabolic
Properties	sky view factor aspect ratio building surface fraction (%) impervious surface fraction (%) pervious surface fraction (%) height of roughness elements (m) terrain roughness class	surface admittance ($Jm^{-2}s^{1/2}K^{-1}$) surface albedo anthropogenic heat output (Wm^{-2})

The LCZ types can be distinguished by the measurable physical properties (parameters) (Table 2). These parameters are partly dimensionless (e.g. sky view factor), partly given in %, m, etc. (e.g. building surface fraction) and their values have different ranges according to the different types. Stewart and Oke (2012) give the typical values of them.The necessity and ideas of the development of “local climate zone” classification system and its structure are presented and discussed in details by Stewart and Oke (2012). LCZs are defined as “regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in horizontal scale. Each LCZ has a characteristic screen-height temperature regime that is most apparent over dry surfaces, on calm, clear nights, and in areas of simple relief.” (Stewart and Oke, 2012). Among them there are ten built types (from LCZ 1 to LCZ 10) and seven land cover types (from LCZ A to LCZ G), and additionally, the types can have variable seasonal or shorter period land cover properties (Unger et al., 2013). The main characters of the types are reflected in their names (Table 1).

In the frame of this new classification system the intra-urban UHI intensity is an LCZ temperature difference ($\Delta T_{LCZ:X-Y}$), not an "urban-rural" difference (ΔT_{u-r}) (Stewart and Oke, 2012).

URBAN HEAT ISLANDINVESTIGATIONOF NOVI SAD: A REVIEW

Novi Sad is located in the northern part of the Republic of Serbia (Figure 7) and in southeastern part of Pannonian Plain (45° 15'N, 19° 50'E). The area of the city is characterized by plain relief with elevation from 80 to 86 m and its climate is free from orographic effects. The Danube River flows by the southern and southeastern edge of the city urban area. Southern parts of the city urban area (Sremska Kamenica and Petrovaradin) are located on the northern slopes of Fruška Gora Mountain (539 m). In Novi Sad the annual mean air temperature is 11.1°C with an annual range of 22.1°C and the precipitation amount is 615mm (based on data from 1949 to 2008).

According to Koppen-Geiger climate classification, the region around Novi Sad is categorized as Cfa climate (temperate warm climate with a rather uniform annual distribution of precipitation) (Lazić and Pavić, 2003;Kottek et al., 2006).

Novi Sad is the second largest city in the country with a population of about 320 000 in a built-up area of around 80 km^2. It is characterized by densely built central area and its surroundings with high buildings and little free space between them. In the northern part of the city is an industrial zone. Green areas in the urban area are found near the Danube, in parks and in suburbs (Unger et al., 2011a).

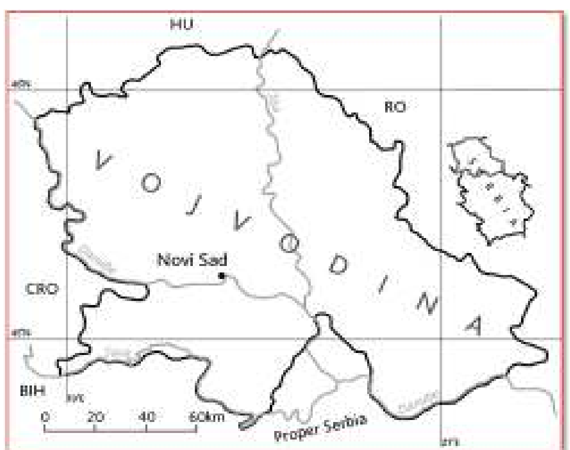


Figure 7. Geographical location of Novi Sad in Vojvodina (Northern Serbia)

In the paper of Lazić et al. (2006) the aim was to present a database (mean, maximum and minimum air temperatures, up to 1990) and trends in urban area, using two meteorological stations: one rural (Rimski Šančevi) and one urban (Petrovaradin). As the results showed, there are increasing trends of mean, maximum and minimum temperatures at Petrovaradin, and in most cases these trends are steeper than trends at Rimski Šančevi. Mostly, trends in Petrovarad in are steeper in morning and evening times, in the winter period and on annual level. Therefore, the results led to the general conclusion that UHI effect has a substantial contribution on air temperature parameters in urban area around the station Petrovaradin.

Popov (1994; 1995) and Popov and Savić (2010) are the first theoretically based publications, i.e. present all parameters, methods and measurements which have to be used in order to work on UHI research of Novi Sad. At the same time, based on meteorological parameters(for 30-40 years) and the structure of urban area, they showed the necessity of defining locations of an urban climate network in order to advance further UHI research in Novi Sad. They compared temperatures between Petrovaradin and Rimski Šančevi stations and noticed that their differences, at the midday terms, are not important. Furthermore, the anomalies of the temperatures in the summer hardly ever exceed 5°C. Contrary to this, the number of the morning and evening terms, when temperature anomalies were over 5°C (sometimes greater than 10°C), are significant, especially in the late autumn, winter and early spring periods. The general conclusion was that these important urban anomalies of the air temperature always appear in stable, anticyclone situations. According to further UHI research in Novi Sad, they emphasized the necessity of an urban station network. Based on the meteorological parameters from two stations and the defined 8 “local climate zones”, they proposed 9 locations in Novi Sad urban area (Figure 8).

Figure 8. A) Local climate zones and B) proposed urban climate network (Popov and Savić, 2010)

The papers from 2011 (Unger et al., 2011a; 2011b)provided a new contribution in UHI research in Novi Sad. They analyzed the spatial distribution of the annual mean UHI intensity pattern. This UHI pattern was estimated by an empirical modeling method developed by Balazs et al. (2009), based on datasets from urban areas of Szeged and Debrecen(Hungary). The urban study area in Novi Sad(60 km^2) was established as a grid network of 240 cells(0.5km × 0.5km). A Landsat satellite image (from June2006) was used in order to evaluate Normalized Difference Vegetation Index (NDVI) and built-up ratio by cells. The pattern of the obtained UHI intensity values show concentric-like shapes when drawn as isotherms, mostly increase from the suburbs towards the inner urban areas (Figure 9). They also proved the accuracy of the model, providing insignificant differences between the UHI intensity value for Petrovaradin calculated by the statistical model (1.66°C) and the measured one (1.8°C). Further work was based on the analysis of the thermal pattern and determination of the local climate classification (LCZ) system (Stewart and Oke, 2010) (Figure 10), in order to determined 10 locations for representative stations of an urban climate network in Novi Sad (Figure 11).

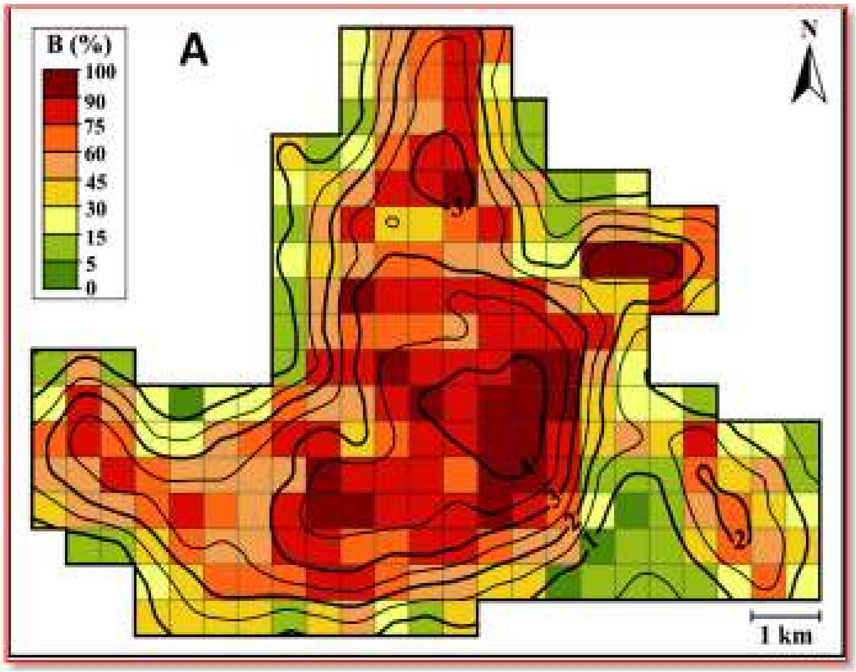


Figure 9. Spatial distribution of the built-up ratio (%) and the modeled annual mean UHI intensity (°C) in the study area of Novi Sad (Unger et al., 2011a)

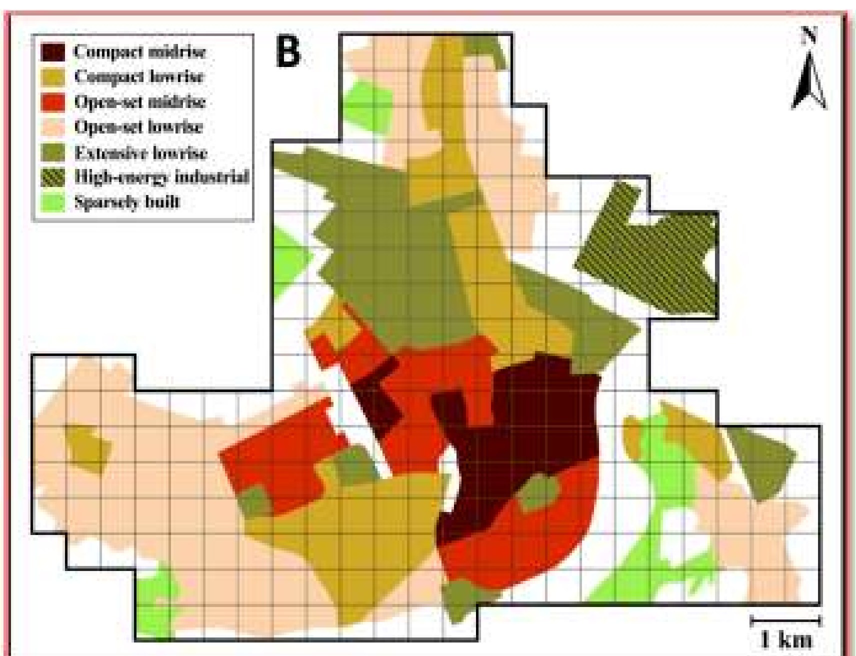


Figure 10. Spatial distribution of urban Local Climate Zones (based on Stewart and Oke, 2010) occurring in the study area of Novi Sad (Unger et al., 2011a)

Figure 11. Satellite image of the study area in Novi Sad with the existing stations and the recommended sites of a10-station urban climate network (Unger et al., 2011a)

Savić et al. (2012) examines the existence and intensity of UHI in Novi Sad. In order to get appropriate results, data from four meteorological stations have been used covering the period of the last 60 years. Values of mean, maximum and minimum air temperature were used to compare urban and rural areas. As the results showed, there are increasing trends of mean, maximum and minimum air temperature at Petrovaradin (urban area) and, in most cases, these trends are higher than trends at Rimski Šancevi (rural area) (Table 3). These differences are the most intense at minimum temperatures and range up to 2.6°C in winter (Figure 12) and up to 2,8°C in summer. According to these studies and previous researches by other authors, minimum air temperatures are appropriate parameters for studying UHI.

Table 3. Annual and seasonal air temperature trends in Rimski Šančevi (1949-2010) and Petrovaradin (1956-1992); * - significance 95%

station	period	T_{sr}	T_{max}	T_{min}
RŠ (ºC/62)	annul	0.9*	0.6	1.3*
	winter	1.3	1.3*	1.7*
	spring	1.6*	1.6*	1.7*
	summer	0.8*	0.5	1.4*
	autumn	-0.1	-0.5	0.5
PET (ºC/37)	annul	0.3	0.4	0.3
	winter	1.0	1.1	1.4
	spring	0.8	1.1	0.6
	summer	0.03	-0.004	-0.03
	autumn	-0.8	-0.7	-0.7

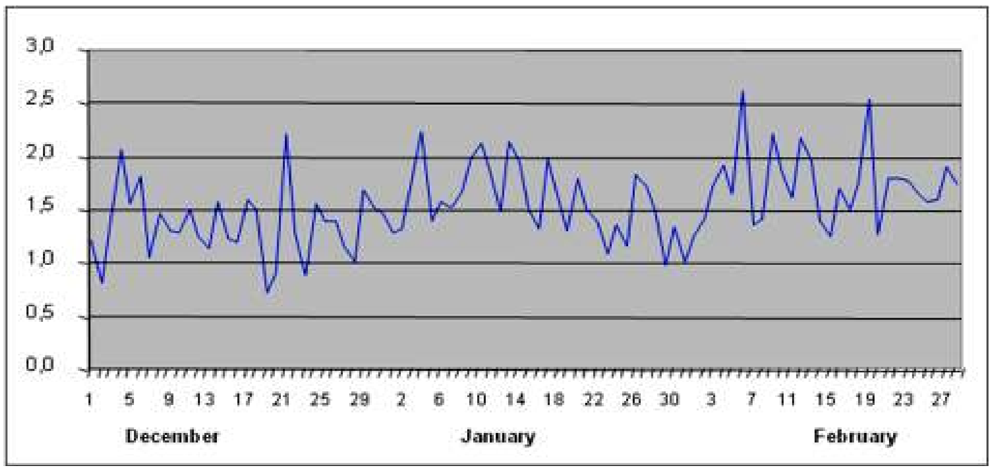


Figure 12. Winter daily minimum air temperature differences (Petrovaradin – Rimski Šančevi) for the period 1966-1992

Further detail research of UHI pattern and its effect on human thermal comfort is needed. The first step can be done through an IPA HUSRB project made by Department of Climatology and Landscape Ecology (University of Szeged) and Faculty of Sciences (University of Novi Sad). The long-term and effective monitoring of these changes is possible with the application of an installed (wireless) monitoring network, whose spatial resolution provides the detection of differences between thermal characteristics of the neighborhoods, and whose temporal resolution allows the exploration of both diurnal as well as seasonal peculiarities. As Szeged and Novi Sad are located in plain areas devoid the climate modification effects of topography, thus the explored thermal (heat load) differences virtually depend on their built-up characteristics and anthropogenic activities. Therefore, these cities are ideal places to explore clearly the climate, in our case primarily the thermal load modification effects of the artificial factors and their temporal and spatial differences in greater detail.

Such type of monitoring networks in these cities and the associated continuous data recording, transmission and processing, as well as the real-time public display of the processed data in a spatial(map) form would mean a unique and pioneering innovation development in Central Europe. This database would be extremely useful as a test bed for the urban parameterizations of weather and climate forecast models. The long-term operation of the network and the resulting database that contains also the parameters related to weather situations, in the future provides a few days (now-casting type) forecast of the expected heat load of the spatial differences within the city as well.

The main aim of this study is to determine the LCZ types in Novi Sad which are representative for the urbanized area of the city using geometric, surface cover and radiative properties from the ten ones listed by Stewart and Oke in their new study from 2012. After LCZ have been determinated they will be used as a base for instalation of an urban meteorological network in the city of Novi Sad. This network will consist of 25 to 30 automatic meteorological stations which will be used for temperature and relative humidity measurements.

METHODS FOR DEFINING LOCATIONS OF THE URBAN METEOROLOGICAL STATIONS NETWORK

Using GIS methods for LCZ mapping developed by Department of Climatology and Landscape Ecology (University of Szeged)we can determine seven properties from the ten geometric, surface cover and radiative ones listed by Stewart and Oke (2012) for any given area inside the Novi Sad based on the available databases. From the initial parameters for classification we missed the H/W since this ratio tend to be too theoretical (it can be clearly calculated just in the case of the regular street network). The surface admittance and the anthropogenic heat output are also lacking, since these data were not available in the study area (Lelovics et al., 2013).

During the determination processes of the other seven parameters the basis of the calculation is the building block and the area belonging to (lot area polygon) (Gál and Unger 2009). Therefore, the buildings touching each other were merged into blocks and then the study area was divided into polygon-shape areas based on these blocks where each polygon consists of the set of points closer to a central building block than to the other blocks. The obtained areas are the lot area polygons of the building blocks (Lelovics et al., 2013).

The calculation processes and the applied databases by parameters used for the selection of the representative sites of the temperature and relative humidity monitoring network stations (Figure 13)are as follows:

- *Sky view factor* (SVF): The input was a SVF database with 5 m horizontal resolution originated from earlier studies (Gál et al., 2009). It was calculated using the 3D building database of Novi Sad with a vector based method. The building database contains building footprint areas as polygons, and the building heights were measured with photogrammetric methods. During the SVF calculation all of the buildings were regarded with flat roofs and the effect of the vegetation was neglected. The SVF values relate to the street level and they are averaged inside the lot polygon areas.

- *Building surface fraction* (BSF): The input was also the 3D building database of Novi Sad which contains the buildings footprints in the study area. BSF is the ratio between the summarized footprint areas and the lot polygon area.

- *Pervious surface fraction* (PSF): The input was a built-up dataset calculated from RapidEye satellite image using NDVI index, a 1:25000 topographic map, a road database and the Corine Land Cover (CLC) (Bossard et al., 2000) database.

The RapidEye image is atmospherically corrected (resolution of 5.16 m) and the Normalized Difference Vegetation Index (NDVI) was calculated using bands 3 and 5 (Tucker,1979) and those points were regarded as covered area where the NDVI was below 0.3.

The CLC dataset was used to locate the agricultural areas as these areas have small NDVI (like the covered areas) because the amount of plants on them is negligible after harvest.

As a second correction the shape of water bodies were digitized in the topographic map because water has NDVI values very similar to the values of some building materials.

As a last correction the road database was used to locate the asphalt roads in the area because on the one hand in the urban canyons these roads are usually under tree cover, and on the other hand the roads (ISF) which slice agricultural areas and do not appear in CLC dataset (Lelovics et al., 2013).

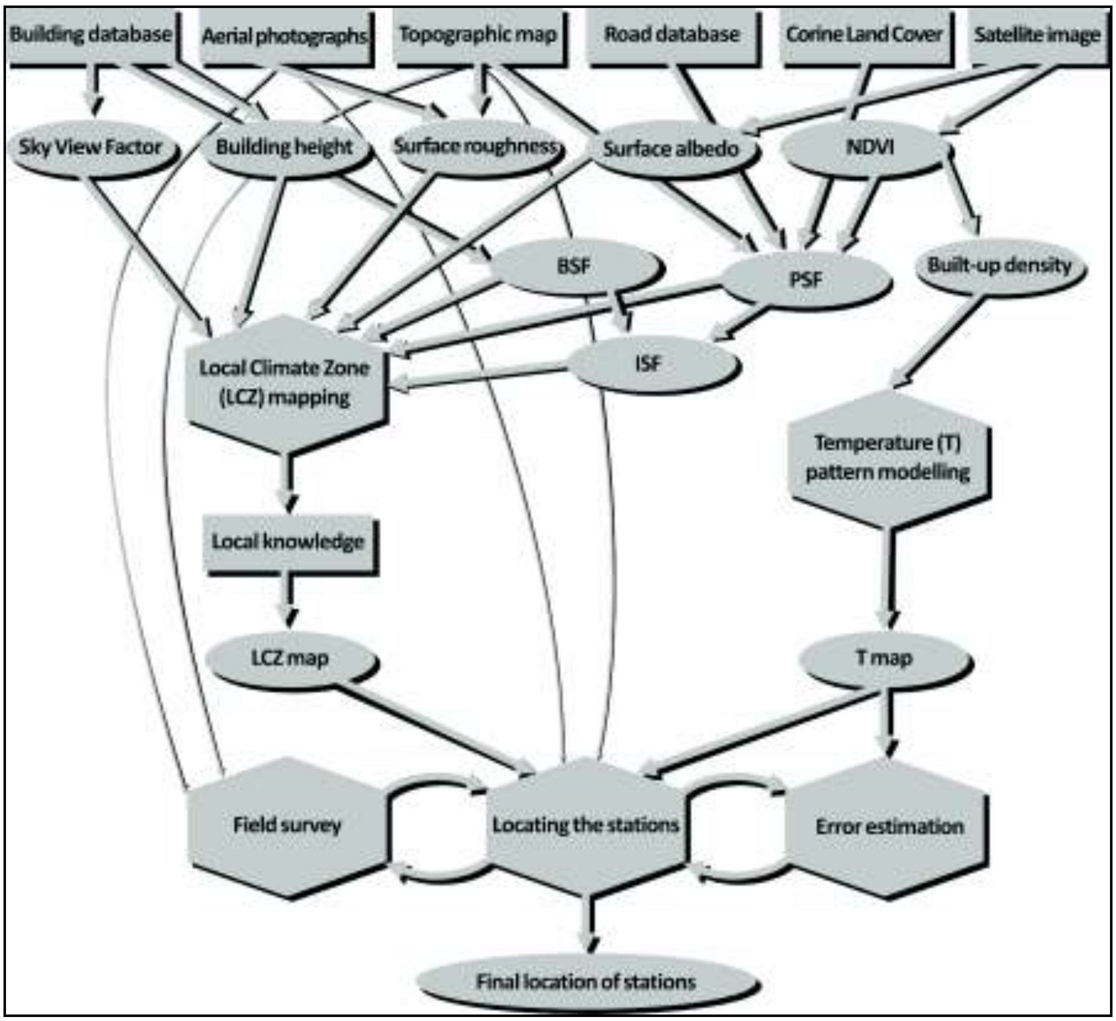


Figure 13. Flow chart of the selection of the representative sites of the temperature and relative humidity monitoring network stations (Lelovics et al., 2013)

- *Impervious surface fraction* (ISF): Its value was calculated using formula: ISF = 1 – (BSF + PSF).

- *Height of roughness elements* (HRE): The input was also the 3D building database of Novi Sad. For each lot area the building heights weighting with their footprint areas were averaged.

- *Terrain roughness class*(TRC): For describing the roughness the Davenport roughness classification method was used (Davenport et al., 2000). All of the lot area polygons were classified into roughness classes with visual interpretation of aerial photographs, the topographical map and the building database.

- *Surface albedo* (SA): As an input we used the atmospherically corrected reflectance values of the 5 band RapidEye satellite image. Broadband albedo was calculated as an average of reflectance values weighted with the integral of the radiation within the spectral range of a given band (Starks et al. 1991).

The modelling of the UHI pattern in Novi Sad is based on our earlier work (for the details see Unger et al., 2011a; Unger et al. 2011b). The applied empirical model is to estimate the spatial distribution of the annual mean UHI using just a few input parameters based on the built-up density (BSF+ISF, but not separately) in a 500 m x 500 m grid which can be determined in a simple way (remote sensing) without having detailed local information about the urban area.

While searching for the appropriate (representative) locations, two criteria were considered. First, homogeneous LCZ areas a few hundred metres (min. 250 m) wide should be around the sites; second, the sites should be located at around the high and low temperature areas, as well as at around the areas of the local maxima and stretches assumed by the modelled pattern (Lelovics et al., 2013).

THE OPERATION OF THE URBAN METEOROLOGICAL STATIONS NETWORK

The urban climate measuring network is located on an urban area of Novi Sad (80 km^2). Meteorological stations measure air temperature and relative humidity and upload the data to a database for later processing and analysis.

The climate stations are located on lamp posts (Figure 14). Climate station has autonomous energy supply (battery) and it can recharge from the lamp post's electricity. When the lamp posts are working (during night when the bulb shines), the station's battery can refill itself so it can operate without the high-capacity replacement batteries and regularly or expensive alternative power sources (e.g. solar panels).

The stations main elements are:

- *Air temperature and relative humidity sensor*- Integrated semiconductor temperature and relative humidity sensor. RH operating range from 0% to 100% with accuracy better than +-3% at the range 20-80%. Temperature operating range from -30°C to +50°C with accuracy limits +-0.4°C at the range 0-30°C.
- *Radiation protection screen*- Glass fibber reinforced with UV resistant galvanized steel. The outer surface of the wing is white. The screen outside dimensions are from 200 mm * 300mm to 250 mm * 350 mm.
- *Measurement data acquisition module*- Low-power usage. Internet RTC clock synchronized. Data measurement frequency configurable (default 1 minute). Configurable frequency of data transmission through the communication module (default 10 minutes). On-site data storage (all measurement data and maintenance information are stored) using EPROM chip.
- *Communication module*- GPRS/EDGE/3G data modems. TCP / IP protocol. FTP transmission. Remote access to the station, status, and data query is possible via modem.
- *Power supply*- 230V power supply (recharging from the lamp post's electricity at the time of lights on). Uninterruptible power supply battery min. 2 days of life.

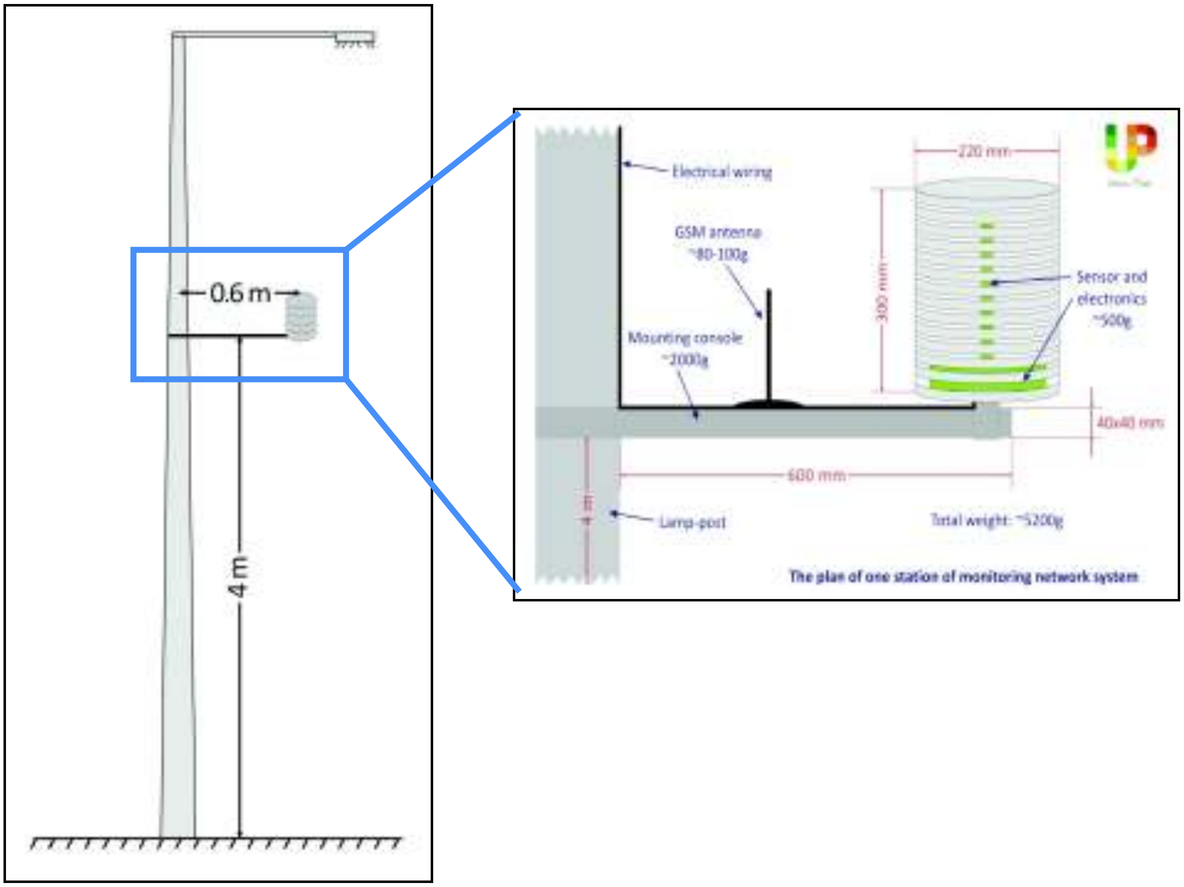


Figure 14. Location and plan of one station of monitoring network system

Except these urban stations, one station near Novi Sad (Rimski Šančevi) which operates under Serbian Hydrometeorological Service provides the data about wind and global radiation, beside the above mentioned air temperature and relative humidity data.

The urban climate meteorological stations periodically read the sensor readings and it stores data into the EPROMchip with the date of the measurement. Also, the station's clock periodically synchronize the time from an Internet time server using its modem.From the data, within a configured interval, several statistics (minimum, maximum, average values within the predefined time and the date and time) were calculated and sent in a message. The report also contains a date stamp and information on the status message (e.g. power supply, battery voltage). Report message is also stored in the data logger.

The stations send data report to the server via FTP connection. If the data transfer is disrupted, the station will attempt to send the report until it is successful. If there is no connection to the central server the station try to send the data until the connection is restored.

The central data acquisition computer is a PC running Linux (Recommended configuration: Intel i5 processor, min. 4MB of RAM, 120GB of SSD storage system, as required HDD / RAID array to the database). The PC has an uninterruptible power supply and constant connection to the Internet with a fixed IP address. FTP server of central computer receives reports of the urban climate station. Applications on the computer saved the received reports to a MySQL database (the raw reports in text files have to be stored also). Data stored in the database can be accessed by authorized users only.

Data processing consists of PET calculation, spatial interpolation and temperature and relative humidity correction. As results, maps and time series of air temperature, relative humidity and PET for the urban area of Novi Sad are obtained. These maps are placed on website of the project and on public screen in Novi Sad so it could be seen by population (Figure 15). Refreshing time of the map is 10 minutes so every 10 minutes a new map with recorded values could be seen. Coldest and hottest points in the city, spatial averages of the different city districts, etc. are among the values that are presented on the website and on public screen.

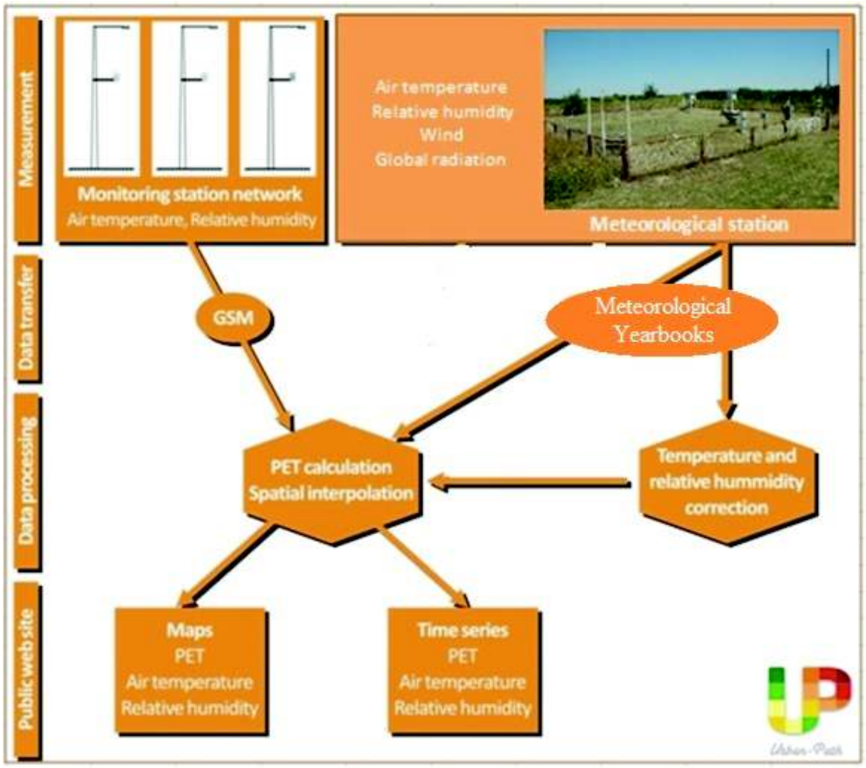


Figure 15. The operation scheme of the urban meteorological stations network

LOCATIONS OF URBAN METEOROLOGICAL STATIONS IN NOVI SAD

On the territory of Novi Sad and its surrounding, locations for 27 meteorological stations were choosen based on the above mentioned parameters and rules. There are 25 urban stations located in the city of Novi Sad, two rural stations (located north and southeast from the city outskirts) and one existing meteorological station located in Rimski Šančevi which works under Republic Hydrometeorological Service of Serbia (Figure 16 and Figure 17).

Figure 16. Urban meteorological stations network shown in Google maps (2013)

Figure 17. Urban meteorological stations network shown in Google Earth (2013)

Station name: ns01
Location: Branko Ćopić Street
City district: Adice
LCZ: open low-rise
Latitude: 45°14'1.93"N
Longitude: 19°47'38.73"E
Elevation: 77 m

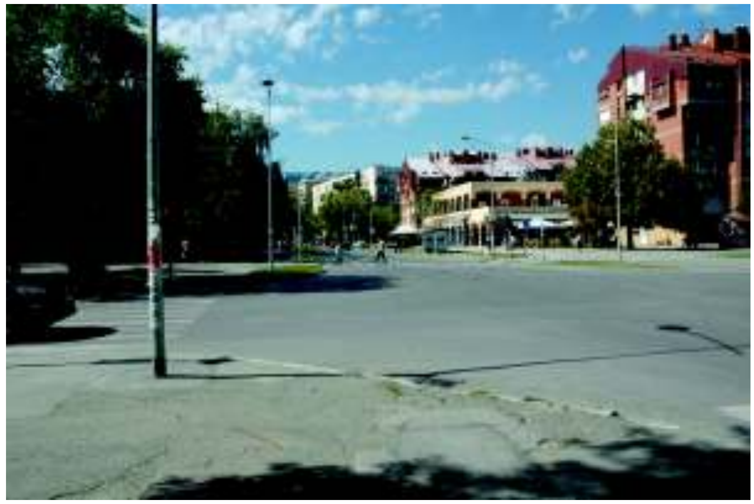
Station name: ns02
Location: Jerneja Kopitara Street
City district: Telep
LCZ: open low-rise
Latitude: 45°14'7.68"N
Longitude: 19°49'15.82"E
Elevation: 74 m

Station name: ns03
Location: Jovana Popovića Street
City district: Telep
LCZ: open low-rise
Latitude: 45°14'34.32"N
Longitude: 19°48'13.40"E
Elevation: 77 m

Station name: ns04
Location: Braće Dronjak Street
City district: Novo Naselje
LCZ: open mid-rise
Latitude: 45°15'10.38"N
Longitude: 19°47'52.17"E
Elevation: 81 m

Station name: ns05
Location: Balzakova Street
City district: Liman 3-4
LCZ: open mid-rise
Latitude: 45°14'11.74"N
Longitude: 19°50'0.62"E
Elevation: 79 m

Station name: ns06
Location: Narodnog Fronta Street
City district: Liman 1-2
LCZ: open mid-rise
Latitude: 45°14'32.59"N
Longitude: 19°50'50.49"E
Elevation: 79 m



Station name: ns07
Location: Miše Dimitrijevića Street
City district: Grbavica
LCZ: compact mid-rise
Latitude: 45°14'43.80"N
Longitude: 19°49'56.36"E
Elevation: 79 m

Station name: ns08
Location: Jovana Đorđevića Street
City district: Center
LCZ: compact mid-rise
Latitude: 45°15'7.46"N
Longitude: 19°51'1.05"E
Elevation: 81 m

Station name: ns09
Location: Uspenska Street
City district: Center
LCZ: compact mid-rise
Latitude: 45°15'18.49"N
Longitude: 19°50'28.60"E
Elevation: 79 m

Station name: ns10
Location: Karađorđeva Street
City district: Podbara
LCZ: compact mid-rise
Latitude: 45°15'58.52"N
Longitude: 19°50'25.73"E
Elevation: 77 m

Station name: ns11
Location: Gundulićeva Street
City district: Podbara
LCZ: compact mid-rise
Latitude: 45°15'50.93"N
Longitude: 19°50'49.61"E
Elevation: 79 m

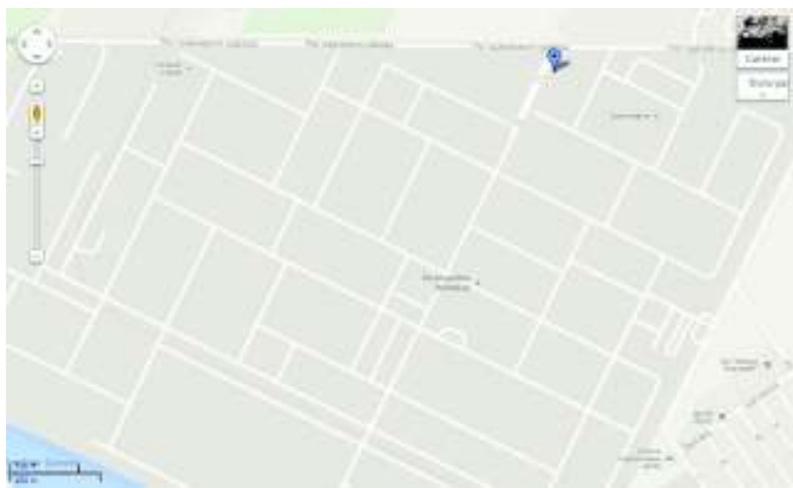
Station name: ns12
Location: Novosadskog Sajma Street
City district: Sajam
LCZ: large low-rise
Latitude: 45°15'14.70"N
Longitude: 19°49'31.15"E
Elevation: 77 m

Station name: ns13
Location: Gagarinova Street
City district: Banatić
LCZ: open mid-rise
Latitude: 45°15'41.21"N
Longitude: 19°49'43.50"E
Elevation: 81 m

Station name: ns14
Location: Milenka Grčića Street
City district: Detelinara
LCZ: open mid-rise
Latitude: 45°15'47.84"N
Longitude: 19°48'42.45"E
Elevation: 78 m

Station name: ns15
Location: Industrijska Street
City district: Industrijska zona-jug
LCZ: large low-rise
Latitude: 45°16'26.04"N
Longitude: 19°49'25.44"E
Elevation: 78 m

Station name: ns16
Location: Put Šajkaškog odreda
City district: Rafinerija
LCZ: heavy industry
Latitude: 45°16'46.45"N
Longitude: 19°52'9.68"E
Elevation: 72 m



Station name: ns17
Location: Otokara Keršovanija Street
City district: Klisa
LCZ: compact low-rise
Latitude: 45°17'15.15"N
Longitude: 19°49'42.52"E
Elevation: 77 m

Station name: ns18
Location: Koče Vasiljevića Street
City district: Klisa
LCZ: open low-rise
Latitude: 45°17'1.63"N
Longitude: 19°50'32.04"E
Elevation: 75 m

Station name: ns19
Location: Bulevar Oslobođenja
City district: Center
LCZ: compact mid-rise
Latitude: 45°15'1.48"N
Longitude: 19°50'15.37"E
Elevation: 79 m

Station name: ve01
Location: Kralja Petra I
City district: Veternik
LCZ: compact low-rise
Latitude: 45°15'11.20"N
Longitude: 19°45'38.44"E
Elevation: 77 m

Station name: ve02
Location: Novosadski put
City district: Veternik
LCZ: open low-rise
Latitude: 45°14'42.88"N
Longitude: 19°46'29.58"E
Elevation: 76 m

Station name: fu01
Location: Grmečka Street
City district: Futog
LCZ: open low-rise
Latitude: 45°14'29.48"N
Longitude: 19°42'33.74"E
Elevation: 79 m

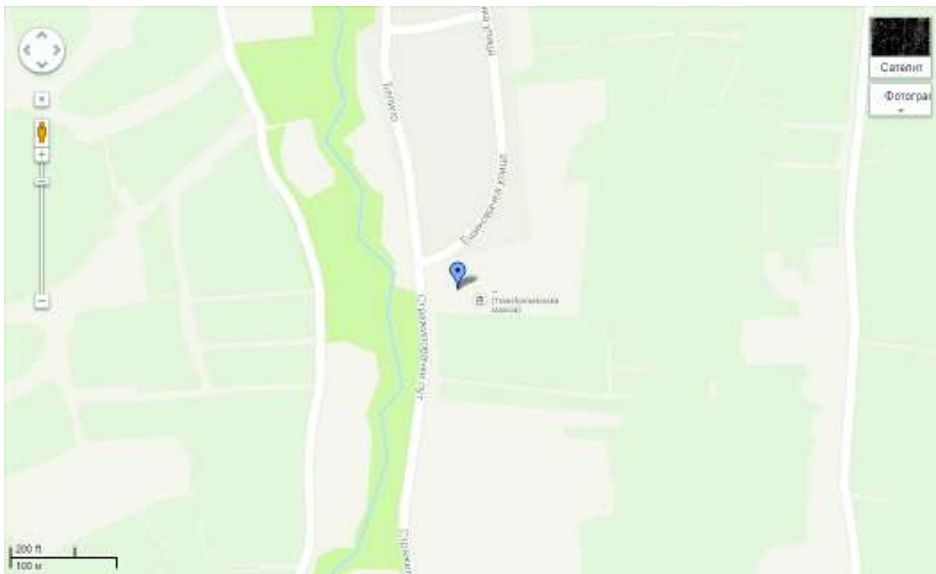
Station name: pe01
Location: Reljkovićeva Street
City district: Petrovaradin
LCZ: compact low-rise
Latitude: 45°15'9.29"N
Longitude: 19°52'34.25"E
Elevation: 76 m

Station name: pe02
Location: Mažuranićeva Street
City district: Petrovaradin
LCZ: open low-rise
Latitude: 45°14'26.17"N
Longitude: 19°52'51.91"E
Elevation: 91 m

Station name: sk01
Location: Železnička Street
City district: Sremska Kamenica
LCZ: compact low-rise
Latitude: 45°13'20.76"N
Longitude: 19°50'43.69"E
Elevation: 118 m

Station name: ru01
Location: Sportski aerodrom Čenej
(8.5 km north from the city outskirts)
Station type: rural station
LCZ: scatteredtrees
Latitude: 45°23'1.62"N
Longitude: 19°49'55.55"E
Elevation: 79 m

Station name: ru02
Location: Transformatorska stanica na izlazu iz
Sremskih Karlovaca (6.5 km southeast from the city outskirts)
Station type: rural station
LCZ: sparsely built
Latitude: 45°11'15.33"N
Longitude: 19°56'14.98"E
Elevation: 116 m



Station name: rš
Location: Rimski Šančevi
(2 km north from the city outskirts)
Station type: rural station
LCZ: low plants
Latitude: 45°19'19.02"N
Longitude: 19°49'46.19"E
Elevation: 81 m

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