This paper has been published in *The International Journal of Environmental Sustainability*, Vol. 9, Issue 1, 119-130

# *The Impact of Green Areas on Mitigating Urban Heat Island Effect: A Review*

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Urban Heat Island (UHI) is considered as one of the major problems in the 21st century as a consequence of urbanisation and industrialisation of human civilisation. The main source of UHI is the large amount of heat produced from urban structures, as they absorb and re-radiate solar radiations. Therefore, Urban Heat Islands develop in areas with a high percentage of non-reflective, water-resistant surfaces and a low percentage of vegetation. Specifically, a lack of vegetation reduces heat lost due to evapotranspiration. Vegetation, particularly in the presence of high moisture levels, plays a vital role in the regulation of surface temperatures, even more than may non- reflective or low-albedo surfaces. There are different ways of reducing the effects of UHI. However, a common measure to mitigate Urban Heat Island is to increase urban green spaces such as parks, street trees and green roofs. This paper discusses the current literature and knowledge about the impacts of green spaces on mitigating UHI. Studies conducted on the influence of greenery on mitigating UHI have indicated that all green spaces help urban areas adapt to the impact of UHI regardless of whether they are parks, street trees or green roofs.

*Keywords: Urban Heat Island, mitigation strategies, urban green space, green roofs*

## Introduction

World urbanization has been growing rapidly since the Second World War. Nowadays, around 50% of the world's population (3.4 Billion) is settled in cities. In addition, it is expected that inhabitation in cities will reach 60% (5.0 Billion) by 2030 which means around two billion more people will reside inside cities by that year (Bowler et al. 2010, 147). The expansion of urban areas affects biodiversity and ecosystem functions, as well as local and regional climate and the quality of life (Luck and Wu 2002, 332). Urban Heat Island (UHI) is one of the ecological results of urbanisation which leads to higher temperature in urban areas in comparison to surrounding rural areas (Li et al. 2011, 3250). The change of the land surface in the urban area and replacement of vegetation by expansively built surfaces (typically paved roads and buildings surfaces) are the main reasons of forming UHI (Voogt 1989, 662).

The "urban heat island effect" can raise air temperature in a city by 2–5 °C. In the evening the difference could be as high as 12 °C (Oke 1989, 336). Elevated temperatures from urban heat islands, especially during the summer, could influence a community's environment and quality of life. There are a lot of undesirable environmental and economical impacts of UHI such as: the deterioration of living environment, increase in energy consumption (Akbari and Konopacki 2004, 195; Akbari and Konopacki 2005, 730), elevation in ground-level ozone (Rosenfeld et al. 1998, 60) and even an increase in mortality rates (Changnon, Kunkel and Reinke 1995, 1504). Therefore, there is an extreme need to estimate strategies that may mitigate the impacts of urban heat islands in urban areas. An adaptation strategy that has been proposed is to 'green' urban areas, fundamentally by increasing the abundance and cover of vegetation (Givoni 1991, 292; Gill et al. 2007, 120).

During recent years, many studies have been conducted in order to explore the role of green areas in moderating the urban climate. These studies could be generally divided into three categories. Firstly, studies which evaluate the effects of green areas in cities at macro level by using meteorological data and satellite images. Secondly, studies that explore the cooling effects of green areas at micro-level by carrying out some in-depth field measurements. Finally, studies that set up some numerical calculations in order to predict the thermal benefits of green areas in cities (Bowler et al. 2010, 147). The aim of this paper is to evaluate the impacts of green areas on microclimate in cities with respect to decreasing air temperature and hence mitigating urban heat island effects. In this regard, this paper reviews studies which compare air temperature between green and non-green areas in order to provide a direct assessment of the influence of green space on temperature and consequently UHI. This review focuses on research that evaluates the impacts of three specific green infrastructures (parks, street trees and green roofs) on reducing UHI, especially with highlighting the role of green roofs.

## Generation of UHI

Urban heat islands are mainly nocturnal features. Differences in the cooling rates between urban and rural areas are the main causes forming UHI. The differences in cooling rates are affected by several factors. These factors could be classified as controllable and uncontrollable factors (Fig. 1). The controllable and uncontrollable factors could further be divided into three categories: (1) cyclic effect variables such as solar radiations and anthropogenic heat sources, (2) permanent effect variables such as green areas, building material, and sky view factor and (3) the temporary effect variables, such as wind speed and cloud cover (Ahmed Memon, Leung, and Chunho 2008, 121).

The heat in an area is generated by sun and power plants as well as industrial processes, vehicles, air conditioners and other sources of anthropogenic heat. Almost all anthropogenic heat comes into the environment instantly and directly. However, only part of solar radiation heats up the environment directly. The natural and man-made urban structures absorb and store the rest of solar radiations continuously in the form of heat energy during the day. Subsequently, while the environment starts cooling down at night, heat energy stored in urban structures is released to the environment and heat it up indirectly (Ahmed Memon, Leung, and Chunho 2008, 121; Oke 1982, 4; Sailor, L. Lu 2004).

The amount of solar energy which is absorbed and then released by urban structures depends on the physical properties of different urban surfaces and their form in urban landscapes, as well as climatic condition and regional meteorology (Oke 1982, 5; Sailor, L. Lu 2004, 2760).

A high percentage of non-reflective, water-resistant surfaces and a low percentage of green areas in a city provide a favourable condition for generating more and more urban heat islands. In particular, materials such as stone, concrete, and asphalt tend to trap heat at the surface (Oke 1982; Landsberg 1981, 12; Quattrochi et al. 2000, 1208) and a lack of vegetation reduces heat lost due to evapotranspiration (Lougeay, Brazel, and Hubble 1996). Vegetation, especially in the presence of high moisture levels, plays a key role in the regulation of surface temperatures, even more so than non-reflective or low-albedo surfaces (Goward, Cruickshanks, and Hope 1985, 139; Voogt 1989, 662).

## Impact of Green Space on Mitigating UHI

Urban materials and vegetation are different in thermal and aerodynamic properties. Therefore, greening urban areas could influence air temperature through different processes (Oke 1989, 340; Givoni 1991, 293). One of these processes and the most fundamental one is evapotranspiration which means losing water from a plant in the form of vapour into the atmosphere. This process consumes solar energy and increases latent heat more than sensible one. Leaves cool through evapotranspiration and therefore the temperature of the air surrounding leaves reduces (Bowler 2010, 148; Taha et al. 1998, 275; Grimmond, T.R. Oke 1991, 1741). In an ideal situation, evapotranspiration could affect the cooling process significantly and cool the air temperature around green spaces by 2-8°C in comparison to surrounding areas (Taha 1997, 100). Based on a study carried out by Leuning et al. (2005), urban evapotranspiation influences the water balance considerably. Through this study they found that in studied areas, the amount of water consumed in evapotranspiration is almost twice the amount of water which is lost through run-off. Therefore, if water is added to the urban landscape, quantifiable benefits such as cooler air temperature and enhanced energy performance will be achieved (Bowler 2010, 148; Leuning et al. 2005).

In addition to evapotranspiation, vegetation reduces the temperature of surrounding air through shading the surfaces they occupy; hence, these surfaces receive less solar radiation and therefore less solar energy is absorbed and converted to heat energy. Moreover, vegetation might affect air movement and heat exchange (Bonan 1997). This impact depends on the type vegetation. For instance, trees might keep warm air beneath the canopy; on the other hand, an open grass field which provides low resistance to air flow might enhance cooling by convection (Bowler 2010).

## Urban Forests

The urban forest could be defined as the trees of the city or a vegetated space within an urbanised site (Kleerekoper, Esch, and Baldiri Salcedo 2012, 3; Ordonez, Duinker, and Steenberg 2010, 3). “Urban trees could be found in stands, like in a park, arranged in lines along streets, or as a single tree” (Ordonez, Duinker, and Steenberg 2010, 3). Urban forests are valuable from the environmental, social and economical points of view. Urban forests affect the urban climate by controlling GHG emissions. For instance, in the USA, urban forests reduce around 23 million tonnes of carbon every year (Nowak & Crane 2002, 382). Urban forests decrease carbon emission by enhancing energy use through reducing albedo, providing shade and cover (Akbari 2002, 123; Heisler 1986, 340; Jonsson 2004, 1312; Scott et al. 1999, 140) as well as regulating the hydrological regime of cities (Sanders 1986, 370).

### *Urban Parks*

Several studies have been conducted to investigate the impacts of urban parks on urban micro-climate. Based on these studies an urban park could reduce its surrounding air temperature by up to 4 ○C (Spronken-Smith and. Oke 1998; Jonsson 2004; Zoulia, Santamouris, and Dimoudi 2009). Vegetation in a park could generate a phenomenon which is called “Park Cool Island”. This phenomenon describes a localized cooling that stands in contrast to Urban Heat Island effect (Shashua-Bar, Pearlmutter, and Erell 2009, 180).

In a study carried out by Cohen et al. (2012), they examined the daily and seasonal climatic behaviour of various urban parks with different vegetation cover and its impact on human thermal sensation in the summer and winter in Tel Aviv, Israel. This study compared the climatic conditions developed in various types of urban green open spaces, exposed open urban squares and street canyons near such sites (Fig. 2). The results illustrated that an urban park with a dense canopy of trees has maximum cooling effect during summer and winter in daytime. In summer it reduces temperatures by up to 3.8 ○C while in winter it reduces temperatures by up to 2 ○C (Cohen, O. Potchter, A. Matzarakis 2012). The results of this study are shown in Table I.

Although most examined urban parks were cooler than their surrounding areas, one fifth were actually warmer than their surroundings (Chang, Li, and Chang 2007). Research concentrated on one large urban park in Nagoya, Japan found that during the summer, the air temperature of the park is 1.9 ○C cooler than urban surroundings, while in winter days, when trees shed their foliage, the park is up to 0.3 ○C warmer than its surrounding (Hamada and Ohta 2010).

The foliage of a tree could reduce 60 to 90% of solar radiation received by ground. The quality of the shade of a tree depends on its density. Therefore, species of trees and plants in a park should be chosen based specifically on the climatic condition of the park (Moufida and Djamel 2012, 78). Moreover, the percentage of trees and vegetation cover in a park could influence the air temperature. According to a study conducted by Potcher et al. (2006) parks with fewer trees tended to be warmer during the day compared to parks with greater tree cover (Potchter, Cohen, and Bitan 2006). A similar result has been evident by Cohen et al (2012) as well. In addition, parks are different in the percentage of non-green areas, especially multi-use parks. It has been proved that increasing paved areas in a park correlates positively with the air temperature difference in studies in Mexico City and Taipei (Barradas 1991; Chang, Li, and Chang 2007).

Moreover, park size is an important factor which could affect the air temperature of the park. Chang et al. (2007) compared the temperature of 61 parks during summer at noon in Taipei City. The results of this study show that larger parks are usually cooler than their surrounding areas while the temperature differences are much more variable for smaller parks (Chang, Li, and Chang 2007). In another study, Barradas (1991) measured the air temperature of 5 parks with different sizes in Mexico City during rainy season. He found that larger parks tended to be cooler than their surrounding in comparison with smaller ones (Barradas 1991).

### *Street Trees*

As street trees are so wide-spread, it seems that they affect urban climate slightly. However, since there are so many they could have significant impacts on the air temperature of the urban areas (Bowler 2010, 152).There are several studies which investigated the effects of trees on the urban microclimate and compared temperatures between sites with trees and treeless sites. It is evident that during the day, the air temperature beneath individual trees (Georgi and Zafiriadis 2006; Golden et al. 2007) and cluster of trees (Taha, Akbari, and Rosenfeld 1991; Shashua-Bar and Hoffman 2000; Streiling and Matzarakis 2003) is cooler than the air temperature in treeless areas. On a sunny day the evapotranspiration of an individual tree could cool its surrounding urban environment with a power equal to 20-30 KW. This power is comparable with the power of 10 air-conditioning units (Kleerekoper, Esch, and Baldiri Salcedo 2012, 31).

In a study carried out by Tsiros (2010), he compared air temperature under the vegetation canopy of trees in suburban streets and at reference points under mostly light wind conditions in five streets in the city of Athens (Greece). For this study, a number of observation points spaced at about 20 meters were selected over its length inside the streets. Then a 'reference point' was selected for each site that comply with the following two criteria:

- The reference point is close to the site (50 to 100 meters from it).
- The reference point is treeless and receives sunshine most of the day.

The measurements were made during a short exceptionally hot weather period in 2007. Results of this research indicate that the street with dense tree shade and minimal traffic load has the highest cooling effect of 2.2 ○C. These results imply the passive cooling potential of shade trees (Tsiros 2010). Trees are different in their ability to cool air temperature. Size of the tree and the characteristics of the tree canopy are key factors which might influence the amount of solar radiation received by urban surfaces (Georgi and Zafiriadis 2006, 198; Bueno-Bartholomei and Labaki 2003).

## Ground Vegetation

There are some research which studied the impacts of ground and short vegetation cover on temperature. These studies indicate that the air temperatures are usually cooler above grass cover compared to above non-green urban surfaces such as concrete (Huang et al. 2008; Yilmaz et al. 2008).

Onishi et al. (2010) evaluated the potential for UHI mitigation of greening parking lots in Nagoya. In this study the relationships between land surface temperature (LST) and land use/land cover (LULC) in different seasons were analyzed by using multivariate linear regression models. Potential UHI mitigation was then simulated for two scenarios: (1) grass is planted on the surface of each parking lot with coverage from 10 to 100% at an interval of 10% and (2) parking lots are covered by 30% trees and 70%

grass. The results illustrate that different LULC types play different roles in different seasons and times. On average, both scenarios slightly reduced the LST for the whole study area in spring or summer. However, the second scenario was more effective in reducing the air temperature (Fig. 3). For an individual parking lot, the maximum LST decrease was 7.26 °C in summer. Consequently, it is evident that vegetation cover could reduce air temperature considerably and hence mitigate the UHI (Onishi et al. 2010).

## Green Roofs

A modern green roof is a conventional roof with a waterproof membrane with layers of drainage and vegetation installed on top of it. A green roof generally consists of five components from the bottom to the top: a roof support, a roofing membrane (membrane protection and roof barrier), isolation, a drainage layer, a growing medium and vegetation (Ouldboukhitine et al. 2011, 2624) (Fig.4).

It has been proved that green roofs could mitigate urban heat islands significantly by removing heat from the air through evapotranspiration and reducing heat absorb, which brings about a decrease of the temperature of roof surface and surrounding air. Moreover, green roofs could diminish urban heat island effects through reducing the need for air conditioning by providing a cooler surface at roof level, hence energy performance of the building is enhanced and less anthropogenic heat is generated (Susca, Gaffin, and Dell'Osso, 2011, 2122; Alexandria and Jones 2008, 488).

In the last decades, green roofs have been extensively investigated in many cities around the world as a tool to mitigate the urban heat island effects. In a study carried out by Rosenzweig et al. (2006), they reported that greening 50% of New York City rooftops would reduce the average surface temperature by an estimated 0.1–0.8°C (Rosenzweig, Gaffin, and Parshall 2006). In addition, Banting et al. (2005) found that by greening 30–100% of available rooftops in Toronto, Ontario, the average air temperatures could be reduced by 0.5–2°C (Banting et al. 2005).

In another research conducted by Alexandri and Jones (2008) they examined the thermal impacts of greening the building envelope on the microclimate in the built environment, for various climates and urban canyon geometries. In this research, the climatic characteristics of nine cities, three urban canyon geometries, two canyon orientations and two wind directions were analyzed. In this regard, they used a two-dimensional, prognostic, micro scale model, developed for the purposes of this study. The thermal impacts of green roofs and green walls on the built environment were examined both inside the canyon and at roof level. The results of this study illustrate that greening the building envelope is an efficient method in order to tackle the urban heat island effects (Alexandria and Jones 2008).

Takebayashi and Moriyama (2007), Hien et al. (2007), and Gaffin et al. (2009) tried to assess the temperature reduction potential of green roofs by using simulation or gathering data. These researches indicate that green roofs could considerably decrease surface temperatures at roof level in comparison with traditional roofs. Hien et al. (2007) found that the surface temperature of a green roof was approximately 18°C lower than that for a conventional roof in Singapore (Hien, Puay Yok, and Yu 2007) (Fig. 5).

Meanwhile, Bass and Baskaran (2001), Sonne (2006), and Cummings et al. (2006) investigated the energy saving potential of green roofs. It is found that there are a range of parameters which influence the energy saving potential of green roofs such as the climate and building characteristics (in terms of materials, insulation, size, operation, etc). For example, Bass and Baskaran (2001) evaluated the heating and cooling energy savings for a one-story office building with a 3,000 m2 green roof in the city of Toronto, Ontario in Canada. A Visual DOE model was used for this study. The results of this study show that by implementing the green roof the heating and cooling energy is reduced by 10% and 6% respectively, with an overall total energy usage reduction of 5% (Bass and Baskaran 2001). The exact same simulation was run in Santa Barbra, California; it became evident that with lower amounts of insulation the cooling savings were increased to 10%.

## Conclusion

The urban heat island effect, as one of the ecological consequences of urbanisation, could affect a community's environment and quality of life. The major source of UHI is the large amount of heat produced from urban structures, as they consume and re-radiate solar radiation, and from the anthropogenic heat sources. Increasing urban green areas is considered as one of the efficient strategies to mitigate UHI. It has been proved that increasing urban green areas such as parks, street trees, short vegetation cover and green roofs could reduce air temperature and hence, UHI through three processes:

- Evapotranspiration
- Increase of direct shading on urban surfaces
- Influence on air movements and heat exchange

Based on several studies, temperature reduction in a treed urban environment can reach up to 4 ○C and it depends on the size of the park, the amount of trees and grass cover in the park and the choice of species. In addition to parks, street trees could influence air temperature significantly. There is evidence that air temperature beneath both individual trees and clusters of trees are lower than temperatures in an open area, at least during the day. Green roofs are an additional means of mitigating Urban Heat Island effect. Green roofs mitigate UHI trough removing heat by evapotranspiration, decreasing heat absorption and also reducing the need for air conditioning. Therefore, it is concluded that urban greening is an efficient method in order to mitigate urban heat island effect and human health consequences of increased temperatures resulting from climate change and hence, improve quality of life in urban areas.

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