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Urban Design Guidelines to Mitigate Urban Heat Island (UHI) Effects In Hot-Dry Cities

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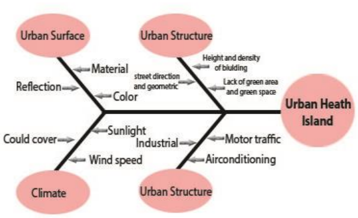
Graphical abstract



Abstract

Global warming and undeniable climatic change in the world have led to decreasing thermal comfort for humans. Urban heat island (UHI) is the most documented phenomenon which has led to the increasing temperature in urban areas. It has received much focus in the past few decades to evaluate the main effective criteria of UHI. Street heat has negative effects on human health and will only worsen in future; these negative effects would double in hot and dry urban area. This paper investigates the effects of UHI in these cities and illustrates the important factors which make them extremely hot. The outcome of this study can be used to determine the key guidelines for urban designers, urban planners, architects and landscape designers to recline the UHI impressions in urban areas and make more thermal comfort for Burgher.

Keywords: Thermal comfort; Urban Heat Island (UHI); hot and dry city; Urban Design Guidelines

■1.0 INTRODUCTION

Our life would be more comfortable with the development of urbanization and industrialization (1). However, this development has also provided many climate change problems to human beings. The importance of climate change and its implications have been widely discussed in the academic community during the past decades. The spatial patterns, growth and development of cities will be impacted by climate change. The problems in the regional urban areas are more serious because of the existing of artificial construction and human activity which have led to the unfortunate effects on the environmental and ecological balance.

Due to these human activities, a phenomenon called an urban heat island (UHI) where a metropolitan area significantly has warmer weather than its surrounding rural area (2). Luke Howard, who first reported on the UHI in the late 1810s, stated that the urban center of London was warmer at night than the surrounding countryside by 2.1 °C (3) and this warming was expected to increase by approximately 1 °C per decade (4).

UHI is considered to be a primarily nocturnal phenomenon (5), which means that the temperature difference between an urban area and its rural surroundings is higher at night. (6) this temporal difference leads to the decrease of diurnal temperature range in built up areas in comparison to rural areas. The opposite is true for the surface temperatures of the urban landscape within the UHI.

Studies illustrate that the enlargement of heat islands at night has a direct relationship with the H/W proportion of street canyons (the ratio between the height of the buildings (H) and the width of the adjacent street). By using surface temperature simulations, it has been proven that the street geometry and the nocturnal heat island are linked (7), (5), (6). One of the ways to provide human thermal comfort in the urban space is by finding a solution to dim the UHI phenomenon as it can be seen in Figure 1. The main aim of this study is to illustrate some offers for diming the UHI in cities with hot and dry climates.

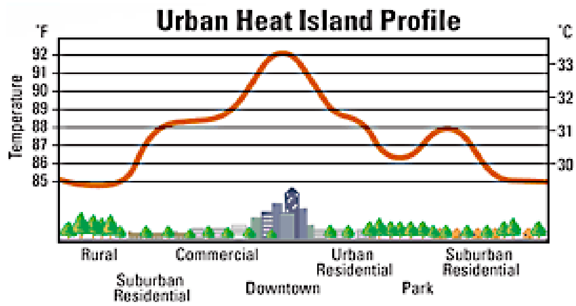


Figure 1 Urban heat island profile of different districts in an urban area (8)

1.1 Causes of UHI

It is obvious that the increasing rate of urbanization exacerbates the negative effects of climate change. On the other hand, energy consumption increased by 14% during the last decade which was mostly due to rapid urbanization. It is estimated that until 2030 at least 61 percent of the world's population will be living in cities. 95 percent of all the population growth will be absorbed by cities in developing countries that will be home to almost four billion people (80 percent of the world's urban population). However, this urbanization may provide the chance for a climate friendly renewal or renovation of the urban shape.

There are some main criteria that led to the increase of UHI in urban cities that are discussed as follows:

-Surface: Land surface material is the main factor which affects UHI. During the day, solar energy is stored in the urban fabric and released back into the environment at night. Therefore, if the difference in the thermal admittance of urban areas is increased in comparison to its rural counterparts, the size of the heat island will also increase (9). The increased emissivity from the sky and wind speed will decrease the size of the urban heat island (10), which means that during calm and cloudless nights the largest urban-rural temperature differences occur (11). Since the urban surface materials have a relatively high thermal capacity, they absorb solar energy during the use of materials that absorb short-wave radiation that increases UHI (12), (13), (14).
-Lack of plants: There is a significant amount of literature available on the impact of green areas and vegetation on air temperature. It was stated that larger parks are normally 1-2°C cooler than built-up areas, (15) but this difference in temperature can reach as much as 5°C (16). Lack of vegetation in the urban area decreases evapotranspiration, shade, and cooling effects of plants that make the city warmer (17), (18) and help UHI.
-High buildings: Tall buildings with continuous slab structures can block the fresh air and wind movement and provide various surfaces for levels to reflect and absorb sunlight that makes urban area warmer; therefore special attention should be paid to their location.
-Human activity: Human activities affect the climate, such as air conditioning of the buildings, motor traffic and industrial production (19), (20). The heat enters into the environment directly and indirectly. Apart from the heat and moisture that these activities release, (21), (22), (23) they also pollute the air and consequently affect the incoming and outgoing radiation.

The buildings and structures in urban developments have a certain influence on the absorption and reflection of solar radiation, the ability to store heat, wind and evapotranspiration (24). Airborne aerosols, which are partly a result of vehicles and industrial activities, diminish the incoming solar radiation and increase its diffusion. The reduction of global solar radiation in most cities is below 10%, but in highly polluted cities this may increase to more than 20% (25), (26). Pollution is identified as the cause of increased absorption of the outgoing long-wave radiation by the atmosphere. This absorbed radiation is re-emitted towards the ground. High levels of pollution in urban areas can also increase the UHI as many forms of pollution change the radioactive properties of the atmosphere (27). Figure 2 shows the causes of the UHI phenomenon in urban areas.

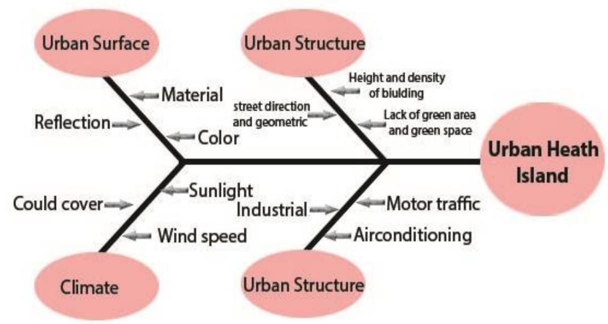


Figure 2 Causes of UHI

1.2 Effects of UHI

This higher temperature will result in locally acute adverse human health as well as economic and environmental impacts (2). According to experts, exposure to excessive heat kills more people each year in the US than deaths from all other weather-related events combined (28)(29). These extreme heat events tend to disproportionately impact the urban poor, elderly, and ill–all populations that tend to lack the economic support system necessary to avoid adverse health impacts associated with extreme heat (30).

Improving UHI would cause the need of more energy for air conditioning and refrigeration in the cities and increase the cost of living (31). Moreover, it is estimated that for each 1°C increase in the UHI intensity, the energy demand would increase 2 to 4% (32). On the other hand, due to rapid urbanization, energy consumption has increased by 14% in the last decade (33) as energy is an important element in human life (34) that becomes a global concern due to a probability of lack of energy in the near future (35).

In the context of Los Angeles, Akbari and his colleagues estimated that 5-10% of the current energy demand of the city is consumed to cool buildings, just to compensate for the UHI increase since 1940 (about 0.5-3°C).

UHI can decrease the quality of water and climate and led many adversely affect to water and climate and followed by much damage to aquatic animals. Plant and animal species are being lost around the world with the rising temperatures at a rate that has alarmed many scientists. Some of the most notable extinctions that are anticipated for the near future are those of the coral reefs, the Sumatran tiger, the Malaysian bear and the Western gorilla. Hot roofs and pedestrian surfaces transfer their heat to storm water which drains to river or lakes (36). Because of the increasing water temperature, many fish and aquatic animals would be shocked and killed by the heat of these bodies of water [37].

2.0 UHI IN HOT AND DRY CITIES

In hot and dry climate cities, UHI will most likely result in higher temperatures and lower air humidity and therefore have a negative effect on human comfort and heat stress in urban areas (38) (see Figure 3). We can adapt to the heat stress by moving into the shade if we feel hot. In other words, even the slightest improvement to the ventilation conditions in densely populated areas can lead to a great reduction in heat stress (39).

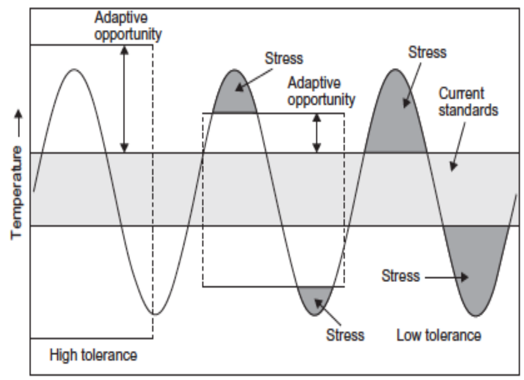


Figure 3 Effect of adaptive opportunity: The greater the opportunity to control the environment, the less likelihood of thermal stress (40)

Cold and heat stress, over exposure to sunlight, insect infestations, air pollution, water pollution, waste, noise, negative effect on energy use (38) and fires are all the features that are exacerbated by the UHI. UHI also leads to chance of heat stroke and heart disease and diminished both mental and physical performance, such as heat cramps, heat syncope, heatstroke and heat exhaustion (41). Negative social and economic impacts of hot weather are also possible consequences of UHI. Unpleasant climate would limit time spent outside to only when necessary, i.e. shopping and commuting to work, and decreasing outdoor social activities, i.e. meeting people in public places (42). A major consequence of this fact is the increasing use of air conditioning, resulting in higher energy costs for the citizens. Frequent power disruption and increasing air pollution are also the consequences of increased power consumption.

3.0 UHI MITIGATION STRATEGIES

The literature on UHI suggests three main mitigation strategies: planting trees in open spaces or along the streets; blanketing rooftops with vegetation (living roofs/ green roofs); and, increasing the reflectivity of built surfaces (43), (44). layout and widening of the streets prevailing winds and street orientation and the height and shape of streets are important (45). For example canopy shade built surfaces and also cool the air through evapotranspiration (46), (47). Green roofs can cool the roof surface of a building through evaporation from the soil media and transpiration from plants, reducing air temperature above the roof which then mix the adjacent air to cool the entire surrounding area (48). These roofs also result in reduced building energy demand in the summer time by reducing the amount of solar energy that is conducted into a building and thus improving the quality of storm water runoff (2), (46). Furthermore, in the cities with limited space for street-level planting, like New York, green roofs could provide additional areas for introducing cooling vegetation into the urban environment.

Surface lightening includes but is not limited to mixing lighter-colored aggregate into asphalt, typically on streets and rooftops. While urban areas typically have large areas available for surface lightening, light-colored surfaces are difficult to keep clean and may lose up to one-third of their reflectivity in a few years due to staining, weathering and soot deposition (49).

According to J. Corburn, (2), land use has effect on temperature changes, including reflectivity of surfaces (albedo) and vegetation density. An albedo of 0.5 suggests that 50 percent of the incident solar radiation is reflected. Surfaces with a higher albedo tend to be cooler than those with a lower albedo. However, as Rosenzweig and his colleagues noted in the NYCRHII final report (2006) (50), "curbside planting, living roofs and light roofs and surfaces have comparable cooling effects" but that "light surfaces required an area many times greater than the area for street trees needed to achieve comparable cooling" rendering this intervention less cost-effective than street tree planting.

Some studies in hot, dry cities show that the increase in H/W ratio will decrease the maximum daytime temperature (51) and in some cases will increase the nocturnal temperature (52). Similarly, the effect of street orientation on air temperature has been studied in these cities as well. Pearlmutter and his colleagues (1999) (53) found out that by day the north-south oriented street was slightly cooler than the east-west oriented street. However their study shows no difference in the temperature by night. Bouria and Awbi (2004) (54) also reported cooler daytime temperatures (1-2°C) in north-south oriented streets in comparison to east-west streets.

4.0 RESEARCH METHODLOGY

This research is based on a deductive reasoning and it is multidisciplinary in character. The overall approach of this research is based on the literature review and qualitative studies. The aim of the literature review as part of this study was to establish a solid theoretical background and to achieve a better understanding of the causes and remedies of the UHI, as recommended in the literature. The aim of the qualitative study was to obtain basic knowledge of urban planning and design processes, including the role of climate and thermal comfort aspects.

These methodologies were combined in different ways in order to obtain more reliable research results. This mixed methodology helped in identifying the strengths and weaknesses of current urban codes with regard to the climate-conscious urban design.

5.0 CRITERIA TO MITIGATE UHI PHENOMENON

5.1 Main Criteria

There are several criteria to control UHI in hot and dry cities which should be investigated: the (H/W) ratio between the height of the buildings (H) and the width of the adjacent street (W), the orientation, reflectivity, conductivity, plot coverage, balconies and vegetation.

H/W ratio: The ratio between the building height and street width is discussed in the literature as a prominent factor and as effective on thermal comfort, especially in tropical climates.

Orientation: Considering thermal comfort, the orientation of the street network in relation to the patterns of sun movement and prevailing winds is an important issue.
Reflectivity: Materials which are used in the roof of the building, street floor and wall surface with different reflectivity can have different effects in warming the environment.
Conductivity: The properties of the materials used in urban environments have tangible effects on the local microclimate. The relationship between thermal conductivity and human thermal comfort outdoors is necessary to investigate.
Plot coverage: As discussed before, there are certain limitations for the location of a building within its land plot and the percentage of the plot that it covers.
Balconies: Provision of shadow is the main strategy in improving the outdoor thermal comfort in hot and arid cities. This can be achieved by balconies, colonnades, pergolas and installation of other devices that offer shadows on the public realm, especially on the pedestrian pathways.
Vegetation: Vegetation and green infrastructure of a city also have been discussed as effective factors in the world of outdoor thermal comfort and reducing UHI.

5.2 Fusion Criteria

5.2.1 Plot Coverage Fusion Vegetation

To ensure adequate ventilation throughout the city, even with weak currents, smaller surface area and lower building density are needed. Between the reservation of urban areas and the goals of climate-friendly urban development, there are often trade-offs. A development of open spaces leads to compact settlement patterns, which are areas with higher sustainability in terms of transport and energy. On the other hand, by the compaction of buildings, the heat island effect is amplified. Therefore it should be tried at least as a compromise to seek development limits; the remaining urban open spaces can counteract the negative effects of compaction.

With a sufficient surface area, a green open space can also have a climate-regulating function besides its role in the urban context as a structural element. A special feature is the green belts as the separation barriers between residential areas and emitting industrial and commercial areas or roads with high traffic. Moreover, green spaces act as air filters, diluting and filtering airborne contaminants and decreasing the heat island effect.

Greening of the streets in urban areas with trees and shrubs can decrease the heat island effect. The shadow of the trees and evaporation and transpiration of the plants will moderate the temperature. At the same time, since streets are usually air channels as well, these plants will cool the air that circulates through the rest of the city (28).

Special attention should be given to the type of foliage selected for street greening. While a certain tree type with a large canopy can provide more shadow, it will also lead into the accumulation of air pollutants on the street level. However, unless there is a significant source of pollution under the canopy, this effect can be ignored. Needless to say, types of plants chosen should be adaptable to the future climate.

The preservation of urban green spaces and unsealed open areas (e.g. agricultural land) is of central importance in the context of climate adaptation. Vegetation structures contribute to the thermal regulation and improve the overall climate and air hygiene situation. Considering the terrain morphological conditions, the type of green and open surface and the course of the ventilation lanes, compensations for the effects can be achieved for stressed areas and heat islands. Taking possible consequences of the climate change into consideration, this urban climate compensation function is of growing importance. Due to the changing climatic conditions, with an increase in negative climatic situations by heat stress, the increase in peri-urban and urban green areas and unsealed open spaces is vital. In addition, the vegetation in peri-urban green areas is under the increasing stress of drought, heat and heavy rain. The consequences require a situation-adapted and increased maintenance effort, e.g. more frequent irrigation or pest control. Using more heat and drought resistant plant species is also recommended.

5.2.2 Conductivity Fusion Orientation

The generation of cold and fresh air through the natural surface is determined by the thermal properties of the materials in that surface. Materials with higher density absorb more solar energy and therefore produce less cold air than those with less density (Figure 4). The size of these fields is important too. Connectivity of fresh-air fields with the inner-city districts through fresh air corridors reduces the heat island effect.

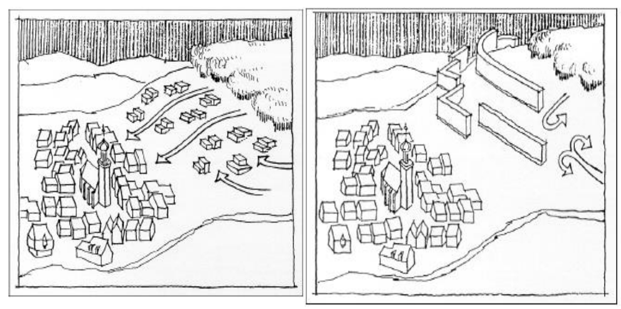


Figure 4 Height building blocks the fresh air

In addition, there are significant strategic places that need special attention, such as the pedestrian zone and the entrance areas of the city. From a climatic point of view, the element of water is particularly well suited due to its positive urban climatic effects as design elements, in particular against the heat island effect.

■6.0 URBAN DESIGN GUIDELINES TO MITIGATE UHI PHENOMENON IN HOT AND DRY CLIMATES

Presented in the following section are proposals for street designs in hot and dry climates which consider human thermal comfort in the future climate. Although they are based on the simulated studies, current urban design practices have also been taken into consideration.

According to these results, provision of shadow is critical in the thermal comfort situation of summer time. Canyons with high H/W ratio lead to a more comfortable environment. However, since these canyons have a poor thermal condition in winter, some streets should have lower H/W ratios special attention should be paid to their location. Significant urban and street spaces include areas and buildings that need to be protected and developed because of their existing identity-forming impact on the entire city, the city's image, and the relationship of citizens with their city. In this context, existing paths, visual connections, and historical references are important

Another trade-off happens in the redevelopment of previously industrial areas which can create a high-density residential district but at the same time eliminate the chance for a fresh-air surfaces. Buildings with continuous slab structures can block the fresh air movement; therefore the majority of the street should be designed for proper summer comfort.

Yet, in order to provide thermal comfort on a larger scale, a combination of streets with diverse H/W ratios is advised. Preferably, the north-south canyons, where the thermal situation is comparatively better, should have a H/W ratio of equal or greater than 2. Deeper canyons with H/W ratios higher than four are desirable for east-west oriented streets.

Increasing the heights of buildings and making the streets narrower are two important ways of growing the H/W ratios. Each of these practices has its own positive value. For example, narrower streets may cause motor traffic problems, and high buildings may result in privacy problems. In the street's design, specia attention should be paid to these items. In order to increase shade for the pedestrian thermal comfort, front setbacks should be banned. In the streets with lower H/W ratios than suggested above, shading devices such as balconies, colonnades and shading trees should be foreseen to provide shade around midday. Deciduous trees are suitable for these cities, as they block solar access in summer and allow it in winter.

Although pedestrian thermal comfort is not constituted only by radiation, an indicator of thermal comfort is affected heavily by the reflectivity level of the building materials; higher reflectivity leads to decreased surface temperatures and increased re-radiation permitted into the environment. Meanwhile, this lower surface temperature leads to better thermal conditions. Therefore, building materials with lower reflectivity should be suggested. Recently, aluminum cladding has been used in the design of commercial and office buildings. Glazed and glossy stones are also very common in residential structures. These materials must be substituted with other materials with suitable properties, at least in the areas near pedestrian pathways.

Changing the codes to permit higher H/W ratios for the streets would be necessary. In particular, higher building heights and projecting upper floors should be permitted and promoted. These changes in the urban codes would lead to a more compact urban design and hence more efficient land-use (28).

Although vernacular architecture is equipped with climate regulating mechanisms, passive design strategies may be insufficient to ensure the required thermal comfort in arid areas as the climate may be particularly harsh. However, these strategies will extend the time during which outdoor thermal conditions are comfortable and therefore promote longer and more frequent use of public open spaces.

It is widely accepted that a redesign of a certain environment has a strong influence on the thermal bioclimatic. (55) Demonstrated in their specific case, the reduction in shading had the most significant impact on thermal comfort. Reduced shading leads to an increase in the areas exposed to direct solar radiation, which in turn increases PET in these areas. Thus, during cold and cool periods, people enjoy more comfortable conditions. Nevertheless, in this situation, thermal stress increases under hot conditions in summer. A compromise should be made between the thermal situations of the two seasons.

■7.0 CONCLUSION

Further research on the topic of this paper is necessary, however the large number of studies shows that people are aware of the importance of climate quality of cities and that researchers discuss their results with urban planners. The goal of this research was to introduce Urban Heat Island and investigate its impact on human beings in urban areas. When we study in hot and dry cities. It is very important to know how we can control UHI and its effects on people. Our suggestion for the mitigation of UHI can be helpful. We also illustrate some guidelines for urban designs in hot and dry climates to prepare human thermal comfort in the future climate. Moreover, similar studies prove that indeed urban design features can mitigate the impact of UHI. However, the urban design paradigms need to be updated in order to accommodate unconventional design strategies. Successful mitigation practices in other countries, especially those with similar contexts, can be helpful in developing future design strategies.

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