Urban heat island in Thessaloniki city, Greece: a geospatial analysis

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Building Design

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«10.8.1986

Ἀληθινό εἶναι ὅ,τι

τό ξαναβρίσκουμε

γιατί μᾶς χρειάζεται»

(Κωνσταντινίδης Α.,

«Η Αρχιτεκτονική της

Αρχιτεκτονικής»,

2004:267)

Abstract

The present master thesis discusses the issue of urban heat island in Thessaloniki city, in Greece, using a geospatial approach to the analysis of the phenomenon. The UHI phenomenon is known almost from the beginning of cities' urbanization. What encourages scientists in a global scale to select it as a study subject is that, the phenomenon becomes more pronounced at these years due to climate change and strong urbanization on a global scale. At the same time, there is a keen interest in the quality of peoples' life in cities in relation to environmental and energy issues that are directly connected to the environment protection and the conservation of natural resources.

Thessaloniki is a big city for Greece and a reference point for the Balkan space but for this work is the field of the UHI phenomenon research. The study was conducted using air temperatures and applying the Kriging Ordinary interpolation technique in ArcGIS. The results showed that the city faces the phenomenon of particular intensity during the summer months, but also it has a strong presence during the winter months. The chargeable event of the phenomenon as demonstrated by this study is the existing urban density, the height of the buildings and the land uses, as residence, retail market and central city's function. Thus, through ArcGIS tools, these urban parameters reclassified and "added" to produce an image that depicts the areas that are most likely to experience the effect of the "warm district". Afterwards, the correlation between the generated image that display potential event UHI in Thessaloniki city and the Kriging Ordinary interpolation temperatures images verify both processes as well. The results are positive as they have high identification rate. Hence, the research illustrated the effect of "thermal areas" in Thessaloniki and found what are the areas within the main city are more likely to develop the UHI phenomenon.

Words Keys: Urban Heat Island, Thessaloniki, Interpolation method, ArcGIS, Urbanization, Building density and height, Urban land uses.

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I would like to express my warm thanks and gratitude to Mr. Alexander Kalathas, GIS technician and employee in Data Marathon Systems, who offered his valuable knowledge on ArcGIS with great patience.

At last but not least, I would like to thank my brother, Eftychios Eftychiadis and my best friend Irene Simitlioti for their support to this exertion.

Ourania Eftychiadou

Architect Engineer

November 30, 2017

I hereby declare that the work submitted is mine and that where I have made use of another’s work; I have attributed the source(s) according to the Regulations set in the Student’s Handbook.

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CHAPTER 1: Introduction

1.1 State of the art

The interdependence between energy and urban planning is very strong. The new morphological framework created in the early 20th century by the requirements of the industrial revolution economy, as well as the new materials, the new constructive thought and style (Lavvas, G.P., 1996; Frampton, K., 1999) creates a new urban framework development, which in its application was not able to escape the overexploitation of land and the application of proper terms and limitations of building. As a result, cities now have serious problems in their operation and cause health problems for their residents, resulting in depreciation of the normal level of people's lives. The current situation in cities undermines the health of the inhabitants and the natural flow of everyday life and seasonality.

CIAM IV identified the dysfunctions of city that is subjecting the same problems today, the lack of adequate green areas and buildings maintenance, due to speculation to maximize the exploitation of the existing resources and capabilities of the urban land, eliminating green areas. However the modern movement in its implementing promoted strongly the grid plan, the Hippodamian urbanization system, which is the rudimentary design of a city’s urban planning, not interested in the specifics of the site, such as the topography, geography, character, and climate, played a special role in the character of today's cities. Today, the existing situation in cities came from the past decades attitude which created a non-friendly environment for human in the developed spaces. Cities are not cut off from the wider natural environment; they are still influenced by nature and suffer from climatic phenomena, earthquakes, volcano eruptions.

There is a relationship of interaction between cities and nature, as nature affects the natural phenomena of cities as well as cities evidenced by the latest scientific studies can affect nature by increasing the percentage of carbon dioxide in the atmosphere is increasing global warming provoke the climate change (Bonan, G., 2012), the rise in temperature in cities is capable to raise storms rates (NASA), but even with the increase of urbanization is suspected to change the climatic conditions both locally and globally (Chakraborty, T., et al. 2016; Manik, T. K. and Syaukat, S. 2015; Dener Lima Alves E. and Lopes, A. 2017; dos Santos Cardoso, R., et al. 2017). Further, big cities because of the large developed land they blame for temperature increasing on the earth and UHI phenomenon as well. The urban heat island effect is more essential than someone can understand at first contact. It is able to cause deaths, to diminish people’s comfort and to raise sharply the demand for energy in buildings (Mirzaei, A.P., 2015).

The phenomenon of the thermal urban islet is perceived by the users, as is commonly accepted that a city is warmer than and its surroundings. Thus, the primary way to determine the phenomenon in an urbanized area is by comparing urban temperatures with outdoor temperatures in the wider region. Therefore, the phenomenon of the thermal isle is linked to the degree of development in a region. The climate of a city is influenced by a positive sign beyond the climate of the place by the form of urbanization, (density, height, proportions of the buildings size and roads width) and the percentage, type and distribution of green space and finally building materials, that have high absorptivity and low reflectivity, resulting in an unpleasant urban microclimate.

The UHI phenomenon has many aspects and peculiarities that occur every time through studies conducted in different urban areas. In what emerges recent studies is the place and its characteristics, which is the phenomenon, is a determining factor in the creation of the UHI. Characteristics of the city, such as the size analyzed to show that there is a different reason for its creation UHI between day and night. (Peng, S. et al., 2012). It has been shown that urban areas that do not have enough green spaces within them are unable to cool quickly. (Zhao, et al., 2014). Moreover, the correlation of UHI with the size, type and shape of the city has shown that the size and type of the city (compact or not) act in a proportional manner to the intensity of the phenomenon, while the elongated shape helps in quick cooling. In addition, population and buildings density, and vegetation fractions can create appropriate conditions for the appearance of UHI (Zhou, B., et al., 2017).

Consequently, it has been understood that urban form has a major role in shaping the thermal effect in urban areas. (Salata K. D. and Yiannakou A. 2013; Kosmopoulos P. & Kantzioura A. 2014; Kantzioura, A. et al., 2012; Rapsomanikis, S., et al., 2014) and that the urban design is connected with the thermal comfort in the urban area (Johansson E. and Emmanuel R. 2006; Yang F., Lau S.S.Y., Qian F. 2011; Shashua-Bar L., Tsiros X. I., Hoffman M. 2012; Ali-Toudert F. and Mayer H. 2007). As land use can affect the urban climate (Bonan G., 2012)

Already, some researches investigations have been made about the city of Thessaloniki like Giannaros, T.M. et al., 2010, where they concluded that Thessaloniki is subject to a mediocre UHI, which is perceived during overnight hours, and reach its maximum size in early morning hours. Moreover, there are studies that focused on the Thessaloniki's UHI characteristics and the wind role on it. (Giannaros, T.M., Melas, D., 2012). While others dealt with the morphology of the urban environment and its effect on the creation of microclimatic conditions (Kantzioura, A. et al., 2012; Kosmopoulos P. & Kantzioura A. 2014)

The aim of this thesis is to study the UHI phenomenon in Thessaloniki, in light of the impact of city’s planning features on this phenomenon. Analytically, the influence degree of existing urban characteristics in Thessaloniki, that were selected to be examined in this study, i.e. urban density, building heights and land uses, as the root causes of the UHI phenomenon. This will be achieved by:

- Creating images that describe the temperatures in Thessaloniki, using the interpolation tool in ArcGIS.

- Defining the UHI phenomenon "gravity" of the urban parameters cause (Reclassify) and create an image (Raster calculator) that illustrates the most likely areas that the UHI effect can manifest, describing the possibility of spatial development of the UHI in Thessaloniki.
- Comparing the temperature images with the generated possibility for UHI image so as to evaluate the all procedure and tools.

This diploma thesis is organized in six chapters. The first chapter introducing the topic of UHI and states the thesis aim and objectives, and display the research methods and tools that used. The second chapter is a theoretical approach to the UHI phenomenon, presenting relevant concepts such as thermal comfort outdoors, urban climate, causes, impacts, and applications. The third chapter deals with the city of Thessaloniki, which provides information on the urban development and population of the city, as well as the prevailing climatic conditions. The fourth chapter presents data collection, the selection of the appropriate interpolation method and the GIS process. The fifth chapter concerns the analysis of the study, concerning the qualitative and spatial analysis data. In the qualitative analysis an exploration was made in a 30-year time series to identify climatic trends but also for the specific features of the climate in the year 2016. The spatial analysis was implemented interpolation Kriging Ordinary using average monthly, minimum and maximum temperatures per month. Additional became an urban form's cartographic analysis through the correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the monthly average temperatures but also the minimum and maximum temperatures. Further, an output evaluation has become, so as to check the work results. Finally, in the sixth chapter the conclusions from the study and the proposals for treatment are formulated.

1.2 Methodology and Tools

The study issue involves a combination of theoretical and methodological approaches. The theoretical approach become via traditional library research as well through the internet, media, papers, and official authorities and services files. In the part of methodological approach, a combination of various methods used in order to ensure the most accurate results. This section includes interpretive and analytical framework, and methods of qualitative analysis. Thus, basic tools that will be used are maps and empirical observation of space. Data collection had been done from competent bodies such as organizations and authorities. The key steps in this part are the data collection and data analysis.

The basic working tool will be the ArcGIS Spatial Analyst which is fully integrated with ArcGIS Desktop to conduct analysis and modeling tasks via ModelBuilder™. By using the ArcGIS Spatial Analyst, is possible to create spatial modeling and good quality spatial resolution mainly based on grid (raster) data. Hence, it can be created a cartographic analysis of grid performance data and an implementation of integrated grid-vector (raster-vector) analysis.

Analytically, it will be done a model of Thessaloniki urban space so as to be possible to extract information from existing data, analyzing spatial relationships, and perform complex functions of grid data. The UHI phenomenon could be examined through cell statistics that can calculate a statistic between multiple rasters, for instance, to analyze a certain phenomenon. A map showing the density of the built environment and the buildings heights as well will be associated with the land-use map to identify vulnerable areas in UHI phenomenon.

Land uses in an area are significant because can regulate and define many issues. They can stimulate the economy and the vitality of a region but also can function and protective, as “with appropriate land use planning, the UHI could be mitigated” (Kardinal et al, 2007). Therefore, their correlation with the temperatures surfaces that will generate from the ArcGIS interpolation will provide excellent information. Further, these temperatures images will be correlated with the city’s existing buildings, so as to extract result for the role of building environment in the phenomenon UHI.

Urban features influence, land use, building height and density, in UHI is defined by a scale (Reclassify). That process, define the gradations of urban indicators and create an equalization of significance of each urban feature in UHI. The three reclassified surfaces for urban UHI factors (land use, building height, and density) are linked by defining a weight with their contribution in the creation of the thermal isle in Thessaloniki. The ArcGIS Raster calculator tool is capable of “adding” these surfaces and generating a surface that gathers all the information from each surface in a percentage that can be determined as an effect quota in the phenomenon. Hence, the generated surface describes the districts that are more likely to experience the UHI phenomenon.

CHAPTER 2:

Theoretical Approach of the Urban Heat island phenomenon

2.1 The city today

Cities are the development models of early human settlements. They are the places where people's socio-economic activities take place, and therefore they are considered centers of innovation and development. Although the original settlements of humans were created to protect them from the natural hazards of nature, today the cities are still directly affected by nature's elements such as weather conditions.

The urbanization (‘exastismos’) takes extreme values in the modern societies of the globalized economy (Tsoukala, 2009). Changes in production and economy structures bring about changes in the spatial structure of cities. During the 21st century there was an increase in the demographic index of urban areas which provoke the spreading of urban areas into rural, forest and semi-urban areas, results a strong change in the balance between structured and unstructured areas.

Cities are the backbone of people's socio-economic activity and they meet human needs such as heating, cooling, transportation, and therefore cities are big producers of pollution and carbon dioxide. Cities today occupy approximately only 2% of the total land, however they are responsible for the 70% of Global economy (GDP), the 70% of Global waste, the 70% of Greenhouse Gas Emissions and for over 60% of Global Energy Consumption (Habitat agenda III, 2017).

The great urbanization that our planet experienced in the 20th and 21st centuries changed the living conditions of most people, as since 2008 more than half of the world’s population lives in urban areas for the first time in known history (United Nations New York, 2008: iii), it is understandable that cities today are important spaces for our civilization but with severe problems in their operation. Cities are exposed to the wider environmental problems of the planet, such as climate change, but also to their endogenous problems such as pollution, transportation, the Urban Heat Island phenomenon, which are a causal link to degradation of urban environment and users' lives.

Nowadays, cities are planned and construct according to economic growth and social needs. Planning focuses on the neighborhood image using green as a design component, satisfying aesthetic design needs, and not as continuity of nature in the city. The land uses change has more consequences as initially could be perceived from an ecological change due to deforestation, creating land for cultivation or habitation. The climate characteristics of a land can alter because of these changes interventions in the natural environment with unpleasant aftermath for the living beings of the planet. The change in natural biogeophysical process can cause climatic change (Bonan, G., 2012).

2.2 Thermal comfort outdoors

Outdoors spaces in a city composed of streets, sidewalks, squares, woods, parks, gorges, and gardens. People use them to move, entertain, relax, and buy. They are also the places where people are exposed to the prevailing weather conditions. Conditions in outdoor urban space are very important as they can determine the thermal comfort of people.

Human‘s comfort mainly influenced from the outer environment. Simultaneously, the human body by nature can adapt to the respective external environment. (Lasker, G.W., 1969; Katzmarzyk, T.P. and William R.L., 1998). The thermal comfort of man is important for both his health and well-being, (Mather, R.,J., 1974), which affects his psychology and performance in his daily duties. Comfort is achieved when the flows to and from the human body are in equilibrium and the skin temperature and the sweating rate are located within the limits of comfort (Fanger, P.O., 1972). The temperature of the environment is just one feature for the feeling human’s comfort, as the comfort in a given environment further, depends on the air’s humidity for the higher temperatures, while for the lower ones depends on the wind speed.

“Thermal Comfort is that condition of mind that expresses satisfaction with the thermal environment” (ASHRAE Standard 55 from: ASHRAE 2001, Fanger, 1970). Thermal comfort is a multifaceted subject as it has many parameters that define it. Thus, thermal comfort is the interaction with the natural environment and depends on the individual’s psychology, the existing architecture, the costume code, the natural processes of the human body and the local climate (Błażejczyk K., 2009; Chappells H. and Shove E., 2004; Hoppe, P., 2002; Brown R. D. and Gillespie T. J., 1986; de Freitas C. R., 1985). During the 20th century, human needs become a priority for the society, and despite the fact that initially the issue of comfort appeared within the army in order to create a comfortable working environment for the soldiers (Fabbri K., 2015), very quickly became the purpose of both human living theories and devices’ manufacturing companies that enhance the quality of life of people.

Studies on the external environment (de Freitas, R.C., 1985; Höppe, P., 2002) address the issue of thermal comfort in a holistic way as the approach is made from the human side as an entity (physiology and psychology) but also from the prevailing urban environment conditions due to urban planning and design.

Outdoor facilities should be thermally comfortable and existing technology could provide solutions to that direction, but the energy cost is high. Hence, the microclimate should be taken advantage for having an outdoor thermal comfort and less energy use (Brown and Gillespie, 1986). Furthermore, thermal comfort in the urban area is directly related to the climatic conditions prevailing in the area that are affected by the design of the space (Johansson E. and Emmanuel R. 2006; Yang F., Lau S.S.Y. and Qian F. 2011; Shashua-Bar L., Tsiros X. I., Hoffman M., (2012); Ali-Toudert F., Mayer H., 2007). Consequently, the microclimate and the mesoclimate (Bokwa A. et al., 2008), of a region can determine the thermal comfort and can be regulated by planning.

The microclimate usually involves a part of the city where climatic conditions are different from the surrounding area. The factors that affect the formation of a microclimate are the height of the buildings, their orientation and their density. Geography and topography, road geometry, i.e. the width of the road in relation to the height of adjacent buildings, have a significant role of the microclimate character. Moreover, the size and layout of open spaces, wind block elements, thermal properties of materials, green layout, radiation and shading, heat emission sources and air pollution can control the comfort degree of an area. (Meijer, I., Santamouris M. courses lectures 2015-2016)

Moreover, there are some studies that focus on the issue of external thermal comfort in relation to humans (Nikolopoulou M. et al., 2001), where human reactions to weather conditions at different times were studied in different cities in Europe (Nikolopoulou M. and Lykoudis, S. 2006). Specifically, the urban heat island is found to have a negative impact on thermal comfort on most of the observed occasions. In particular, a 1,5°C increase in the urban heat island intensity appears to result to an average 1°C increase in discomfort index and 1,4 °C increase in approximated wet bulb globe temperature of the urban area on about 50% and 75% of the cases, respectively. (Giannaros, T.M., and Melas, D., 2012).

2.3 Urban climatology

"The study of the physical, chemical and biological processes operating to produce, or change the state of, the atmosphere in cities is called urban meteorology. The study of the resulting preferred states of their atmospheres is urban climatology." (Oke, T.R., 1984). Thus, urban climatology is the weather conditions that are expected in an urban area.

Luke Howard was the first who highlighted that temperatures between London and its surroundings deviated significantly. So today is considered the founder of urban climatology (Mills G., 2008) with his study of the London climate and his book "The Climate of London" observed the city's increased temperature in relation to the countryside (Oke T.R., 1982).

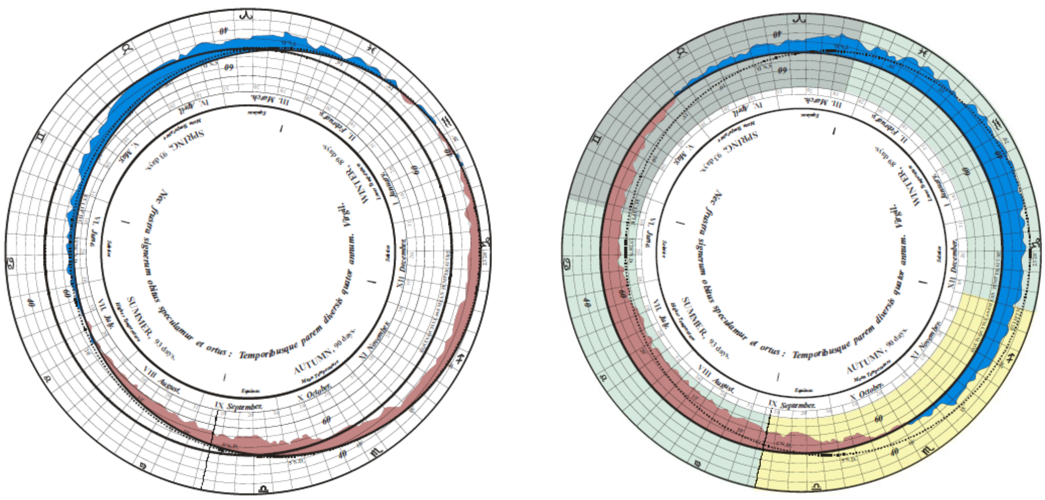


Fig. 1: The yearly cycle of Temperature.
(Source: Howard L., 1833, “The Climate of London”:
Accessed from: http://www.urban-climate.org/documents/LukeHoward_Climate-of-London-V1.pdf, at 30-07-2017)

More recently, Oke is the one that extensively involved in Urban Climatology (1979: Boundary Layer Climates, 1984: Methods in Urban Climatology). Urban climatology is a different branch of climatology as the existing city conditions influence the atmosphere of the city, forming a different environment in relation to the countryside. In particular, the study of "Methods in Urban Climatology" in 1984 set a framework in methodology and techniques in use in urban climatology. Further he defined the field of science: "The study of the physical, chemical and biological processes operating to produce or change the state of the atmosphere in cities is called urban meteorology." (Oke, T.R., 1984).

Oke, T.R devoted a large number of his studies on the phenomenon of the thermal urban islet (in 1973: City size and the Urban Heat Island; in 1981: Canyon geometry and the nocturnal urban heat island: Comparison of the scale model and field observations; in 1982: The energetic basis of the urban heat island. 1975: Urban heat island dynamics in Montreal and Vancouver), so he is considered one of the leading scientists who dealt with the subject.

At the same time, Bornstein R. in US was another studier who was dealt with urban climate issues and the thermal island (in 1968: Observations of the Urban Heat Island Effect in New York City; in 1975: The two-dimensional URBMET urban boundary layer Model; 1977: Urban-Rural wind velocity differences; in 1977: Observations of Mesoscale Effects on Frontal Movement through an urban area; in 2000: Urban heat islands and summertime convective thunderstorms in Atlanta: three case studies).

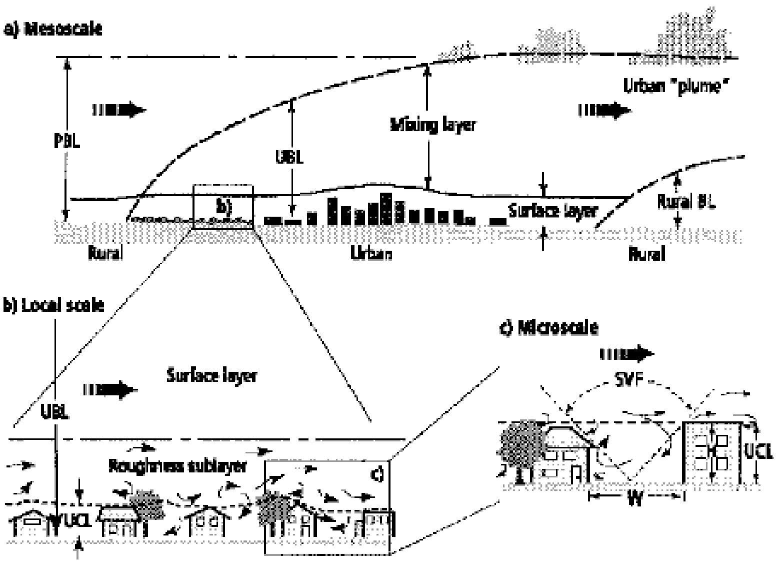


Fig. 2: The urban climate in various scales: microscale, local scale and mesoscale.
(Source: Oke, T.R. “Observing urban weather and climate using 'standard' stations”.
Accessed from: http://www.eurasap.org/35/paper1.html at 30-07-2017)

Climatic parameters determine the climate of a region. The main climatic parameters are radiation, temperature, wind and humidity. (Chronopoulou-Sereli, E. and Flokas, A.A., 2010). According to G. Mills (2016), “there are clear links between the climate of a settlement and its potential sustainability”. That’s why urban climate is a popular field of research that attracts the interest of researchers from different specialties, such as Architects, Physicians, Urban Planners, and Meteorologists. Thus, the each approach has great interest in the subject of each specialty. Urban climatology is in an embryonic level of development and the so far knowledge on the subject is not applied for urban planning. That happens because science fields are completely separate. (Mills G., 2016).

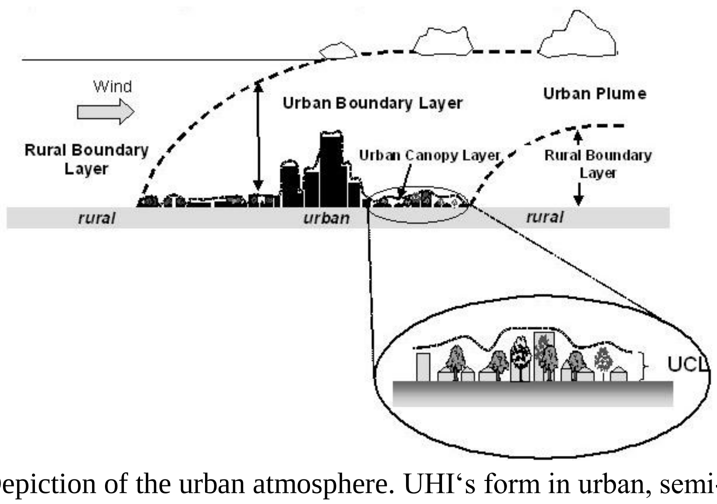


Fig. 3: Depiction of the urban atmosphere. UHI‘s form in urban, semi-urban and rural environment.
(Source: Voogt A. J. (2004). “Urban Heat Islands: Hotter Cities”.
Accessed from: actionbioscience: http://www.actionbioscience.org/environment/voogt.html)

“Fundamental to the issue of scale is the distinction between the urban canopy layer (UCL) and the urban boundary layer (UBL). This distinction, originally applied to UHIs by Oke (1976), has been a guiding principle in urban climate research of all types. In the UCL (roughly from ground to roof level), processes of airflow and energy exchange are controlled by micro scale, site specific characteristics and processes. The UBL, above roof level, in contrast, is that part of the planetary boundary layer whose characteristics are affected by the presence of the urban surface (or its land-use zones) below and is a local to meso scale phenomenon controlled by processes operating at larger spatial and temporal scales. The distinction goes beyond mere scale, therefore: it reflects different assemblages of processes. The patchy and heterogeneous nature of the urban surface has significant implications in the interpretation of measured energy budgets and in the design of tower-based flux studies.” (Arnfield A.J., 2003)

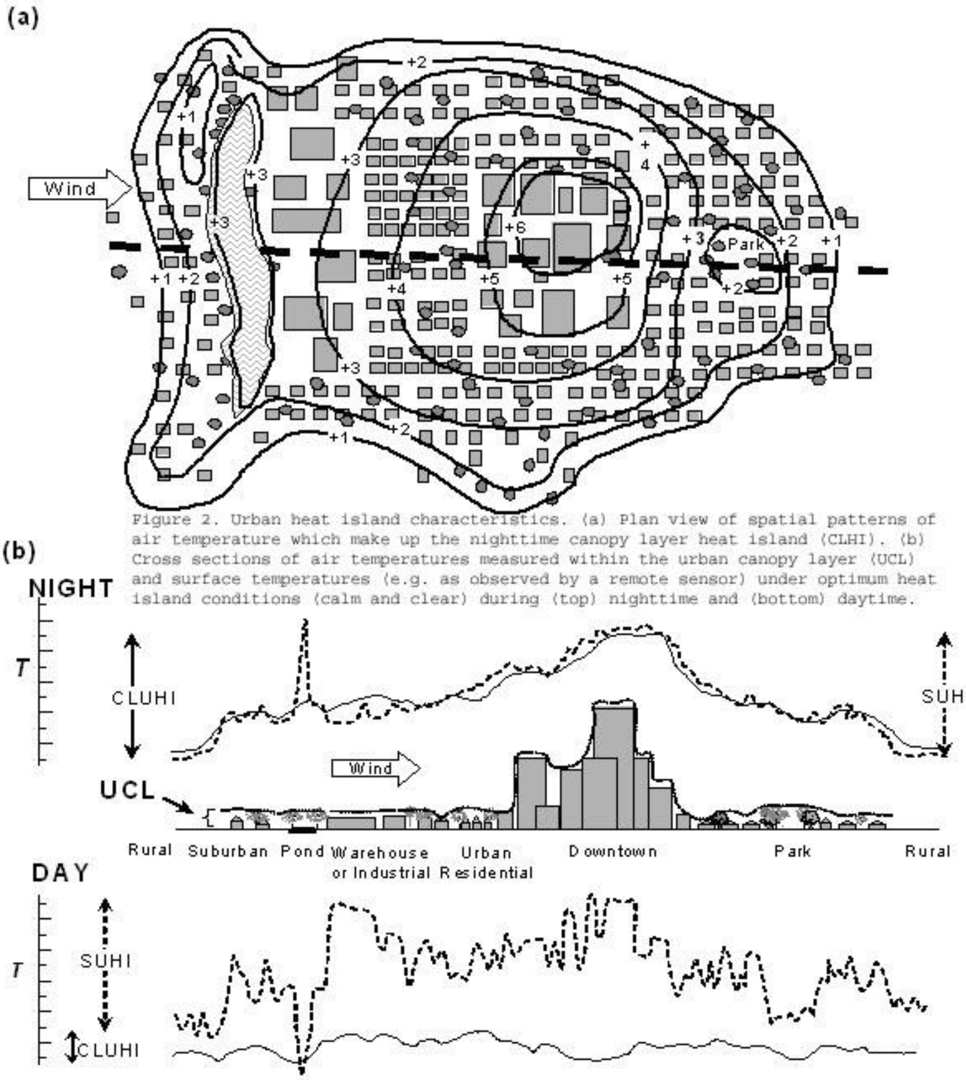


Fig 4: The depiction of the phenomenon UHI.

(Source: Voogt A. J. (2004). “Urban Heat Islands: Hotter Cities”. Accessed from: actionbioscience: http://www.actionbioscience.org/environment/voogt.html)

“Urban climatology has benefited profoundly from conceptual developments in boundary-layer climatology, broadly defined. In particular, recent enhancements of the roughness sub layer and of the implications of heterogeneity and flux source areas have found extensive application in both the interpretation of urban energy balances and their measurement.” (Arnfield A. J., 2003).

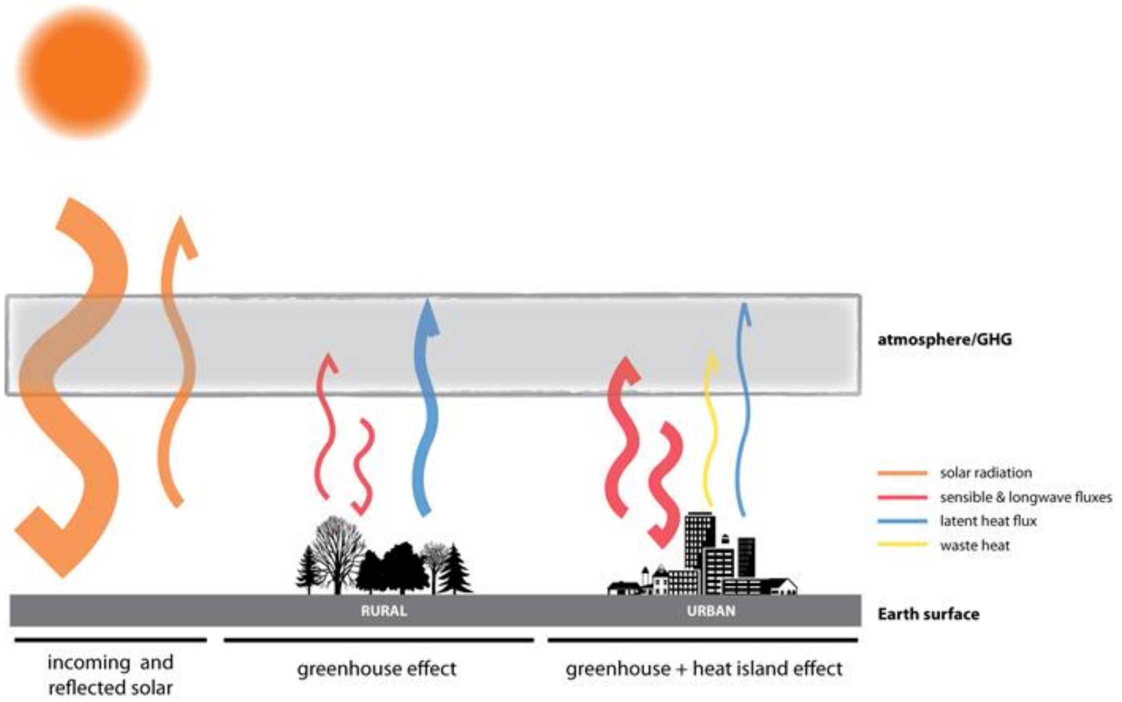


Fig. 5: The function of solar radiation, greenhouse effect and heat island effect.
(Source: Urban climate Lab.
Accessed from: http://www.urbanclimate.gatech.edu/, at 04-08-2017)

City conditions, a catalytic effect on its climate, are the degree of urbanization, its size, land uses, population size, rate of pollution, material surfaces, city morphology, geometry, topography, orientation, existence of water element, and quantity and type of existing green. Cities are never the same as they have different characteristics. “Hence the transferability of results from one to another is fraught with difficulty” (Oke, T.R., 1984). Factors that determine the urban climate are many and different and it is conceivable that the urban climatology and in particular of the thermal urban islet has many aspects.

2.4 The historical evolution of the city's climate change

The phenomenon “Urban Heat Island” was first investigated and described by Luke Howard in the 1810s, although he was not the one to name the phenomenon. (Source: http://www.ftrctlb.com/node/155). After L. Howard, there were many scholars like Lorenz-Libernau, von. in 1890 with his study "Resulte forstlich-meteorologischer", then Geiger, R. in 1927 with his study "Das klima der bodennahen luftschicht"; afterwards

Ungeheuer, H. in 1934 with his study: "Microklima in e. Buchenwald am Hang "; thereupon Kratzer, in 1937 with the study of "Das Stadtklima", Wolfe, J. N., R. T. Wareham, and H. T. Scofield, in 1949, "Microclimates and macroclimates of Neotoma, a small valley in central Ohio"; the Geiger, R. in 1950 "The climate near the ground"; the Brooks, in 1952, "Atmospheric Radiation and its Reflection from the Ground", and Parry, M., 1956, "Local Temperature Variations in the Reading Area", who dealt with urban climate by focusing on the UHI issue.

It is perceived by the number of scientific studies concerning the urban climate during the first half of the 20th century that there is a keen interest in the subject, as during this period major rebuilding takes place in the cities because of the new modern materials (known by the late 19th century) (Lavvas G.P., 1996; Frampton, K., 1999) and on the other hand because of the great wars that took place during this period.

During 70s and 80s, scholars were interested in climatology issues influenced by the oil crisis (1972) and shifting interest of society in environmental issues. Hence, we observe studies such as the Lawrence, E.N., in 1971, “Urban Climate and Day-of-the-Week”, the Bond, P.G., in 1974 "Horizontal temperature patterns in and around the city of Melbourne with respect to their importance in the concentration of pollution", the Oke, T.R. in 1973 "City size and the Urban Heat Island", the Lyall I.T. in 1977 “The London heat island in June-July 1976”, the Nunez, M. in 1979, "The urban heat island", as Karl T.R., Diaz, H.F. and Kukla, G. in 1988 with their study "Urbanization: Its Detection and Effect in the United States Climate Record",

Since the 1990s, it confirmed the existence of global warming after the study of historical temperatures for confrontation the urban heat-island effects. (Source: The Discovery of Global Warming: The Modern Temperature Trend, January 2017. Accessed from: https://history.aip.org/history/climate/20ctrend.htm#N_39_). Most studies, within the decade, were focused on the UHI phenomenon, Jones, P. D., et al. (1990) “Assessment of urbanization effects in time series of surface air temperature over land”, Meyer W. B. (1991) “Urban Heat Island and Urban Health: Early American perspectives”, Moreno-Garcia M. C. (1994) “Intensity and form of the urban heat island in Barcelona”, Morris, C.J.G. In 1995, "The urban heat island in southeastern Australia".

During the 2000s, studies were conducted that concerned studies in areas outside Europe and the US, Dixon P. G. and Mote T. L. (2003) “Patterns and Causes of Atlanta’s Urban Heat Island–Initiated Precipitation” and Souza L. C. L., et al., (2007). “Urban heat islands and electrical energy consumption in a Brazilian city”. Over the current decade there is a strong interest in the issue of UHI (Buttstädt M. and Schneider C., 2014), across the globe as it employs more people, as the largest proportion on the planet are the urban population (UN 2000), and society sensitized to environmental issues, particularly on the global warming issue and particularly in most affected regions, i.e. tropical-subtropical, (Chakraborty, T., et al., 2016); Manik, T. K. and

Syaukat, S. (2015); Dener Lima Alves E., and Lopes, A., (2017); dos Santos Cardoso, R., et al., (2017).

In addition, it is observed that a large number of studies originated in China, which after its rapid growth and urbanization faces the UHI problem, (Liu L. and Zhang Y., 2011; B. Yang, et al., 2015). Indeed become large in spatial extent studies, (L. Zhao et al., 2014).
It seems that the UHI phenomenon is parallel with the development of the settlements. A historical review and assessment of urban heat island research in Singapore by Roth M. and Chow T.L.W., (2012) showed that urbanization is a major factor in coming into being the UHI phenomenon in Singapore. The same thing is confirmed by Ren, G.Y., Chu, Z.Y., Chen, Z.H., Ren, Y.Y., (2007), who studied the annual and seasonal average surface temperature of 1961-2000 and 1981-2000 at the two stations of Beijing and Wuhan Cities and their nearby rural stations, and concluded that temperatures increased significantly with the urbanization presence. Thus, they attribute the annual urban warming accounting for about 65-80% of the overall warming in 1961-2000 and about 40-61% of the overall warming in 1981-2000.

Apart from the evolution of the phenomenon's study we should consider that the excessive population growth over the last few centuries, due to the improvement of people's living conditions and the technology and science advances, has caused a great destruction of natural ecosystems for the conversion of land into agricultural use, or pasture, or residential use. It is estimated that 112.610 km^2 of land in the US is covered by human constructions such as buildings, roofs, streets, car parks, that is, the size is as much as the extent of the state of Ohio. (Elvidge et al., 2004 from Bonan, G., 2012). "Land-cover change and human uses of land greatly affect natural Earths biogeochemical cycles". (Bonan G., 2012)

2.5 The phenomenon of the thermal urban isle

Urban thermal plume is the long cloud of hot rising air, above of urban areas, from the lower altitudes of the Earth's atmosphere because of the urban heat emission and it has been mentioned as urban heat island (UHI) (Hsu Sheng-I, 1981). The dense urban fractions appear larger temperatures in relation with their less urbanized surroundings and the rural area, especially during the night (Quattrochi et al. 2000; Oke 1982). Eventually, UHI is the local urban foci with unusual heat, dissimilar to their vicinity, making spatial enclaves of warmth changing the city's atmosphere.

The UHI intensity is often quantified by the air temperature difference between urban and rural areas. (Lee, S.H. and Baik, J.J., 2010). The intensity in urban areas depends primarily on the intensity of the existing solar radiation but further, the density of urbanization is absolutely responsible for temperature rising during the summer night hours. The most common result of the phenomenon is at the night time temperature not recedes from the city's environment but in the contrary, the night time temperatures may be higher than of day time. (Oke, T.R., 1982; IPCC, 2001). The giant cities have a large share of responsibility for increasing their temperature and aggravating the urban heat island phenomenon as well as the general rise in temperature on the earth. (Mirzaei, A.P., 2015).

“Photo synthetically active radiation is also significantly depleted under much polluted atmospheric conditions. Jacovides, et al., (1997) found reductions in the global irradiance of this quantity of more than 18% in some circumstances. Incoming longwave radiation is generally believed to be increased by urban areas, either due to the increased warmth of the urban atmosphere (UHI) or enhanced atmospheric emissivity brought about by the presence of particulate and gaseous pollutants (Oke, 1979b, 1982). Suckling (1981) found consistently larger in Brandon, Manitoba, in Canada compared with the rural environs (average 10% increase, maximum 20%). Slightly smaller percentage changes found by Estournel et al. (1983) for Toulouse were shown to be largely a result of increased urban atmospheric temperatures rather than pollution.

Neglecting soil heat flux, which is near zero when averaged over a day (Campbell, 1977), net radiation can be partitioned between sensible and latent heat. This partitioning of energy is commonly expressed as the Bowen ratio (sensible heat/latent heat) and yields valuable information on the microclimate prevailing at the earth's surface. Sensible heat causes the elevation of daytime air temperatures above those existing under nighttime conditions. Under ideal night conditions temperature will tend toward the dew point temperature, with the minimum value usually occurring just before sunrise. For a specific Bowen ratio on any given day, the greater solar radiation load, the greater is the heating of the air. This results in a larger difference between daily maximum and minimum air temperatures. (Bristow, L.K. and Campbell, S.G., 1984).

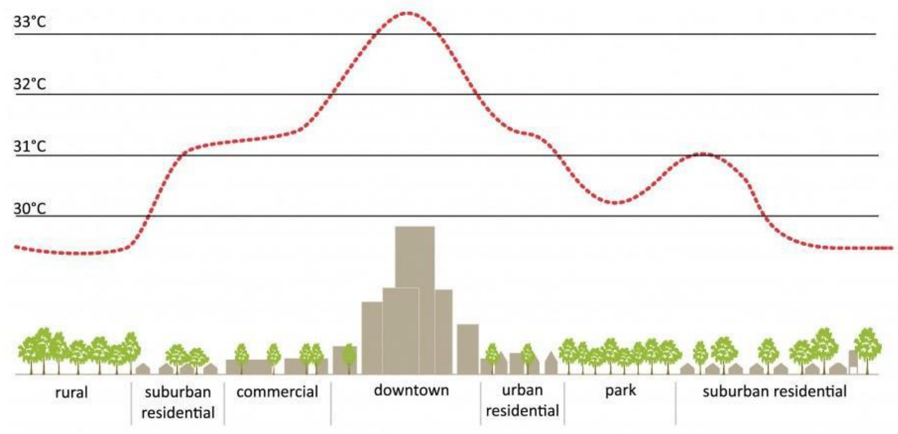


Fig. 6: The Urban Heat Island.

(Source: EPA, 2008. EPA’s report on the environment. Accessed from: https://cfpub.epa.gov/roe/documents/EPAROE_FINAL_2008.PDF, at 05-08-2017)

“The elevated air temperature of a city, urban heat island (UHI), increases the heat and pollution-related mortality, reduces the habitats’ comfort and elevates the mean and peak energy demand of buildings” (Mirzaei, A.P., 2015). UHI has dual mainly consequences to society, on the one hand concern citizens' health and on the other the financial burden. UHI undermines the thermal comfort of people as the heat stress, which people feels in the city especially during the summer months, strangles their well-being and provokes many primary deaths in vulnerable age groups. Further, the handling of extreme temperatures brings peak in cooling energy demand burdening individually and socially with the cost of consumed energy for cooling.

There is an extensive series of studies and studies on the UHI phenomenon both for different cities around the world (Dixon, P.G. and Mote, T.L., 2003; dos Santos Cardoso R. et al., 2017), as well as studies that study specific aspects of the subject UHI, such as urban morphology (Alobaydi D. et al., 2016; Ali-Toudert F. & Mayer H. 2006; Golany, G.S., 1996), its correlation with energy consumption (Souza L.C.L., et al., 2007), with urbanization (Jones, P.D., 1990), with health (Meyer, B.W., 1991).

The urban heat island has become the target of recent research aiming at improving urban climates and energy efficiency of cities. In the warm, mid- and low-latitude cities, the typical heat island intensity averages up to 3-5°C on a summer day, adding to discomfort and increasing the air conditioning loads, whereas in some temperate and cold, high-latitude cities a 2°C heat island is considered as a mild asset in winter. Some of these cities have been built to retain the urban heat (Taha, H., et al., 1988).

Moreover, there are recent studies about the UHI phenomenon that show variable aspects of the phenomenon. A study (Zhao et al., 2014) which based on 65 cities in North America found that there are geographic variations in daytime (ΔT) and annual mean daytime and nighttime temperatures are positively correlated with the humidity and population. Further, they observed that when urban areas are streamlined, less vegetation more buildings, than surrounding non-redevelop areas, the city’s heat outflow to the outside environment is small. In an another study (Zhou B., et al. 2017), worked on the influence of city size and urban form have on the Urban Heat Island (UHI) phenomenon in Europe and find a complex interplay between UHI intensity and city size, fractality, and anisometry. They found that among the largest 5,000 cities, the UHI intensity increases relatively with the city size and with the fractal dimension, but decreases with the anisometry. The size has the strongest influence, followed by the compactness, and the smallest is the influence of the degree to which the cities stretch. Accordingly, from the point of view of UHI alleviation, small, disperse, and stretched cities are preferable.

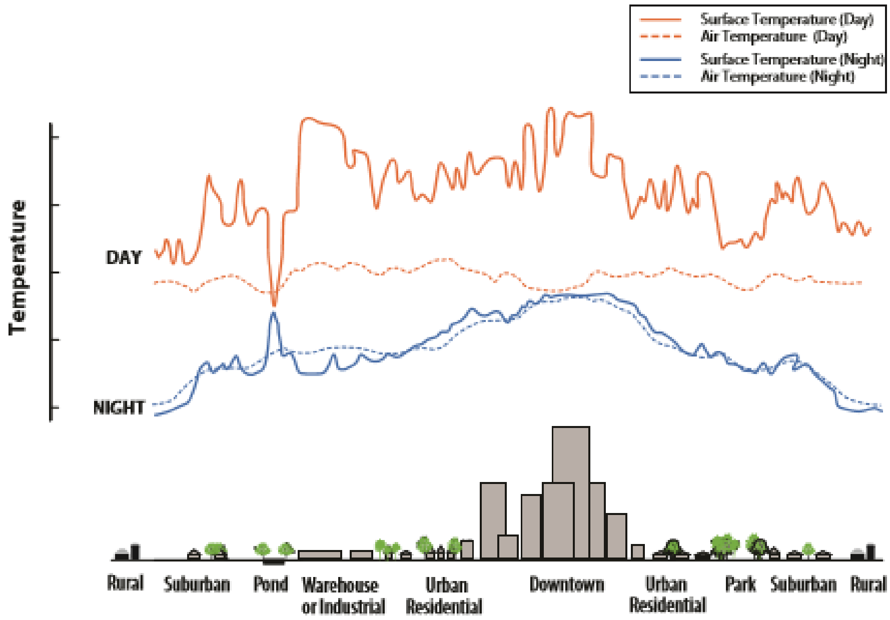


Fig. 7: Day's and night's surface and air temperature.

(Source: EPA, 2008)

Peng, S. et al. (2012) study the surface urban heat island intensity (SUHII) of 419 global big cities and they came across with the average annual daytime SUHII (1.5 ± 1.2 °C) is higher than the annual nighttime SUHII (1.1 ± 0.5 °C) ($P < 0.001$). No correlation have been found between daytime and nighttime SUHII across big cities ($P = 0.84$), suggesting different driving mechanisms between day and night. The nighttime SUHII distribution correlates positively with the difference in albedo and nighttime light between urban area and suburban area, while the distribution of daytime SUHII correlates negatively across cities with the difference of vegetation cover and activity between urban and suburban areas. These show that vegetation feedbacks in attenuating SUHII of big cities during the day, in particular during the growing season.

"In Europe, the UHI intensity of urban agglomerations exhibits a size dependency, and can typically reach a maximum of approx. 3°C in summer and 0,5°C in winter." (Zhou B., et al., 2017). Though the warmer air temperature within the UHI is generally most apparent at night, urban heat islands exhibit significant and somewhat paradoxical diurnal behavior. The air temperature difference between the UHI and the surrounding environment is large at night and small during the day. The opposite is true for skin temperatures of the urban landscape within the UHI. (Roth, M., et al., 1989).

A different study from the others that concern UHI is the Lemonsu, A., et al., (2013) study, where they discovered that during summer, the warming trend is more sensed in the surrounding countryside than in Paris and suburbs due to the soil dryness. As a result, a substantial decrease of the strong urban heat islands is noted at nighttime, and numerous events with negative urban heat islands appear at daytime. A 30% decrease of the heating degree days is quantified in winter between present and future climates. Inversely, the summertime cooling degree days significantly increase in future climate whereas they are negligible in present climate. However, in terms of accumulated degree days, the increase of the demand in cooling remains smaller than the decrease of the demand in heating.

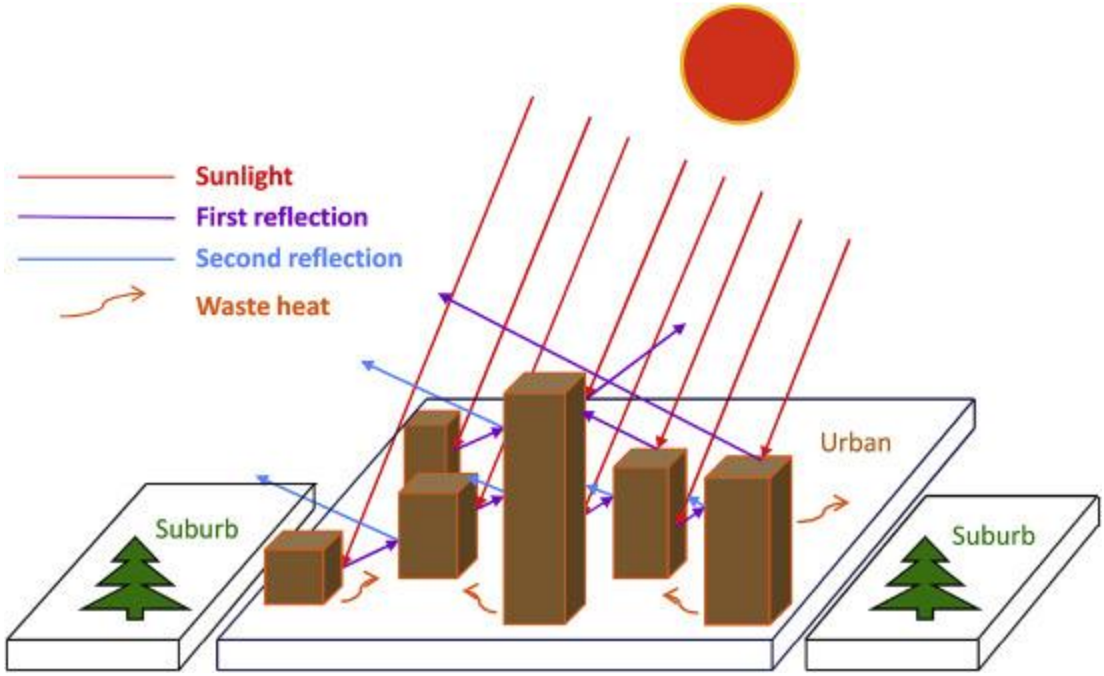


Fig. 8: Schematic diagram of UHI formation mechanism in a city.
(Source: Guo-Yu, R. E. N. "Urbanization as a major driver of urban climate change." Advances in Climate Change Research 1 (2015): 001. Accessed from: https://www.researchgate.net/publication/283513048_Urbanization_as_a_major_driver_of_urban_climate_change/figures?lo=1, at 19-10-2017)

The UHI phenomenon has many parameters and can be studied and accessed on various scales although the microscope gives a better resolution for the urban level it is difficult to expand and cover a larger area due to the large economic cost and complexity of the parameters involved. In contrast, meso-scale and large-scale are not capable of evaluating accurately the phenomenon study results. (Mirzaei A. P., 2015).

2.6 Identification of the phenomenon in urban areas

The UHI changes the microclimate of an urban area. Its factors can be categorized into (i) external and (ii) intrinsic (Oke, T.R., 1982). External factors include the location (latitude) (Wienert, U., and Kuttler, W., 2005) background climate (in particular wind) (Zhou, B., et al., 2013; Imhoff, M. L., et al. 2010), proximity to water courses (associated with sea- or lake-breeze circulation), etc., whereas intrinsic ones depict city-specific features (e.g. city size, land cover fractions, anthropogenic heat releases) which, despite being outcomes of long-run urbanization, can be regulated and reshaped.

The heterogeneity of urban surfaces, the varied climate patterns and their different combinations in each city lead to different expression of the UHI phenomenon. Further, “urban heat island intensity depends, among other parameters, on the temperature itself” (Camilloni I. & Barros V., 1997). Urban elements store heat during the day, which is then released slowly over the evening. That happens due to the thermal properties of the surface materials and the building geometry which traps the heat stored during the day. Other causative factors are the artificial heat released into the urban atmosphere by combustive processes from vehicles, industrial activity and the heat that escapes from commercial and domestic air conditioning (Morris, C.J.G., 2006).

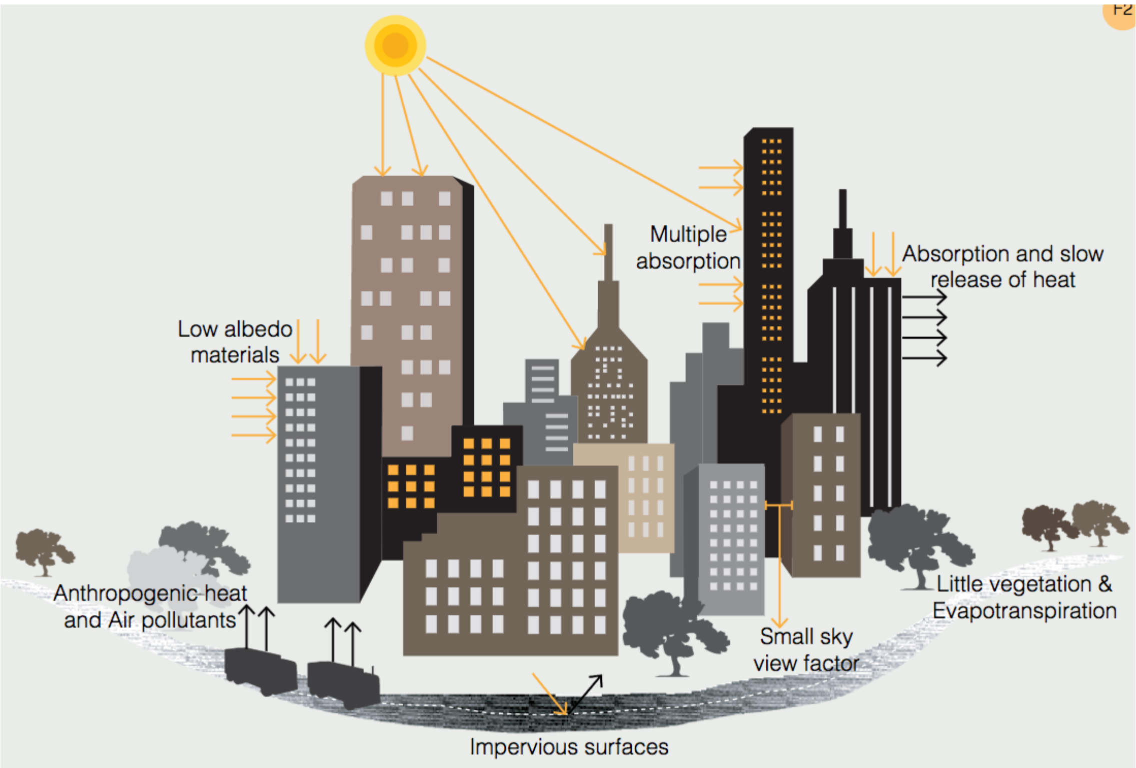


Fig. 9: Urban Heat Island Effect Display.
(Source: TARU Leading Edge, Handbook on Achieving Thermal Comfort, Volume I, 2014, Accessed from: http://www.acclimatise.uk.com/network/article/heatwaves-and-cool-roofs-reimagining-concrete-solutions-to-a-rising-urban-problem, at 10-08-2017.)

The urban thermal isle phenomenon is determined from different factors, by the construction materials, the form and the way the city operates. Thus the origins of the phenomenon are the urbanization of the natural environment, i.e. its conversion from natural or rural environment to urban environment. The construction materials modify the physical properties of the area’s natural surfaces. Because the city's surfaces are more absorbent and not reflective (not reflect much solar radiation-low albedo), so they heat up, thereby the accumulated radiation of the day during the night is emitted to the urban environment. (Meijer, I., Santamouris M. courses’ lectures 2015-2016) Reducing green and blue lands from the ground there is lack of vegetation and moisture, so as it is not feasible for urban areas to cool themselves through evaporative cooling. Hence for many cities' the construction materials' evapotranspiration proportion is smaller than the physical environment resulting in a microclimate with low moisture content, that is significant element for having a cooler environment.

The largest urban temperature regulator is the degree of urbanization of a settlement as weather stations data give warming in large cities at 0.16 °C $(10yr)^{-1}$ and data from small cities show the urban warming at 0.07 °C $(10yr)^{-1}$. (Ren, G., et al., 2008). Furthermore, the form of the urban environment with tall buildings and narrow analogue streets does not allow the appropriate degree of urban area's cooling. Tall buildings hinder the free movement of air, which could be relieving from the emitted high temperatures from the materials.

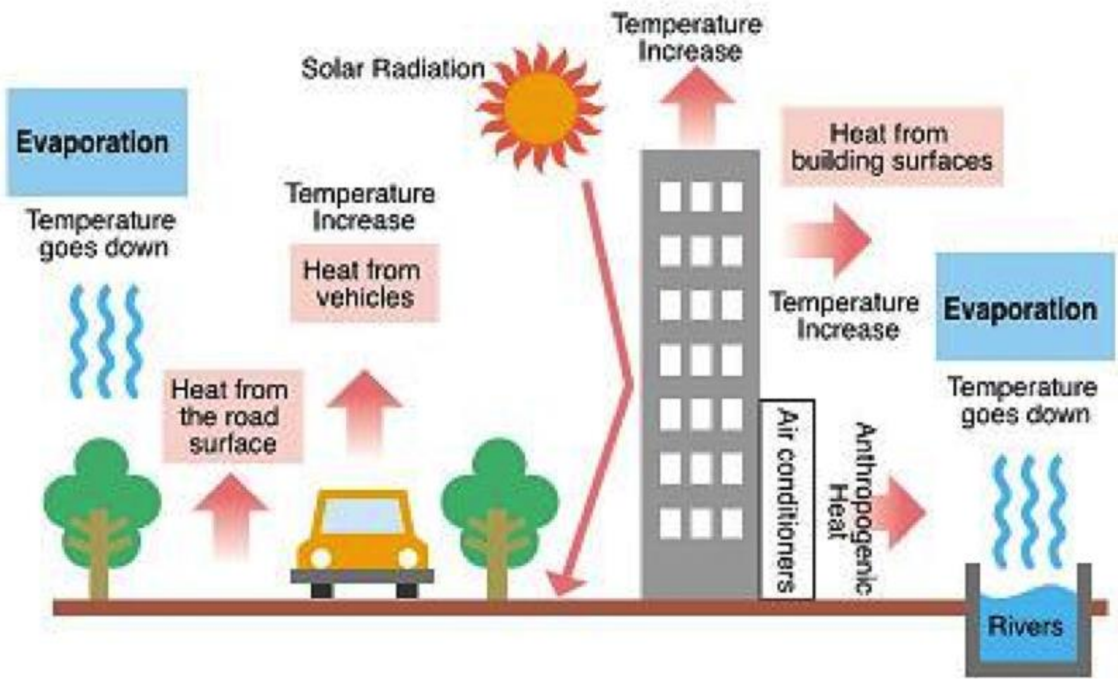


Fig. 10: The way UHI phenomenon occurs.
(Source: Green Ribbon. Accessed from: http://www.gardinergreenribbon.com/heat-island-effect/, at 06-08-2017)

Urban area's operation transmits to the environment heat and pollution. Anthropogenic activities (vehicles, heating and cooling systems, electrical appliance) release heat which adds to the air temperature. The airborne pollution on one side traps the heat and on the other redirects the heat to the lowest levels of the atmosphere making the city's microclimate intolerable. So, the high levels of pollution in urban areas can also increase the UHI, as many forms of pollution change the radiative properties of the atmosphere (Oke, T. R. 1982).

Factor that formulate the UHI phenomenon are the city size, since it has been shown that larger cities tend to have higher UHI intensities. Further, the fractal dimension is another cause, which represents an established measure to characterize the compactness of a city. Anisometry quantifies to which extent a city's length is greater than its width. As for example, cities extending along valleys, rivers, country borders, etc. The increased absorption and trapping of solar radiation in built-up urban fabrics associated with high thermal admittance of construction materials and the urban canyon structure. Population density, built-up density, and vegetation fractions can also directly or indirectly contribute to the formation of UHI (Zhou, B., et al., 2017). The same point of view has Mirzaei, A.P., (2015), “Highly populated areas…resulting in more released anthropogenic heat, a higher blockage effect against urban ventilation, a higher absorption of solar radiation due to the implementation of artificial materials, and eventually a reduced long-wave emission to sky due to the blockage effect of buildings” (Mirzaei, A.P., 2015).

Seasonally, UHI shows up both in summer and winter, even in Alaska, and some cities exhibit a heat island effect, largest at night. (Hajto, M.J., et al., 2013; Hinkel, K.M., et al., 2003; Reducing Urban Heat Islands: Compendium of Strategies). Atmospheric conditions play an important role in the development of the heat-island. Chandler (1964) noted that the magnitude of the London heat-island depended on prevailing weather conditions; 1933 and 1934, which were noted as typically mild, calm and dry years, produced particularly strong heat-islands.” (Lyall, I.T., 1977; Escourrou, G., 1991).

On the other hand, a different global study comprehensively assessed the dependence of UHI on various urban intrinsic factors, regardless of geographic and climatic factors (Clinton, N. & Gong, P. 2013). Urbanization transforms the natural adaptation mechanisms of nature, as it creates a new environment with artificial materials, which have a different reaction from natural materials, with a high degree of adaptation and mitigation. In addition, concrete rectangles, urban flumes are different from organic nature geometries.

“Urbanization is quickly transitioning communities from the natural rural vegetation to man-made urban engineered infrastructure. The anthropogenic-induced change has manifested itself in microscale and mesoscale increases in temperatures in comparison to adjacent rural regions which is known as the urban heat island (UHI) effect and results in potentially adverse consequences for local and global communities.” (Golden, J.S., 2004).

Urban Heat Island phenomenon is complexity. Its intension has to do with many parameters. It depends on the hour of the day, the season, and the general weather conditions. The phenomenon is perceived by both the emitting temperature from the surfaces and the air temperature. The factors determining the urban thermal isle are the geographic position of the city, namely the latitude, climate, topography, i.e. the presence of a liquid element, mountain mass, etc., the time, that is, the time of the day and the season, the weather (wind or nebulosity), the city's size, its structure, i.e. the materials, the geometry, the green spaces, the way the city function, The energy consumption, the transport, the pollution (Oke et al., 1991).

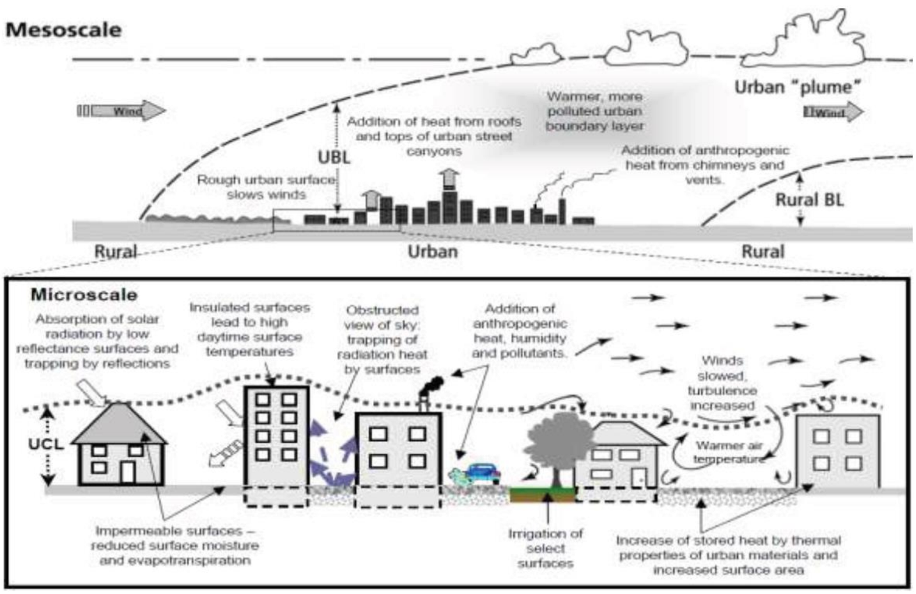


Fig. 11: UHI's mode of activity in Mesoscale and Microscale
(Source: Voogt, J., 2007 from: "How Researchers Measure Urban Heat Islands". Accessed from: https://swap.stanford.edu/20120109061918/http://www.epa.gov/heatisland/resources/pdf/EPA_How_to_measure_a_UHI.pdf, at 16-8-2017]

The surface/air temperature relationships are significantly influenced by advection from adjacent land uses. Thermal admittance and evapotranspiration are determined to affect strongly the surface-air temperature relationships at a periodically irrigated grass site. (Stoll, M.J., and Brazel, A.J., 1992). Additional, can be referred the land use change from man's activities, as deforestation, urbanization, and cropland can influence the climate with a dynamic way. The alteration in nature's bio geophysical procedure is capable to affect as far as the local and Earth's climate.

2.7 Urban thermal plumes and climate change

The Industrial Revolution is a landmark period for both mankind and the planet Earth. Until then the atmospheric content of carbon dioxide increased only by about 25% from the human activities. (Schneider, H.S., 1989). Joseph Fourier was the first that realized the importance of greenhouse effect for the Earth's climate in 1827 in his treatise on the temperature of the globe, he pointed out that the atmosphere is relatively transparent to solar radiation. (Held, I.M.; Soden, B.J., Nov 2000). "The argument and the evidence was further strengthened by Claude Pouillet in 1827 and 1838, and definitely proved experimentally by John Tyndall in 1859, and more fully quantified by Svante Arrhenius in 1896" (Khan, Z. H., Alom M., 2015), who linked the greenhouse effect with carbon dioxide (Svante A., 1896). "The qualitative picture first painted by Fourier and Tyndal has, of course, been confirmed and refined" (Held I. M.; Soden B.J., Nov 2000).

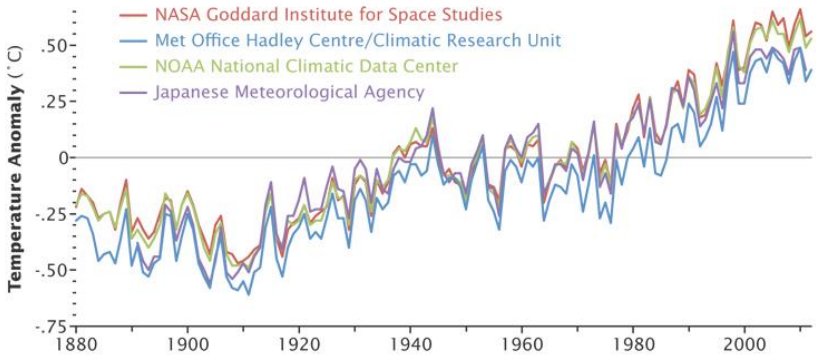


Fig. 12: Temperature Measurements 1880-2010 of various sources.
(Source: http://inhabitat.com/new-nasa-report-shows-scientific-consensus-on-global-warming-from-four-independent-institutions/nasa-global-warming-report, at 10-08-2017)

Later, the British engineer Guy Stewart Callendar (1898-1964) was one of the first scientist who assumed the global warming trend studying the historical temperature records in 1930s from Europe and North America found out that the planet warmed by about one degree Fahrenheit (about half a degree Celsius) from 1890 to 1935. Scientists today know that that Callendar's hypothesis was almost right, because the temperature rising that he observed was due to natural variations, and not of the greenhouse effect. Global warming due to the human-caused greenhouse effect became definitely measurable in 1980s. (Source: The Discovery of Global Warming: The Modern Temperature Trend, January 2017. Accessed from: https://history.aip.org/history/climate/20ctrend.htm#N_39_).

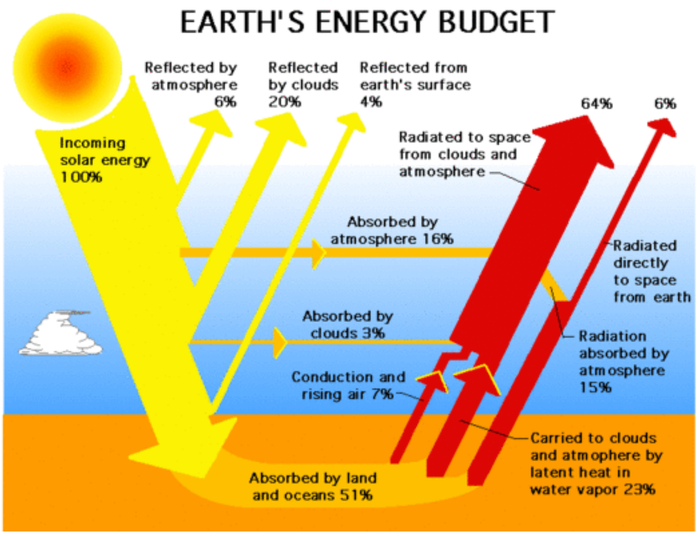


Fig. 13: Earth's Energy Reflections
(Source: https://www.nasa.gov/audience/forstudents/5/features/F_The_Role_of_Clouds.html)

As early as 1978, J.H. Mercer has highlighted the danger of the phenomenon created by the encasement of long wave radiation in the earth's atmosphere due to the increase in carbon dioxide because of human activities, which leads with geometric accuracy to the rise in temperature on the earth, melting ice and the inevitable rise of water (Mercer H. J. 1978). However, during the next decade, with the help of satellite measurements, the phenomenon has been verified by quantifying it by discovering that the greenhouse effect increases the temperature of the sea surface creating a vicious circle in the whole situation. (Raval, A., Ramanatan, V., 1989)

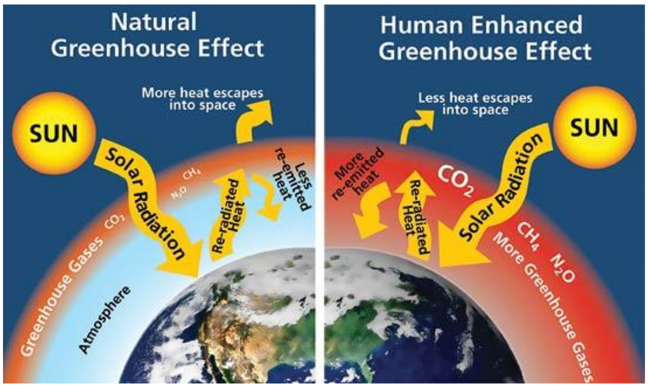


Fig. 14: The operation mode of the Greenhouse effect in a normal way and in the presence of increased amount of carbon dioxide.

(Source: https://socratic.org/questions/how-is-the-greenhouse-effect-related-to-global-warming, at 09-08-2017)

“This localized regional effect (UHI) is in addition to IPCC (1996) estimates that put the potential of global warming to be +1.4°C to +5.0°C (+2.5°F to +10.4°F) over the next 100 years, in addition to the 0.6°C temperature increase already observed during the 20th century.” (Golden, J.S., 2004).

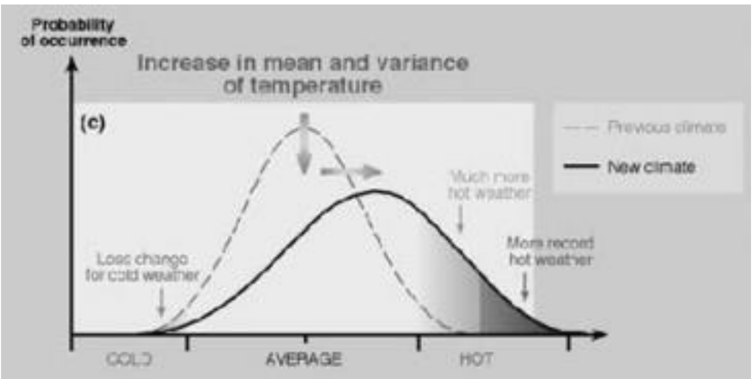
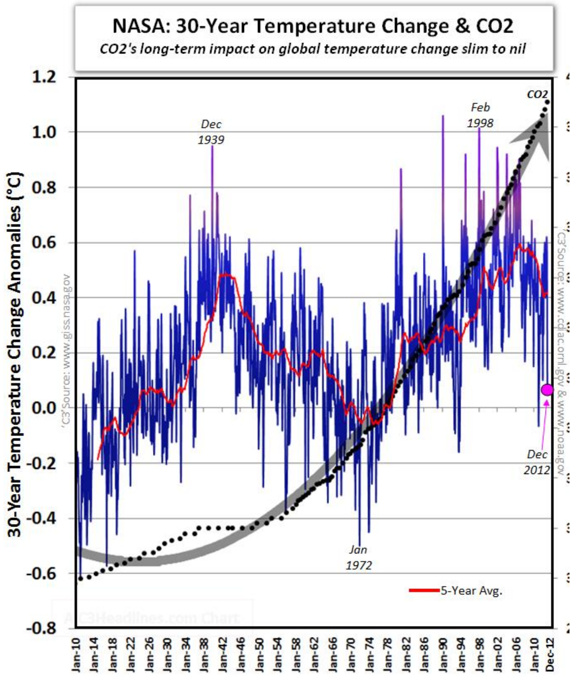


Fig. 15: Potential for increased hot weather due the global climate.

(Source: Golden J.S. 2004 from IPCC 2001, Climate Change, Third Assessment Report, at 09-08-2017).

As can be seen by following the NASA diagrams, which concerned the thirty year temperature change with the CO2 correlation, the Earth's temperature trend is increasing and frequent phenomena occurring with extreme temperatures. It seems that a possible prediction would give rise to prices for the future temperatures that will occur. It is apparent that the temperature dependency of the percentage of CO2 in the earth's atmosphere is clearly proven.



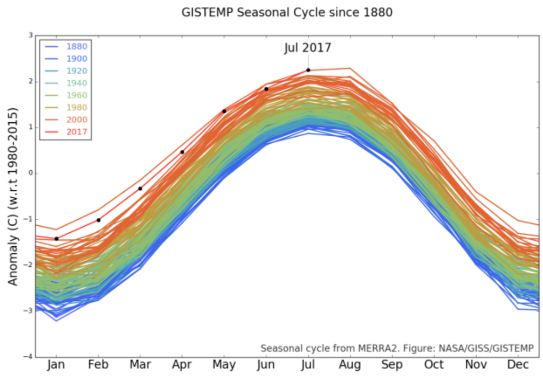


Fig. 16 & 17: Thirty year temperature change and CO_2
(Source: http://www.c3headlines.com/2013/01/nasa-climate-research-human-co2-has-little-impact-on-long-term-climate-change.html, at 15-08-2017)

Carbon dioxide has only a very small percentage (1/3 of 1%) of the Earth's atmosphere but its coexistence with water vapor and other gases such as methane and the chlorofluorocarbons (CFC's) change the planet’s climate creating the phenomenon of Greenhouse. Scientists have the opinion that increasing the concentration of carbon dioxide and other gases will increase the heat trapping and warm the climate.

According to Mitchel F. B. J.'s calculations in 1989, the rise of temperature from the Industrial Revolution is about $2Wm^{-2}$, which in the next 50 years can rise to more than $4Wm^{-2}$. The extra warming of Earth by human interventions as a whole over the past 100 years is about $2Wm^{-2}$ (Mitchel, F. B. J. 1989). The concentration of CO_2 in the atmosphere is a result of anthropogenic emissions from fossil fuels, forest clearing, and other land use practices (Bonan, G., 2012) .Terrestrial ecosystems are thought to absorb a big portion of annual emission of CO_2. Enhanced photosynthesis is a result of the climate change because of increase concentration of CO_2 in the atmosphere. “Climate model simulations show that the carbon cycle has a positive feedback on climate.” (Bonan, G., 2012). According to NASA “July 2017 was statistically tied with July 2016 as the warmest July in the 137 years of modern record-keeping, according to a monthly analysis of global temperatures”. [Accessed from: https://climate.nasa.gov/news/2618/july-2017-equaled-record-july-2016/]

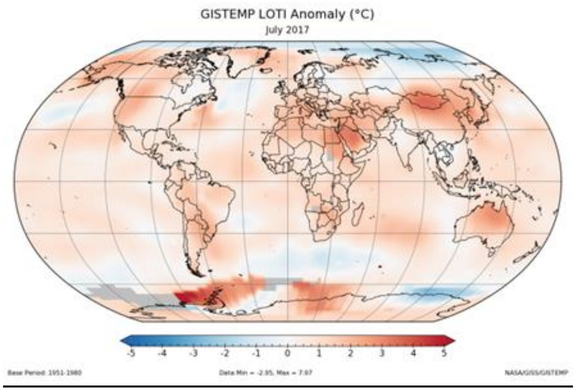


Fig. 18: Global temperatures anomalies.
(Source: https://climate.nasa.gov/news/2618/july-2017-equaled-record-july-2016/, at 15-08-2017)

Due to the human-induced change in global climate into warmer the scientific interest is high and the studies concerning the urban climate of different cities in the world are many. Further, climate change and the UHI phenomenon is a burning issue for world's organizations and so they include it on the agenda of discussion topics. Hence, the Habitat agenda III (Article 54) refers to the urban thermal islands as an urban areas problem for which the United Nations is bound to be resolved for promoting a sustainable urban development. (Source: Habitat agenda III).

Further, the international climate agreements that have taken place so far to protect the environment by focusing on climate change are related to a UNFCCC basic international convention. One of the three conventions adopted at the Rio World Summit in 1992. In 1997, countries adopted the Kyoto Protocol, which introduced legally binding emission reduction targets for developed countries. More recently, the Paris climate conference was held in 2015, the parties reached a new global agreement on climate change. The agreement is a balanced outcome and includes an action plan to limit global warming to "well below" 2°C. (Source: European Council / Council of the European Union.)

A recent publication by the UN, the amount of carbon dioxide in Earth's atmosphere has been grown during 2016. That means that it could be a sea level rise by 20 meters and an increase in temperatures by 3 °C. In particular, atmospheric concentrations of carbon dioxide (CO_2), totaled 403.3 parts/million(ppm), from 400,0 in 2015, reported in the annual report Greenhouse Gas Bulletin issued by the World Meteorological Organization (WMO). Maybe this seems to be a small rise amount but the growth rate is 50% faster than the average of the last decade, raising CO_2 levels 45% above pre-industrial levels, and even beyond the range of 180-280 ppm seen in recent glacier cycles and warmer periods. (CNN.gr).

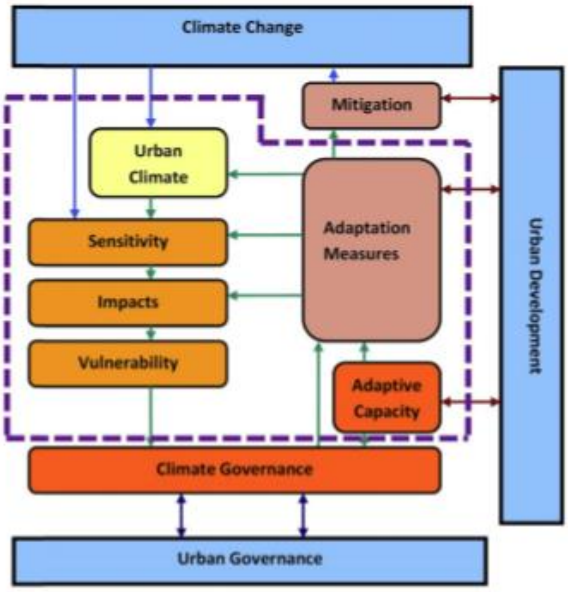


Fig. 19: “Climate Proof Cities research (dashed line) within the larger system of climate change, urban development, urban governance and climate governance”.
(Source: Albers, R. A. W., et al., 2015).

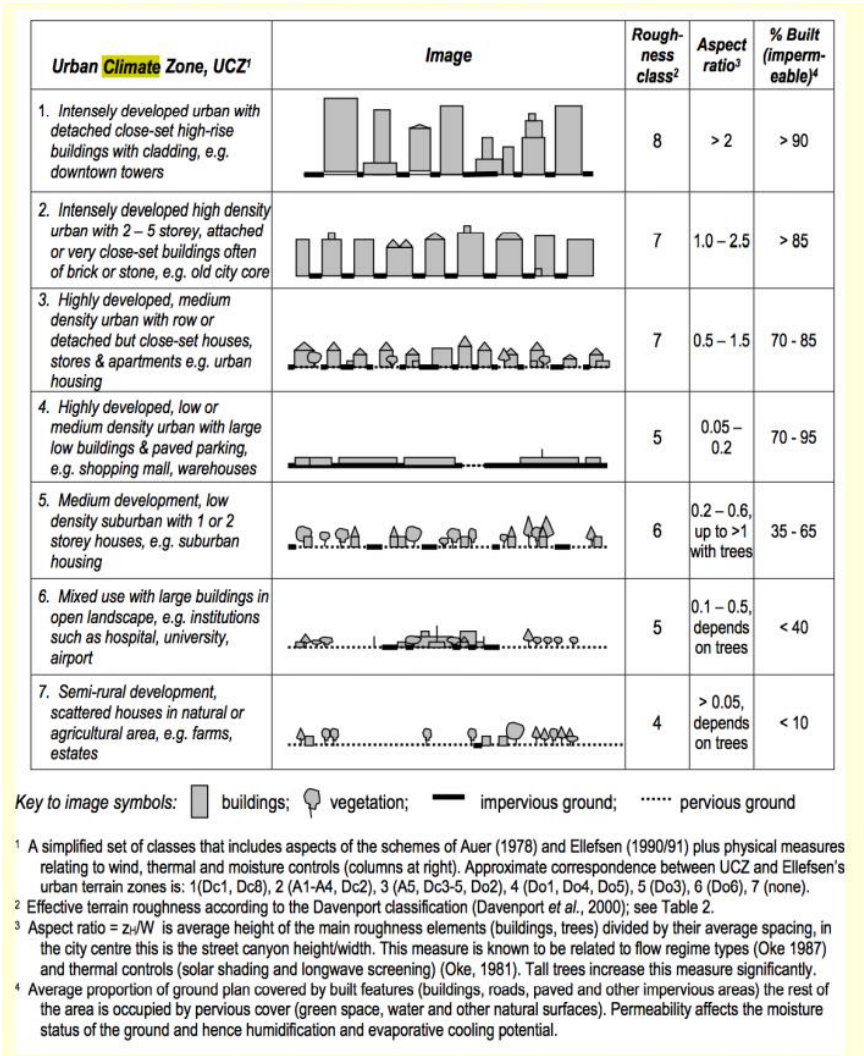
The modifications in energy production and consumption for daily operations as heating and cooling can display the impact of climate changes on the urban environment. Cartalis, C., et al., (2001) studied the climate changes in Greece making a simulation for climatic scenarios for the 2030, which describe potential reductions in the emissions of greenhouse gases, and calculate the heating and cooling degree days for the same year. The study’s results show that the amount of heating and cooling degree days will decrease for heating and increase for cooling, compared to the year 1990. Further, it was found that the most affected areas were Attica and central Macedonia regions, Aegean and Crete islands for extra cooling degree days, whereas it was found that less energy will be needed for heating for the most of the country. (Cartalis, C., et al., 2001).

There is a portion of scientists who are reassuring about the issue of climate change and claim to be the normal course of the climate. However, all the above information strongly indicate that margins are narrowing and immediate measures to mitigate the phenomenon have to be taken, as both indications and studies show that there is a non-normal strong climate change.

2.8 City as a storage heater

The possibilities of new materials (concrete, steel, asphalt and glass) and the new building technology, which developed since the end of the 19th century, build the 20th century cities creating large surfaces of concrete and asphalt. The properties of these building materials have shaped the current cities as well as the nature of their problems, such as environmental pollution, waste of resources and energy, urban thermal islands, degradation of the natural needs of the inhabitants for a suitable living environment.

Cities' construction materials are mostly concrete, asphalt and building iron. The properties of these materials determine their strength, construction and heating properties. Analytically, cement is the basic material of the concrete, is a hydraulic binder, a finely ground inorganic material which, when mixed with water, forms a paste that hardens and acquires different properties. Concrete is a building material produced by mixing cement, water, aggregates, and additives. Asphalt is a solid body, dark, found as a deposit or as a residue of oil distillation. The mix of asphalt - gravels - sand and bituminous limestone (asphalt mastic) is the material covered by the roads. Final, building iron is not exposed to the outer environment and it will not concern in the present.



Urban Climate Zone, UCZ[1]	Image	Roughness class[2]	Aspect ratio[3]	% Built (impermeable)[4]
1. *Intensely developed urban with detached close-set high-rise buildings with cladding, e.g. downtown towers*		8	> 2	> 90
2. *Intensely developed high density urban with 2 – 5 storey, attached or very close-set buildings often of brick or stone, e.g. old city core*		7	1.0 – 2.5	> 85
3. *Highly developed, medium density urban with row or detached but close-set houses, stores & apartments e.g. urban housing*		7	0.5 – 1.5	70 - 85
4. *Highly developed, low or medium density urban with large low buildings & paved parking, e.g. shopping mall, warehouses*		5	0.05 – 0.2	70 - 95
5. *Medium development, low density suburban with 1 or 2 storey houses, e.g. suburban housing*		6	0.2 – 0.6, up to >1 with trees	35 - 65
6. *Mixed use with large buildings in open landscape, e.g. institutions such as hospital, university, airport*		5	0.1 – 0.5, depends on trees	< 40
7. *Semi-rural development, scattered houses in natural or agricultural area, e.g. farms, estates*		4	> 0.05, depends on trees	< 10

Key to image symbols: buildings; vegetation; impervious ground; pervious ground

[1] A simplified set of classes that includes aspects of the schemes of Auer (1978) and Ellefsen (1990/91) plus physical measures relating to wind, thermal and moisture controls (columns at right). Approximate correspondence between UCZ and Ellefsen's urban terrain zones is: 1(Dc1, Dc8), 2 (A1-A4, Dc2), 3 (A5, Dc3-5, Do2), 4 (Do1, Do4, Do5), 5 (Do3), 6 (Do6), 7 (none).
[2] Effective terrain roughness according to the Davenport classification (Davenport *et al.*, 2000); see Table 2.
[3] Aspect ratio = z_H/W is average height of the main roughness elements (buildings, trees) divided by their average spacing, in the city centre this is the street canyon height/width. This measure is known to be related to flow regime types (Oke 1987) and thermal controls (solar shading and longwave screening) (Oke, 1981). Tall trees increase this measure significantly.
[4] Average proportion of ground plan covered by built features (buildings, roads, paved and other impervious areas) the rest of the area is occupied by pervious cover (green space, water and other natural surfaces). Permeability affects the moisture status of the ground and hence humidification and evaporative cooling potential.

Fig. 20: Urban Climate Zone comparison.
(Source: Satellites, Weather and Climate Module 42: Anthropogenic climate change: Urban heat islands. Accessed from: https://www.uvm.edu/~swac/docs/MOD42_Urban_Heat_Island_Oswald/eoswald_SWAC_module_42_UHI.pdf, at 16-08-2017).

The exposed areas of a city, i.e. building shells and public spaces (pavements, parks, squares), are decisive for the values of urban temperature, air and surfaces. These values can reach "50-70 °F higher" (Taha, et al., 1992) from normal country values. “Throughout the daytime, particularly when the skies are free of clouds, urban surfaces are warmed by the absorption of solar radiation. Urban areas surfaces tend to keep inside them the heat than those of the surrounding rural areas. By virtue of their high heat capacities, urban surfaces act as a giant reservoir of heat energy. For example, concrete can hold roughly 2,000 times as much heat as an equivalent volume of air. As a result, the large daytime surface temperature within the UHI is easily seen via thermal remote sensing.” (Lee, H.Y., 1993).

These materials have different thermal properties compared to the natural environment. The physical properties of these materials are particularly important for the effects on the energy balance of the city are the reflectivity of the solar radiation and the emission factor. Reflection refers to the property that a material does not absorb but reflects the incident solar radiation, so it does not heat up. While, the emission factor refers to the emission property of the energy-heat materials absorbed.

Another characteristic observed in the phenomenon in the urbanized areas is that during the daytime urban-rural climatic differences are small. Nighttime urban-rural climatic differences, however, are often significant-air temperature is warmer within cities at night, long-wave radiant heat load is greater, wind speed is often lower, and inside air temperature of characteristic urban buildings is warmer. (Clarke, J.F., 1972). The large heat capacity of materials preserves their high surface temperature and continues to heat city’s lower atmosphere at night. (Asaeda, T, et al., 1996). “The density and heat capacity of the transmitting material depends upon the composition, temperature, and for soil, the moisture content.” (Doll, D., 1985).

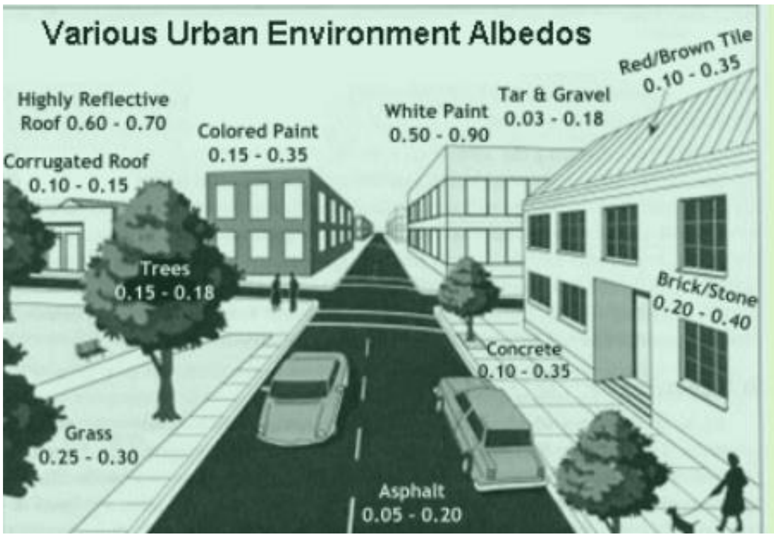


Fig. 21: Urban space albedos.
(Source: Satellites, Weather and Climate Module 42: Anthropogenic climate change: Urban heat islands. Accessed from: https://www.uvm.edu/~swac/docs/MOD42_Urban_Heat_Island_Oswald/eoswald_SWAC_module_42_UHI.pdf, at 16-08-2017)

Asphalt, as a construction material, has the ability to have higher temperatures than other materials, especially during the summer period, and therefore releases a large amount of heat to the atmosphere due to the sensible heat flux and infrared radiation. The infrared radiation is absorbed at high speeds from 200m into lower atmosphere layer. The absorption rate of infrared radiation is larger and then rapidly emitted from the surface into the urban environment. The small reflectivity of the asphalt and its moderate heat conductivity is the major reason for its unique thermal performance. Hence, the day store of a large heat amount provokes also large heat releasing to the atmosphere at night. (Asaeda, T, et al., 1996).

“The high concrete thermal conductivity and low heat capacity allow the concrete to respond rapidly to surface warming during the morning hours.” (Doll, D., 1985). According the Doll, D., (1985) study, concrete increases the heat storage term in relation of soil. The ground heat storage and sensible heat flux for a blackened concrete are larger than for an unpainted concrete. On concrete surfaces, the ratio of ground heat storage to net radiation is larger than one at night and smaller than one during the day. This ratio is discontinuous at sunrise and sunset transition periods. Although soil’s ratio shows similar temporal behavior except that on average, there is a smoother transition at sunrise (Doll, D., 1985).

According researches (Akbari, H., et al., 1999; Doll D., et al., 1985) concerning the thermal behavior of construction materials, it was first discovered that the color of the materials plays a very important role and that the properties of the materials originate from their composition. Analytically, it is found that the average diurnal curve of surface energy fluxes for blacktop is greater at nighttime and daytime magnitudes in relation to concrete. Material's albedo degree is the reason for the amplitude difference. On the other side, the diurnal variation for soil in relation to concrete and blacktop at nighttime is about half of those of concrete and blacktop. Soil's daytime values are larger than concrete but less than blacktop. The surface energy flux is the largest for the blacktop and the smallest for the soil over the nocturnal period. The surface temperature of the blacktop is higher than the soil during the night with the concrete having an intermediate temperature. Furthermore, the cooler daytime temperature for the soil may be associated with evaporation effects which reduce the amount of surface energy flow (Doll, D., et al., 1985).

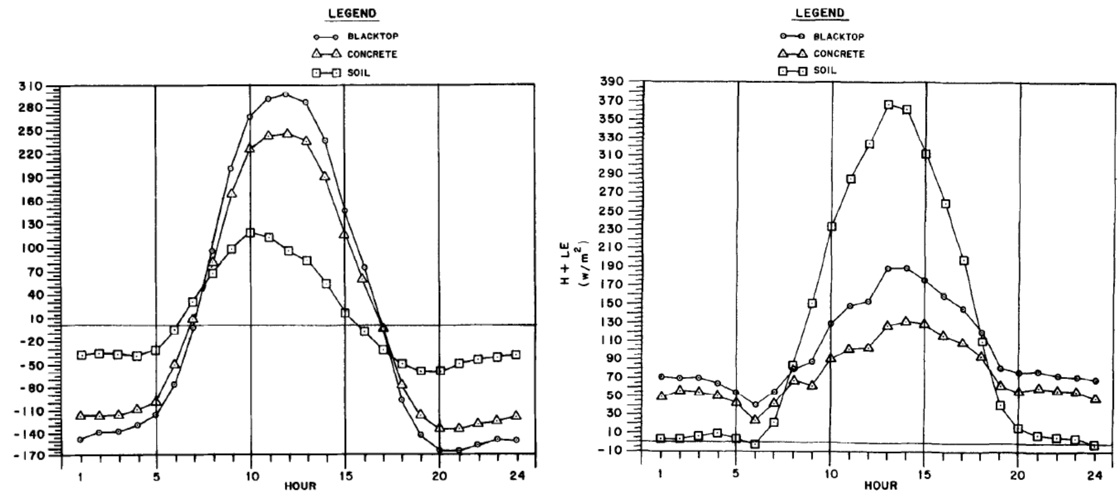


Fig. 22 & 23: Mean diurnal ground heat flux at the surfaces of the concrete, blacktop and soil sites (Left). Mean diurnal variation of sensible plus latent heat flux (H+LE) for concrete, blacktop and soil (Right).[1]

(Source: Doll D., 1985).

During the night the UHI effect is more active as the accumulated heating from solar radiation and every possible heat form during daylight hours amplify the city's storage structure of sensible heat with the resulting the stored heat to be unshackled (Doulos, L., et al., 2004). In some cities it is more noticeable as material's lower heat conductivity causes a hotter day, while large heat conductivity makes a hotter night (Asaeda T, et al., 1996).

A study on the thermal influence of building roofs (Simpson J.R. and McPherson E.G., 1997) demonstrates the importance for the energy balance of color and thermal insulation of the building shell, which influences the urban temperature. Beyond that, the decisive factor to shape a local aggressive urban temperature is the form and the construction material, of the urban relief. (Oke, T.R., et al., 1991). Always, according to the study, "urban" greenhouse and surface emissivity "are not involved in this process, while the interaction of street geometry and the heat island is intense.
The surface heat island greatly affects the intensity of the city's phenomenon and is determined by the geometry and topography of the streets, so high surface temperatures can exist not only in the city center but also at the city’s edges when the streets are narrow (Barring, L., et al., 1985).

On the other hand, Eliason, I. (1990/91), in his study of Gothenburg, does not detect a great difference in surface temperatures between different urban planning geometries, but finds discrepancies between the urban center and the countryside, which is cooling more quickly during the night hours. It is noteworthy that the air temperature difference in the city compared to a large park is (4 °C on average), which is of the same order of

[1] Latent and sensible heat, are types of energy released or absorbed in the atmosphere. Latent heat is related to changes in phase between liquids, gases, and solids. Sensible heat is related to changes in temperature of a gas or object with no change in phase. (Source: http://climate.ncsu.edu/edu/k12/.lsheat)

magnitude as the temperature difference between the city and the country (3.5-6 °C). In this case, an important role is played by latitude, but also that it runs through water channels, has a large percentage of green, and the urban density is not large.

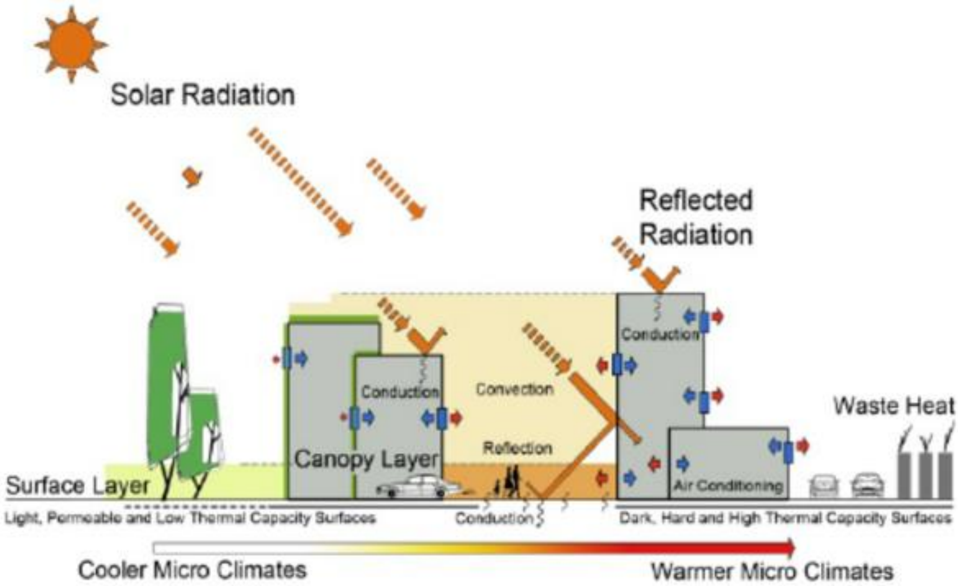


Fig. 24: Urban structure, landscape, land-cover and metabolism contribute to the Urban Heat Island effect in cities.

(Source: Sharifi E., 2015).

The recognition of the importance of land uses was made with many relevant studies linking the city's thermal islands to the existing land use. Thus, it should be noted that surface and air temperatures are directly affected by neighboring existing land uses and city functions, for example, a green area may affect surface area/air temperatures (Stoll, M.J. and Brazel, A.J., 1992). Also, through the studies, they found that the change of land use, to wit the conversion of agricultural or forestry land into urban, leads to geometrical precision in the expansion of the phenomenon as well "during 1991–2000, the estimated UHI intensity has increased by 0,11 °C per decade in the spring and has fluctuated in other seasons throughout China resulting from land use change" (He, J., 2007). Deepening the effects of land uses in UHI phenomenon and the particular characteristics of them as industrial areas are warmer and green-planted areas, or next to a water element, are colder during the day. In contrast, urban islands overnight have little to do with existing land uses (Roth M. et al., 1989).

2.9 The City under the influence of the UHI phenomenon

A thermal island or Urban Heat Island (UHI) is called the urban phenomenon in which the temperature in a city is greater than of its suburbs and rural areas that surround it. Climate change heat waves' make harder the urban living for residents and with severe economic losses due to the increased cooling needs and health problems that they are caused due the extreme temperatures. The UHI phenomenon is more perceptible during the night hours in the summer, specially, when there are no strong winds that make the feeling of the atmosphere more bearable.

The phenomenon occurs mainly in the city center due to its construction materials, mainly of cement and asphalt, which because of their low reflectivity tend to absorb the sun's radiation during the day and emit it to the environment during the night. Additionally, anthropogenic activities enhance the phenomenon, as they increase the temperature of the urban environment and the pollution generated by them catches the temperature as a long wavelength of radiation is re-emitted to the ground by the pollutants present in the atmosphere creating a vicious circle. Moreover, the reduced exhaust due to the lack of green in the city center in not at all helpful in the tackle of the UHI. If someone considers that cities now occupy a large area population due to urbanization and urban dispersion in the region reaches the phenomenon to become an epidemic in the cities.

The urban environment has many problems with the quality of air and the space in general. In the summer months due to the natural temperature rise, the coexistence of extra heat from machine operation and their emissions, as well as the existence of the UHI, the situation in cities is unbearable. The main impacts of the urban thermal isle are the degradation of the quality of life of the city's inhabitants and the negative impact on their health, resulting in vulnerable social groups such as the elderly, people with chronic health problems and children becoming victims of the heat waves and the existence of the UHI phenomenon.

Studies carried out in the context of examining the effects of the urban heat phenomenon on human health have converged that is an increasingly important public health problem (Harlan, S.L., et al., 2006; Kovats, R.S., and Hajat, S., 2008). “Heat waves are the most prominent cause of weather-related human mortality in the US (Changnon, S.A., et al., 1996 from: Davis, R.E. et al., 2003). Specifically, “UHIs have the potential to directly influence the health and welfare of urban residents. Within the United States alone, an average of 1,000 people dies each year due to extreme heat.” (Changnon, S.A., et al., 1996).

All this situation appears to be a result of climate modification due to urbanization because during heat waves the death rate from heat-related ailments is often much higher in cities than in rural areas, (Clarke, J. F., 1972; Kovats, R.S. and Hajat, S., 2008), which can be predicted from population density, a simple measure of the urban condition.” (Buechley, R.W., 1972). Effects on human health are important as there are high rates of death, as well as heat strokes and respiratory illnesses in helpless age groups (old people, children and people with health problems), especially during the days of heat waves and the phenomenon is worsening. Beyond high death rates, excessive heat causes many problems for people, such as skin eruptions, heat fatigue, heat cramps, thermal syncope, heat exhaustion and heat stroke. Most of the heat-related illnesses (in the absence of skin eruptions and heat cramps) have essentially consequences of varying severity of failure in the thermoregulatory system (Koppe, C. B., et al., 2004).

Studies in central Europe and the UK concentrated on the analysis of heat islands during the night-time period. Data from all cities show that maximum UHI values developed at night. The maximum UHI intensity was reported for the city of Lodz (12°C), and the minimum for Vienna (1,6°C). UHI has no relation with the city size. (Santamouris, M., 2007). In the table below are displayed cities in Europe that exhibit disorder at their physiological temperatures. Urban environmental degradation from the phenomenon is a serious additional problem for cities because, beyond excessive heat, the air quality is burdened by aerobic pollution. Simultaneously, the unusually increasing hot and humid days, at least partially related to anthropogenic climate change, suggest that a long-term increase significantly in heat-related human mortality could occur (Davis R.E., et al., 2003).

Table 1: European cities and maximum temperatures (UHI).

City	Maximum urban heat island (°C)
Lund (Sweden)	2
Parma (Italy)	3
Reykjavik (Iceland)	3
Lünen (Germany)	3.5
Osnabrück (Germany)	3.5
Valencia (Spain)	3.6
Biel (Switzerland)	4
Reading (United Kingdom)	4.4
Lisbon (Portugal)	4.5
Annecy (France)	5
Fribourg (Switzerland)	5
Gothenburg (Sweden)	5
Giessen (Germany)	5.5
Cologne (Germany)	5.7
Freiburg (Germany)	6
Graz (Austria)	6
Rome (Italy)	6
Stockholm (Sweden)	6
Stolberg (Germany)	6
Szeged (Hungary)	6
Vienna (Austria)	6
Bochum (Germany)	6.6
Malmö (Sweden)	7
Munich (Germany)	7
Sheffield (United Kingdom)	7
Uppsala (Sweden)	7
Zagreb (Croatia)	7
Athens (Greece)	7.5
Aveiro (Portugal)	7.5
Essen (Germany)	7.5
Karlsruhe (Germany)	7.5
Moscow (Russian Federation)	7.8
Barcelona (Spain)	8
Bucharest (Romania)	8
Helsinki (Finland)	8
Lódz (Poland)	8
Sverdlovsk (Russian Federation)	8
Utrecht (Netherlands)	8
Amsterdam (Netherlands)	8.7
Irkutsk (Russian Federation)	9
Berlin (Germany)	10
Birmingham (United Kingdom)	10
Cita (Russian Federation)	10
Dortmund (Germany)	10
London (United Kingdom)	10
Lipeck (Russian Federation)	12

(Source: Werert, (2001) from Koppe, C., et al. 2004).

A study in two cities showed the difference of UHI, between urban and rural areas, where nocturnal urban heat islands of 4-7 °C are to be associated with heat waves, which “magnify night time temperatures” (Kovats, R.S. and Hajat, S., 2008) in the urban areas. Hence, during heat waves inhabitants of urban areas may experience sustained thermal stresses both day and night while inhabitants of the outlying environs often obtain some relief from thermal stresses during nocturnal hours (Clarke J. F., 1972). This demonstrates how the phenomenon troubling bourgeois compared with rural residents and how much burden their health continuously specially during the summer months. Urban “populations are acclimatized to their local climates, in physiological, behavioral, and cultural terms” (Kovats, R.S. and Hajat, S., 2008), because cities have follow a prototype of developing that has disregarded the local climate, the local architecture, the normal human living levels, i.e. fresh air, green open spaces and not noise pollution. Normally human capacity to adapt to varied climates and environments is considerable.

Table 2: Human’s fatalities in some countries in Europe because of heat waves in August 2003.

Country	Fatalities	Other details
France	14,802	Temperatures soared to 104°F in parts of the country; temperatures in Paris were the highest since record-keeping began in 1873
Germany	7,000	High temperatures of up to 105.4°F, the hottest since records began in 1901, raised mortality some 10% above average
Spain	4,230	High temperatures coupled with elevated ground-level ozone concentrations exceeding the European Union’s health-risk threshold
Italy	4,175	Temperatures in parts of the country averaged 16°F higher than previous year
UK	2,045	The first triple-digit (Fahrenheit) temperatures were recorded in London
Netherlands	1,400	Temperatures ranged some 14°F warmer than normal
Portugal	1,316	Temperatures were above 104°F throughout much of the country
Belgium	150	Temperatures exceeded any in the Royal Meteorological Society’s records dating back to 1833
Total	35,118	

(Source: Earth Policy Institute, from: Golden, J.S., 2004).

Human health studies in relation to prevailing weather conditions, particularly the heat wave, and the prevalence of the UHI phenomenon in cities, combined with heat waves in the summer months, correlate the phenomenon with social data, such as a study on Barcelona during the summer of 2003 where they studied whether the excess mortality that occurred in relation to age, gender and educational level. The result of the study was that the episodes were prone to women from all social groups, the elderly, but people with a very low level of education were the most victims (Borrell, C., et al., 2006). Similar study at Phoenix revealed that the poor, minority inner-city neighborhoods, similar to those in many cities, lack adequate housing, shade, and green open space. In addition, the building stock is old without any amenities with modern HVAC systems that improve living conditions. (Harlan, S.L. et al., 2006). Thus, the phenomenon UHI is capable of bringing further urban degradation per neighborhood and causing abandonment, decline in property values and urban shrinking.

Health problems caused by extreme temperatures can cause financial burden on both patients and the health system. In addition, the effects of the unusual high temperature prevalence on the geographical location and the usual climatic conditions of a region, which also strengthens the urban phenomenon of the thermal island, in addition to health problems for residents and excessive energy consumption (Kunkel, K.E., et al. 1999; Changnon, Jr. A., et al., 1996), for the cooling of workplaces and dwellings, which is an additional thermal burden of the urban atmosphere by the heat they produce during their operation, it causes also waste of energy. The charge has two beholden, on the one hand the users who pay the price of the energy consumed and on the other hand the charge of the company, which may need to buy electricity from the neighboring countries at a high price, due to damages of the system overloading, but also from a possible blackout that will have to compensate companies for damages that have been caused.

This proven through scientific studies is that the phenomenon affects the natural functions of nature. In NASA discovered that the UHI phenomenon makes vegetation in cities to stay green longer every year, compared to surrounding rural areas. This can be used as a mitigation tool for heat in urban areas (Cook-Anderson, G., 2004). Further, urban heat-islands provoke more summer rain over and downwind of major cities, in particular J. Shepherd, M., found a 12-14% increase in rainfall in the northeast suburbs of Phoenix from the pre-urban (1895-1949) to post-urban (1950-2003) periods. (Gutro, R., 2006; Goddard Space Flight Center, 2018).

In addition, a study dealt with the rain history in Athens city from 1891 to 2010. It is observed from the data analysis that there is an upward trend of 0.8% at the beginning of the period (1891), reaching 3.2% end of the period (2010), i.e. it is a 400% rise. The increasing trend has been even more pronounced since the late 1980s. At the same time, the days with a height of more than 50mm, which are considered rare and are capable of creating floods, in all 120 years of research, it is observed that for 72 years there was no day with a 50 mm mark. The upward trend is evident as in 1891 it has 0.2% and reaches 2.8% in 2010. (Gialamas, I.)

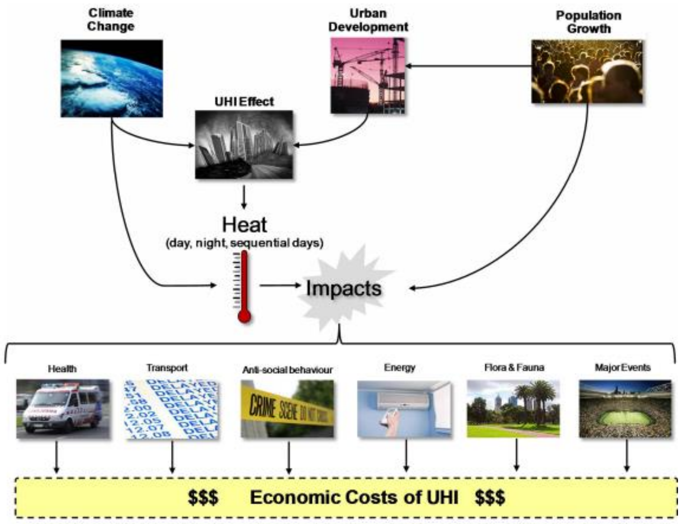


Fig. 25: Fields that have economic consequences due to the thermal urban isle.
(Source: AECOM Australia Pty Ltd. 2012)

According to Anderson, C. A., & Anderson, K. B. (1996), heat is associated with increased aggressive human behavior. Similar, in Cohn, E.G.'s (1990) study, have showed positive correlation of heat and crime. Moreover, Anderson, C. A., et al.'s, (1997) study discovered that for every temperature increase of 1°F, the number of serious and deadly assaults increased by about 3,68 per 100,000 people. Additionally Auliciems, A., and DiBartolo L., (1995) study, correlated calls to police and maximum air temperature, during all seasons and they ascertained that, "the Tw max correlation trace is positive throughout the year, but the dominant influence until about June is pressure; thereafter the association is primarily of temperature. The first half of the year, the association with pressure is a negative one, which switches to positive during June-August, and then back to negative in September until the end of the year" (Auliciems, A., and DiBartolo L., 1995). All above studies prove that the atmosphere temperature increase can have also a social impact. Respectively, the urban thermal isle can affect negatively a city's habitants in terms of security and thus generate financial losses.

Table 3: Economic impact for selected cities considering both device longevity and operating cost, restricting the inquiry to air-conditioning systems.

Two annual UHI-induced costs for selected cities

City	GDP (billion US$)	Excess cost AC repair (million US$)	Excess cost AC operation (million US$)	Cost of both as % of GDP
Ottawa	40	3.6	6.1	0.02
London	452	174	4.1	0.04
Dallas-Fort Worth	268	24	238	0.10
New York	1133	58	31	0.01
Phoenix	156	60	376	0.28
Paris	460	100	18	0.03
Athens	73	50	62	0.15
Tokyo	1191	720	147	0.07
Seoul	218	364	83	0.21
Moscow	181	3.1	1.8	0.003
Delhi	93	29	186	0.23
Sydney	172	75	57	0.08
Beijing	99	77	89	0.17
Shanghai	139	44	99	0.10

(Source: Miner M.J., 2016)

Urban areas account for approximately 75% of world energy consumption (Bretzke, W-R., 2013, from Miner M.J., et al., 2016). Every electronic device is degraded by operating above ambient temperature. Examining heat island of Phoenix, in Arizona, US, the average annual operating cost for air condition per household is predicted to be US$ 228 for 3°C temperature increasing (seasonal). A cost ratio of 3.54 is applied between higher-income and lower- to middle-income countries, based on residential air condition energy consumption. Further, lower-income nations the economic drain would likely be higher in percentage terms. (Miner M.J., et al., 2016)

Generally, the annual cost of the urban heat island in Phoenix is estimated at US$ 479 million, based on the 3°C UHI magnitude (Golden, et al., 2008 from: Miner, M.J., et al., 2016). More specifically, automotive excess costs total US$ 43 million dollars in the 3°C increase, or approximately US$ 28,22 per working person per year. Alongside, reduction in the coefficient of performance of an air-conditioning unit due to a 1°C increase in ambient temperature is estimated to cost each household approximately US$ 76/year, while the excess repair expense only costs each household approximately US$ 11/year. Total excess costs imposed by A/C systems operating in a 1°C urban heat island amount to an annual cost of US$ 126 million for Phoenix alone (based on working residents). That is the observed on 3°C UHI in Phoenix absorbs 0.3% of the US$ 156 billion local economy. (Miner, M.J., et al., 2016). According to the data from the above study implies that the costs incurred only for 1 ºC or 3ºC are exorbitant either for an individual or for a whole society.

There are other economic impacts and these include: increased fuel costs associated with powering air-conditioners in vehicles, increased repair cost associated with vehicle breakdown due to over-heating, increased administration cost associated with local governments handling heat induced complaints from local residents, increased revenue for businesses that sell products or services that are more desirable during hot weather (e.g. drinks, ice creams, public pools etc.). (AECOM Australia Pty Ltd. 2012)

Another area that may have a negative impact on the UHI phenomenon is the decline in the value of real estate. This can happen as the living conditions in the neighborhood show high rates of heat in relation to other neighborhoods as it will have high building densities and inhabitants, lack of green and open public spaces, old building stock, unable to respond to comfort conditions, which are imperative, in dealing with the heat. One can argue that all of these properties enhance the aesthetics of a neighborhood and raise house purchase prices in a neighborhood and they are not related to the UHI phenomenon, but on one hand all these features are interrelated, and on the other hand the discomfort in a particular environment Is a determining factor in the formation of demand and prices.

An environmental impact of UHI is the excessive demand for water as it is a direct priority when prevail hot weather conditions, for every living organism on the planet. This often leads to the wastage of valuable water by the citizens, resulting even in its lack but even in the reduction of its quality. In addition, water infrastructure due to multi-use during the summer months is seriously damaged and repair costs are passed on to consumers.

2.10 Thermal isle effect and Greek city

Areas with mild climates face more than others with colder climates the unpleasant effects of the UHI phenomenon during the summer and earn the scientific interest because of the phenomenon. Thus, there is a strong interest in countries around the Mediterranean and areas that lie on the tropical Cancer and Capricorn zones, with a common feature among them that they have experienced intense urbanization in their territories. On this frame, the scientific interest on the subject is great for the "mediterranean climates seem to have been particularly well served by heat island studies during the period; results have been reported for Athens, Greece (Philandras et al., 1999), the three Spanish cities of Barcelona (Moreno-Garcia, 1994), Madrid (Yague, et al., 1991) and Granada (Montavez, et al., 2000) and various locations in Israel (Goldreich, 1995)." (Arnfield, A.J., 2003).

The urban thermal islet phenomenon is a reality for the Greek cities, which are urbanized according to the Athens' building standards, mainly due to the type of urbanization, but also to the anthropogenic factor (great dependence on the use of cars, industrialization, the operation of various devices and machines). The Greek residence building typology has repeatedly implemented in the construction in the Greek cities, creating deep ravines between the building blocks. Because of the applied continuous building system along the roads and the proportion of minimum free space between them the urban environment at the ground level becomes stifling because the wind cannot move freely and on the other hand the building materials of the city emit the heat they have absorbed during a summer day. The lack of sufficient green and open spaces exacerbates the discomfort of the inhabitants and strengthens the phenomenon of unnatural heat in the urban fabric.

Cities are located in small latitudes, which come against in a more intense way with higher temperatures; the issue of UHI is popular. The Greek cities admittedly compact cities with high urban densities will experience more intensely the effects of climate change in the future because of their structure and the way they function. Consequently, Greece, a country in the Mediterranean basin with hot dry summers and usually mild winters, the phenomenon finds fertile ground for its development within the cement cities. Therefore, there are many studies dealing with the UHI phenomenon in Greece and particularly in Athens and Thessaloniki as for example, Livada, et al., 2002; Kolokotsa, et al., 2009; Giannopoulou, et al., 2011; Giannaros, T.M., Melas, D., 2012; Kosmopoulos, P. and Kantzioura, A., 2014 Giannaros, M.T., et al., 2014; Kourtidis, K., 2015.

Urban climate studies in Greece began in the 1980s. At first, Katsoulis, B.D., Theoharatos, G.A., (1985) proved in eighties that Athens face the UHI phenomenon with different intensity according to the season and the temperatures fluctuations, which is created from natural and man-made processes. They attribute Athens UHI to the urbanization and a long-term variation affecting the local microclimate. They focused on two periods 1891-1950 and 1951-1980. On the first period mean and maximum temperatures showed an increase but in the next period they observed that minimum temperatures increase.

Other researches in this initial study stage of the phenomenon in Greece were made by Katsoulis B. (1987), who examined the climate change in the city of Athens for the period 1858 to 1982, where he related his research with the urbanization of the city. Further, in 1988, Katsoulis, B. and Kambetzidis, H., studied the characteristics of the long-term precipitation series at Athens (1858-1985) have been statistically analyzed, which was one of the longest in south-eastern Europe.

At the next decade Proedrou M. et al. (1997) examined the variations and trends in annual and seasonal air temperatures in Greece were examined on the basis of ground measurements for 25 stations during the period 1951–1993 and Philandras et al. (1999) studied the effects of urbanization in Athens examining the mean monthly maximum and minimum air temperature for the period 1925–1996.

Only just in 1998, the intensity of the heat island in the city of Thessaloniki had been studied, for the 1950-1995 period, by Balafoutis Ch. and Makrogiannis T. They used daily data of minimum air temperatures from one urban and one rural station so as to estimate the monthly course of the heat island effect during the last 46 years. Thus, the effect of urbanization on temperature characteristics examined by comparing the temperature values of the University campus AUTH, a urban station, and the Macedonia airport, a rural station, in a far distance of 15 km. They found out that a remarkable heat effect in the city exists for the reporting period. (Balafoutis Ch., Makrogiannis T., 1998).

However Athens remains the most wanted city for urban climate studies. Hence, there is a large number of studies that concern this kind of subject and deal with all aspects of the topic. The impact of urbanization is catalytic for the UHI phenomenon. This was also shown by their study Philandras, C.M., et al. (1999), who examining the mean monthly maximum and minimum air temperature for the period 1925±1996 in Athens. The existing small urbanization effect before the Second World War period increased after the war and up to about 1990, when the effect became stationary. The urbanization affects mainly the maximum temperature and the warmer seasons of the year. Further, the temperature of the sea breeze increased because of buildings, while the rapid increase of city's population and vehicles' number after 1970 burden the whole situation with UHI. The urbanization effect on maximum temperatures of NOA amounts about 2 ºC in spring, summer and less in fall, while no urbanization effect is clear in winter. (Philandras, C.M., et al. 1999).

Studies that examine factors that aggravate the UHI effect become study objects for its optimal understanding, for example in a pedestrian canyon in Athens, in Greece measured the air flow inside and outside the canyon as well as the air and surface temperatures inside the canyon. (Santamouris et al., 1999a). Moreover, the distribution of ambient air temperature in a city and the urban heat island intensity are investigated during the summer period in the major Athens region where ambient air temperature data are recorded at twenty stations. A neural network approach, based on predicted or recorded hourly values, is designed for modeling, predicting and estimating the air temperature at each station. (Santamouris et al., 1999b)

In 2000 decade the interesting for IHU issue generally increased. According to a study done for Athens, it was studied the impact of the urban climate on the energy consumption of buildings. Higher temperatures in the city centers affect the heating load of urban buildings may be reduced up to 30-50% compared to buildings located in suburban areas. During the winter period, the heating load of centrally located urban buildings is found to be reduced up to 30%. The minimum COP value of the air conditioners in the central Athens area is reduced by up to 25%. (Santamouris et al., 2001). Thus, it is observed that the phenomenon has a significant impact on energy consumption and efficiency of thermal comfort adjustment devices.

Livada et al. (2002) with their study "Determination of places in the great Athens area where the heat island effect is observed" define places in the major Athens area where the heat island effect occurs. From this research for Athens it is mainly observed that the central and the west industrialized parts of the city of Athens develop intensely the "urban" heat island effect. Nevertheless, district variations as regards the heat island intensity can be found in some regions, located close to the city center and eastward of it, characterized by thick vegetation of trees or by "open areas". Moreover, in places near the seaside the air temperatures are higher in the cold period of the year not because of the urbanization but mainly due to the influence of the sea, which favors the maintenance of high air temperatures. (Livada et al., 2002).

Founda, D., et al., (2004) studied surface air temperature record of 105-year (1897–2001) in the city of Athens, where they generally found there is a tendency to increase the temperature for all time of the year in particular the mean temperature in summer increased 1.23 and in winter increase 0,34 °C. The results showed that in the period (1992–2001) there is a significant increase for all seasons and warm events take place more frequently.

Charalampopoulos, I. and Chronopoulou-Sereli, A., found that less built-up areas have less temperature with a difference which reaches 2,8°C and urban park has significant influence on the thermal spatial pattern despite the fact that it is small (Charalampopoulos, I. and Chronopoulou-Sereli, A., 2005). Further, Kassomenos and Katsoulis (2006) examined the characteristics of the morning Urban Heat Island (UHI) in Athens basin, using and analyzing mesoscale and synoptic data covering the period 1990–2001. The UHI estimated for the 0600 Local Time (LT) minimum temperature differences for rural and urban areas of the city. The analysis results in 7 UHI classes and a strong UHI was found for the 1 to 3 of days. The UHI is largest on nights with clear skies and low relative humidity. In all seasons the UHI switches on rapidly in afternoon. During spring and summer, sea breeze commonly reduces and delays the UHI. Additionally, mesoscale and macroscale phenomena were examined during the different UHI classes through a weather type scheme. (Kassomenos P. A., Katsoulis B. D., 2006).

Santamouris et al (2006) studied the impact of the UHI in Athens; specifically the repercussion of the phenomenon on energy demand because of the need of extra cooling. According the results the heat island ranges up to 1,5 to 2 times the city's area, which ought to deal with extra CO2. (Santamouris, et al., 2006). In another study a combination of satellite imagery and meteorological data were used to explore the spatial and temporal evolution of a heat wave that resulted in record high temperatures in Athens Greece. MODIS and Land SAF data were verified against the surface air temperature over the Athens area obtained from a network of available surface observation stations, showing significant correlation. On average the observed daytime differences vary between 2,5 °C to 5,8 °C. (Retalis, A., et al., 2010).

Moreover, Giannopoulou et al. (2011) examined the major Athens area so as to analyze the characteristics of the heat island phenomenon during the summer season. They divided the area in five geographic zones according the different thermal features and it is found that the differences between the mean and maximum daily air temperatures, were statistically significant, showing that the five these areas had different temperature conditions. Higher air temperatures are found in the industrial western part of the city and also the center while the lower values were presented at the northern and the eastern parts. The intensity of the UHI found to be about 5 °C. (Giannopoulou, et al., 2011)

A UHI study in Athens was done using thermal infrared images are being acquired by satellites for more than two decades enabling studies. These satellite images, Land Surface Temperature (LST) maps, showed the thermal patterns for the quantitative analysis. More than 3000 LST images of the area acquired by MODIS sensor. Three districts Megara, Elefsina-Aspropyrgos and Mesogeia around Athens picked for daytime study. These presented similar behavior, gradually increasing maximum temperature during the summer season and reaching top temp in mid-July. Further, the thermal intensities compared to a suburban area had difference at 9–10 °C and were found to be highly correlated to their areal extent. At night-time, Athens center developed a typical UHI spatially coinciding with the dense urban fabric presented the maximum temperatures at the end of July. The mean spatial extent of UHI in Athens was 55,2km2, whilst its mean intensity was 5,6 °C. The proposed automatic extraction process can be customized for other cities and potentially used for comparison of LST patterns and UHI behavior between different cities. (Keramitsoglou, I., et al., 2011)

Giannaros', T.M., et al., (2013), study of the urban heat island over Athens (Greece) with the WRF model used a numerical simulation, which showed higher air

temperatures than its surroundings during the night, the temperature difference is less in early morning and mid-day hours. While, the minimum and maximum intensity of the canopy-layer heat island has a typical diurnal cycle, it occurs in early morning and during the night. (Giannaros, T.M., et al. 2013).
In another study in Athens is highlighted the role of urban form and function; specifically vegetation, narrow streets and a relatively high volume of traffic the land use and the buildings high and their color, population density play an essential role for the UHI formation (Rapsomanikis, S., et al., 2014).

The summers in Athens can be very hotly burdened by the aerobic pollution of the urban atmosphere. The average temperature ranges from July to 33,5°C and the heat wave is a common phenomenon during the summer months. (Kourtidis, K., et al., 2015), and then often exceeding 37ºC (Giannaros, T.M., et al., 2014). Further, the city experiences a strong UHI effect as reported in several previous studies (Katsoulis and Theoharatos, 1995; Philandras et al., 1999; Santamouris et al., 2001; Keramitsoglou et al., 2011).

There are also many studies for city of Thessaloniki city, which has been vigorously urbanized over the past century and today also faces the phenomenon of the thermal urban islet and scientific interest is alive for the study of this particular subject. In Giannaros, T.M., and Melas, D., (2012), they examined the impact the urban environment through the air temperature, using the daily mean, maximum and minimum temperatures values for every year's season, studying near-surface temperatures data in seven sites in the greater Thessaloniki area with an econometric approach to analyzing data. They found that the UHI phenomenon in Thessaloniki is stronger in the nighttime than in the daytime and decreases with increasing wind speed, Thessaloniki's heat island appears to decrease when wind speed exceeds 4 m/s. Further, the observations of the maximum urban heat island intensity range from 2°C to 4°C during the warm and from 1°C to 3°C during the cold part of the year, showing a smaller variability during the summer months than in the winter. Greatest values are more usually observed following sunset, whereas minimum values are detected during solar peak hours. The center of the city is found to exhibit the highest discomfort index and approximated wet bulb globe temperature values. (Giannaros, T.M., Melas, D., 2012).

Urban heat island of Thessaloniki is presented during night-time and its intensity can reach up to 8°C (Stathopoulou et al., 2004). UHI intensity is about 2,7°C to 4°C between urban and rural Thessaloniki's areas, while suburban areas are 1,2°C cooler than the central urban areas and 1,5°C warmer than the surrounding rural areas (Mihalakakou et al., 2004).

While, Teli D. and Axarli K. (2008) focused on the bioclimatic approach to outdoor design. Giannaros, T.M. et al., (2010) explore Urban Heat Island (UHI) in the Greater Thessaloniki's area selected as representative of "urban" and "suburban" areas and using hourly air temperature data covering the period from June through September

2008. They pointed out that the urban zone is heated faster than the suburban surroundings, especially in early morning hours. They concluded that the city of Thessaloniki is subject to a mediocre UHI, which is perceived during overnight hours, and reach its maximum size in early morning hours. (Giannaros, T.M. et al., 2010). Kantzioura's, A. et al., (2012), paper presents a study that investigate the influence of urban morphology in microclimatic conditions in Thessaloniki, Greece. They measure how the temperature of building's surfaces vary and interact during the day and according to the microclimatic parameters; structure's geometry, street orientation and configuration of the building blocks (height of buildings, width of road) and materials thermal properties. According the results the maximum surface temperatures observed in the street canyon and at the first floors. (Kantzioura, A. et al., 2012),

Salata K. D. and Yiannakou A. (2013) studied a region of Kalamaria, Thessaloniki, and its relationship with urban form and climate change. Kosmopoulos P. & Kantzioura A. (2014) studied the influence of built environment in the microclimatic condition in a neighborhood of Thessaloniki. The urban geometry, the position and the height of the building inside the urban canyon, the orientation are factors that influence the surface temperature and microclimatic conditions (air temperature, wind speed, wind direction). The maximum surface temperature is observed, correlates with the orientation, the height of the opposite buildings and shadowing and the microclimatic conditions. Additionally, urban morphology is an important factor that affects the microclimatic and living conditions inside the urban centers. (Kosmopoulos P. & Kantzioura A. 2014).

Studies for other cities in Greece are not proportional to the number that exists in relation to Athens and Thessaloniki but they do not cease to give extraordinary information about the UHI fact. Hence, Kolokotsa et al. (2009) analyzed the results of the urban heat island research for a coastal Mediterranean, middle sized city, named Chania, in Crete, in Greece. The study focuses on the UHI study of the 2007 summer season, in relation to non-urban areas and in relation to local climatic conditions. The intensity of the phenomenon here occurs during daily hours, with values up to 8°C. Generally, the UHI intensity presents a constant trend fluctuating between 1,5°C and 2°C, because of the local winds. The phenomenon is attributed to highly populate urban structures, buildings, the anthropogenic heat, and the limited green spaces.

Another study example from a coastal middle sized city in Greece is the study Papanastasiou, D.K. and Kittas, C., (2011) examined the phenomenon UHI into a medium-sized coastal city in central Greece, in the Volos city. The maximum temperature difference between the city center and a suburb is 3,4°C and 3,1°C during winter and summer, respectively, while during both seasons the average maximum UHI intensity is 2,0°C, while the higher UHI intensities are observed in winter. It starts developing after sunset and reaches its maximum intensity until 22:00 LT in 50% of the days, while in summer it starts developing about 1 h after sunset and reaches its maximum intensity until 02:00 LT in 66% of the days. In addition, they discovered a correlation with the rate of use of public space, that is, with the frequency that residents move more intensely outdoors apparently with their cars.

The development of the phenomenon, according to a survey by Santamouris M., (2007), has nothing to do with the size of the city. Consequently, the type of urbanization transforms microclimatic conditions into cities.

2.11 Mitigation Strategies of UHI

Since the radical treatment of the phenomenon UHI is impossible because it would have to overturn the way of living in cities and the production way of goods, it became clear that even the mitigation of this phenomenon is beneficial because with only some actions-measures can significantly reduce the elevated temperature in city areas. These actions have to do with the proper exploitation of known physical laws and with the materials properties.

The form and materials of urban space buildings are the reasons for UHI creation as they have great thermal mass. As, during the day urban buildings collect the heat of the environment and at night they do the opposite, they emit it to the urban environment. Therefore, it is perceived that what is of great importance is the degree of reflection of the solar radiation and the absorption presentence, as, the radiation absorption and emittance from the building materials are able to heat the urban atmosphere. Somehow, the classification of materials in “cold” and “hot” (Doulos, L., et al., 2004) materials is based on the degree of albedo and thermal emitting as their high degree of low surface temperatures on the materials.

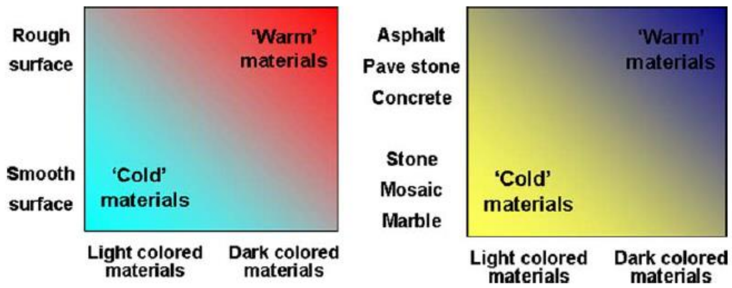


Fig. 26: Cold and hot materials.

(Source: Doulos, L., et al., 2004:248)

Building materials of buildings and urban space, and in particular the coating materials of external urban surfaces, have the most important role in shaping the prevailing outdoor temperature. There are studies that have categorized the materials according to their thermal performance and physical properties into 'cool' and 'warm' materials and focus on the effect of color, the surface's relief. (Doulos, L., et al., 2004).

Interestingly, researchers are addressing the issue of mitigating the UHI phenomenon with the same fervor that they are studying the phenomenon itself. Thus, Stathopoulou, M., et al., (2009), studied a surface heat island study of Athens using high-resolution satellite imagery and measurements of the optical and thermal properties of commonly used building and paving materials. (Synnefa A., et al., 2006a; Niachou, A., et al., 2001).

"Non-urban surfaces cool more rapidly than urban surfaces as building materials are stores of heat. Vegetation and surface emissivity appears to have a cooling effect on urban surface temperatures.... The spectral reflectance and the infrared emittance of the samples were measured and their SR and SRI were calculated. It was found that the coolest options are light-coloured coatings, marble, stone and membranes. Additionally, it was demonstrated that many dark-coloured materials are characterized by low near-infrared reflectance." (Tselepidaki, I., et al., 1992).

Apart from the climate change that occurs in the physical properties of building materials, it is the most important factor in the appearance of UHI in cities. The temperature absorbed by the materials during the day is emitted into the urban atmosphere during the night. Asphalt is heated than other materials, especially during the summer months (Asaeda, T., et al., 1996), with result to burden the urban environment. Specifically about asphalt's thermal behavior is due to the low degree of emission and its moderate transferability. "Surface's lower heat conductivity of a material may make a day hotter, on the contrary large heat conductivity makes a night hotter." (Asaeda, T., et al 1996).

Urban surfaces are dark with low albedo combined with vegetation lack that affects the urban climate resulting in the presence of UHI. Soil's evaporation is another factor of making a surface cooler than concrete or asphalt. Urban areas get hotter than rural settings not only because their ability to cool. Evaporative is reduced, but also because they reflect less incoming solar energy. Asphalt, in particular, has low albedo; it absorbs almost all the solar energy falling on it. This, combined with asphalt's inability to evaporate water, means that streets and parking lots paved with this material often reach blistering temperatures on sunny summer afternoons. (Akbari, H., et al., 1992).

Tables 4 & 5: Materials reflectance properties.

Coating Reflectances	Solar	UV	VIS	NIR
Triangle Coatings, Toughkote	0.85	0.12	0.90	0.87
National Coatings, Acryshield	0.83	0.11	0.89	0.85
Triangle Coatings, Trilastic	0.83	0.11	0.88	0.86
Guardcoat	0.74	0.10	0.79	0.76
Koolseal elastomeric	0.81	0.14	0.88	0.81
MCI elastomeric	0.80	0.12	0.87	0.81
Triangle Coatings, high reflectance # 7	0.84	0.12	0.89	0.86
Utrecht acrylic artist's color, titanium white	0.83	0.16	0.90	0.83

Reflectance of asphalt shingles

Asphalt shingle reflectances	Solar	UV	VIS	NIR
Antique silver	0.20	0.06	0.22	0.19
Black	0.05	0.04	0.05	0.05
Coral	0.16	0.05	0.16	0.17
Dark Brown	0.08	0.05	0.08	0.09
Gray	0.08	0.06	0.08	0.09
Green	0.19	0.08	0.21	0.20
Light Brown	0.19	0.07	0.19	0.20
Medium Light Brown	0.10	0.05	0.10	0.11
Medium Brown	0.12	0.06	0.12	0.12
Saddle Tan	0.16	0.05	0.16	0.18
White	0.21	0.06	0.24	0.21

(Source: Berdahl, P. & Bretz, S.E., 1997).

"The use of reflective coatings can significantly reduce surface temperatures" (Synnefa, A., et al., 2006). The rough and dark colored surfaces tend to absorb more solar radiation than the smooth, light colored and flat surfaces. Therefore the dark colored surfaces are warmer than the light colored. (Doulos, L., et al., 2004). Synnefa, A., et al (2006), measurements exhibit the thermal performance of a concrete tile on which has been applied a reflective coating is superior to the performance of a white marble and mosaic tile. Specifically, “A “cool” coating can reduce a white concrete tile’s surface temperature under hot summer conditions by 4 °C and during the night by 2 °C. It can be warmer, than the ambient air by only 2 °C during the day and cooler than the ambient air by 6 °C.” (Synnefa, A., et al., 2006). Material overlays can greatly help to lower the temperature in urban areas and improve the microclimate of an area by optimizing the sensible thermal comfort by reducing the UHI effect. In addition, they can act to reduce the energy required and have a positive effect on the energy balance.

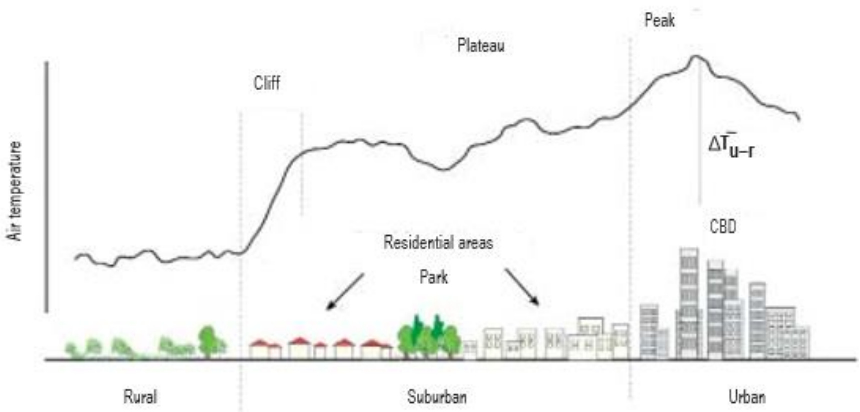


Fig. 27: Temperature variation in relation to space.
(Source: Bittan 2003 from Koppe, C., et al. 2004).

Through the technology these new products in the market are able to change the physical properties of the surface of the materials. Many researchers have been studying how effective these products are to address the UHI phenomenon, as Synnefa, A., et al., (2006b), who proved that the use of reflective coatings can significantly reduce surface temperatures in that degree that the thermal performance of a reflective coating concrete tile is superior to the performance of a white marble and mosaic tile, which are considering “cold” materials, by 4 °C and during the night by 2 °C. The same results in another study exhibit that cool materials present much lower surface temperatures than common materials and this can contribute significantly to lowering urban ambient temperatures and mitigate the effects of heat islands in Europe (Santamouris, M., 2007). Cool roofing (Akbari & Sezgen, 1993; Bretz & Akbari, 1997; Parker et al., 1994) is another form of UHI mitigation. This approach has modeled the impacts of increasing albedo on rooftops (Bass et al., 2002). Akbari’s research found that black roofs typically have a 6% rate of reflectivity and low emissivity values while highly reflective white roof membranes can have reflectivity and emissivity values greater than 80%. (Golden, J.S., 2004).

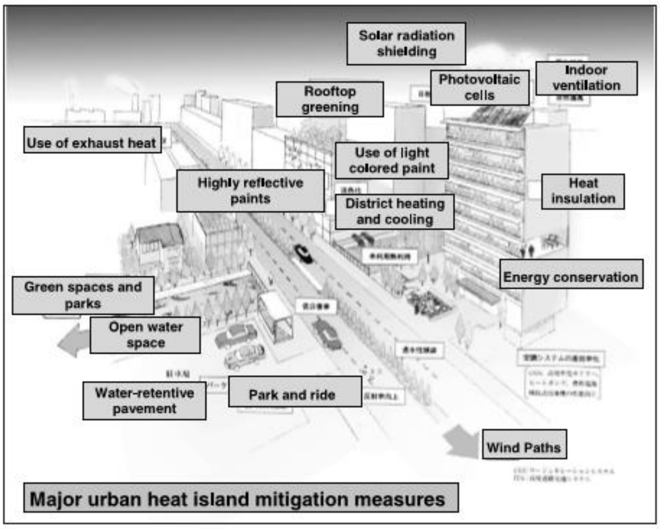


Fig. 28: UHI mitigation measures for indoor and outdoor.
(Source: Toshiaki Ichinose from Yakamoto Y. 2006:70).

A factor that can help to the UHI mitigation is the vegetation. The urban space as it is known is a place where the green is limited. The studies that explore the simple peoples' experience that under a tree the feeling is cooler and relieving in a hot summer day certify the human experience itself. "Trees and light color surfaces are inexpensive and effective ways to mitigate urban heat islands. Using white surfaces to increase the albedo of urban heat islands may be an easy way to conserve energy, save money and reduce pollution. Experiments have shown 20-40% direct saving by increasing the albedo of a single building and computer simulation indicates that the indirect effects of wide – scale albedo changes will nearly double the direct savings." (Rosenfeld, A. H., et al., 1995). The green roof beyond their ecological form and image, it supposed to function in mitigating the intense climatic effects for the urban environment on the shell of buildings, but as it proved finally it is just a thermal insulation for the building. (Del Barrio, E.P., 1998; Theodosiou, T.G., 2003; Eumorfopoulou, E., & Aravantinos, D., 1998, Niachou, A., et al., 2001; Zinzi, M., & Agnoli, S., 2012). Hence, green roofs can positively influence the urban climate indirectly as the demand for extra energy decreases.

The emitted infrared radiation from the various buildings and street surfaces impinges on the surroundings surfaces and is entrapped inside the canyon. (Doulos, L., et al., 2004). Urban planning and urban design are very important to address the effects of the UHI phenomenon because, as evidenced by many previously mentioned publications, they can determine the appropriate sunlight and ventilation of an urban unit. The geometry and orientation of the roads that define the building blocks are key parameters for adjusting the energy balance of a settlement. For example, the height and shape of the buildings and the way they are placed on the ground are decisive for the character of the microclimate. In addition, with the proper planning can be enhanced the Oasis effect[2]. It had already been noticed since 1972 the essential role of the land uses: “It is suggested that excess deaths occurring in urban areas during periods of extreme heat can be significantly reduced through appropriate urban land use.” (Clarke J. F., 1972).

“Trees are most effective if they shade buildings, but the savings are significant even if they merely cool the air by evapotranspiration.” (Rosenfeld, A.H., et al.,1998) According the simulations of Akbari H. and Taha H. (1992) increasing the green cover of the neighborhood by 30% (three trees per house) and increasing the albedo of the houses by 20% (from moderate-dark to medium-light color), the heating energy (Toronto) can be reduced by about 10% in urban houses and 20% in rural houses, whereas cooling energy can be reduced by 40 and 30%, respectively. Speaking for money on different houses the annual savings in heating and cooling costs ranged from $30 to $180 in urban areas and from $60 to $400 in rural zones. (Akbari H. and Taha H., 1992). Vegetation in cities beyond the benefits they offer to improve air quality, reduce noise, enhance aesthetics, and additionally regulate local temperature with shading and evapotranspiration, and indirectly save energy. On the other hand, according the Zhou B. et al. (2017) study parks, greenery and green roofs are shown to have a limited positive influence on a neighborhood’s climate because the dew that they offer reaches only some meters peripherals.

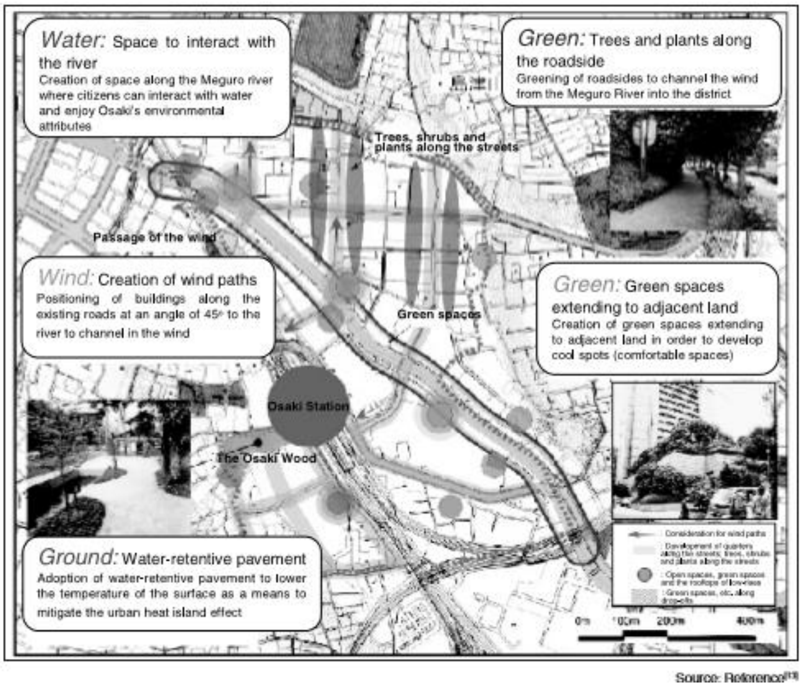


Fig. 29: UHI mitigation measures for outdoor spaces.
(Source: The Shinagawa City (Tokyo). (Japanese): http://www2.city.shinagawa.tokyo.jp/jigyo/05/bijyon_s.pdf, from Yakamoto Y. 2006:77, at 17-08-2017).

[2] The phenomenon of a cooling effect caused by vegetation (Givoni, 1991; Kai et al., 1997; Oke, 1987). According to Oke (1987), an isolated moisture source always finds itself cooler than its surroundings, due to evaporation cooling. The desert oasis is the most obvious example of this situation. Givoni (1991) suggested that in a well-vegetated area, a cooling effect will develop mainly due to the shading provided by the trees. Kai et al. (1997) described the oasis effect phenomenon as evaporation cooling due to differences in energy balance between the oasis and the surrounding desert (Source: Potchter O., et al. 2008).

In many areas with warm climate and significant sunshine, there are many examples of light-colored surfaces (ceilings, walls, roads) in their traditional architecture (e.g. the Cyclades) so as to reduce solar gains (Le Corbusier, 1923). The enhancement of bioclimatic architecture, concerns the design of buildings and spaces (indoor - outdoor) based on the local climate. It is an integrated design that takes into account the optimization of the urban planning organization and the formation of free public spaces, the appropriate layout of buildings (optimal orientation), sustainable building, and the formation of an appropriate microclimate.

Urban heat island mitigation strategies will become essential for the future of urban development. It may become necessary to apply these methods to reduce the harmful impacts of increasing temperatures and the urban heat island. Improvement of urban structure is unavoidable if we want to improve living conditions in cities and at the same time reduce energy needs by protecting the environment. Investing in nature's mechanisms (GI) it is possible to mitigate and adapt to unexpected environmental changes (floods and heat waves). Hence, it is also possible to mitigate UHI phenomenon strengthening the evapotranspiration mechanism improving (increase albedo, green and blue grid) surfaces.

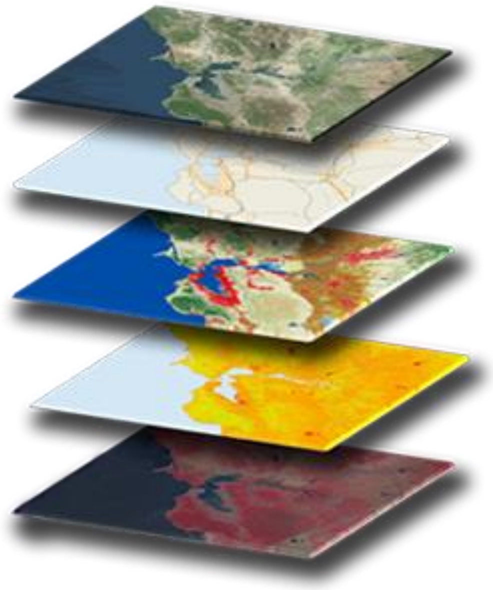
"The design and implementation of systems and techniques of a bioclimatic nature to improve microclimatic conditions in open urban spaces is one of the most important mitigation techniques." (Gaitani, A. N. et al., 2011). Another study on the implementation of efficient passive cooling mitigation techniques can optimize the local urban microclimatic environment, improving in summer time, the thermal comfort conditions, decreasing the temperature and homogenising the air and surfaces temperatures as it is enhancing the air flow in zones of low wind speed. (Gaitani, A. N. et al., 2011). A similar application is the study by Fintikakis, N., et al, (2011) in Tirana, Albania. The use of passive cooling techniques involving cool materials, solar control and additional vegetation as well as earth to air heat exchangers can reduce the peak summer ambient temperature up to 3°C, while surface temperatures are decreased up to 6–8°C. (Fintikakis, N., et al, 2011)

The correlation of the appropriate urban design with the energy is obvious and is proven by studies being made. In a study in Los Angeles, if peak power for air conditioning will be avoided it can reach about 1,5 GW (more than 15% of the city's air conditioning). Cool roof and paving surfaces and 11millions more trees could reduce ozone by 12% in Los Angeles and additional to reduce the L.A. UHI by 3°C. These translate to 12% improvement. These strategies can further to reduce air-conditioning use in a LA home by half and the national A/C saving is about 10% of A/C use. Beyond the economic benefits there is the imminent smog reduction. (Rosenfeld, A.H., et al., 1998).

2.12 GIS Methods

The GIS since 1962, when Roger Tomlinson,[3] "the father of GIS" (University Consortium for Geographic Information Science), captured the concept of mapping on the computer, has done a lot in both the evolution of computers and their capabilities, but also in the evolution of GIS itself as a geometric data processor.

"Geographic information system (GIS) includes hardware, software, data, procedures and people." (Law M. and Collins A., 2016). It helps the user to visualize, question, analyze, and interpret data to understand relationships, patterns, and trends. (Source: http://www.esri.com/what-is-gis)



Picture 1: GIS Data Layers

(Source: ESRI)

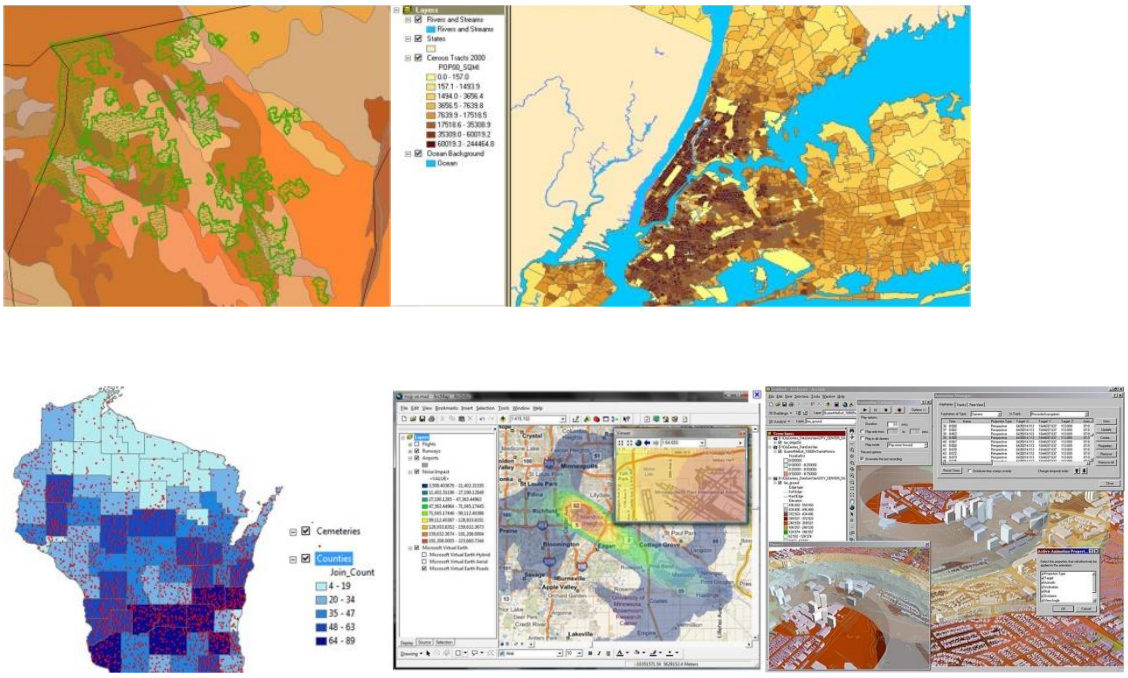
The ArcGIS as software through its basic applications of ArcMap, ArcCatalog, ArcToolbox and ArcGlobe, which have different functions but are interconnected, gives many possibilities to the user. While additional tools are the Spatial analyst, 3D analyst, Geostatistical analysis, και ArcPress etc.

"A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data…Coupled with this data is usually tabular data known as attribute data. Attribute data can be generally defined as additional information about each of the spatial features….GIS is more than

[3] "The first event was the establishment of the Canada Land Inventory (CLI) in 1962. CLI set out to produce about 1,500 maps of land use and land capabilities at 1:50,000 and 1:250,000 scales. Though the maps were made by traditional manual methods, Roger Tomlinson (then employed by Spartan Air Services of Ottawa) convinced the head of CLI that computers could be used to automate map analysis. CLI invited Tomlinson to define the functional requirements of what would later be called the Canada Geographic Information System. His carefully considered use of the qualifier "geographic" caught on and has created opportunities and challenges for the discipline of geography ever since." (Source: "The 50th Anniversary of GIS". Accessed from: http://www.esri.com/news/arcnews/fall12articles/the-fiftieth-anniversary-of-gis.html at: 10-10-2017).

just software. People and methods are combined with geospatial software and tools, to enable spatial analysis, management large datasets, and the display of information in a map/graphical form.” (Research guides: University of Winconsin-Madison Libraries.)

GIS can be used as tool in both problem solving and decision making processes, as well as for visualization of data in a spatial environment. Geospatial data can be analyzed to determine through mapping where things are, their quantities, densities, find what is inside and what is nearby and the change. “Employing points, lines, and polygons to model real-world geographic forms, this easy-to-use resource provides geographers, researchers, and practitioners a valuable bridge between theory and the necessary software to apply it. It contains sections on point distribution, point pattern analysis, linear features, network analysis, and spatial autocorrelation analysis.” (Wong, WSD and Lee, J., 2005)



Pictures 2-6: GIS Possibilities.

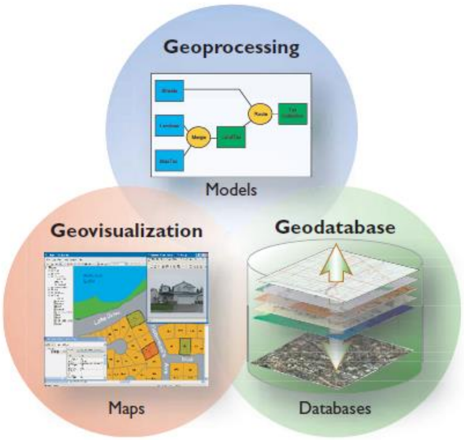
(Source: Research guides)

GIS can do data input, from maps, aerial photos, satellites, surveys, and other sources - data storage, retrieval, and query - data transformation, analysis, and modeling, including spatial statistics - data reporting, such as maps, reports, and plans (Foote, K.E. and Lynch, M.,1995).

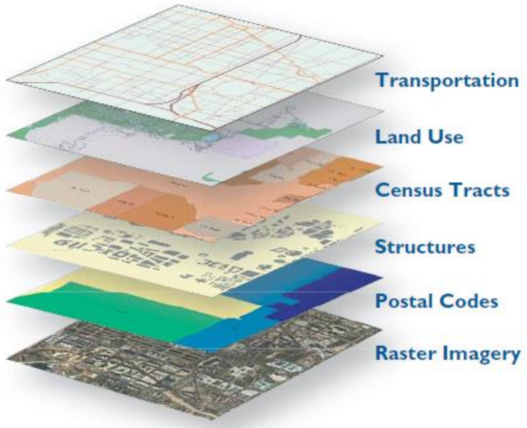
Geoprocessing is a framework and set of tools for processing geographic and related data. The large suite of geoprocessing tools can be used to perform spatial analysis or manage GIS data in an automated way. (ESRI1)

The Geostatistical Analysis extension provides a range of spatial analytical tools to explore and predict uncertainties. It enables Geostatistical Analyst Toolbox. (GIS Geography). Geostatistics is a field of statistics dealing with field data and spatial data.

It uses methods for modeling spatial correlation and make predictions for unknown sites that is the interpolation.



The three views of GIS



GIS integrates many types of spatial data.

Pictures 7-8: The GIS function.
(Source: ESRI "ArcGIS 9: What is ArcGIS?")

2.13 Choosing the right interpolation method

Interpolation methods are used when there is insufficient data to be processed for sufficient locations in space and there is need to extrapolate for a particular area and results for a particular area should be output. That is, one of the possibilities of the interpolation method is to calculate and fill in the gaps created by the lack of data.

Spatial interpolation techniques use observations of the same variable in another site. The methods used to estimate temperature for unknown locations can be categorized on one hand to deterministic interpolation methods (inverse distance weighting, non-linear interpolation as spline techniques, etc.) and statistic interpolation methods (different varieties of Kriging) and on the other hand data-based methods (regression, artificial neural networks, etc.) (Di Piazza A., et al. 2015 from: Burrough, P., et al., 1998)

A challenge in spatial analysis is that a spatially continuous variable is interpolated by point samples. Three interpolation methods which are commonly used for modeling the spatial distribution from point data are Inverse Distance Weighting (IDW), the Spline and the ordinary Kriging. (Ranade, P., et al., [Accessed at 29-09-2017].

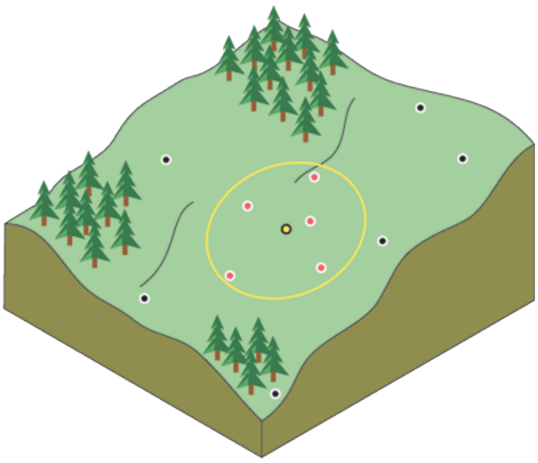
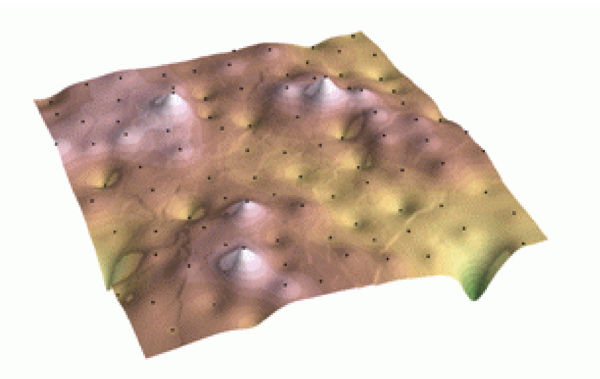
Spatial analysis is a series of actions for handling original data information with target to extract contemporary and considerable spatial information. The spatial analysis can be performed with a Geographic Information System (GIS), which provides spatial analysis tools for calculating statistical features and conducting geoprocessing activities as data interpolation. Thus, spatial interpolation is the procedure of the ability to calculate the values of unknown locations using only known values from some acquainted sites. Specifically, temperatures in areas with unknown data can be calculated just using measurements from nearby meteorological stations. In reality, interpolation uses vector points with known values for price appreciation in unknown places to create a raster surface that covers a full range and the result is a raster layer. Consequently, the main interpolation quality controller is the density of meteorological station locations as well as the surface morphology of the surface.

2.13.1 Deterministic Methods

IDW interpolation

The IDW (Inverse Distance Weighted) is an interpolation procedure which weighs the sample token so that the influence of one token on another decreases with the distance from the unknown new unknown token. The weighting is divided into sampling points by using a weighting factor which controls how the weighing effect decline as the distance from the new point increases. The larger the weighting factor, the smaller the influence of the influence points when they are removed from the unknown point during the interpolation process. As the factor increases, the value of the unknown point approaches the value of the next observation point. (Sluiter, R., 2009).

The IDW interpolation method is based on the principle that the values of the sample closest to the area in which there are no values have the greatest influence - the weighting in calculating the missing value is higher than the other values at other locations farther away from the point calculation. The certain method calculates a specific grid cell value of the sample data point values near each processing cell using the mean value of the surrounding values in the positions. In fact, it uses a linearly weighted combination of sampling points, which is a function of the inverse distance.

Picture 9 (Left): IDW neighborhood for selected point. (Source: ESRI)
Picture 10 (Right): IDW Interpolated Surface; Courtesy: ESRI. (Source: GIS Resources)

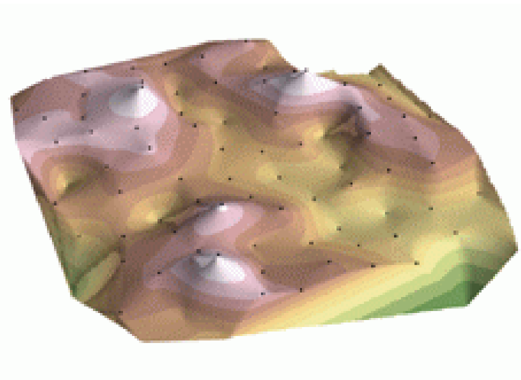
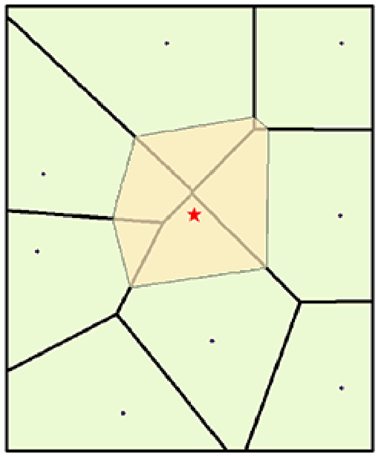
Since the calculation of the missing points when the method uses higher power assigns (defined in ArcGIS) takes into account the values of the points in the nearest positions and the created image shows strong fluctuations producing a non-smooth surface but when it is using lower power assigns the closer points are calculated to the smallest weight then more weight is given to the values of the positions that are further, then the resulting surface is smoother. A disadvantage of IDW is that the result of the generating image is that the different surfaces are displayed with an intense sharp way. Hence, the definition of the number of power is decisive for the results.

The best IDW results are obtained when the sampling is quite dense compared to the local variation. If the sampling is sparse or non-homogeneous, the results may not adequately represent the desired surface. (Watson and Philip 1985). The method tends to produce "bull's eye patterns". It not exist any extrapolation: All interpolated values are in the area of the data points (De Smith, et al., 2007). IDW is used in meteorology. Usual it is used with a combination of linear regression models. The results of IDW were worse than the results of Kriging and the linear regression model. (Sluiter, R., 2009; ESRI).

Nearest Neighbourhood (NN) and triangulation

The Natural Neighbor (NN) method is a geometric estimation method that uses natural districts which are generated around each part of the dataset. That method attributes the value of the closest observation of a particular grid cell. (Sluiter R. 2009).
NN interpolation finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas to interpolate a value (Sibson, 1981 from ESRI). This interpolation method, like IDW, is a weighted average insertion method. It has many positive properties, can be used for both interpolation and extrapolation, and generally works well with concentrated dispersion points. In another weighted average method, the basic equation used in natural interpolation of neighbors is the same as the basic equation used in the IDW interpolation. With this method, large input point data sets can be efficiently processed. When using the Natural neighbor method, local coordinates determine the influence of a scattering point on the output cells. (GIS Resources)

Natural Neighbors interpolation instead of finding an interpolation value use and weight all points proportionally by their distance. This method works best when sampling points are distributed with unequal density. It is a good technique for all uses and has the advantage that you do not need to define parameters such as radius, number of neighbors or weights. (GIS Resources)

Picture 11-12: Left pic: NN Courtesy: ESRI, Right pic: Example of Voronoi polygon (NN) created around interpolation point.
(Source: Left pic: GIS Resources: https://www.gisresources.com/types-interpolation-methods_3/, Right pic: ESRI)

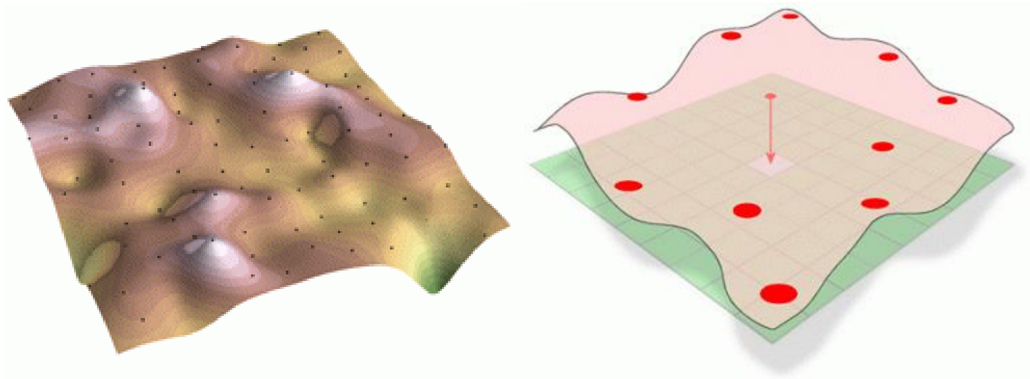
The Triangular Irregular Networks (TIN) interpolation uses sampling points to produce a triangle-shaped surface based on the closest neighbor information.
Surface slope derives from_the three adjacent points and it can be used to calculate the value for specific grid-cells.

NN and TIN method are quick and easy, but the interpolated surfaces are not look realistic always. The drawback for both is the lack of success measures. Methods work better when multiple data points exist. Additional data cannot be considered.
The application of both methods in meteorology is limited, but can be successfully used for dense measurement networks.

Polynomial functions (splines)

The polynomials functions operate as the polynomials of the class. Generally speaking, they are global interpolators meet the criteria by fitting many polynomials in districts with overlapping areas. Algorithms are used for normalizing-smoothing the generated patterns and define different methods among the existing spline methods. The spline interpolation method calculates unfamiliar fold values of a surface for known values. (Sluiter R. 2009). Considerate that polynomial functions are a good interpolation method for monthly and yearly climate elements but they do not have the expecting results for days and hours. Spline method has not so good perform as Kriging, linear regression models and IDW do. (Tveito et al., 2006).

Spline is deterministic interpolation method that uses a mathematical function through the input data minimizing the surface curvature so as to create a smooth surface following faithfully the input points. Splines are able to produce precise surfaces from a few sampling points and retain small features (Anderson, 2008). Spline uses curved lines to calculate a cell value that’s why it has better results for gently varying surfaces as temperatures have. The ArcGIS Spline is Radial Basis Function.



Picture 13-14: Display with Spline method.

(Source: ESRI: GIS Resources)

The method advantages are that it is a great tool for estimating the maximums above and below the minimum points and it creates a smooth surface effect. It drawbacks are that cliffs and fault lines do not work well because of the smoothing effect and when sampling points are close and have exceptional value differences, Spline interpolation does not work as it should. That happens because the Spline method uses slope calculations to calculate the shape of the flexible rubber sheet. (Source: GIS Resources).

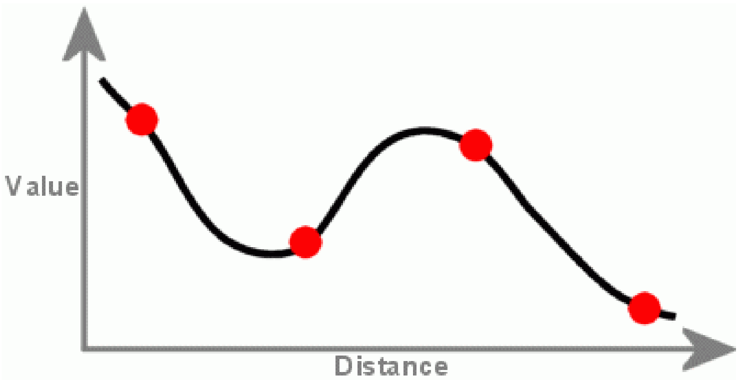


Fig.30: A surface created with Spline interpolation passes through each sample point and may exceed the value range of the sample point set.

(Source: GIS Resources).

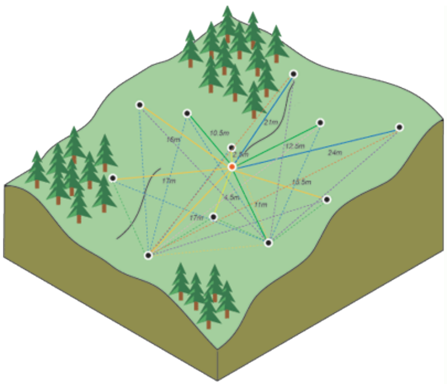
The Spline method allows analysts to decide between smooth curves or tight straight edges between measured points. Advantages of splining functions are that they can generate sufficiently accurate surfaces from only a few sampled points and they retain small features. A disadvantage is that they may have different minimum and maximum values than the data set and the functions are sensitive to outliers due to the inclusion of the original data values at the sample points. This is true for all exact interpolations, which are commonly used in GIS, but can present more serious problems for Spline since it operates best for gently varying surfaces, (i.e. those having a low variance). (Nawal K.G.,et al., 2013).

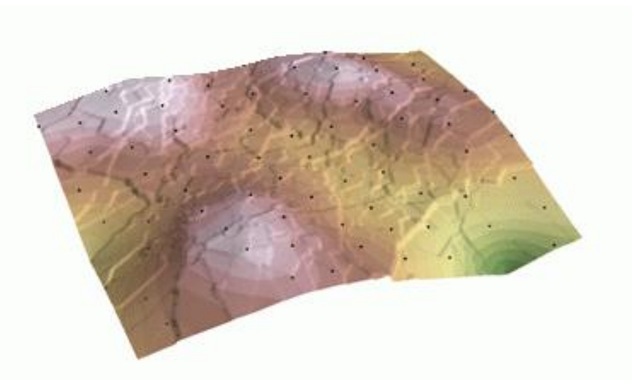
2.13.2 Probabilistic methods

Probabilistic methods incorporate the concept of randomness and include methods like linear regression models, geostatistics and optimum interpolation. “Kringing was developed by a French mathematician Georges Matheron” (Cao, W., et al., -). McDonnell & Burrough (1998) have shown that for applications in geosciences, when data is sparse enough, proved that Kriging is the best available interpolation technique (Sluiter R. 2009).

Kriging interpolation is based on the assumption that the spatial change of a continuous feature is often too irregular to form with a simple function. The change can best be described by a surface with a feature known as a regional variable. The method is a fast, accurate interpolator and generates smooth displays. The method is flexible; results can be generated in addition to forecasting charts, such as predictions, errors and probabilities. The disadvantage is that large required decision-making. The measure of success is through predictive errors or through cross-validation. (ESRI).

The Kriging method is a geostatistical interpolation technique that the distance and the degree of variation between known data points when estimating values in unknown areas. A Kriged estimate is a weighted linear combination of known sample values around the point to be estimated. It creates an estimated range from a scatter set of points with z values. This function assumes that the distance or direction between the sampling points reflects a spatial correlation that can be used to explain the change in the surface. The Kriging tool sets a mathematical function to a certain number of points, or all points within a predetermined radius, to determine the output value for each location. Kriging is a multi-step procedure. It includes exploratory data statistical analysis, modeling of variations, surface creation and (optionally) exploration of a surface of variance. Kriging is most appropriate when you know that there is a spatially related distance or directional bias in the data. (Source: GIS Resources)





Picture 15: Kriging-The image shows the pairing of one point (the red point) with all other measured locations. This process continues for each measured point. (Source: ESRI)
Picture 16: Kriging method picture result. (Source: ESRI: GIS Resources).

Kriging is based on the regionalized variable theory that assumes that the spatial variation in the phenomenon represented by the z-values is statistically homogeneous throughout the surface (for example, the same pattern of variation can be observed at all locations on the surface). This hypothesis of spatial homogeneity is fundamental to the regionalized variable theory. The speed of execution is dependent on the number of points in the input dataset and the size of the search window. Low values within the optional output variance of prediction raster indicate a high degree of confidence in the predicted value. High values may indicate a need for more data points. (ESRI)

The predicted values are derived from the measure of relationship in samples using sophisticated weighted average technique. It uses a search radius that can be fixed or variable. The generated cell values can exceed value range of samples, and the surface does not pass through samples. Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The weighted value of points inside the neighborhood is calculated using an inverse distance weighted interpolation or inverse exponential distance interpolation. This method interpolates a raster using point features but allows for different types of neighborhoods. Neighborhoods can have shapes such as circles, rectangles, irregular polygons, annuluses, or wedges. (GIS Resources). Unlike IDW and Spline, Kriging is a method based on spatial autocorrelation and it uses semivariogram. (Ranade, P., et al.)

Many scientists used the method and they gained a view depending on their results. In any case, however, they agree that it is a great method for processing data and exporting remarkable results. Thus, "The best results at the annual scale have been obtained using the ordinary Kriging of residuals from linear regression" (Di Piazza A., et al. 2015). "Kriging exponential and Kriging spherical have the best interpolation precision. For mean temperature and the minimum temperature, the order of interpolation precision is Kriging-exponential ≈ Kriging spherical >IDW >Spline > Kriging-Gaussian, and for the maximum temperature, the order is Kriging-exponential ≈ Kriging-spherical >IDW > Kriging-Gaussian >Spline." (Cao, W., et al., -).

Ordinary Kriging is the most widely used of the Kriging methods and is the default. It is the basic form of Kriging. It makes the estimation through a linear combination of the known values. The correlation between the data, as described by the variogram, determines the weights. The mean value is unknown and so fewer assumptions are made. The method assumes intrinsic stationarity, but unfortunately meteorological variables are not stationary. In some case this problem can be overcame by using different areas sizes and shapes. Usually, it is applied in meteorology, often as part of residual Kriging or indicator Kriging. (Sluiter R. 2009).βIn ordinary Kriging, the weight depends on a fitted model to the measured points, the spatial relationships among the measured values around the predicted location, and the distance to the predicted location. (Cao, W., et al., -).

2.13.3 Evaluation of interpolation methods

Scholars who have used the various methods of interpolation in their studies because of their research lead to conclusions about what method they consider to be optimal for data processing. So the views are many and there are not many times when they are contradictory. Thus, an opinion example is, “the most used and promising techniques are universal Kriging and linear regression models in combination with Kriging (residual Kriging) or IDW. When there are available less than 30 measurements IDW or splines may be a better choice.” (Sluiter R. 2009).

Similar opinion have Hofstra, N., et. al., (2008) “Global Kriging as the best performing method overall” (Hofstra, N., et. al., 2008). In the same way Yang, J.S., et al., (2004) “Kriging interpolation is recommended due to its considerations of prediction confidence in error map and spatial autocorrelation between sampling sites. Cokriging is suggested for areas with rough terrains and large variation in elevations.” (Yang, J.S., et al., 2004)

Others trying out more methods are able to evaluate methods through their results. “Statistical results of minimum temperature by using Kriging methods are the best (which has the lower estimation error) followed by IDW and then Spline.” (Nawal K.G.,et al., 2013). “Ordinary kriging and IDW provide more accurate estimation than Spline method.” (Nawal K.G.,et al., 2013). While, “similar to the Spline functions, IDW is sensitive to outliers.” (Bhowmik, A. K., & Cabral, P., 2011).

Like IDW interpolation, Kriging weights from nearest surrounding measured values data so as to predict unmeasured locations. However, the Kriging weights for the surrounding measured points are more sophisticated than those of IDW because it just uses a simple algorithm based on distance, but Kriging weights come from a semivariogram that was developed by looking at the spatial nature of the data. To create a continuous surface of the phenomenon, predictions are made for each location, or cell centers, in the study area based on the semivariogram and the spatial arrangement of measured values that are nearby. (ESRI)

“The study identified IDW as the best method for interpolating surfaces, followed by IDW and KRIGING then SPLINE…. IDW is most likely to produce the best estimation of a continuous surface of air temperature….. Residual KRIGING seems to be adequate for the spatial interpolation of air temperature…..” (Mookken M., et al., 2011).

A review of the literature indicates that a regionalized variable such as temperature, which is strongly correlated with elevation, would be well disposed to Kriging and Cokriging. Due to the additional effort Kriging and cokriging entails, it was decided to compare the effectiveness of Kriging and cokriging in estimating maximum and minimum temperature at unsampled locations with other less computationally intensive techniques such as inverse distance weighted averaging, cubic splining, the trend surface analysis (TSA), polynomial regression and lapse rate methods. Kriging and cokriging have also received some criticism due to the subjective nature of variogram fitting - a central component of Kriging (Phillips and Watson, 1986). In addition to the aforementioned methods, this research introduces optimal inverse distance weighting where the inverse weighting parameter is chosen on the basis of minimum mean absolute error." (Collins Jr. F. C., Accessed at: 29-9-2017).

The IDW and Spline are referred to as deterministic interpolation methods because they are directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. A second family of interpolation methods consists of geostatistical methods, such as Kriging, which are based on statistical models that include autocorrelation—that is, the statistical relationships among the measured points. Because of this, geostatistical techniques not only have the capability of producing a prediction surface but also provide some measure of the certainty or accuracy of the predictions. (ESRI). Moreover, Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. (ESRI).

CHAPTER 3:

The city of Thessaloniki

3.1 Thessaloniki geographically

The city of Thessaloniki is located in northern Greece in the Central Macedonia Region; it is the capital of the Regional Unity of Thessaloniki and is the next largest city in Greece after Athens (800,000 population).

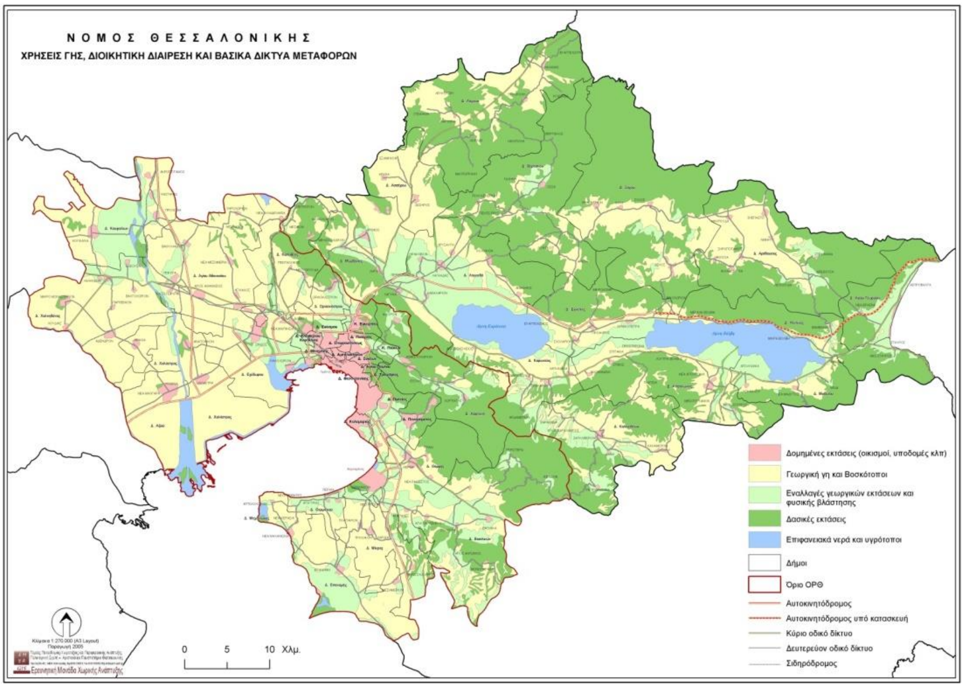


Chart 1: Regional union of Thessaloniki: Land use, Administrative division and basic Transport networks.

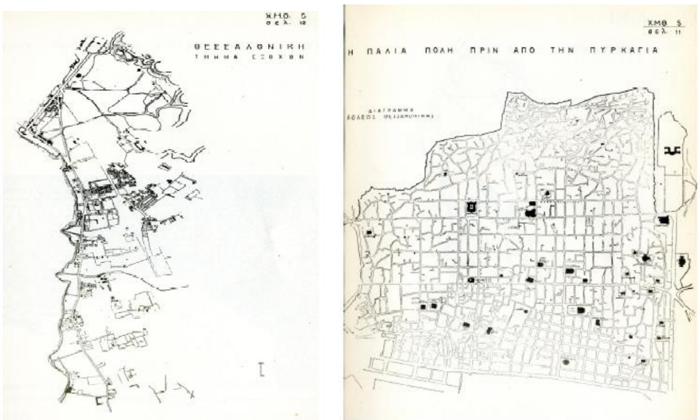
(Source: EMCHA- AUTH).

The city of Thessaloniki lies on the tip of the Thermaikos bay and is surrounded by the Cedar Hill (Sheich Sou) and its surrounding urban forest. In the northeast of the city the mountain “Chortiatis” (1.200m) is the city’s benchmark, while on the contrary side there is the Thessaloniki’s plain.

The north part is a compact configuration of the urban fabric that includes the center and the old town, which extended north and northwest and are part of Thessaloniki's urban complex with a dense building structure with residential and secondary production land uses. The southern part of the city is also a compact and more extensive of the Northwest development along the sea. It extends, in the wider urban area, with a dilapidated residential network that is in the northwest region and occupies the southern part of the regional unity.

3.2 Thessaloniki’s Urban Planning history

Thessaloniki is a city with a long history, allegedly founded in 315 BC by Kassandros, King of Macedonia. From the late 19th century, something seems to change in the city's urban planning as the coastal walls were demolished in 1869, and only 10 years after 1879 there was an expansion beyond the boundaries of the city according to the Turkish plan for the area. During these years outburst of fires were a common phenomenon in the city and it was an opportunity for modernization.



Charts 2 & 3: Left: “Exoches” area of Thessaloniki
Right: The city before the fire of 1917.
(Source: Thessaloniki’s Spatial Study of Triantaphyllides)

In 1890 there were two large suburbs in the northwest and the southeast of the Golden Gate. While the main extension of the city without a particular plan was made to the East and out of the walls in an area known as Hemidie. The coastal part of this wider area at the east, known as "Exoches" (countries) or "Pyrgoi" (towers) area (today in the wider area on both sides of Basilissis Olgas Street), was a housing estate of the upper class that wanted to be housed outside the city. (Gerolimpou, 2008:164 in "Thessaloniki's Emerging Maps Memories" (“Thessalonikis Anadixis Charton Anamnisis”) from: Savvaidis, P.).

After the mid of 19th century, the town planning regulation was changed with the legislative code of 1864 and 1891. Thessaloniki, during the period from 1850 to 1912, was developed within the framework of the modernization of the Ottoman urban space. During this period there are gradual changes in the economic activities siting of the city. The urban fabric is transformed from organic to Hippodamian and gradually the wall is demolished. The city extended outside the city borders, the harbor area reformed and consolidated the railway station build and the western central area of the city formed. (Avdelidis, [199-])

Chart 4: The Fire zone.

(Source: thess.gr [Accessed at: 6-7-2010])

In the first decades of the 20th century the events that influenced Thessaloniki's urban history and character were:

- the 1917 fire and the Thessaloniki city's design by Ernest Hebrard. "The fire of 1917, five years after the liberation of the city and five years before the Asia Minor disaster, is a landmark in the history of the city" (Gerolimpou, 2008:164 in "Thessaloniki's Emerging Maps Memories" ["Thessalonikis Anadixis Charton Anamnisis"]). "The old poly centered structure changes into a single center and the functions of the center are reorganized with transferring industries off the city center and a new siting of urban functions." (Avdelidis, [199-])

- the exchange of populations because of the Minor Asia disaster, where large amount of refugees settle down in the city and its surroundings

- the internal migration so as to find work in industrialized urban centers.

"In the 1960s, was commissioned to Ioannis Triantafyllidis, Professor of Aristotle University, from the Ministry of Public Works, to draw up a Spatial Planning Study for Thessaloniki which he completed in 1968. The study's influence on the principles of the modern movement is based on the detailed planning and organization of the land uses. Triantafyllidis study has never acquired a binding character because this approach came in contradiction with the Greek reality and the existing residential development of Thessaloniki." (Alexandropoulou, Makraki - Karachaliou, 2009)

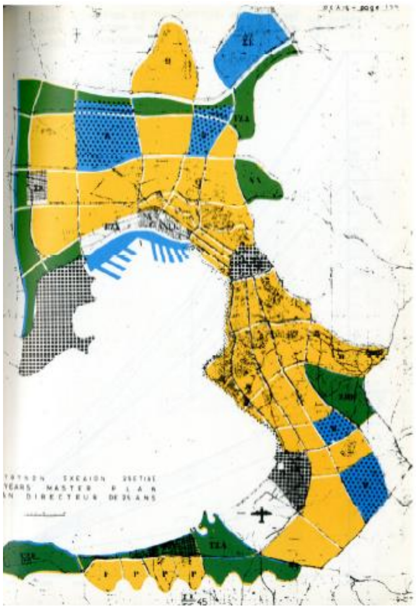


Chart 5: The 25th years 'Managing plan for Thessaloniki'.
(Source: Thessaloniki's Spatial Study of Triantafyllidis I.)

In 1983, in the frame of the Urban Reconstruction Operation (EPA), the Thessaloniki Housing Directorate drew up a report entitled "Reconstruction of Thessaloniki", which included basic objectives for the town planning organization, in order to constitute the framework for the preparation of the General Urban Planning. The report was the basis for the drafting of the Decree on the Regulatory Plan. (a.a)

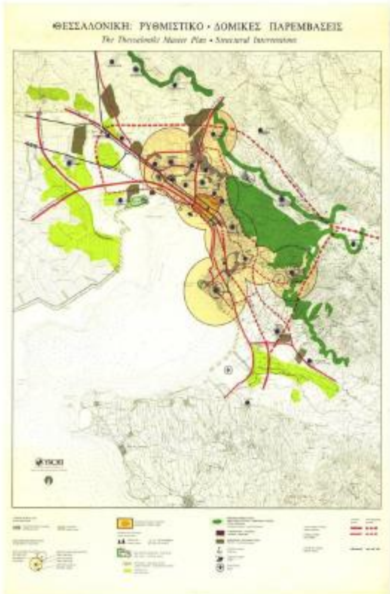


Chart 6: The Regulatory Plan of Thessaloniki (1985): Structural interventions.
(Source: DIPEXOS KM DAMTH)

The Regulatory Plan of Thessaloniki (RPT) was established by the Law 1561/1985 (Government Gazette 148A'/6-9-1985), "Regulatory Plan and Program for the Protection of the Environment of the Greater Area of Thessaloniki and other provisions”. The objectives that have been set are to protect and enhance the city's historical and cultural heritage by a key axis of development and action for protecting the natural environment and social equality, improving the quality of life for the inhabitants by upgrading the living space expanding the options for the basic functions of the city (home, work, recreation).

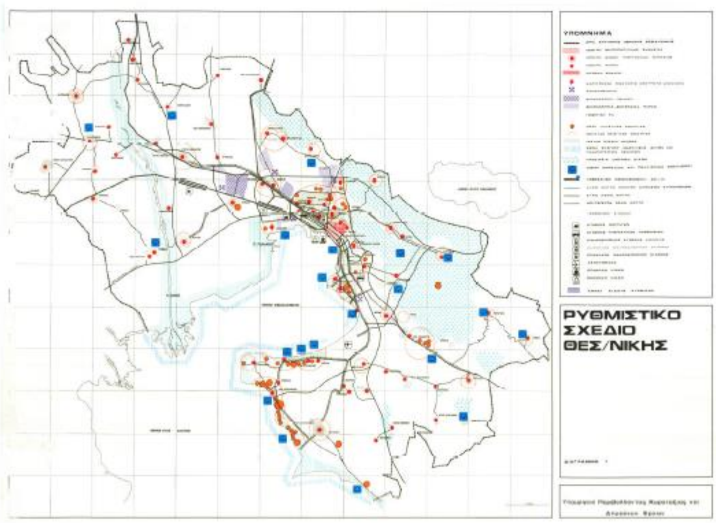


Chart 7: Basic development directions (1985).
(Source: DIPEXOS KM DAMTH)

In the 1980s and 1990s, arrangements were made under Law 1561/8524 (ZOE), the planning areas outside the city, and the General Urban Plan (GG 420Δ’/1993) for the city’s urban planning complex. Some of these regulatory and planning documents apply and become redevelopment works of historical sites of the center and of the old town, urban planning organization that improved the city’s shaped area and made improvements related to the siting of the central functions. (Avdelidis, [199-])

Following the adoption of the Thessaloniki Master Plan, two studies were prepared on the initiative of the Regulatory Planning Organization for Thessaloniki (ORTHE) but with no significant impact on the city's urban planning; more were exercises on paper than studies that applied. The "Thessaloniki Strategic Plan for the 21st Century" was drafted in 1995 and the "Strategic Plan for Sustainable Development of Thessaloniki" was drafted in the period 2000-2002.

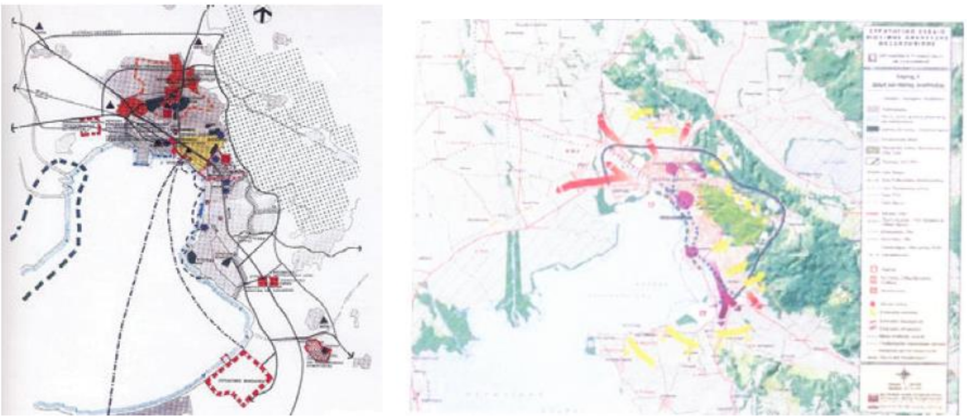


Chart 8 & 9: Chart Left: Thessaloniki's Strategic Plan for the 21st Century.
Chart Right: Strategic Plan for the Sustainable Development of Thessaloniki.
(Source: Alexandropoulou, Makraki - Karachaliou, 2009.)

According to the Strategic Plan of Sustainable Development of Thessaloniki for the update of the Thessaloniki Regulatory Plan, the scenarios proposed for the boundaries of the Metropolitan Area are as depicted on map 16. However, the study has not yet been institutionalized.

Chart 10: Strategic Plan of Sustainable Development of Thessaloniki.
(Source: ORTHE)

3.3 Population and housing developments

In 1917, the urban area of Thessaloniki appears to have an area of approximately 9.69 km. The city, which was extended outside the walls in the 18th and early 19th centuries, occupies a new area of 223% of the surface of the old city. The bulk of the new urban fabric (82% of the extension) formed coastal and south of the old town until Kalamaria, which still characterizes the current form of the city. Northwest expansion is significantly smaller (about 10%), while smaller new urban fabric appear at the northeastern edge of the old city (2.5% of the extension) and Pylea (5.3% of the extension). While, in the 1933-34 Thessaloniki's mapping, the structured area had been doubled at approximately 19.35km^2. (Avdelidis, K., [199-]).

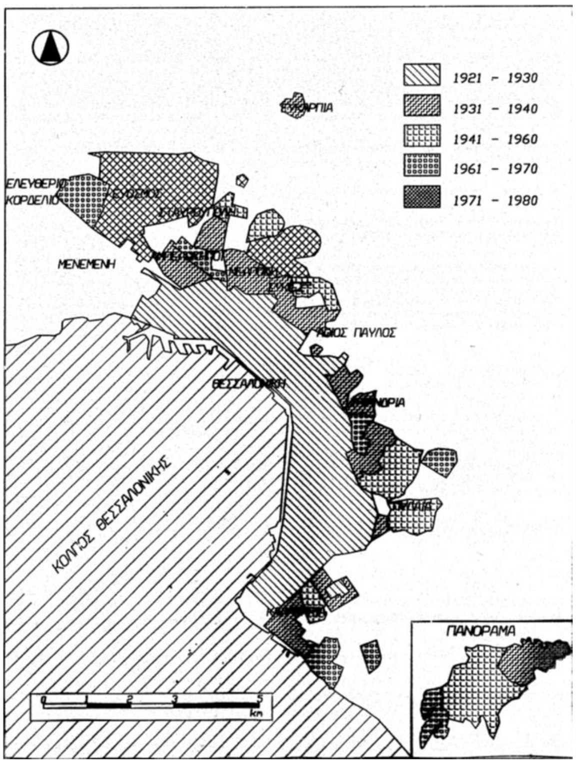


Chart 11: The gradual expansion of Thessaloniki until the 1980.
(Source: Giannakou, (2009), p.470)

In the post-war period, as it appears on the map below (Avdelidis, K., [199-]), the urban development complex of Thessaloniki is increasing in population and to a large extent mainly the western and northern regions of the city. The internal migration was observed mainly in the 1960-70s, which was related to the industrial development of the city, reformed the city. That new working population settled in the North and West of the city so as to have proximity to industries and crafts where they were working.

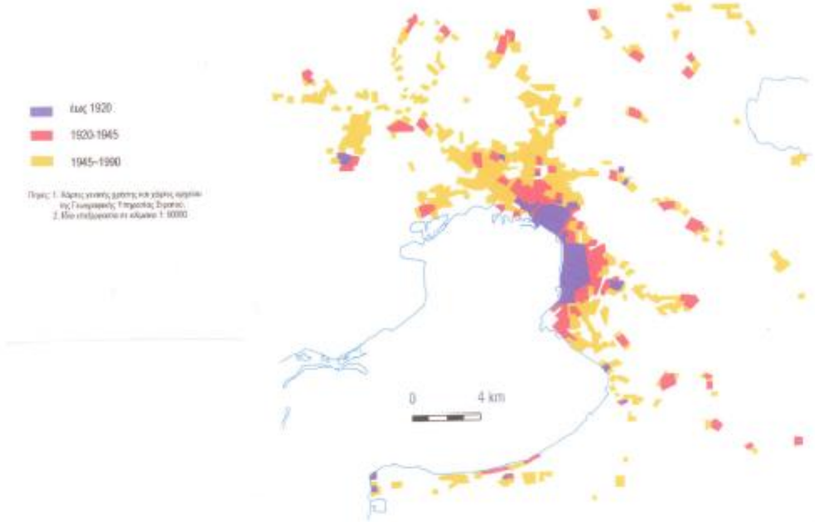


Chart 12: The depiction of the expansion of Thessaloniki.
(Source: Avdelidis, K., [199-])

In the 1982 map, the new surface of Thessaloniki's urban complex had been increased by 255%. That happened to two directions at the northern area – it was occupied about 74% of the total extension - along the main transport routes to Kalochori, northwest to Sindos, Oreokastro, north-east to Lagadas and at the southern area - with a surface corresponding to the remaining area's 26% of the total extension- orienting eastwards towards Panorama and southeast to Thermi. (Avdelidis, K., [199-]).

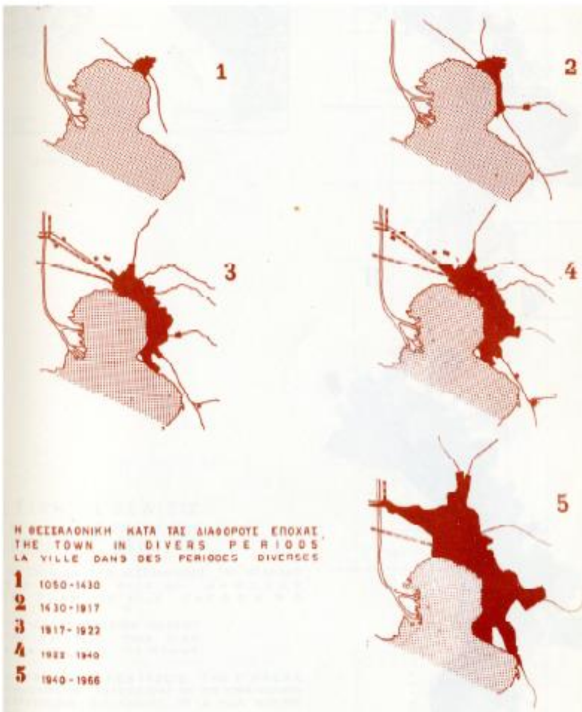


Chart 13: Chart of the expansion of Thessaloniki.
(Source: Triadafyllidis Spatial Study)

According to Avdelidis, K., (199-), the urban fabric of Thessaloniki in 1920 was 9,69km^2. In the period 1920-1945 the new area added to the city was 19.4 km^2 i.e. an increase of 199,7%. While in the next period 1945-1990 the area of the new urban fabric was overturned by an additional 74,1km^2, i.e. an increase of 255%.

Table 6: Population change of the city by geographical unit from 1961-2001.

Γεωγραφική ενότητα	Πραγματικός πληθυσμός					Μεταβολή 1991-2001	Μεταβολή 1981-2001
	1961	1971	1981	1991	2001		
ΣΥΝΟΛΟ ΧΩΡΑΣ	8.388.553	8.768.641	9.740.417	10.259.900	10.964.020	6,86	12,56
ΝΟΜΟΣ ΑΤΤΙΚΗΣ	2.057.974	2.797.849	3.369.443	3.523.407	3.761.810	6,77	11,64
ΚΕΝΤΡΙΚΗ ΜΑΚΕΔΟΝΙΑ	1.320.532	1.407.391	1.601.420	1.704.343	1.871.952	9,83	16,89
Ν. ΘΕΣ/ΝΙΚΗΣ	546.286	711.990	871.580	944.426	1.057.825	12,00	21,37
Ε. Π. ΘΕΣ/ΝΙΚΗΣ	471.716	648.518	807.906	875.695	981.933	12,13	21,46
Π. Σ. ΘΕΣ/ΝΙΚΗΣ	380.648	557.360	706.180	749.048	800.764	6,90	13,39
Δ. ΘΕΣ/ΝΙΚΗΣ	250.920	345.799	406.413	383.967	363.987	-5,20	-10,44
Π.Ζ.Θ. & ΛΟΙΠΗ ΠΕΡΙΟΧΗ	91.068	91.158	101.726	126.647	181.169	43,05	77,43

(Source: ELSTAT Elements from: "Design Office SA")

It can be noticed from the above ELSTAT table population data (Table 6), the 1981 is a milestone for the Municipality of Thessaloniki because there was a continuous increasing change in the population and from then there is a decrease. This is not a shrinking city phenomenon but just a moving people outside the center looking for a better environment to live as the population precedence is rising for city' s outside areas.

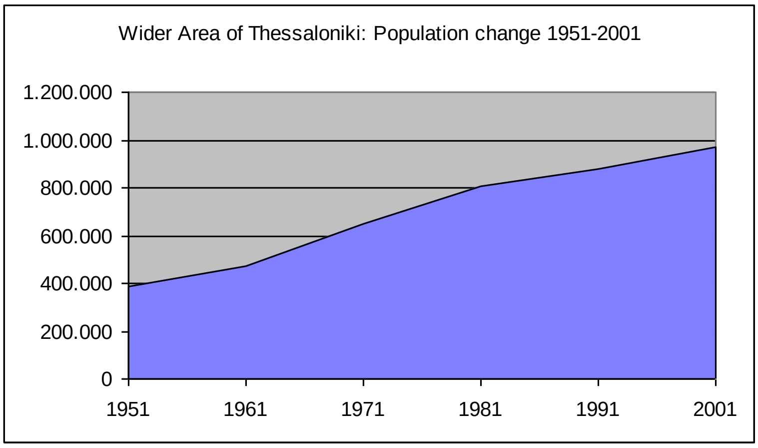
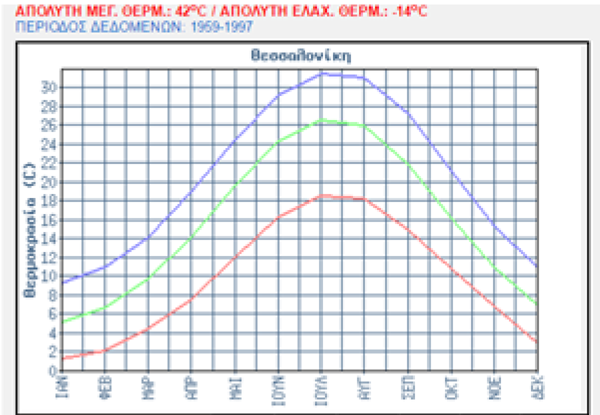


Fig. 31: Population change from 1951 till 2001.

(Source: ELSTAT data)

3.4 Thessaloniki’s climate data

Thessaloniki’s climate is Mediterranean and humid but also carry with mainland characteristics. Specifically, under the climatic conditions the most rainfall occurring from November to March with the annual rainfall can reach 450mm. The end effect snow is mainly for the surrounding mountainous city. (Source: http://www.meteo-news.gr/2013/09/to-klima-tis-thessalonikis.html)



1ο Εξάμηνο	ΙΑΝ	ΦΕΒ	ΜΑΡ	ΑΠΡ	ΜΑΙ	ΙΟΥΝ
Ελάχιστη Μηνιαία Θερμοκρασία	1.3	2.2	4.5	7.5	12.1	16.3
Μέση Μηνιαία Θερμοκρασία	5.2	6.7	9.7	14.2	19.6	24.4
Μέγιστη Μηνιαία Θερμοκρασία	9.3	10.9	14.2	19.0	24.5	29.2
2ο Εξάμηνο	**ΙΟΥΛ**	**ΑΥΓ**	**ΣΕΠ**	**ΟΚΤ**	**ΝΟΕ**	**ΔΕΚ**
Ελάχιστη Μηνιαία Θερμοκρασία	18.6	18.3	14.9	10.8	6.8	3.0
Μέση Μηνιαία Θερμοκρασία	26.6	26.0	21.8	16.2	11.0	6.9
Μέγιστη Μηνιαία Θερμοκρασία	31.5	31.1	27.2	21.2	15.4	11.0

Fig. 32: Thessaloniki’s temperature diagram
(Source:http://www.hnms.gr/hnms/greek/climatology/climatology_region_diagrams_html?dr_city=Thessaloniki_Mikra, at 02-09-2017)

The temperature shows the highest values in July and the lowest in January. The annual temperature range is exceeding 20°C. The average annual air temperature is around 16°C, the lowest average temperature (January) around 5,5°C and higher (July) around 26,5°C. (EMY)

During the year, approximately 140 days are with a maximum temperature above 25°C and about 70 are more than 30°C, while 107 are patios and 73 overcast. The sunshine hours are between 2,400 and 2,600. The annual rainfall is around 400-500 mm, and in recent years is quite low. (EMY)

Table 7: Thessaloniki's climatic table describes the frequency of rain, sunshine, cloudiness etc.

ΜΗΝΑΣ	Μέσος αριθμός ημερών με ΒΡΟΧΗ	Μέσος αριθμός ημερών με ΚΑΤΑΙΓΙΔΑ	Μέσος αριθμός ημερών με ΧΑΛΑΖΙ	Μέση μηνιαία ΕΝΤΑΣΗ ΑΝΕΜΩΝ (m/sec)	Μέσος αριθμός ημερών με ΘΥΕΛΛΩΔΕΙΣ ΑΝΕΜΟΥΣ	Μέση πίεση στην επιφάνεια της ΘΑΛΑΣΣΑΣ (hPa)	Μέση ΗΛΙΟΦΑΝΕΙΑ (ώρες)	Μέση ΝΕΦΟΚΑΛΥΨΗ (όγδοα)
ΙΑΝ	10,7	0,2	0	3	0,6	1018,7	98,7	4,9
ΦΕΒ	10,3	0,7	0	3,1	0,5	1016,8	102,6	4,9
ΜΑΡ	12,4	1	0	2,9	0,3	1016	147,2	4,9
ΑΠΡ	10,8	2,1	0	2,8	0,1	1013,1	202,6	4,4
ΜΑΪ	10,3	6,1	0	2,6	0,1	1013,7	252,7	4,1
ΙΟΥΝ	7,3	7,2	0,2	3,1	0,2	1013	296,4	3,3
ΙΟΥΛ	5,2	5,2	0	3,4	0,2	1012,8	325,7	2,1
ΑΥΓ	4,4	4,4	0	3	0,1	1013,3	295,8	2,1
ΣΕΠ	5,7	2,9	0	2,9	0,2	1016,3	229,9	2,7
ΟΚΤ	8,7	2,3	0	2,6	0,2	1018,9	165,5	3,9
ΝΟΕ	11,3	1,9	0	2,6	0,5	1018,4	117,8	4,6
ΔΕΚ	11,8	0,7	0	2,9	0,6	1017,9	102,6	4,8

(Source: http://www.weather.gr/, at 02-09-2017)

Table 8: Thessaloniki's climatic table describes the city's temperatures.

ΜΗΝΑΣ	Μέση ΘΕΡΜΟΚΡΑΣΙΑ (°C)	Ελάχιστη ΘΕΡΜΟΚΡΑΣΙΑ (°C)	Μέγιστη ΘΕΡΜΟΚΡΑΣΙΑ (°C)	Μέση ΣΧΕΤΙΚΗ ΥΓΡΑΣΙΑ (%)	Μέση Μηνιαία ΒΡΟΧΟΠΤΩΣΗ (mm)	Ελάχιστη Μηνιαία ΒΡΟΧΟΠΤΩΣΗ (mm)	Μέγιστη Μηνιαία ΒΡΟΧΟΠΤΩΣΗ (mm)
ΙΑΝ	5	-14	20,8	76,3	36,9	0	99,6
ΦΕΒ	6,7	-12,8	22	73,6	40,3	0,3	167,2
ΜΑΡ	9,6	-7,2	25,8	73	45,7	4,7	95,1
ΑΠΡ	14,2	-1,2	31,2	68,5	36,1	3,4	108
ΜΑΪ	19,5	3	36	64,1	44	0,1	97,7
ΙΟΥΝ	24,2	6,8	39,8	56,1	31,6	1	85,6
ΙΟΥΛ	26,5	9,6	42	53,4	25,6	0	78,5
ΑΥΓ	25,8	8,2	38,2	55,7	20,8	0	97,5
ΣΕΠ	21,8	2,6	36,2	62,2	26,2	0	135
ΟΚΤ	16,1	-1,4	30	70,1	40,6	0	150,5
ΝΟΕ	10,9	-6,2	26,6	77,3	57,7	6,4	179,1
ΔΕΚ	6,7	-9,2	20,6	78	52,9	0,2	153,9

(Source: http://www.weather.gr/, at 02-09-2017)

The city is strongly influenced by the sea to the south. The climate of Thessaloniki can be described as Mediterranean with generally hot and dry summers, and mild and wet winters. The annual mean temperature is 15,9°C, the annual mean relative humidity is 62,4%, the annual mean precipitation is 448,7 mm, the annual mean wind speed is 5,6m/s, and the prevailing wind direction is north-west [Climatological values averaged from 1959 to 1997 (Hellenic National Meteorological Service)]. In addition, the city is exposed to frequent sea breezes throughout the Giannaros, T.M., Melas, D., 2012

As for the wind, it is varied by seasons: winter dominate the north, northwest, coming from the Axios valley (Vardaris) and less Western wind while spring dominate the most frequent northwesterly (sea breezes). The summer is dominated by northerly winds, caused from the annual stream and northwesterly winds from the sea breeze. In September reduced the southwest winds, while from November dominate again the Northerners and Westerners winds. (Source: http://greek-weather.org/viewtopic.php?f=158&t=1462&start=0)

The Thessaloniki's settlement is located in climate zone Γ, according to the National Greek Technical Guide and the energy efficiency building regulation.

3.5 Characteristics of Thessaloniki's urban space

Thessaloniki is a typical Greek city that was developed in the 20th century based on the Law of the "exchange providing" ('antiparochi'), that is, the maximum exploitation of the building possibilities that permitted by the building law and with the minimal surfaces for open unstructured communal spaces (roads, squares, pavements) that allow for the necessary city's sunshine and ventilation.

The urban complex surrounds Thessaloniki Municipality, is also densely monolithic and encloses the main city, with a double effect that strengthens the presence of the UHI phenomenon in the city. That is, on the one hand the dense construction of solid buildings with high thermal mass absorb the solar radiation and emit it during the night, on the other hand the intensity of the winds decreases and their direction is changed which does not help their free movement and cooling during summer months.

In general, the city is cemented and asphalted entirely without having parks with natural terrain or materials with high reflexivity. The traffic in the city is huge and the pollution caused by cars is noticeable. The city has not many, large or unified green spaces. Nevertheless there is a remarkable urban park by the sea the 'Nea Paralia' Park, where the natural surfaces are again limited. Sidewalks on secondary roads are very small and dysfunctional for the movement of pedestrians, let alone for vulnerable groups such as the disabled people and mothers with baby strollers.

The building system in most cases is the "continuous building system" where one building is in contact with the next one without front yards creating a continuous frontier on the boundary with small-pavement walkways and streets. There is an open space at the back of the building, which create an inside free space in the center of the building block. Buildings' coverage on the plots is about 80% leaving a minimum free unstructured land-space in the middle of the formed building blocks which in almost all cases are not accessible spaces; their operation has been limited as a cement-clad space that gives the right of ventilation and sunshine on the back flats of the block. The morphology of the buildings is the classic type of building, which developed in the Greek cities during the time of intense urbanization that is the multi-storey building (polykatoikia).

Chart 14: Map with visualization of building regulation for Thessaloniki's districts.
(Source: Own taking photo, there is no mentioned map editor, map owner: Decentralized Administration of Macedonia-Thrace.)

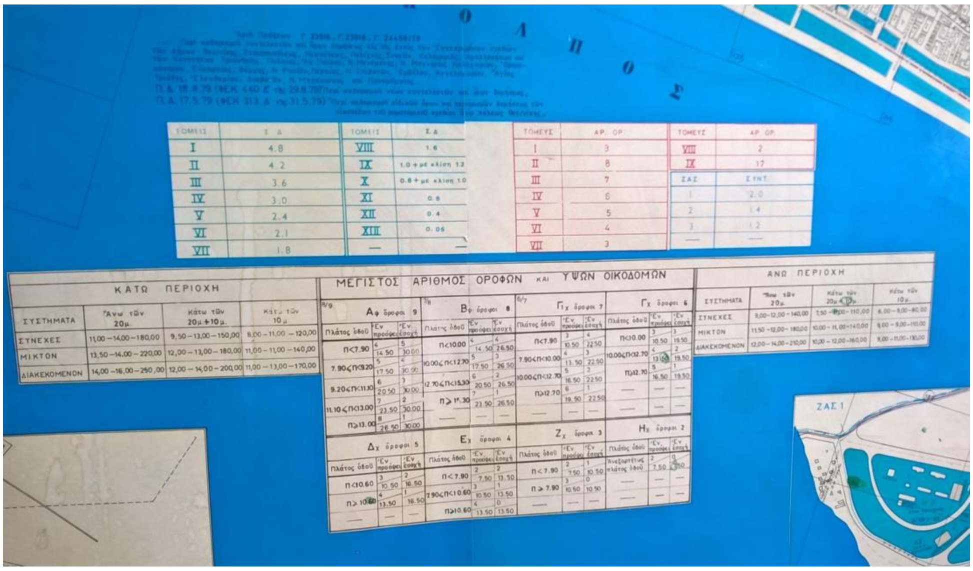


Chart 14a: Detail of the above map of the permitted urban sizes during the planning years of Thessaloniki.
(Source: Own taking photo, there is no mentioned map editor, map owner: Decentralized Administration of Macedonia-Thrace.)

Thessaloniki's building stock is old with its maximum amount of it have been built in the 1960s and 1970s. This means that the buildings have no thermal insulation, nor modernized heating and cooling facilities. On the contrary, these buildings have central heating system burning oil, and some of them installed individual natural gas burners. For covering cooling needs they installed individual split air-conditioners. Most of the openings have been renovated but they do not meet the appropriate latest specifications of building technology.

Urban land uses in the Thessaloniki city are mixed, mainly residential, retail and services. The mix of functions in the city minimizes in many cases the use of motorized vehicle movements and keeps the city alive but also creates city problems such as high concentration of pollution from anthropogenic functions that take place in the city.

It is observed that most shops mainly on busy roads are occupied, in relation to other neighbor regions, despite the current difficult economic situation. In the most city's buildings, on the ground floor are commercial shops and services and on floors residence and service bureaus. It observed that there is social stratification in buildings generally developed per floor, i.e. the poorest social classes live in the lower floors and the most robust live in a higher floor. Furthermore, it was observed compared with the habitation routes wherein the width of the roads is narrow, residing in majority poorer social classes in multistory buildings.

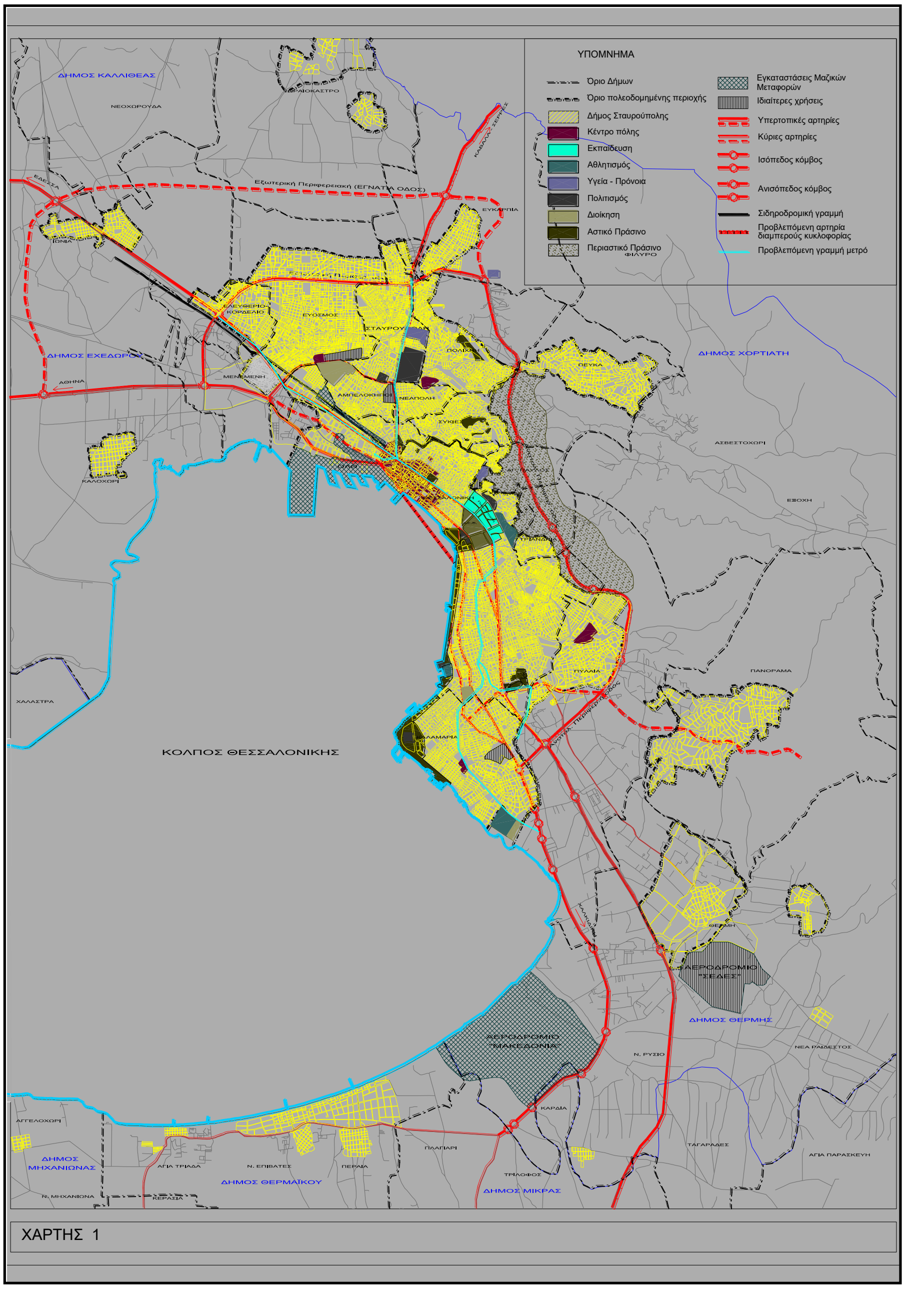


Chart 15: Map of functions and urban land uses of the city of Thessaloniki.
(Source: Personal archive from AUTh (Prof. Giannakou Athena)

The environmental dominant characteristics of the study area are the urban character and the location near the sea. Furthermore, the study area's topography has generally small slopes except for the 'Ano Poli' district. The city is oriented to north-south. The materials that prevail are the building materials (concrete, asphalt and tile coating) with low reflectivity, high absorption and large heat capacity. The vegetation and natural soil as coating material are less than minimal. The building density is high resulting in significant obstacles for the wind passes. All these features affecting the local microclimate as temperature and relative humidity, the irradiation conditions, the flow of the wind etc. There is no vegetation and ecosystem, no water recovery system, no local renewable energy sources, such as solar energy, wind energy, geothermal energy, and biomass.

The streets resemble canyons as the buildings heights are high till 24m. (8 stores) and the widths of the secondary roads are small average 6-10 m. This can provide thermal protection but also creates limited ventilation during the summer months. Specifically, the apartments that are located on the building back side or at narrow streets, and most, those which are on lower floors or at north-northwest-north-eastern orientation there is a lack of natural lighting and insolation in general. Hence, the neighboring buildings located opposite, are functioning as sun blocking and deprive the winter insolation.

It was observed that the area has become impersonal and has lost the human scale. The pavements are not in good condition. The design of the public space is finite and does not meet the needs of residents and the principles of bioclimatic design and sustainable development. In the urban and impersonal character of the area observed degradation spots even within the private spaces. The car parking is one of the big city’s problems and leading to degradation of residents and visitors life quality. There is a high noise level because of cars, the air quality is poor as there is pollution and dust, and the ways of access is limited as the transport system is one-dimensional and oil dependent. The study area resources are unexploited and the existing neighborhood operating energy system is perfectly connected to the compatible forms of energy.

The configuration of the urban environment of the study area is characterized by:

- the high urban density that is small distances between buildings because of streets dimensions (street width-height buildings) and large land building coverage percentage on the plots
- a large amount of buildings and people
- the geometry of the blocks
- pollution and poor air quality,
- the lack of green areas and open spaces,
- materials that dominate are asphalt and cement, high thermal absorbency and low reflectivity,
- few public and private outdoor spaces,
- non-uniform distribution of light and shade in buildings and public places.

Urban heat island and urban canyon are the urban climatic factors that contribute to the form of urban climate and its characteristics. The building materials and compact building volumes reducing the average wind speed and creating vortices. Reducing the wind speed then ventilation and cooling reduce also, and so there are no thermal comfort conditions. Regarding the effect of urban canyon wind intensity to major roads as Egnatia, Tsimiski, Monastiriou, is strong. Further, the temperatures which develop on the vertical faces of the buildings alter the temperature that exist on surrounding roads and that probably is affect the local wind speed and direction.

The urban heat island is intensified with the topography of the urban fabric and monolithic construction because the air velocity is reduced through the streets, resulting thermal discomfort and concentration of pollutants. In the study area, the phenomenon of urban heat island effect, i.e. the increase in temperature especially during the summer months, as it has all those features that enhance the phenomenon:

- o The geometry and design of urban space
- o The lack of sufficient green spaces and GI
- o The anthropogenic heat sources and air pollution
- o The thermal properties of construction materials used in buildings and outdoors in urban spaces
- o The decreased reflectivity of the material,
- o The weaker winds in the urban environment.

The general form of the building environment in Thessaloniki influences the energy balance because the features and the geometry of urban space determine both the degree of solar radiation absorption and emission from building materials. In Thessaloniki city's center the height of buildings and the width of the roads are such that on one side the solar radiation during the day is absorbed to a large extent, because of un-successive reflections and the other the wind is impossible to flow through so as to cool the space. Thus, the surface temperature is increased because of the solar radiation and the air temperature is increased because of the surfaces' heat emission and the non-existence of the wind.

The effects of heat island cause degradation of the residents' quality of life and provoke negative effects on their health. There are many incidences during summer time with heart attacks and strokes in the elderly group. The increased energy consumption for internal cooling during the warm period increases the peak load. Further, it creates more air pollution and an unbearable environment in the city due to the hot air extracted from the air conditioning with combination with the heat emission from the materials.

The majority of city's buildings are solid, in contact with the ground and in contact with other buildings, so buildings have limited somewhat heat exchange with the outside environment, due to the greater thermal mass and the lower exposed surface. The buildings are developed with a typical floor and sides, with apertures and balconies, are organized uniformly on each floor. So every balcony has a dual role as an outer space for residence and offers sun protection to the downstairs apartment. The penthouses in most buildings subside and the buildings' ceilings are bramble horizontal roofs, which have problems with waterproofing and insulation.

As far as the building stock concerned, general the blocks need renovation as it is many years in use and initial construction was not attentive. Broadly the buildings' energy efficiency is poor and the site inspection the above energy parameters are hardly fulfilled by the rule. Unlike the features in the existing buildings are:

- Lack of insulation and airtight frames
- Openings on the building sides in accordance with the requirements of the conventional mode of architectural design
- Lack of sun protection
- Inability side to side building ventilation
- The color of the outer surface of the buildings are outdated
- Absence of indirect solar gain systems
- Walls with thickness of 15 cm are the thermal mass of buildings
- Dissimilarity in buildings' forms because of the individually rebuilding (windows, railings etc.)
- High energy demand due to the lack of insulation which cause significant thermal losses and the air conditioning function during the summer.

Furthermore, the environment that encompasses the city of Thessaloniki consists from a rich natural environment, Natura 2000, Galikos, Axios, Loudas and Aliakmonas Rivers, Sheich Sou - Chortiatis forests and reforest able land, the sea, Makedonika Tempi (Agios Basilios and Volves lakes) and agro-ecosystems (Axios, Mygdonia, Langadas, Anthemounta plains). There is a mix of land uses and urban concentrations with indefinite boundaries that contradict each other across of high density of transport network infrastructures.

There is a high level of greening unequal distribution among the other municipalities of the UCT. Thessaloniki municipality shows the lowest indicator values for existing green areas, with the ratio of communal green areas per inhabitant in the municipalities of Thessaloniki to be at 2,6m^2/inhabitant. While with regard to existing green areas in non-urban areas, there are also large differences between the municipalities of the UCT with the Municipality of Thessaloniki having 7,3m^2/inhabitant. (ORTHE: Papamichos N., et al., 2006)

CHAPTER 4:

Data and Methods

4.1 Data Collection and study area selection

The temperature time series data collected from various sources. These were public and private operators, as well as individuals that engaged with meteorology.

The public data providers are, the EMY (National Meteorological Service), which maintains a meteorological station at Macedonia Airport outside the city of Thessaloniki, and the Department of Meteorology and Climatology (GMC), which is the meteorological station of Aristotle University which is located in Thessaloniki.

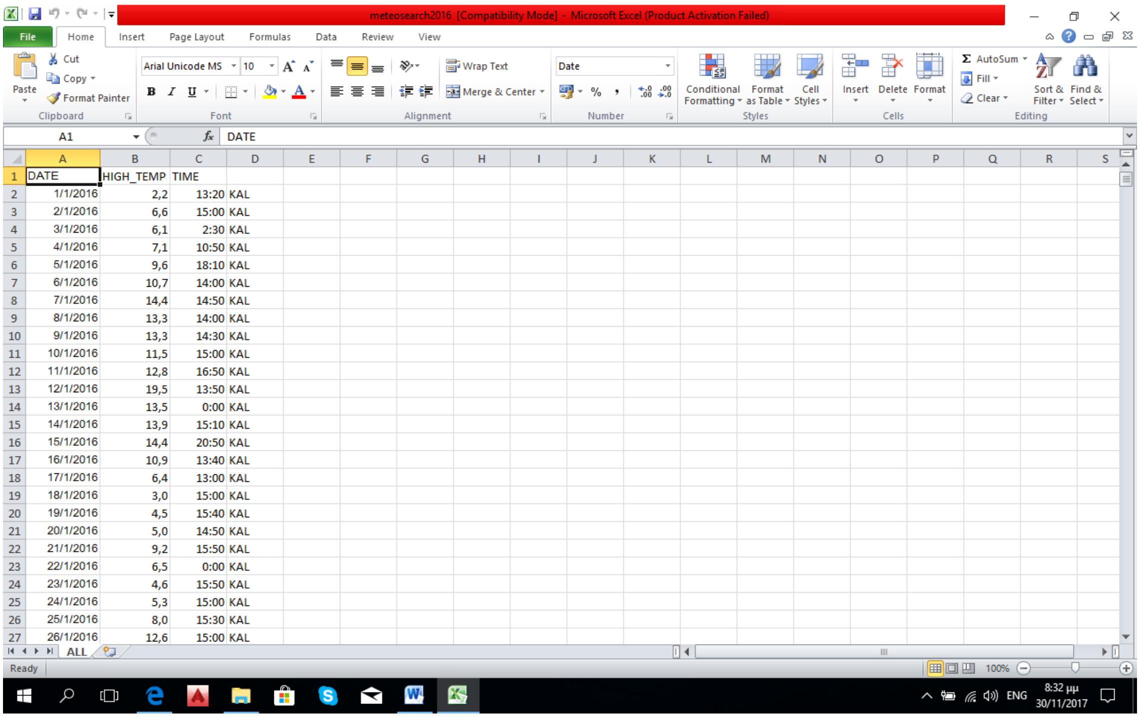
Temperatures data have been downloaded for four (4) meteorological stations: Sindos, Lagada, Nea Michaniona, and the Naval base in Kalamaria from the “meteosearch.gr” website.

Further, it has been downloaded temperatures time series data that refer to 15 Meteorological stations (ITHESSAL40, ITHESSAL49, ITHESSAL12, ITHESSAL6, ITHESSAL13, IRETZIKI2, IKALAMAR5, ITHESSAL28, ITHESSAL50, IU039AU02, I1197, ITHESSAL2, ITHESSAL7, IAGIOSPA2, IKALAMAR10), wit to the data in the Municipality of Thessaloniki and its surroundings from the “wunderground.gr” website.

Further a private meteorological station the “meteothes.gr” located in the historical center of the city of Thessaloniki provided complete data on climate measurements for this work.

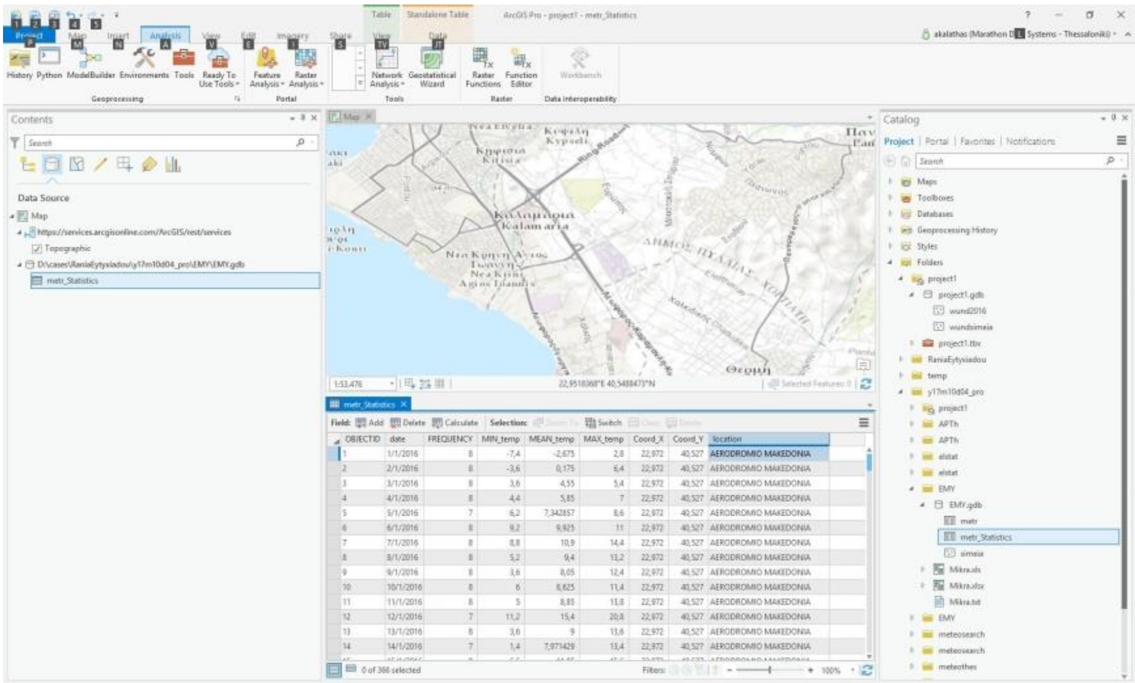
The decisive factors for choosing the meteorological stations and the study year were the identification of the data for the different meteorological stations for an entire year and the completeness of the data. Thus, the 2016 year, that it had been choose, it had the more completed and accurate data in most of the meteorological stations.

An important stage of this work was the data control and processing because the chosen sample should be reliable, so that the results to be equally reliable and realistic. Hence, after the data collection, quality control was performed for their completeness and accuracy and at this stage some initially selected meteorological stations were excluded due to the high incompleteness of the data. In the next step, the processing of the data, it has been appropriately configured for their introduction to ArcGIS PRO.



Picture 17: A configured temperatures time series, suitable for its introduction to ArcGIS.

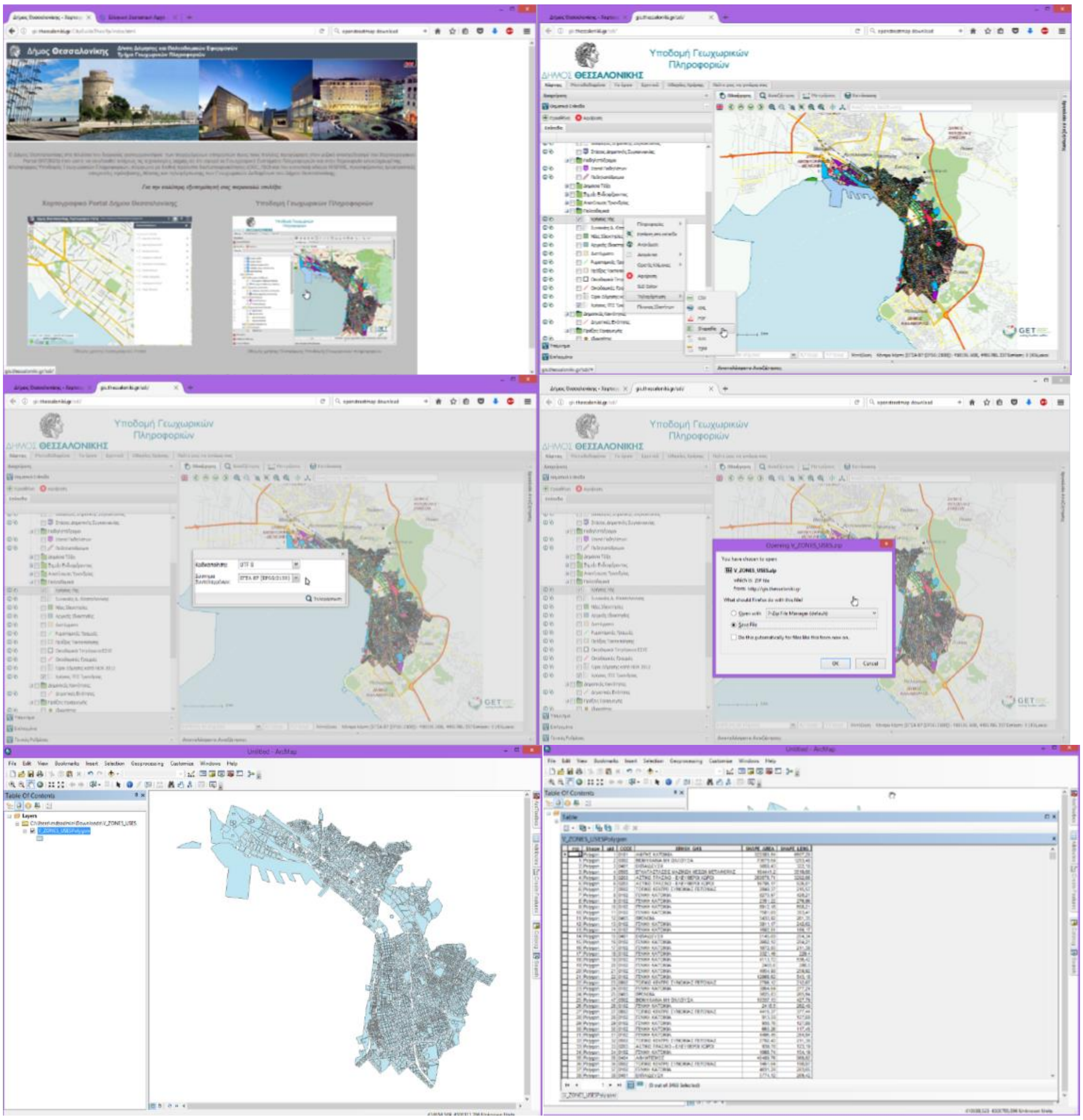
(Source: Own editing)



Picture 18: ArcGIS Temperature Input.

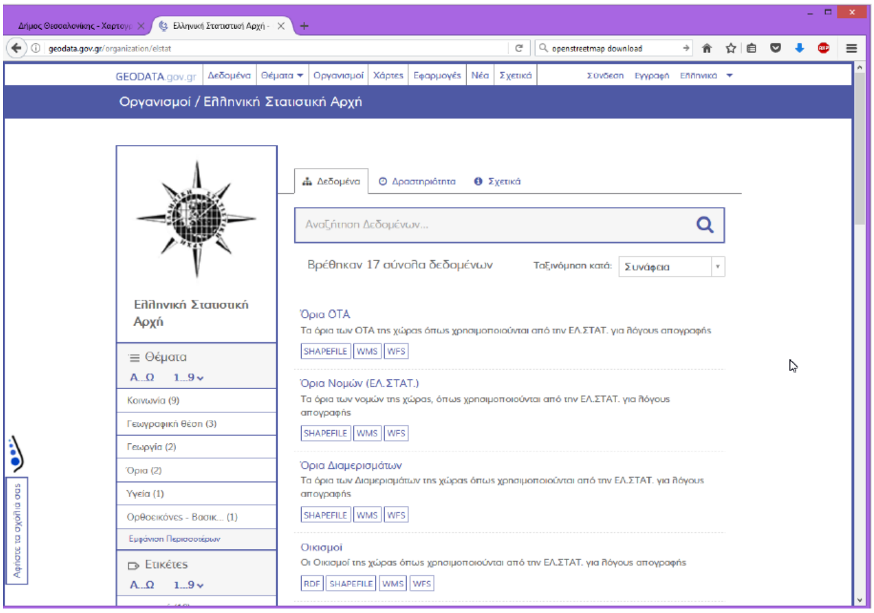
(Source: Own editing)

Another important data for this work were the urban land uses. Thus the current study used data from the Municipality of Thessaloniki and specifically the urban land uses for the Municipality of Thessaloniki in GIS format, as the procedure seems below.



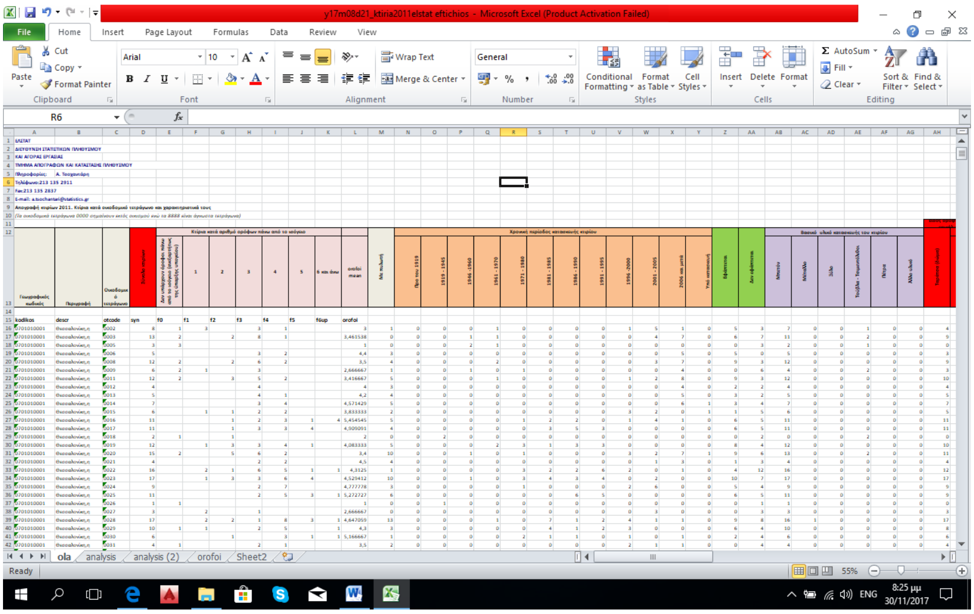
Picture 19-24: Download process of land use from Municipality of Thessaloniki in GIS format. (Source: Own editing)

As well as data from ELSTAT concerning the building blocks of the city and specifically the floors of the buildings organized by building block.



Picture 25: ELSTAT's site.

(Source: ELSTAT.gov.gr)



Picture 26: ELSTAT data.

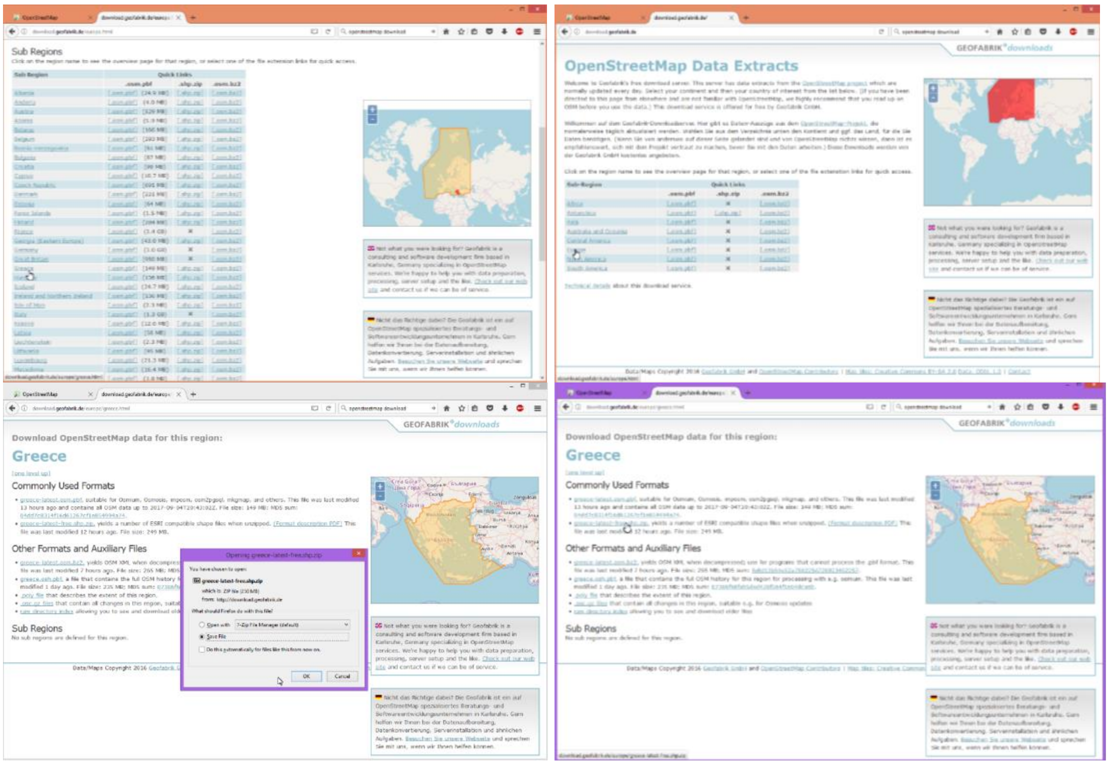
(Source: ELSTAT & Own editing)

The study area chosen was the geographical area of Thessaloniki Municipality, as the information that had been gathered was complete and spatially identifiable for the particular area.

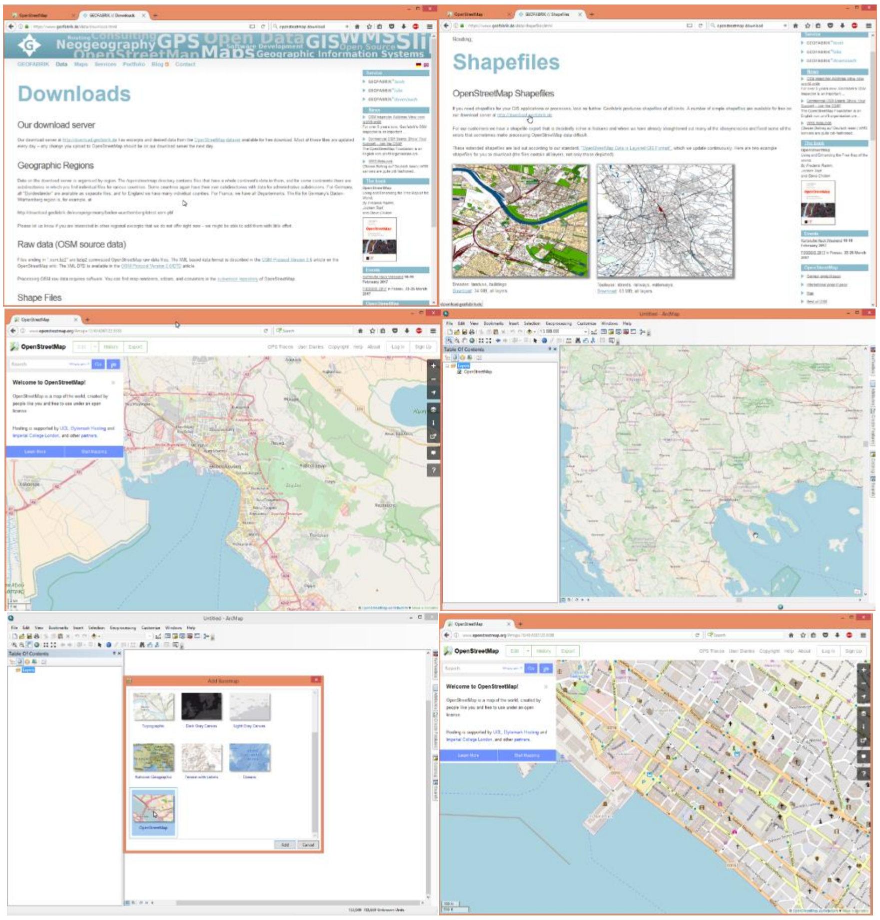
4.2 GIS Process

4.2.1. Find cartographic backgrounds

ArcGIS has the capability to offer cartographic material backgrounds from around the world that the user can download from ArcMap. Finding the background becomes an easy task for the user. Thus, for the current work an orthophotos background was searched with the process, as shown in the pictures below.



Pictures 27-30: The steps from downloading the map.
(Source: Openstreetmap Data)

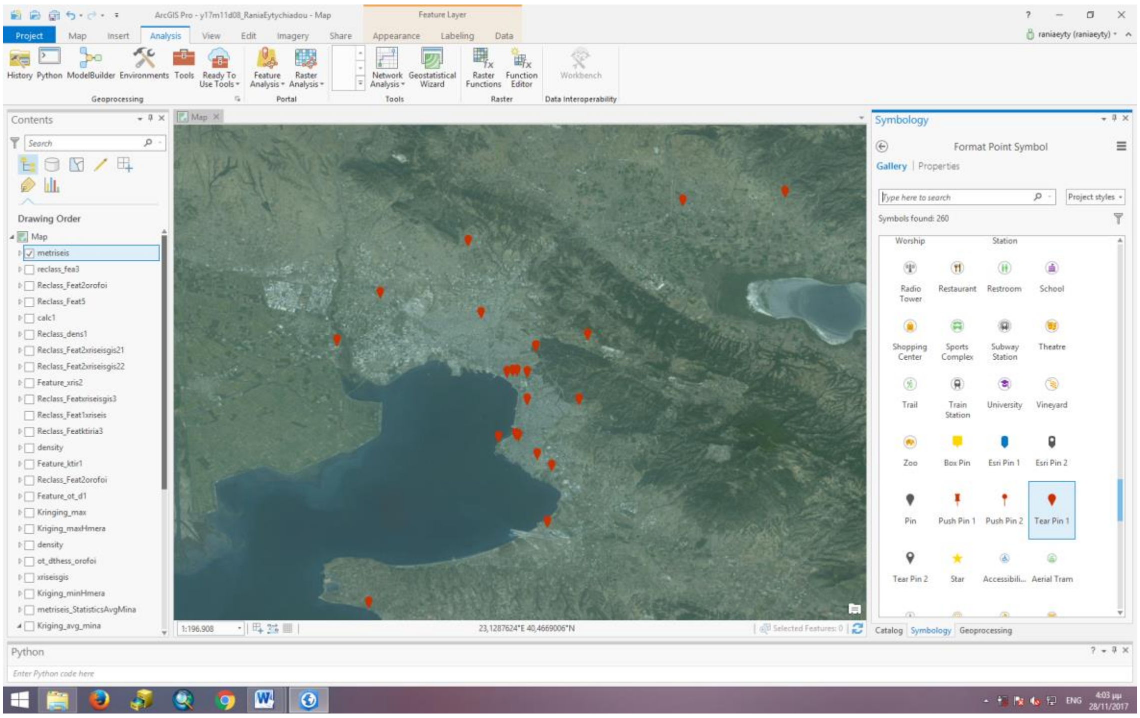


Pictures 31-36: The steps from downloading the map.
(Source: Openstreetmap Data)

Having downloaded the map from Openstreetmap Data, the next stage is the location of the meteorological stations in the city of Thessaloniki and its wider area.

4.2.2. Introduction of Meteorological Stations and Data in ArcGIS

The "introduction" of geo-spatial meteorological stations in ArcGIS is a basic stage for the processing of temperature data. Their introduction includes the precision of their positioning in the EKsxA geo reference system. After the introduction of each meteorological station, the specially processed temperature data for each location was introduced. The data is complete to a high degree which ensures the reliability of the result. On the other hand, the created network by meteorological stations is adequate and includes stations both inside and outside the city, which will provide complete information on temperature fluctuations and facilitate the subsequent process with ArcGIS.

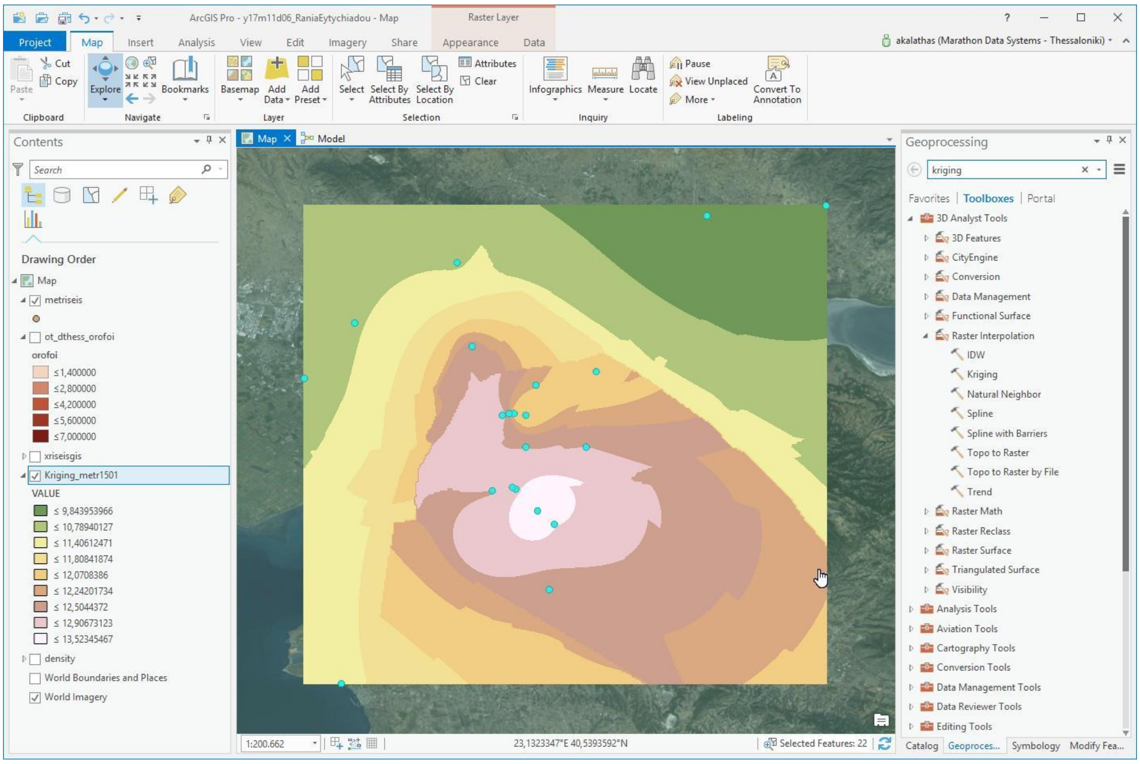


Picture 37: The chosen meteorological stations at Thessaloniki's area.

(Source: Own editing)

4.2.3. Application, Evaluation and Selection of interpolation method

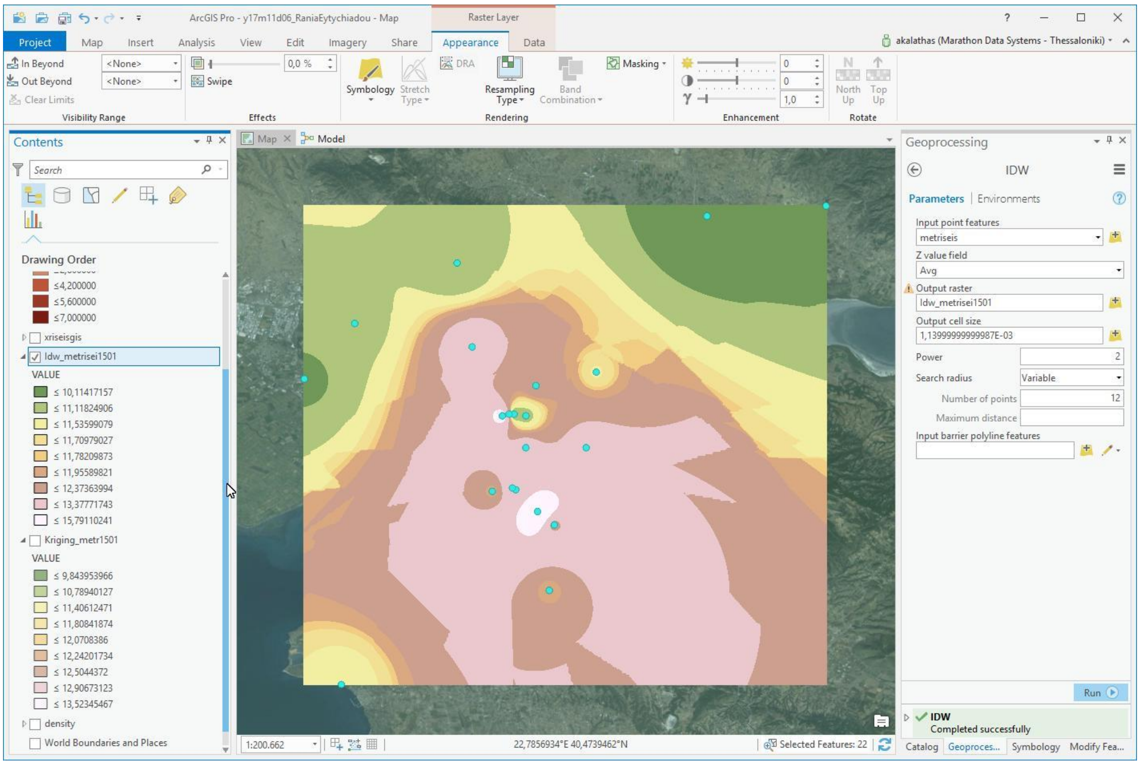
Apart from studying the literature on the interpolation method and the researchers' views on the methods themselves in the previous chapter, in order to select the interpolation method for the Thessaloniki study, different available ArcGIS interpolation methods was performed for a random date on 15-01-2016, so as to select the interpolation method, evaluating the generated images results, that will be applied to the interpolation process.



Picture 38: Interpolation with Kriging.

(Source: Own editing)

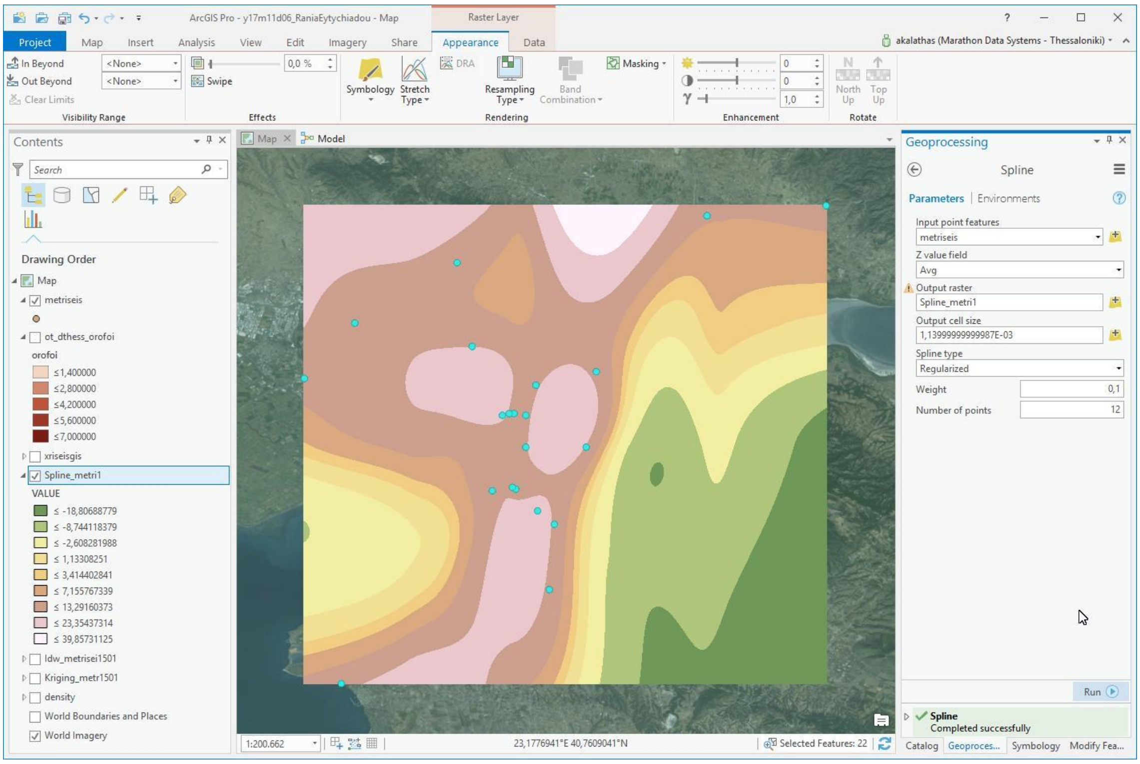
With the Kriging method, the resulting image has a circular general configuration and grows concentrically, creating a centrally focal point. The temperature gradient is in the actual frames (9.84 to 13.52) and shows a smoothness. Weather stations are distributed in all temperature ranges. The produced image seems to be related to the existing background of the city, as the lower temperatures exist in the Northern and peripheral regions of the image, while the high temperature gradients extend to the south of the city that is an urbanized area.



Picture 39: Interpolation with IDW.

(Source: Own editing).

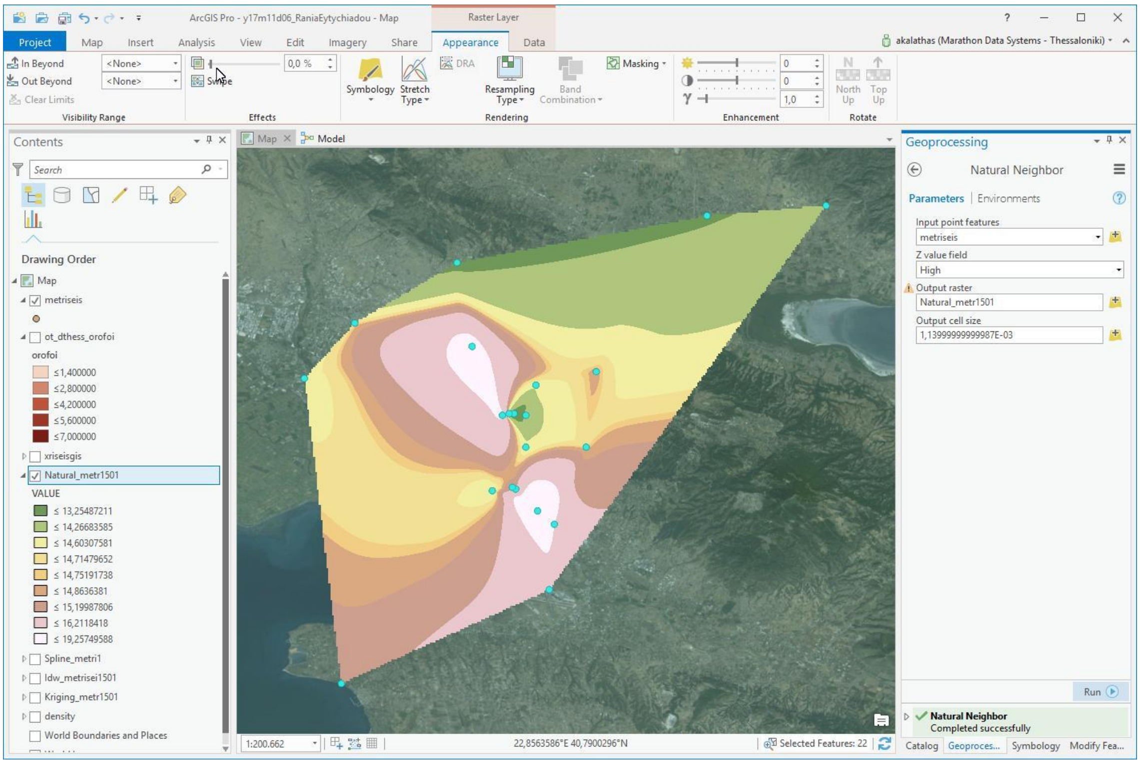
Initially, it is observed that the IDW interpolation method creates many “outbreaks” that are unrelated to each other. The range of gradations ranging in really levels (9,84 to 15,79). Weather stations are distributed in different gradations, but there is a large temperature (pink) that dominates and unifies a large surface, eventually losing the detail of the result.



Picture 40: Interpolation with Spline method.

(Source: Own editing).

The interpolation with Spline method extracts a result that gives a smoother image. However, the temperature gradient is very large and not real (-18.80 to 39.85), and it has a wide range beyond the existing temperatures. It is noted that the limit of changing a rating is exactly where the meteorological stations are located and all of them are in the same temperature gradient, and the mean temperatures are visually abridge. It sets vague color gradations that set high temperatures in the north of the map and, on the contrary, low temperature in the southeast, something that is wrong with the background of the city and the all other interpolations results. At the end, it is noted that the spatial gradients are not distributed equally.



Picture 41: Interpolation with Natural Neighbour (NN).
(Source: Own editing).

The Interpolation with Natural Neighbor (NN) method outlines the analysis area with the location of external meteorological stations. The meteorological stations location is distributed across all temperature gradients indicating that it takes into account the temperature details. It created two high-temperature poles, as the city actually developed, and the gradation is around them. The grading seems to be correct in relation to the underlying city background. Temperature limits (13.25 to 19.25) have a small range; however, the method manages to produce a good image result because of outdoor weather stations with lower temperatures which delineate the area of analysis.

Evaluating all four interpolation methods it is noted that the two methods presenting a more realistic situation are the Interpolation Ordinary Kringing Spherical and Natural Neighbor (NN) methods. Between the two methods for this work, the Kringing method is preferred because on the one hand it has a uniform temperature gradient and on the other is suggested by most temperature researchers as the most reliable analytical and processing tool.

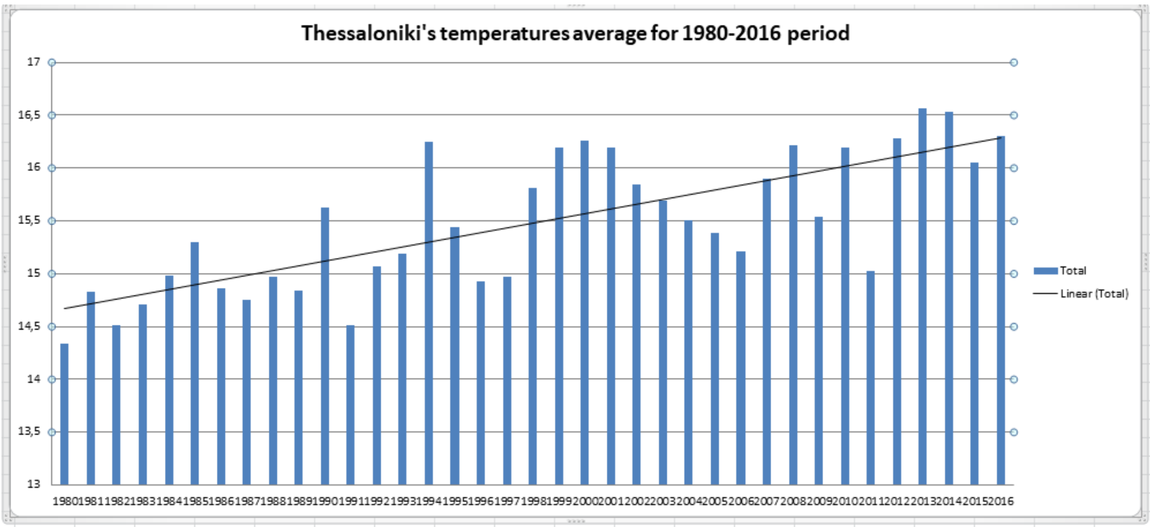
CHAPTER 5:

The Analysis

5.1 Qualitative analysis - Descriptive data statistics

The UHI phenomenon in the city of Thessaloniki is a reality, according to previous studies that have been done on this subject for the city. Thus, Giannaros, T.M., and Melas, D., 2012; Kantzioura, A. et al., 2012; Giannaros, T.M. et al., 2010; Mihalakakou et al., 2004 have certified the existence of the thermal isle in the city of Thessaloniki.

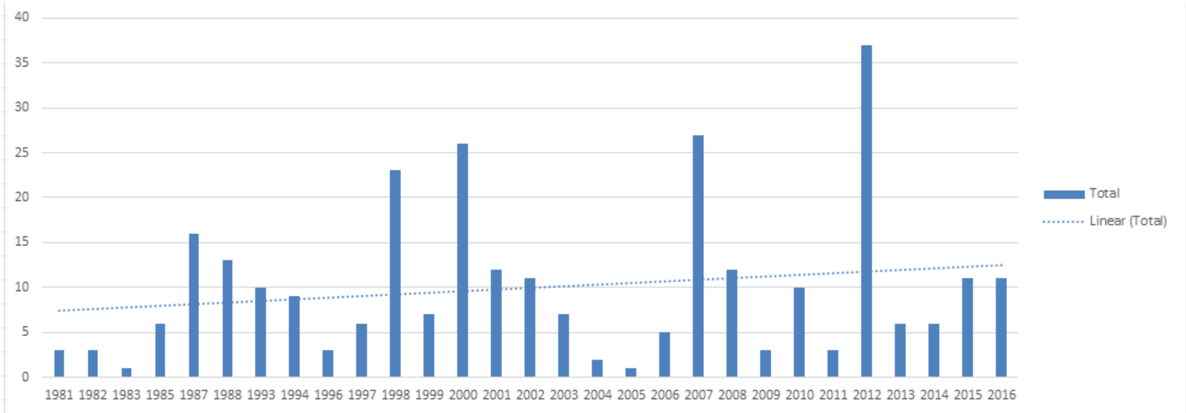
The present study used daytime temperatures for the year 2016. According to the air temperature data that were granted by the EMY, which consisted of a 30 year time series, this was a very good opportunity to study them in order to determine the temperature trend. Hence, it was found that in general the hottest year was in 2014, while the cooler in 1980. While the highest temperature was 43,4°C in 2007, while the lowest was 9,8°C in 2001.



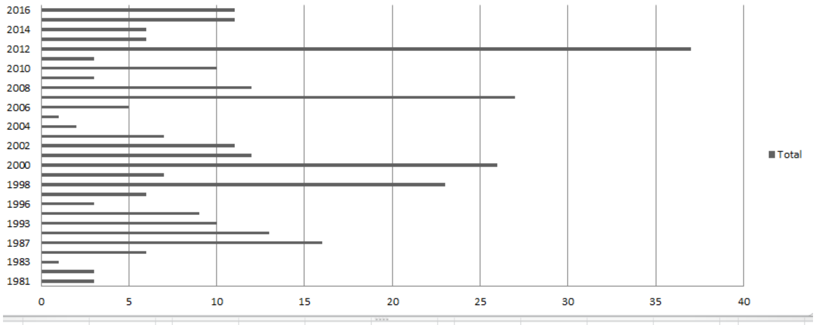
Graph 1: Thessaloniki's temperatures average for 1980-2016 period.
(Source: Own editing)

It is observed, in a first approach, from EMY's data that the city of Thessaloniki in through of a 30 year time horizon had a rise in temperature that can be attributed to both the overall climate change and the percentage increase of urbanization.

From the study by Gallo, K. P., Easterling, D. R., Peterson, T. C. J. (1996), it is obvious that both citify and land uses directly affect ambient temperatures. Consequently, it can be said that, part of the rise in the city's temperature is also due to the intense urbanization of the city. During these thirty years, the rise in temperature has been more pronounced since the 1990s, when the city and mainly the neighbor settlements highly urbanized because of the institutionalization of development- master plans (GPS and SXOOAP) and the expand of urban space began.



Graph 2: The frequency that the temperature exceeded 35°C, in three-hour measurements. (Source: Own editing)

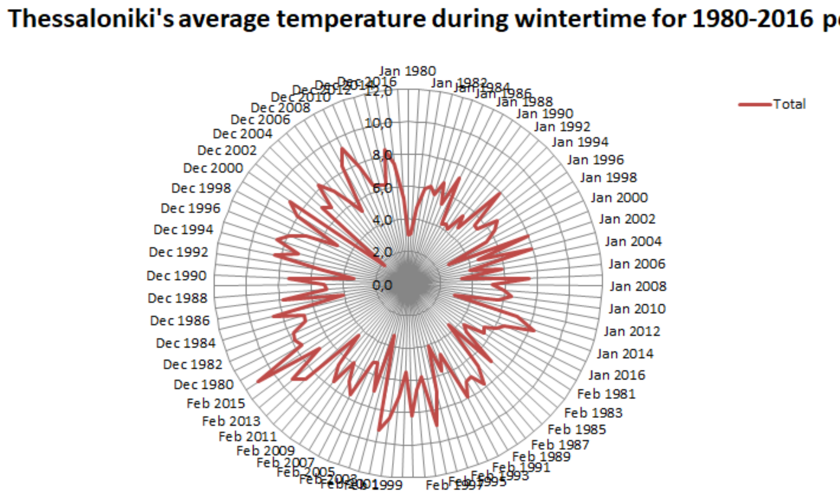


Graph 3: The frequency that the temperature exceeded 35°C, in three-hour measurements. (Source: Own editing)

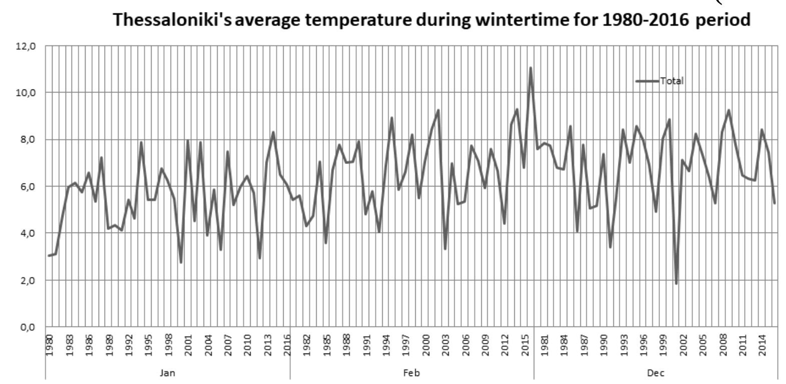
The 2012 was the year when temperature exceeded the 35 °C most of the time and 2007 follow, which the whole was of and the warmest year in the thirty years. In contrast, 2005 and 1983 were the years that showed the lowest-tension temperature.

It appears that as the years go by, the heat wave as summer phenomenon is more common with characteristics its repetition during a hot season (e.g. 2012) becomes more frequent. Also, it is shown that, from 1981 to 2016, eight years occurred heat wave from 0 to 5 times, 9 years showed a heat frequency of 6 to 10 times, 6 years showed a heat frequency of 11 to 15, one year showed a heat wave frequency of 21 to 25, two years showed a heat incidence of 26-30 times while one year from 36 to 40 times.

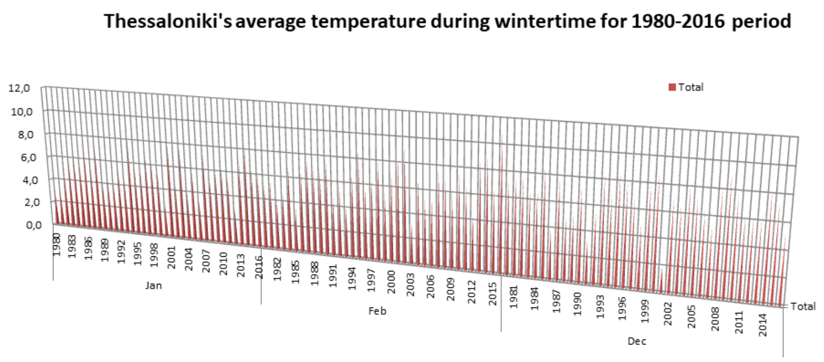
However, no further safe conclusions can be drawn for the course of the heat wave phenomenon as a longer time series of data is needed.



Graph 4: Thessaloniki’s average temperatures during wintertime for 1980-2016 period.
(Source: Own editing)

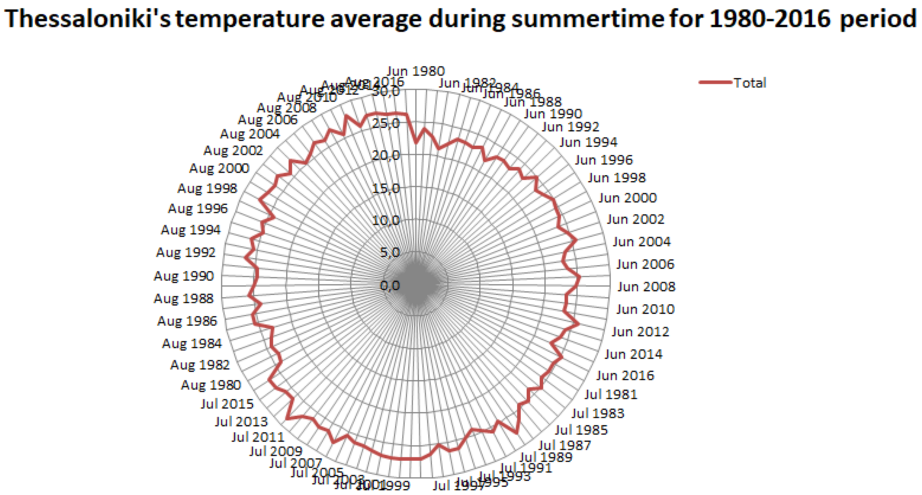


Graph 5: Thessaloniki’s average temperatures during wintertime for 1980-2016 period.
(Source: Own editing)

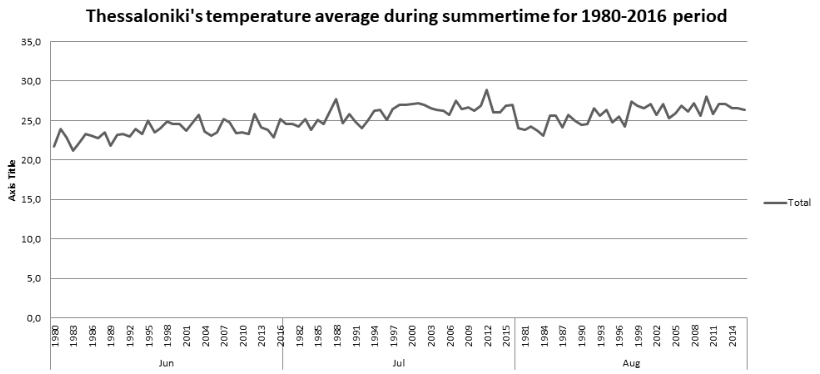


Graph 6: Thessaloniki’s average temperatures during wintertime for 1980-2016 period.
(Source: Own editing)

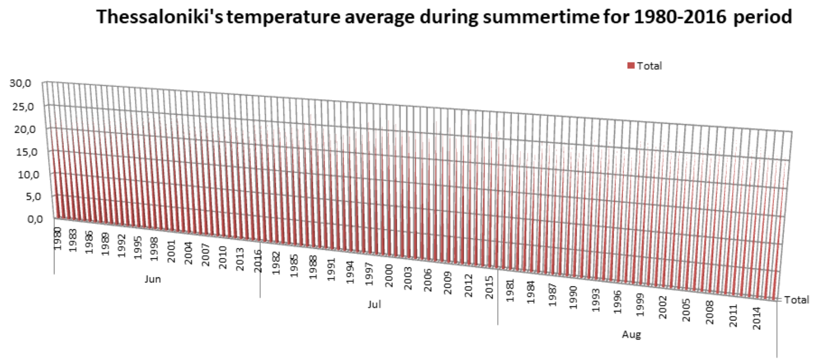
The above diagrams show the temperature fluctuations during the winter period of thirty years organized monthly. It is observed that in December 2001 it was the year with the lowest temperature, while February 2015 was the warmest. It is noted that there is a tendency for temperature rise during the winter period. However, there is a marked variation in the average temperature each month per year. Generally January seems to be giving the lowest temperatures followed by February as warmer. December seems to give warmer temperatures than the other two.



Graph 7: Thessaloniki's average temperatures during summertime for 1980-2016 period. (Source: Own editing)



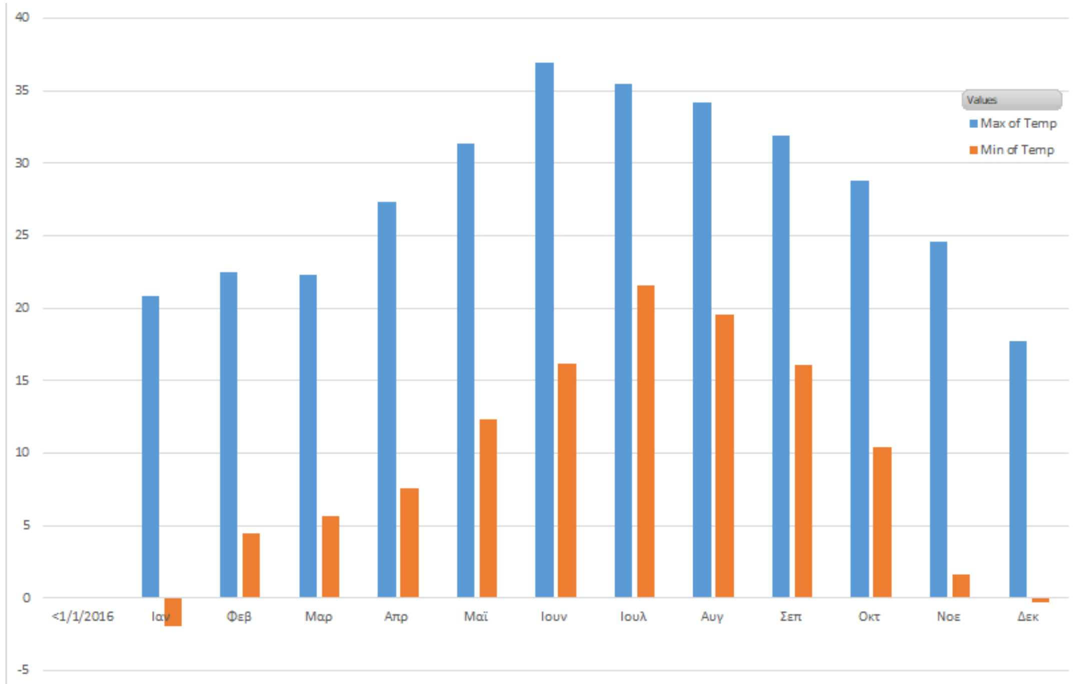
Graph 8: Thessaloniki's average temperatures during summertime for 1980-2016 period. (Source: Own editing)



Graph 9: Thessaloniki's average temperatures during summertime for 1980-2016 period. (Source: Own editing)

The above diagrams show the temperature fluctuations during the summer period of thirty years organized monthly. Thus it is observed that July 2012 was the year with the highest temperature, while June 1983 was the colder one. There is smoothness in temperatures without significant fluctuations such as winter temperatures. There is an ascending course in temperatures. June is the coolest while July and August are the warmest.

With the method Pivot tables[4], in particular for 2016 and based on the weather data from the weather station ‘meteothes.gr’, the below chart is produced. It has been chosen this particular station, ‘meteothes.gr’, for two reasons, firstly its location in the heart of the city, which is the narrow area of interest of the study and also the maximum completeness and detail of the data, which reduces the possibility of error in the process. It is noted that the maximum temperature recorded in June followed by July and August. On the contrary, minimum temperatures appeared in January, followed by December and November. It can be observed that the winter months have the most significant deviations between the maximum and the lower temperatures, while the summer months show a smoother (near) temperature variation with July being smoother, followed by August. September and June have a variation between maximum temperatures that are twice the smallest.



Graph 10: The maximum and minimum temperatures in 2016 (base station meteothes.gr).
(Source: Own editing)

In addition, the dates with the warmest and coolest indications per month were isolated from the process. It is observable that the difference between maximum and minimum temperatures is proportionally higher in the winter months (e.g., 20 degrees difference), whereas during the summer months this difference decreases (e.g., 10 degrees difference).

[4] **Pivot tables** summarize data; they can be used to find unique values in a field. Hence, someone can quickly see all the values that appear in a field and also find typos, and other inconsistencies.

Maximum & Minimum temperature in 2016 per month and the exact performed date				
Month 2016	*Max of Temp*	*Min of Temp*	*Max temp Date*	*Min temp Date*
January	20,8	-1,9	12/01/2016	01/01/2016
February	22,5	4,5	15/02/2016	06/02/2016
March	22,3	5,7	22/03/2016	15/03/2016
April	27,3	7,6	14/04/2016	26/04/2016
May	31,4	12,3	31/05/2016	03/05/2016
June	36,9	16,2	23/06/2016	08/06/2016
July	35,5	21,6	10/07/2016	18/07/2016
August	34,2	19,6	03/08/2016	13/08/2016
September	31,9	16,1	03/09/2016	23/09/2016
October	28,8	10,4	04/10/2016	31/10/2016
November	24,6	1,6	08/11/2016	30/11/2016
December	17,7	-0,3	10/12/2016	31/12/2016
Meteorological station: meteothes.gr				

Table 10: The maximum and minimum temperatures in 2016 per month.
(Base station: meteothes.gr).

(Source: Own editing)

There are differences in the air temperature values of the meteorological stations located in the city and outside the urban complex of the city due to the topography of their location and the relief of each location. Thus, it can be observed that, as a general rule, the areas in Thessaloniki are warmer than those that are outside the urban complex, except in those cases where the areas typically have higher temperatures such as Lagadas or lower ones such as area of Nea Michaniona.

5.2 Spatial Analysis: Results and discussion

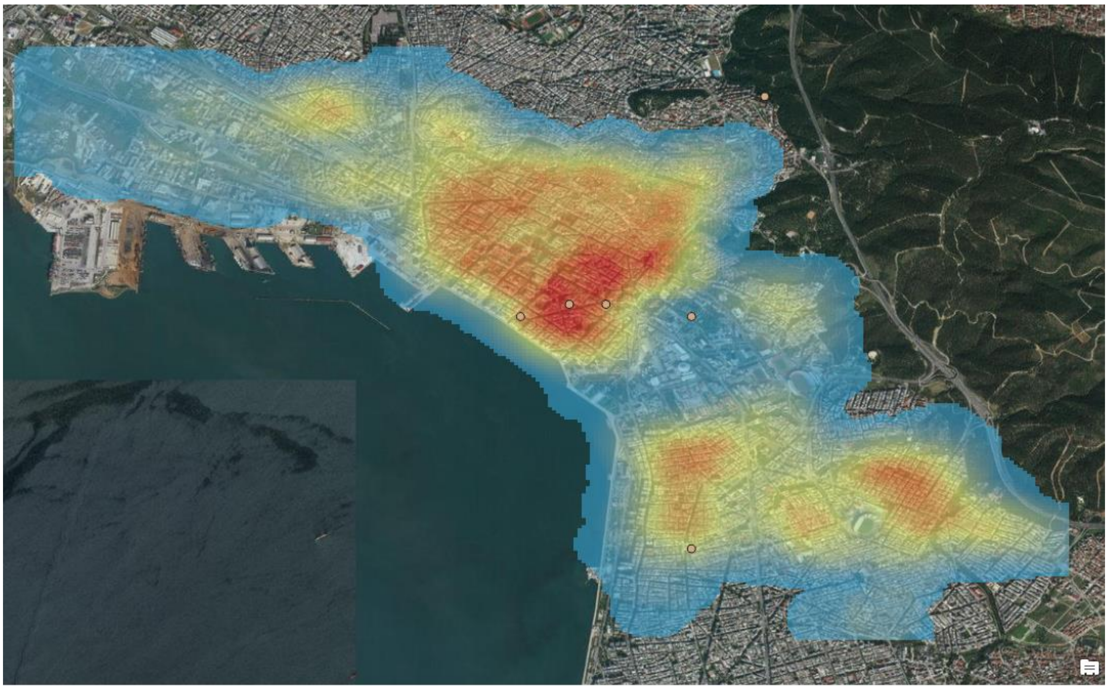
According to the 2007 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the urban heat islands and global warning other land-use changes have biased the land-based temperature record. This means, urbanization that is generating the phenomenon under study, not only generates the phenomenon itself but it is also capable of changing the global climate in conjunction with the change in land use.

Consequently, urbanization and land uses play a catalytic role in the climate (Kalnay, E. & Cai, M. 2003). The formed temperature is not always the result of climatic parameters. On the contrary, parameters such as urban density, land use, and building heights should seem to be related to the UHI phenomenon.

Having implemented the Interpolation Kriging Ordinary, surfaces were generated depicting the temperature gradient over the city of Thessaloniki and its periphery. Thus, the correlation of temperature images with images of urban density, building height and urban land use can give results about the thermal isle phenomenon in the city of Thessaloniki.

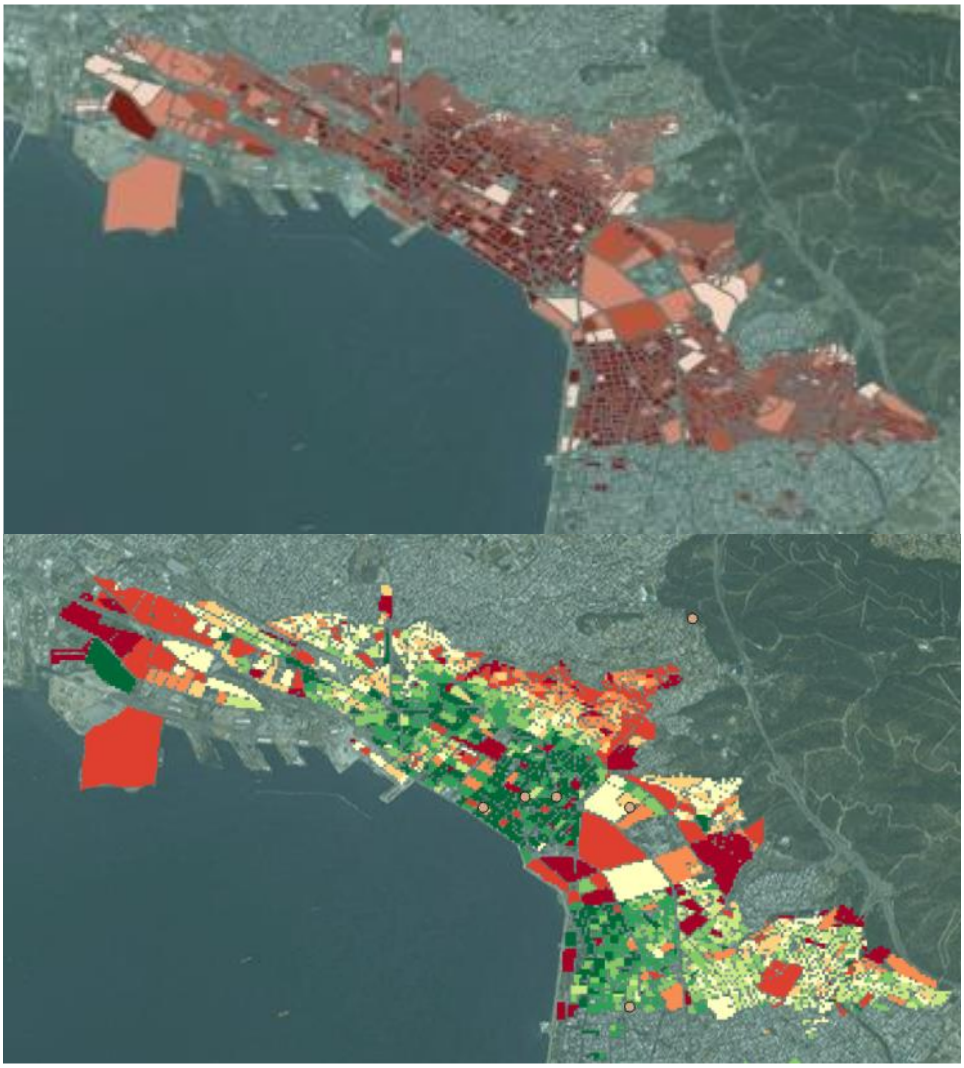
According the results of data processing in ArcGIS there is the possibility to illustrate the information. Specifically, the building density in the city of Thessaloniki is observed to have bipolarity. The North part essentially concerns the main city center with the central functions of the city, which is more concentrated and more intense (dense) while the South part is divided into three sub-centers.

A zone perpendicular to the sea that created by the area of the International Exhibition, the extent of the two Universities, the military installations, the Byzantine Museum and the Town Hall, bisects the dense city's construction. The area that extends westwards from the northern part of the city is relatively sparse built with three regions distinguishing due to more densification from the whole region, Xirokrini, Panagia Faneromeni and Vardari area (Courts). On the southern side, the areas that seem to have a greater build-up in the area are the Agia Triada area adjacent to the buildings' interruption district, Kato Toumpa and Ano Toumpa.



Picture 42: Building density in the city of Thessaloniki.
(Source: Own editing)

Results from studies showed that the canopy structures, the urban morphology and contrary mixed land uses are reasons of the surface UHI's procreation (Hung T., et al., 2005). It is noted that in addition to the high density of the building, i.e. narrow streets and a small percentage of free land plots, the number of floors in these areas is large (7 floors). That combination results in urban gorges being created in the areas, non-sunny apartments during the winter and difficulty in ventilating during the summer months.



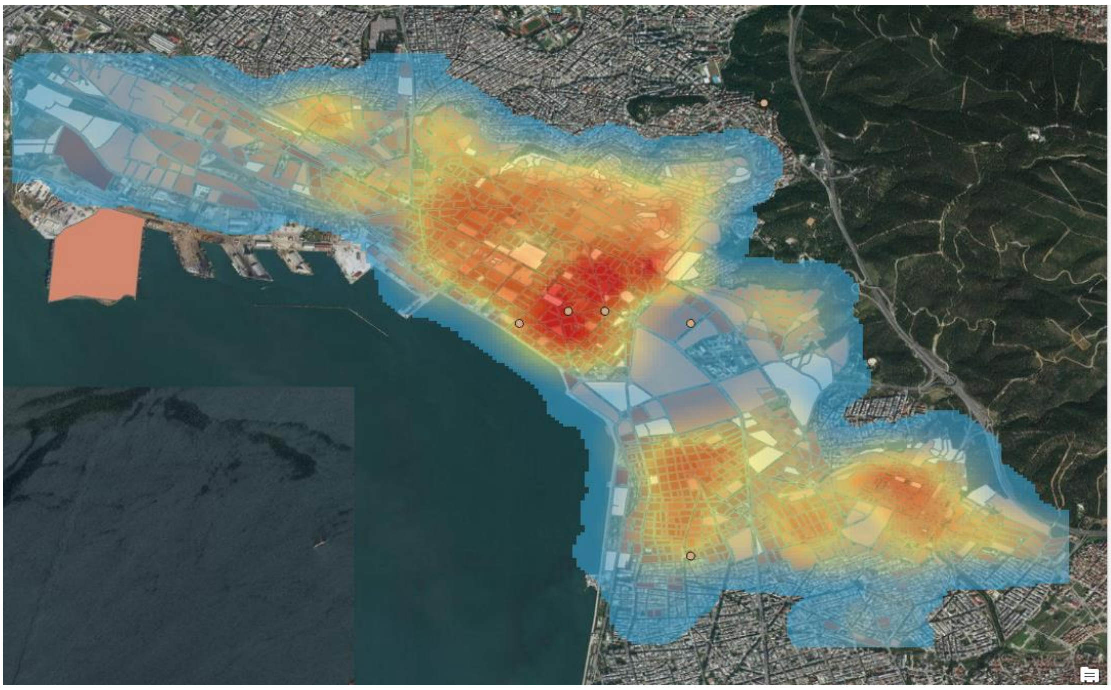
Pictures 43-44: Illustration of the buildings' height grading in the city of Thessaloniki: Green represents the areas with buildings high while the red areas with buildings of lower height. (Source: Own editing)

Correlated the two information's backgrounds cumulative, that are the buildings' density and buildings' height, it appears clearly that the northern area of the city, which already has mentioned, (Ypodromiou- Navarino-Kamara-Agia Sofia area), it has the highest building density and building density. Consequently, the certain area may give more pronounced characteristics of the phenomenon UHI.

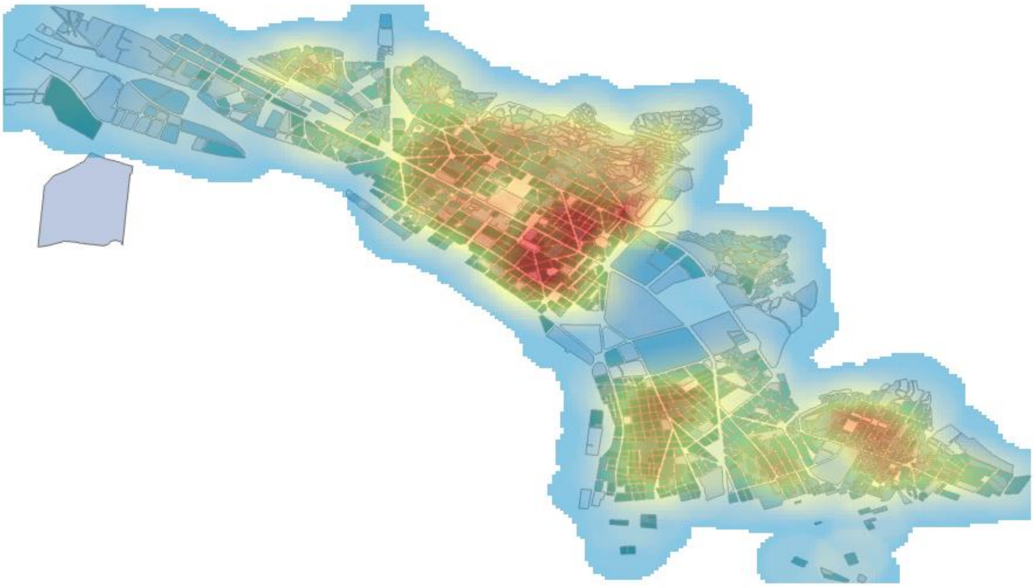
According to the 2007 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the urban heat islands and global warning other land-use changes have biased the land-based temperature record. This means, urbanization that is generating the phenomenon under study, not only generates the phenomenon itself but it is also capable of changing the global climate in conjunction with the change in land use.

Consequently, urbanization and land uses play a catalytic role in the climate (Kalnay, E. & Cai, M. 2003). The formed temperature is not always the result of climatic parameters. On the contrary, parameters such as urban density, land use, and building heights should seem to be related to the UHI phenomenon.

The correlation of temperature images with images of urban density, building height and urban land use can give results about the thermal isle phenomenon in the city of Thessaloniki.



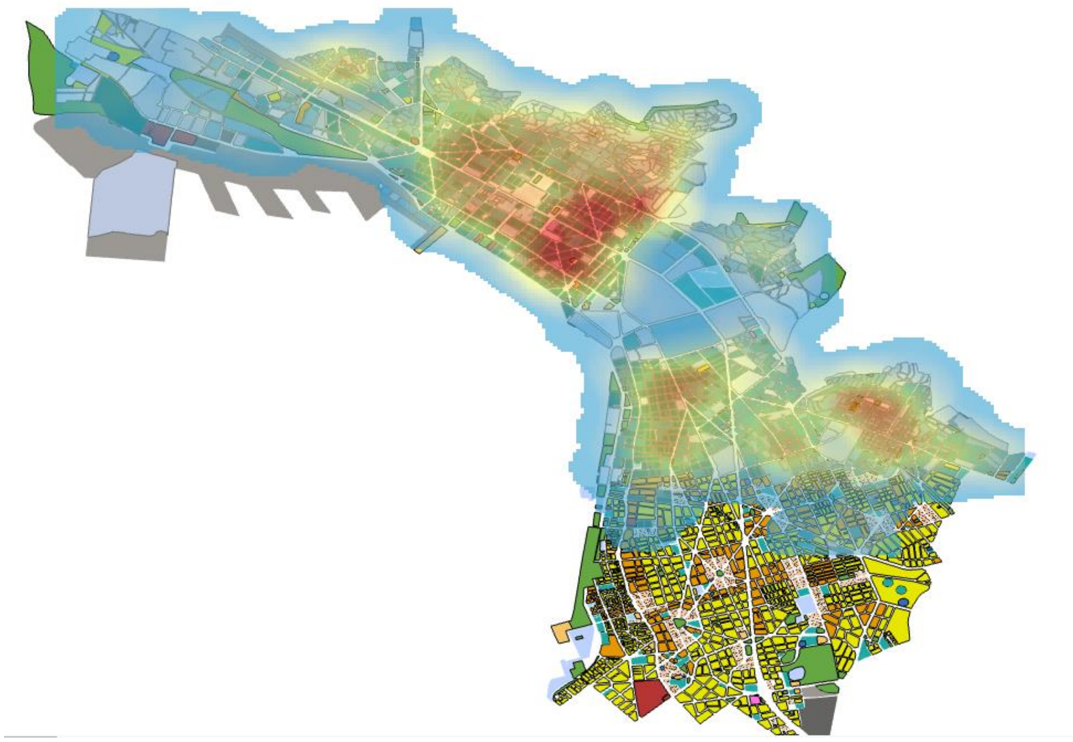
Picture 45: Correlation of number of floors per building block and building density. (Source: Own editing)



Picture 48: Visualization of the correlation of two factors of the UHI, the urban density and the height of the buildings, through ArcGIS of Thessaloniki city.

(Source: Own editing)

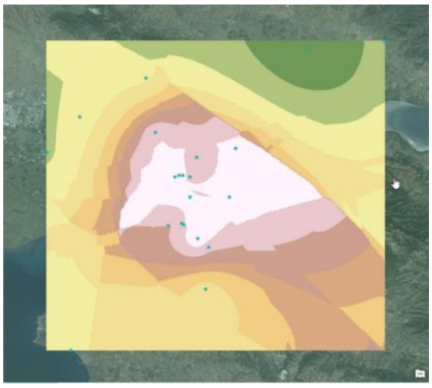
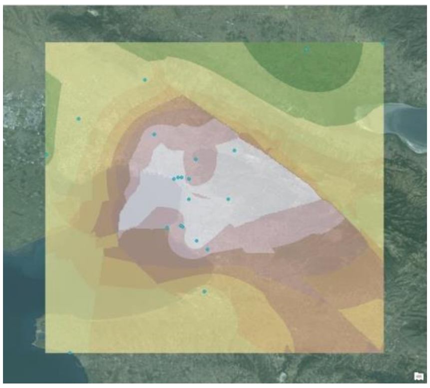
Correlating the three subjected factors of the phenomenon, urban land uses, urban density and building heights, it is observable the areas that are more densely build and have the greatest heights in buildings are areas that have extensively 'general residential' and 'pure residential' land uses, as well as city's 'central functions' land use.
It will be interesting to observe apart the area of Ano Poli, in the next sub-chapter, which consists mainly of small plots and there is a dense low buildings with small uncovered spaces on the plots and small widths on the streets.

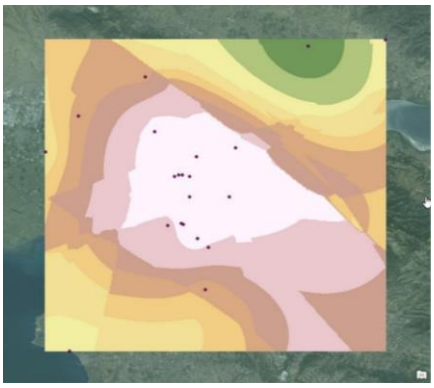
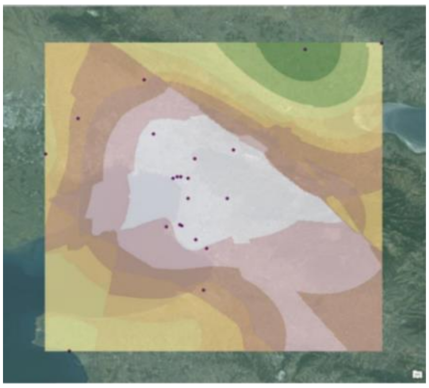


Picture 46: Visualization of the correlation of the three factors of the UHI, the urban density, the height of the buildings and the land use through ArcGIS of Thessaloniki city.
(Source: Own editing)

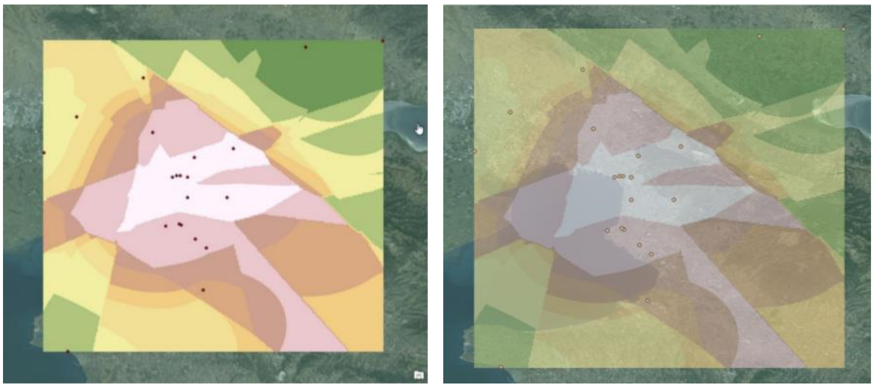
The ArcGIS images that produced with performing Interpolation Kringing Ordinary show the phenomenon of visualization throughout the year 2016 and it applied for specific dates that emerged from the data qualitative analysis. Hence for each month, the specific days that recorded the maximum and minimum temperatures, as well as, the average temperatures (Table 10) were the days that selected. The result was to produce 36 (= 12months x 3) images that represent two-dimensionally the temperature variation in the city of Thessaloniki. Also, a model was created that used minimum and maximum temperatures throughout the year and produced 365 images for minimum temperatures and 365 images for maximum temperatures.

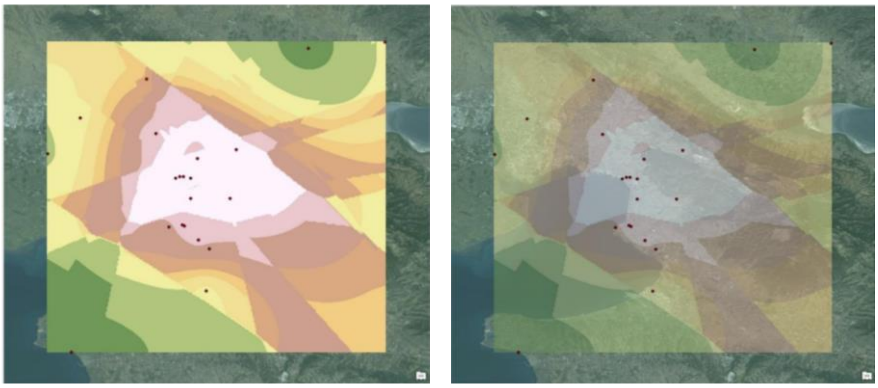
Performing Interpolation Kringing Ordinary using average monthly temperatures[5]

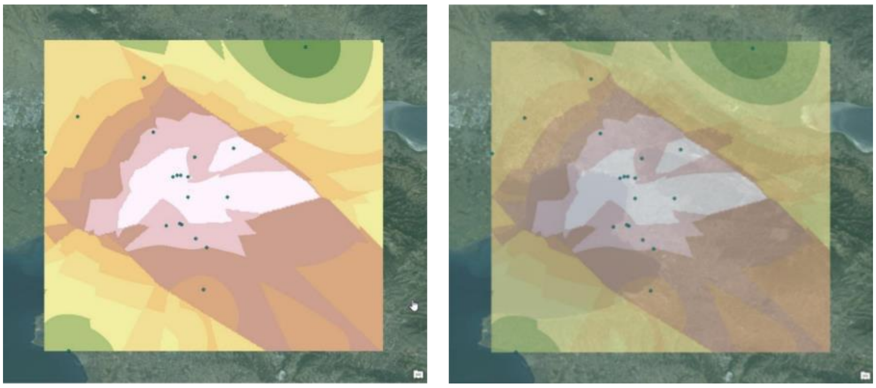


January 2016

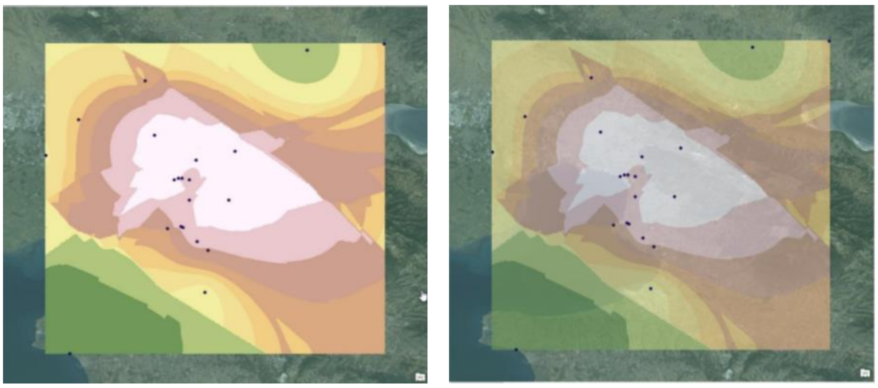


February 2016

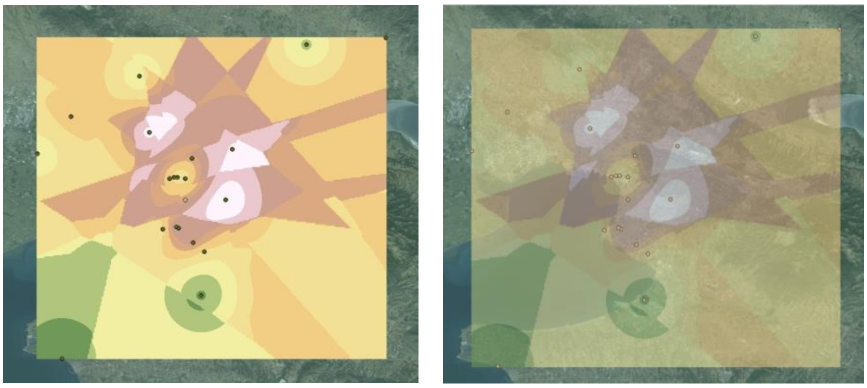
[5] Temperatures range is as shaped by the program without any intervention. This means that the formulations are proportional to the existing temperatures and not defined at specific imaging limits and colors.


March 2016

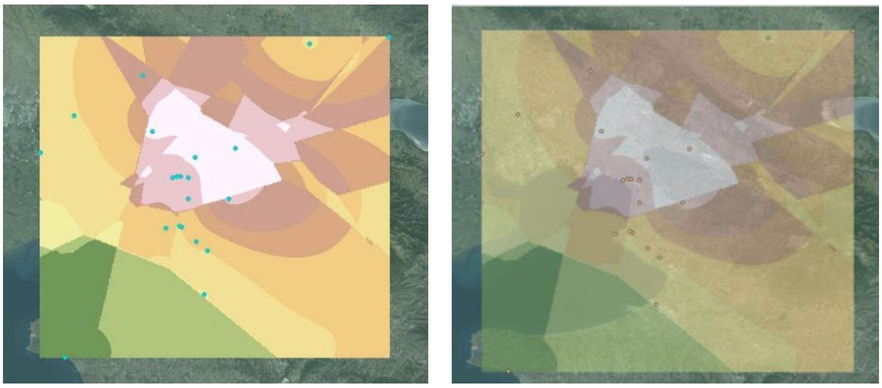

April 2016


May 2016

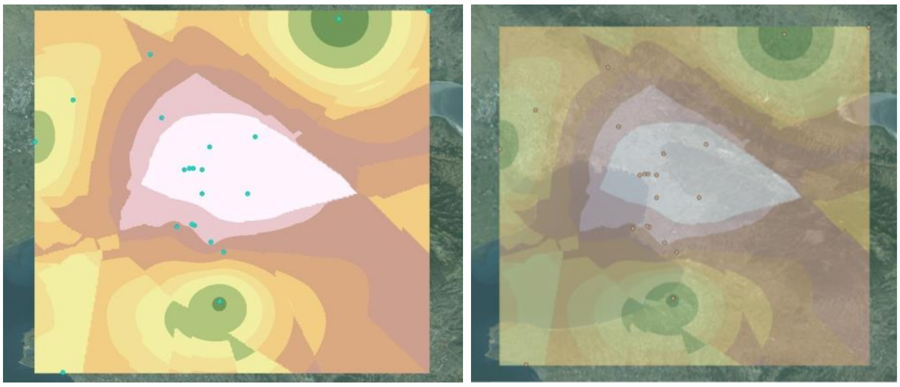

June 2016



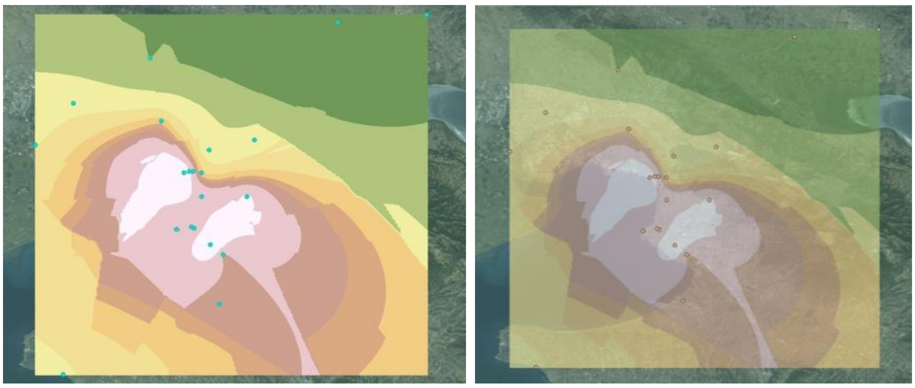
July 2016



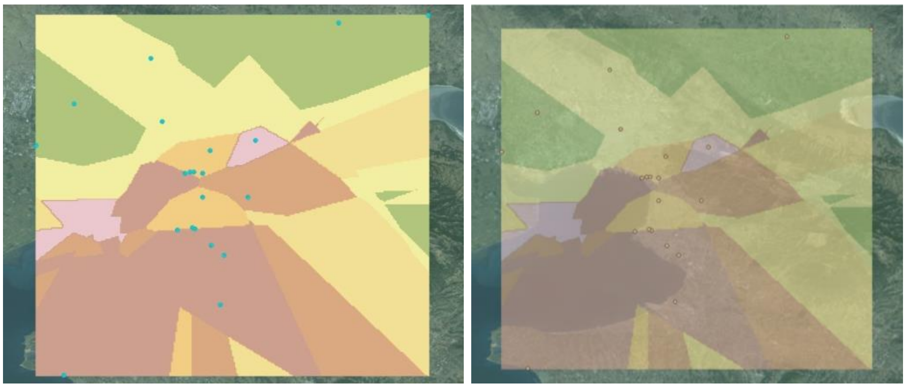
August 2016

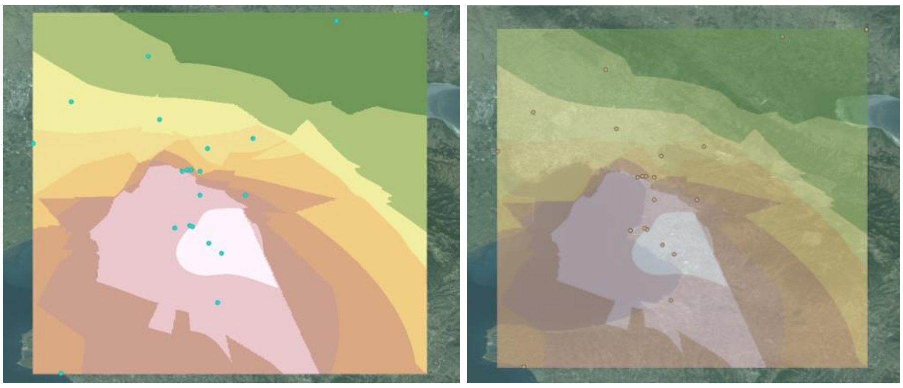


September 2016



October 2016


November 2016


December 2016

Pictures 47-70: Illustrations of performing Interpolation Kriging Ordinary using average temperatures per month.

(Source: Own editing)

Generally, high temperatures "follow" the structured environment and always appear above the structured environment. The IHU phenomenon is more clearly reflected during the winter months. The configuration of the temperatures is circular with maximum temperatures being above the city. It indicates that the city has a higher average temperature than its surroundings. During the cold months, the thermal isle phenomenon is more easily distinguished, as the city’s center is anti-dimensional warmer of its periphery. During the cold months, the sea shore keeps higher temperatures in relation to the built environment while in the hot months it is colder. Mostly, in summer areas outside of Thessaloniki give higher temperatures of the main city.

The city of Thessaloniki is always the protagonist of the high temperatures. At the same time, the city’s bipolarity reference West-East among residents, seems to be the same in temperatures as well, Ampelokipoi, Evosmos, Stavroupoli, which are the main areas in the West of the city, differ in temperature from the eastern regions of Kalamaria and Pilea, that possible due to proximity to the sea are cooler.

During the warm months, the symmetry of the concentric arrangement is lost and a more fragmented layout is created, which continues to reflect the UHI phenomenon as the city center maintains the highest temperatures.

There is a line that defines the change in temperatures in the north of the city from here and out begins the forest area of ‘Sheich Sou’, where winter or summer has the minimum temperatures on average.

In that area it was noticed that the Sheikh Su forest area is interrupted by a dense building strip consisting of the settlements of Pefka, Asvestochori and Exochi, where ther is a warm microclimate area that converges with the temperatures of the main city, these settlements are at an altitude and nearby to the forest area.

These areas are characterized by the land use of residence and the urban densities are large but the heights of the buildings do not exceed the 3 or 4 floors. From that, it is concluded that urban density plays a very important role in the formation of high temperatures. It is possible, location, altitude (mountainous area) and surrounding area (forest) do not justify that temperatures can be the same as the main city.

Perea is a suburban settlement that is heavily urbanized on the coast of the Thermaic Gulf, south of the airport area. What is observed is that during the summer months of high temperatures, the area has a lower temperature than the city of Thessaloniki, although it is considered to be a heavily urbanized area with buildings of 5 floors heights, with a detached free system of building but with large building rate (Structure factor 0.8) but with 50% coverage.

Compared to the city of Thessaloniki, which has buildings up to 8 floors, a continuous building system with a coverage rate of up to 90%, this indicates that the density of urbanization is an important factor in the generation of UHI. In addition, could be said that reasons for the Perea’s lower temperature is associated with the orientation of the settlement, and that it is not bordered by a urban area (Town Planning Complex) such as Thessaloniki, but with an agricultural and forest area and perhaps the high temperatures can be detonated faster. Further, the building density should have a greate role in high temperatures development.

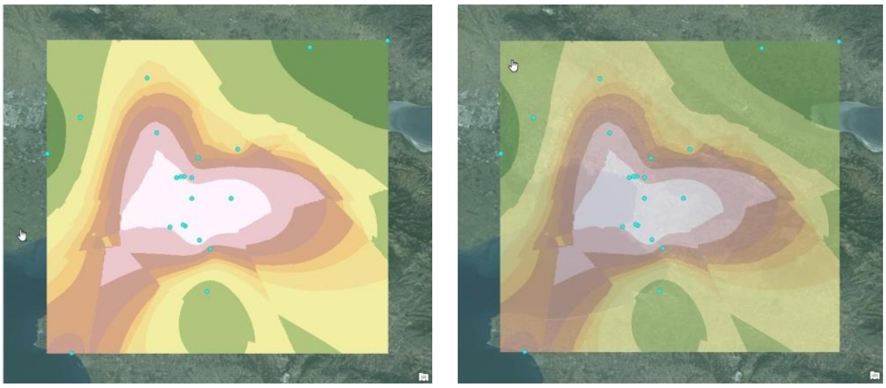
The airport weather station, which is located in an area that is mainly asphalted and attracts high temperatures due to the material but has a low percentage of height and coverage on the ground buildings, it is observed that the recorded temperatures are always lower than the center of the city.

In the area of Kalochori, an area located in the West of the city, surrounded by the Thermaic Gulf and the Gallikos River, with resindence and industrial land use, with 2 floors height buildings and low urban density, freely around, has lower temperatures than the city of Thessaloniki. Likewise, the industrial area (Sindos) of Thessaloniki, which consists mainly of buildings with a height of 6-8 meters, with large coverings (dense construction), minimal green with industrial land uses, has lower temperatures compared to the city center. This shows that the combination of high density and high

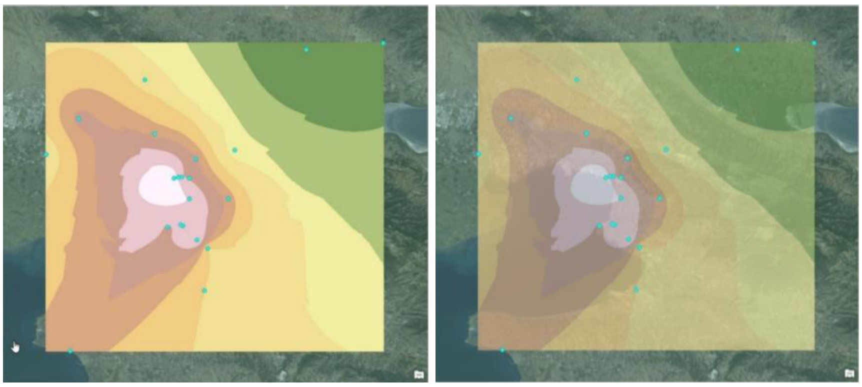
buildings gives high temperatures in the city. In addition, it can be said that the microclimate of each region formed by various factors that determines the temperature. This is shown in the case of the settlement of Langadas, which is a settlement located in a lowland area beyond the Kedrinos Hill and Derveni which spatially describe the city of Thessaloniki and its urban complex and has its own intense microclimate.
The conclusion is that for the creation of the UHI phenomenon there must be specific parameters such as degree of urbanization, i.e. the total unified area of an area that is developed. The degree of urban density as demonstrated in all cases with UHI, the urban area of Pefka-Asvestochori-Exochi, the center of Thessaloniki, as well as the western and eastern sub-centers, is a main reason of its creation.

Buildings heights, especially in combination with the high degree of urban density seem to be involved in UHI creating. As concerns, land uses it appears that residential land use, the use of retailing, which are in the same buildings with the dwellings because of the land uses mix, and the central functions of the city, creates a tension in the phenomenon in the city center, in the urban area Pefka-Asvestochori-Exochi,and the Western and Eastern sub-centers. It shows that these land uses generate intense human activity such as buildings heating and cooling, heavy use of motorized vehicles, devices operation, and so they create higher temperatures in the area.

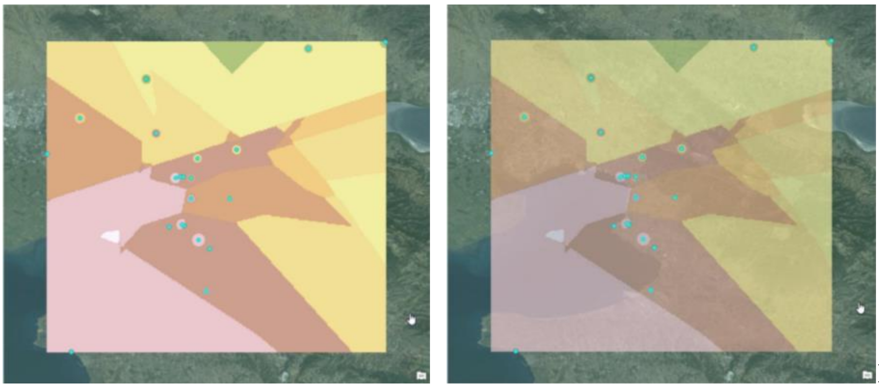
Performing Interpolation Kringing Ordinary using Minimum temperatures per month



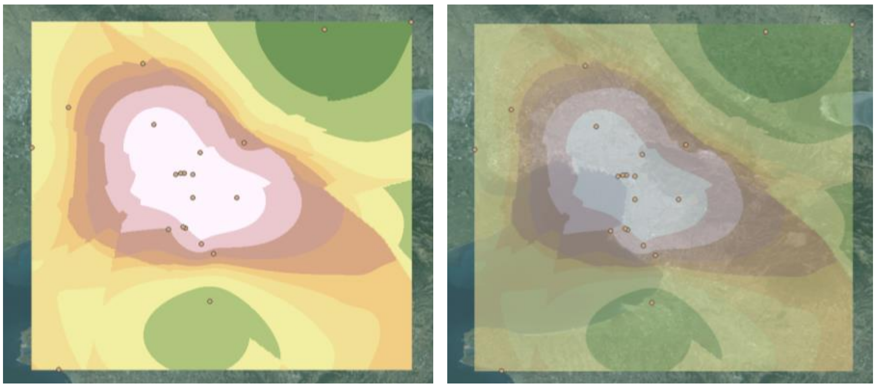
01-01-2017 min



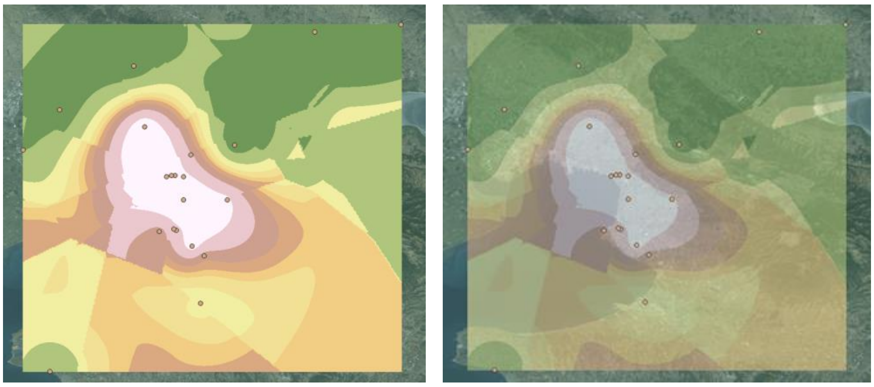
06-02-2017 min



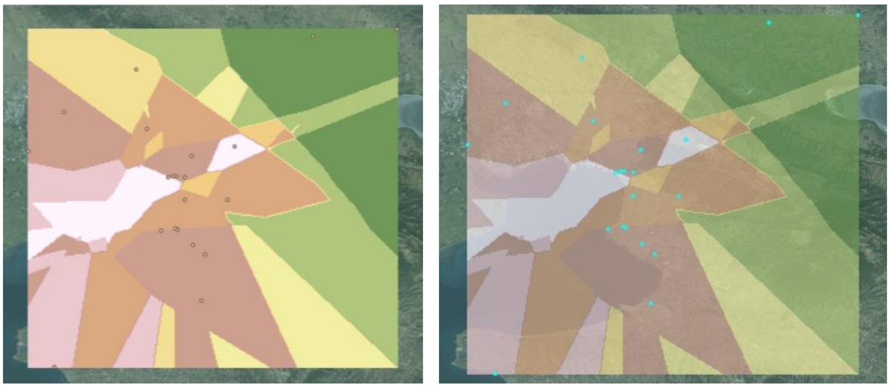
15-03-2017 min



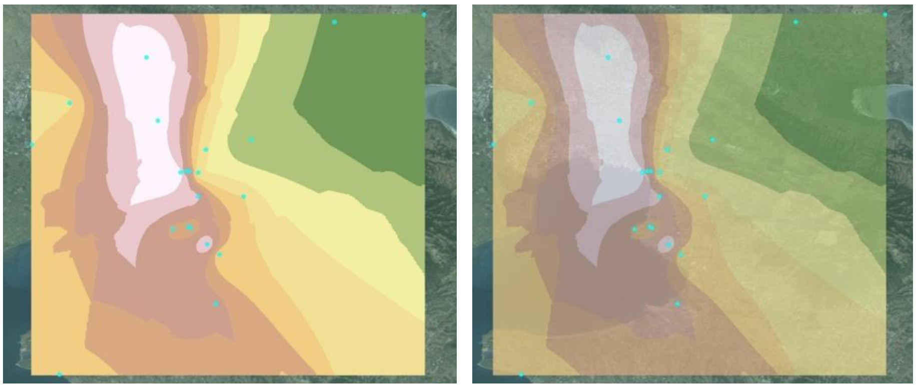
26-04-2017 min

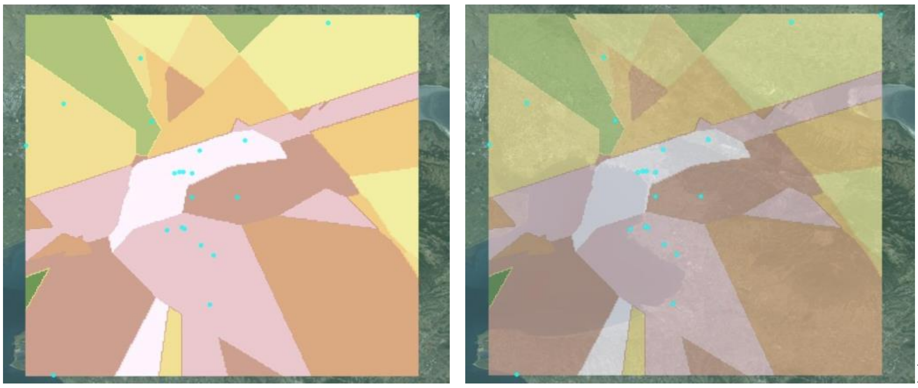


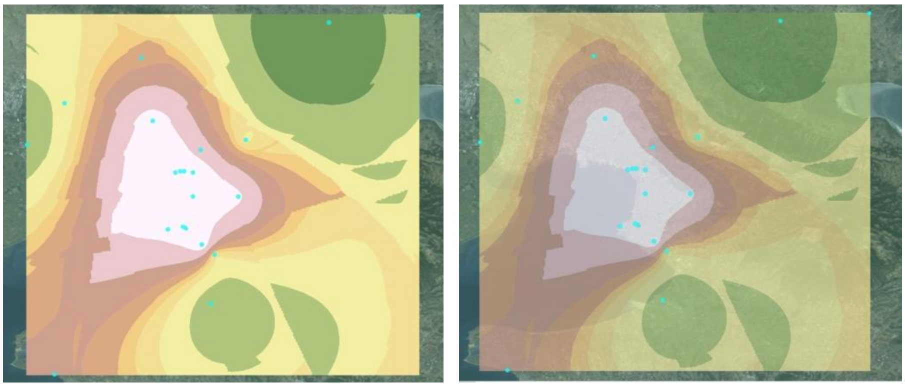
03-05-2017min

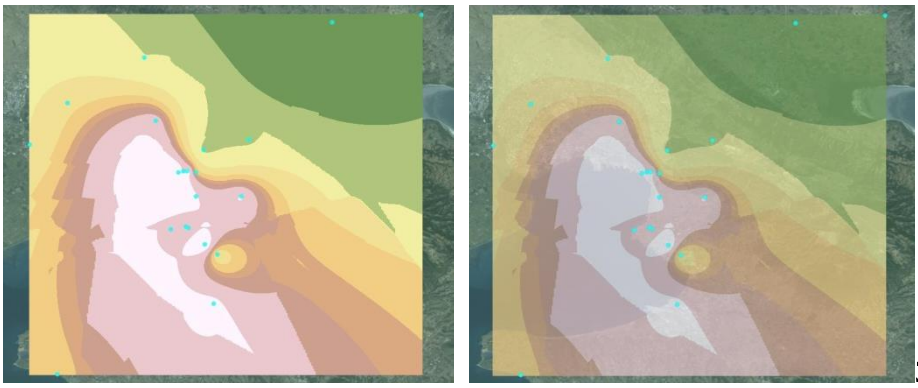


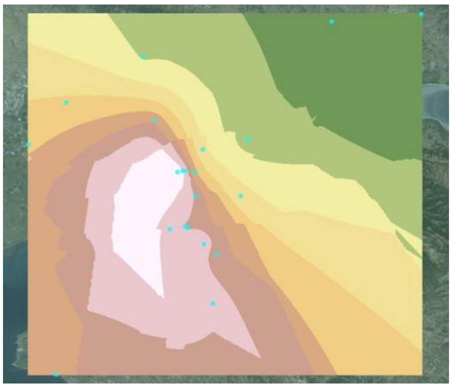
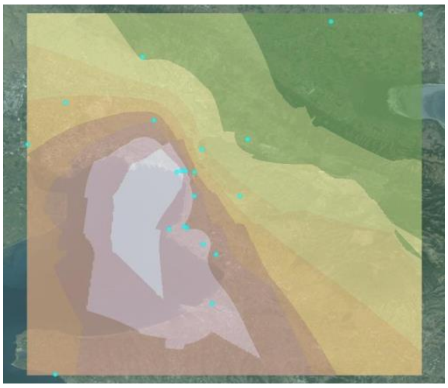
08-06-2016 min

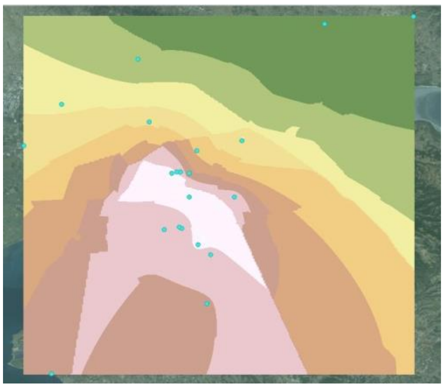
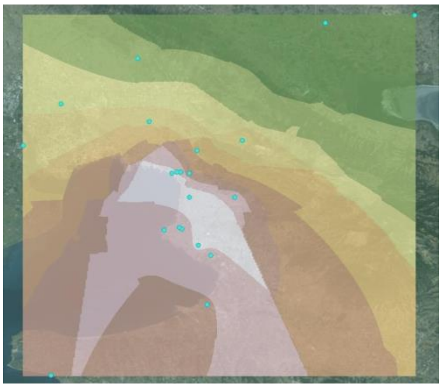

18-07-2016 min


13-08-2016 min


23-9-2016 min


31-10-2017 min



30-11-2016 min



31-12-2016 min

Pictures 71-94: Illustrations of performing Interpolation Kringing Ordinary using minimum temperatures per month

(Source: Own editing)

Minimum temperatures reasonably concern the night hours of the day and the minimum temperature within each month. It seems clear that the phenomenon is best suited to the minimum temperatures. So the wider area of the city has the minimum temperatures.

The coldest months for Thessaloniki are traditionally January, February and March. In these months it is clear at images that cold temperatures prevail over hot temperatures and "invade" the city from the periphery. Intermediate temperatures appear to have shrunk while larger and smaller temperatures occupy a larger surface area on the image that is possibly the UHI effect at the lowest temperatures appears clearly.

During the summer months (June, July, August) it is noted that the hottest areas are the center and the western districts (Ampelokipoi, Evosmos, Stavroupoli) and the urban zone (Pefka-Asvestochori-Exochi). This indicates that these areas experience more intense UHI at night. The common feature of these areas is intense urbanization with high urban densities.

The immediately high temperatures following areas in the east are Kalamaria, Pylea and Perea, which are densely populated areas. Pylea has tiled roofs and 4 floors high and Kalamaria buildings are 5 to 8 floors with terraces.

Panorama, a semi-mountainous suburb of Thessaloniki for high incomes, has a high UHI equal to Kalamaria (August). The settlement is densely structured, with an open-plan building system, with tiled-roofed detached houses surrounded by forest land. Also in close proximity is the settlement of Thermi, which is a densely built settlement and suburb of Thessaloniki that has a maximum coverage of 70% and buildind Factor 0,8 everywhere free with height 3-4 floors.

The conclusion is that tile roofing as a coating material does not help particularly to tackle the phenomenon.
Strong urbanization and high densities are the driving force of the phenomenon
The detached free system (Thermi, Panorama) has a positive effect on the phenomenon more than the continuous building system, as compared to the Kalamaria region, they present a thermal phenomenon.
It seems that the city of Thessaloniki with its monolithic character influences the neighboring areas by raising their temperature, as it happens in Ano Poli.
However, the UHI is a matter of the city center.

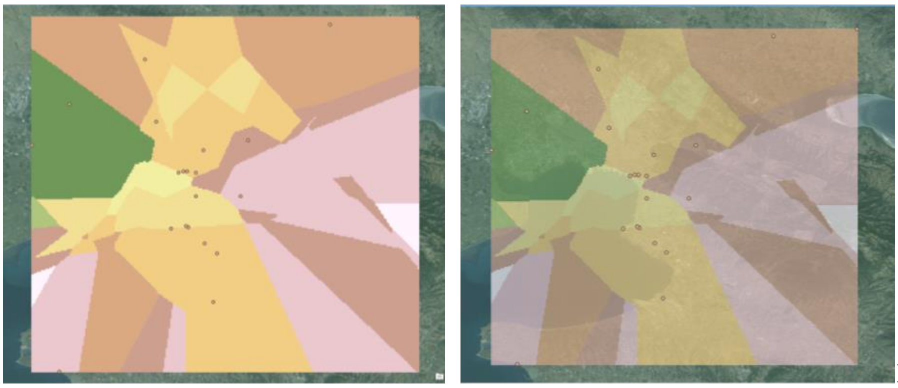
It is noted that during the months of weather changing, the transient weather months (September, October, November, April, May) the gradient on the pictures that produced from Kriging interpolation is unequal, with the average values occupying less surface in the imagery. This means that there is a big difference between "indoor" and "outdoor" city's temperature values.

Generally, it is noticeable by studying the minimum temperatures during the cold months of the year that there is a clean high temperature concentration above the developed districts. Similarly, in the hot months it seems that the structured areas maintain the higher temperatures. Just the temperature depiction centralized character over the city loses its uniformity and it is fragmented into "random" surfaces.

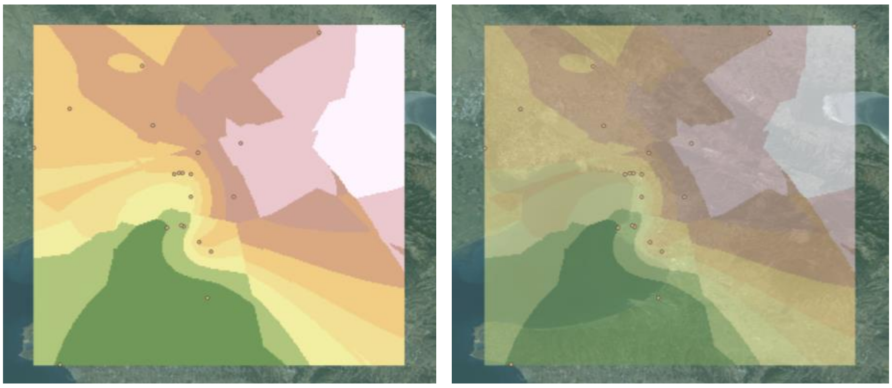
The sea plays a calming role in temperatures; it keeps its higher temperatures in relation to the land (built environment) during the cold months and vice versa it is colder during the hot months compared to the land, confirming the natural cycle configuration temperatures between land and sea.

The city's periphery seems to maintain the cooler temperatures particularly in the North and Northwest, while the South-Southwest wider region is more densely built giving higher temperatures. It is noted that the microscopes of each region play a decisive role in the formation of local temperatures and affect their wider area. In conclusion, minimum temperatures more clearly reflect the UHI effect.

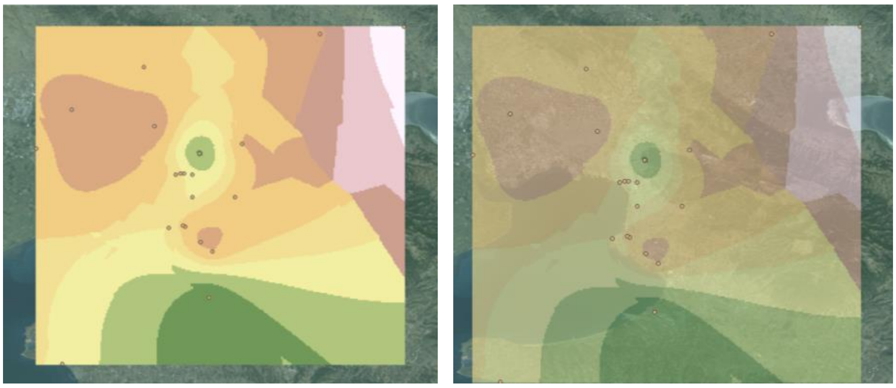
Performing Interpolation Kringing Ordinary using Maximum temperatures per month



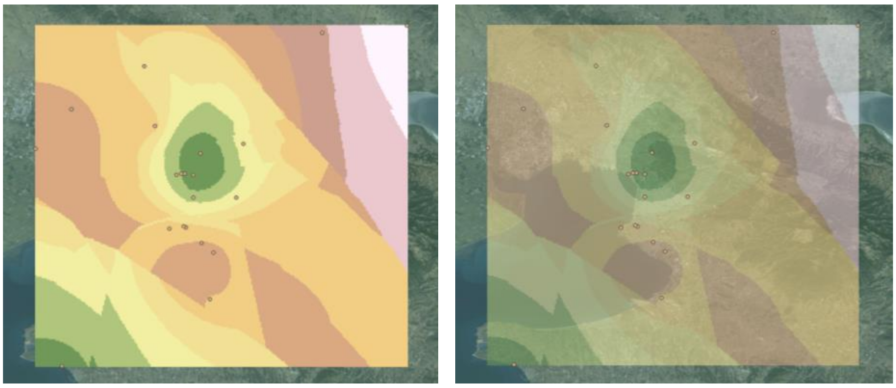
12-01-2016 max



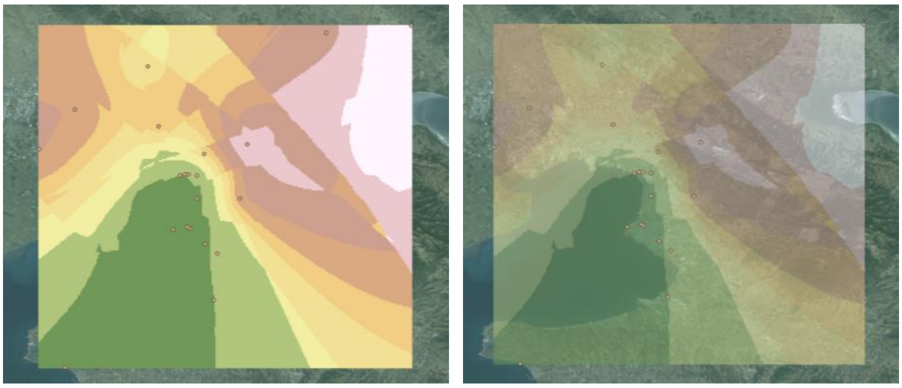
15-02-2016 max

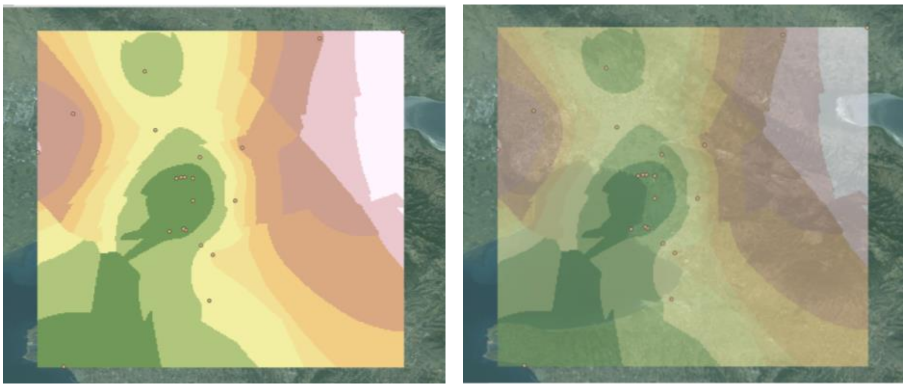


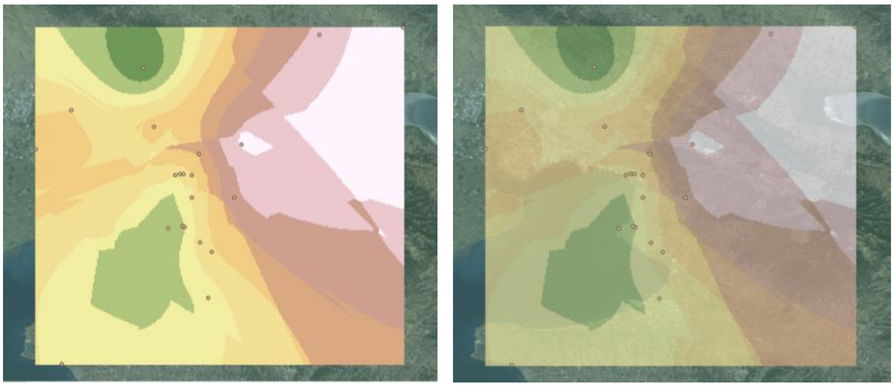
22-03-2016 max

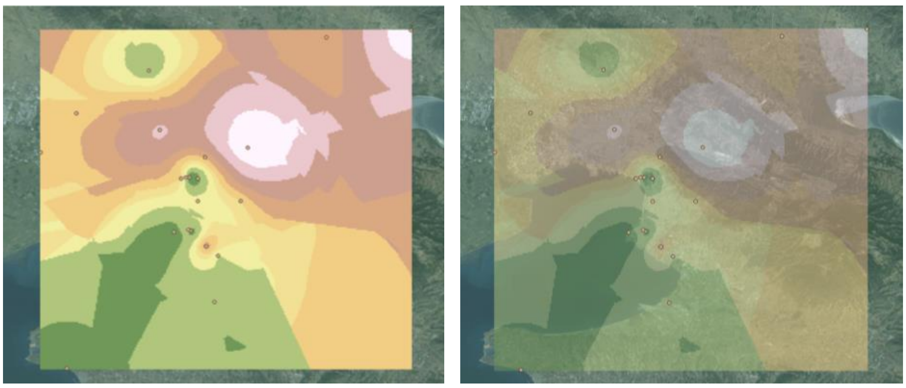


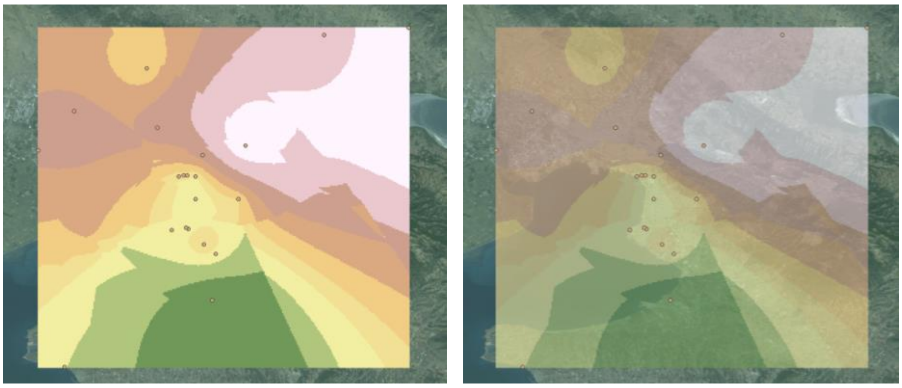
14-04-2016 max


31-05-2016 max

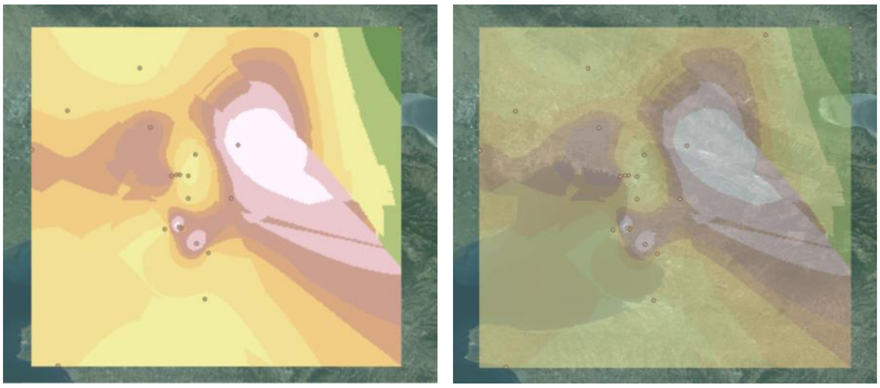

23-06-2016 max


10-07-2016 max

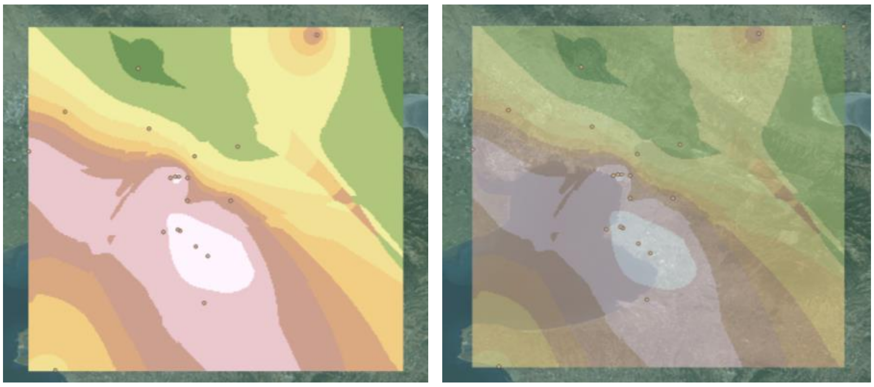

03-08-2016 max



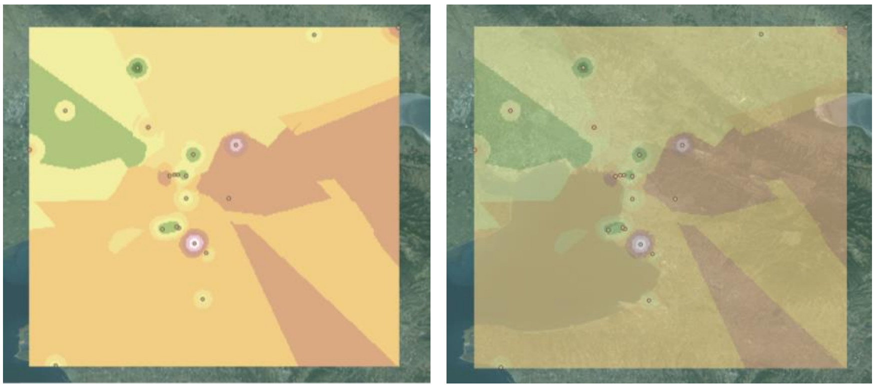
03-09-2016 max



04-10-2016 max



08-11-2016 max



01-12-2016 max

Pictures 95-119: Illustrations of performing Interpolation Kringing Ordinary using Maximum temperatures per month.

(Source: Own editing)

At high temperatures it is noticed that the city of Thessaloniki is not the leading. It means that the city is not easing due to the large building heights, especially during the winter months. Coarsely, the maximum temperatures seem to capture the prevailing weather conditions on the day, and at the same time more distinctly depicted the several distinct regions with their microclimates. The microclimates of the areas appear clearer at maximum temperatures.

The urban area of Pefka-Asvestochori-Exochi continues to give maximum temperatures in both winter and summer months. This indicates that either there is a hot microclima in the area due to the relief or the urbanization that exists acts as a heat transmitter and forms a warm area although it should be reasonably cooler due to the altitude and forest nature of the area. While, Kalamaria district in maximum temperatures during the intermediate months seems to have thermal inertia while during the summer months are cooler. Hence, it seems that at maximum temperatures the relief, the wider environment (sea, agricultural land, forest land) affects the temperatures that create the microclimate of the area.

On the contrary, the maximum winter temperatures form "random" polygons. The sea still retains a cooler position in the city's temperature range. While local microclimates make a strong appearance (14-04-2017 max) where the Mygdonia basin has higher temperatures than the coldest winter city, as well as highly densified M. Thermaikos also has a lower temperature.

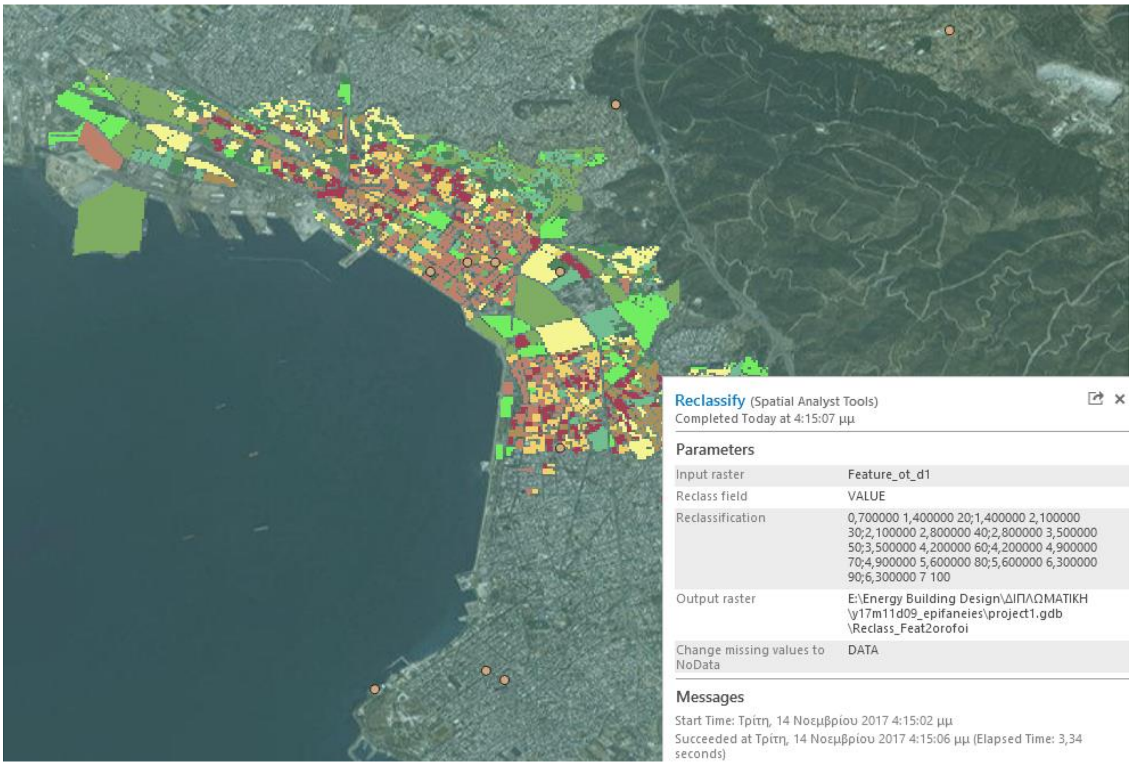
The areas oriented to the North - Northwest (Vardaris) have lower temperatures while those facing South - Southeast give higher temperatures. This implies that microclimate is the result of particular local characteristics and may affect positively or negatively the climatic condition of a district. Similarly, the Mygdonia basin presents a particularly warm microclimate in hot and cold months.

However, the IHU phenomenon is impressed in the city of Thessaloniki during the winter months.

5.3 Urban form's cartographic analysis

Having implemented the Interpolation Kriging Ordinary, surfaces were generated depicting the temperature gradient over the city of Thessaloniki and its periphery. In the next stage of the analysis the existing values of the three factors of land use, urban density and building heights were reclassified6, defining the gravity of each factor contributing to the creation of the UHI phenomenon in the city of Thessaloniki.

Initially, the process of reclassified through ArcGIS created a surface related to the heights of the buildings, as shown in the picture 122 below where it is observed that the heights of the buildings are located in the center of the city but developed with a bipolarity with an interference region.

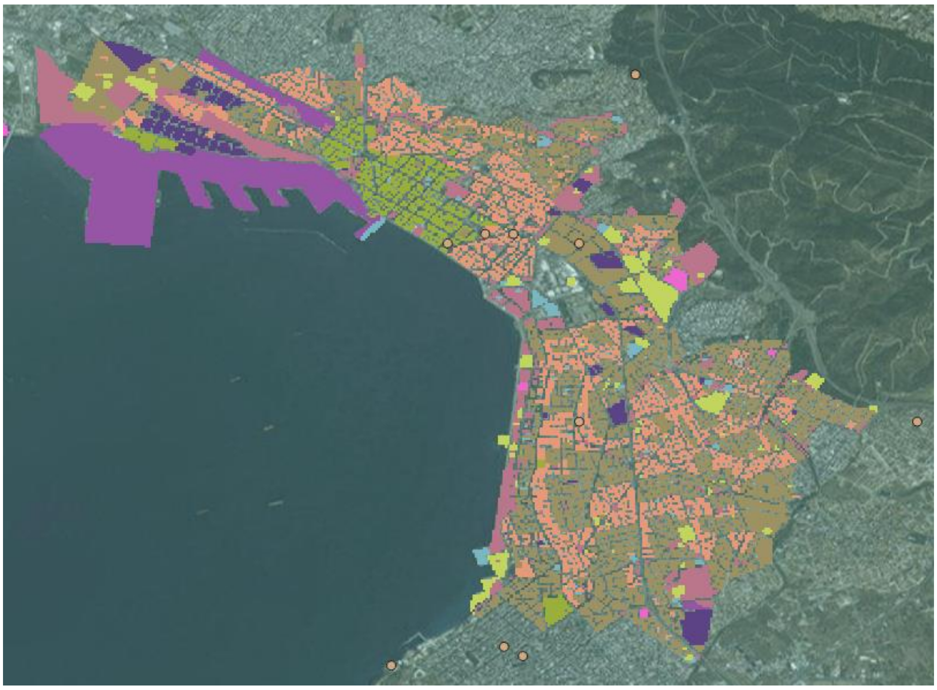


Picture 120: Reclassify the buildings height: Coffee represents the areas with buildings high while the green areas with lower height buildings.

(Source: Own editing)

[6] The process of taking input cell values and replacing them with new output cell values. Reclassification is often used to simplify or change the interpretation of raster data by changing a single value to a new value, or grouping ranges of values into single values for example, assigning a value of 1 to cells that have values of 1 to 50, 2 to cells that range from 51 to 100, and so on. (Source: http://support.esri.com/en/other-resources/gis-dictionary/term/reclassification).

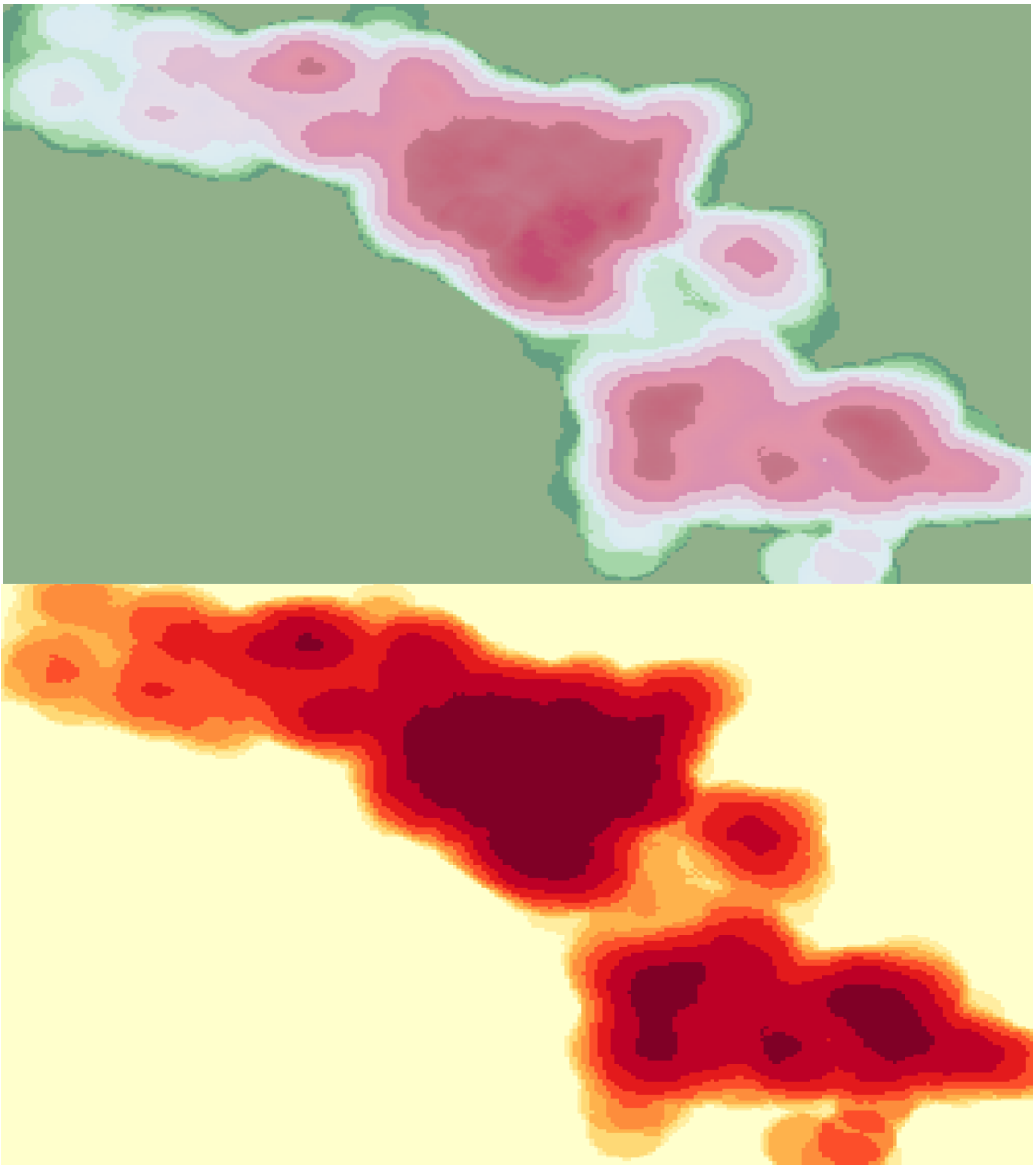
Similarly, surfaces were created for land use in Thessaloniki, where the land uses that set to have the same gravity value on the phenomenon were joined by giving the following listed pictures.



Pictures 121-122: Illustration of the reclassification of urban land use: Consolidating the weights of uses.

(Source: Own editing)

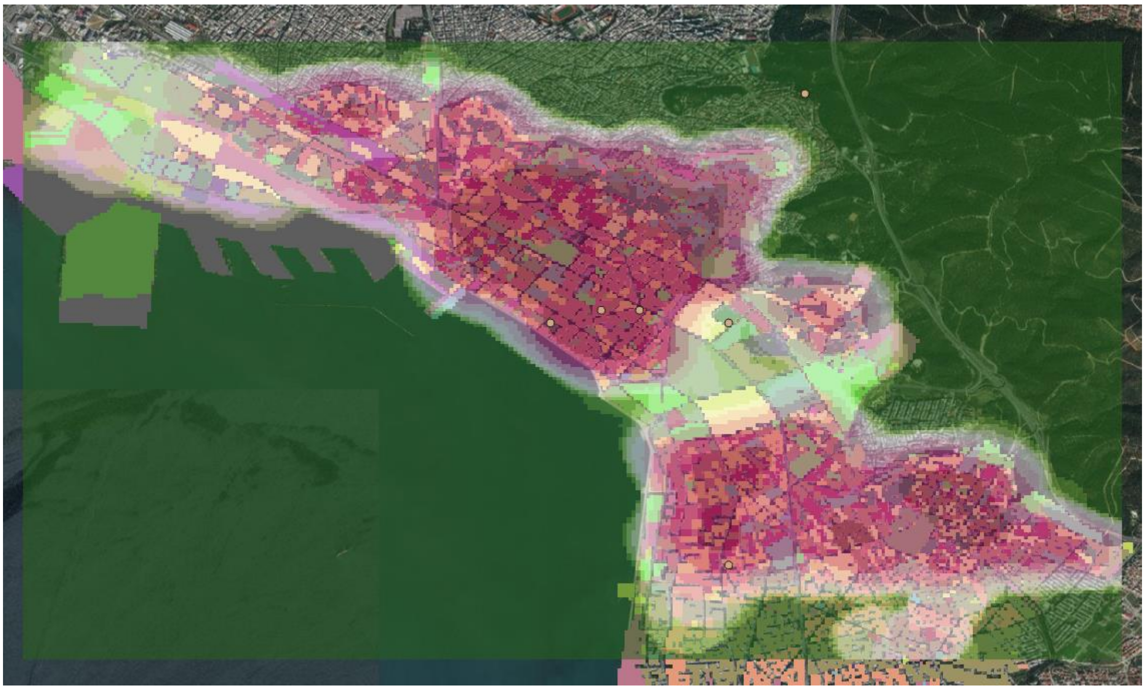
The result after the urban density reclassify for the Thessaloniki city is the following surface. This shows areas that are and graduated. Hence, emerging areas clearly showed that are densely structured and their classification.



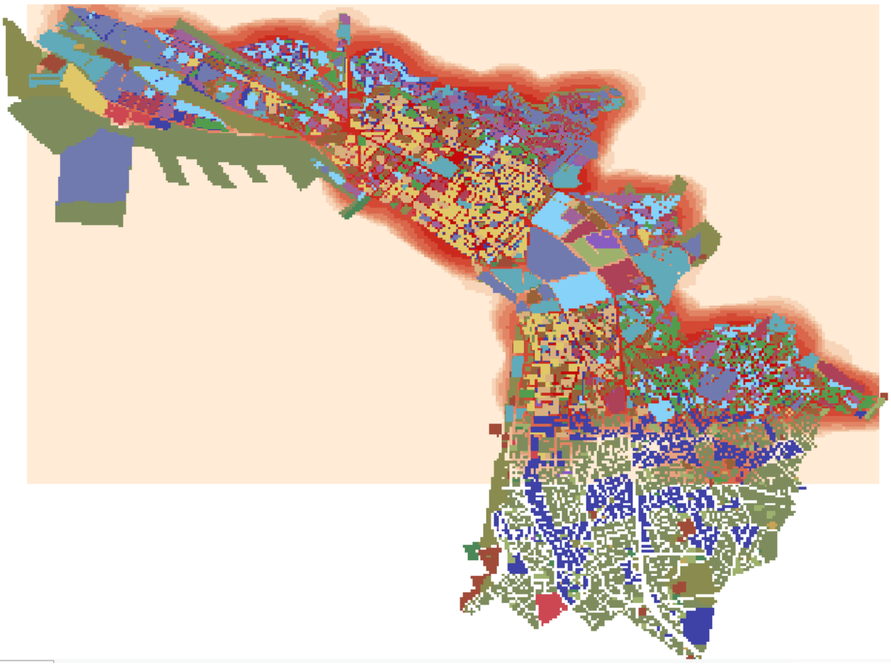
Pictures 123-124: Visualization of values' reclassification of urban density through ArcGIS of Thessaloniki city.

(Source: Own editing)

At this analysis stage it was made a correlation with the already reclassified generated images from ArcGIS in various combinations and it found on the one hand the reclassify which became highlighted the gradation of the factors in the areas of the city so as to be more easy reading of the results and they seem to be logic compare to surfaces before the reclassify processing.



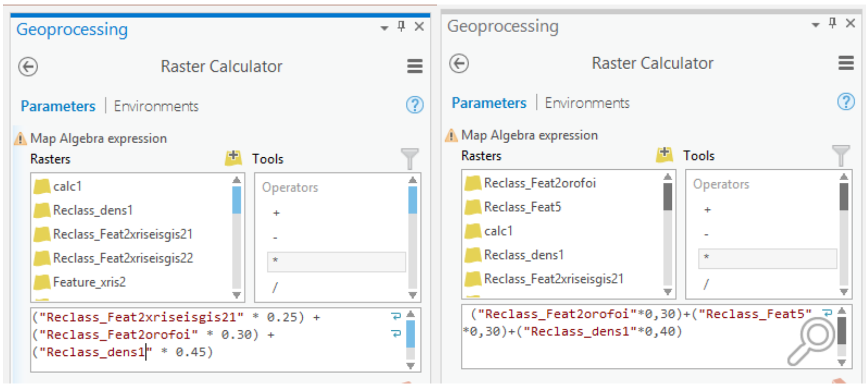
Picture 125: Illustration from the correlation of images reclassify buildings height and density.
(Source: Own editing)



Picture 126: Illustration of the combination of the three reclassified factors of UHI (urban density, urban and urban) and the gravity definition of each factor.
Areas with yellow shades may be more burdensome than UHI according to this research.
(Source: Own editing)

The degree of urban parameters influence, land use, building height and density, in the urban thermal phenomenon, was defined by a scale of the present study (reclassify).

With this process, the gradations of urban indicators are “normalized”. In the next step of the applying method, it had been created an overall equalization of significance of each urban parameter in the UHI phenomenon for the gravitational modeling of the "thermal neighborhood" phenomenon. The three reclassified surfaces for urban UHI factors (land use, building height, and density) should be linked by defining a weight with their contribution in the creation of the thermal isle in Thessaloniki. The ArcGIS raster calculator tool[7] is capable of “adding” these surfaces and generating a surface that gathers all the information from each surface in a percentage that can be determined as an effect quota in the phenomenon. Furthermore, there is the opportunity to make different tries changing the importance of each factor and selecting the most suitable combination rates. In the present study although there were no particular variations, the second test was selected.



Pictures 127-128: Raster calculator procedure. Left the 1st try, right 2nd try.

(Source: Own editing)

Pictures 129-130: Visualization of mingling the three reclassified UHI factors (land use, building height, and urban density) in Thessaloniki city. 1st try

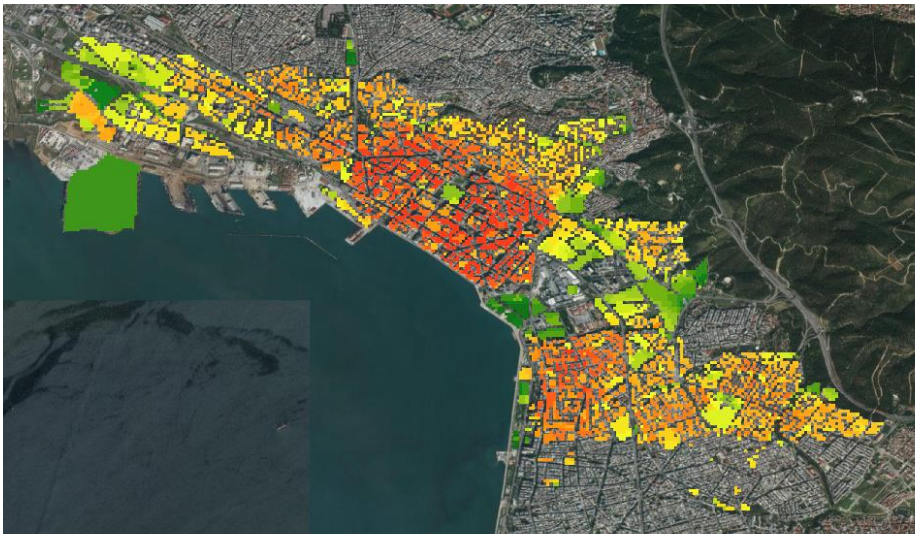
(Source: Own editing)

[7] The Raster Calculator tool allows creating and executing Map Algebra expressions in a tool that will output a raster. Like other geoprocessing tools, the Raster Calculator tool can be used in ModelBuilder, allowing the power of Map Algebra to be more easily integrated into the workflows.
(Source: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-raster-calculator-works.htm)

Pictures 131-132: Visualization of mingling the three reclassified UHI factors (land use, building height, and urban density) in Thessaloniki city. 2nd try

(Source: Own editing)

The image associated with the temperature images includes the gravity of the three urban parameters, density of building heights and land uses as assessed by the study for their involvement in the phenomenon.

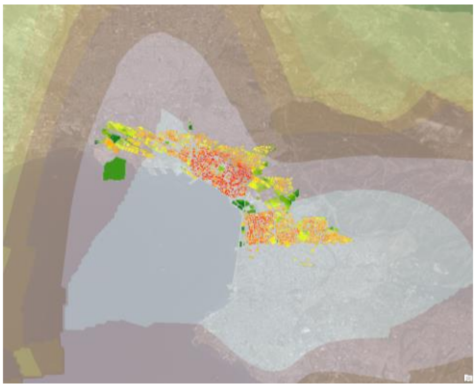


Picture 133: Illustrating the combination of the three factors of UHI creation and the weighting of each factor (2nd try).

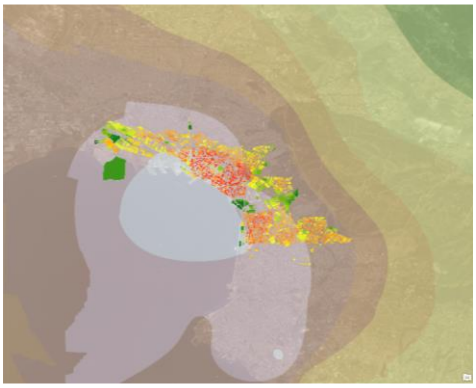
(Source: Own editing)

The analysis is completed by correlating the surface that results from the Raster Calculator tool with the surfaces related to temperatures that came after the applying the Kriging interpolation method. This correlation will show how reliable the surface results are, as the potential areas where the UHI effect will develop more strongly should be matching with the higher temperature surfaces. Beyond that, there will be additional results regarding the form of the city, the characteristics of the thermal isle phenomenon, even the factors.

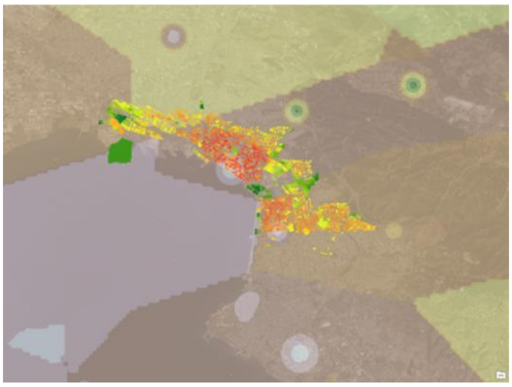
Correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the minimum temperatures.



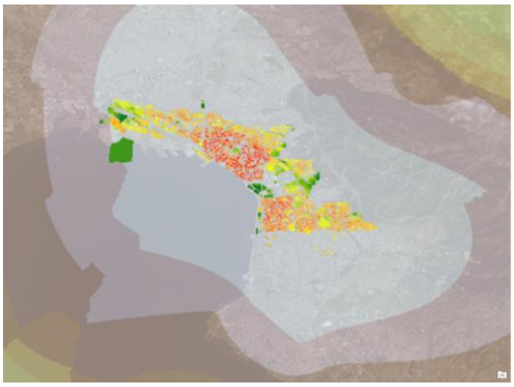
January's min temp on 01-01-2016.



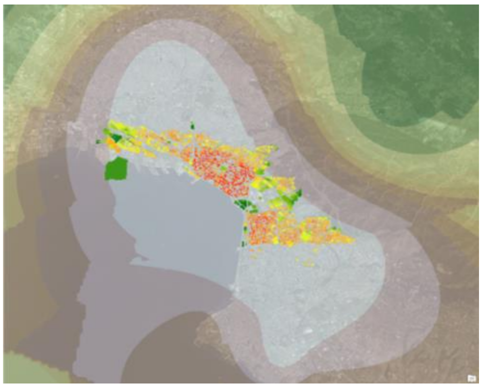
February's min temp on 06-02-2016.



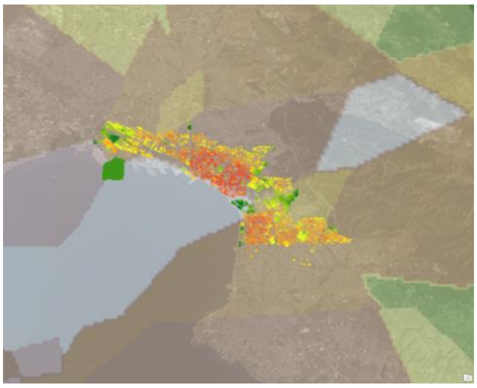
March's min temp on 15-03-2016.



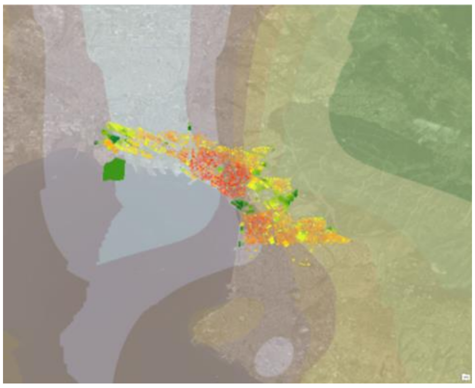
April's min temp on 26-04-2016.



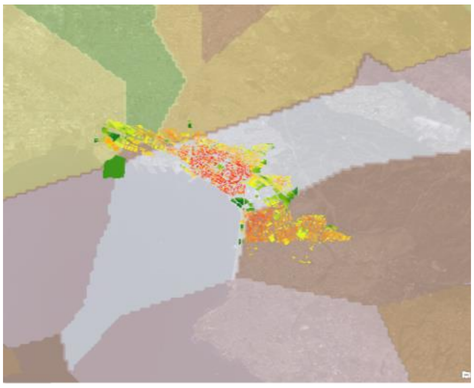
May's min temp on 03-05-2016.



June's min temp on 08-06-2016.

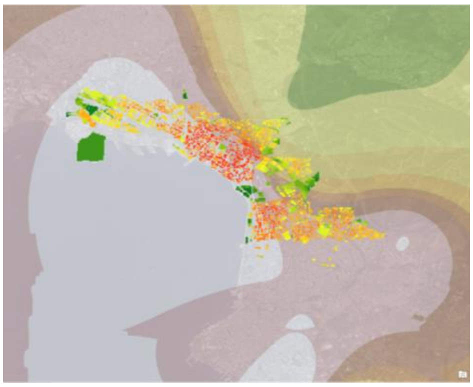


July’s min temp on 18-07-2016.



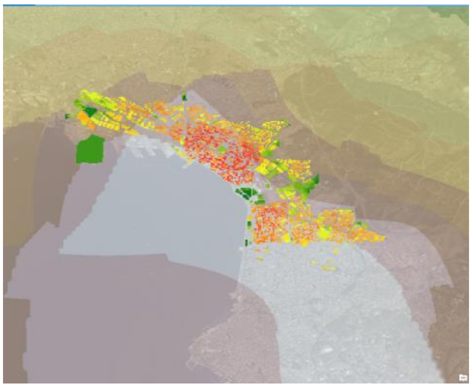
August’s min temp on 13-08-2016.

September’s min temp on 23-09-2016.



October’s min temp on 31-10-2016.

November’s min temp on 30-11-2016.



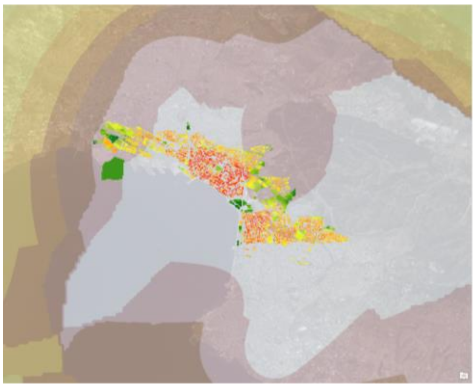
December’s min temp on 31-12-2016.

Pictures 134-145: Correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the minimum temperatures.
(Source: Own editing)

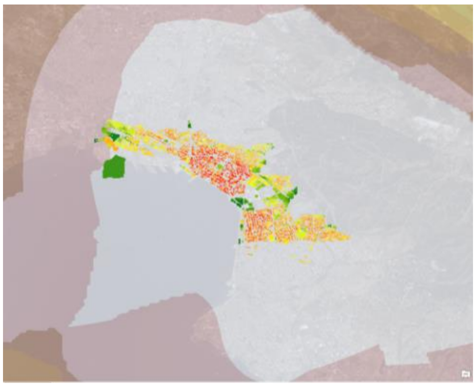
In general, someone can notice that the "red areas" are identical to the configured maximum temperatures. Particularly in the winter months, the identification of the "red" areas with high temperatures exists in a large percentage. This suggests that the small temperatures best reflect the UHI phenomenon and the assumptions that have made about the gravity of the urban parameters are correct.

Very typical is the case of March where a high temperature outbreak is created within the city in both parts, North and South. In contrast, during the summer months (June, July and August), there is not a high rate of identification of the "red" areas with high temperatures, as it seems that the maximum temperatures are formed outside the city for reasons we have mentioned above.

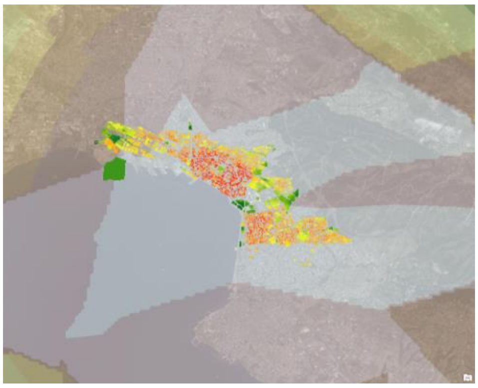
Correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the monthly average temperatures.



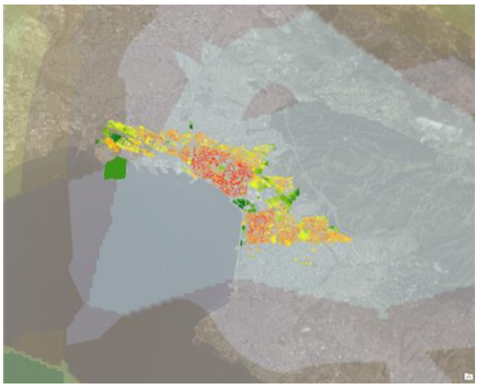
January's 2016 average temperatures.



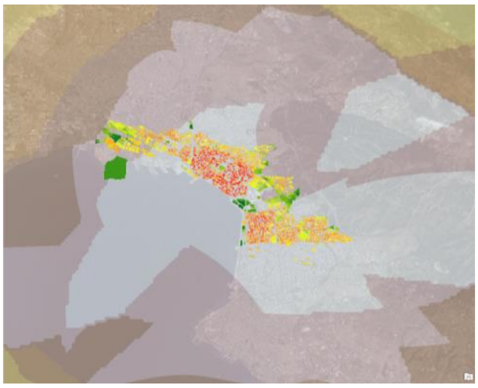
February's 2016 average temperatures.



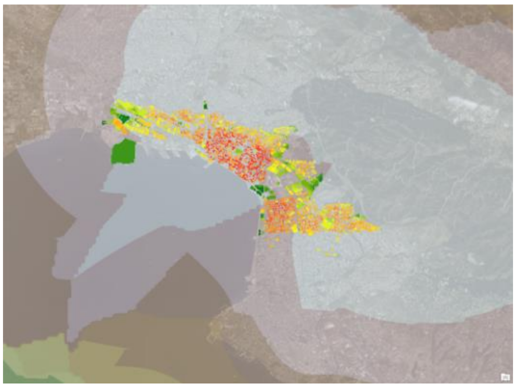
March's 2016 average temperatures.



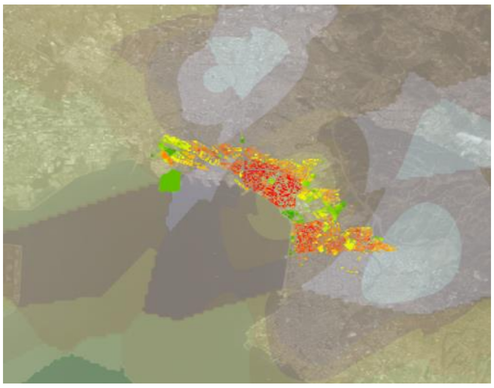
April's 2016 average temperatures.

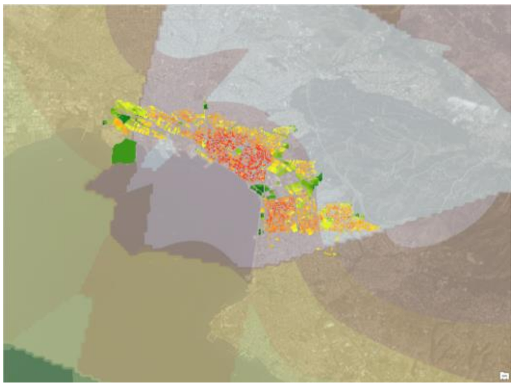


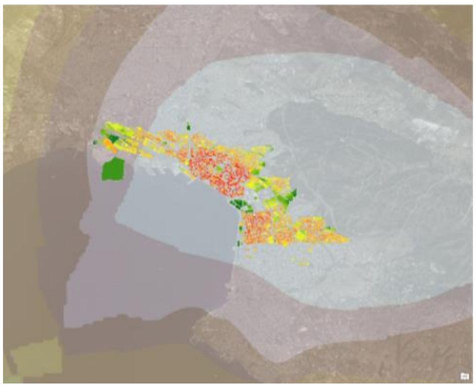
May's 2016 average temperatures.

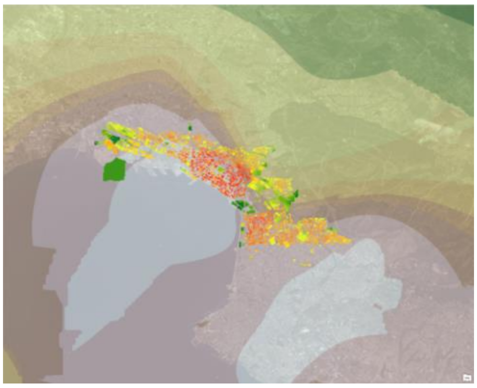


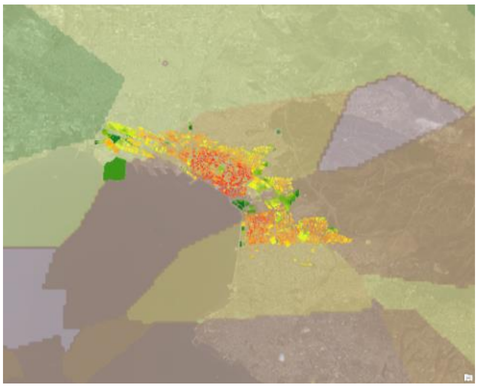
June's 2016 average temperatures.

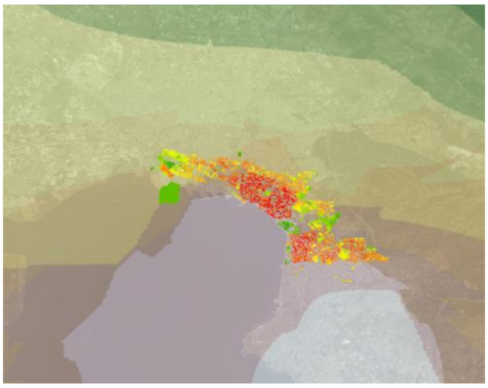

July's 2016 average temperatures.


August's 2016 average temperatures.


September's 2016 average temperatures.


October's 2016 average temperatures.

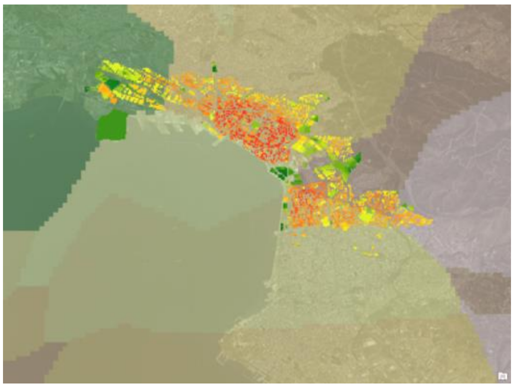

November's 2016 average temperatures.


December's 2016 average temperatures.

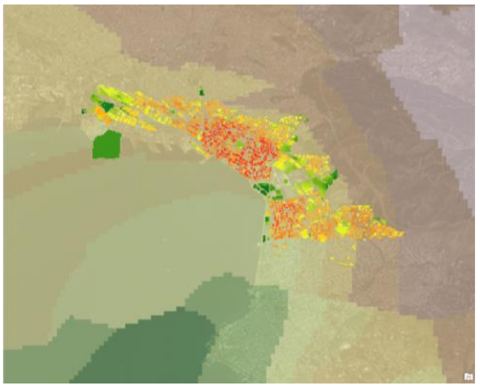
Pictures 146-158: Correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the monthly average temperatures. (Source: Own editing)

The correlation with monthly average temperatures with the image of likelihood area of a UHI event generally appears to be successful, especially in the winter and in the intermediate months. The matching rate is higher than the minimum temperatures in the month. That is positive, for this work's credibility as the average monthly gathers a trend of the month while the minimum or maximum temperatures refer to a particular day. Therefore, this shows that the illustration of the phenomenon is correct.

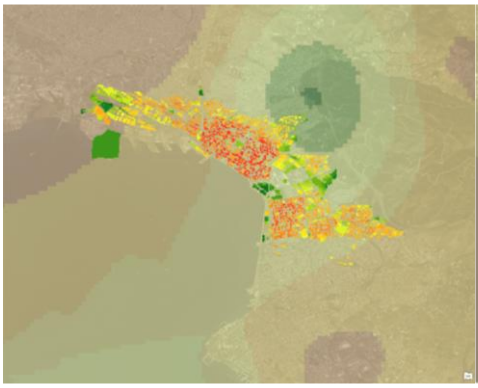
Correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the maximum temperatures.



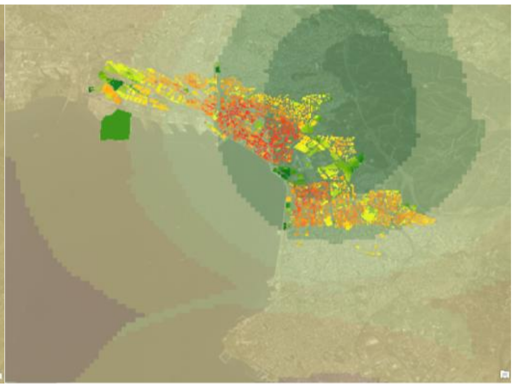
January's max temp on 12-01-2016.



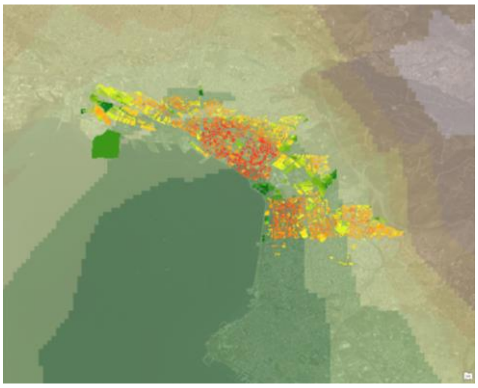
February's max temp on 15-02-2016.



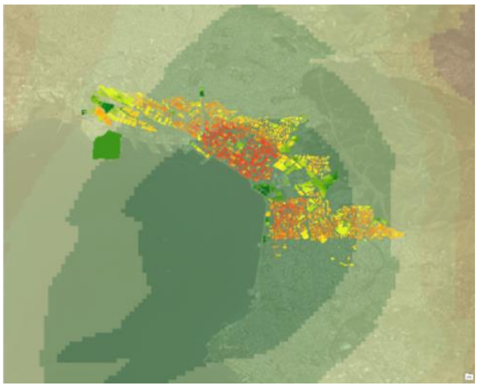
March's max temp on 22-03-2016.



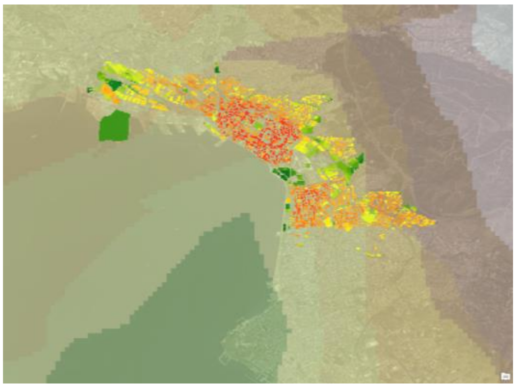
April's max temp on 14-04-2016.



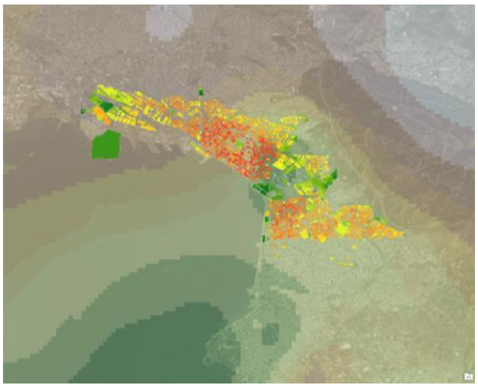
May's max temp on 31-05-2016.



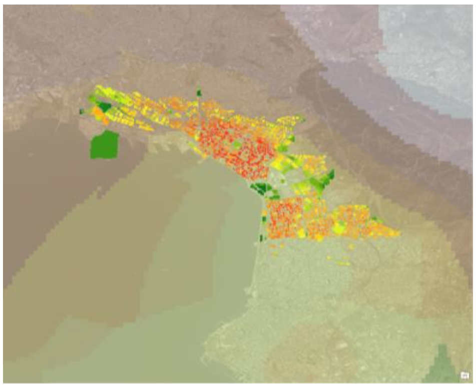
June's max temp on 23-06-2016.



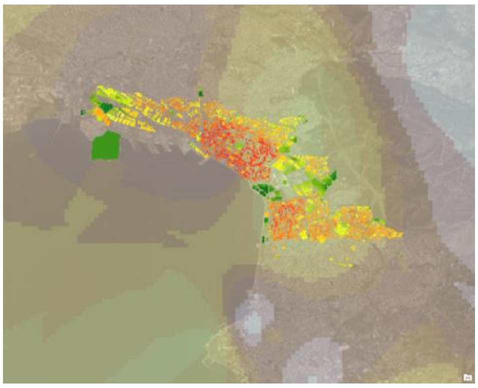
July’s max temp on 10-07-2016.



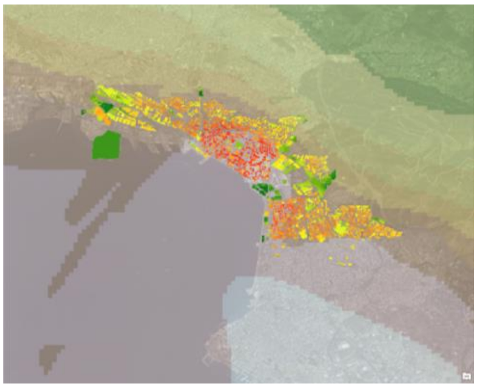
August’s max temp on 03-08-2016.



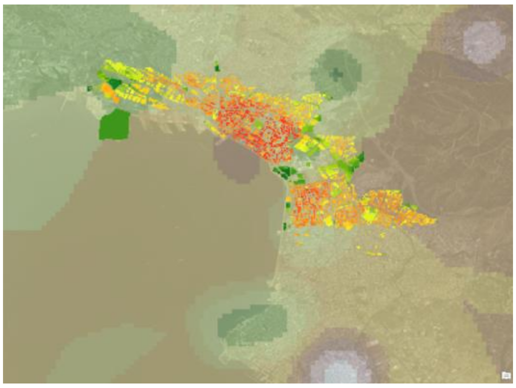
September’s max temp on 03-09-2016.



October’s max temp on 04-10-2016.



November’s max temp on 08-11-2016.



December’s max temp on 10-12-2016.

Pictures 159-170: Correlation between the surface image of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the maximum temperatures.
(Source: Own editing)

As far as the maximum temperatures are concerned, as noted above, the maximum temperatures are mainly formed outside the city for the reasons given. Hence, there is no match with the "red" areas of the UHI depiction. However, in the month of November (cold month), there is a coincidence between the high temperature and the "red" area in the center of the city in the wider area of the Hippodromiou, which has high densities, high buildings heights, and residential and retail for uses land. Conversely, it is noted that the unified area of universities (Macedonia and Aristotle), Kotta camp, City Hall and coastal park, which separates the city into two distinct parts (North and South) and which has a higher percentage of green areas than the neighboring densely built areas and high floor build but not large densities show a strong cold microclimate on the hottest day of August as well as in April, May and June.

In addition, it is worth noting that in the winter and in the middle months there is no matching between "red" areas and prone areas to UHI, but the temperatures that prevailing within the city of Thessaloniki, are also hot in the temperature range.

The phenomenon of better description of UHI phenomenon using minimal and average temperatures has already been described by other scholars (Sluiter, R., 2009; Cao, W., et al., Nawal K.G., et al., 2013). Thus, since the higher temperatures do not correctly describe the urban thermal phenomenon in images created by applying the Kriging interropolation; we can say that the study has responded adequately to that group of maximum temperatures.

5.4 Evaluating output

Evaluation is generally considered to be a tool for the accuracy of the results of every project that had been carried out, but also is a way to assess the methods used τo performs the project. Thus, the same work should evaluate the results by reviewing the methods that have been used with a view to their possible correction or even to do a revision of the initial placement of the maker or the researcher.

Kriging ordinary interpolation, which was chosen to be applied in the present study, has yielded reliable results as surface gradations, which generated by the ArcGIS, are representative for each season and can be interpreted by the logic, for example, cold sea in relation to the dry land in summer, warmer in relation to land in winter, the areas facing the north (M. Thermaikos) is mainly cooler than the other areas. Further, the stratification of temperatures on the produced surfaces by the application of Kriging ordinary is reasonable and, it is observed that, it take into account the details of the recorded temperatures given by meteorological stations.

As far as the UHI effect is concerned, the smallest temperature pictures as well as the average temperature images better reflect the phenomenon of thermal isle as it appears that the higher temperatures in relation to the circumference prevail in the city during the night hours. On the contrary, the maximum temperatures (during the day) better capture the existing microclimates of the areas, as shown by the images produced the city is in many cases cooler than its surroundings. The confirmation of the UHI effect through ArcGIS surfaces is an additional positive evaluation of this method because the effect has been confirmed by other relevant studies discussed above.

Correlating the surface that concentrates the weight of the urban planning parameters with the surfaces generated by applying the Kriging interpolation, it is possible to evaluate both the Kriging result and the gravity effect result of urban parameter. According to the results of the correlation, seems in general, that the images are interdependent. In particular, when correlated with the minimum temperatures, it appears to be a combination of the results as the high probability areas of occurrence of the urban thermal islet phenomenon is within the areas with the maximum temperatures in the city. The same is confirmed also by the correlation with average temperatures images.

On the contrary, the correlation with the surfaces created by the maximum temperatures does not indicate the location between the high temperatures of the city and areas that are most likely to develop the UHI effect. This means that the UHI effect occurs during the night hours when there are the minimum temperatures, while during the day the maximum temperatures occur outside the city, which verifies that the existing microclimates of each district are the outdoor temperature regulator.

6.0 CONCLUSIONS

Inferences

Climate change is already a reality and the impact on people living in urban areas is often dramatic. Climate phenomena are manifested in a more intense way, with the result that it is not possible for construction or for humans to cope with their severity. Heavy heat in cities is a climatic phenomenon that comes from climate change due to the general rise in temperature on earth and the intense urbanization that has taken place in the cities. According to this study, the presence of the UHI phenomenon in the city of Thessaloniki was confirmed, through the study of generated GIS images by applying interpolation, the temperatures within the city and more in the dense urban areas were increased.

The height and density of the building is proof of the degree of exploitation of urban land. In the case of the city of Thessaloniki, there are areas such as its historical center, which has been the maximum possible exploitation on the surface of the city. However, it seems that this practice is the reason for the degradation of the area as a residential area, as it caused the phenomenon of local overheating in the city. An additional important reason is the low percentage of urban green in the city of Thessaloniki; even in accordance with the statutory urban land uses is minimal in proportion to other structured uses. There are not many free spaces (squares, parks, unstructured plots) and where the configurations are made of conventional building materials with low reflectivity.

The sea is decisive both for shaping city's character and local weather conditions and consequently forms the climatic character of the city. There is a "heat inertia" in the transition months the city operates as a static heat accumulator which, depending on the sign being charged, emitting the corresponding temperature. Observing the max temperatures city is colder in April, May and June compared to its surroundings, while in October, November and December it is relatively warmer than the region. That happens probably because during the first warm months after winter, the materials of the city's constructions are already cold and they maintain this heat in contrast during the first cold months after the summer they maintain higher temperatures. Therefore, the city operates as a static heat accumulator which, depending on the sign being charged, emitting the corresponding temperature.

During the day, the temperature is affected by local microclimates, the natural cycle of land and sea temperatures, and less than urban factors. On the other hand, the minimum temperatures clearly reflect the phenomenon and finally it turns out that the high density and the heights of the buildings as well as the land uses greatly affect the UHI phenomenon in the city of Thessaloniki. It has been observed that the development affects the local climate. Consequently, the character and degree of development has a catalytic effect on the creation of areas with climatic conditions that are largely different from those prevailing outside the urban area.

It was observed that the minimum temperatures reflect better the "warm urban district" phenomenon on the produced images by the application of interpolation. That proves that the phenomenon takes place during the night in the city of Thessaloniki. In contrast, during the day, the temperature is affected by local microclimates, the natural cycle of land and sea temperatures, and less than urban factors. Thus, all year long, the maximum temperatures are formed mainly outside the city.

At both minimum and maximum temperatures, there are some areas that retain their own particular microclimates. General weather conditions affect the temperature of a region but the microclimate of a district can shape the area's climatic character. Thus, it can be observed in generated pictures with the maximum temperatures, the areas outside the city give higher temperatures due to the microclimate that can be shaped by local features such as the relief, the existing green, the orientation, and the existence of water.

The urban space attracts high temperatures and IHU phenomenon is more clearly reflected during the winter months. It should be noted that the temperatures considered, in this study, are air temperatures and the lower temperatures refer to the night hours in the daytime while the maximum temperatures refer to temperatures during the day, which depend on the heat of the solar radiation. Thereafter, the minimum temperatures more realistically reflect the existence of the UHI phenomenon, where during the night time, the natural (sun) and artificial (anthropogenic) heat sources are missing.

Land uses are a very important factor in shaping the city's temperature. Each of us has the relieving experience of being under a tree or in a park during summer midday. It is noted that areas with high density and heights of buildings but also under certain land uses such as dwelling and central city functions have the greatest contribution to the urban heat phenomenon, as in the main city, the Town Planning complex and the suburbs as well. That happens because these urban land uses provoke intense human activity such as buildings heating and cooling, heavy use of motorized vehicles, devices operation, incurred more heat to the environment.

However, on the zone area of Macedonia and Aristotle Universities' campus, military camp, city hall, there is a green area and a meteorological station recording the city's temperatures, so there is a detail of the temperature display, it is observed that in general temperature is entrained by the city's center temperature and in some cases curb the intensity of the phenomenon, but not in a strong way. Consequently, it is understood that the higher temperatures of the city affect significantly areas that should have lower temperatures.

The surrounding area of an urban area to a specific use, namely residential, forestry, agricultural, can critically influence the temperature of that urban area. In particular, large urban concentrations adversely affect the rapid "relief" of heat of an urban neighborhood within that urban concentration. While an area adjacent to forest or agricultural land is easier to get rid of the thermal load.

Urban density, building height and urban land uses play a significant role in the emergence and maintaining of the UHI phenomenon. During summer months it is observed in neighborhoods with high densities that there is an intensity of the thermal phenomenon as the air is not allowed to pass freely between the buildings and cool. Thus, the surface area of buildings acts as a heating accumulator that amass solar energy during a summer day and during the night it emits the excess heat in the immediate urban environment, creating this stifling feeling in the outer urban environment.

Nonetheless, according to images that produced by the minimum temperatures, it is observed that high temperatures are more pronounced in the areas where there are high urban density and building heights. Hence, it has been confirmed that the density of buildings, which refers to a minimum of free space in the urban space on narrow-width roads and large plots' coverage, is an important factor in the appearance and maintenance of the hot urban microclimate phenomenon configuration in a neighborhood. Consequently, the degree of building density is a criterion for degradation of an area.

Further, the building system plays a significant role in the way the phenomenon event. Hence, in building areas with a ubiquitous free building system and not so high (Konstantinopolitika), UHI values are as great during winter as there are larger losses from buildings that are free from all sides. While in areas with a continuous building system with the same heights (Malakopi) the losses during the winter months are smaller. Thus, a further conclusion is that the buildings do not have adequate thermal insulation and this is an important factor of city's energy degradation. Furthermore, the area of Ano Poli (Upper Town), which is within the study area and which maintains traditional forms of construction, low building heights but large urban density, is observed to maintain a microclimate of its own due to the construction or the formation of the soil (intense ground inclinations, South orientation towards the sea) but it does not cease to be significantly influenced by the hot temperatures.

The phenomenon of excessive heat in cities beyond the environmental degradation it can bring both economic and social degradation, as sultriness can become a deterrent to visiting a region and cause economic downturn. Hence, sultriness degradation of urban areas can be another urban phenomenon and cause additional urban problems. Thessaloniki, in a significant part, is energy-intensive, not because it is entirely dependent on electricity and use old systems of heating and cooling, but because its building stock is old in poor condition with many operational problems and cannot intellectually cover the new energy and quality of life emerging needs. Therefore, upgrading or even replacing them is necessary. In the future, the city of Thessaloniki appears to be facing many intense climatic challenges, such as the rise in temperature and water levels, and at the same time the dwindling of living conditions in the city due to the lack of green, basic infrastructure of a city (pavements, water supply networks, parks) and the low level of quality of the city's buildings. There is so much to be done to equip the city against these dangers.

Suggestions for improvement

The sustainable approach in a city's planning and design focusing on environmental quality so as to mitigate the urban environmental problems is now one way direction for facing a city's problems. Further adaptation is a main planning component as climate change has already taking place. At the same time the urban space ought to offer functionality, versatility and aesthetics ensuring to the residents safety, health, and prosperity.

The purpose is the conclusions that will be drawn from this work could be proposals to be incorporated into the institutional framework governing the way of building and urbanization for the future avoidance of the phenomenon. Thessaloniki's urban environment and energy upgrading should become within a holistic framework for the development and not with unilateral proposals, as it has been shown in practice that way of addressing issues occur often to be the most expensive ones and without the expected results. Hence, the chosen interventions in Thessaloniki city have to be applied in all three levels of planning: urban planning level, urban design level, and buildings design level.

Urban planning level

In urban planning level though, it is important, from an energy point of view, the transporting system to be energy efficient and non-polluting, to have mixed land uses and functions and variety of the built environment, in a high occupancy density creating a compact settlement structure that is energy efficient, with sustainable use of resources (minimum exposure to thermal charges). The urban mobility should reduce private car use promoting sustainable urban transport systems. Reducing the circulation of motor vehicles in the city mitigate pollution and heat production. It should be adopted such as bike paths, pedestrian paths, clean public transport, charging points for electric vehicles, etc. The width of big streets should be reduced while the necessary configurations will be done for green development, pedestrian movement, bicycles and cars. Moreover, preventing car traffic within the city either with parking fines or urban tolls (London and Stockholm) can be a quick solution. Changing the use of roads in pedestrian streets and redeveloping them in green infrastructures.

Decentralization of heating and cooling production systems outside the urban space promote the district heating and cooling. The district heating and cooling is a good solution for cities when the desired is not to burden further the city center with extra pollution. A central boiler will be used and from there will be hot or cold water diverted through underground pipelines. It is an ecological and economic way to offer the required internal conditions. The production is done by a fuel consisted of various combustible raw materials produced or imported by an area (oil, lignite, natural gas, biomass, waste, industrial waste heat, etc.). Ongoing sales price of thermal energy is much lower than the conventional. With the present increases in oil prices the cost of heating with district heat is below of 50% of the respective heating oil costs (WWF). It is considered as a successful investment as in other cases the cheap pricing immediately attracted the citizens of the areas applied in France, Denmark and Sweden.

Technologies that promote a clean and smart way of living as a solar car station can provide refueling with "green" electricity to electric vehicles in order to operate ecologically. According to the British Association for Environmental Transport each square meter of photovoltaics per year is equivalent to one barrel of oil. It is an excellent business idea that supports the profitable service and further development of the tourism industry. The income generated from electricity production will be used essentially to finance the repayment of the Solar Position Park, leaving a significant extra profit to the investor who thereby obtains free shaded infrastructure for cars. (Parksol).

Governance and policy are both very important keys to communicating and implementing change as they should mobilize people for voluntary actions and find a positive response and involvement from the urban community. Policies should also organize urban innovative actions to upgrade the urban environment by promoting eco city in combination with technology. Usage of innovations in technologies and practices such as volunteering, time banking, and cyclical economy can help indirectly in addressing increased heating in the city, as reduce the increased energy consumption and actually contribute to reducing the effects of climate change.

The continuous building system is more energy efficient because of the compact nature of buildings with fewer exposed surfaces in the solar radiation and in the open air. Maintaining human scale in design, buildings should not be disproportionately high in relation to the width of the streets; creating urban ravines that cannot de facto be sunbathe and properly ventilate the buildings and the road itself.

The sustainable urban development is the main pillar for the city's problems and climate adaptability but further the implementing new technologies and promoting the Smart city can significantly improve costs and energy consumption. Hence, the natural environment is protected by minimizing the energy required and the urban environment will earn the required quality resulting from the use of the systems.Moreover, changing land uses and urban functions where this is necessary so as to reduce the UHI effect, and where this is not entirely possible, the mix of land uses is a solution with integrating GI in the city.

Promoting underground buildings so as to have the energy benefits because of the minimum thermal loses and their top can easily use as green space and be a GI. May be in a formed city is difficult to construct because of the maximum building exploitation will be need big natural surface inclination but it can be a unique good practice example. Promotion of using galleries in urban buildings that will unify the back yards of the building blocks with the front public space can convert them into "semi-open" gardens could be an excellent solution environmentally aesthetically, and socially.

It is necessary to do enhancement of city's natural environment with GI integration that is physical elements applications, nature-like, creating an infrastructure that works for nature's and community's benefit. "Incorporating GI into the urban space is gaining popularity as a cost-effective and long term measure for mitigating climate change impacts associated with proliferating grey infrastructure globally" (CABE, 2010; Hamdouch and Depret, 2010; Llausàs and Roe, 2012; MEA, 2005; Schäffler and Swilling, 2013; Thaiutsa et al., 2008 from: Tiwary, A. 2014).
City upgrading should be done through redevelopments involving technical projects that will promote the microclimate of the area, aesthetics and operation with the installation of GI. Urban green should be strengthened by promoting GI in the legislative and technical field as "green urban infrastructure has been indicated to reduce the effects of climate change in urban areas, providing thermal comfort by shading vegetation" ((Krasny and Tidball, 2009; Cameron et al., 2012; Farrugia et al., 2013), from Demuzere M. et al, 2014). GI can be combined with existing Gray Infrastructures.

Urban design level

The urban space becomes interesting and acquires an identity by the elements that compose it. The urban design is the tool that it can upgrade the urban space with bioclimatic principles of the surrounding space aiming to improve the microclimate and ensuring appropriate conditions (thermal, aesthetically and safety) of public space in order to make it more pleasant, utilitarian, and sustainable, ensuring quality in the city. Tackling the heat island effect in Thessaloniki can be done by improving the urban environment, the use of cold materials and vegetation and the reduction of anthropogenic heat and pollution emissions. Improving the microclimate of

Thessaloniki’s urban area through redesigning appropriate city’s urban parks, sidewalks, pavements, un-build plots, open-air shading systems of urban space.

Vegetation provides shade, evaporative cooling and improves thermal comfort. Trees’ shading is able to reduce a surface temperature, so planting extra trees seems to be a good practice because of reducing ambient temperature in summer. Deciduous trees provide shade in the summer, allowing winter insolation of space and buildings. Generally the trees can act as a protective barrier against unwanted winds or can redirect the desired winds in favor of summer comfort. Creating many scattered green spaces with their integration into an extensive green network parallel to the roads, significantly increase the amount of green in the city. That linear urban green areas along the operating roads can create a linear park form which will have a dual role, on the one to isolate the street visually and acoustically from the sidewalk and bikeway, providing security and tranquility to pedestrians and on the other hand it will consist an important green space for the city offering all the benefits a park provides to its users.

Additionally, the uncovered areas of land behind the buildings, in principle are incorporated and made accessible to residents and are properly configured to form neighborhood socialization spaces and accommodate land uses and functions as an urban park (green), garbage collection area, air cooling system installation space etc.

Evaporative cooling in the urban public space is an option that should be adopted in order to regulate the area's air temperature, especially in summer using a bioclimatic method. The process works when the air is passing from a water body, causing its evaporation. The air then is cooled and enriched with water vapor. The direct natural cooling techniques that can further to be applied in a city are fountains, artificial streams in the park areas and the buildings’ courtyards. Since the study area is located close to the waterfront, the sea breeze will help in the cooling of the area. To enhance the cooling of the city by the use of water it was selected in the new city’s shaped public spaces, to contribute to the reduction of the air temperature by cooling due to evaporation and by contact of hot air with the cold surface of the water

Using integrated photovoltaic (IP) elements, have excellent results in both ways, gives us the opportunity to have useful elements in the public space of high aesthetics and to produce green energy without consuming valuable urban space with the solar systems. IP can be on the public lighting, solar pergolas in urban or private spaces, along the pavements as canopies of transport stations. Using photovoltaic systems for energy production and public space lighting, it can be achieved a reduction of anthropogenic heat and consequently the decrease in air temperature.

The colors of the buildings and the materials will be in the range of light colours to enhance the reflectivity of heat. The reflectivity of solar radiation and the emission factor, offer a significant contribution to the city's energy balance. The use of materials with high reflectivity has the effect of reducing the amount of radiation absorbed by the building envelope and urban structures. The high emissivity materials easily release energy absorbed. Cold materials should be placed both in public urban areas and in private spaces, so as to minimize the phenomenon of urban heat island effect.

At the same time, passive cooling systems can be used for both buildings and for public spaces. Earth to air heat exchanger has very good effectiveness to cool the air in summer, using the ground - where temperature is lower (heat sink). The system consisted of a pipe system placed at a depth of 1-3m. The air is introduced either from outside or from inside the building, circulating in the pipelines with the use of fans and enters the building at a lower temperature. At the same time, it can operate in winter, helping to warm the cold outside air. It can be combined with an air conditioning application, contributing to saving energy for cooling and heating of the building by reducing the temperature of incoming-outgoing air gap from the system, thereby reducing the necessary capacity of the system and the energy it consumes. (CRES). This system can also be applied in public places (Peristeri case study, upgrading of open public spaces bounded by the streets: Ioannina, Pefka, Imathia-Cactus, Kedron & Fintikakis, N., et al, (2011), Tirana research)

The proposals in urban design level are:

- Upgrading-Redesign the existing open spaces (squares, streets, gardens, groves, islets, courtyards)
- Implementation of green and GI
- Use appropriate coating materials (cold)
- Use structures to shade urban space (pergolas etc.).
- Promoting a holistic-bioclimatic design with adaptation to the local climate.
- Implementation of solar panels in the public space
- Revision of the legislative framework on urban interventions to promote bioclimatic planning
- Mandatory Certifications with the LEED_Leadership in Energy & Environmental Design in Urban Design constructions with the LEED AP Neighborhood Development.

Buildings design level

The improvement with appropriate reconstruction and improvement interventions of the existing building stock will upgrade directly the formed urban environment. The buildings upgrading with energy interventions is an important aspect on ensuring the effectiveness resource efficiency. Ensuring the energy efficiency of existing and future buildings, which is both global and European priority, as the buildings consume 40% of the final energy, energy economy is promoted. The renovation of the existing building stock can have an important impact on energy efficiency of buildings and improve the quality of life of the residents and users.

Improving the performance of buildings has resulted in the reduction of operating costs both for the tenants of housing and for business. Buildings ought to be upgranted with implementations such as, thermal insulation so as to block heat transfer to the outside urban area in winter wasting energy, improved opening characteristics with low U-value and high air tightness, green roofs, shading systems and regulation of sun lighting using permanent external shading systems (architectural ledges, porticos, shadings, overhangs) and even moving shading depending on the orientation (vertical blinds on south-facing vertical blinds on the east and west). Further, double energy shells and planted walls on parametric surfaces of buildings in addition to thermal insulation is a good practice. Incorporating solar sites-greenhouse in continuity with the building improve peoples' living conditions. Use vegetation either with appropriate planted deciduous or evergreen trees or using climbing plants in appropriate positions (East-South-West), on pergolas.

In addition renewable energy sources will be used such as passive solar systems (elements of bioclimatic design) for heating, cooling, and lighting. The integrated energy upgrading of buildings, the design in the direction of energy saving and improving thermal comfort is an essential element of the project, so the buildings are (almost) zero energy balance and minimum carbon footprint by incorporating:

Reduction of heat loads using sunshades, cool materials of high reflectivity coefficient surfaces and other sun protection systems, installation of natural cooling techniques by radiation and evaporation applications. Further, the use of openings for natural ventilation of the interior of buildings and ensuring the best night ventilation conditions is another bioclimatic way of cooling. Natural ventilation is performed by appropriate designing of the openings in the shell and internal walls and when there is no opportunity of moving openings then will be installed lockers in the upper and lower part of the dividing interior walls that allow the movement of indoor heat air to outside and introducing fresh cold air into the interior.

Should be promoted energy-efficient electromechanical installations (heating, cooling, ventilation, lighting) and especially renewable energy sources for heating/cooling (individual solar thermal systems (or centrally embedded in buildings or groups of buildings), solar cooling systems, geothermal heat pumps). Moreover, renewable energy sources ought to be integrated in buildings or in the surroundings (photovoltaic systems integrated into buildings and small wind turbines suitable for the built environment) for electricity.

Taking into account that building stock will be maintained and that there is very little potential of passive solar systems application (solar walls, solar spaces-greenhouses, solar patios and passive solar systems of isolated gain, solar panels outside the building envelope), since there is a space crunch, not everywhere good orientation and weakness of adequate insolation, the design team turned to the application of energy production systems, which can be integrated into the building and do not occupy valuable urban space.

The vegetation acts as a natural air conditioner for urban areas as it shades the buildings blocking the absorption of solar radiation inside. This results in better conditions of thermal comfort and reduces energy consumption for cooling.

The use of fans, especially the ceiling fans, enhances the natural ventilation feeling with minimal power consumption. In practice, the use of ceiling fans reduces the need for manual air conditioning systems for many hours per year. Another cooling way is the ventilation chimney (airways) utilizes the natural draft effect, since the hot air is conveyed upwardly and thereby creates a stream within the spaces in combination with suitable openings of the building. When there is not a strong current of air around the building, the system can be operated with a fan, which is integrated in the upper part of the chimney, ensuring continuous alternation of indoor air. Additionally, in areas with strong winds aeration towers can be applied which significantly protrude from the roof of the building, bearing openings to the major direction of the wind and are able to "capture" the cold air flows and to direct them into the conditioned space, aided by a fan. Thus, the buildings’ stairways could be converted into ventilation chimneys.

Application of new technologies in buildings (Smart Buildings) will provoke the required energy saving and will improve the quality of life of users. At the same time, the BIPV (Building Integrated Photovoltaics) systems have excellent results in the aesthetics of space as they can also shade, walls, as pergolas on terraces, glazing and other elements of the façade are a good solution for energy upgrading. Enable the solar energy of the roof, facade sunshades and transparent glazing. Hence, it is possible to exploit surfaces that otherwise would have no utility and we convert those areas into green energy production units.

The thermal protection of the building envelope is very important and beyond the insulation it can be accomplished with the application of a green roof. Usually green roofs consist of a layer of vegetation, which grows in a special plane, wherein the construction and the plant selection depends on the type of roof and also on the climatic conditions of the area. Interesting is not just having non accessible green roofs on the buildings but to form urban vegetable gardens on the terraces, which can be spaces with versatile uses, offering thermal protection in both winter and summer. Thus, the roofs of buildings, which are a large unexploited and inaccessible currently places can become green roofs, where vegetables will be cultivated by the residents of the each building. The vegetables to be produced will be consumed by themselves. So on the one hand the requirements for green roofs will be covered having green benefits, and on the other hand, offer occupation to the residents, who will grow seasonal vegetables for their household, having indirect economic advantage and an opportunity to socialize. Consequently, promoting urban gardens on the buildings roofs and on uncovered plots of land, through legislation seems to be a good idea.

Using reflective materials beyond public spaces - sidewalks - squares can also be used on roofs and facades of buildings. Specifically cold materials can be used, in building shells in coatings and dyes (photo catalytic high reflectivity coefficient paintings-mixed with titanium dioxide).

Epilogue - A last word for the city.

Cities are not simply a set of buildings, but are much more. Planning cities and buildings should be intertwined to ensure easier deal of issues, to improve the daily lives of residents. It should be ensured a pleasant environment by meeting the appropriate hygiene and aesthetic conditions but at the same time ensuring the necessary elements for the daily lives of the residents such as the energy.

Energy is essential and ensures the high living level; in particular the energy produced in a sustainable way is one that ensures a clean environment to live. The energy planning should be incorporated in the planning and design procedure of cities and buildings, in order to strengthen the sustainable development both for city and for society and to ensure a high living environment benefitting the users. After so many mistakes in the urban planning and design but also many examples of good practice we ought to change our thinking way about the city and not just the way we practice.

Many years now scientists are discussing the sustainability and the development that can come through them and many examples around the world have been made. Unfortunately it is still treated as an ideal condition and not as the reality for the majority of applications. This fact should trouble equal scientists, politicians and users. I hope in future cities to eliminate the negative environmental image and become life shells for people and their ecosystem, where there will be a real good quality of life with low energy or even zero energy indexes.

This study dealt with the phenomenon of urban heat island with study case the city of Thessaloniki. The main conclusion of this, as well as many other studies dealing with the issue of the city, is that there is a connection to the city's issues. One drags another. All conclude that the problem-solving formula is common to all; therefore the city should be dealt with in a holistic way that solves the problem fundamentally rather than rough and superficial. Hence, the present research will continue with the focusing of the UHI phenomenon in the city of Thessaloniki, with the aim of deepening the study in its parameters, its impact on the population and finally its treatment.

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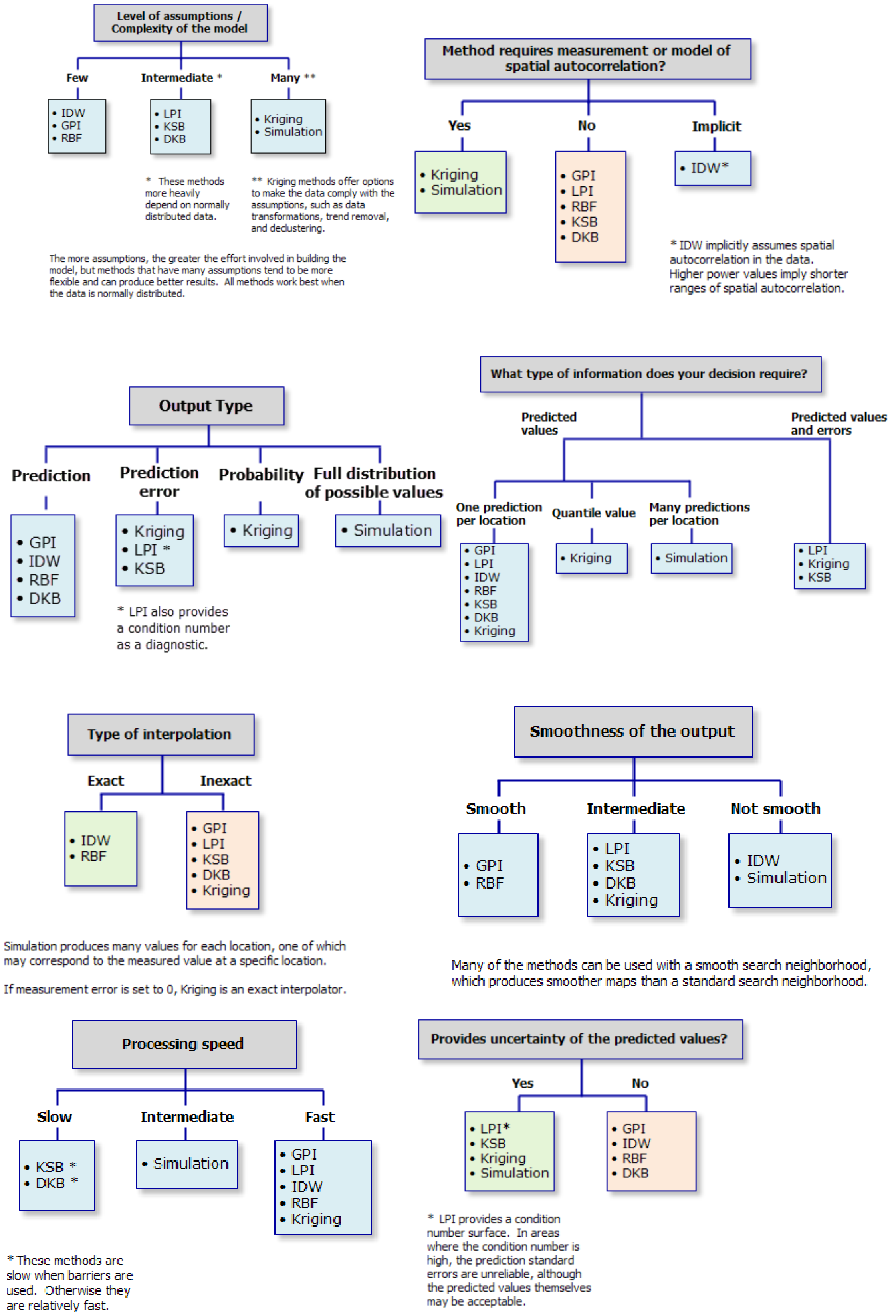
APPENDICES



Diagrams concerned interpolation ArcGIS characteristics.

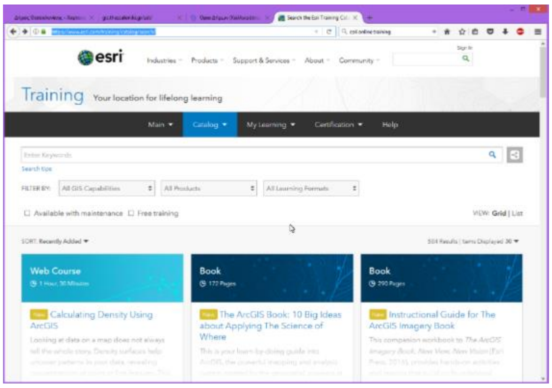
(Source: ESRI)

The classification trees use the following abbreviations for the interpolation methods:

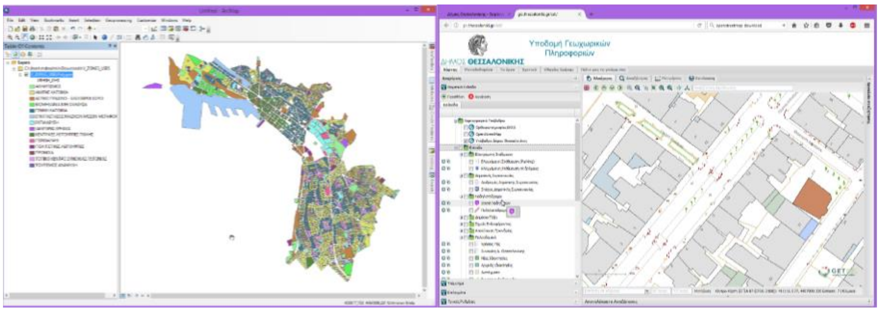
Table: Abbreviations for the interpolation methods.

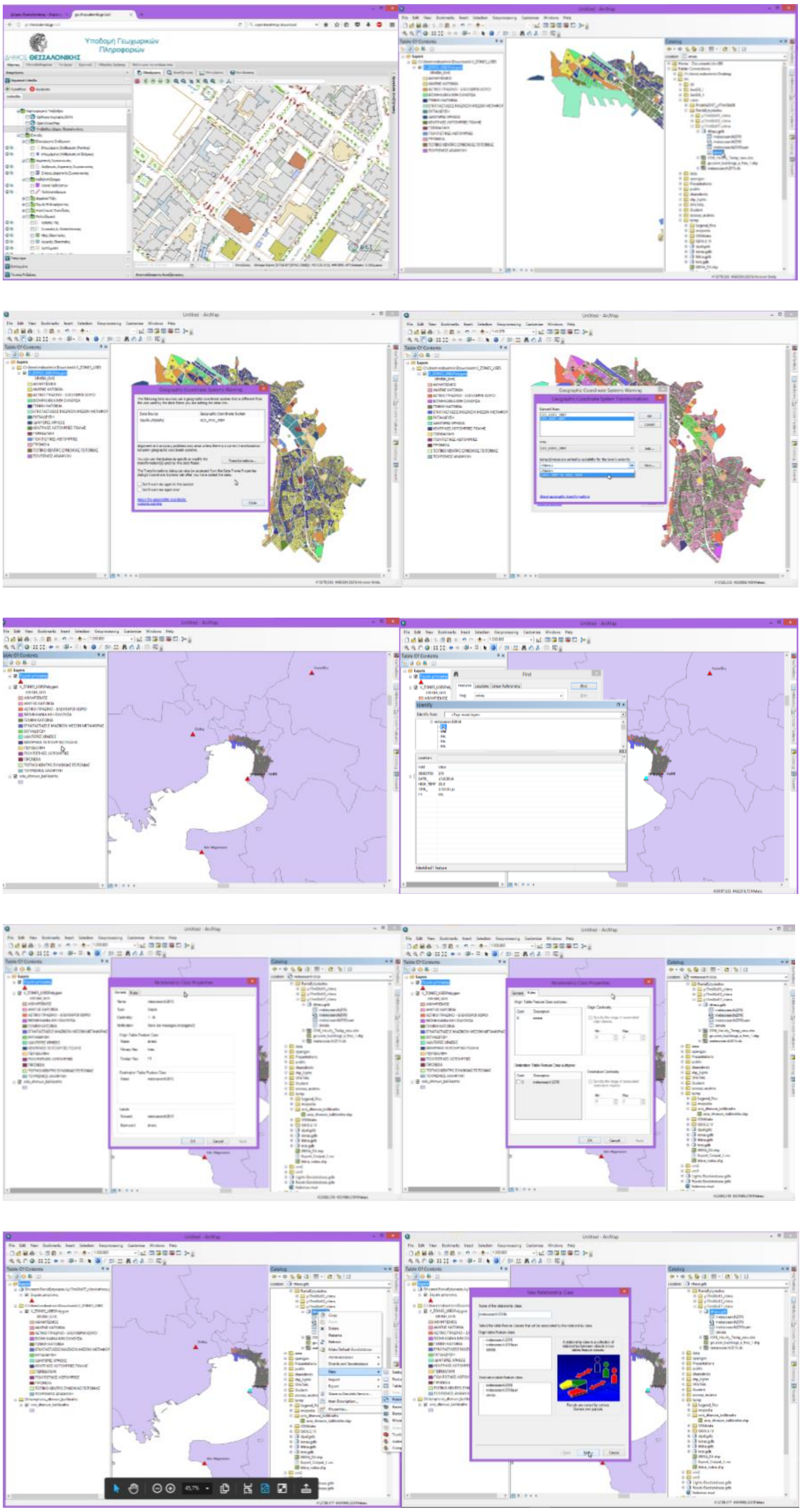
Abbreviation	Method name
GPI	Global Polynomial Interpolation
LPI	Local Polynomial Interpolation
IDW	Inverse Distance Weighted
RBF	Radial Basis Functions
KSB	Kernel Interpolation with Barriers
DKB	Diffusion Interpolation with Barriers
Kriging	Ordinary, simple, universal, indicator, probability, disjunctive, and empirical Bayesian kriging
Simulation	Gaussian geostatistical simulation, based on a simple kriging model

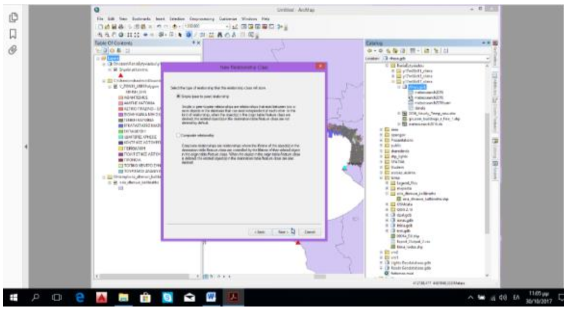
(Source: ESRI)

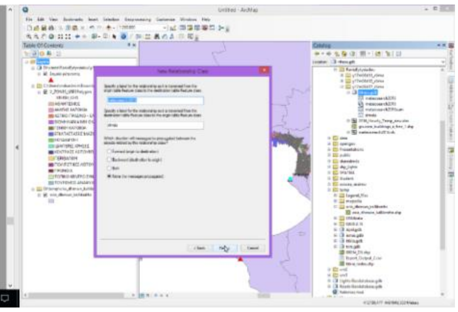


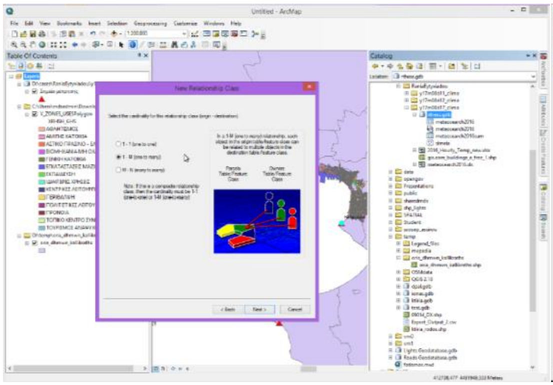
Esri site.

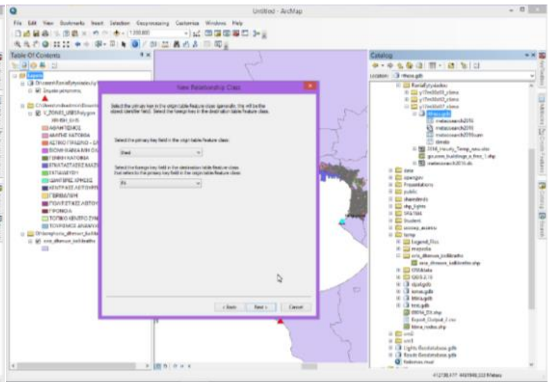


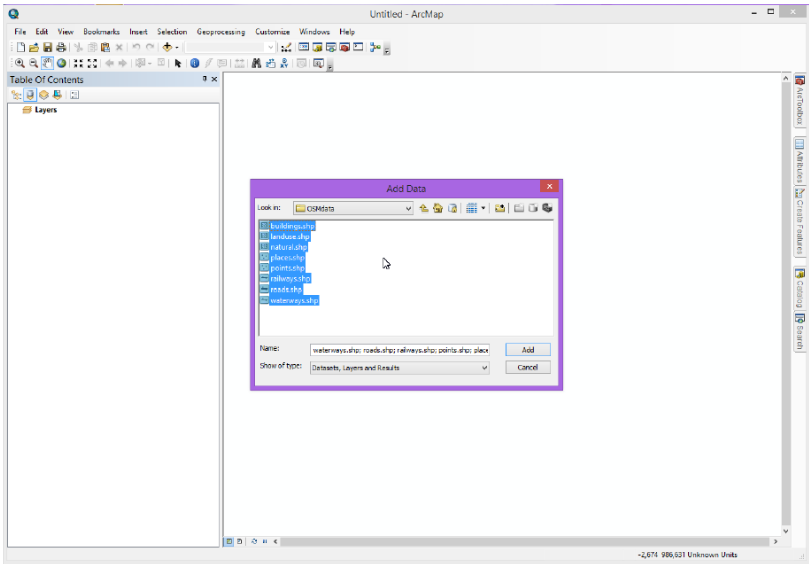








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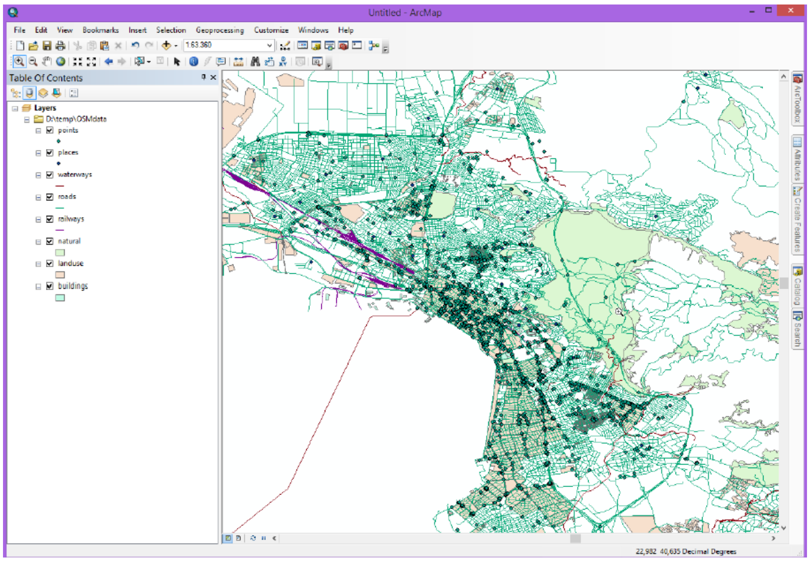
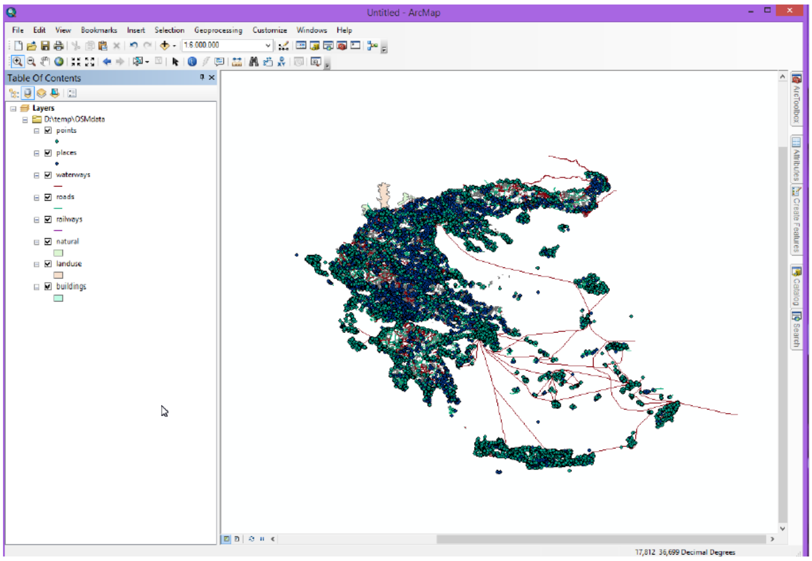
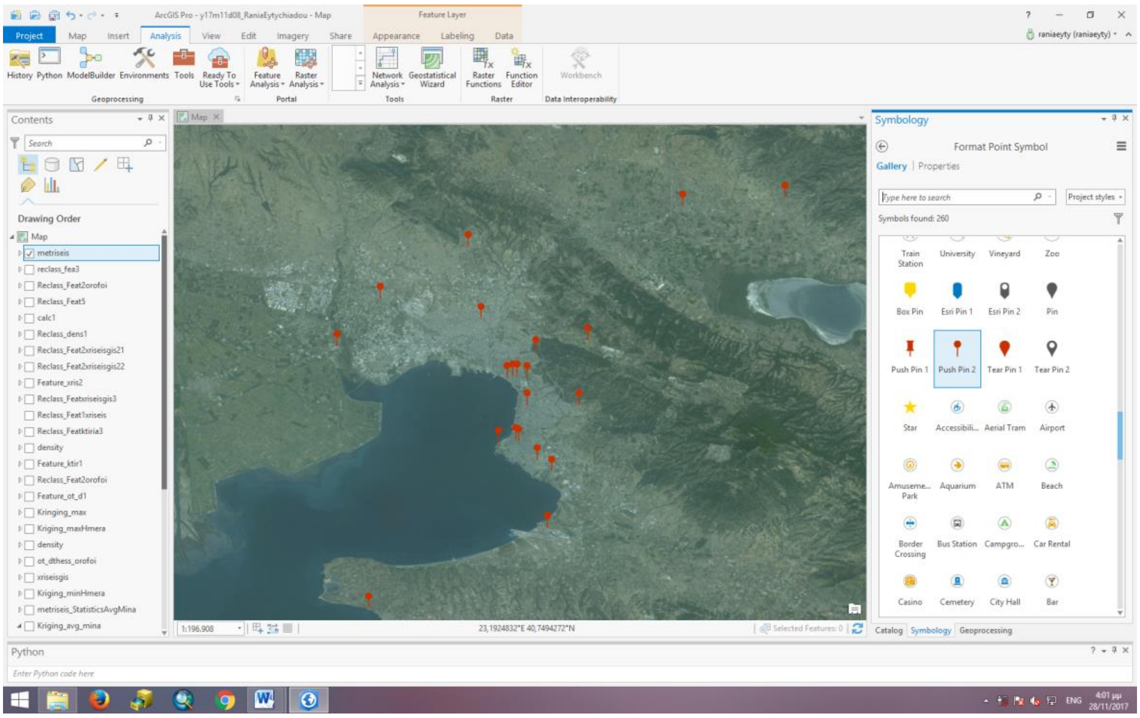


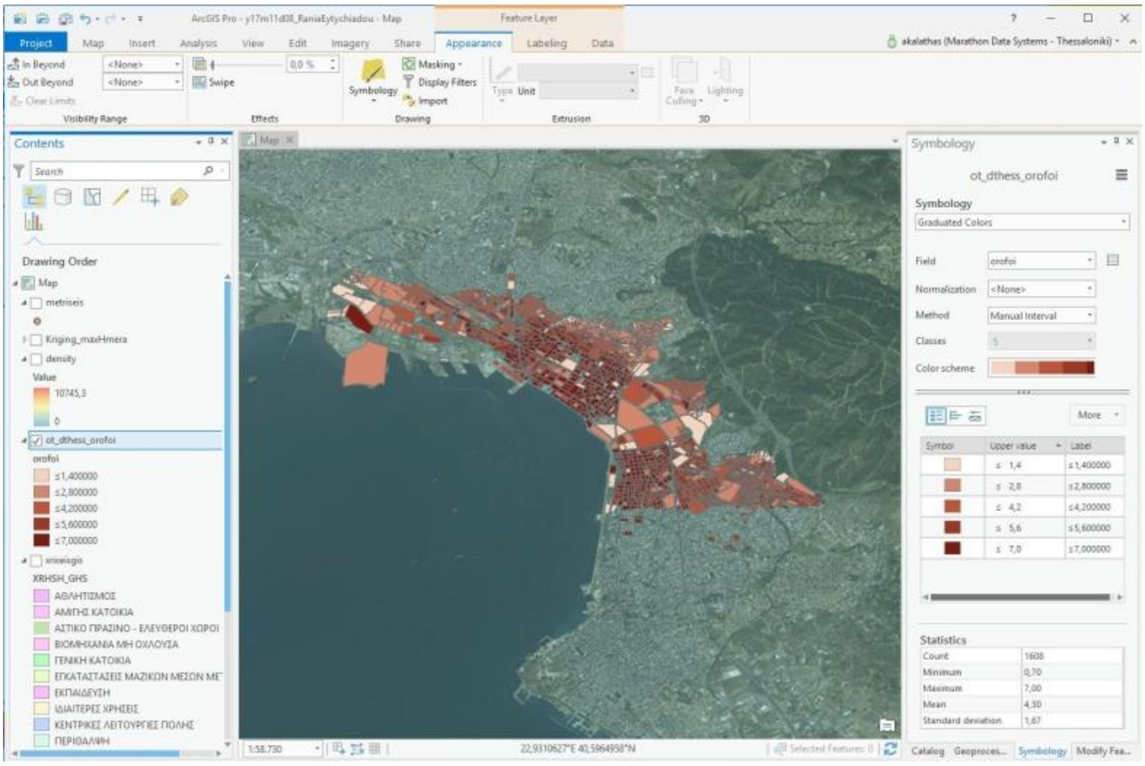


Land uses downloading from Municipality Thessaloniki’s site.



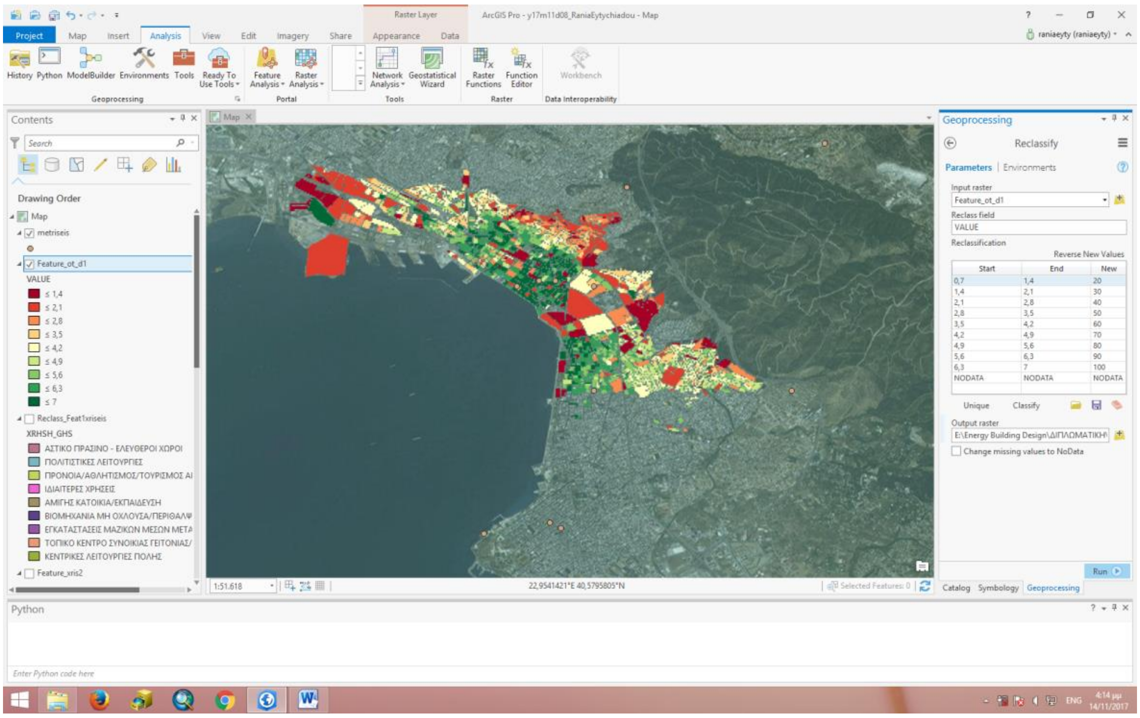
Meteorological stations location.

(Source: Own editing)



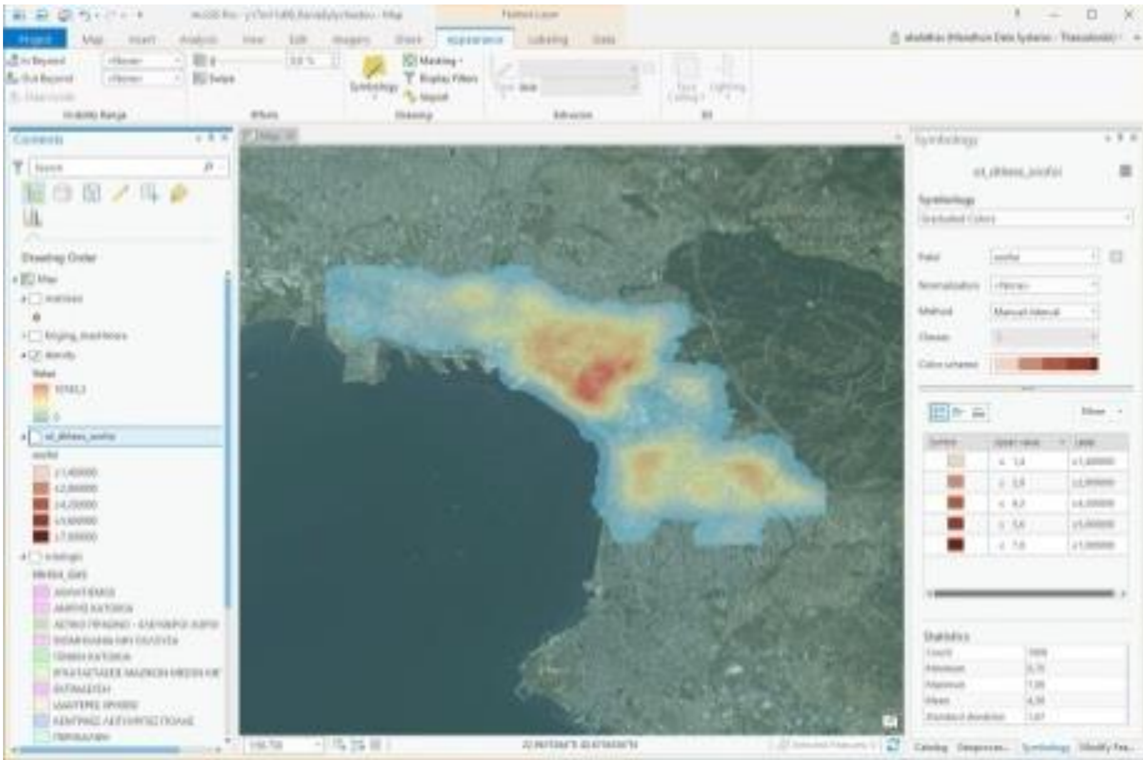
Building's heights in Thessaloniki's city.

(Source: Own editing)



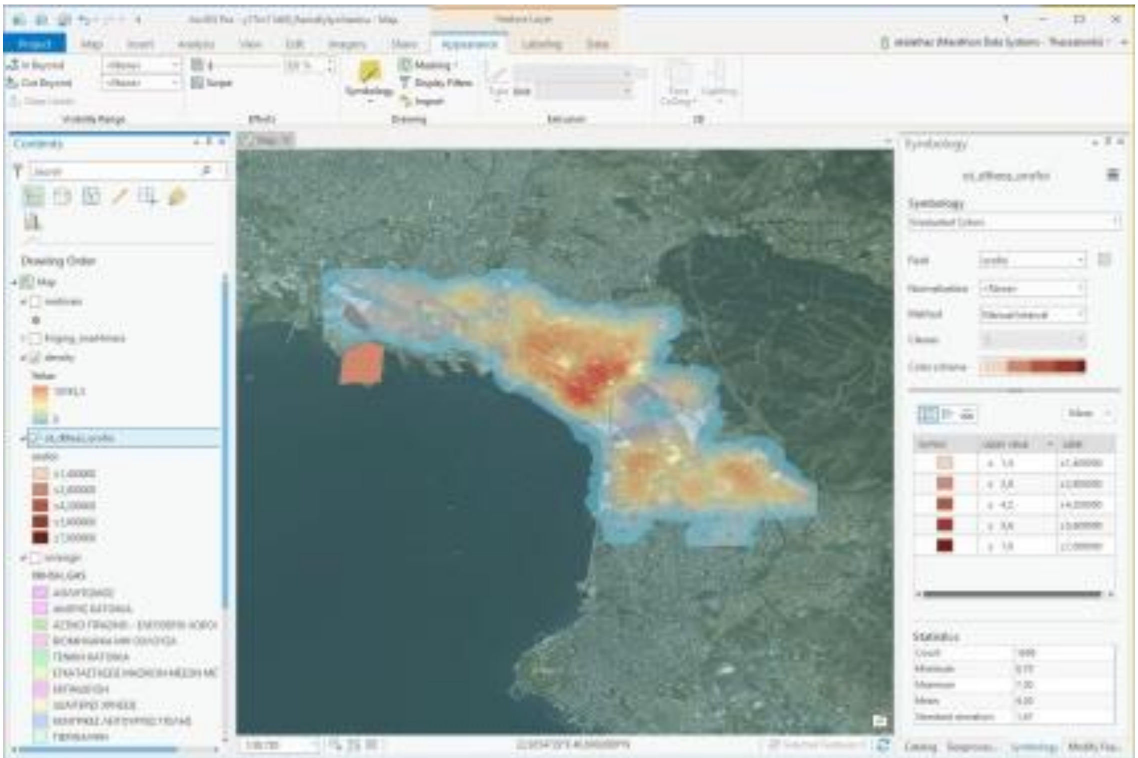
Building's heights in Thessaloniki's city.

(Source: Own editing)

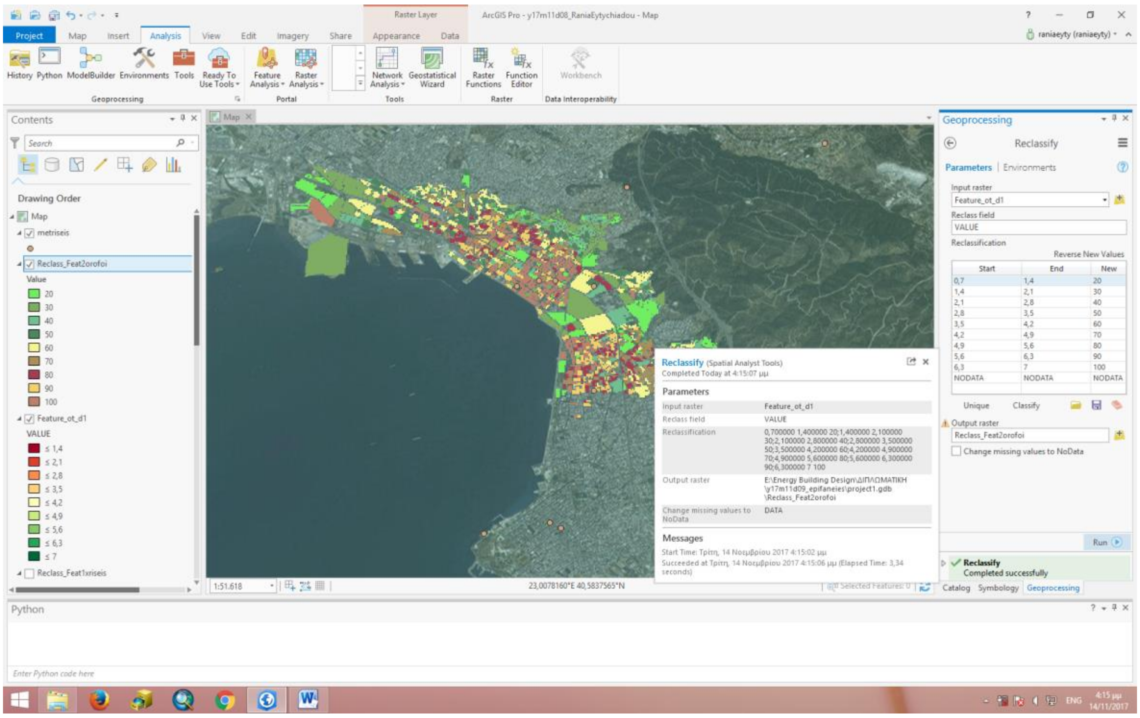


Thessaloniki's Building Density.

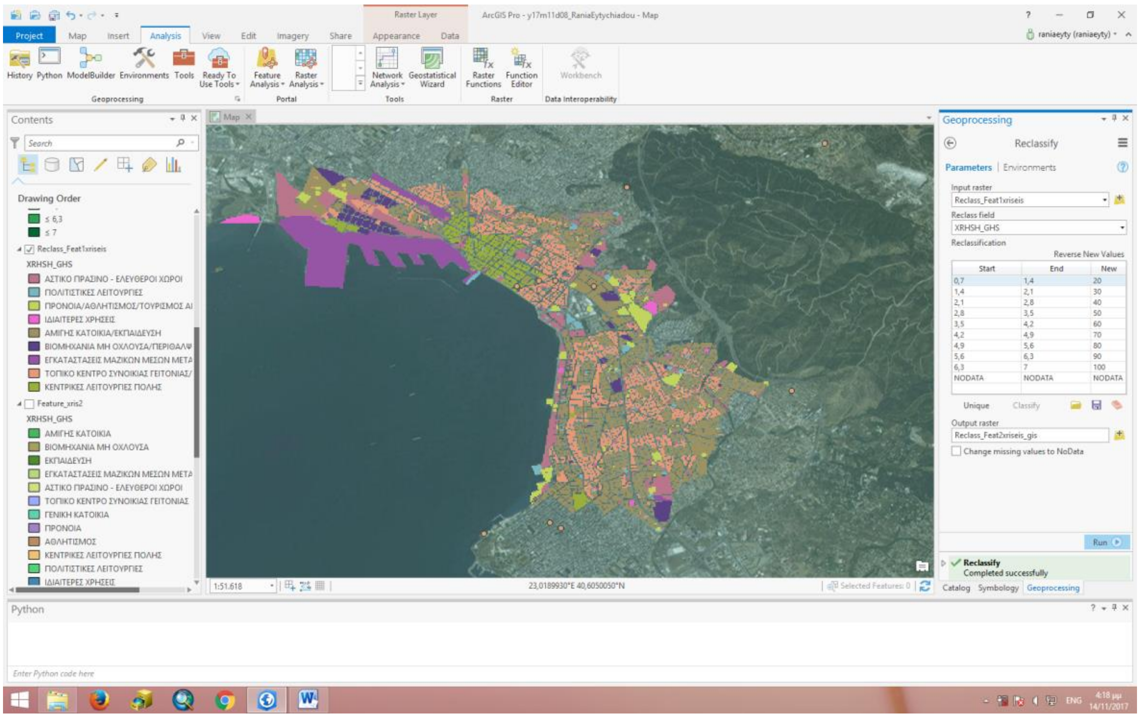
(Source: Own editing)



Correlation of number of floors per building block and building density.
(Source: Own editing)

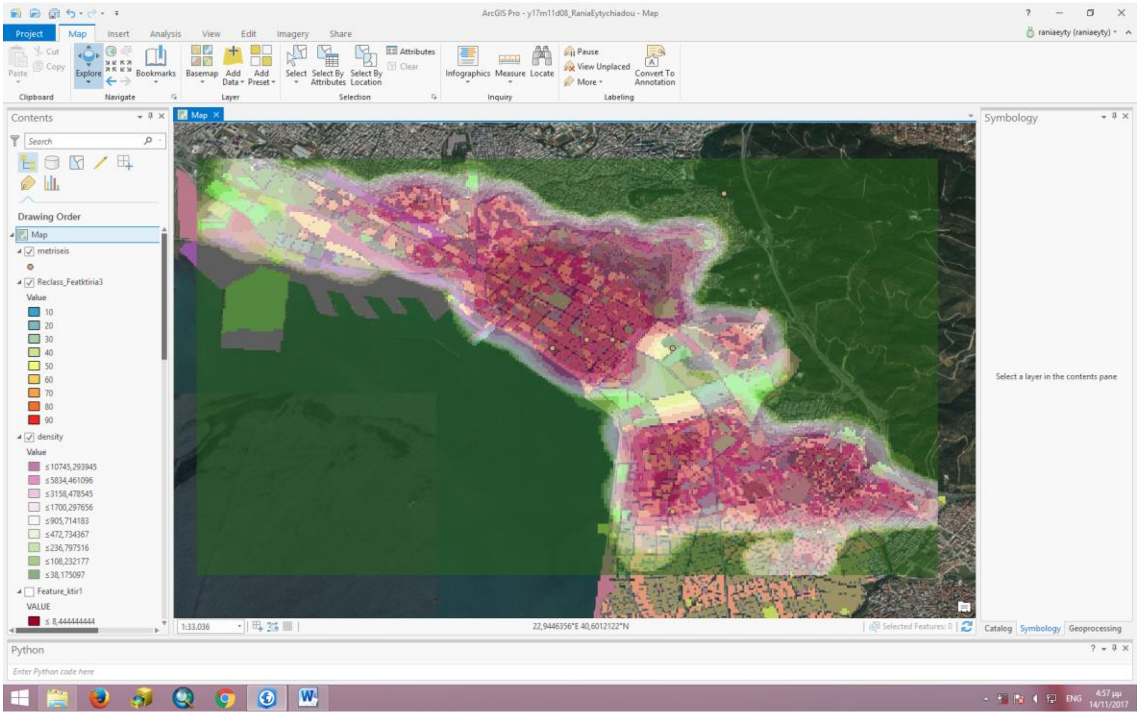


Reclassify the buildings height.
(Source: Own editing)



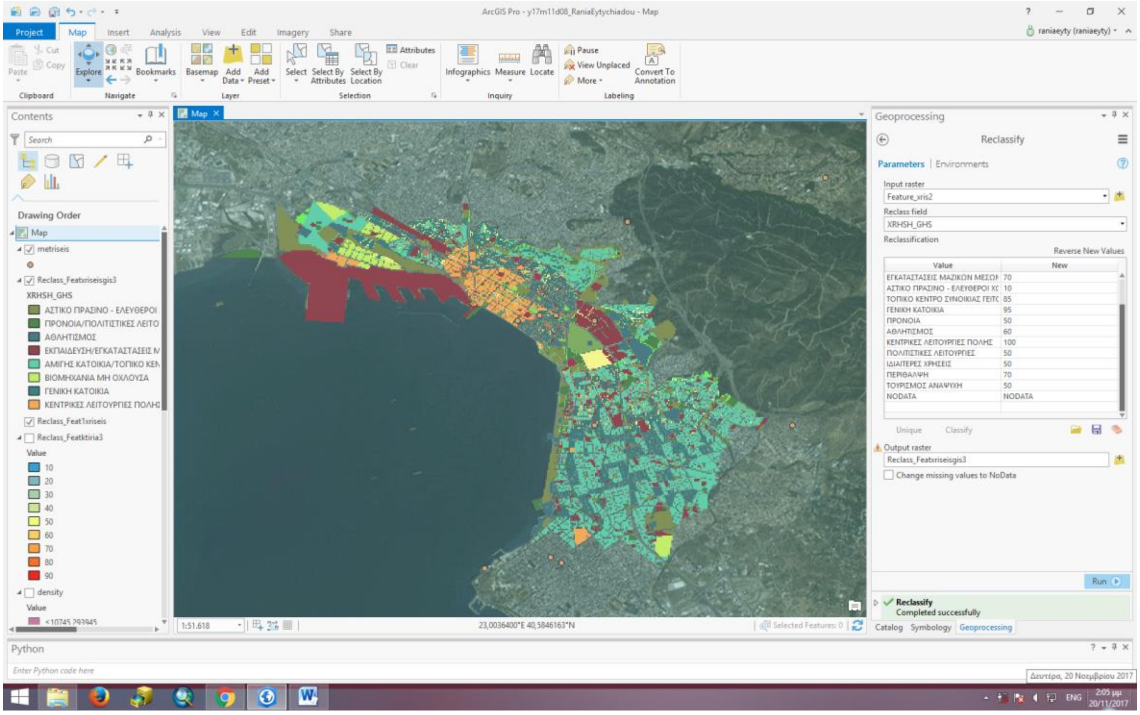
Reclassify the land uses.

(Source: Own editing)



Correlation of reclassified buildings height and density.

(Source: Own editing)



Reclassify land uses.

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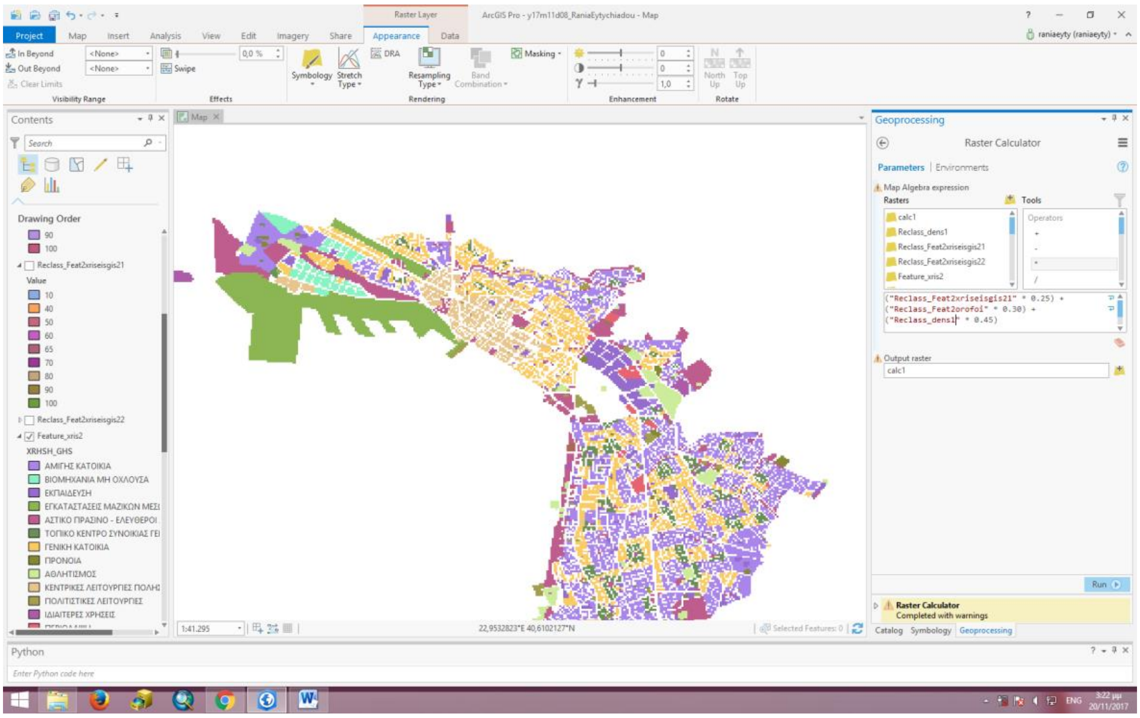
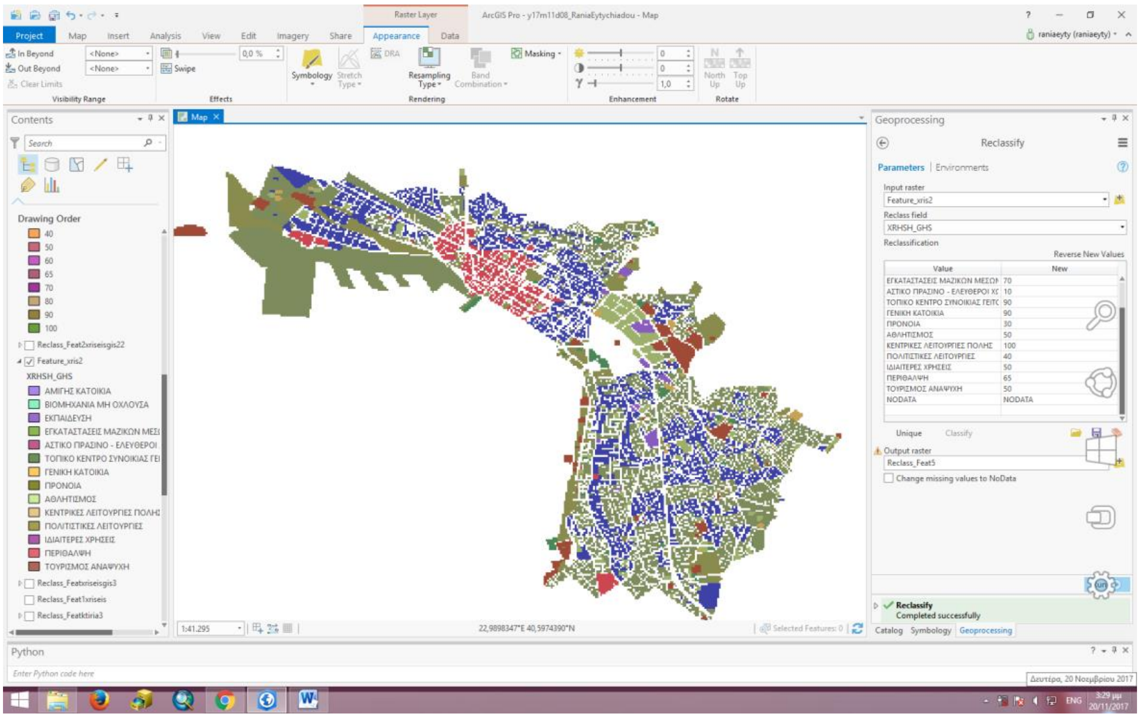


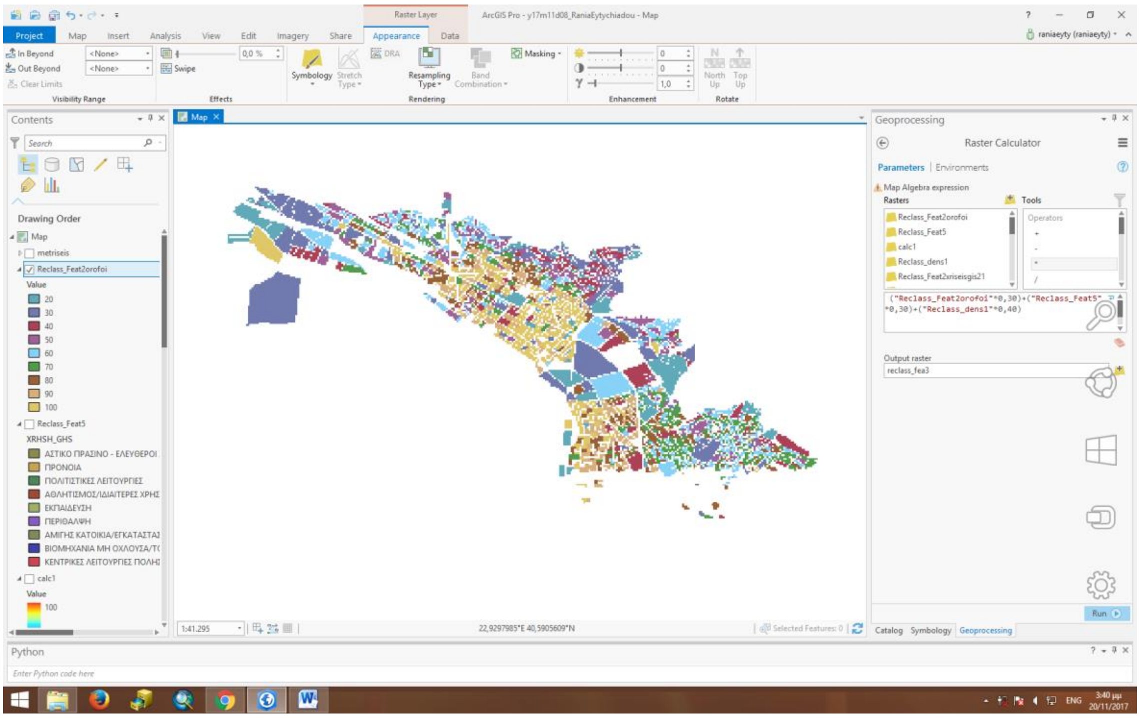
The result of adding the reclassify surfaces to the gravity ratio (1st try).

(Source: Own editing)



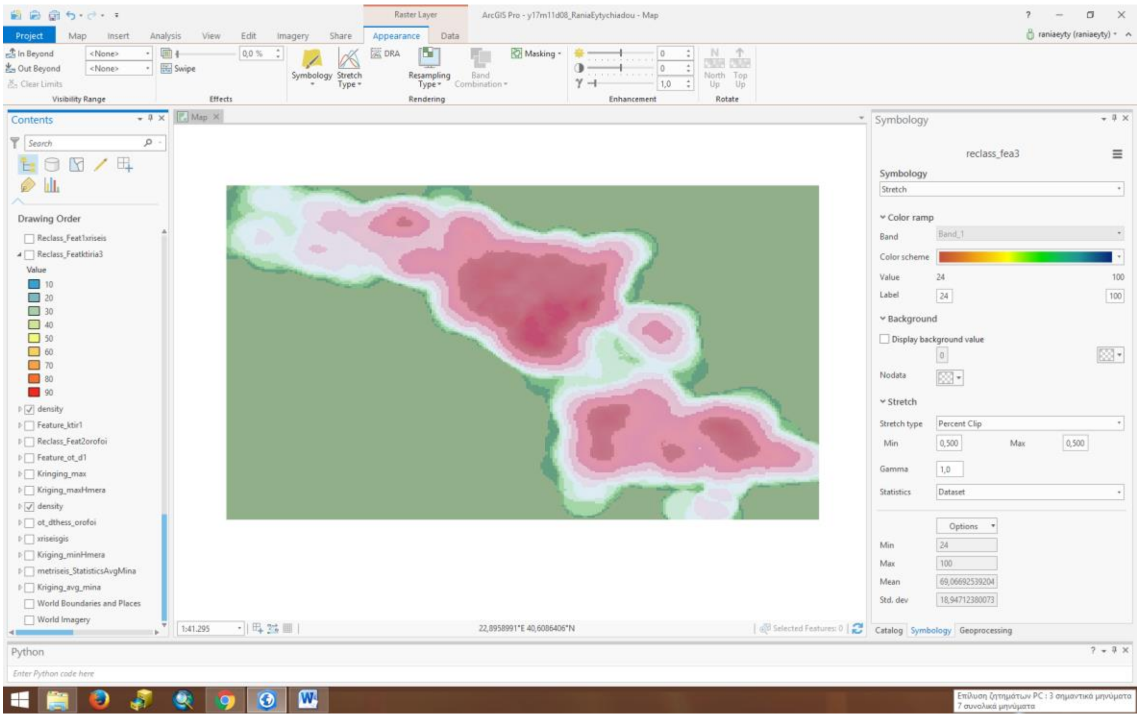
The result of adding the reclassify surfaces to the gravity ratio (2nd try).

(Source: Own editing)



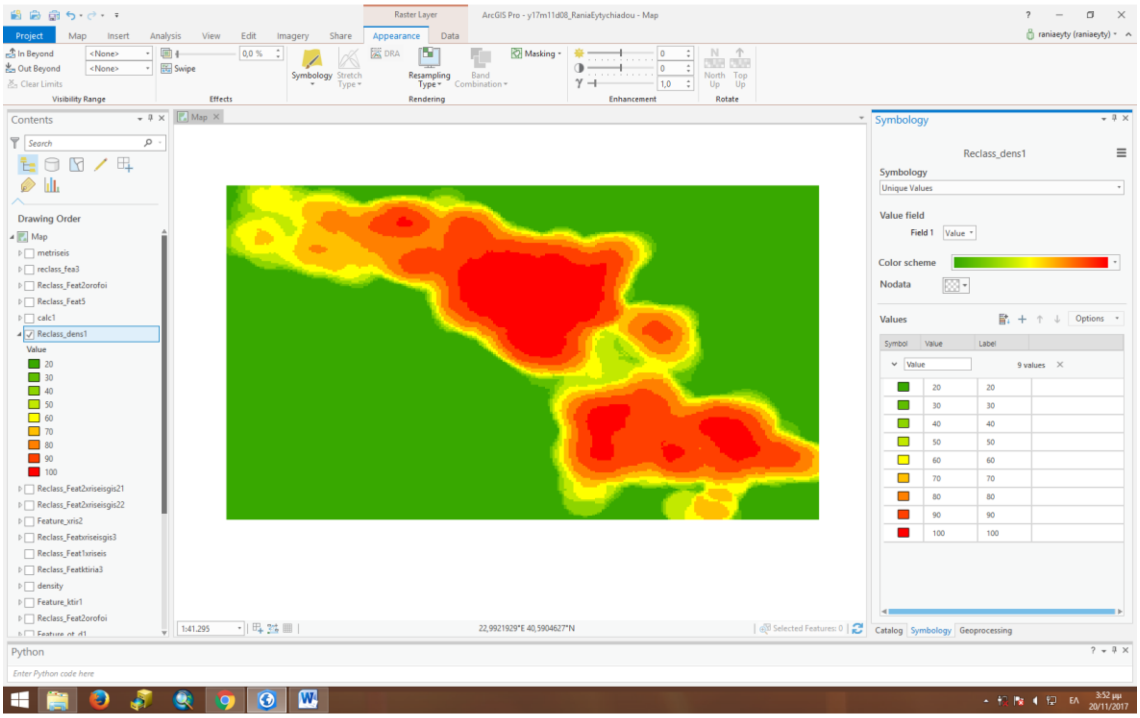
The result of adding the reclassify surfaces under the weight ratio buildings height in UHI (2nd try).

(Source: Own editing)



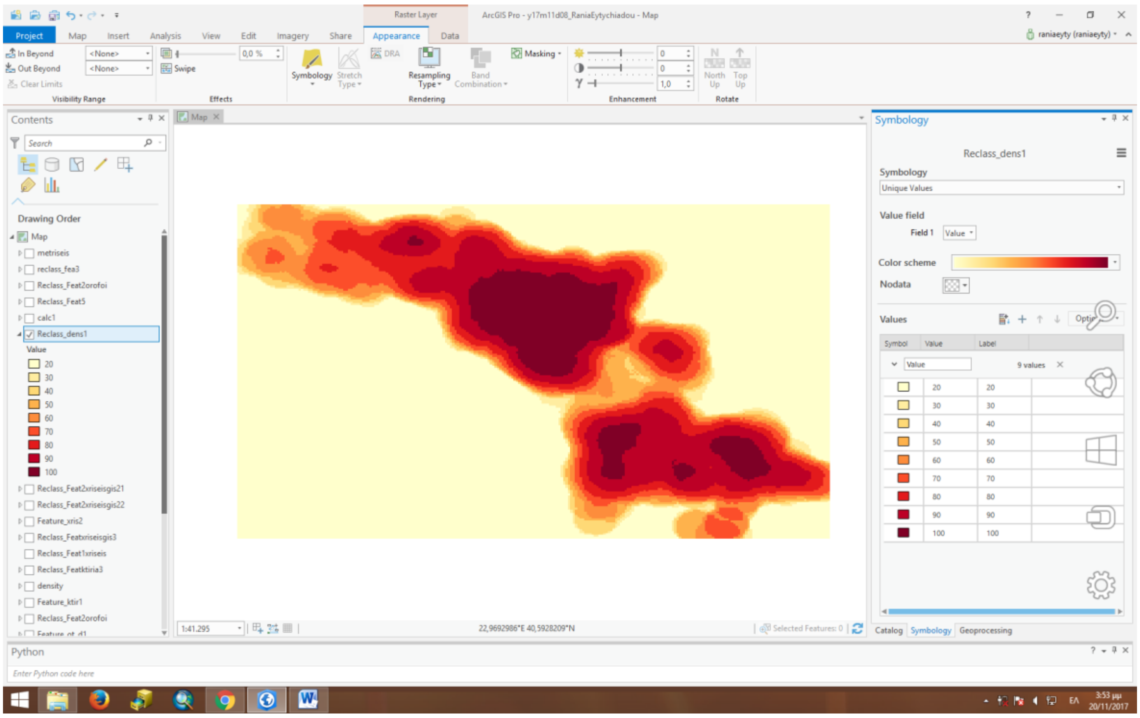
Building density weight.

(Source: Own editing)



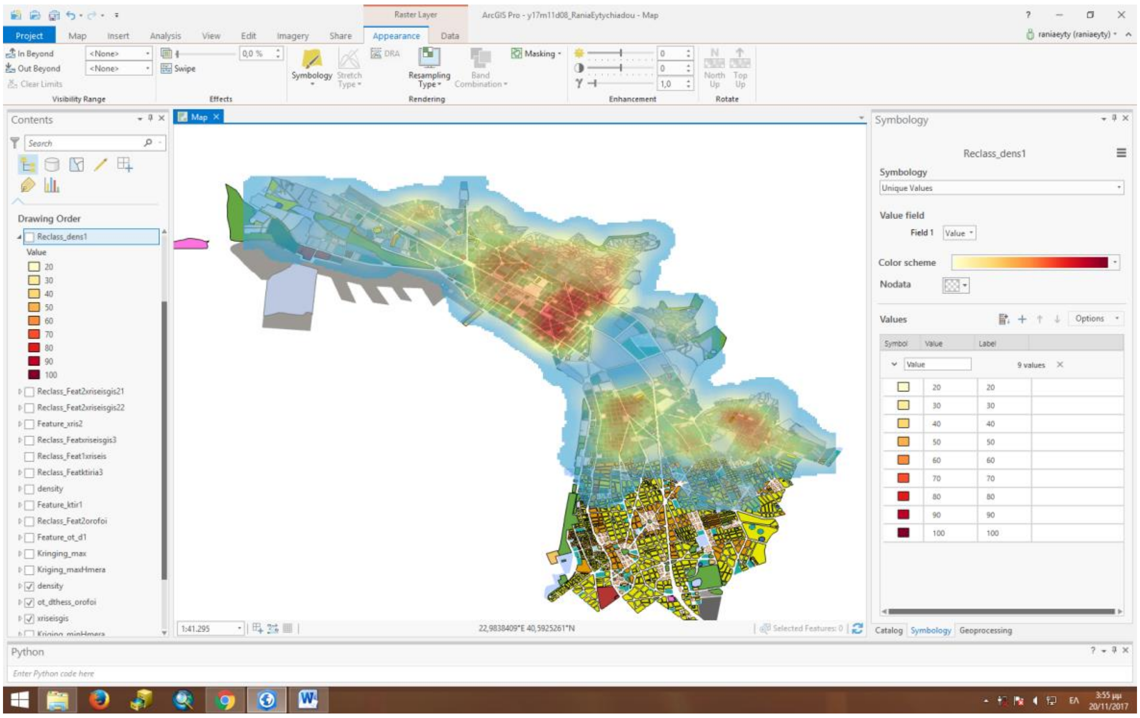
Building density weight.

(Source: Own editing)



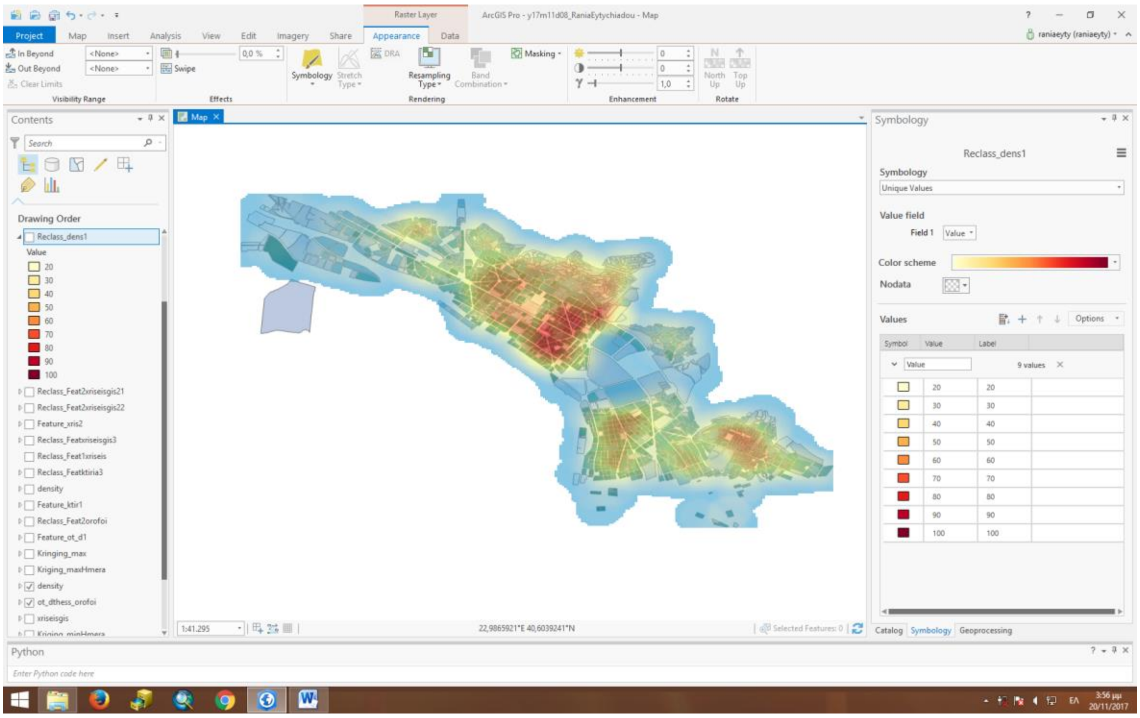
Building density weight.

(Source: Own editing)



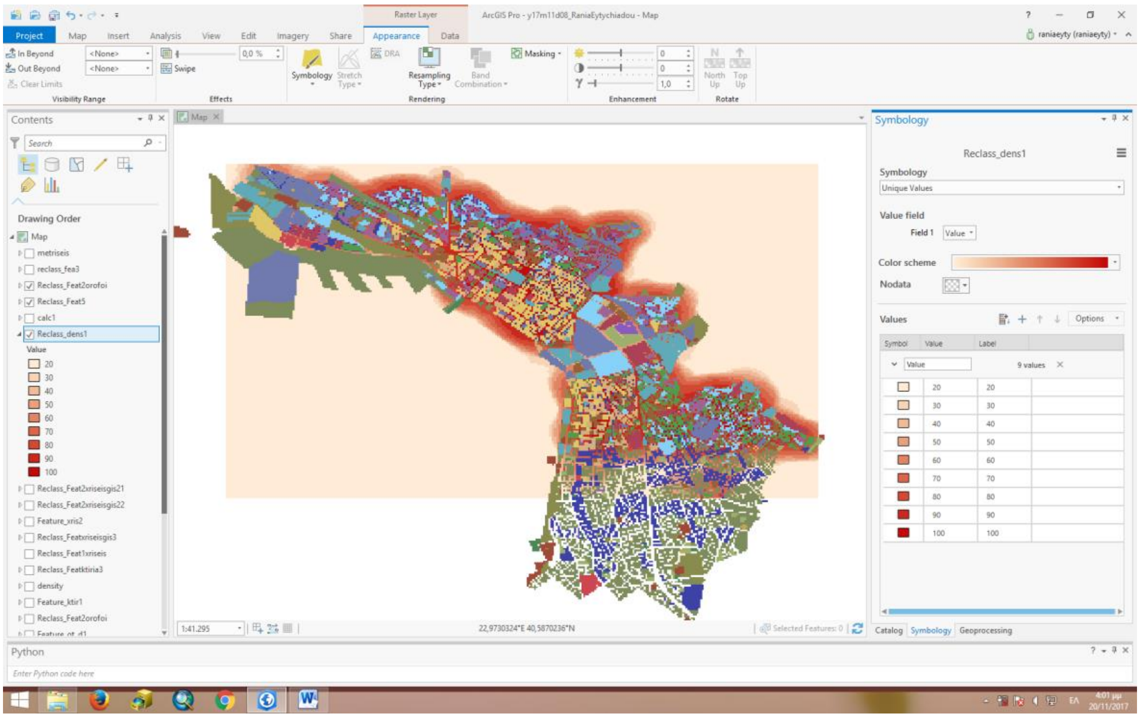
Correlation of building density, floors and land uses.

(Source: Own editing)



Correlation of building density and floors.

(Source: Own editing)



Correlation of reclassified building density, floors and land uses.

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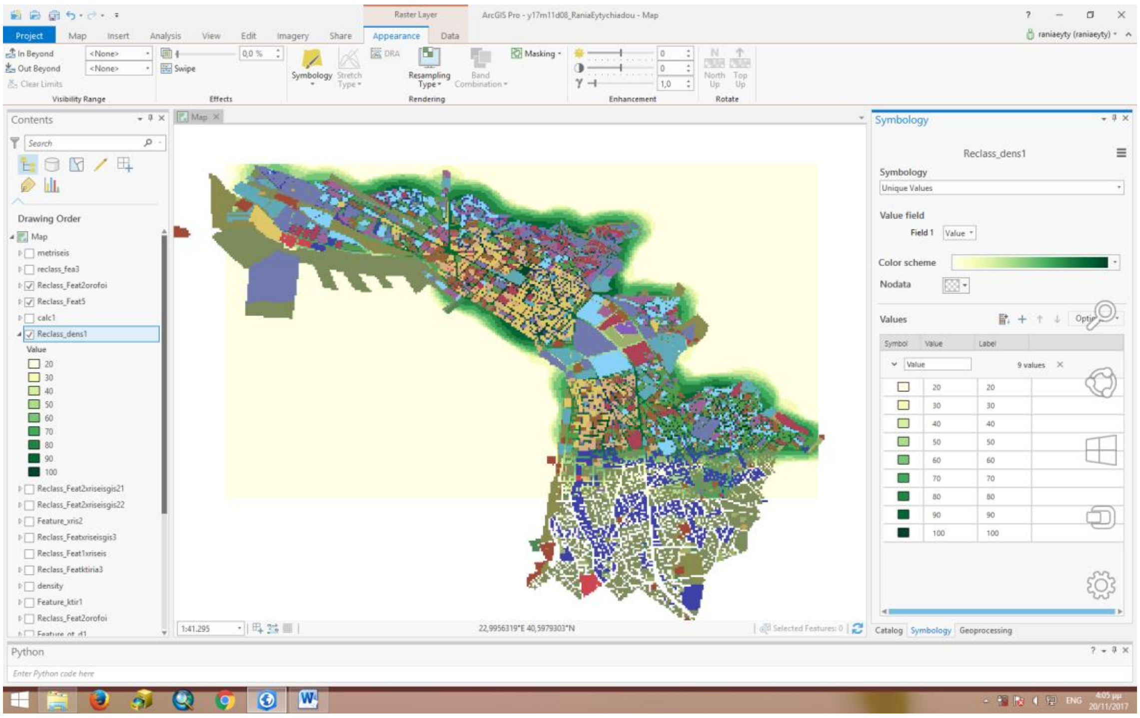
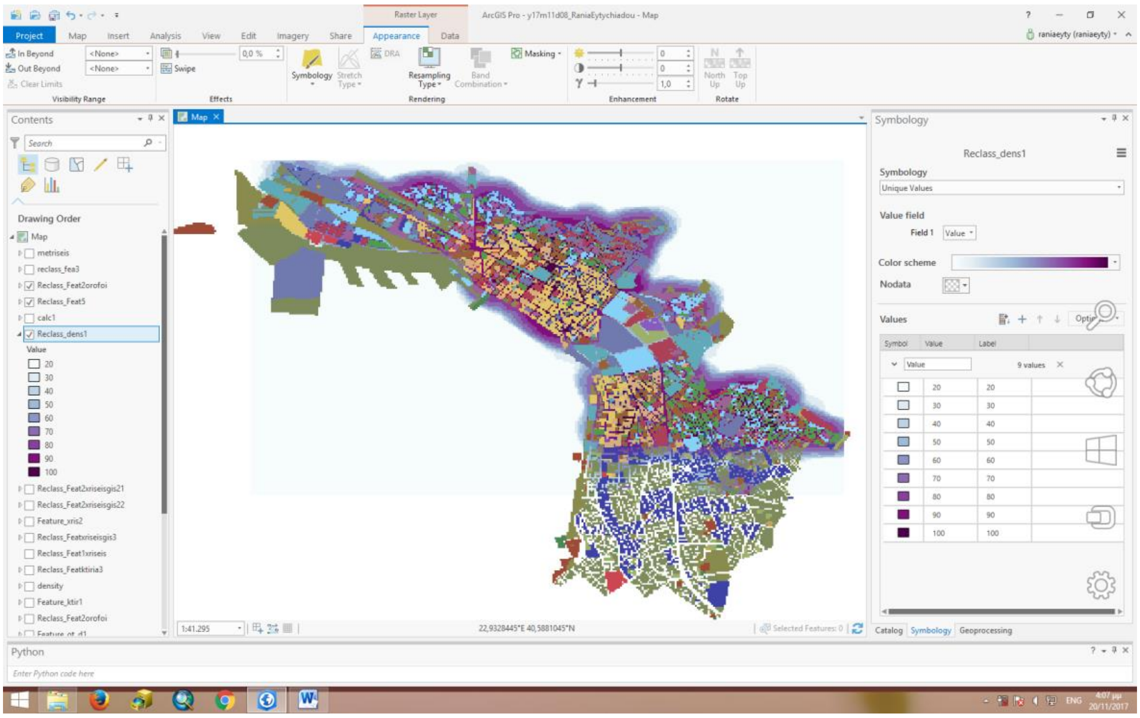


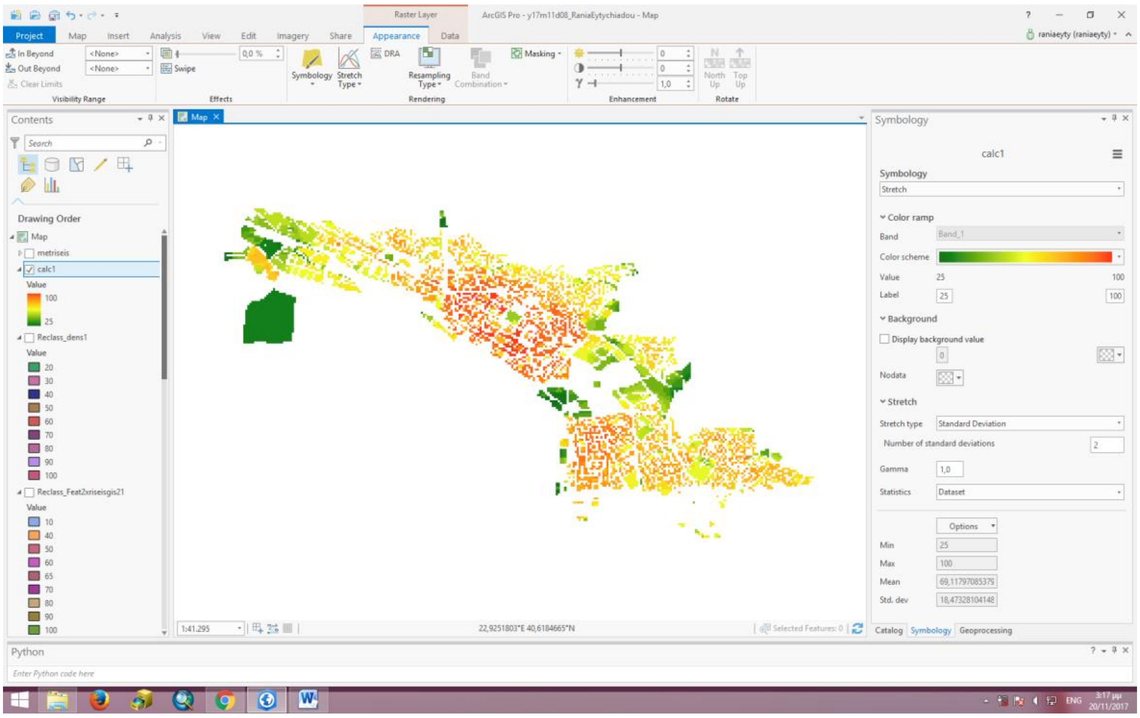
Correlation of reclassified building floors and land uses.

(Source: Own editing)



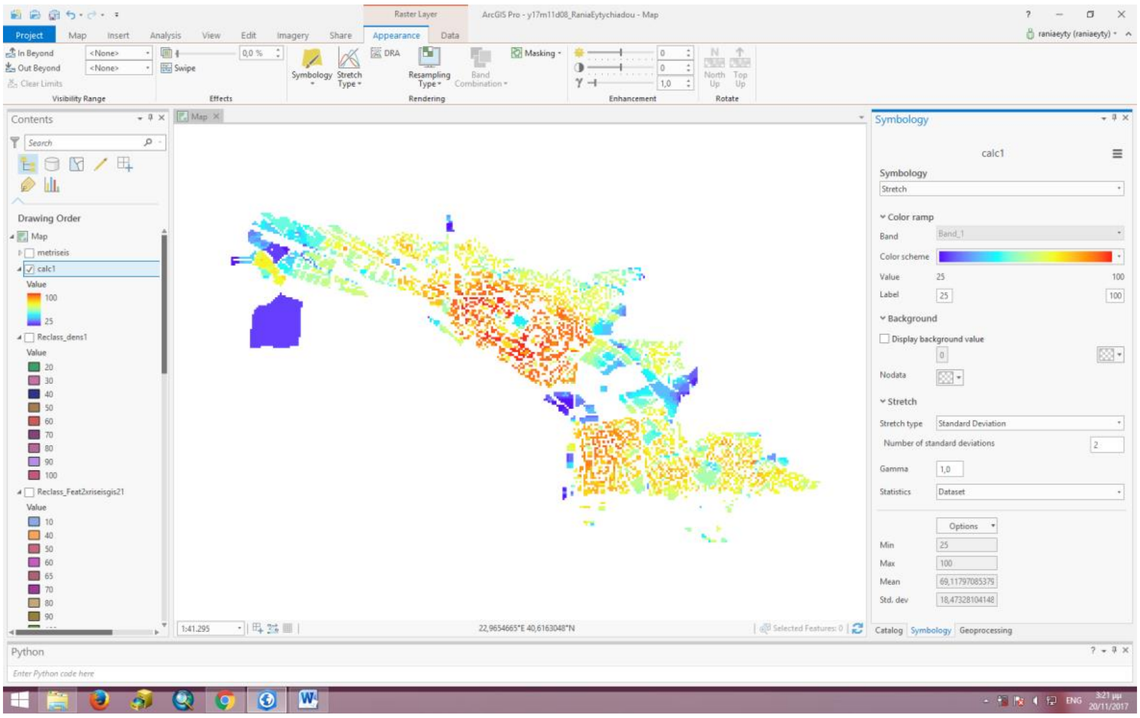
Correlation of tree reclassified UHI factors: building density, floors and land uses.
Which illustrates which areas show the UHI effect more strongly.

(Source: Own editing)



Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (1st try)

(Source: Own editing)



Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (1st try).

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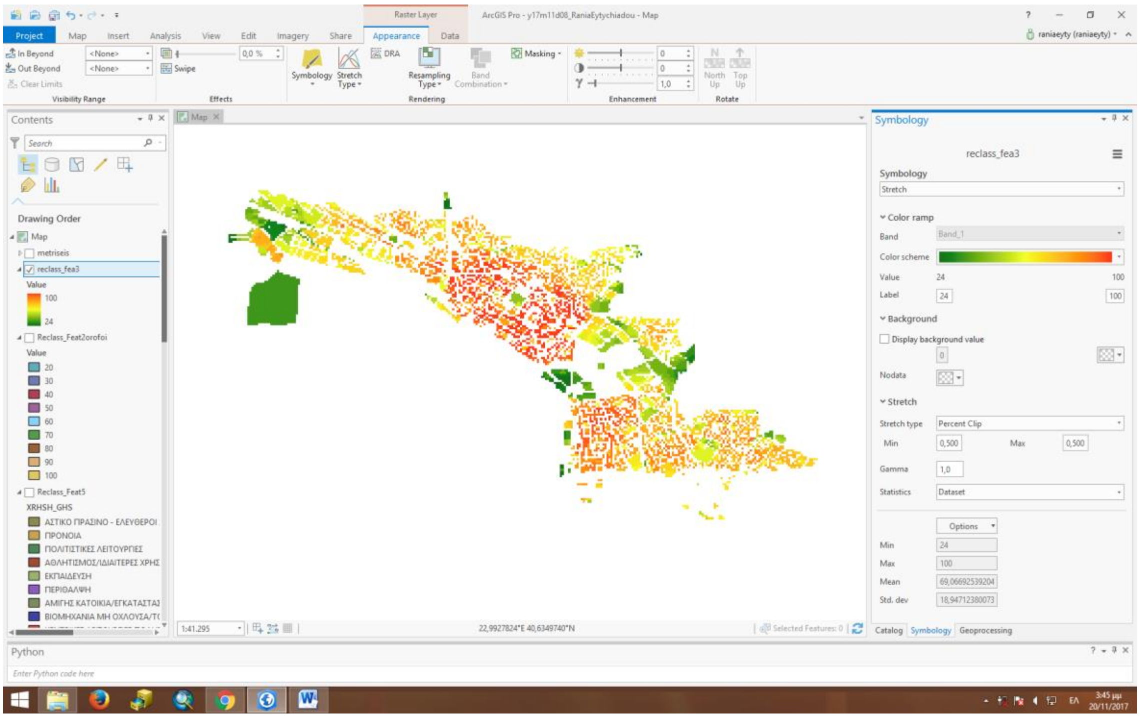
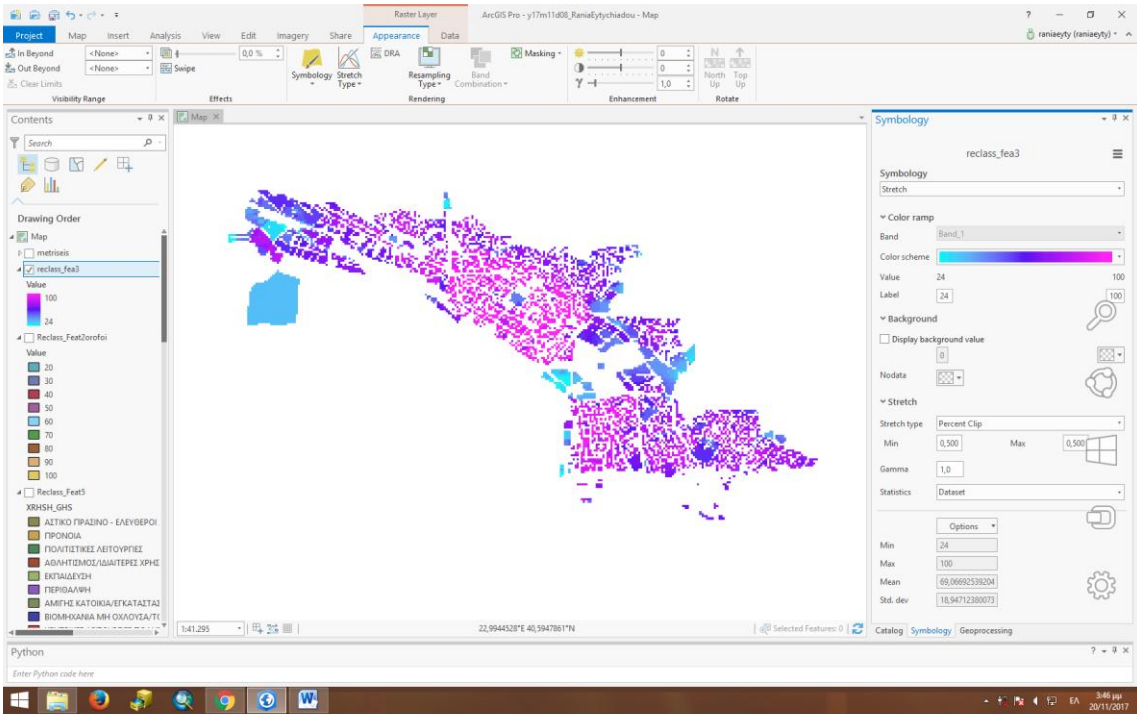


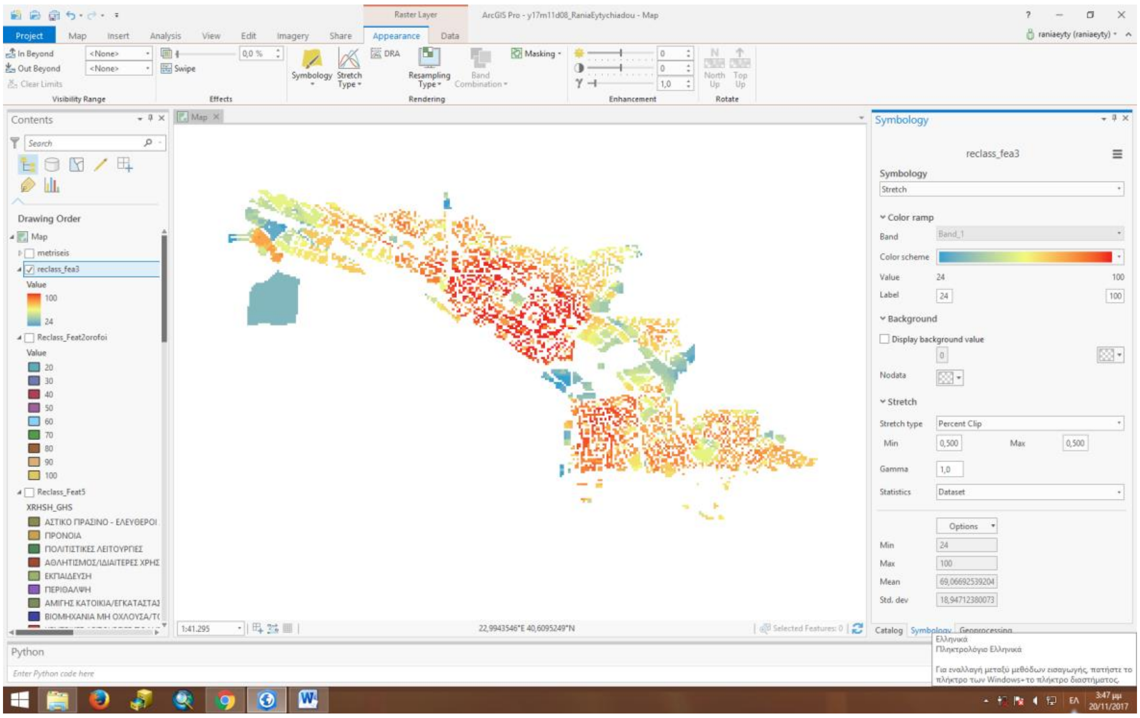
Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (2[d] try).

(Source: Own editing)



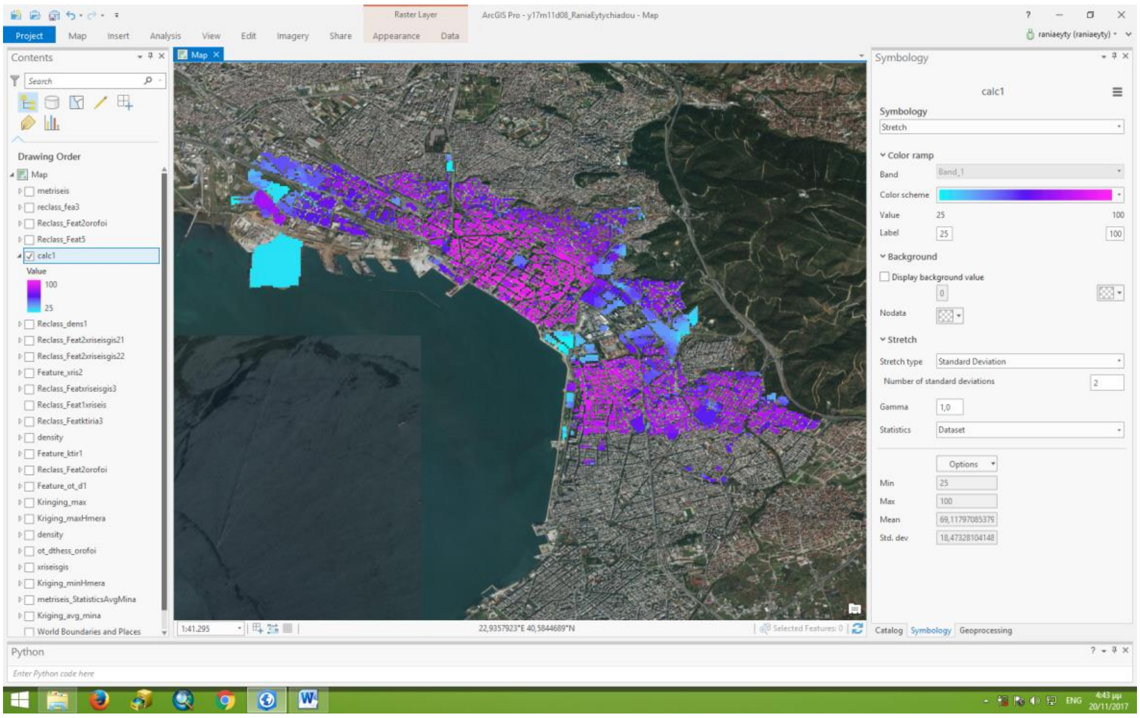
Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (2[d] try).

(Source: Own editing)



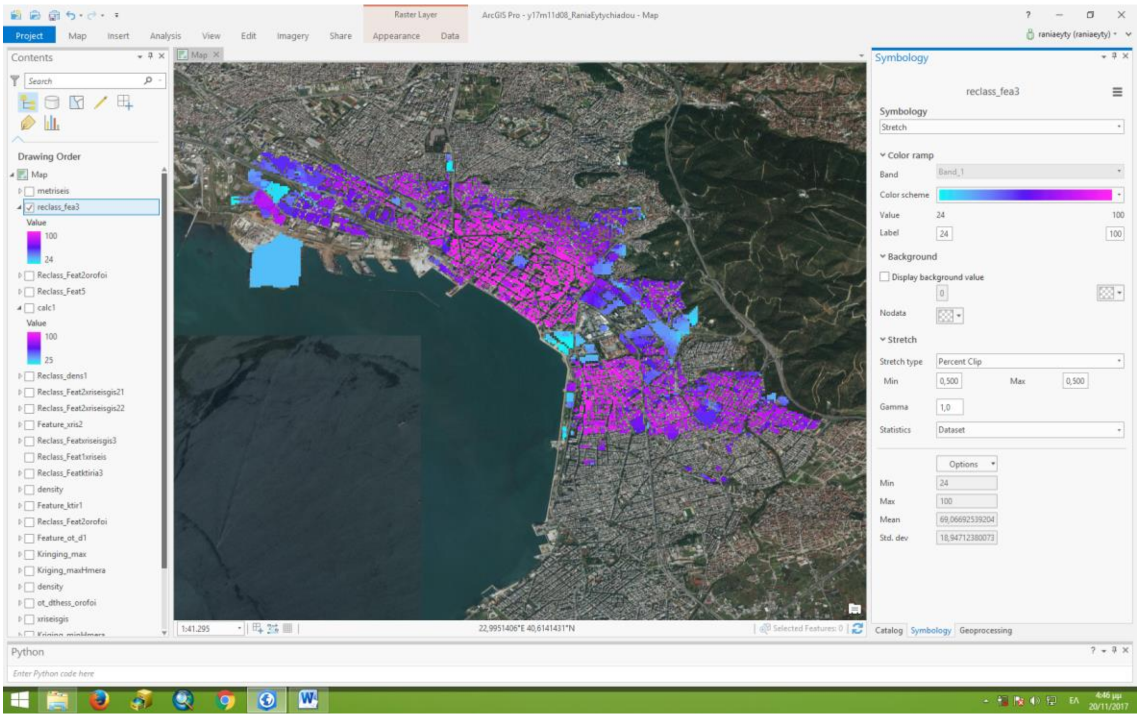
Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (2[d] try).

(Source: Own editing)



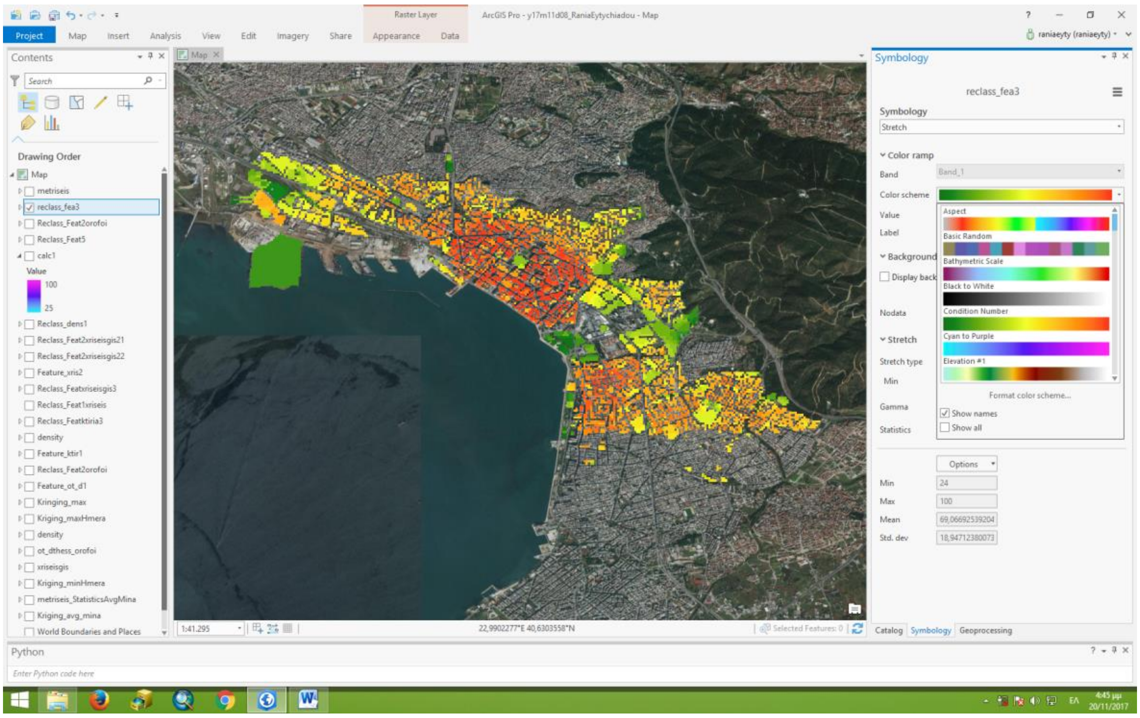
Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (1[st] try).

(Source: Own editing)



Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (2^{d} try).

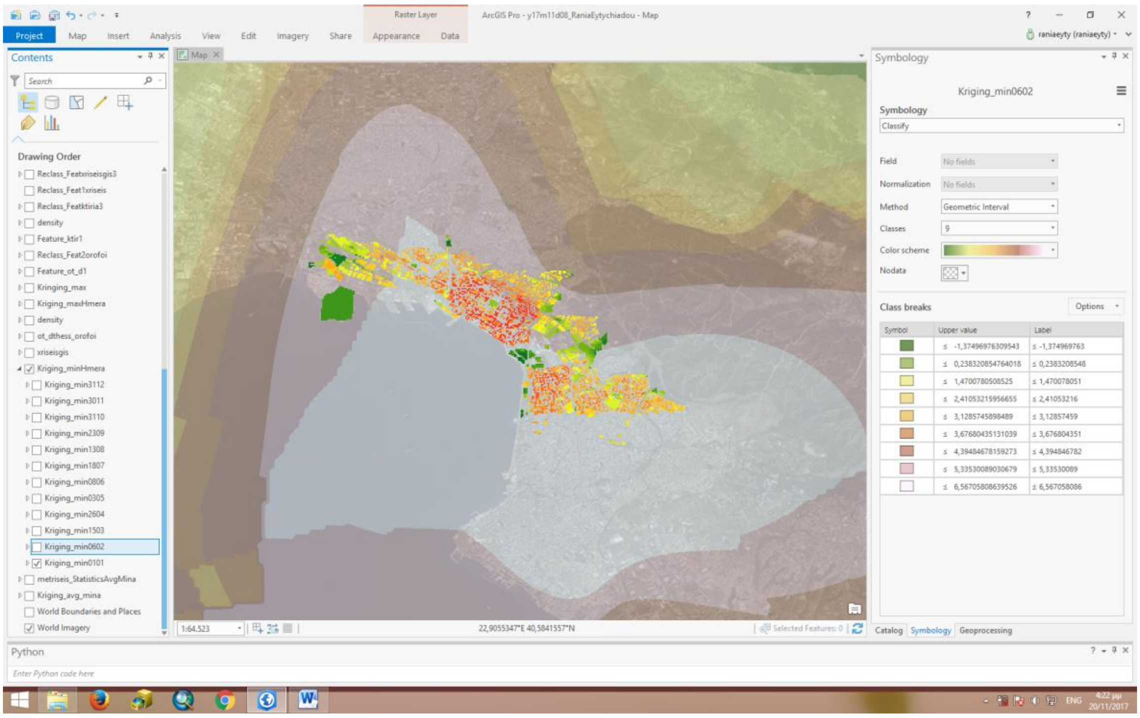
(Source: Own editing)



Adding the UHI creation factors in Thessaloniki (land uses, floor-building height, density) using the ArcGIS tool raster calculator. (2^{d} try).

(Source: Own editing)

Correlation between the display surface of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the minimum temperatures.



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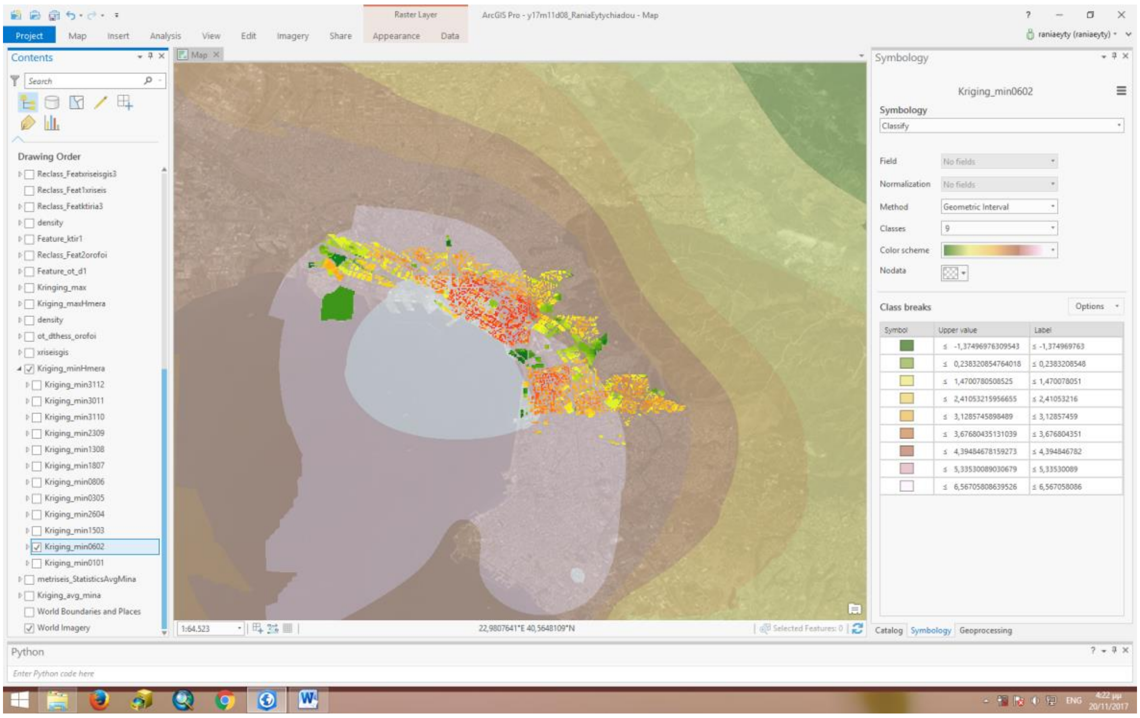

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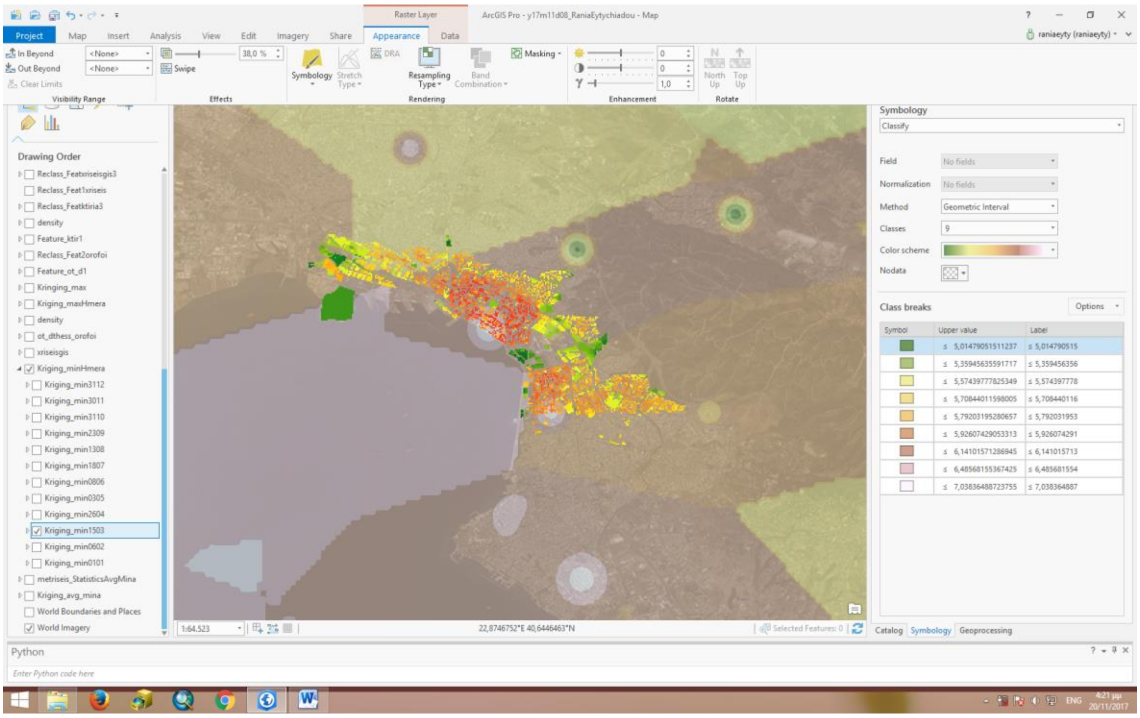

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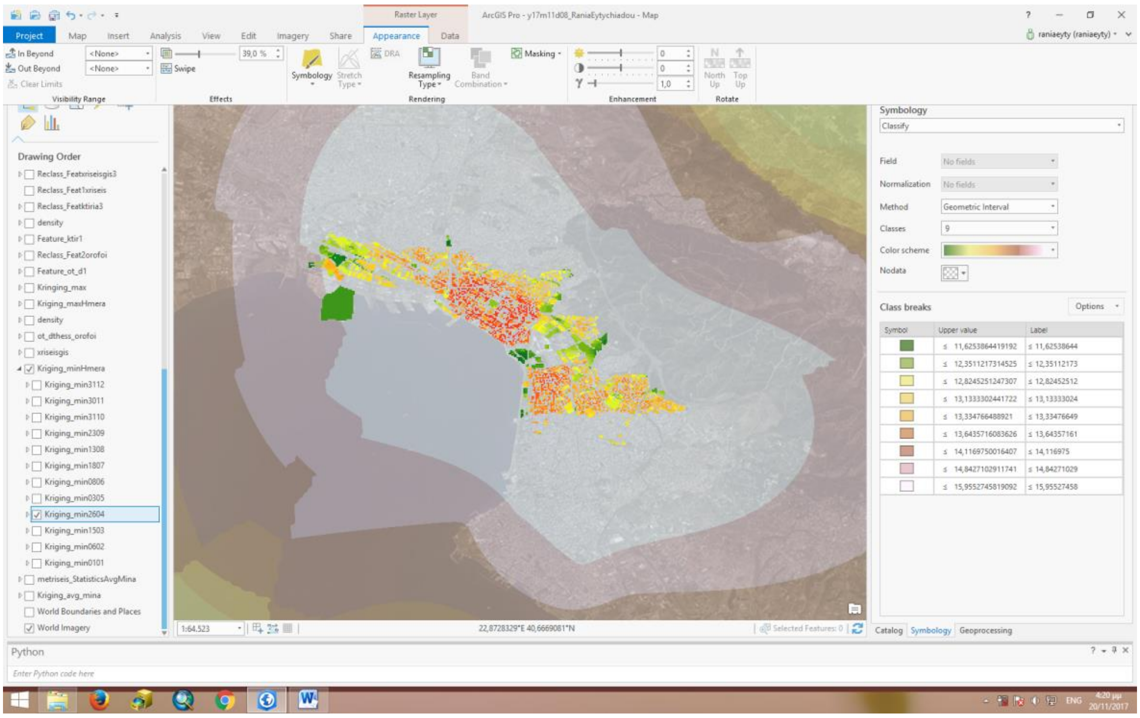
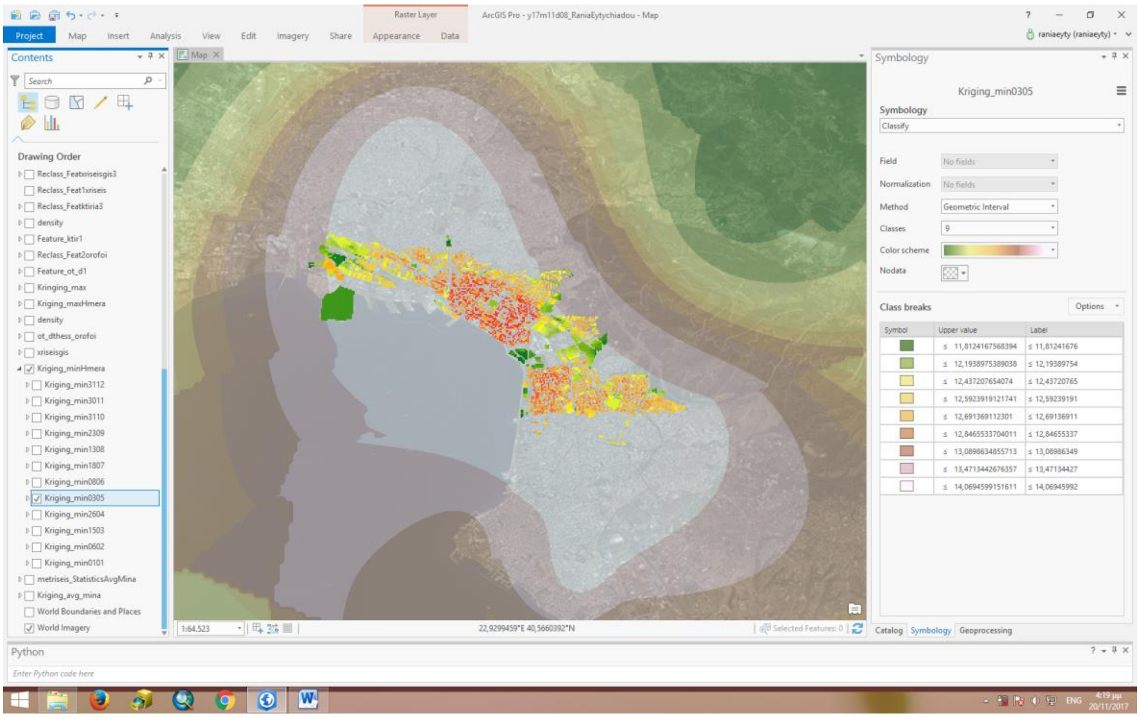


(26-04-2016 min temp)



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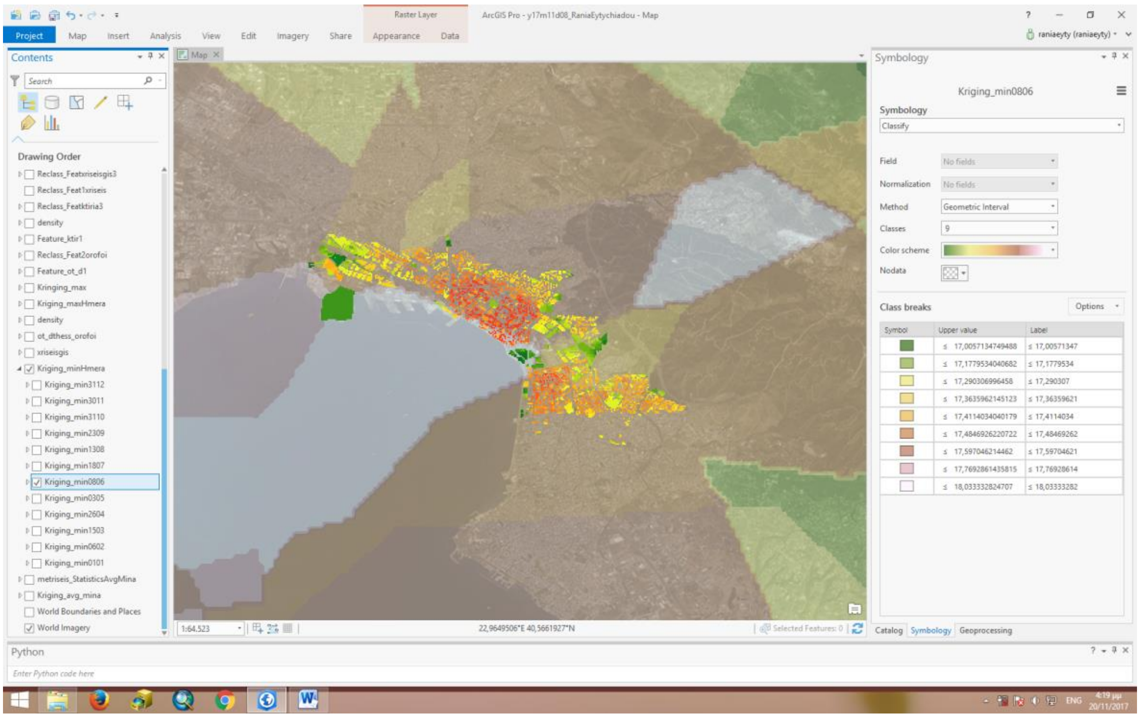
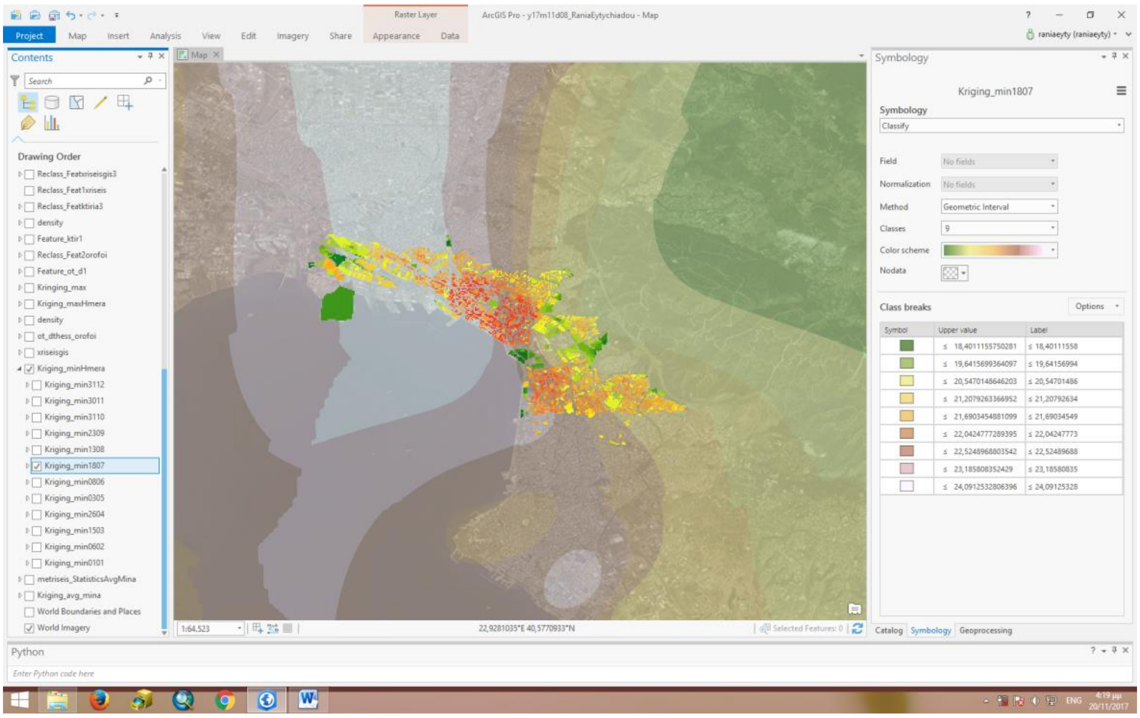
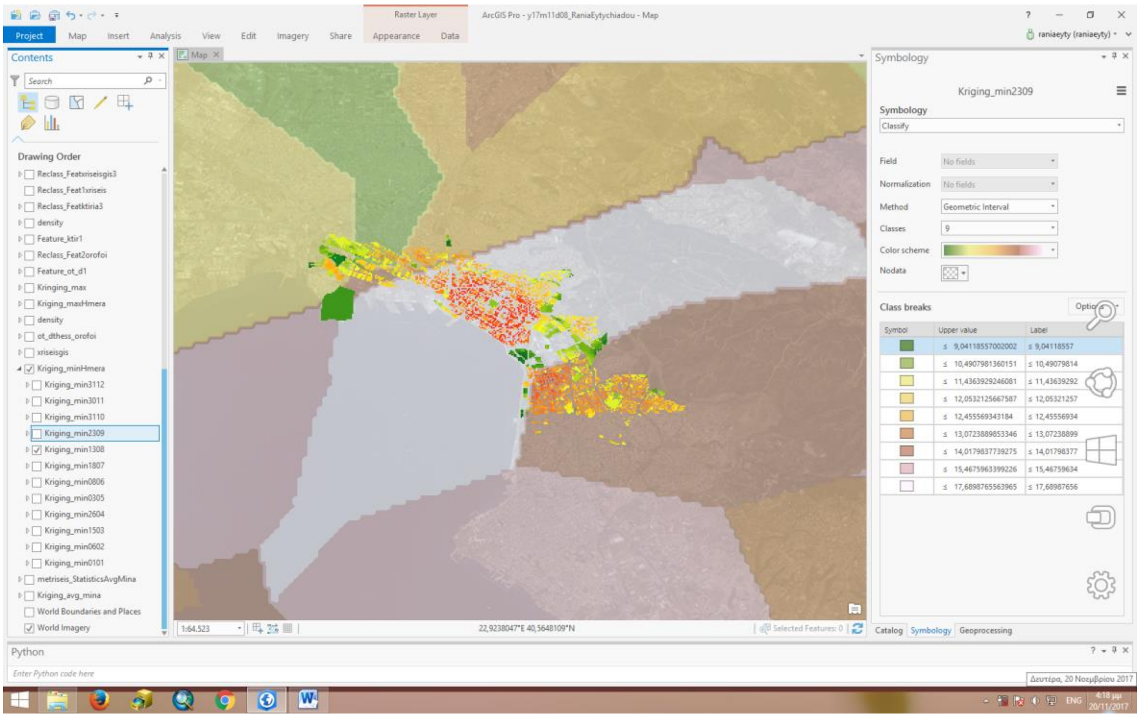


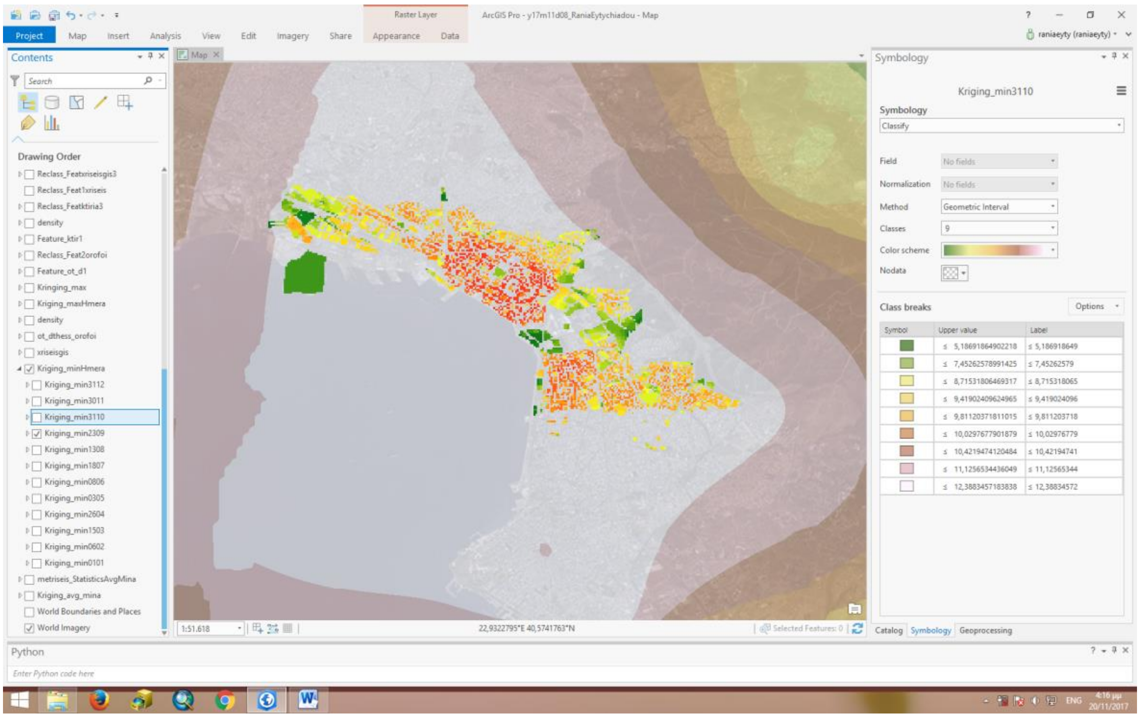
(08-06-2016 min temp)



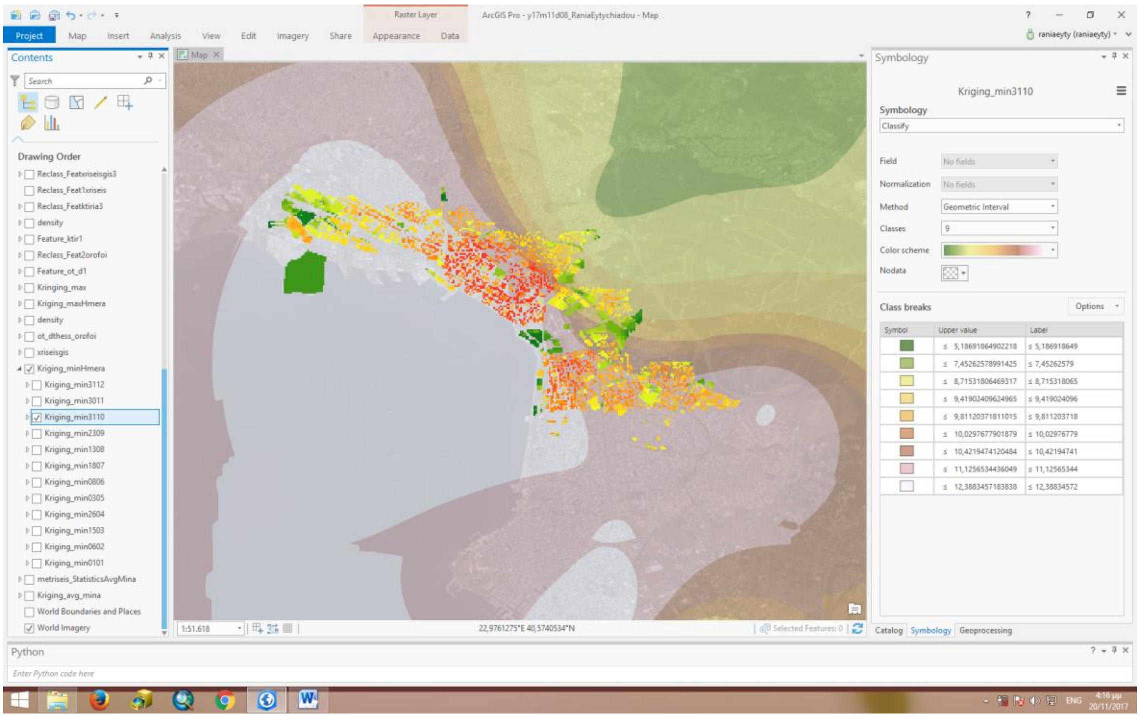
(18-07-2016 min temp)



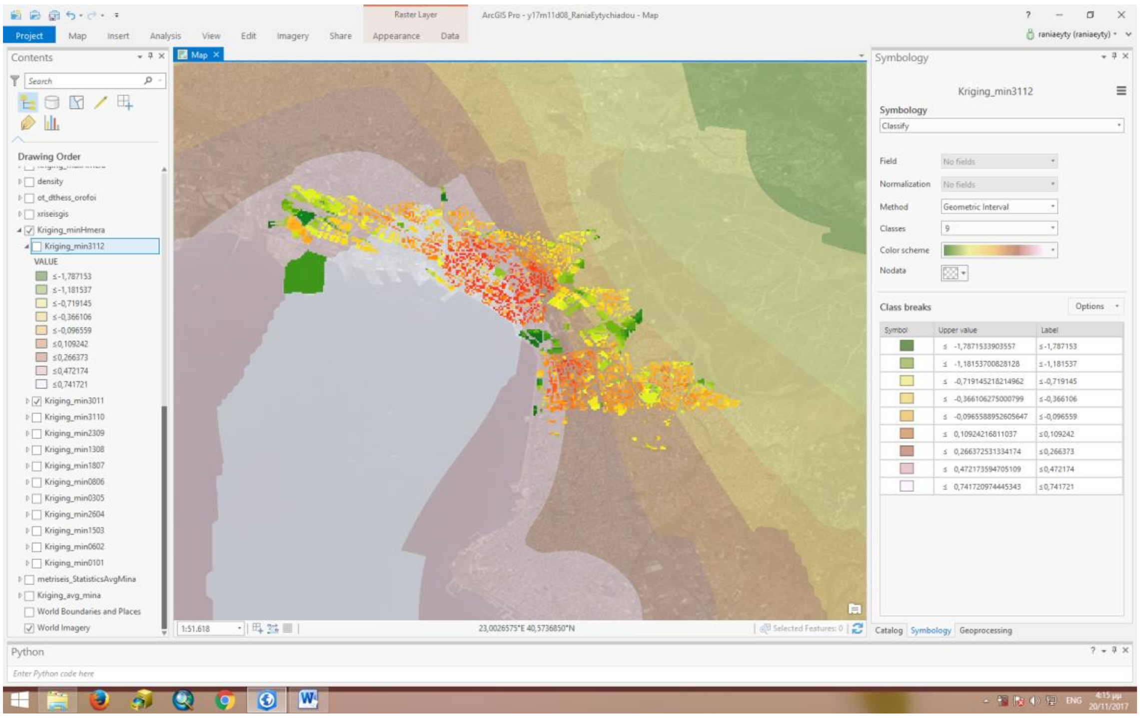
(13-08-2016 min temp)



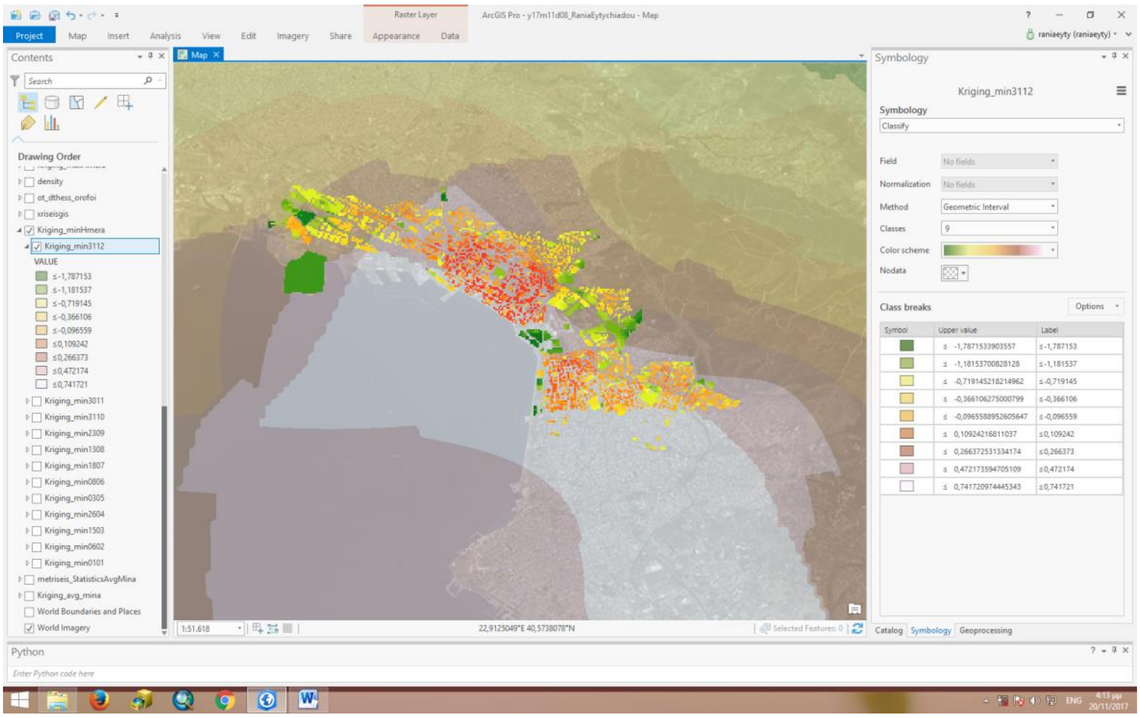
(23-09-2016 min temp)



(31-10-2016 min temp)

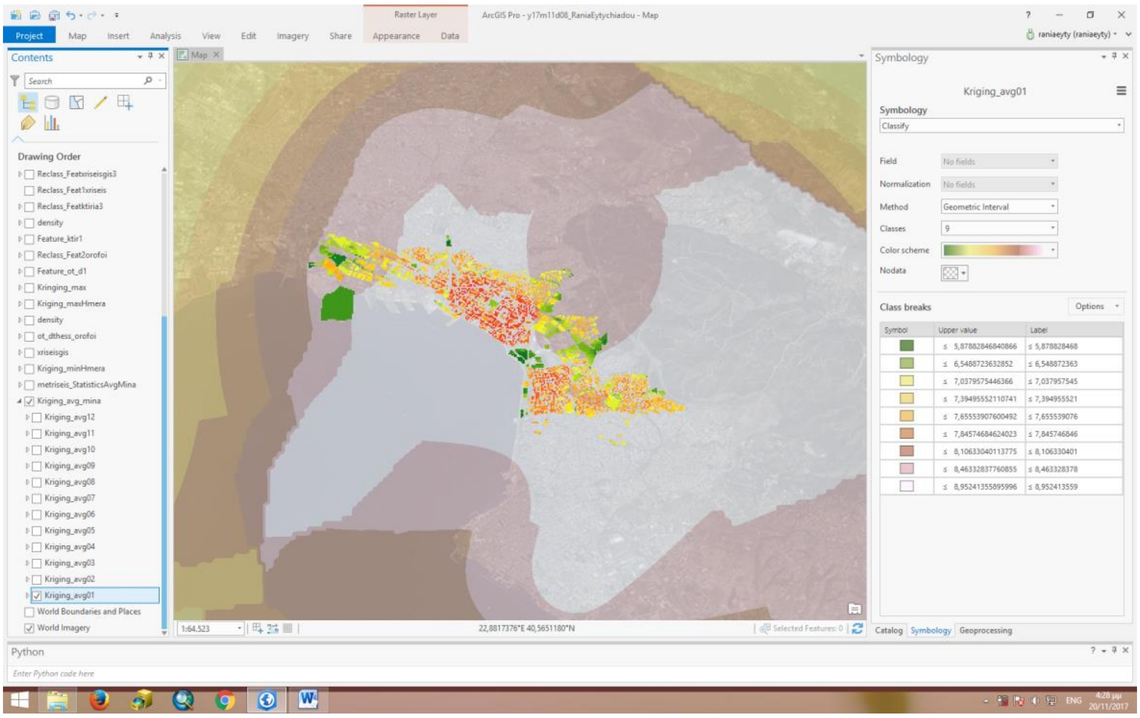


(30-11-2016 min temp)

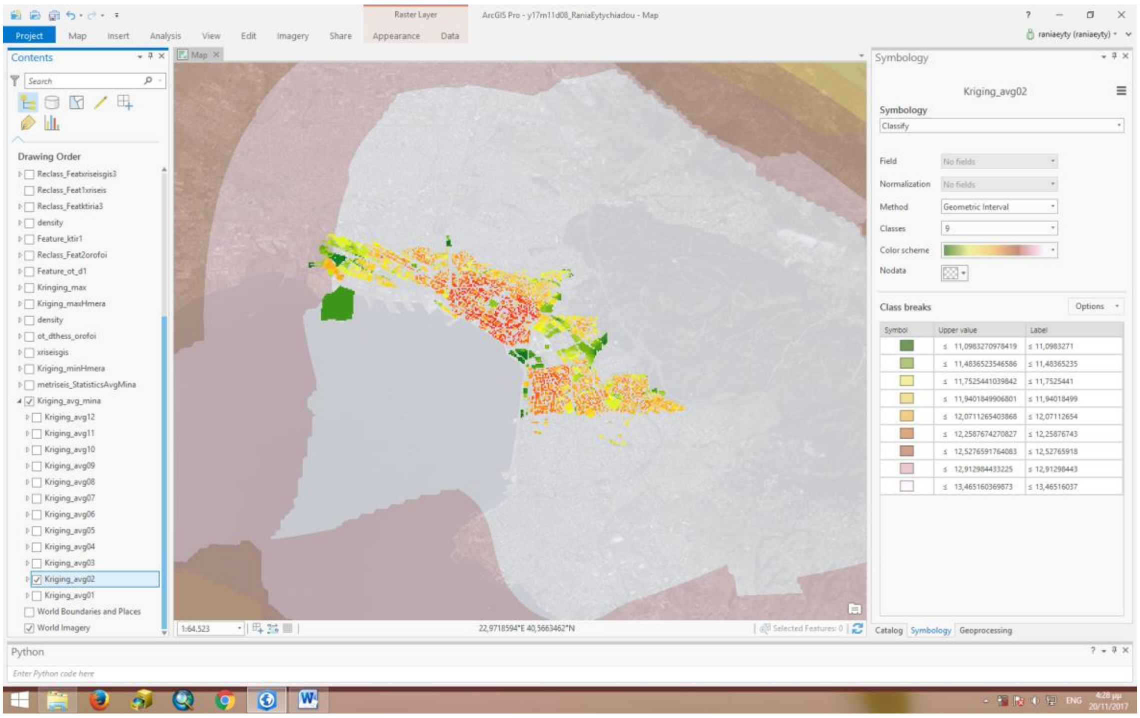


(31-12-2016 min temp)

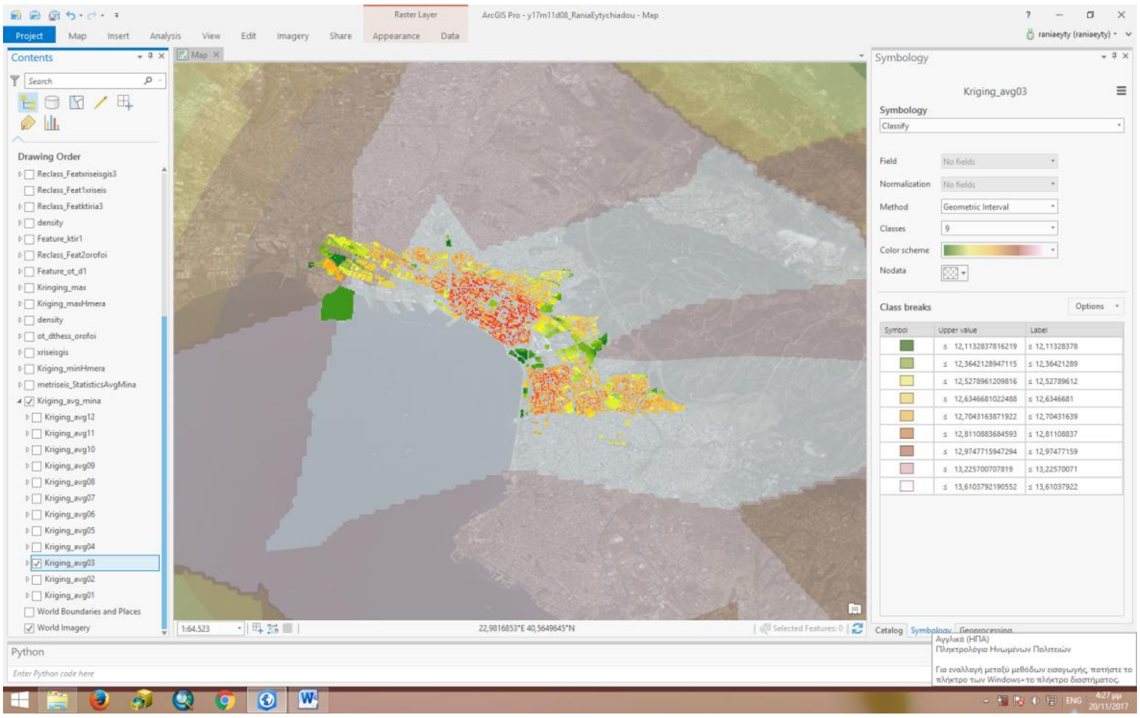
Correlation between the display surface of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the monthly average temperatures.



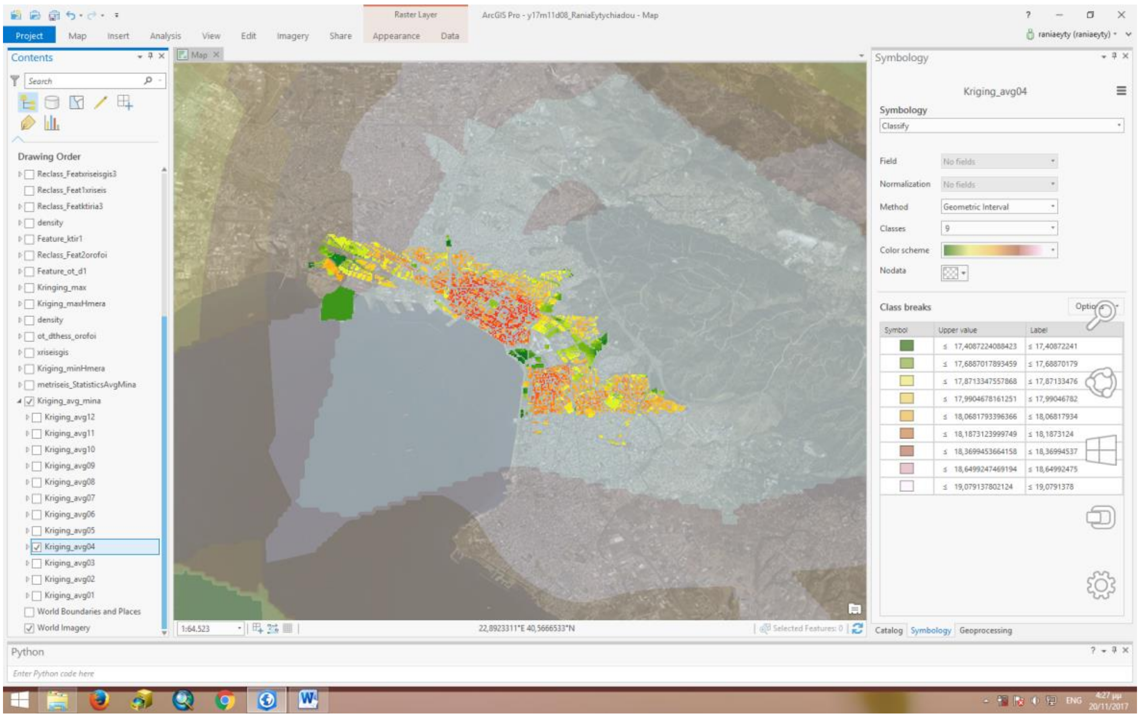
(January average temperatures).



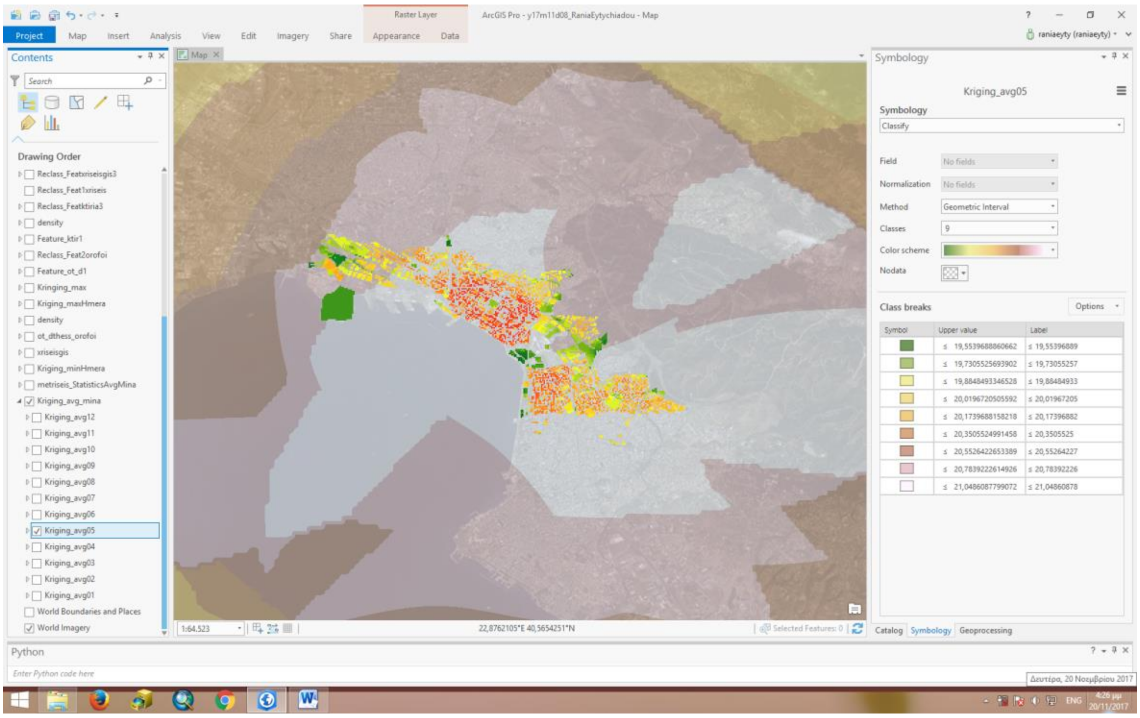
(February average temperatures).



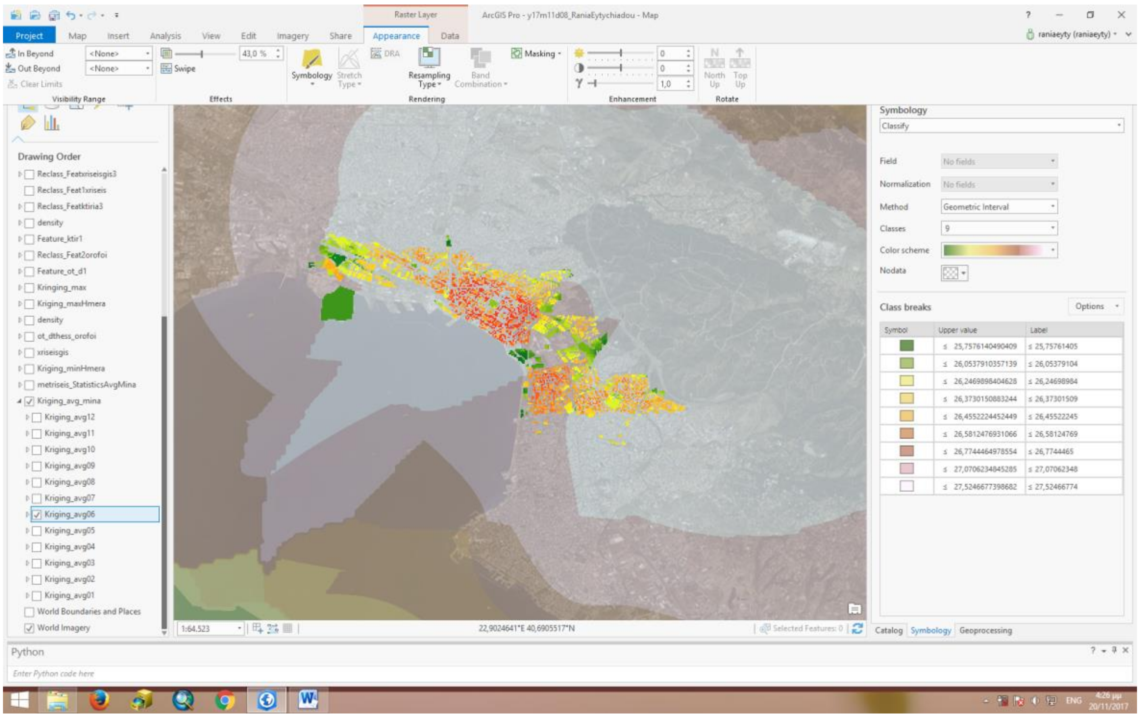
(March average temperatures).



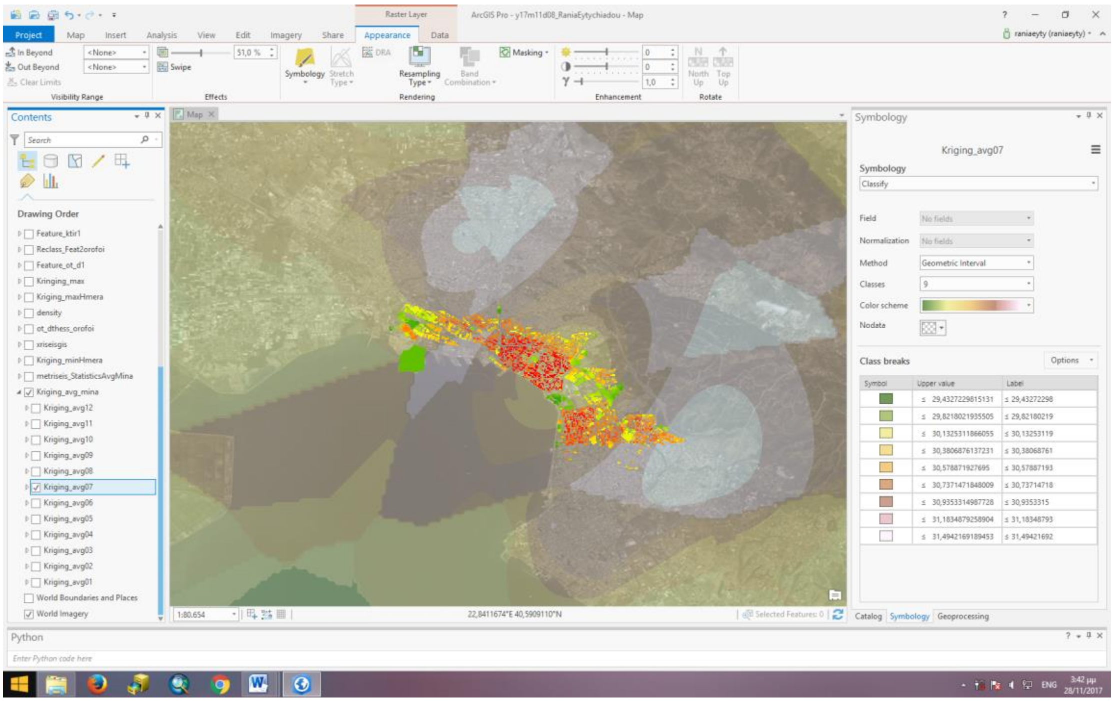
(April average temperatures).



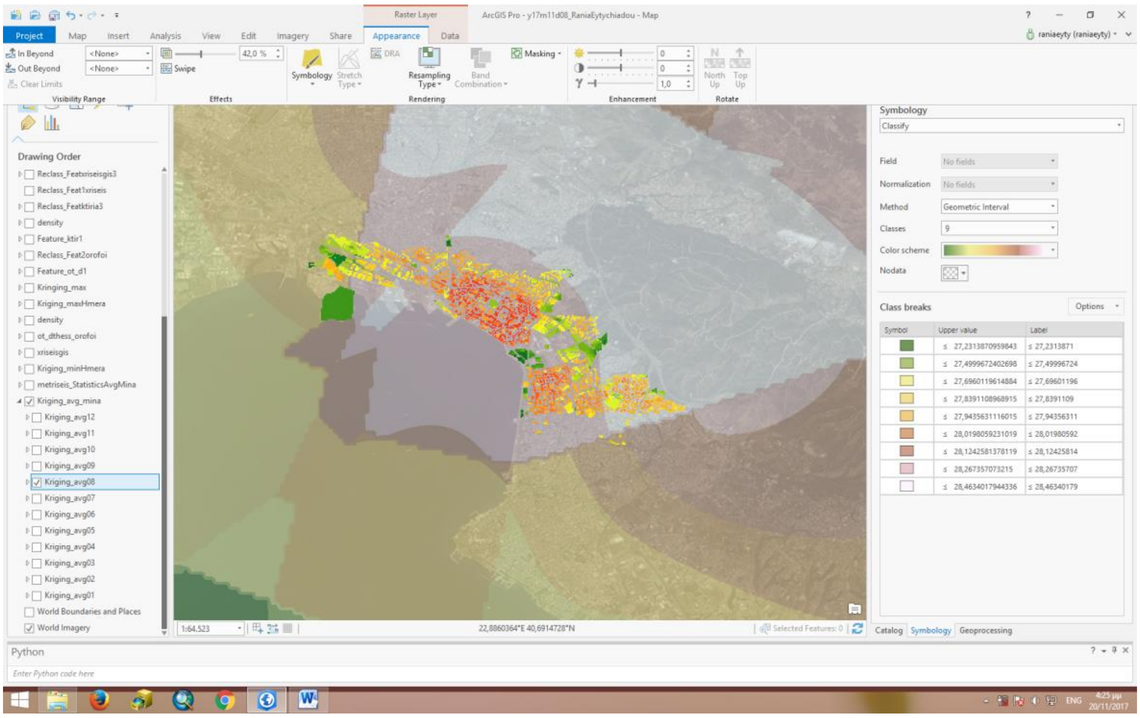
(May average temperatures).



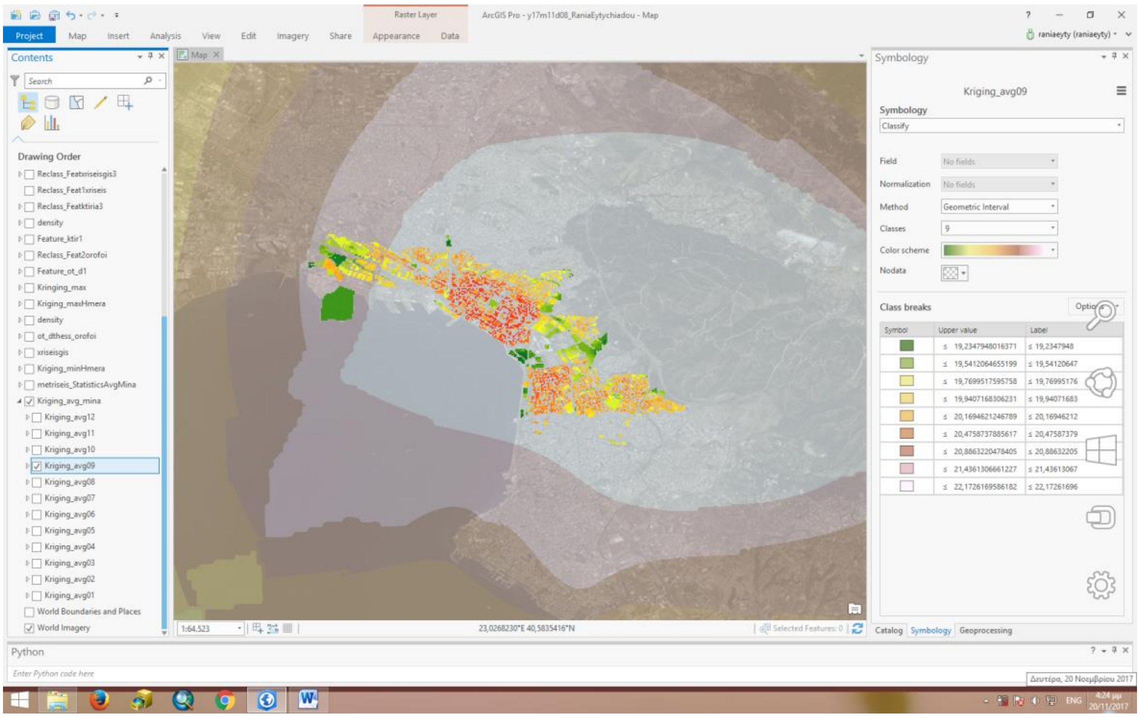
(June average temperatures).



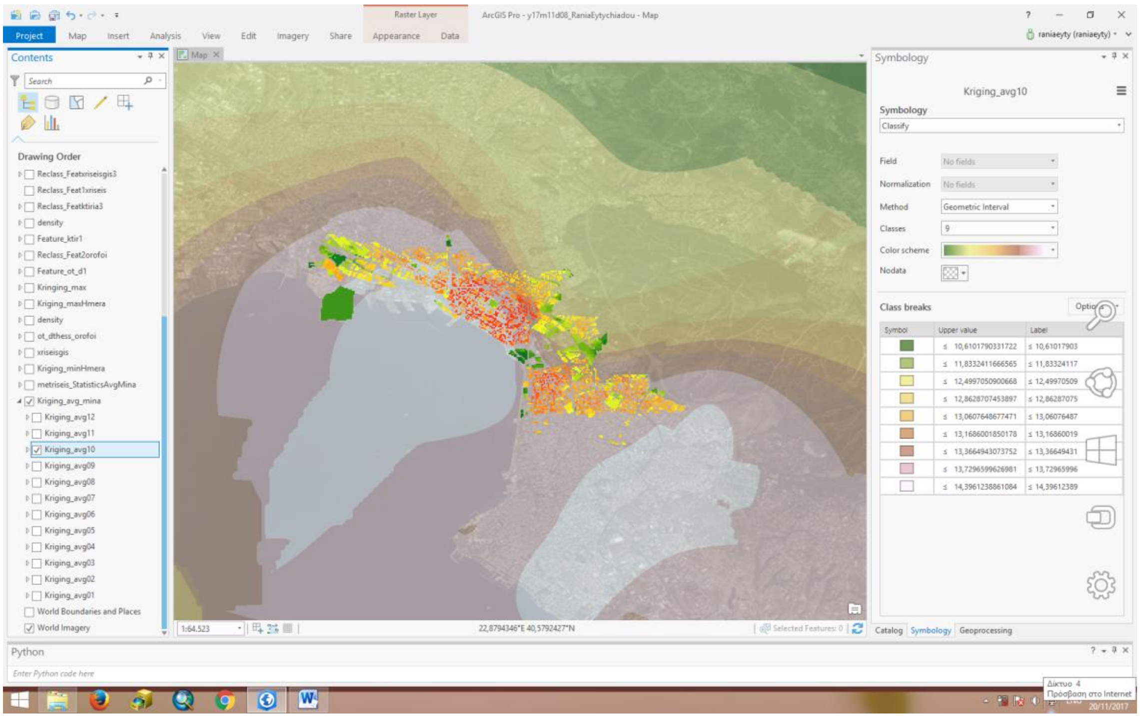
(July average temperatures).



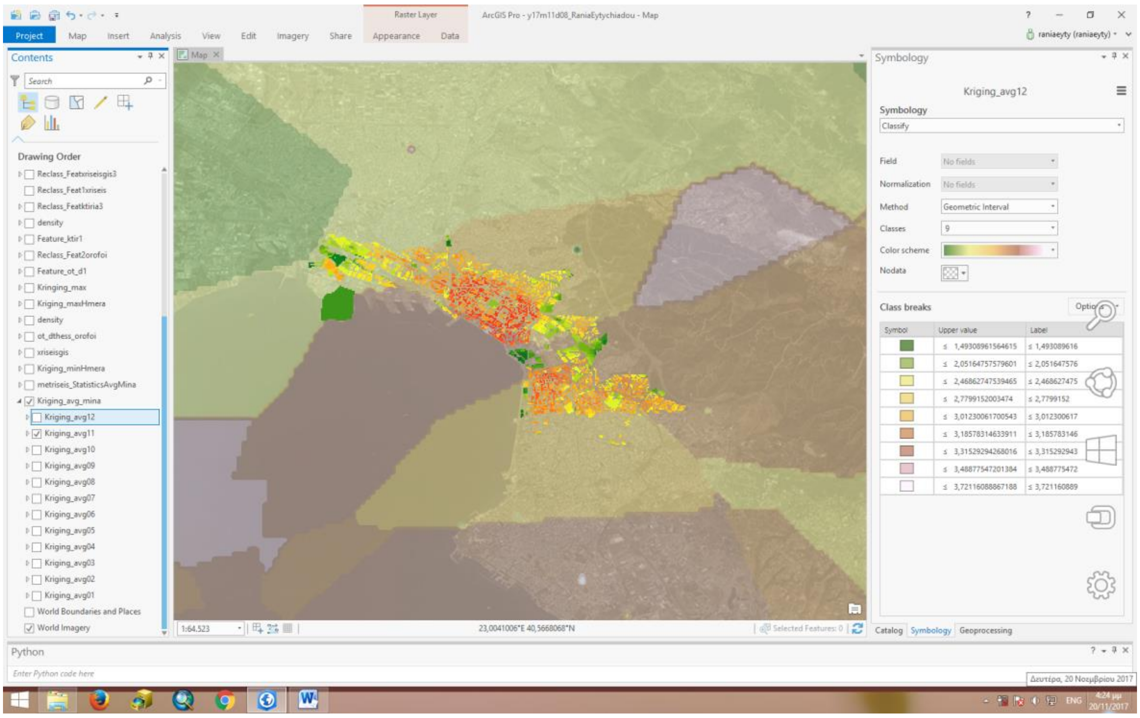
(August average temperatures).



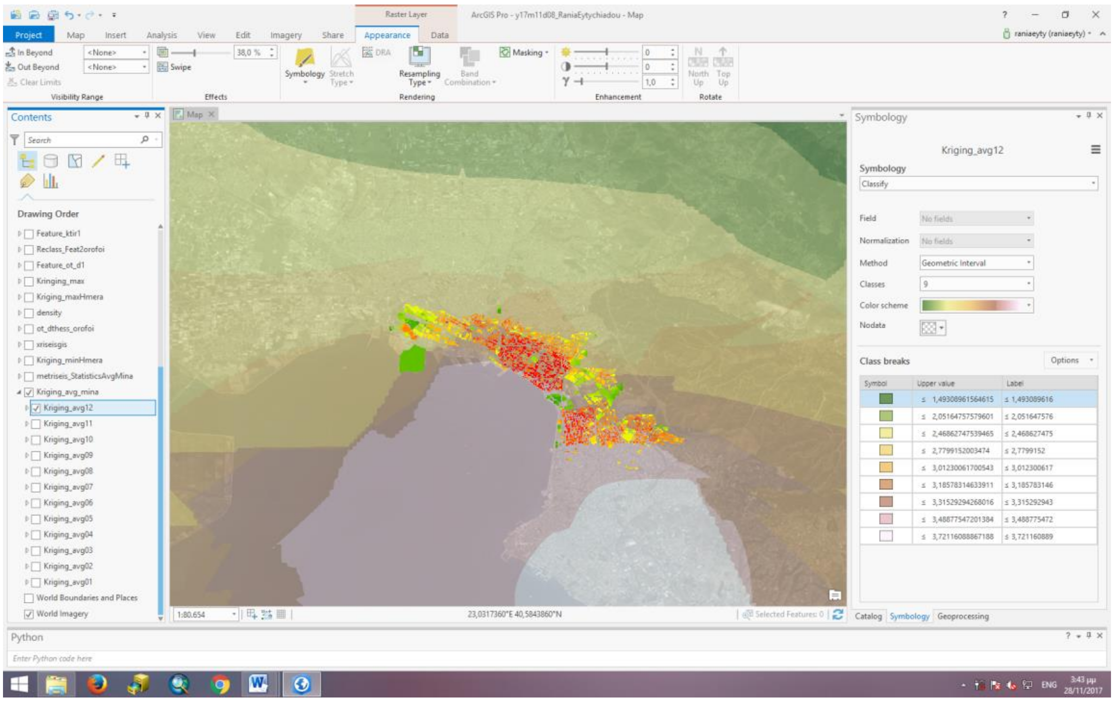
(September average temperatures).



(October average temperatures).

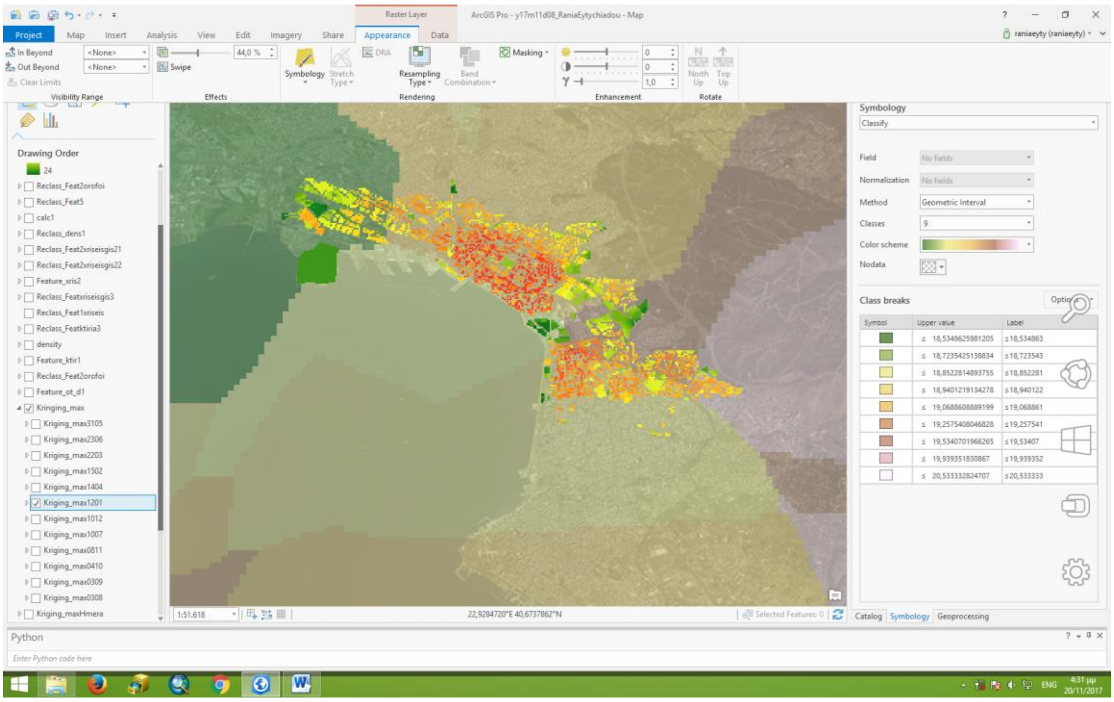


(November average temperatures).

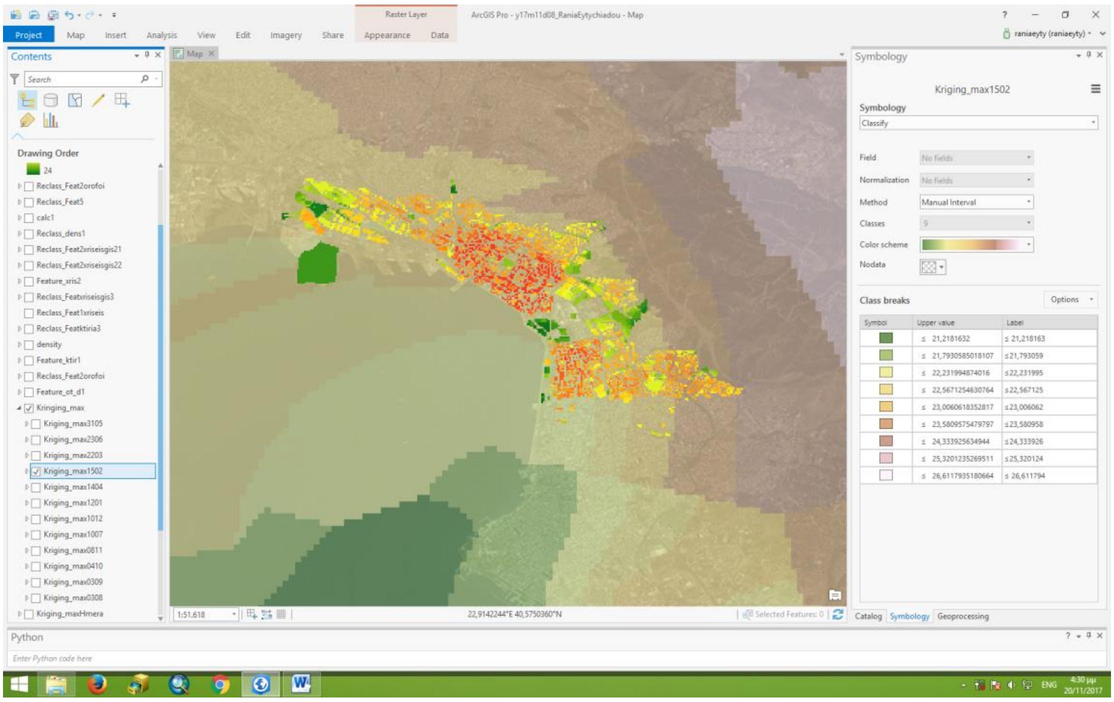


(December average temperatures).

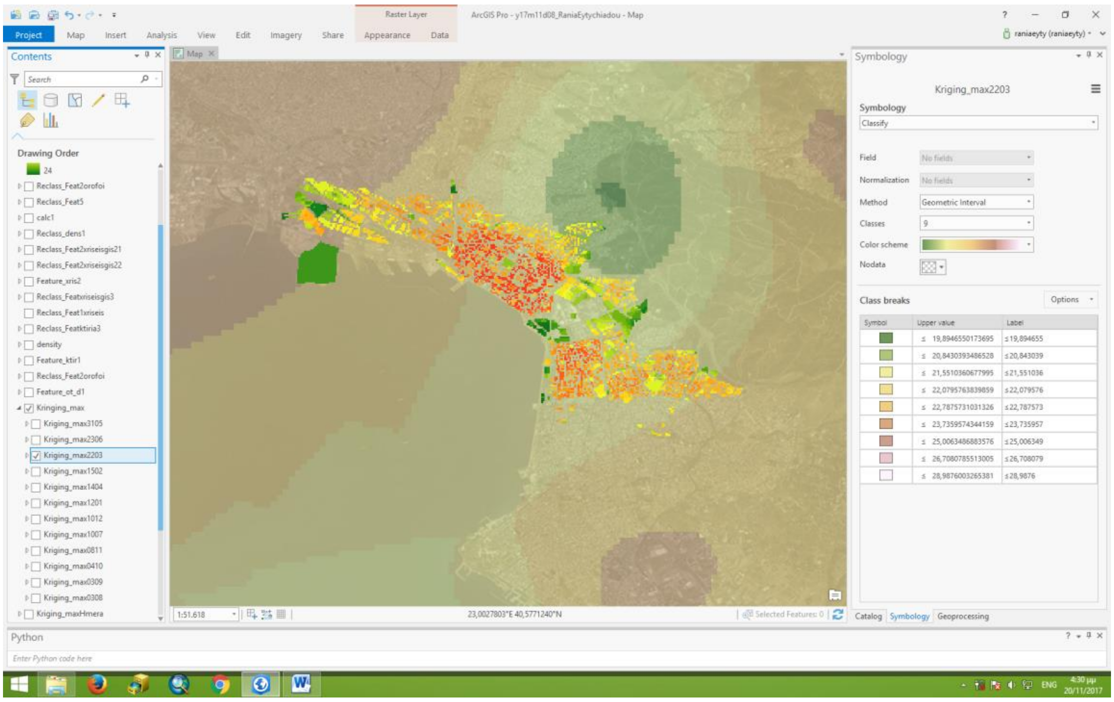
Correlation between the display surface of UHI phenomenon occurrence in Thessaloniki and the Kriging interpolation surface using the maximum temperatures.



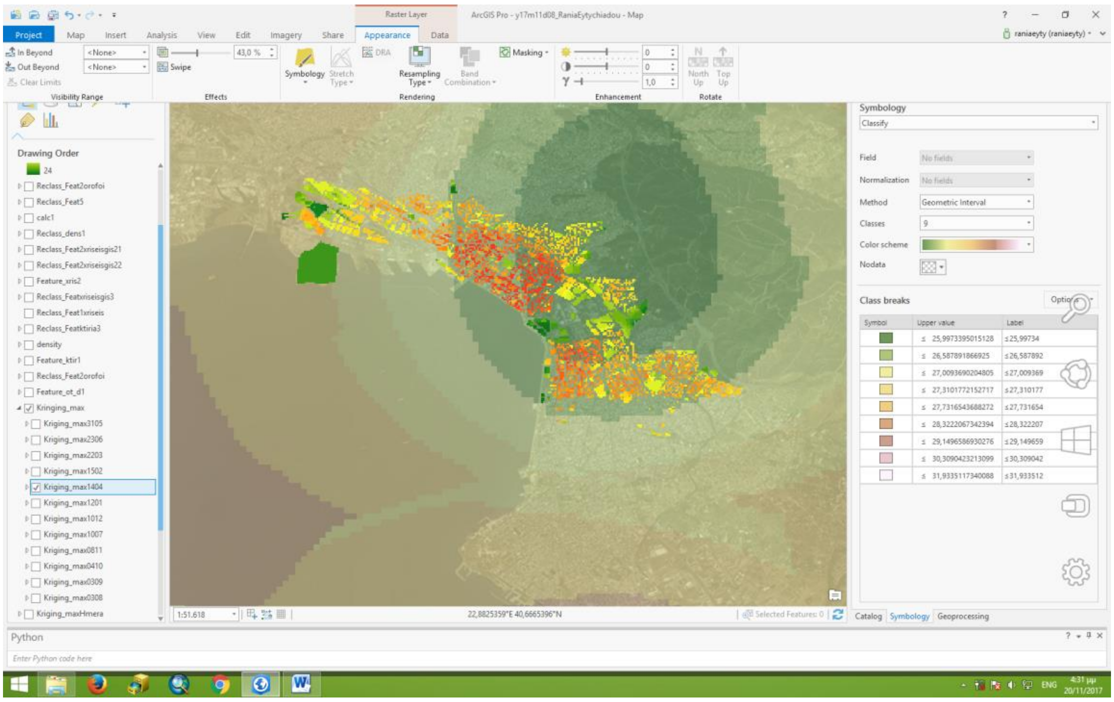
(12-01-2016 max temp)



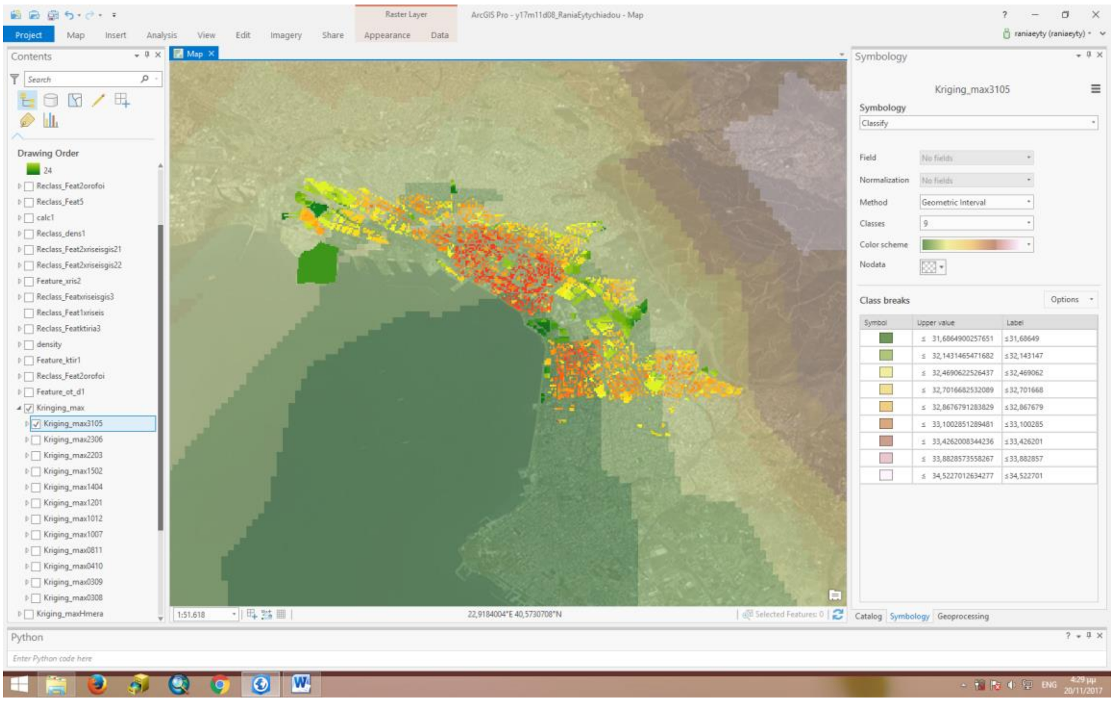
(15-02-2016 max temp)



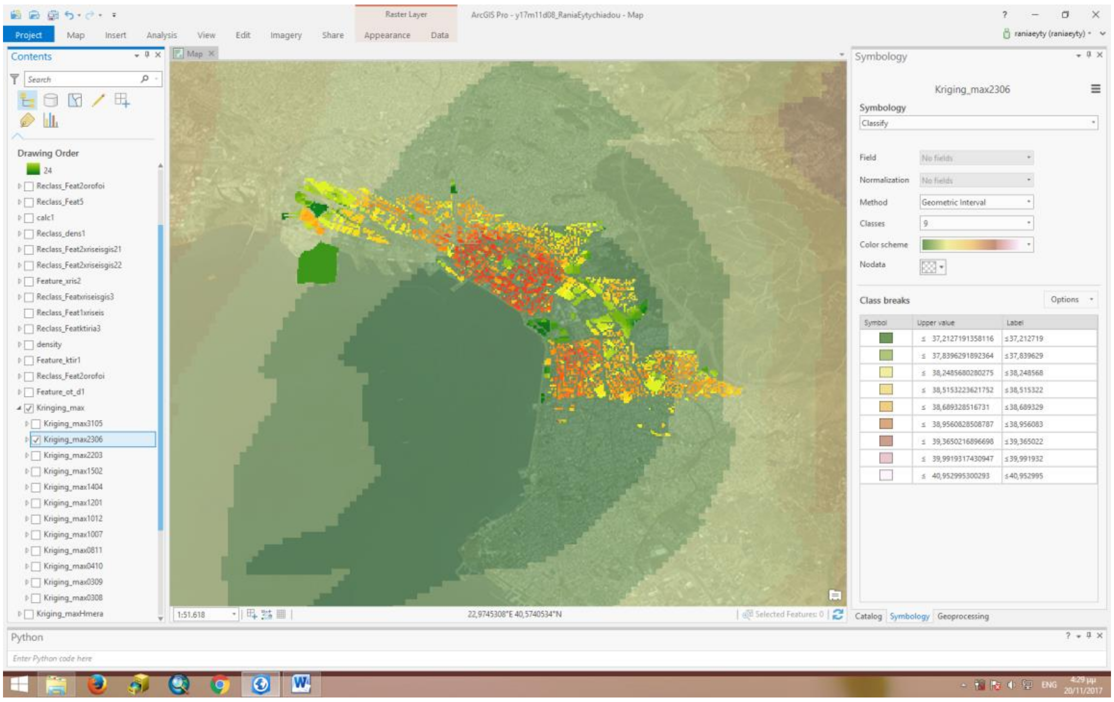
(22-03-2016 max temp)



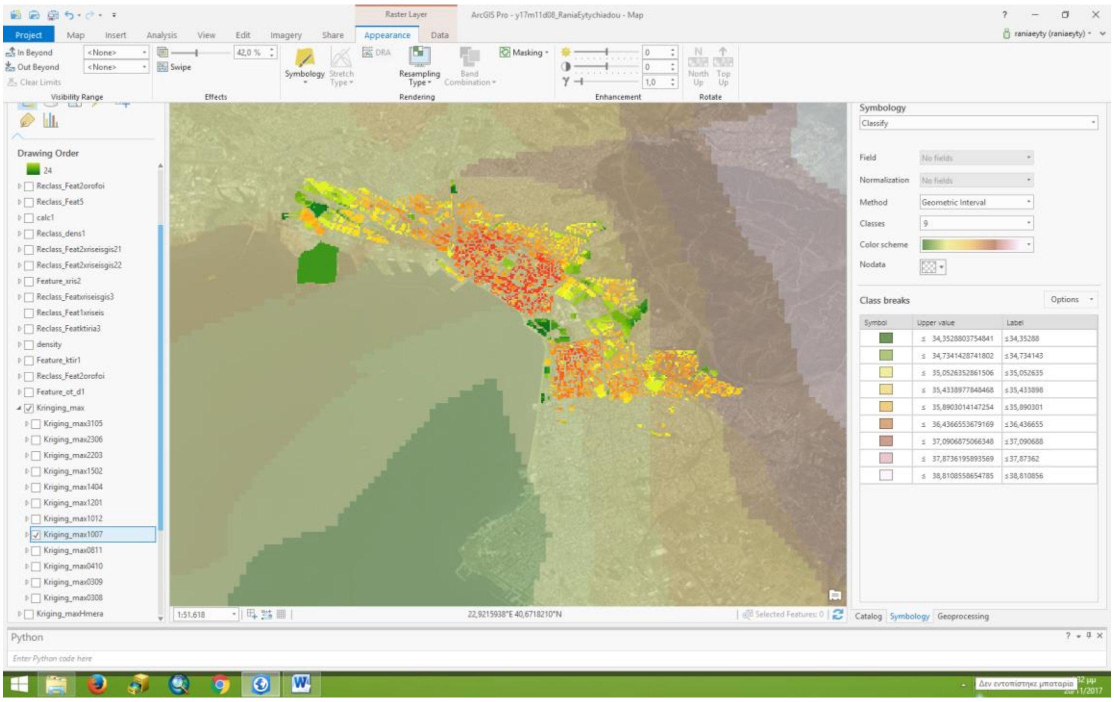
(14-04-2016 max temp)



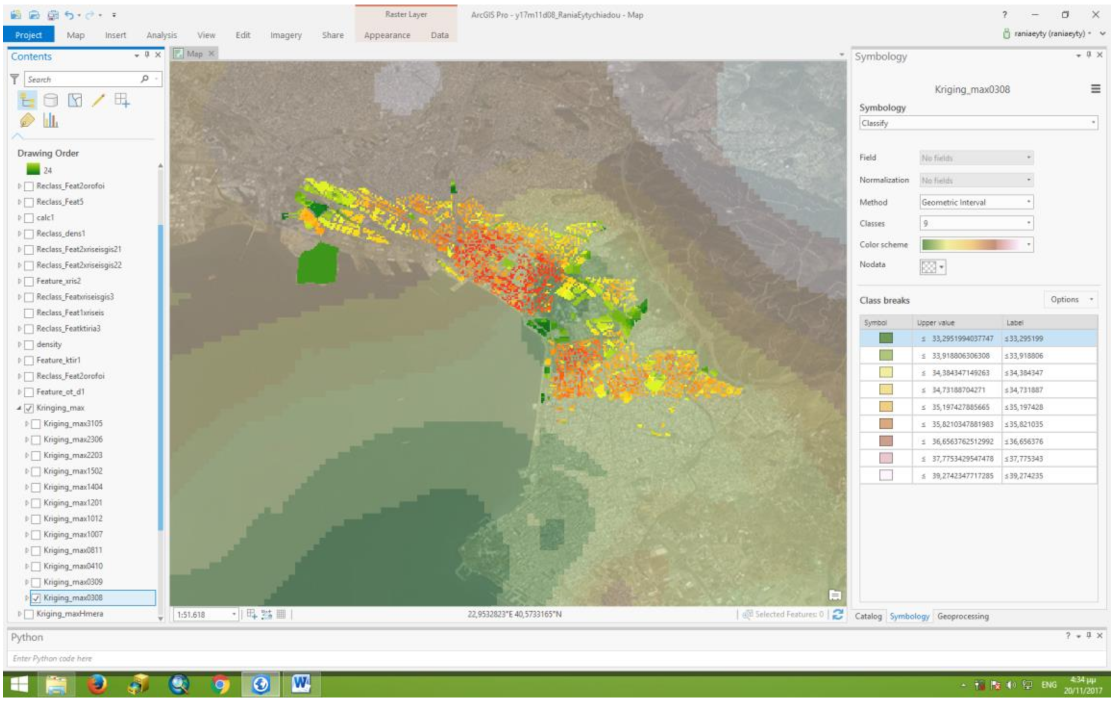
(31-05-2016 max temp)



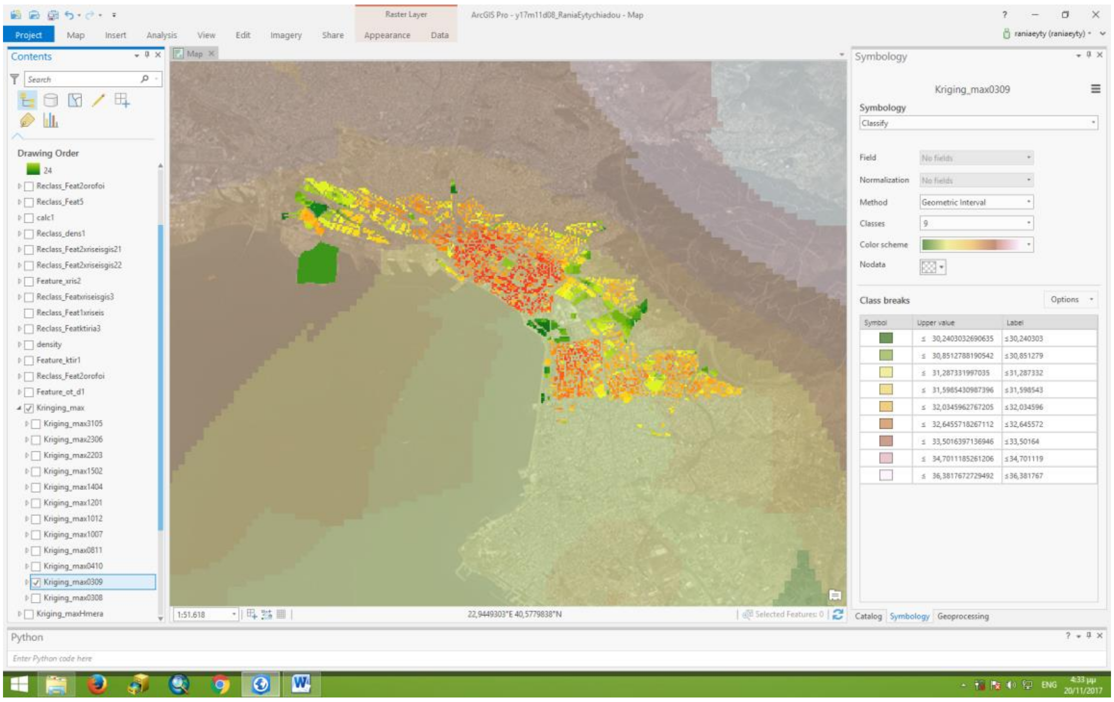
(23-06-2016 max temp)



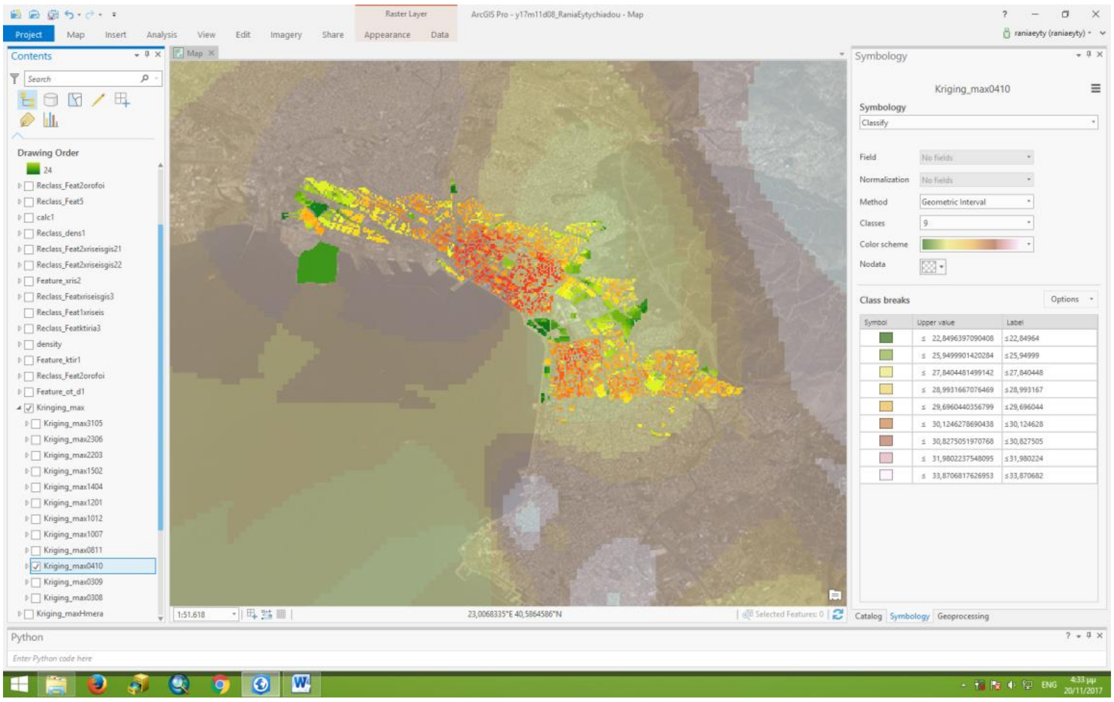
(10-07-2016 max temp)



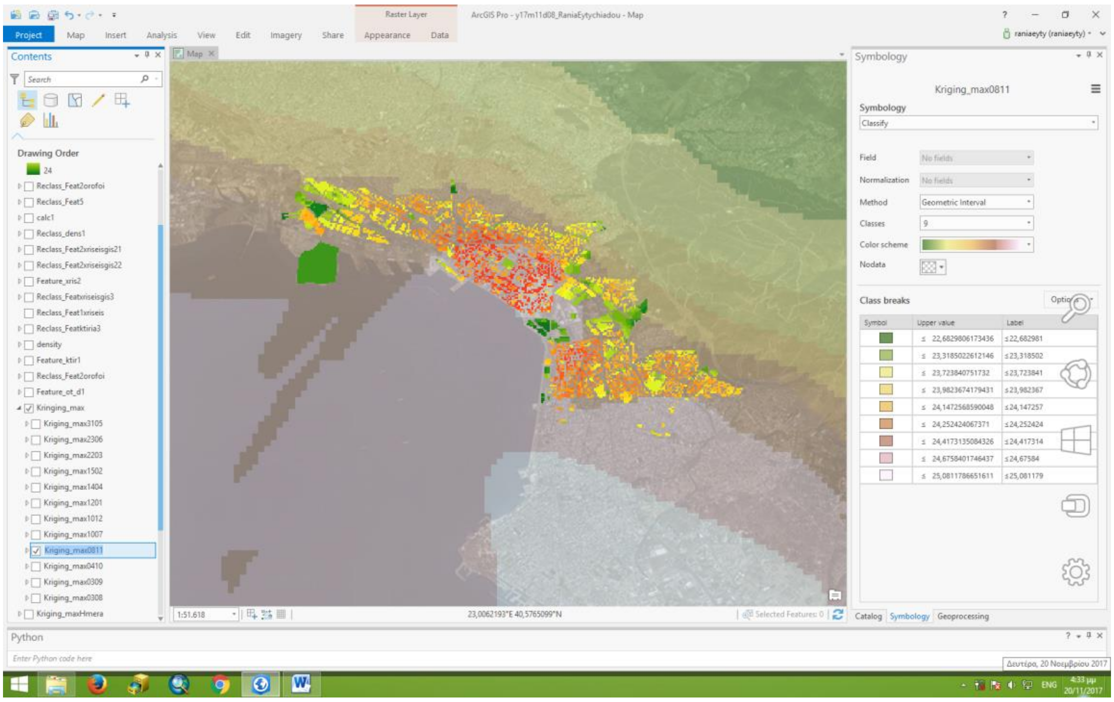
(03-08-2016 max temp)



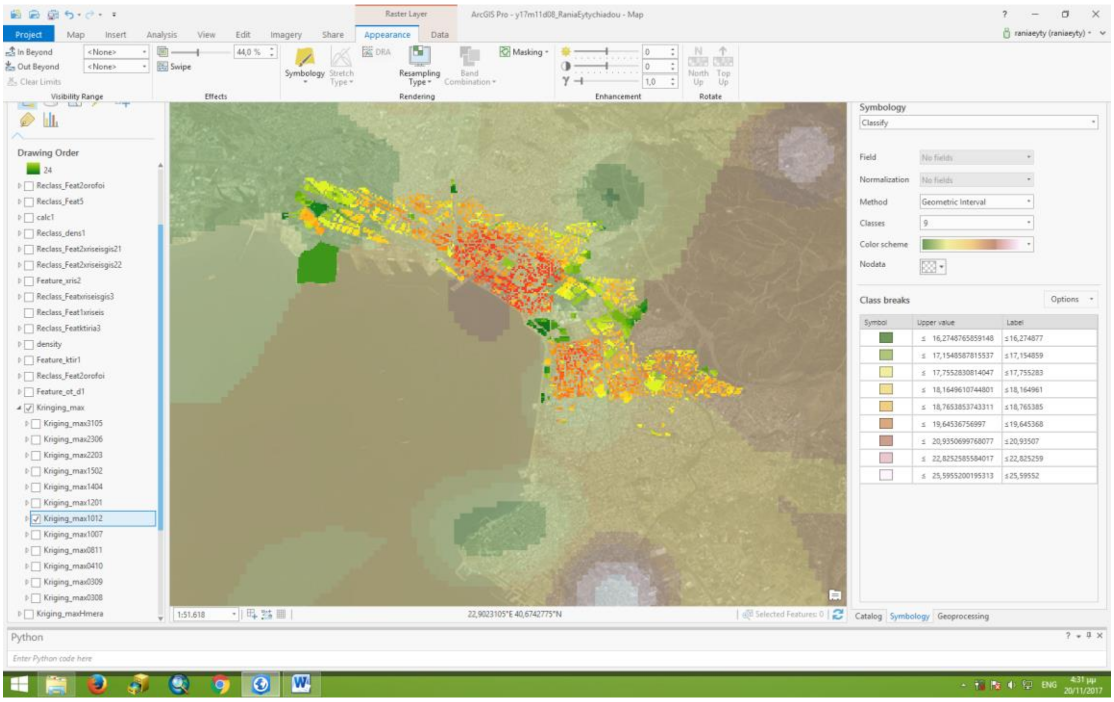
(03-09-2016 max temp)



(04-10-2016 max temp)



(08-11-2016 max temp)



(10-12-2016 max temp)