Strategies for Mitigating Urban Heat Island Effects in Cities: Case of Shiraz City Center

Abdollah Mobaraki

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Urban Design

Eastern Mediterranean University
February 2012
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Urban Design.

Assoc. Prof. Dr. Özgür Dinçyürek
Chair, Department of Architecture

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Urban Design.

Assoc. Prof. Dr.Beser Oktay Vehbi
Supervisor

Examining Committee

1. Prof. Dr. Naciye Doratli
2. Prof. Dr. Şebnem Önal Hoşkara
3. Assoc. Prof. Dr.Beser Oktay Vehbi

ABSTRACT

In the late years, urban heat island became one of the important problems generally in big cities as a part of climate changes and is a sort of reflection of global warming in local scale. As an outcome of global warming, urban heat island has negative effects on public health, quality of life and energy consumption.

Urban heat island is temperature difference between urban and rural areas. This difference occurs due to the increase in population and urbanization process of the cities with the increase of the asphalt and built –up surfaces and accordingly decreasing the green spaces and evaporation surfaces. Not only the higher population, but also the increase in the industrial and commercial uses and dense vehicular traffic also affect the intensity of urban heat island in the city centers.

According to the literature review, there are two main factors that increase the urban heat island in cities. These are city parameters and meteorological parameters. Consequently, intensity of urban heat island shows difference in each city according to the physical, morphological characteristics such as location, size, and density of their built-up areas, land uses, population and air pollution together with climatically characteristics.

Today, Shiraz city, which is one of the biggest cities of Iran after Tehran, is under the pressure of rapid urbanization and population increase. Thus, the main aim of this study is to determine the impact of the factors that increase the intensity of urban heat island in Shiraz city center. Based on the main aim, the thesis has been organized as four chapters. In the first chapter, introductory part is given, and then in the second chapter the urban heat island, its types, causes and mitigation strategies has been reviewed. Consequently, in the third chapter the urban heat island in Shiraz city center is analyzed based on selected four districts around it. These four districts are selected due to having higher population size, building density, industrial uses and less green surfaces. In the last section conclusion and recommendations are given.

As Shiraz developed rapidly, hard surfaces replaced with green ones. These hard surfaces, industrial and commercial uses, dense traffic and high population size in the city produce high amount of heat especially in the newly developed districts around the main center. In order to reduce the intensity of urban heat island in Shiraz, strategies for building and urban scales are developed based on the literature review. These strategies are using more green elements, albedo materials in the city and on the building's vertical and horizontal sections.

Keywords: Urban heat island, city parameters, density, urban geometry, Shiraz.

ÖZ

Son yıllarda, kentsel ısı adası özellikle büyük kentlerde değişen kent ikliminin bir parçası olarak ve küresel iklim değişiminin yerel ölçekte ortaya çıkış halidir. Küresel iklim değişimi gibi insan ve diğer canlıların sağlığı, insanların yaşam kalitesi ve enerji tüketimi üzerinde olumsuz etkiler yaratmaktadır

Kentsel ısı adası kent merkezleri ile kırsal alanlar arasında oluşan ısı farkıdır. Bu ısı farkı kentlerde yaşayan nüfusun artması ile yeşil alanların ve buharlaşma yüzeylerinin azalması ve beton ve asfaltla kaplanmış yüzeylerin, yapısal alanların artmasıdır. Sadece nüfus artışı değil, endüstriyel, ticari yapıların artması ve araç tarfiğinin de yoğunlaşmasu kent içindeki ısının artmasına neden olmaktadır.

Kentsel ısı adaları konusunda yapılan çalışmalar incelendiğinde, kent içindeki ısı adasının oluşmasında iki önemli unsure vardır. Bu unsurlar, kentin fiziksel özellikleri ve meteorolojik özellikleridir. Kentsel ısı adalarının yapısı, büyüklüğü ve etki alanı her kentin kendine özgü fiziki özellikleri, morfolojisi, kültürel ve sosyo-ekonomik yapısı, arazi kullanış biçimlerine bağlı olarak farklılık göstermektedir.

Günümüzde, Iran'ın Tahran'dan sonra ikinci büyük kenti olan Şiraz kenti hızlı kentleşme ve aşırı nüfus artışı baskısı altındadır. Bu araştırma Şiraz kentinde kentsel ısı adasının ortya çıkmasında etken faktörleri ortaya koymayı amaçlamaktadır. Bu amaca bağlı olarak çalışma dört ana bölümden oluşmaktadır. Birinci bölüm giriş kısmı ve ikinci bölümde ise kentsel ısı adası, tipleri, etkileri ve bunu azaltma

statejileri özetlenmektedir. Ardından, üçüncü bölümde Şiraz kent merkezi ve onu saran yüksek yapı yoğunlu, nüfus, endüstri kullanımı ve az yeşil alanların çoğunlukta olduğu dört bölgede kentsel ısı adasının oluşumuna etki eden faktörler analiz edilmiş ve sonuçları verilmiştir. Son bölümde ise çalışmanın sonucu ve öneriler yer almaktadır.

Hızlı kentleşme nedeni ile Siraz'da, sert alanlar, yeşil bahçe ve orman alanlarının yerini almaya başlamıştır. Bu sert alanlar, endüstri, ve ticari kullamınları, yoğun trafik ve nüfus artışı nedeni ile kent içinde ve özellikle bu kullanımların olduğu alanlarda hava sıcaklığı artışı gözlemlenmektedir. Siraz kentinde kentsel ısı adası yoğunluğunun azaltılamsı için, literature çalışmasından elde edilen bilgiye gore önerilen startejiler bina ve kent ölçeğinde yapılmıştır. Bu öneriler kentte ve bina yüzeylerinde daha fazla yeşilin ve ısıyı yansıtan sert yüzey malzemelerinin kullanılmasıdır.

Anahtar kelimeler: Kentsel ısı adası, kentsel özellikler, bina yoğunluğu, kentsel geometri, Şiraz

To My Lovely Family

ACKNOWLEDGMENT

I would like to give my warmest thanks Assoc. Prof. Dr.Beser Oktay Vehbi for her continuous support and guidance in the preparation of this study. Without her invaluable supervision, all my efforts could have been short-sighted.

Besides, I sincerely appreciate Prof. Dr. Sebnem Onal Hoskara, Prof. Dr. Naciye Doratli and Assoc. Prof. Dr. Mukaddas Fasli for reading the draft of my thesis. I feel honored bound to have them as my jury members

My gratitude also goes to my close friend, Mr. Omid Nasseri, Mr. Mohsen Shojaee Far, Ms. Mojdeh Nikoofam and Ms. Sanaz Saeedi whom help me a lot to complete my thesis.

I owe quit a lot to my family who allowed me to travel all the way from Iran to Cyprus and supported me all throughout my studies. I would like to dedicate this study to them as an indication of their significance in this study as well as in my life.

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Chapter 1

INTRODUCTION

1.1 Background and Significance

Urbanization negatively affects the environment strongly through producing the pollution, the modification of the chemical and physical parts of the atmosphere, plus the soil surface covering on the ground. Referring to be a collective effect of all the impacts is the UHI modified as the increase in temperature of any human-made place, concluding in a well-defined, separate "warm island" among the "cool sea" defined by the lower temperature of the locations next to natural lands. Great different level of temperature verification is being found between urban and suburban places after the sun sets down, due to heat releasing from buildings, streets, and other constructions, which were absorbed during the day. However, heat islands might form on any rural or urban places, and at any distance scale, cities are favored, due to their surfaces are prone to remove big amount of quantities of heat. Knowing these, the UHI negatively affects the residents of urban-related environments, and people plus their associated ecosystems is placed far from their cities. Actually, UHIs have been connected in-directly to climate change since their contribution to the greenhouse impact, consequently, to global warming.

The urban air temperature is eventually increasing all around the world. Many issues become its reason, like lessening of green spaces, low wind velocity because of intensification of building and changing roads covering coating materials. “This might produce hotness by human energy release as a part of anthropogenic heat and attraction of solar sun energy to dark or gloomy surfaces and facades. This problem in future will be accelerated by the usage of air conditioning that will again release heat to the environment." (Crutzen, 2004). New buildings are replacing with green places resulting in material change, which coating surface of the earth. It affects the attraction of sun energy, plus the changing of the forms of earth surface, that is human-made uneven earth,influence the airflow.

Expecting the fast and huge growth of population in the close future, application of heat island decreasing mitigation to decrease energy consumption and develop vitality and the quality of life in cities become significant.

Various strategies developed by different studies to reduce the temperatures of UHI. It could be accomplished in many different ways; the first primaries are shifting dark surfaces into light reflective surfaces then and improving green elements. Dark color surfaces, like gloomy facades and roofs may attract more heat than bright surfaces that reveal sunlight. Black color surfaces are usually hotter than light color surfaces (up to 21°C) and the extra heat is transferred inside the building, making real need for cooling. Through shifting to light color roofs, buildings could use 40% energy less.

Planting and growing trees will help to cover cities from incoming solar radiation; they even might help to increase evapotranspiration that reduces the air temperature. Trees and plants could decrease energy costs by 10-20%. The concrete and asphalt of our cities cause increasing runoff that decreases the evaporation percentage, therefore to increases temperature.

In line with these initial discussions, the subject matter of this thesis is to determine the factors increasing the UHI effects in Shiraz city center. The research carried out in this thesis is presented in four chapters in total. In the first chapter, the problems related with UHI, aims and objectives of the research, followed by the research questions will be presented. Besides, the overall research methodology will be introduced followed by the significance and limitations of the research. The second part will present literature review through theoretical framework. The third part will be case study data collection, analysis and evaluation and the forth part will be conclusion and recommendations.

1.2. Statement of the Research Problem

One of the main problems in Shiraz today is the uncontrolled, haphazard development of the city. "As cities develop, paved areas, surfaces and buildings substitute with the natural landscape. Gloomy surfaces like parking lots, roofs and roads attract the greatest amount of heat. Large masses of the reinforced concrete and steel structure buildings absorb and produce huge amount of heat, which in turn radiated to the surroundings. Accordingly, in urban areas temperatures can be more above suburban areas" (EPA, 2005).

According to literature review on urban heat island, the commercial centers are mostly some degrees warmer than the areas around cities. The intensity of UHI varies from one city to another but in extreme case; a rural-urban temperature contrast of 20°F (11°C) has been reported (Sham Sani, 1990/1991). The situation in cities/urban areas is obviously more complex, following modification of the atmosphere by urbanization, pollution dispersion takes place in a different manner from that of observed in rural areas. The local climate in Shiraz is moderate, which commonly lies within and above the built-up area. Temperatures are normally high in the central district comparing to the suburban areas around the city and usually greatest by night (Sham Sani, 1990/1991).

Rapid population growth exerts and aggravates pressure on living space with a consequent deterioration in environmental quality. According to statistics, the population of the city- Shiraz- has raised from170,656 in 1956 to1,053,025 in 1996 census, and that is due to the increasing levels of urbanization of the city. The population density in the city also increased because of the increasing number of migrants searching for better working opportunities, services, and facilities (Movahed, 2004). Consequently, rapid changes the city has been occupied by multi-storey buildings and high commercial buildings that dominate the skyline, and they have a dramatic effect on the microclimates of the city (Sham Sani, 1990/1991). The continuous constructions in the city have replaced its lush gardens and greenery. Furthermore, human activities (urbanization) in Shiraz intensify the amount of heat produced (Sham Sani, 1990/1991). Due to the transportation systems, industrial plants, and heating ventilation and air conditioning (HVAC) systems that is installed for cooling the building to lower the internal temperature to suit human thermal comfort inside the buildings, heat production become a primary problem in city. As a result, the urbanization and human activity are major factors in increasing the intensity of UHI and contribute significantly as one of the reason of the UHI.

Shiraz city is one of the Iranian cities that have historical, cultural, social, and economic activities located in the south of Iran. The city today is under the pressure of urbanization and climatically factors. Especially in summers, raised temperatures derive from the using of low albedo material in urban spaces and increasing numbers of buildings and construction in city causes decrease in trees and vegetation. Therefore, in high-density areas air temperatures grows too much. Lack of greenery, generally and low quality of albedo facades in urban spaces are quite important issues of the HI intensity in Shiraz.

1.3. Aim and research questions

One of the significant goal of this study is to determine the urbanization and meteorological (climatical) factors on the intensity of UHI and then to provide strategies both for urban and building scale for decreasing the negative effects of UHI in the case study of Shiraz city center. Urbanization factors that affect Shiraz city center are discussed as city factors, its location, the city size, buildings densities, geometry of urban spaces, topography, land use, wind speed, air pollution and surface water proofing.

Based on this aim, the following research questions will form the framework of the study. This research is going to answer the followings two main research questions as its main task:

- What are the main factors increasing UHI problems in Shiraz city center?
- Which strategies will help to decrease UHI effect in urban and building scale in Shiraz city center?

The answer of the following sub-questions will be dealt with throughout the research to be able to answer these two questions:

- What is UHI?
- What are the causes of UHI?

- What are the factors affecting UHI?
- What are the criteria for reducing the UHI effect?
- How does urbanization process effect Shiraz city center's UHI intensity?
- How will urban heat island affect the Shiraz city center in future?
-

These questions outline the purpose and the scope of this study, which was to determine if a city with green roofs, more vegetation, and albedo materials has an overall beneficial effect of lowering outdoor temperatures within that city. The beneficial effect of lowering the city temperature then will have a decreasing the effect of UHI.

The objectives of this research, therefore, listed as follows:

- To understand the concept of UHI and its types;
- To understand the causes/impacts of UHI in cities;
- To determine the effects of UHI;
- To explore the factors that affects the intensity of UHI;
- To define the urbanization effect in Shiraz city center;
- To determine the strategies for decreasing UHI effect in urban and building scale in Shiraz city center.

1.4 Limitations

According to UHI hazards, Shiraz as one of the metropolitan cities of Iran face with the effect of this 21 century's threat, because of pollution, population growth, urbanization and physical problem of urban environment. Although the pollution of

Shiraz is not as much as Tehran, capital city of Iran, according to population growth in the last 20 years, physical characteristics of Shiraz, the districts around the historic city center led UHI intensity to increase.

Due to the buildings' height, heavy traffic, industrial (factories) buildings that surrounded the main city center, the heat island effect is higher than other districts. Therefore, the districts that have multi storey buildings, high density, commercial and industrial uses will be analyzed to determine the intensity of UHI in city center of Shiraz.

1.5. Methodology

This thesis is basically a qualitative research, since literature survey reveals that most of the researches and studies on UHI are quantitative and this thesis will provide a basis for further quantitative studies and suggestions. The methodology of the study includes literature review, data collection and data analysis. Methodology of the research can be organized under three parts (Table 1.1):

- **Theoretical framework through literature review**
- **Case study application including data collection, analysis and evaluation**
- **Recommendations and conclusion**

This thesis composed of four chapters. Chapter 1 introduces the problem definition and reason for selection Shiraz city center. Chapter 2 includes the **theoretical framework** through literature review on the previous studies and case studies related with UHI effects in cities. The causes, effects and factors that increase its intensity are reviewed in this part. Data are gathered from articles, books and internet.

The **case study application** that includes data collection, analysis and evaluation is presented in Chapter 3. For data collection, this study is based on qualitative and quantitative data from analysis and statistical information that includes physical analyses and observation. For physical analysis, existing maps of Shiraz city have been collected for finding out effects of UHI based on urban parameters in the city. Besides, new maps have been developed for modifying the existing ones. Some statistical information has been used for defining climatical (meteorological) parameters.

Finally in Chapter 4, answers to the research questions that are also the research findings are drawn and **recommendations** are made to decrease UHI effect in Shiraz city center.

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Table 1.1.Methodology of Research

Chapter 2

LITERATURE REVIEW: URBAN HEAT ISLAND EFFECT IN CITIES

2.1. Introduction

This chapter reviews the concept of urban heat island (UHI)'s effect, its impacts, types, causing factors and effects. Also the factors that affect the intensity of UHI is explained. After sources related with mitigation strategies that were used by different cities and then each factors that mitigate the UHI effect is explained such as green roof, vegetation, using albedo material, white pavements, etc. Finally based on the literature review, the strategies/factors in urban and building scales will be developed for decreasing the UHI in cities.

2.2 Overview of Urban Heat Island (UHI)

"Urban heat island is a name to define the heat parameters of atmosphere and surfaces in town and cities to compare with suburban areas." (Voogt, 2005). HI (heat islands) are the reason of urbanization, when roads and paved ,buildings, covering facades gain the heat in day, then gently release it in the evening time keeping urban areas hotter than surrounding locations. Urban heat island effect caused by urban materials absorbing solar radiation which cause an increase temperature in the area with respect to neighboring rural areas (Mulik, et.al. 2009, Wan et.al, 2009, Haselbach & Gaither, 2008).

“The urban heat island (UHI) can be described as a pattern of temperatures upper in urban areas than in the surroundings” (Montavez, 2000). “In other words, a heat island is a high density city area which has higher temperature than the surrounding suburb areas” (Wikipedia, 2005). Based on the EPA report (2005): “urban air can be 2-6°C hotter than the surrounding countryside during summer”. In addition, Voogt in 2004 mentioned that, “urban heat island is a condition where unexpected climate changes occur when rapid urbanization took place in the city centers. Moreover, the temperature of various exterior surfaces increases and the city air considerably become warmer in the late afternoon.” (Voogt, 2004)

“The surface of the earth has experienced various changes because of anthropogenic activities over the past half century, including mostly deforestation and urbanization” (Ownes, 1998). In the United States, urban areas have rapidly increased since World War II, because economic growth has increased the housing supply and suburbanization (Adams, 1984).

The urbanization and changes in land uses have consequent in environmental impacts related to microclimate. The natural areas are replaced by hard landscape materials, such as concrete, glass and metal. Natural features, including vegetation, water bodies and soil, increase the retention of thermal energy by a natural mechanism called evapotranspiration (Rodgers et al., 2001), which decreases the thermal energy percentage achieving by surface and heat percentage that is re-emitted into the atmosphere. However, anthropogenic activities have resulted in changes in surface energy balances, with a rising in sensible heat flux instead of latent heat flux (Stull, 1988).

Table 2.1 presents the thermal properties of construction materials, which have larger heat storage than greenery and other natural creatures, resulting in the absorption of a huge quantity of heat energy into urban surfaces in daytime. This absorbed thermal energy is then slowly released in the urban regions between the afternoon and night. This excess heat energy produces urban and suburban temperatures 1°C to 6°C higher than those in rural areas (Rodgers, 2001).

	Density (σ) Kg/m^3	Heat capacity (c) J/m^3 /K	Thermal conductivity (K) W/m/K
Dry clay soil	1.6*10^3	1.42	0.25
Saturated clay soil	2.00*10^3	3.10	1.58
Asphalt	2.11*10^3	1.94	0.75
Dense concrete	2.40*10^3	2.11	1.51

Table 2.1. Physical Properties of Several Materials (Oke, 1987).

The UHI effect exists due to the greater heat retention of buildings and man-made surfaces like asphalt and concrete, compared to the lesser heat retention and cooling properties of vegetation, which is more abundant in the countryside. Urban streets normaly have a few trees and other kinds green plats to cover buildings and cool the air by evapotranspiration. At last, urbanized land shade tends to remain less surface water from precipitation than what natural land support. “The UHI temperature effect can be dignified according to the urban canopy layer, which refers to the space below the rooftops of buildings, and the mesoscale, that refers to local temperature measurement " (Voogt, 2002). Figure 2.1 is a normally used depiction of a "typical" heat island effect on near-ground temperature.

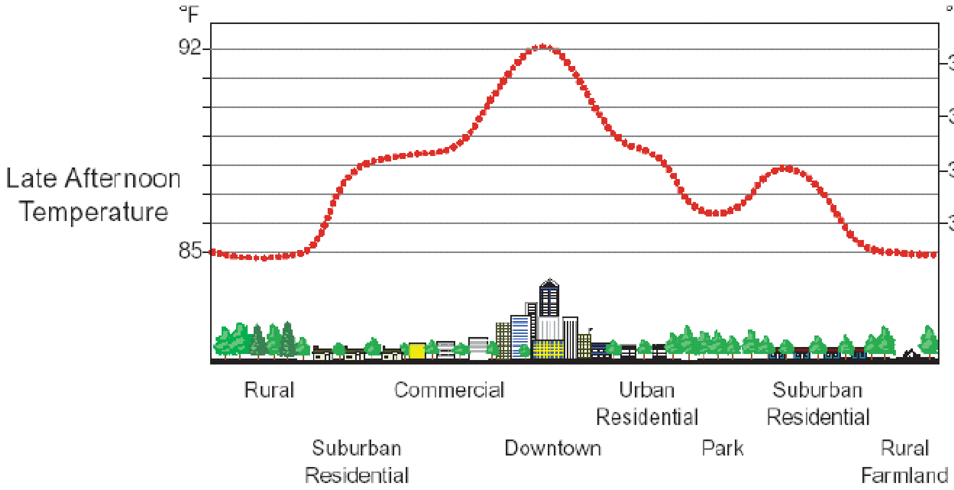


Figure 2.1 Urban Heat Island Profile.
(Source: Estes, 2003)

The atmosphere in the cities that have sources of pollution and heat can also produce a heat island effect. "In a densely built-up areas, it is possible to see the dome of warm air, that is cause of urban heat island (Emmanuel, 2005). Moreover, Asimakopoulos in 2001 mentioned: "the temperature differences between urban and rural (suburban) areas belong to the heat that attract from the streets, roads and the same constructions with dark surfaces during the day and the reflection of it after sunset".The following arguments of Oke and Landsberg (1981) are found important according to the subject of this research. The size , effects and intensity of urban heat island may have variations in different time and spaces that have variety in their regional, meteorological and urban characteristics (Oke, 1987). Therefore, the urban character and metoerological factors of each city have great impacts on the UHI characteristics.

According to Landsberg (1981), the most noticeable climatic indicator of urbanization is heat island that present in all urban fabric in cities. Because of higher temperatures in the cities, the use of air conditioning and as well as electricity demand increase. Due to the usage of this electrical powers in buildings cause the air pollution and increase intensity of urban heat island (Asimakopoulos, 2001).

High percentage of non-reflective surfaces, low percentage of greenery and vegetated, water-resistant surfaces and moisture surfaces cause heat island. Materials like stone, asphalt and concrete, act as trapping the heat at the surface, particularly, (Oke, 1982; Landsberg, 1981) and lack of plants and greenery caused reduction of heat due to evapotranspiration (Lougeay, 1996).

The UHI effect leads to the way that urban surfaces or land covers as pavement and buildings, reflects to solar radiation, mostly during summer. Meanwhile all materials attract the sun radiations, building materials, such as asphalt and concrete, achieve higher rate of solar radiation through the day than natural land cover surfaces do.

"The intensity of the UHI effect is generated by the addition of pollution and anthropogenic heat to the air" (Taha, 1997). Landsberg (1981) also expressed that, because of high population density, city centers have a tendency to use higher energy than surroundings. However, the increasing demand for air-conditioning during the summer months and the reduction of need for heating in the winter are the results of urban heat island effects. Within the usage of electric power and fossil fuel generation, local and regional air pollution was creating an impression. As a result, urban heat island effect may cause an increase energy demand (for air conditioning), cause discomfort or health problems for people. For these reasons, the urban heat island effect is important to study, especially in looking for potential ways to mitigate it. Before giving more detailed information about mitigation strategies, the types, causes and effects of UHI are explained to understand the concept clearly.

2.3. Types of Urban Heat Island

The types of urban heat islands that found from literature review as the **boundary**, **canopy** and **surface** layer heat island (Oke, 1979, Voogt, 2004). In addition, Voogt (2004) explained: "the increasing temperature of the urban air settings refers to the boundary and canopy layer heat islands. The HI (heat islands) happens in various layers or parts of the urban atmosphere" (Figure 2.2).

2.3.1 The Canopy Layer

"The urban canopy layer happens in the canopy layer heat island" (Voogt, 2004). "This refers to the buildings which the layer of air neighboring to the city surface extending up to their average height" (Voogt, 2004). The canopy layer including air between the roughness items such as streets with an upper boundary exactly under the roof level. In UHI studies, canopy-layer air temperatures are usually measured at about the height of people or the lower stories of buildings, between 1.5 and 3 m above ground. If that temperature is warmer than the temperature at the same height in nearby rural areas, then this is termed a UCL heat island (Oke, 1976, 1995).

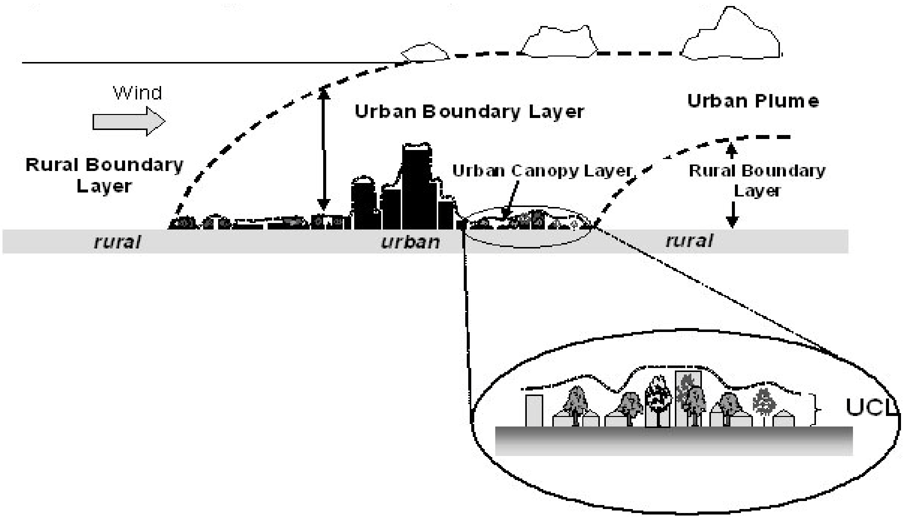


Figure 2.2: The Layers of the Urban Atmosphere.
Source: http://www.actionbioscience.org/environment/voogt.html

2.3.2 Urban Boundary Layer

The heat island (HI) that forms in the boundary atmospheric layer above the city is the **urban boundary layer (UBL) heat island** (Oke, 1987, 1995). "This atmospheric layer could range from 100 meters in thickness at night to one kilometer during the day in composition" (Voogt, 2004). "The canopy layer is located at the bottom of boundary layer, with the higher influence of boundary subject to the urban surface" (Weng & Taylor, 2003).

2.3.3 Surface Heat Island

The remotely sensed UHI. It is surveyed by using thermal infrared data, which allow to compensation of land surface temperatures. Normally, the relationship between the near surface air temperatures and land surface temperatures have found so close. Thus, the surface UHI is a trustable indicator of the atmospheric UHI.

In order to find out urban heat island effects in cities, UC layers that consist of surfaces of buildings, the street, the enclosed air volume, the open air space at roof level and roads can be studied in local level.

2.4. Causes of Urban Heat Island

Urban heat islands are caused mainly due to the reduced radiant heat loss to the sky from the ground level of densely built urban centers. Most of the radiation is emitted from the roofs and walls of upper story of buildings and lack of greenery in urban spaces and on the building surfaces.

The weather conditions and geographic location of cities as well as their urban characteristics affect the development of UHI in cities. The Heat Island Group (2005) also has mentioned that: "presence of more gloomy urban surfaces, absence of vegetation and urban geometry are three main causes of UHI".

2.4.1 Urban dark surfaces

Because of reflectivity or low "albedo", gloomy surfaces contribute to HI (heat islands) (Voogt, 2004). According to the Heat Island Group: "albedo is a kind of material which reflects more sun-light than the dark surfaced materials." Covered land uses and buildings with gloomy and dry surfaces, absorb sunlight. This produces thermal energy, causing the surface to become hotter". To complete the above statements Voogt (2004) believed that, natural ground and forest with light and dry surfaces, have a high albedo also they have a cooler surface temperature, because, they reflect sunlight. Besides, a report in EPA (2005) stated, "the low quality of albedo materials is the main result of heat island effect. The heat that is kept in gloomy/dark surfaces is the main consequence of temperature raise." For more obvious view Figure 2.3 shows the albedo values of some usual surfaces in the urban areas.

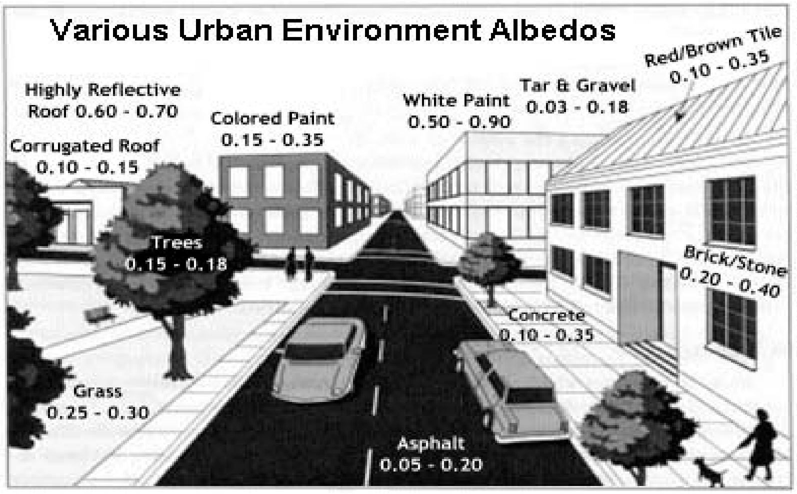


Figure 2.3: The Albedo of Some City Surfaces.

(Source**:** http://www.ghcc.msfc.nasa.gov/urban/urban_heat_island.html)

2.4.2 Lack of Vegetation

It is also obvious that the continuous increase in built-up surfaces, throughout urbanization, constitutes the main reason of UHI formation. Using green surfaces for built-up activities has negative impact on two cooling mechanism: shade and evapotranspiration. Shade and evapotranspiration cools the atmosphere (Fig. 2.4) by blocking the sun radiation from the low albedo surfaces and by the absorbing the water in the leaves also help to remove heat from the air (The Heat Island Group, 2005).

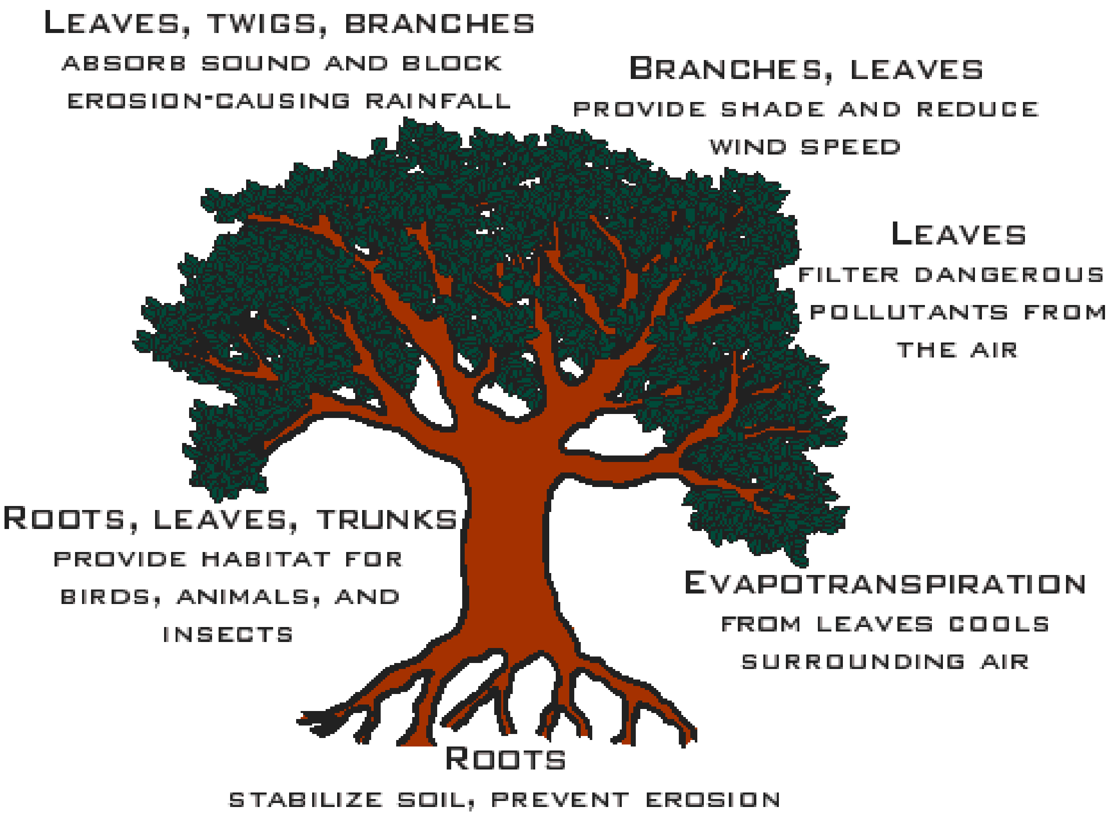


Figure 2.4: A Sample of Different Functions in Environmental Regulation, And Climate Controlling
(Source: Estes, 2003)

According to Oke (1991):

“(a) As a result of interchange between screened skyline and buildings canyon radiative geometry cause to remove the lack of long wave emission from street canyons. Several road and building surfaces in the middle of canyons feel the radiation

(b) The heat which generated by gloomy (dark color) surfaces during the day, the façade material of buildings and pavements are important because this heat will re-emit to the atmosphere above the city during the night. Moreover, the reduction of vegetation due to the replacement of buildings and streets with natural landscapes cause to decrease air temperature through transpiration and evaporation.

(c) Anthropogenic heat is produced by animals, human beings and as well as other stationary sources.

(d) The effective albedo of the system is decreased by canyon radiative because of the double reflections of the short-wave radiation by the canyon surfaces.

(e) More energy is putting into latent and sensible heat by the reduction of evaporating surfaces.

2.4.3 Urban geometry

Urban geometry indicates the amount of buildings' space and dimensions within a city, which is a supplementary parameter that affects urban heat island growth, especially at night. Wind flow and energy absorption are affecting the intensity of urban heat island. The air temperature in city centers is higher than the rural areas, especially at night (CPPD, 2008).

CPPD researchers (2008) sometimes concentrate on a direction of urban geometry named urban canyons that could be illustrated by a relatively narrow road lined by tall and large buildings. In day times, urban canyons could have comparing effects on one side; tall buildings could make shelter, decreasing surface and air temperatures (Fig. 2.5). On the other side, when solar radiation received from surfaces in canyon, the sun energy is reflected, after that it will be attracted by building exterior wall which later decrease the urban/city overall albedo and could raise the temperature.

Figure 2.5: High Rise Buildings in Dallas Downtown
(http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf)

Asimakopoulos et al. (2001) states that: human activities in different types, for instance, loss of vegetation (deforestation) or changing the use of surfaces form greenery to buildings, highways; are capable of influencing the climate. On a local scale, it is vital as well, because they transform the albedo, thermal and moisture performance and surface roughness.

As a summary, Asimakopoulos (2001) expressed the following: as the causes of UHI roots,

- The complex exchange of heat between buildings in urban streets which act as canyons retaining heat.

- The thermal properties of buildings materials that kept the heat within the fabric of urban areas.
- Heat released from combustion of fuels, and animal metabolism.
- The urban greenhouse effect, helps increase the heating effect of the incoming radiation on the polluted and heater urban atmosphere.
- Reduced evaporative cooling due to impervious surfaces.
- Turbulent transfer of heat, by air movement, from within streets is reduced.
- Reduced vegetation due to ever increasing demand for land.

2.5. Effects of Urban Heat Island

Urban environmental features can threat the viability belonging to the locations such as where the less number of people would prefer to be in built-up areas, and downtowns for other uses such as commercial, residential, or entertainment. “These changes in the preferences of the people make them to migrate and this result an urban expansions in many cities. Due to the migration of these people from the city centers, these areas become stable for years (Estes et. al. 2003).

As has been occurring in many developing countries, UHI events affect the local nature and population in different ways, including the quality degradation of air, hazards to public health and switch the meteorological situations.

2.5.1 Air quality

“Increased daytime temperature, reduced night time cooling, and higher air pollution levels with UHI can affect human health by contributing to general discomfort, heat and exhaustion and health-reflected mortality. Heavy traffic (motor vehicle) are leading source for air pollution. As temperature increases, the demand for energy to power air-conditions requiring power to increase their output. In summer time, the demand results in higher emission of the pollutants they generate and leads to have air pollution” (CCPD, 2008).

“The UHI effect can elevate the air temperature, work as stabilizer effect to sun radiation and may subsidize to formation of ozone. If urban heat island can be mitigated, the important reduction of ozone level will be the result. This can reduce the budget for greater knowledge of relationship between urban heat island and ozone levels” (CCPD, 2008).

2.5.2. Public health

Rise in air temperatures are not bringing just un-comfortability but could make temperatures down from hot to a real hot point, which is dangerous for public health. “Low quality of air and high temperature is particularly harmful for elderly people, disables and children. But for healthy people low quality of air and extreme heat can play as a harmful hazard for good health and physical situation.” (Oke, 1981)

2.5.3 Global warming

The UHI events potentially contribute in the global warming. High hot temperature rate needs the higher electricity demand for air-conditioning, that later increases the nitrogen, sulfur, and specific matter in the air. The big amount of greenhouse gases occurred due to the high-energy production that is also reason for larger scale climatic effects on the process of global warming. (Oke, 1987)

2.5.4. Meteorological effects

Urban climates and local meteorological conditions are one of the determinants of urban heat island. Additionaly, urban heat island creates natural storms that are often intensively move throughout cities. According to Lyman, “moderate rainstorms may turn into full-blown thunder and lightning storms. Houston, for example, has realized a 40 percent increase in lightning strikes. Lightning frequency is not seasonal but it is due to the result of the urban heat island effect and air pollution regarding the researchers finding (Lyman, 2002).

2.6 Factors affecting the intensity of UHI

“Urban heat island intensity depends on the amount or number (population) of people living in the area, morphology and size of the urban area. The changes between the maximum city temperature and contextual suburban temperature introduced as urban heat island intensity (UHII)” (Terry A.Ferrar, 1976, Oke, 1982).

Urbanization in terms of increased urban density and increased use of automobiles, increased impervious surfaces has resulted in increased urban temperatures. The temperature elevation in the center of the cities is the largest during the nights, conveying that the heat island phenomenon is nocturnal phenomenon. “UHI is a phenomenon in which the urban temperature is higher than its surrounding rural regions which may happen in between the day or night” Givoni (1998). He (1998) also pointed out the following points: “during clear and still-air nights the biggest differentiation of the urban temperatures occurs like about 3 - 10°C. Besides, according to Bonan (2002), high density, mix use areas are about 5 to 7°C hotter than surroundings districts that have single use with less density. According to him, the city centers in many urban areas are 2°C warmer than sub-urban areas. There are several items that influence the temperature rising in cities. Consequently, UHI could be separated into two groups which is made by variety of issues: (1) **meteorological parameters**, like wind speed, cloud cover and humidity; (2) different factors of the urban structure (**urban parameters**), like the size of cities, the built-up areas density, and the buildings' heights ratio to the distances between them and population size, anthropogenic heat and urban canyon could strongly affect the size of the urban heat island.

Chandler (1976), Landsberg (1981) and Oke (1982) also mentioned vegetation cover, water body of the city, population size, speed of wind, topography, anthropogenic heat, water overflow are the main city and meteorological parameters that increase the intensity of urban heat island.

Table 2.2 shows and classifies these items and factors (as mentioned before) in brief and defines the influence on UHI. Since the main goal of the thesis is to define the factors on the formation of UHI effect in cities, the following section explains each factor in more detail.

Table 2.2.Effects of Meteorological Factors and Urban Parameters on Urban Heat Island

(Oke, 1981)

2.6.1. Meteorological Factors

Meteorological factors include temperature, precipitation, humidity, wind and sunlight. Because of current meteorological situations companied with size of HI companied with pollution intensification in cities, and high percentage temperatures could guide to upper stages of smog formation and lower wind speeds may cause pollution over the city atmosphere.

“In cities cloud cover, the air temperature and rainfalls are higher than suburban areas the wind speed in low but gusts are regular. The ground level air quality will decrease because of low wind speed and inadequate air interchange” (WHO, 2004) and increase the percentage of UHI formation over the city.

2.6.2 Urban Parameters

Deterioration of the urban environment is resulted by the rapid development of urbanization, increasing population and industrialization. “Deficiencies in development control have important consequences for the urban climate and the environmental efficiency of buildings. Increasing densities are referring to reduction in the size of housing plots, and the potential for traffic congestion and the replacement of buildings with natural landscapes” (Asimakopoulos et al. 2001).

“Actually, urban climate can be affected by the physical structure of the urban areas and this has impacts into the increase of urban heat island intensity (UHII)” (Santamouris, 2001). Therefore, the urban climate differs from the climatic conditions of the surrounding rural areas and it is essential to describe the mean features of it. The general effects of urban structure on its climate can be divided in the categorized groups in the following way:

2.6.2.1. Location of the city

"Topography, wind speed and direction, temperature, humidity, fog, precipitation, inversion prevalence varies in different location of specific region. The main cause of differences in these variations are the length between city and sea, height from the sea level, bearing of slopes, and the situation and the topography of urban area" (Givoni 1998).

2.6.2.2 The size of the city and population

Increasing the size of the urban areas, moving the large amount of people from the suburbs to the urban areas are causes of urbanization. Standard of living such as vehicular traffic, air conditioning in the summer, intensity in the use of electrical power for heating in the winter, and industrialization plus the density and size of the population are the reasons for the urban heat island phenomenon. As described before by Oke (1982) "the intensity of urban heat island and the population of the city have a direct relationship. Accordingly there is a direct relationship between higher population in cities and the heat island intensity."

2.6.2.3. Density of built-up area

Local climate in each discrete of urban areas affects the density of the several built-up surfaces. Givoni (1998) states that two types of factors affect the temperature variations between the urban and the rural areas; (1) the cloud cover, humidity, and wind speed that are **climatic factors**; and (2) the size of cities, building density, and the relation of buildings' heights in compare with the distance between them that are the **city parameters**. In addition, "Other parameters can also affect UHI formation like high density, shading and inappropriate orientation. If proper interventions are advised and implemented in the city planning decisions, better climate conditions can be handled" (Che-Ani, et. al. 2010).

2.6.2.4. Urban geometry

"The repetition of urban canyon is characterized the urban (city) geometry of a city." (Emmanuel 2005). "Pollutant dispersion studies, energy consumption of buildings, heat and mass exchange between the buildings and the canyon air are important and depend on air circulation and temperature distribution within urban canyons" (Asimakopoulos et al. 2001).

Emmanuel (2005) describes the definition for urban canyon as the three-dimensional space bounded by a street and the buildings that enclose the street. Urban canyons restrict the view of the sky dome (characterized by the sky view factor SVF), cause multiple reflection of solar radiation, and generally restrict the free movement of air (Fig. 6).Building height and the street width ratio helps to define the geometry of the long urban canyons.

2.6.2.5. Thermal properties of fabric

According to some of the authors (Landsberg 1981; Oke 1982; Quattrochi, 2000) "stone, concrete, asphalt and the gloomy materials have a tendency to hold heat at the surface". Akbari (1997), Taha (1997), Konopacki (1998) were all agreed on: "These kinds of materials attract the solar (heat) radiation during the day and retain it in urban fabric at night; urban surface released this stored heat slowly. The correct and the useful albedo is the one that is absorbing less amount of solar radiation. In the urban area where there have been, use of high albedo material in building exterior surfaces (white ones); it is proven that these materials decrease the urban temperature.

2.6.2.6. Surface waterproofing

On one hand, UHI increases due to the lack of porosity materials in urban surface, great number of water-resistant surfaces and non-reflective surfaces, on the other hand evaporation decreased in the city according to lack of vegetated and moisture trapping surface. Goward et. al stated that, green areas and soft landscaping elements are regulating the surface temperature, more than gloomy and low-albedo materials in surfaces (Goward et al. 1985) and “evapotranspiration reduce heat lost due to a lack of vegetation” (Lougeay et al. 1996).

2.6.2.7. Anthropogenic heat

“Anthropogenic heat further contributes the UHII’s effect into the urban atmosphere” (Taha 1997). As a result of high population density, an urban center seems to have higher energy demands than suburban areas. However, Landsberg (1981) believed: “high demand for energy in the winter is the result of the heat island effect that is increasing due to the demand for air-conditioning through the summer- time”. Beside Oke (1982) believed that: fossil-fuel burning and electric power generation in local and regional urban areas cause high percentage of air pollution.

2.6.2.8. Air pollution

In general, wide ranges of pollutions are generated in to urban areas. Smokes from the cars, industrial activities and air conditioners are three most important sources of air pollutants. Variations of the contribution of industrial sources to air pollution from one urban area to another occur due to the type and the number of the industrial facilities in a town or city.

2.6.2.9. Landuses

Different types of land uses have different impacts on heat island. Especially industrial and commercial zone and their inappropriate locations generate high temperature in the cities. High densely populated areas, surroundings and commercial areas can be considered as the most significant parameter to produce heat.

2.6.2.10. Wind speed

The UHI intensity increase because of warm air stagnates in the urban canyon due to the high density building and low albedo surfaces constrain evaporation which is also prevent to have good wind speed in the city.

As stated above the characteristics of the UHI are related to both the intrinsic nature of the city, such as its size, population, building density and land uses, and external factors, such as climate, weather and seasons (Oke, 1982). Also, there is a close relationship between UHI intensity and population (Landsberg, 1979; Lo and Faber, 1997).

Figure 2.6 shows this relationship for European, Australian and North American cities. The geographical locations of cities are important, including the nature of soils, the presence of water, topographical features, vegetation and land uses. There is also a relationship between UHI intensity and area city size (Oke, 1982).

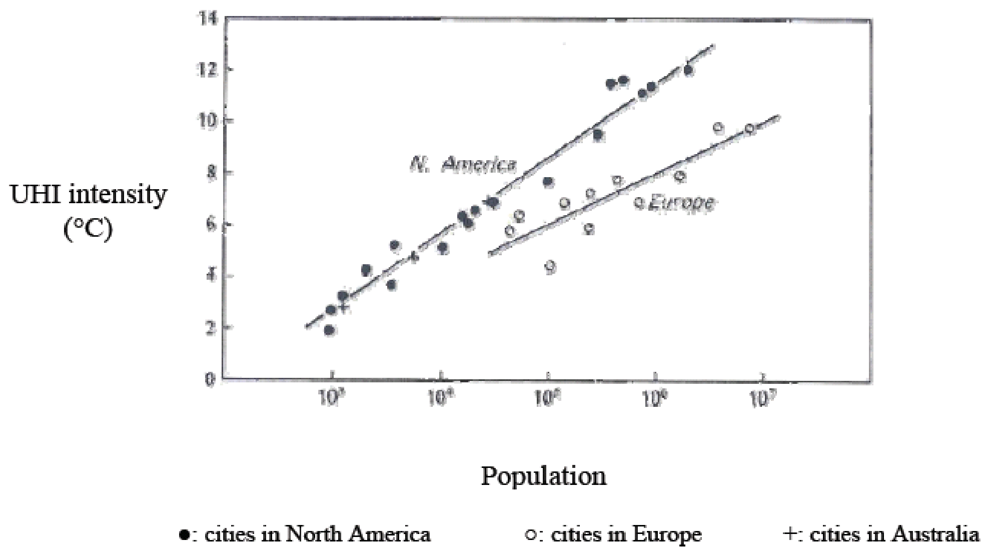


Figure 2.6. Relationships Between Maximum UHI İntensity and Population (Landsberg, 1979).

Urban heat island is mainly affected by the two factors, urban parameters- pattern and structure, density, location of the city and climatic issues such as increasing temperature, reducing humidity and wind rate can also be major factors on formation UHI. Therefore, in the following section the UHI mitigation strategies are review in order to decrease UHI effects in cities.

2.7. Review on the UHI mitigation strategies

In order to find mostly used mitigation strategies by different countries, it is aimed to make review related with this topic. Therefore, different authors' mitigation strategies and their aplications on different cities are explained in this section.

Several studies have focused on methods to minimize the effect of the UHI. Two major factors must be considered to improve the urban environment: **albedo** and **vegetation**. Bretz et al. (1998) examine the effect of highly reflective materials in decreasing the absorption of solar radiation. According to Taha et al. (1997), "the impact of a 15% increase in albedo would be a decrease in air temperatures of approximately 2.8°C over the central areas of Los Angeles. Also, a 15% increase in vegetation cover would lead to a similar result. Finally, the results show that simultaneous increases in albedo and vegetation cover would decrease air temperatures by 2-5°C over the Los Angeles urban region".

Vegetation in urban areas reduces the UHI effect and the amount of energy needed for cooling. Shaw and Bible (1996) provide a general overview of this approach. Akbari et al. (1997) also conclude that "vegetation clearly has an important role for urban temperatures and energy use. Trees intercept rainfall, mitigate pollution and reduce wind speed." They also provide shaded areas and decrease temperature by evapotranspiration. More detailed research about the effect of vegetation on the balance of surface energy is available in Grimmond et al. (1996).

There is likely to be a relationship between the amount of trees and energy consumption (Sturman, 1998). However, it is very difficult to uncover this relationship (Kjelgren and Montague, 1998). The thermal properties of the surrounding environment have a large effect on the response of trees. For example, higher temperatures on asphalt surfaces cause decreased evapotranspiration from leaves. In other cases, some plants emit biogenic hydrocarbon, which leads to an increase in ozone concentration, although the reduction in temperature would decrease photochemical activity (Sturman, 1998).

New urban development design (urban geometry) should then be a compromise between the environmental engineers, architects, and urban planners. It is very crucial that these professionals are educated about the importance of climatic factors for urban design and planning (Evans and Deschiller, 1996). Cooperation or consensus building through discourse and education must be achieved, because technical issues cannot be separated from social, economic, and political issues, and stakeholders who have different viewpoints must engage in analytical reviews and decision-making processes.

Corburn (2009) reports on “such a co-production in the case of the UHI in New York City, which has contributed to a more scientifically legitimate decision-making process that is publicly transparent and accountable for”. Golany (1996) describes “a set of basic factors that can be used for an urban design that is **thermally efficient, including the site selection of individual dwellings and an urban layout for a given climate**.” Adjustments should be made in response to the prospective impacts of several factors, such as airflow and shade.

Asimakopoulos (2001) mentioned that “**the urban geometry (design and construction of urban buildings and its components)** are parameters that have negative affect on energy usage. These factors are listed as**:**

(a) The pattern and mode of the main transportation network with a specific orientation. For implementing solar energy saving techniques, the pattern where building located on both side of the street is not suitable.

(b) The space between the building to building and the ratio of the building height to the street width, are the factors may create a long shadow, which do not help to have solar energy inside the building.

(c) The size of building plot, which can control the size of the building and interior spaces can be located on the south direction.

(d) The height of the buildings that can act as a curtain wall in densely built urban centers they result to have airflow and sunlight.

(e) The replacement of vegetation by concrete and tarmac cause lack of greenery

(f) The energy demand increase when the building principles and codes that in many circumstances gives permission to have tall and bulky buildings form on a plot.

It must also be mentioned that less intensive winds and higher temperature are causes of UHI effects. In addition, UHI formation can directly affected by inappropriate orientation, high density and lack of shading elements. A need for air conditioning especially in hot summer times and cold winter times increase the need for energy and produce pollution (Shahmohammadi, 2011).

After making a research on mitigation strategies in general and also depending on the main aim of this thesis, the following section aims to determine the mitigation strategies for decreasing the UHI effect both at urban and street scales for cities without changing their existing planning systems.

2.8. Strategies for mitigation UHI effect in urban and building scales

While many factors contribute to urban heat island formation (see Table 2.3), this section focuses on mitigation strategies such as vegetative cover, urban geometry and surface properties because they have positive effect on decreasing energy consumption and as well as UHI in urban spaces.

Based on the research about the mitigation strategies, it has been decided to divide the UHI mitigating strategies into two scales: urban and building scales.

This thesis focuses on three main strategies- providing more vegetation, using albedo materials and careful design for newly constructed buildings- in each scale regarding to the literature review in section 2.4 and 2.7. The combination of these two categories helps to decrease UHI effects in urbanized cities (Table 2). In the following sections, these strategies will be presented according to the above considerations.

2.8.1. Providing landscape elements in urban and building scale

Energy consumption reduction has been provided in urban and building scales to provide an appropriate landscape that also decreases UHI effects with a biologically related solution to reduce urban heat by the usage of vegetation. “Vegetation provides important shading effects as well as cooling through evaporation. Some examples include (Che-Ani, 2010):

- Providing shade around individual buildings by trees and vegetation to reduce their temperature especially roofs, east, west and south sides of the building. This may cause to reduce air conditioning for interior of the buildings

- For parking lots, roads and other open spaces vegetation and trees can also be affective to reduce the heat, which can reduce the re-emitted heat at night.

- Location of cars under shading parking areas will help to decrease evaporative emissions that contribute to raise the level of urban ozone

In order to improve the external climatic conditions, it is necessary to provide landscaping the surrounding area. As stated by Asimakopoulos et al. (2001), "trees generate shading that;

(1) Reduction the penetration of sun radiation to the facade.

(2) Reduce energy usage for cooling.

(3) Decline the amount of the heat coming to inside of the buildings in order to create shaded surfaces with a lower temperature.

Sailor (1994) mentioned that increase in UHI depends on low evaporation of heat in urban areas. The heat balances can change to new levels, if vegetation is located on urban surfaces. Moreover, in various locations of urban areas buildings and construction must be located in natural landscape and vegetation, the same as bodies of water to cause energy consumption reduction. Hence, most of the cases recommend using green spaces in different layers. Therefore, most of the cases supposed to use green elements in vertical and horizontal sections of buildings.

2.8.1.1. Vertical green spaces on building

Green sections of the buildings as well as cities that supplies natural air-condition could importantly reduce the energy needed for cooling them.

Santamouris (2001) believed in: "When vegetation is located on the built-up surfaces, the temperature in these areas can change to new conditions (cooler environment) that the rural areas have. It is assessed that consumption of energy when water is evaporated from an average tree during a sunny day in summer, this provide a cooling influence in external buildings that is like to five average air conditioners”. Furthermore, Chrisomallidou (2001) demonstrates that urban buildings can be shaded when placing plant on their envelope. She points out that internal temperature has been improved in winter and summer whit utilization of the green roof that even the benefits are great for the interior spaces of buildings. This technique; that usage of vegetation is one of the most efficient ways for decreasing temperatures near, in and on the building facade.

2.8.1.2. Horizontal green spaces (Green Roof) on buildings

Green areas on roofs reflect heat, reduce demands to thermal ventilation and filter air-condition. Reduction of the temperature in cities during hot summer months is provided with the use of greeneries on horizontal and vertical sections.

Ani (2009) point out “the advantages, which are following, could be received with effectively all green roof structure systems:

- According to the building size, climatic condition and type of the green roof energy heating and cooling costs can be saved;
- A green roof would not just absorb heat, however it also strain the air;
- The vertically and horizontally located green elements on the buildings are able to cool cities in summer days. Through this evapotranspiration process, green elements take in and use heat energy from their environment.

2.8.2 Using suitable materials on exterior surfaces of the buildings and urban areas

The characteristic of the facades is an important item on the defining the canopy layer air temperature in the city. Voogt said that, “the temperatures can be low near green areas and high in more densely built up areas. Particularly surface temperature depend on the surface condition which means that white color surface are cooler that gloomy/dark color surface that absorb and store the heat during the day.” (Voogt, 2004).

“If the surface of albedo increases this has a direct affect on the energy balance of a building. Cities are categorized by reduce effective albedo as a result of two contrivances” (Santamouris, 2001):

(1) Absorption of solar radiation in darker buildings and urban surfaces in more than others with white materials.

(2) The effective albedo is eliminated by the multiple reflections inside urban canyons.

As Asimakopoulos (2001) pointed out, many studies have been experienced to evaluate the benefits of albedo change and show the advantages of applying reflective surfaces. In all cases, the temperature of the roofs mainly decreased and by using facades materials with a high albedo decrease the energy demand that is coming on to the facade and create color indoor spaces. Therefore, using reflective materials for pavement, roof materials and building envelopes can be one of the factors for reduction of heat island effects and improve the quality of city (Voogt, 2004).

2.8.2.1. Using high albedo materials on building surfaces

The amount of solar radiation absorption depends up on character of albedo surfaces and facades. Urban temperatures have been cooled down with high albedo materials used in building surfaces like white ones (Akbari, 1997; Taha, 1997; Konopacki, 1998).

For the performance of urban thermal environment and building facades, the selection of materials usage is important. During the daytime, high albedo, material can decrease the solar heat gain. The high albedo materials have low temperature than low albedo ones. Since reduction in air, temperature is the result of lower surface temperature and eventually causes to improve urban thermal environment with the association of urban ambient temperature and surface temperatures of the building facade (Hien, 2002).

The differentiation of building facade temperature with different colors is the result of simulation which shows that dark color materials are around 7ºC warmer than the ambient air temperature in compare with light color materials which are 2-3ºC warmer than the surrounding areas (Hien, 2002).

“Cooling energy can be handled if the color of the facade changes from dark to light color” (Hien, 2002).In high rise buildings, exterior surfaces play an important in controlling the cooling load of the building while the roof has significant influence particularly under the roof just on the top floor.

The facade temperature in high albedo materials is always low and this helps high decrease the surface temperature in urban areas. In other words high albedo materials decrease the façade temperature as well as urban temperature because there is strong relationship between these two parameters (Shahmohammadi, 2010).

2.8.2.2. Using white pavement instead of asphalt

By using white pavements, surface temperature can be decrease and this leads us to have cool air in urban spaces. Reduction of energy consumption in urban areas has direct relationship to reduce the temperature of town and cities. For instance dark color pavement like asphalt can reach 63°C heat in compare with light pavements with temperature of 45°C in the same situation (Santamouris, 2001).

2.8.3. Providing appropriate orientation for buildings

Natural ventilation is an effective strategy in hot climate that is used as the most effective passive cooling technique to afford cooling during days as well as night times (Asimakopoulos et al. 2001). In order to reduce UHI effect, there can be some proposals related with natural ventilation:

1. The correct location of openings according to the direction of prevailing wind could create healthy indoor air environment and efficiently supply natural air moving.
2. Natural air movement by ventilated roofs controls overheating.
3. Varieties in height of the buildings could supply better wind.
4. Enough space between well-oriented buildings is good for air circulation.

2.8.4 Sustainable transportation for eliminating air pollution

Local governments face increasingly difficult decisions about transportation issues and land use policies in their communities. The usage of public transportation, green vehicle and cycling could help to decrease energy consumption (fuel-efficient), air pollution and finally low impact on the environment. The cooperation between transportation departments and the municipalities in metropolitan cities to improve public transportation, pedestrian sidewalks and streets in urban areas can decrease air pollution and anthropogenic heat, which has direct effect on reducing UHI effects.

Strategies for mitigation UHI effects in cities	
In urban scale	**In building scale**
Providing landscape in open spaces	Providing landscape elements in different layers of buildings Vertical green spaces Horizontal green spaces (green roofs)
Using albedo materials in urban areas • High albedo • White color for façade • Light color for pavements	Using albedo materials on external surfaces of buildings • Light color for buildings facade
Providing appropriate orientation for buildings • Building Orientation • Variety in building heights for wind • Creating voids in ground levels	Providing void decks and arranging openings according to prevailing wind to encourage natural ventilation. • Building orientation • Promoting natural ventilation on facade organization
Sustainable transportation for eliminating air pollution	

Table 2.3. Categorizing Different Strategies for Energy Consumption Reduction (added from literature)

In the following chapter, the case study of Shiraz will be introduced. The city parameters are analyzed and then the effects of UHI in the city will determine. Based on these results, mitigation strategies will be suggested for the city.

Chapter 3

URBANIZATION PROCESS AND UHI EFFECTS IN SHIRAZ

3.1. Introduction

In this chapter, the effect of Urban Heat Island factors, in the Shiraz city center as one of the metropolitan cities of Iran will be evaluated. Although the effects of UHI on Shiraz is not as much as Tehran which is the capital city of Iran, but in this chapter it is tried to evaluate and propose solutions to control and decrease the intensity of UHI in Shiraz.

For this propose this chapter includes 7 parts, in the first section (3.1) the introduction has been presented. In the second part (3.2), the urbanization process in Shiraz, which has an impact on increasing UHI in the city, will be explained. The third section (3.3) is about selection of case study area and it is followed by section (3.4), which is methodology of analysis. The fifth section (3.5) is about determining UHI effect in Shiraz related with building (city development). In the sixth section (3.6) strategies for decreasing the UHI, effect in Shiraz will be explained. The last part (3.7) in this chapter is Determining UHI effect in Shiraz.

3.2. Urbanization process in Shiraz

Since the focus of the thesis is to develop mitigation strategies for Shiraz city center and the districts around, which has pressure of the urbanization today, it is necessary to discuss the impacts of urbanization in Shiraz.

“Iranian population, living in cities is increasing dramatically about nine-fold during 1956 to 2011 when 21st century has begun. So the majority of Iranian people understand that they have a lot of trouble in urbanization because the population has expanded from 8.4 million to 75 million” (Movahed, 2004)

Nowadays, the majority of urban population is immigrating to suburban areas. “Many people who are living in rural places and small towns are rushing to big cities because they are able to utilize better facilities, good-looking building and the most important point more opportunity for occupations. So a lot of vegetation and green areas should be vanished to make places for additional people that it decrease natural places and ruin our environment that it certainly has many effects in our life. It is obvious because of these mentioned events; the quality of our life is reducing”. (Movahed, 2004)

“Since 1921, the statistical measurement of the population of Shiraz illuminate that Shiraz population is increasing by 46 fold, while it had been predicted just 15 times. It indicates to a disaster growth in Shiraz.” (Shiraz Municipality). “In Shiraz the central point of permission area for building is by 200 hectare in one year. During past 80 years the surprise increase of population of Shiraz is caused many of cultivable grounds and productive areas is filled with buildings and complexes. The majority of rural people are rushing to the cities so many agricultural area is disappeared because of their immigration”. (Movahed, 2008)

Karimi in his studies mentioned the rapid modernization in Iran based on replacement of modern buildings and avenues in and through old structure of the urban fabric of cities. These forms of intervention in old part of the city has shaped formal isolation in the old core and destroy its traditional structure that cause crowded out vegetation from the historic part in 20 century (Karimi, 1997, 2002).

Master planning in Iran started in 1960s but the last version of master plan for Shiraz belongs to 10 years ago. With respect to generated maps, it has been found out that the concentration of new urban development was mostly in north-west direction (Fig 3.1). “It is because of geographical position and morphological emplacement of Shiraz plain. The city is restricted to the north by Babakoohi and Sa’di tallness, into the south by Sabz-Pooshan heights and in eastward is terminating to coasts of the Maharloo lake that the underground water table is quite high, so the only and the best places for new constructions are north western parts of Shiraz plain”. (Movahed, 2006)

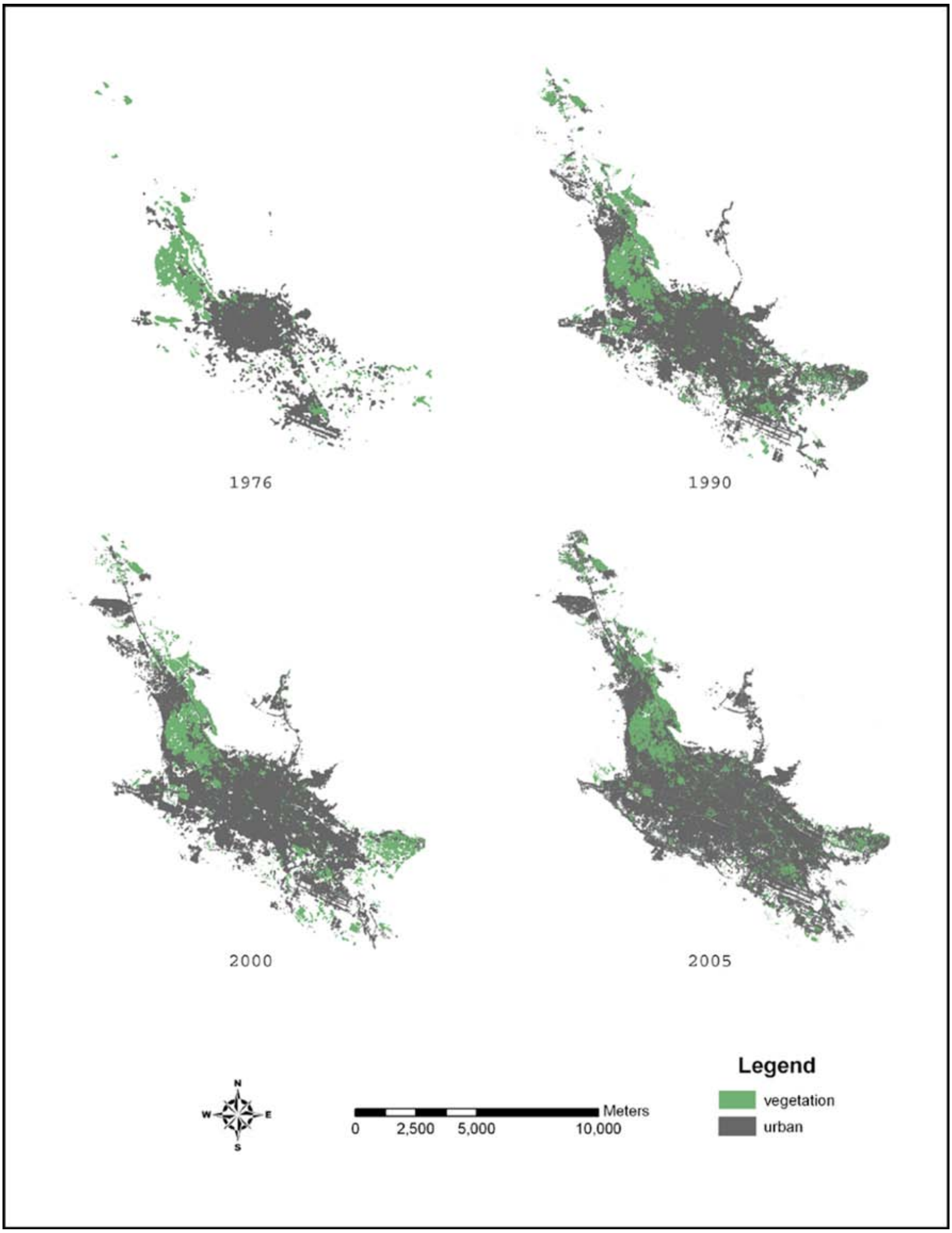


Figure 3.1. Expansion of Shiraz in Last 50 Years (Ibrahim, Sarvestani, 2009)

As a result of population growth in the last 20 years, many gardens of Shiraz have been destroyed. The attraction of these sites for new residential and commercial development creates a great and specific potential for new urban formation. Unlikely these changes make deterioration of old core modifications, which are adaptive, equal, slow and in the opposite make rapid growth for new modern changes in a bigger scale (Sarvestani et. al., 2009).

Due to the rapid expansion of the city, vegetation loss was too much in size comparing to built-up and population growth. As shown in Table 3.2, since the middle of 70's to early years of 90's, despite of greater rate of built-up growth, the gentle rate of vegetation growth was also available, but after that the percentage of construction became slower until 2000, this was by two causes, first start of a period of stagnancy in urban construction and economic problems and second change in construction pattern from horizontal to vertical

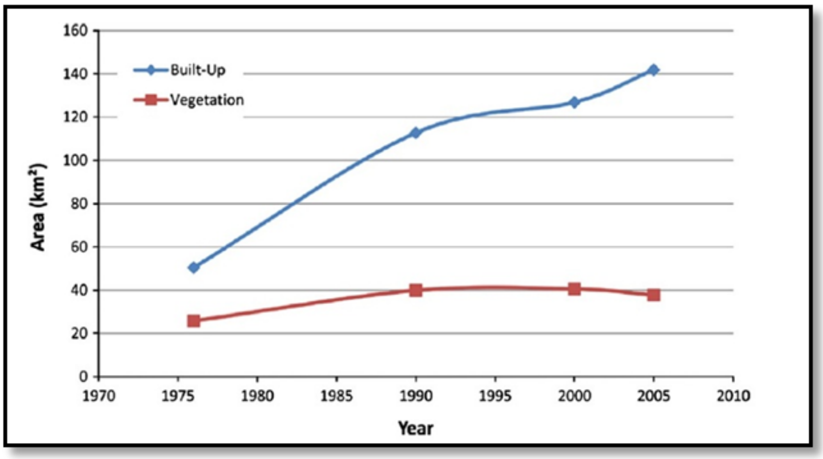


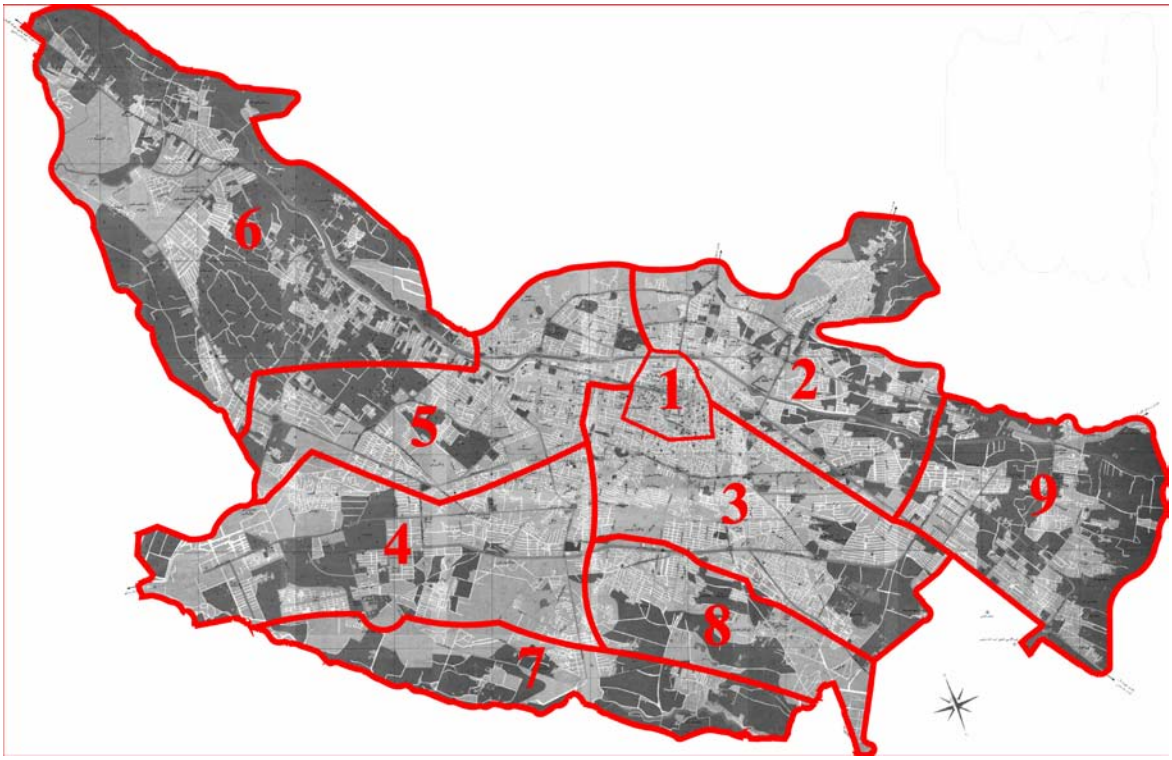
Figure 3.2. Construction And Greenery Growth During 1976-2005
(Sarvestani, et. al., 2009)

Construction, which means most of the new buildings were multi storey. "From the start of 2000 as a result of socioeconomic reasons and high public interest and injection of great values of financial resources into real estate market, the rate of construction increased dramatically and unfortunately in some parts displaced vegetation cover" (Sarvestani et. al, 2009).

As a result of this All these factors create increase in UHI effect in the city, especially the traditional district, which is surrounded by these new developing high densities, crowded and noisy districts.

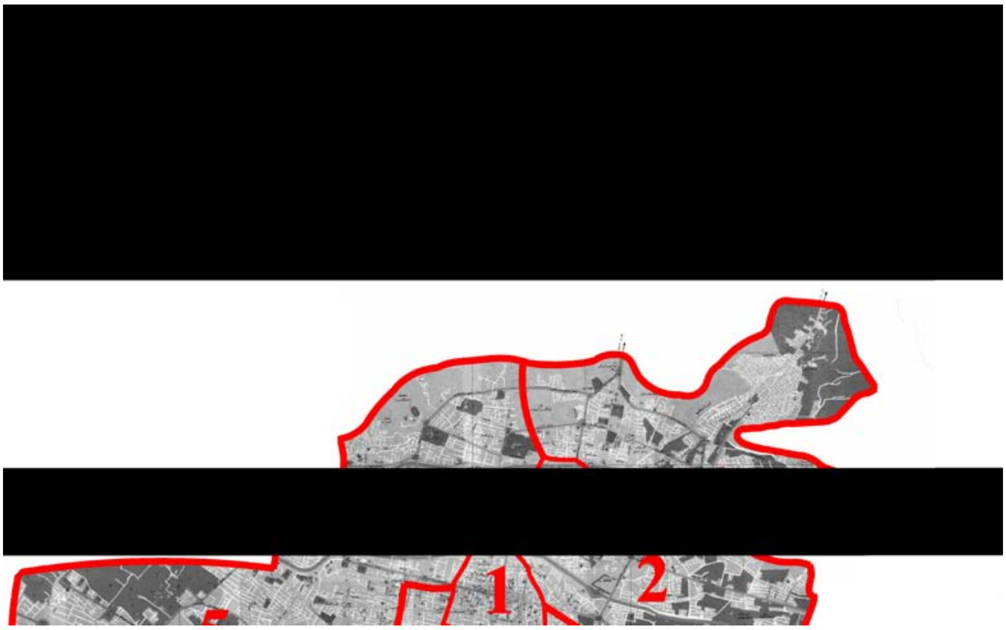
3.3. Selection of the Case Study Areas

The city is divided to 9 districts, (traditional zone and 8 new development areas), (Map 3.1).



Map 3.1. Districts in Shiraz According To Municipality Division
Source: Shiraz Municipality

The traditional zone of the city, that has high density with maximum two storey buildings and narrow organic streets with less traffic rather than other districts, is surrounded by districts, which have high-rise apartment blocks with dense traffic as a result of rapid urbanization. In this study, the effects of UHI on the traditional district is tried to be determined by analyzing the districts surrounding it. Accordingly, five districts (historic center of the city and four districts around it) have been selected regarding to several criteria like building height, high density of built up areas, land uses, population and, traffic. The case study areas are shown in Map 3.2.



Map 3.2. Selected Districts for Analysis

3.4. Methodology of analysis

As discussed in Chapter 2, urban heat island intensity is affected by two factors: (i) meteorological items like the humidity, cloud cover, and also wind speed, (ii) urban structure issues includes the size of cities, the building density of areas, water bodies, the ratio of buildings' heights, topography, and greenery surface.

Accordingly, in order to determine the effects of UHI in Shiraz city center, it is necessary to conduct thorough analysis. In this chapter, the city will be analyzed regarding its natural, man-made and functional characteristics. The analysis stage is essential for defining current problems related with UHI and developed suitable proposals. In order to have all required information about the case study areas, the analysis in UHI effects should be based on city's physical (natural and man-made) and meteorological factors. The result of natural and man-made analysis are discussed in line with the UHI issues.

Accordingly, the analysis should be carried out:

- For the natural environment
- For the man-made(built) environment
- Documentary research (statically information related with population, meteorological conditions, etc.)

The following section will explain the data collection and the methodology of the analysis carried out on the case:

- *Investigation of the Natural Environment*
- *Consideration of the Man-made (built) Environment*
- *Documentary research (population, size of city, meteorological factors,) etc.*

- **Investigation of the Natural Environment**

Natural factors are one of the determinants of form, physical and functional characteristics of city's outdoor spaces and building masses. For the purpose of natural environment analysis, the identification of topographical features, greenery areas, plantation, landscape, flora/fauna, soil, water, climatic features have been searched for Shiraz city.

- **Consideration of the Man-made (Built) Environment**

The analysis of the man-made / built environment can be carried out under two sub-headings: (i) the urban pattern analysis and (ii) the functional analysis.

- *Urban pattern analysis*

Urban pattern analysis has included locational, historical urban pattern, architectural evaluation and transportation analysis. The result of these analysis have impact on the intensity of UHI.

a) *Locational Analysis* showing the situation of the area within the country / region / city / district.

b) *Historical developement* including information on physical, social, economical background and structure of the concerned area; the historical development, changes and growth of the area, in other words, the development process of the area; when needed the morphological development of the area.

c) *Urban Pattern Analysis* helps to determine the form of development, solid-void relations, building heights, street pattern and density in the city.

- *Architectural Evaluation* will be done for gathering information about construction materials and building color in the city for defining thermal properties of such materials and their effects on UHI in city.

- *Functional Analysis* (Land use, density, transportation):

Land use survey providing information about the distribution of functions on the area concentrating on the ground and upper floor uses and *transportation* will be analyzed in order to identify air pollution regarding the high number of industrial activities and dense motorways.

3.5. Analysis of natural environment

3.5.1. Topography & Water

"The situation of Shiraz is in the south of Iran and the northwest of Fars Province, the inland around 200 km from the Persian Gulf. It covers a land area of about 451 km² (Shiraz municipality, 2001). "With an average elevation of 1500 m above sea level, The city is located in the north-west to south-east elongated valley surrounded by the Zagros mountains; Baba Koohi and Ahmadi Heights are continued to the north, Sabz Pooshan Heights in the south and Derak Heights to the west (Fig. 3.3), the existence of these mountains cause to have low wind speed and keep the air pollution on the city. The Rudkhaneye Khoshk (Dry River) flows through the northern part of the city seasonally, ending in the Maharloo Lake to the East" (Sarvestani, et. al., 2011).

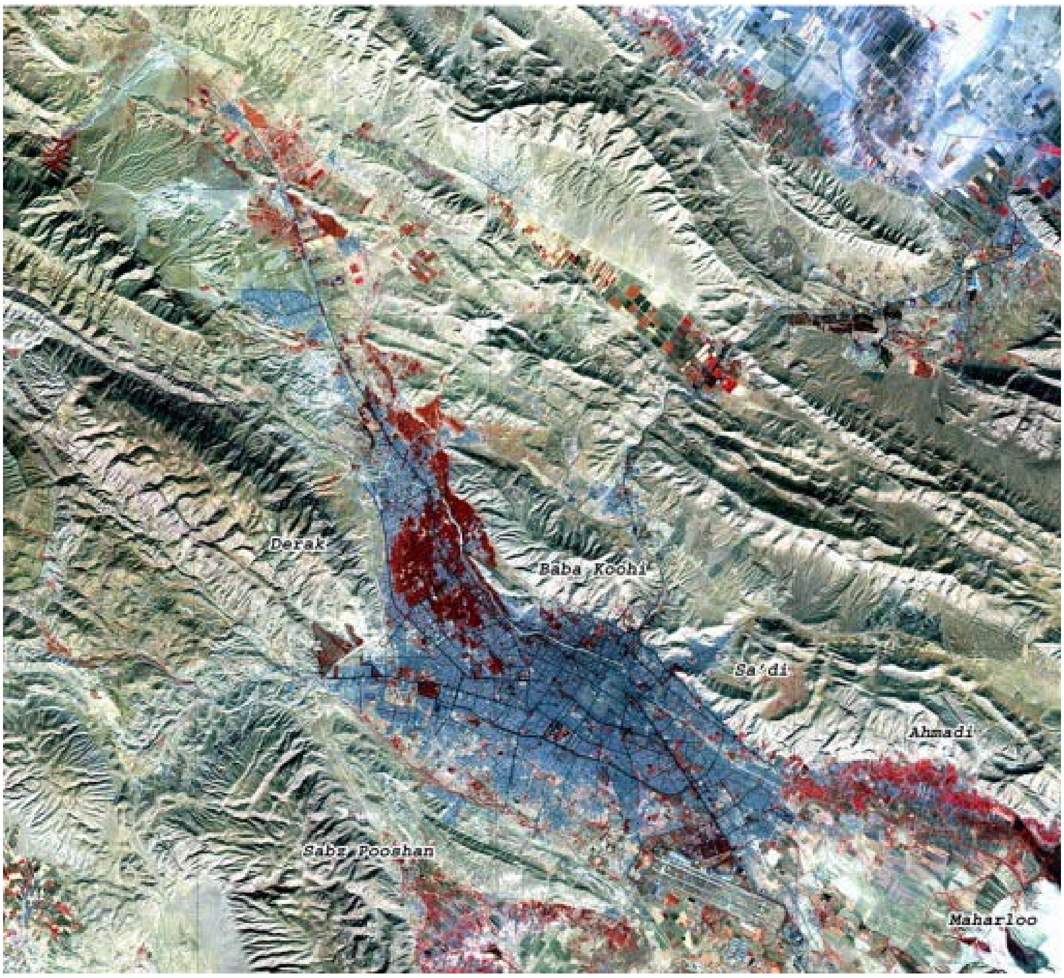


Figure 3.3. Shiraz plain and its surrounding (Sarvestani, et. al., 2011)

3.5.2. Climate

Shiraz has a moderate climate with regular seasons (Table 3.1). The city is bordered to the north and south areas by two high mountain ranges. “The principal wind directions in the city are mostly from the south and southwest to north and northeast” (Hadad, et. al., 2003). Given its geographical setting, expansion in Shiraz is limited to the east–west direction. “The rainfall in recent years, during which an atmospheric condition have changed perceptibly, has been comparatively sufficient, and has reached 23 inches in a year, but the average rainfall is between 14 and 18 inches” (Hadad, et. al., 2003).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average temperature, C°	6	8	11	18	23	28	30	30	25	20	12	8	18
Average Maximum temperature, C°	11	13	17	24	30	35	37	36	32	27	18	13	24
Average Minimum temperature, C°	1	3	6	11	16	20	23	22	17	12	6	3	12
Average rain days	4	5	5	2	0	0	0	0	0	1	3	4	24

Table 3.1. Shiraz Weather Data (United Nation, 2011)

3.5.3. Vegetation

"The destruction of trees for urban use is a major explanation of degradation in many regions" (Shepherd, 1989). Shiraz is popular for its green places and gardens. It includes great number of gardens. Because of upcoming population growth in Shiraz, lots of these gardens might be lost to build apartments. Lots of these gardens for which Shiraz was popular are now long lost, however, it still has many parks and gardens that are specifically pleasant to wander in summer. "Statistical data of Shiraz shows that, Shiraz public green field such as Parks, street-center gardens and squares has changed from 9.07 square kilometers in 1997 to 6.56 square kilometers in 2011. About 103000 Hectare of Forest around city and nearby agricultural areas is lost according to the migration of the people from suburban areas to the city" (Shiraz Municipality). Unfortunately in 20th century many part of Shiraz green lands are changed to residential buildings. Trees are lost mainly because of the expansion of building construction. Figure 3.4 shows the dwindling of Shiraz green areas in last century.

Figure 3.4.Shiraz green areas in last century (Movahed, 2004).

3.6. Analysis of Built environment

In this part of research, man-made environment characteristics of Shiraz city will be determined. For determining the UHI effects in city, its formation, size, density and buildings height and materials are some of the parameters that need to be analyzed. So, in the following lines, the physical and functional characteristics of the city will be presented.

3.6.1. Locational Analysis

Shiraz, a metropolitan city in the southwest of Iran and it is the fifth most populated city in Iran (Fig. 3.5). Shiraz has a population of 1,517,653 in an area of 451 km2 and is situated 1450 m above sea level. It is the capital of FARS province, which has a home to one of the two capitals of the very ancient Persian Empire circa 700 BCE (Persepolis). The city is bordered to the north and south areas by two high mountain ranges. Given its geographical setting, expansion in Shiraz is limited to the east–west direction.

Figure 3.5. Location of Shiraz in Iran map (http://images.google.com/)

As Falamaki (1978) stated: “the old city of Shiraz came up from the extension of a vale, which is located from west to east. In this direction, the vale is getting thinner, less water, and not good for farming and agriculture. This city had political and good strategic accesses, so that made the city more develop. Although in there was a favorable condition in the west part of the city for farming, but since 3rd and 4th HEJRI SHMSI, before becoming the city big city Shiraz, there were huge amount of settlement in the east part of the city , and next to the river.”

The current Shiraz is located at the intersection of the two main roads, which is located in the west-east axis of the city. One of the roads is the main roads, which is located in the west-east axis of the city. One of the roads is the main access way of ISFAHAN to the south and east-south of the country (Iran), and the second one is the connection of the west – south of country to the center of Iran. Therefore, the city was mostly giving the business and facility service to the whole country (Falamaki 1978).

3.6.2. Historical development of the city

History of Shiraz belongs to pre-Islamic era. The form of architecture, shape of the residential buildings, streets networks and other buildings like mosques, shrines and covered bazaar create a picture of Islamic city from Shiraz. Between 16 and 17 century, the city categorized to its quarters (mahallas) and the streets formed organic according to the forms/shape of mahallas. During 18 century Shiraz became the capital city of Iran and many infrastructures like drainage system is made, the city walls were rebuilt and many new administrative building had been constructed and the city expanded to the outside of the wall city. The historical factors and process that contributed to the creation and development of Shiraz and its traditional residential areas are the micro – geographical conditions, and its strategic and economic location on the intra-regional trade routes and the cultural evolution of its people.

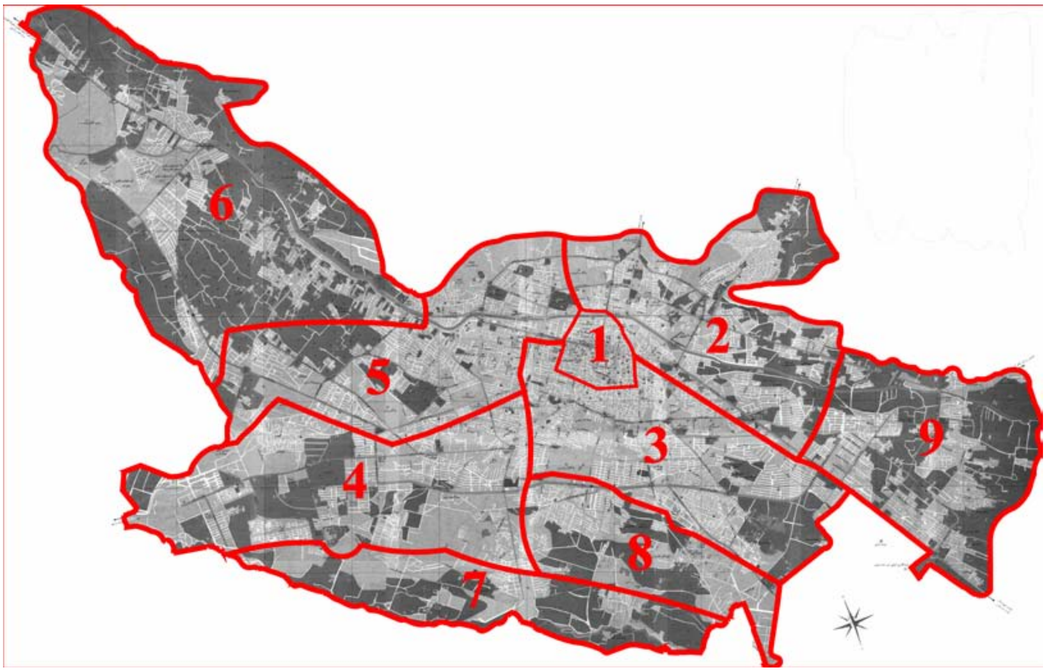
Because of rapid urbanization and the migration of people from rural areas to cities master planning started in Iran during 1960s. The first master plan of Shiraz was designed by Tehran University in 1966 and it is shown that the city was expanded according to the limitation of by to high mountains from north and south to the North West. The main master plan, which is designed by Naghsh Jahan Pars Consultant in 1988, shows the density of buildings and the organic forms of streets because that is more visible around the traditional part of the city. The analysis shows that the density and height of the buildings, which are started from those years, affects the temperature and the intensity of UHI the accelerated in last decade (Fig. 3.6).

Figure 3.6. Development of Shiraz before 16 century up to now

3.6.3. Urban pattern analysis

3.6.3.1. Districts of Shiraz

The city is divided into nine regions (Map 3.3), which is include of the old part (main center) of city and eight other regions. The historic center of the city contains a large amount of residential building since 7th century, and covered 360 hectare of the whole city with 75,000 populations (2003 census), which more than 50% are not local (Shiraz Municipality).



Map 3.3.Shiraz Division Map (Source: Municipality of Shiraz)

District 2 is located in the north part of Shiraz with the area of 1774 hectare, which is 14 percentage of the whole city; the population of this district is 191405. The majority (70%) of buildings in this area is residential and the rest are mix uses (Shiraz Municipality). The location of district 3 is in the south and east part of the historic area with the area of 1680 hectare and 263134 populations. More than 80%

of the buildings in this district are residential and the rest belongs to retails and commercial (Shiraz Municipality). District 4 is located in the south west of the city with the area of 2318 hectare with the population of 19632. Although the majority (60%) of the building in this area is residential but the location of cemetery factory and commercial building shows that this district is one of the new areas among nine others (Shiraz Municipality). District 5 with the area of 2235 hectare and the population of 212491 is located in the west part of the city. The residential buildings in this area are around 75% and the rest are commercial and retails (Shiraz Municipality). District 6 is the newly development area of shiraz, located in the north west of the city with the area of 2779 hectare and the population of 79083. The district has low density in compare with other areas and more than 85% of the district is residential and the rest (15%) are retail and commercial (Shiraz Municipality). District 7 is located in the south part of the city with the area of 1502 hectare and the population of 171628. 80% of the buildings are residential and the rest are mix use and retail (Shiraz Municipality). District 8 is located in the south part of the city with the area of 1736 hectare with the population of 163042. More than 80% of the building in this area is residential and the rest are commercial and retails (Shiraz Municipality). District 9 is located in the northeast with the area of 1478.9 hectare and the population of 176544 is another district with low density (Shiraz Municipality). According to the buildings' density, traffic, height of the buildings and the factors, which are affecting the intensity of UHI, the historic center and four other districts around it are selected to analyze and find out the solutions to decrease the effect of UHI.

3.6.3.2 Form of the development of Shiraz

Urban land uses are forming many landscapes in urban areas also; they have deepened effected on the region of Iran. Shiraz is one of the most beautiful and excellent city in Iran where also is one of the most crucial town in the medieval Islamic world. In the urban structure, Falamaki (1978), believed, “Shiraz has dense structure in new and historic urban development to compare with like desert cities. And such city with the moderate climate and regular seasons, become very exceptional city, which is reflecting a kind of liberated feeling.” the new urban growth was mostly concentrated in north-west because of geographical position and morphological emplacement of Shiraz plain. Shiraz is covered from the north by Babakoohi and Sa’di heights, south by Sabz-Pooshan heights and in eastward is terminate to coasts of the Maharloo Lake. So the only and the best places for new constructions are northwestern parts of Shiraz plain (Movahed, 2006). In terms of street development, in historic area the streets are organic and narrow. In the other four new developments, the municipality tried to create grid-iron street pattern (section 3.6.2) which is visible in some parts of district 4 and 5 but according to the location (surrounded by mountains)of the city, it seems that in 4 new development districts, streets are organic as well but more wider.

By paying attention of to figure ground analysis (Solid and void analysis) it is shown that the percentage of solid areas in districts 1, 3 and 5 is more that districts 2 and 4 (Map 3.4). This shows the buildings’ density\ in these three districts is more than the other two. This shows that the hard surface areas are more than soft spaces and it increases the climatic condition (air temperature) in the outdoor and as well as indoor spaces. Also regarding to the distance between buildings along the streets, it is clear that in district 2,3 and 4 , there is 4:1 ratio and as discussed chapter 2 (see section

2.3.1 and 2.6.2.4) in urban canopy layer section this affect to have more heat on their facade and also affect to get efficient day light into the indoor spaces. Because of these issues, air conditioners are used for heating or cooling the spaces.

Map 3.4. Figure Ground Analysis and Urban Canyon Analysis

3.6.3.3. Building density and heights

According to the of building's heights and the building density analysis in the five selected districts, the analysis results are shown that districts 2, 3 and have high rise buildings and more population in comparison with the districts 1 and 3 which have more old structure and density. The district 1(historic center) is more dominated by one and two storey buildings, district 2 and 3 are dominated by 2, 3, 4 and 6 storey buildings, and districts 4 and 5 are dominated by 3,4,6 and 8 storey buildings (Map 3.5). According to the high-rise buildings and more population in districts 2, 3 and 4, there is temperature change between day and night time which also calls for increase in UHI in and around the districts.

Map 3.5.Building's Density and Height in Five Selected Districts

3.6.3.4. Architectural Evaluation

- ***Construction Material***

Generally, Shiraz is divided two zones, one part is old and another is modern. The historical part of Shiraz has various gates and districts which are for different period of time. The modern zone has occupied much more area of the city and has encircled the old zone. Surveys (Municipality data) on the period of construction of the buildings in the historic part show that brick and clay (Fig. 3.7) dominate the building material in this district.

Figure 3.7.Building's Material in Historic Zone of Shiraz

Districts 2 and 3 are made by concrete and steel structures which are covered by stone and yellow brick, district 4 and 5 are also made by concrete and steel structure that covers by brick and the combination of glass and stone in elevations (Fig. 3.8).

Figure 3.8.Buildings' Material in the 4 Districts around the Historic Zone

- ***Building Color***

Regarding to the surveys (Figure 3.9) and according to the information collected from Shiraz municipality the majority of the building facades in the five selected areas are made by yellow brick, stone, glass and concrete which are catches the sun heart during the day and reflect it during the night. According to the historic background of district 1, the majority (90%) of buildings are made by yellow brick and clay blocks, in district 2 and 3 the facades (80% & 85%) are covered by yellow brick and stone and district 4 and 5, the buildings' façade (85% & 90%) are made by stone, dark stone and the combination of brick, stone and glass. Accordingly, based on dark colored and unreflective building color and contrast material districts 4 and 5, have higher temperature than other 3 districts.

Figure 3.9.Buildings' color in the selected districts

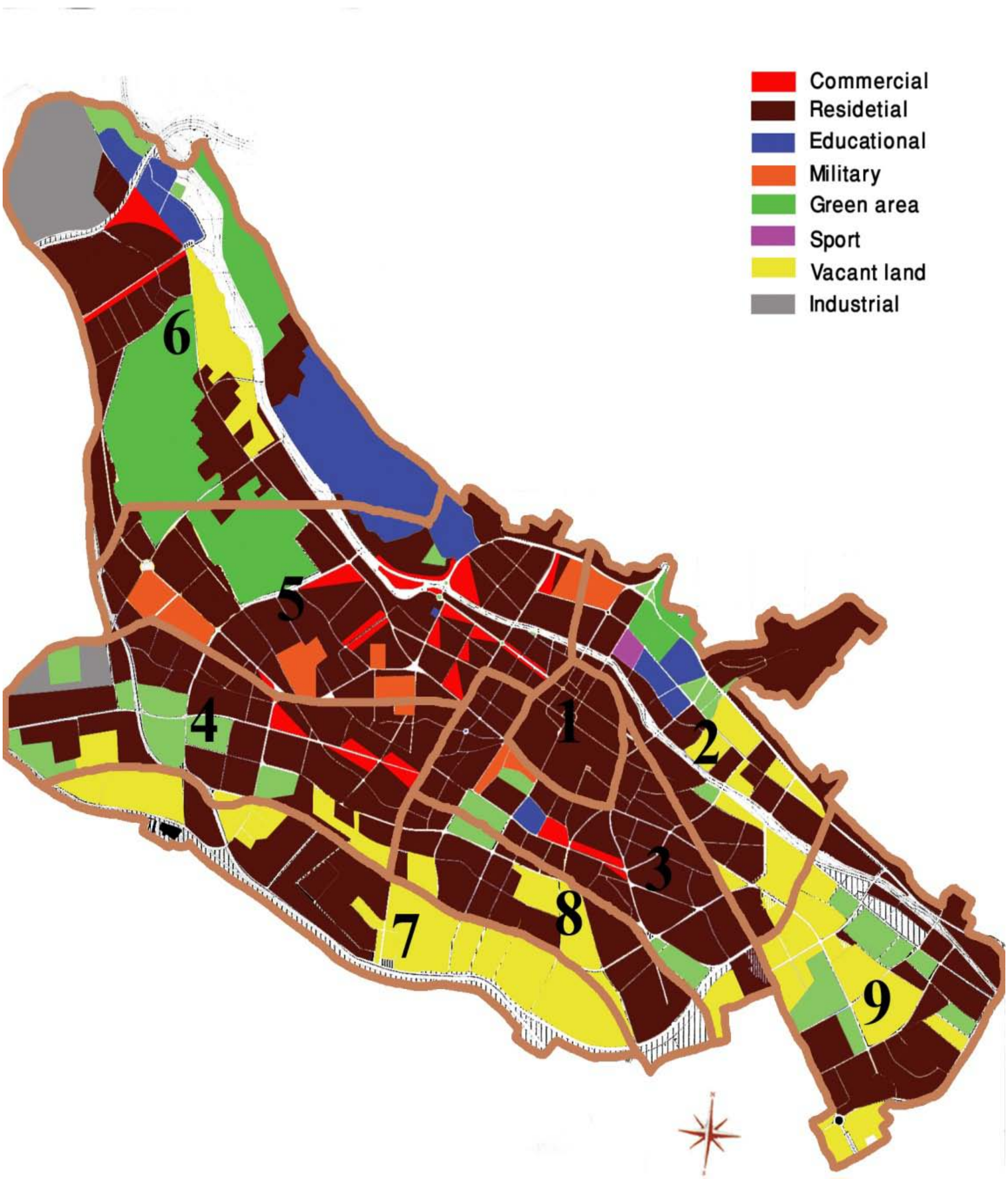
3.6.4. Functional Analysis

The majority of gardens for private usage have been vanished and these areas have been occupied by buildings in the last decades. From 1991 to 2010, nearly 100000 new houses and flats, commercial and industrial buildings have been built in the city (Map 3.6). The floor area of those new homes and apartments are approximately 22,000,000 square meters and a large percentage of new buildings are more than 4 storey height (Shiraz municipality).

Regarding land use survey 80% of total buildings in historic part are residential with 2 storey and 20% are retail and mix uses. In district 2 this average is changed to 70% residential and 30% retails and mix use, district 3 and 5 have the same percentages which are 80% residential and 20% retails and mix use, but in district 4, 60% are residential, 30% are retails and mix use and 10% are industrial that the main industrial area is belongs to cement factory.

3.6.5. Transportation Analysis

In terms of transportation, the majority of streets in Shiraz are two way with the sidewalks for pedestrian. The city does not have any pedestrian street, all vehicular streets are covered by asphalt, and dark stone and mosaic cover pedestrian ways on the sides. According to public transportation Shiraz is Iran's third Bus Rapid Transit which has seven lines with more than 50000 buses and 47 kilometers metro in 3 lines and 21 stations (Shiraz municipality). The important point about transportation is that less than 40% of streets have greenery around (Shiraz municipality) and the other streets and alleys are covered by asphalt, which is horrible and has a high effect to increase urban heat island.



Map 3.6. Shiraz Land Use Map

In the following table 3.2, the summery of the analysis results for 5 selected districts are presented.

criteria	District 1	District 2	District 3	District 4	District 5
Location in the city	Center	North	Southeast	Southwest	West
Area	360 Hectare	1774 Hectare	1680 Hectare	2318 Hectare	2235 Hectare
Population	75,000	191405	263134	19632	212491
Land-use	80% residential, 20% retail & mix uses	70% residential, 30% retails & mix use	80% residential, 20% retail & mix uses	60% residential, 30%retails & mix use, 10% industrial	80% residential, 20% retail & mix uses
Building Density	High	High	High	Middle range	Middle range
Construction material	Brick& Clay	Concrete & Steel	Concrete & Steel	Concrete & Steel	Concrete & Steel
Building material	Brick& Clay	Stone & yellow brick	Stone & Yellow Brick	Brick, Stone & Glass	Brick, Stone & Glass

Table 3.2. Comparison among built environment characteristics of the 5 selected districts

According to above table and by considering the factors that affect the intensity of UHI, it is visible that districts 1, 2 and 3 are under the pressure of UHI in terms of population, building density and land uses in compare with districts 4 and 5. But according to building materials specially the materials that are used in facades districts 4 and 5 are more affected in compare with other 3 districts because the material and the colors that are used in these two districts are darker and have low albedo quality.

3.7. Determining UHI effect in Shiraz

Since the main aim of the research is to determine the factors on intensity of UHI in Shiraz city center, in this section, depending on the result of the analysis, the effect of UHI in Shiraz will be explain under meteorological and urbanization (city) factors.

3.7.1. Meteorological Factors

Changes in cloud cover, intense air pollution and current meteorological condition, urban heat island increase in the city center. These factors will reduce wind speed and may create a tendency to keep pollution concentration over urban areas especially on city centers with high density structure and population (Shahmohamadi et. al., 2009).

In Shiraz, because of the location of city and topography (Zagros mountains; Baba Koohi and Ahmadi Heights in the north, Sabz Pooshan Heights in the south and Derak Heights to the west), lack of cloud cover, lack of precipitation (low rainfall during the year) and low wind speed, ground-level air quality decreased and accordingly the percentage of UHI formation increase over the city.

3.7.2. Urbanization Factors

Migration from villages to cities causes urban sprawl, which leads to increase in the land uses. The land started to be used for new constructions and therefore, the green areas, forest or agricultural lands are damaged. In the city, due to this rapid expansion, the green areas have been decreased and city has become full of buildings with high population and heavy traffic. The increasing numbers of buildings have crowded out vegetation and trees (Asimakopoulos, 2001). Regarding the urbanization process in the city, the newly developed districts with high-density building affects the climatic condition because they are placed in their plots without taken climatic factors into considerations. All these parameters are the sign for increasing the urban heat island intensity in the city. In the following lines, the city parameters that are also having impact on the city's climatic condition are presented.

3.7.2.1. Location of the city

As Givoni (1998) stated, the topographical condition of cities directly affect wind flows. Zagros Mountains directly prevents to have prevailing wind through the city therefore it increase heat and as well as urban heat island. In Shiraz, Zagros Mountains that surrounds the city from south and north direct don`t allow removing the air pollution that is brought by south and south east prevailing wind into the central urban areas. This condition also may cause to keep pollution over the city and increase reversal in Shiraz (Fig. 3.10).

Figure 3.10.Zagros Mountains in Shiraz as Obstacle and Aggregation of Pollution

As discussed above, the existence of the mountain prevent to have air circulation and high wind speed therefore, the percentage of pollution increase in the city. Also, because of topography conditions, the warm air coming over the canopy layer in the central part of the city and then it attracts pollution from other sections of the city.

3.7.2.2. The size of the city and population:

Due to the changing needs of the population, they want to be close to the city center and accordingly, they moved from suburbs to the city. Due to this expectation of the residents, city enlarged and become more crowded. As described before Oke in 1982, the heat island intensity is related with the size of the urban population as well as of its standard of living like intensity of winter hotness, vehicular traffic, summer air conditioning, and industrial plants. The most important reasons in the changes of city size are rapid and unfitting urbanization, higher population (Table 3.3), (as discussed in section 3.2), annually biological activities will be the source of large amount of energy in urban thermal temperature. These activities make a large amount of energy consumption that causes UHI (Alijani and Safavi, 2007).

Year	POPULATION
1921	85000
1956	170659
1966	269865
1976	425813
1986	848289
1996	1053025
2006	1442842
2011	1517653

Table 3.3.Population of Shiraz (Source: Shiraz Central Statistical Office)

3.7.2.3. Density of built-up area:

In Shiraz, due to the migration of the people from rural areas to the city center, the authorities and private sectors has to build new accommodations in order to afford the housing needs of these immigrants. Also because of the increase in the population of the city, the density of the built-up area and the temperature in the city center increase. As discussed in chapter 2, all these factors help to increase intensity of heat island in the cities. The façade of the buildings and their indoor spaces are also affected by the heat gain due to their locations. If five or more story buildings are closely constructed, then it cannot be possible to get the sunlight, air circulation into the indoor spaces, and force the people to use energy for heating and cooling purposes. (Fig. 3.11). Accordingly, districts 1, 2 and have more affected with UHI in compare with districts 4 and 5 in terms of density and building height analysis.

Figure 3.11.High Density of Built Up Area In Shiraz

3.7.2.4. Urban geometry

As discussed before, the urban geometry is sum of the urban canyons in the city. Urban canyon is described by Emmanuel (2005) as the three dimensional space over the buildings and street and it is view of the sky dome which is formed by the sun radiations and air (Fig. 3.12). Regarding to building height analysis in Shiraz, complex urban geometry especially around the historic center and west of the city increases friction created by a rough urban surface.

Figure 3.12.Urban Geometry from West View Of Shiraz

3.7.2.5. Thermal properties of fabric

Gloomy materials like asphalt, stone and concrete tend to keep and release heat slowly on facades (Landsberg 1981; Oke 1982; Quattrochi, 2000). These kinds of materials rise urban surface temperature in urban fabric during the night by the solar radiation, which is fascinated and uphold before. Urban temperatures have been proven to cool down by high albedo building surfaces such as white materials (Akbari & Taha 1997; Konopacki, 1998). According to construction material and building color analysis in the 5 selected areas of Shiraz, except the historical zone, the materials that increase the urban heat island intensity are used.

These materials are brick, asphalt and concrete and as before mentioned they do not reflect the sun light, but absorb the heat and increase the temperature in the city (Fig. 3.13).

Figure 3.13.Urban Construction Material in Shiraz

3.7.2.6. Surface waterproofing

The condition of surface and/or soil that is resistant to absorb the water, generate the moisture and surface with less vegetation affect the level of evaporation in the cities and cause UHI intensity. Particularly, greening such surfaces and having high moistures help to regulate the surface temperatures (Ani et. al., 2009). In Shiraz, newly constructed buildings due to the urbanization, replaced with the vegetations. As presented in section 3.5.3, cutting out the green areas and constructing concrete buildings prevent to have enough evaporation and also increase the temperature (Fig. 3.14).

Figure 3.14.Lack of Porosity in Shiraz Urban Space

3.7.2.7. Anthropogenic heat

The effect of UHI intensity is depending on the contribution of anthropogenic heat into the urban atmosphere (Taha, 1997). High densely population areas in urban centers tend to use more energy than surroundings (Landsberg, 1981). As discussed in chapter 2, during summer time the demand for air-conditioning is more than other seasons, in turn force people to use more fossil fuel burning and electric power generation that cause increase air pollution in local and regional areas throughout the year. The increase absorption of solar radiation in boundary layers happens because of pollution created by emission from power generation. (Oke, 1982) and donates to the construction of reverse layers. In Shiraz, increasing large number of buildings and population (see section 3.6.3) is the reason of energy consuming by air conditioning, which is eventually removed to the surrounding, moving up the temperature of urban areas. Through an exact population growth consideration, metros and buses could not support all areas of the city. As a result, lots of people are forced to use their own cars that will create massive traffic jam. The size of Shiraz city is large as well, that has heavy traffic jam. Driving with own automatic cars in huge scales certainly have effect on fuel consuming and generates more heat.

3.7.2.8. Air pollution

As discussed in chapter 2, the dense traffic and industrial activities are two main pollutants in the cities. In Shiraz, factories (like Shiraz cement factory in district 4), vehicular transportation and Zagros Mountains which covers north and south that reduce wind speed are the most important factors of air pollution (Fig. 3.15).

Figure 3.15.Air pollution in Shiraz

3.7.2.9. Land uses

Replacement of vegetation with new buildings and industrial land uses, which are located in south and southwest of Shiraz (district 4) result a lot of troubles and problems. Industry settling in unfitting place without paying consideration to hygiene rules are caused the city (Shiraz) air pollution, more over south and south east prevailing winds convert factories spare materials to the urban areas (Movahed, 2008).

3.7.2.10. Wind speed

The city of Shiraz is growing from the extension of a valley, which is located from west to east. The principal wind directions in the city are mostly from the south and southwest to north and northeast. Lower wind speeds in the city due to of high density inhibit evaporation cooling plus causing warm air stagnates in the urban canyons and pollutions retain that help to raising the UHI intensity. Local variants in topography may affect the wind speed. The existing of Zagros mountain ranges around the city can affect the formation of urban heat island. In Shiraz, north, south and west Zagros Mountains do not let the air pollution take out which is brought by south and southeast prevailing wind into the urban spaces. Table 3.3 shows the result of meteorological and urban factors on the selected areas.

According to the analysis result (see table 3.2) and based on the discussion on this section, it is visible that the 5 selected districts are under the pressure of UHI intensity in compare to the rest districts and without paying attention this hazards, it can spread and affect the other four districts in the same way. It is the responsibility of governments and municipality to concern about the material and implementation of new buildings and streets’ cover to decrease the effects of UHI in selected areas and finally the whole city.

Table 3.4.Effects of Meteorological and Urban Parameters on Urban Heat Island (Shiraz City Center)

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1. Introduction

The adverse effects of UHI includes the deterioration of living environment, increase in energy consumption, elevation in ground-level ozone and even an increase in mortality rates. Higher urban heat is appeared because of the anthropogenic heat removed from cars, power plants, air conditioners and also other heat sources, then because of the stored heat and re-radiated by enormous and complex urban foundations. Massive quantities of solar radiations are mostly kept and re-radiated in urban areas because of huge construction material and reduced sky view items. The urban places own less greenery because of its typical land use. High roughness formation is the challenge of urban places that decreases the convective heat removal.

Accordingly, the current problem of UHI (those discussed in chapter 2) and the need to solve them for future led to make this research. The main focus of this research is to determine the factors that cause UHI intensity in Shiraz as a case due to the wrong usage of the materials for construction and street paving, anthropogenic heat released from vehicles, density of buildings around the historic city center, and etc. Based on these problems, it is needed to improve the using of albedo materials, increase the greenery of the city and provide appropriate orientation for new buildings.

Thus, the effect of two main factors the urbanization and meteorological (climatical) factors on the intensity of UHI are studied and then strategies both for urban and building scale proposed for decreasing the negative effects of Urban Heat Island in the case study of Shiraz. In order to achieve the main purpose of this study, the following research questions were form the framework of the study. This research intended to answer the followings two main research questions as its major task:

- What are the main factors increasing UHI problems in Shiraz city center?
- How strategies will help to decrease UHI effect in urban and building scale in Shiraz city center?

To be able to answer these two questions, the answer of the following sub-questions are dealt with throughout the research:

- What is UHI?
- What are the causes of UHI?
- What are the factors effects of UHI?
- What are the criteria for reducing the UHI effect?
- How is urbanization process effect’s Shiraz UHI intensity?
- How will urban heat island affect the Shiraz city center in future?

In order to achieve the research aims and answer to the research questions, the research is organized in three main parts. The first part was the theoretical framework through literature review; the second part was the case study applications that include data collection, analysis and evaluation; fourth part was the research findings.

1. The Literature Review on keywords: In Chapter 2, deeper literature review was presented on the main keyword - UHI, its types, causes, effects and mitigation strategies that used by different countries.

2. Data Collection, Analysis and Evaluation: In order to find the effects of UHI, the case study method has been used. Therefore, Shiraz city center in Iran has been selected as case study area. The methodology of the data collection and analysis methods were presented in section 3.3. As discussed in Chapter 2 , for determining the city parameters that have effect on intensity of UHI requires first deeper analysis in the natural, man-made structure of cities. Physical and functional analysis were therefore made to gather information about the urban pattern, solid-void relationship, construction material, building color, land use and transportation, etc. in the case study area. Some of the analysis is not directly used for the data evaluation such as historical analysis but they are also presented in order to have general information about case study areas.

3. Conclusion: According to the data gathered from data analyses and some statistical sources, the meteorological and city parameters were determined for determining the UHI pressure in the city center of Shiraz were presented in Chapter 4. The research findings together with answers to the research questions, recommendations and agenda for future research were presented in Chapter 4.

After this brief summary of the research process, the following lines will now present the main findings of the research that are also answer for the two main research questions;

- What are the main factors increasing UHI problems in Shiraz?
- Which strategies will help to decrease UHI effect in urban and building scale in Shiraz?

This thesis tried to determine the main factors increasing the UHI intensity in Shiraz city center through case study research. In order to obtain these factors, literature review was done and the meteorological and urban parameters were found as two main factors effecting UHI intensity. Since the city center of Shiraz is bounded by high-density, crowded districts with less green areas, it was decided to analyze UHI intensity in these districts. Shiraz traditional city center and 4 districts around was analyzed regarding (1) the meteorological parameters as humidity, the cloud cover, , and wind speed by some statistical documents; and (2) different factors of the urban structure (urban parameters), like the size of cities, the built-up areas density, and the buildings' heights ratio to the distances between them by the help of analysis.

As reviewed in chapter 2, there are some mitigation strategies for decreasing UHI in cities. According to the result of the analyses and based on the main aim of the study, these strategies are developed based on city scale and building scale. These strategies are easily applied in the cities without changing their urban planning decisions.

According to result of analysis, the reason for intensity of UHI in the Shiraz city center is rapid uncontrolled urbanization, which also increases the population. Higher population also increase energy consumption, creates high traffic and air pollution. in the city, the existence of factories (industrial facilities) also increase pollution and elevating the urban temperature. High buildings density in the districts around city center and lack of prosperity material in urban surfaces create cause an evaporation decreased in the city made intensity of urban heat island. Based on the all factors that increase UHI in Shiraz city center, the following lines are presents some strategies for decreasing the UHI effects in the city.

4.2. Strategies for decreasing the UHI effect in Shiraz

Urban heat island is one of the main significant risky issues in the city, which can create a big challenge in 21 century for urbanization. How to mitigate the influence of harmfulness of urban heat island and make the sustainable cities would be considered as the main problems towards our now generation of scientists and engineers. In the previous section, the main challengeable problems and the influence of urban heat island about Shiraz city are discussed. Put the effects of UHI on all sides of urban environment into consideration, causes reviewing ways of how to reduce the risky situation of UHI. "One of the principle influences of heat island is enhancing the temperature of the center in the cities. This cause many reasons which are not sustainable, increasing the usage of energy for getting to welfare temperature and leading many of people become depression and aberration in their molarity and after all above point city become unlivable environment for an appreciate life." (Ani et. al., 2009). The main aim of this section is to define the requirement to decrease the urban heat island event and propose some solutions in order to mitigate UHI effects and have Shiraz city more livable and healthy.

4.2.1. Achieve Sustainable Transport for Mitigating Air Pollution

Shiraz is facing a real big treatable and challenging factor, which is using motor bikes, cars and more over the growth of commuting and transporting, by knowing great obstacle to get sustainable development. Crowding and heavy traffic in streets and pollution already are facing us in the 21 century, and current situation might be more awful than before they developed. Therefore, some suggestions such as: making streets, and also paths more comfortable for pedestrian and vehicles (determinated for people who are walking or using bikes could be prepared to invite people using these modes of transporting), bring facilities and services next to each other decreasing the need for driving and furthermore reducing distances, expanding bus and metro lane networks plus, encouraging people for using public transportation system could be useful resulting in gaining the sustainable transportation and reducing the risk of air pollutions in the Shiraz city center. To achieve this goal the transportation department is responsible to improve the quality public transportation to invite people using buses and metro instead of their own cars.

4.2.2. Increasing the Albedo of Building Materials

"The albedo materials, which are used of facade or surface of buildings, are responsible for catching the quantity of heath sun. Some materials of facade are able to have suitable effect in absorbing the rays of sun. For instance utilization of white color materials can decrease the temperature of cities." (Akbari & Taha, 1997, Konopacki, 1998). The most considerable factor for thermal actions and performance of building facades plus the urban thermal events is selecting the materials and light colors. Materials with high albedo could decrease the heat of solar achieved by the surface temperature of the material on days. The temperature of material with low albedo is higher than the surface temperature of the material. For Shiraz city, due to hot weather in summer, Albedo with less catching and materials with light colors are being used for facade for buildings and environments to lead the decrease the temperature of areas and cause to have a better temperature in our surrounding.

Technical Department of Planning and Architecture is the main source to consider and control the usage of high albedo materials to decrease the effects of UHI.

4.2.3. Placing Vegetation on Buildings

As greenery area is covered surfaces of urban areas it leads new condition. To sum up the temperature of environment become lower and get closed to welfare weather. Chrisomallidou (2001) states "that the surface of the building is surrounded by vegetation which provide suitable shading. For example the use of green roof in a building improves the temperature of interior buildings in all season especially in winter and summer". "As a result the utilization of vegetation in the surface of building might be one of the techniques that is decreasing the heat of our environment. " (Ani et. al., 2009). For Shiraz city, the usage of plats in balconies or using different spaces of hot surfaces, like walls and roofs of buildings, with greenery for improving the urban thermal environment could have advantages to decrease the temperature and the influence of UHI.

- *Using Green Roof*

The usage of green roofs could gain some benefits for new construction in Shiraz such as; saving on energy heating and cooling cost, reduction of temperature during the day and night specially in summer, filtering the moving of air across it, in process of photosynthesis, plants changes water, sunlight/energy and carbon dioxide, into oxygen and glucose. Therefore, using of these green roofs is for decreasing harmful effects of UHI plus for preparing reduction of air pollutions.

- *Using Cool Roof*

Buildings and constructions in a dark colored roof would use more percentage of energy for air conditioning comparing a “cooler” building. Cool roofs in new buildings show both fast and long-term savings in cost of building energy, decreasing building heat attraction as a white color reflective roof, make savings on summer air conditioning expenses, develops thermal efficiency of the roof insulation, decrease the un-necessary power need, leading in less pollution plus greenhouse gas emissions, supply saving of energy and, reduce the influence of urban heat island. These models of roofs can decrease harmful affecting on urban heat island and offering to decrease the use of energy. The municipality and town planning department should be stricter about the rules and encourage the architects to use more greenery (vertically and horizontally) for their future design to decrease the effect of UHI.

4.2.4. Reducing Anthropogenic Heat

Based on the previous statements, anthropogenic heat is supposed as one of the most significant items in the city -Shiraz- heat island effect, particularly, in crowded and central areas. In districts, 4 and 5 have mostly commercial facilities and industrial lands that located in one space are the reason of increasing of population and motor vehicles and also raising the amount of energy using. Large amount of buildings and population are the reasons of energy consuming air pollution and high urban temperature. Consequently, it might be suggested to distribute industrial and facilities trading in some different locations of the city that could reduce pollutions gather in central parts and anthropogenic heat in a specific location. The municipality is the main source to spread the functions in all parts of the city and move the industrial function from the city to suburban areas to reduce the traffic and decrease air pollution and urban temperature in central part of the city.

4.2.5. Increasing Wind Speed

High levels of smog forming could be caused by high temperatures; moreover, the lower wind speed may lead to remaining of pollutants on urban areas. In north and south of Shiraz, mountains do not allow removing the air pollution that is brought by south and southeast dominantly into the urban parts, which is lead to weather pollution, particularly, in west and central areas plus raising inversion. Warm air falling down in urban canyons if not air-conditioned by cool suburban air. In addition, winds with lower speeds in the city inhibit evaporation cooling. Thus, the most suitable way is to supply efficient wind for decreasing heat weather in the urban areas. The meteorological organization and municipality are two source that can cooperate with each other to decrease air temperature and also the effect of UHI in urban areas specially in Shiraz city center.

4.3. Concluding remarks

This research aims to summarize and review the most urban heat island phenomena. Different parameters and their importance that affecting the urban heat islands intensity has been reviewed and described. The benefits and disadvantages, with the possible mitigation of urban heat islands were also supported. As a result, the UHI is strongly occurred by anthropogenic heat and uncontrolled development, which covers the design and planning parameters. It was also concluded from the literature, that there is a need to develop methods for determining the UHI reduction with a change in the design and planning parameters.

The rapid urbanization that Shiraz faces with the migration of rural dwellers to the city will create demand for more services and infrastructure, drive real estate development and add to the number of components. Considering for planning a UHI mitigation strategy for Shiraz city was suggested to have greenery and albedo materials.

Location of industrial land uses (for example cement factory) in the city, commercial land uses in central city and dense traffic congestion (air pollution) are the reason of rising anthropogenic heat and at last UHI effects. It could be really well worth for reducing the influence of Shiraz urban heat island in order to manage industrial places in rural ones, to make better commuting systems and to achieve high wind flow into the inner city for avoiding of weather pollution. Saving and reducing energy needs, improving the quality of environment and air besides, saving human being health in city places might be happening by reducing the impact of urban heat island.

The urban heat island mitigation effect from combining asphalt-covered streets and pedestrian ways around them with other materials used in addition to grass or greenery. Higher temperatures in paved (asphalt) urban areas may indirectly create a negative feedback by generating greater evaporative demand. This may further enhance the UHI effect between urban and nonurban settings in the future.

The relationship between wind speed and UHI intensity imply changes in the magnitude of the UHI effect over the city. The geometry in the middle of a greenery spaces and the dense-morphology of an urban places are quite vary from each other, which has a quite direct influence on wind and shelter distributions.

The up-growing amounts of buildings and construction in center of the city-Shiraz- and different parts around it have crowded out greeneries, vegetation and trees. Therefore, air temperature rises particularly, in areas with high density. The real need for vegetation, greenery and the low albedo of urban surfaces are quite important parameters regarding the heat island foundation effect in those 5 mentioned districts.

4.4. Agenda for future research

This research can help to find the effect of UHI on the cities and its hazards for human beings in the future. In other words, such research like what is done here can create a strategy for each city and in the local scale for a city to reduce the effects of UHI and improve the health and quality of life. Thus, these strategies applied in and every city without changing their city planning decisions. These directions could be regarded as the positive points of the research.

Based on the positive and negative aspects, in the following lines, some agenda for future research are given.

As a suggestion for future, new research should be considered in different locations, for instance, by selecting UHI in different cities with the same weather conditions and topography to have comparative data and get better results. That is why findings of the case studies cannot be generalized for other cases in different places.

Another suggestion for future research can be, the same analysis in the same case study areas can be repeated. This will lead new studies to make comparison between findings and to see changes throughout years. In other words, a comparative case study can be carried out over a determined time-span.

It is believed that, the existing body of this thesis has a rich theoretical background about the urban heat island. The researchers and future works can also reach theoretical background about UHI and its hazards for future generation. Local and central authorities such as municipalities, town planning department can also get benefit from data collection and data analysis, which have been drawn by the author of this research.

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