Urban Heat Islands:
Causes, Impacts, & Mitigation

Senior Project

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1. PROJECT DESCRIPTION AND RELEVANCY

1.1 Description and Purpose

The purpose of this project is to understand the factors contributing to the urban heat island effect and why it is important to consider when planning a city. This senior project will review the factors that contribute to an urban heat island, what kind of effects urban heat islands have on our city's and their inhabitants, and how the effects can be mitigated and minimized. This project will review current mitigation strategies that have been developed to combat urban heat islands and analyze the benefits that can be attained from these mitigation strategies. Case studies will be used to understand the relative effectiveness of current mitigation strategies. The project will conclude with a review of costs and issues that may be present when attempting to mitigate an urban heat island before giving a final set of recommendations that a city can use when mitigating an urban heat island.

1.2 Relevancy to Planning

Aspects related both to 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 contribute to the intensity of urban heat islands. Urban planners affect design, layout and policy decisions that are made within a city every day. Because of this, it is imperative that planners understand urban heat islands and how to protect their cities from excess warming and the negative impacts that result from warming such as, adverse health impacts, and air and water pollution.

2. INTRODUCTION

2.1 What is an Urban Heat Island?

In our world today, urban populations are increasing rapidly in size as more and more people continue to leave rural areas to migrate to cities. Because of this rapid urbanization, cities require large amounts of energy in order to function properly. Although cities occupy only about 2% of the earth's surface, city dwellers consume over 75% of the total energy resources available to carry out every day activities in the urban environment (Madlener & Sunak, 2011). As an urban area develops, changes occur in the natural landscape. Buildings and roads begin to replace open space and vegetation, causing surfaces that were once pervious and moist to become impervious and dry. These changes lead to the development of a phenomenon known as an urban heat island (UHI). UHIs occur when a densely populated urban area experiences significantly higher temperatures than the surrounding rural or less populated area. When naturally vegetated surfaces such as grass and trees are replaced with non-reflective, impervious surfaces, those surfaces absorb a high percentage of incoming solar radiation, causing a warming effect (Taha, 1997). The heat 'island' is the result of an unintended climate alteration due to a modification of land surfaces, caused mainly by an increase in urbanization and anthropogenic activities. Urban heat islands are an important issue because they can pose both health and environmental risks due to increased heat exposure and enhanced levels of air pollutants, specifically ozone. It is imperative that city planners take the heat island effect into account when planning for a city to ensure the best actions are being taken to create a healthy environment for all inhabitants.

3. BACKGROUND

3.1 History

Luke Howard, a British chemist and amateur meteorologist, was the first to recognize the effect that urban areas have on local climate. Between 1800-1830, Howard studied weather and climate in London and analyzed temperature records through which he was able to detect and describe the urban heat island phenomenon many decades before any other researchers. His studies showed that temperatures in London, compared to those simultaneously measured in the surrounding countryside, were 3.7°F warmer at night, and cooler during the day (Mills, 2008). He attributes the concentration of smog (which he called 'city fog') to this phenomenon. Following Howard's pioneering effort in researching the urban heat island effect, many researchers since have continued to study this phenomenon.

Since Howards first contributions toward studying urban heat islands, many researchers have following in his path. The makeup of urban areas differs across the world, causing the heat island effect to be more magnified in certain locations rather than others due to geographic variances. Researchers suggest the annual mean air temperature of a city with one million or more people can be 1.8 to 5.4°F (1 to 3°C) warmer than its surroundings, and on a clear, calm night, this temperature difference can be as much as 22°F (12°C). (U.S. EPA, 2008).

3.2 How are Urban Heat Islands and Climate Change Related?

Urban heat islands refer to the elevated temperatures in developed areas compared to more rural surroundings. The warming effect that results from urban heat islands is an example of local climate change. Local climate changes differ from global climate changes in that their effects are confined to the local scale and decrease with distance from their source. Global climate changes, such as those caused by excess greenhouse gas emissions, are not locally or regionally confined, though the impacts from urban heat islands and global climate change are often similar. For example, both urban heat islands and global climate change can increase energy demand, mainly through heating and cooling, and both can cause an increase in air pollution and greenhouse gas emissions.

3.3 How Do Urban Heat Islands Form?

Many factors contribute to the formation of urban heat islands. In part, heat islands are caused by a reduction of vegetation and evapotranspiration, a higher presence of dark surface with low albedo, and increased anthropogenic heat production (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017). As vegetation is replaced by asphalt and concrete for roads, the natural cooling effects of shading and evaporation of water from soil and leaves (evapotranspiration) is minimized. In addition, dark

surfaces, such as roads and rooftops, absorb the sun's heat, causing surface temperatures and overall ambient temperatures to rise (University Corporation for Atmospheric Research, 2011). Tall buildings and narrow streets can trap air between them and reduce air flow, causing an additional warming effect. Anthropogenic activities also contribute to the formation of heat islands through waste heat from vehicles, factories, and air conditioners (University Corporation for Atmospheric Research, 2011).

4. FACTORS AFFECTING OCCURENCE AND INTENSITY OF URBAN HEAT ISLANDS

4.1 Weather

Weather influences formation of heat islands particularly through wind and clouds. Under calm and clear weather conditions, heat island magnitudes are largest because these conditions maximize the amount of solar energy reaching urban surfaces and minimize the amount of heat that can be convected away (U.S. EPA, 2008). In addition, calm weather also causes the warm air to be kept in the built environment for an extended time. Conversely, when winds increase, the air is mixed, and the heat island effect is reduced (Voogt, 2004).

4.2 Geographic Location

Geographic location and topography influence climate of an area as well as the characteristics of the rural surroundings. Regional or local weather influences, such as local wind systems, may impact heat islands; for example, coastal cities or cities near large bodies of water can experience a cooling effect as large bodies of water moderate temperatures and generate winds that convect heat away from cities (Voogt, 2004). Nearby mountain ranges can also play a role in heat island formation by either blocking wind from reaching a city or creating wind patterns that pass through a city (Voogt, 2004). Cities that are surrounded by wet rural surfaces can experience a cooling effect from their environment, especially in warm humid climates. Local terrain will have a greater impact on heat island formation when larger-scale effects, such as prevailing wind patterns, are relatively weak (U.S EPA, 2008).

4.3 Time of Day and Season

Heat islands can occur year-round during day or night. The urban-rural temperature differences are often larger at nighttime, because rural areas cool off much faster than cities at night (Soltani & Sharifi, 2017). During the day, cities absorb solar radiation from urban surface materials, and retain much of that heat in roads, buildings and other structures, causing the maximum heat island effect to occur approximately three to five hours after sunset (University Corporation for Atmospheric Research, 2011). Seasonal variations in weather patterns can also have an effect on heat island frequency and magnitude. Heat islands of cities located in the mid latitudes usually are strongest in the summer or winter seasons (Voogt, 2004). Although heat islands occur year-round, their occurrence during the summer months is typically of larger concern to public policy makers because of the higher temperatures from increases in electrical demand, elevated air pollution, and heat-stress related mortality and illness (Rosenzweig et al., 2006).

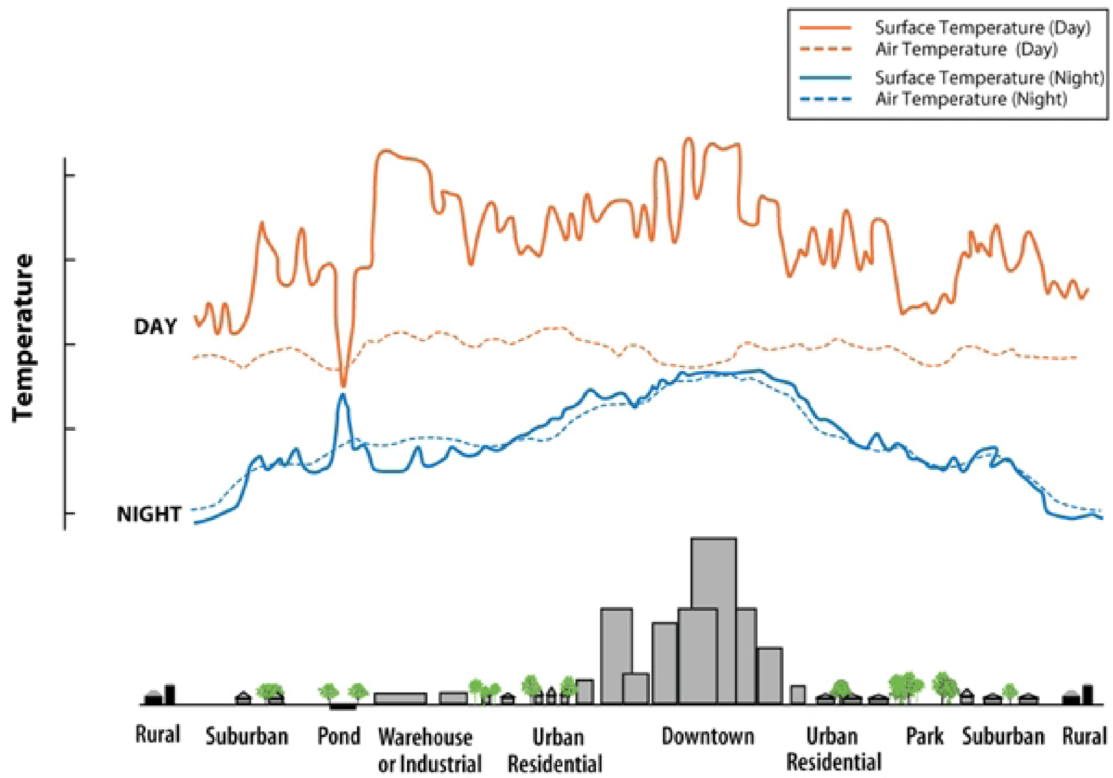

Figure 1: Surface and atmospheric temperatures vary over different land use areas. Surface temperatures vary more than air temperatures during the day, but they both are similar at night. Source: U.S. EPA, 2008

4.4 City Size

Size and shape of cities can also affect the magnitude of the UHI effect. A larger, more densely populated city will be warmer than a less populated rural area due to increased activity. In addition, aerodynamically, cities have a different shape than rural areas. If a city is covered in large, tall buildings, the buildings will act as obstacles and reduce wind speeds, thus increasing the UHI effect (University Corporation for Atmospheric Research, 2011).

4.5 City Form

The volume, orientation and layout of buildings in a city affect the exposure of urban surfaces to solar radiation (Soltani & Sharifi, 2017). This in turn affects shadow patterns, heat exchange, and airflow in urban spaces. Certain structures and city geometry favor heat islands such as dense building materials that are slow to warm and cool and store a lot of energy (Voogt, 2004). Impervious surfaces that replace natural surfaces lead to a drier urban area, where less water is available for evaporation. In addition, dark surfaces such as asphalt roads absorb more sunlight and become much warmer than light-colored surfaces.

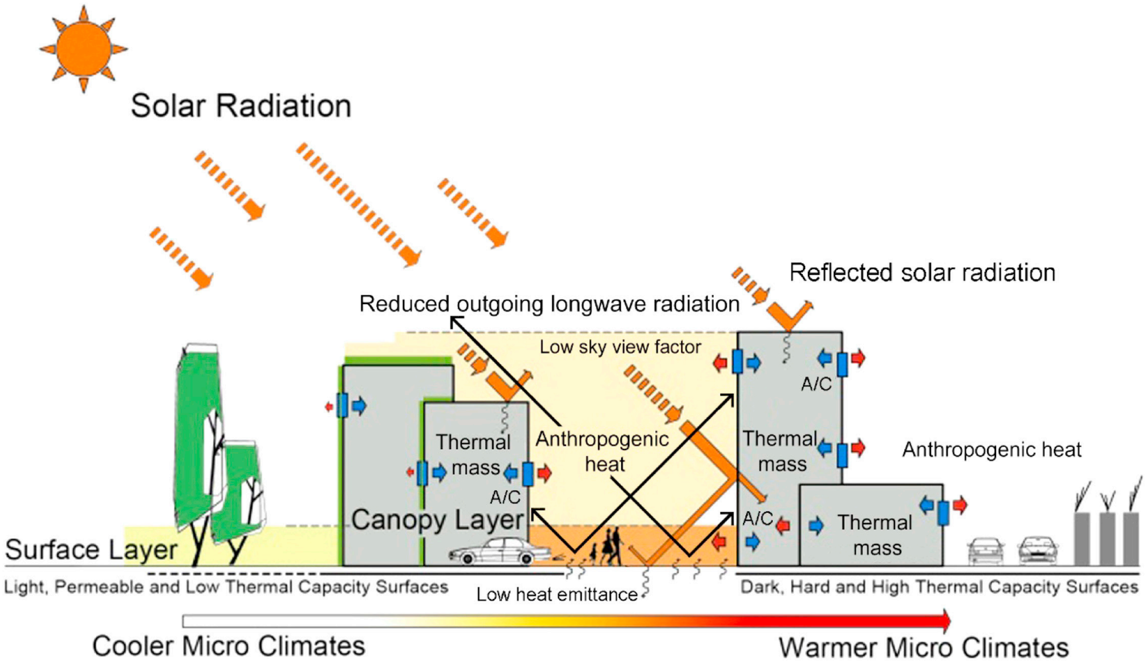

Figure 2: Urban size, form, and function contribute to the UHI effect in highly developed areas. Source: Soltani & Sharifi, 2017

4.6 City Function

Human activity can increase heat island temperatures through energy use, and production of excess heat through consumption. Anthropogenic heat, or human-made heat, is primarily caused by fossil fuel combustion, mainly through indoor heating and cooling and transportation (Soltani & Sharifi, 2017). Anthropogenic heating usually has the largest impact during the winter season of cold climates due to building heating. In the summertime, anthropogenic heat is caused by high energy use for building cooling. Anthropogenic heat can directly raise near surface air temperatures while air pollution increases absorption of radiation in the lower troposphere, often contributing to the creation of an inversion layer (Rosenzweig et al., 2006). The inversion layer then prevents rising air from cooling at the normal rate, and limits dispersion of pollutants that are produced in the urban area (Rosenzweig et al., 2006).

5. IMPACTS OF URBAN HEAT ISLANDS

5.1 Human Health

Increased daytime surface temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality. Studies have consistently shown a relationship between high temperatures and an increased number of deaths in cities, and as extreme heat events continue to occur and magnify, heat related deaths will increase (Harlan & Ruddell, 2011). Certain populations such as young children, seniors, chronically ill individuals and people working outdoors are especially vulnerable to heat related illnesses.

5.2 Air Quality and Greenhouse Gases

Urban heat islands increase demand for energy consumption during the summer when temperatures rise. Currently, most electricity in the United States is produced from combusting fossil fuels (U.S. EPA, 2008). Thus, pollutants from most power plants include sulfur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and mercury (Hg). These pollutants contribute to air quality problems which are exacerbated by higher temperatures (U.S. EPA, 2008). In addition, fossil-fuel-powered plants emit greenhouse gases, particularly carbon dioxide (CO2), which contribute to global climate change.

5.3 Water Quality

Urban heat islands degrade water quality through thermal pollution. Hot pavement and rooftop surfaces transfer their excess heat to stormwater, which then drains into storm sewers and raises water temperatures as it is released into streams, rivers, ponds, and lakes (U.S. EPA, 2008).

5.4 Animals

Temperature changes associated with urban heat islands can cause changes in the availability of food and water, which affects eating and foraging habits of animals. Temperate climates typically experience an extended growing season as a result of the warming caused by urban heat islands (Schochat, Warren, Faeth, McIntyre, & Hope, 2006). This extended growing season can alter breeding strategies of inhabiting species and cause problems for the species (Schochat et al., 2006). Thermal pollution of water bodies affects all aspects of aquatic life, especially the metabolism and reproduction of many aquatic species. Rapid temperature changes in aquatic ecosystems as a result from warm stormwater runoff can cause stress to aquatic life (U.S. EPA, 2008).

5.5 Energy Use

Higher summertime temperatures cause an increased demand in energy consumption through air conditioning. The increased demand for energy puts excess pressure on the power grid and can sometimes result in blackouts or brownouts during hot summer months (U.S. EPA, 2008).

6. MITIGATION STRATEGIES

6.1 Vegetation/Green Spaces

In urban areas, where only a fraction of the surface is covered by vegetation and surfaces tend to be water-resistant, potential surface cooling from vegetation and soil is reduced (Rosenzweig et al., 2006). Trees and vegetation help cool surface air temperatures through shading and evapotranspiration, making vegetation a simple and effective way to reduce urban heat islands. Evaporation, the conversion of water from a liquid to a gas, occurs in the surface of the soil around vegetation and from trees as they intercept rainfall on leaves. Transpiration takes place when trees and vegetation absorb water through their roots and emit it through their leaves. Together these processes work together to form the process of evapotranspiration which works by using heat from the air to evaporate water, cooling the air in the process (U.S. EPA, 2008).

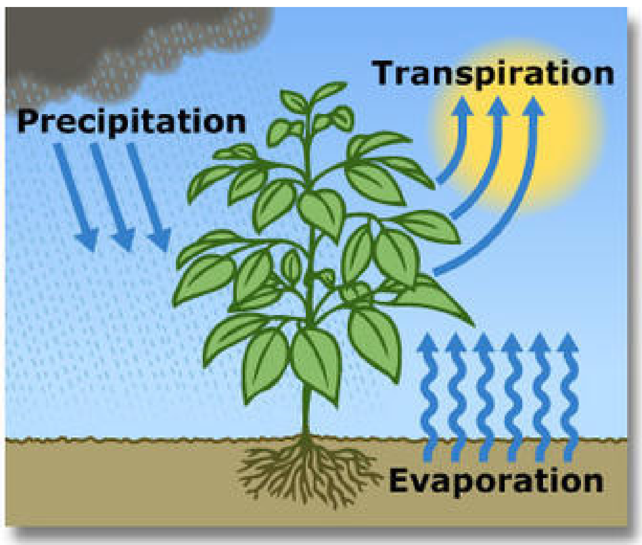

Figure 3: The process of evapotranspiratio. Source: USGS

In addition to the benefits from evapotranspiration and shading, trees and other large vegetation can also serve as windbreaks to reduce the wind speed around buildings (U.S. EPA, 2008). These benefits can have both positive and negative effects in the summertime, however, in the wintertime, reducing wind speeds can provide substantial energy benefits.

In order for trees to provide the most energy efficient benefits, they must be planted strategically around buildings and other infrastructure. Researchers have found that a building's height, orientation, and distance between trees and vegetation can affect the rate of cooling, therefore, trees can be harmful to an energy efficiency strategy if they block useful solar energy in the winter, when the sun is low in the sky, without providing much shade during the summer, when the sun is high in the sky (U.S. EPA, 2008).

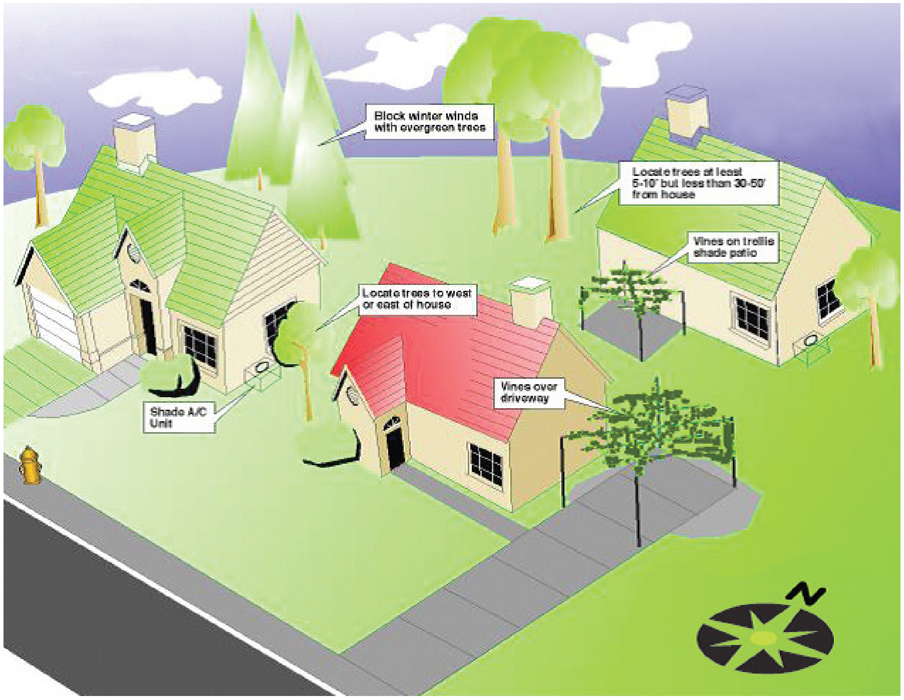

Figure 4: Tree Placement to Maximize Energy Savings. Source: U.S. EPA, 2008

Benefits of Planting Trees and Vegetation:

•Reduced Energy Demand and Usage: Trees and vegetation provide shade for buildings, resulting in a cooling effect and a decreased demand for air conditioning.

•Reduced Air Pollution and Greenhouse Gas Emissions: By reducing energy demand and use, greenhouse gas (GHG) emissions will decrease. Trees and vegetation also absorb pollutants in our atmosphere through dry deposition.

•Pollutant Removal through Dry Deposition: Dry deposition refers to the absorption of gases and particulate matter by plants. Plants take in pollutants which then react with water inside the plant to form acids and other chemicals. Plants can also intercept various pollutants as they are being carried by the wind. These two processes can help to reduce various pollutants in the urban environment such as particulate matter (PM), nitrogen oxides (NOX), sulfur dioxide (SO2), carbon monoxide (CO), and ground-level ozone (O3) (U.S. EPA, 2008).

•Carbon Storage and Sequestration: Trees remove carbon from the atmosphere as they grow, and then store that carbon to later release into the soil as the tree dies (U.S. EPA, 2008).

•Reduced Evaporative Emissions: Shade from trees can help keep parked cars cooler, lowering the level of evaporative emissions that are released, especially from their gas tanks (U.S. EPA, 2008).

•Enhanced Stormwater Management and Water Quality: Urban forests and vegetation and soils can help to reduce stormwater runoff and can intercept rainfall thus absorbing water that would otherwise become runoff.

•Improved Human Health and Comfort and Enhanced Quality of Life: Trees and vegetation provide multiple benefits to human health and comfort such as improving air quality by reducing harmful pollutants and providing a cooling benefit through shade and evapotranspiration. In addition, trees and vegetation also provide an aesthetic value, habitats for many species, and can reduce noise.

Figure 5: Urban Forest. Source: Heather Doucet, 2018

6.2 Green Roofs

A green roof, sometimes referred to as a living roof, is a rooftop that has a vegetative layer growing on top. As with trees and vegetation elsewhere, green roof vegetation can provide shade and cool the ambient air through evapotranspiration. A green roof can help to reduce surface temperatures which helps buildings stay cooler because less heat flows through the roof and into the building (U.S. EPA, 2008). In addition, lower green roof temperatures result in less heat transfer to the air above the roof, which can help keep urban air temperatures lower as well (U.S. EPA, 2008).

Figure 6: Temperature Differences between a Green and Conventional Roof. On a typical day, the Chicago City Hall green roof measures almost 80°F (40°C) cooler than the neighboring conventional roof. Source: National Center for Excellence/ASU

There are two types of green roof systems: an extensive green roof and an intensive green roof. An extensive green roof is typically made up of hardy, alpine-like groundcover (U.S. EPA, 2008). These roofs are designed to require little human maintenance or interference once they are established. Because extensive green roofs are made up of a thin layer of vegetation, they do not require much added structural support, making them a cost-effective option. On the other hand, an intensive green roof is more akin to a fully accessible garden or park (U.S. EPA, 2008). Intensive green roofs require more structural support to accommodate extra weight. In addition, they need irrigation systems in order to keep them growing.

Figure 7: Example of extensive and intensive green roofs. Source: Ramcon Roofing, 2011.

Benefits of Green Roofs:

•Reduced Energy Usage: Green roofs help to reduce energy use by saving energy that would

otherwise be needed to cool and heat the buildings they shelter.

•Reduced Air Pollution and Greenhouse Gas Emissions: As mentioned in the “Benefits of Trees and Vegetation” section, green roof vegetation also removes air pollutants and greenhouse gas emissions through dry deposition and carbon sequestration and storage. In addition, the reduced energy demand from green roofs also helps to reduce air pollution and greenhouse gas emissions.

•Enhanced Stormwater Management and Water Quality: Green roof vegetation can help to reduce the rate of stormwater runoff, and also serve as a place for rainfall to be absorbed into the plants and soil.

•Improved Human Health and Comfort and Enhanced Quality of Life: Green roofs help to improve human health and comfort by providing and cooling effect in buildings during the summertime and an insulating effect in buildings during the wintertime. In addition, green roof vegetation provides habitats for all kinds of urban animal and insect life.

6.3 Cool Roofs

The term cool roof refers to a roof that has been designed to reflect more sunlight and heat than it absorbs (U.S. Department of Energy, 2012). Cool roofs can be made of multiple materials such as a highly reflective type of paint, a sheet covering, or highly reflective tiles or shingles (U.S. Department of Energy, 2012). Cool roofing products can remain approximately 50 to 60°F (28-33°C) cooler than traditional materials during peak summer weather (U.S. EPA, 2008).

Figure 8: White tiled cool roof. Source: Silver Leaf Contracting.

While both green roof and cool roof strategies reduce the level of heat available for transfer to the air or to buildings, the mechanisms for green roofs and cool roofs to reduce urban heat islands are different. A green roof increases the evapotranspiration in urban areas through plants and soil, while a cool roof increases the reflection of incoming solar radiation in urban areas by increasing the albedo of roof surfaces (Li, Bou-Zeid, & Oppenheimer, 2014).

Figure 9: Metal Cool Roof. Source: Patrick Bulot

A cool roof is designed to reflect more sunlight and absorb less heat than a traditional roof. The two radiative properties that characterize cool roofs are solar reflectance and thermal emittance. Solar reflectance, or albedo, measures a roof's ability to reflect sunlight and heat away from a building. Thermal emittance refers to the relative ability of the roofing material to release absorbed heat as invisible infrared light. Together, these values are incorporated to create a value known as the Solar Reflectance Index (SRI). SRI represents a materials temperature in the sun, measured on a scale from 0-100, with a higher value representing a cooler roof.

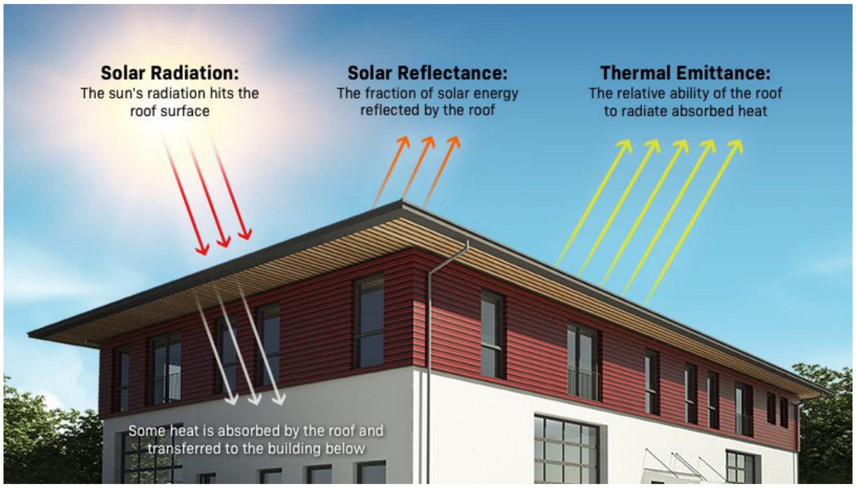

Figure 10: How a cool roof works. Source: American WeatherStar

Benefits of Cool Roofs:

•Reducing Energy Use: A cool roof transfers less heat below to the building that it shelters, therefore the building stays cooler and requires less energy for cooling.

•Reduced Air Pollution and Greenhouse Gas Emissions: Reduced energy use from cooling will translate to a reduction of air pollutants and greenhouse gas emissions being released into the atmosphere.

•Improved Human Health and Comfort: Lower indoor temperatures from the cool roof will improve human health and comfort

6.4 Cool Pavement

Traditional pavements such as concrete and asphalt can reach temperatures of up to 120–150°F (48–67°C) in the summertime (U.S. EPA, 2008). These surfaces contribute to urban heat islands, especially at nighttime, by trapping and storing heat during the day re-releasing it at night. Hot pavements can also heat stormwater as it washes over the pavement and into local waterways, causing the water to warm and impairing water quality.

Figure 11: Thermal infrared (left) and visible (right) images of a road with light and dark segments. The infrared image shows that the light segment (bottom) is about 17°C (30°F) cooler than the dark segment (top). Source: Larry Scofield, APCA)

Similarly to "cool" roofs, "cool" pavements are designed to reflect solar radiation to help lower surface temperatures and reduce the amount of heat absorbed into the pavement. Solar reflectance, or albedo, and thermal emittance work together to keep cool pavements cool. Permeability is an additional factor that must be included when manufacturing cool pavement. Permeable pavements allow air, water, and water vapor to pass into the pavement through voids and into the soil or other supporting materials below. Wet pavements can lower surface temperatures through evaporative

cooling, similarly to vegetative evaporative cooling.

Figure 12: Cool pavement coating applied to a street in Los Angeles. Source: For Construction Pros

Currently, few studies have been conducted to measure the role that pavements have in forming urban heat islands, or the effectiveness of cool pavements in reducing temperatures. However, researchers at Lawrence Berkeley National Laboratory have estimated that every 10 percent increase in solar reflectance has the potential to decrease surface temperatures by 7ºF (4ºC) (Pomerantz, Pon, Akbari, & Chang, 2000). Further, they predicted that if pavement reflectance throughout a city were increased from 10 percent to 35 percent, the air temperature could potentially be reduced by 1ºF (0.6ºC) (Pomerantz, Pon, Akbari, & Chang, 2000).

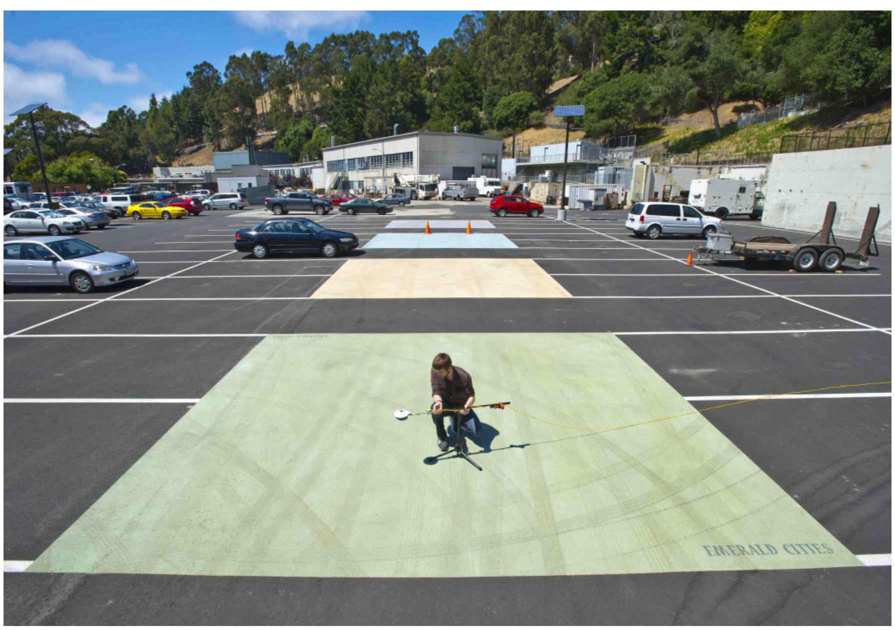

Figure 13: Lawrence Berkeley National Laboratory's Heat Island Group has converted a portion of a parking lot into a cool pavement exhibit. Source: Lawrence Berkley National Laboratory

Benefits of Cool Pavements:

•Reduced Energy Use: Cool pavement has the potential to significantly reduce ambient air temperatures. This would result in significant benefits in terms of lower energy use and reduced ozone levels.

•Air Quality and Greenhouse Gas Emissions: Decreased energy demand will result in lower associated air pollution and greenhouse gas emissions.

•Water Quality and Stormwater Runoff: Cool pavements with lower surface temperatures will help to reduce the temperature of stormwater runoff before it enters nearby water bodies.

7. Case Studies

7.1 Parks and Green Areas: *The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon*

In the past, studies have shown that in order for a green space to have a significant positive influence on an urban area, the green space must be large. While smaller green spaces are still effective, their benefits are usually less evident. This study took place in a garden of Lisbon over a 6-day period during the summer of 2006 and 2007. The Garden Teófilo de Braga is located in the city district of Campo de Ourique, a dense area with a population of approximately 17,500 at the time of the study. The garden is 95 x 61 meters in size and surrounded by residential and commercial buildings comprised of varied colors and materials.

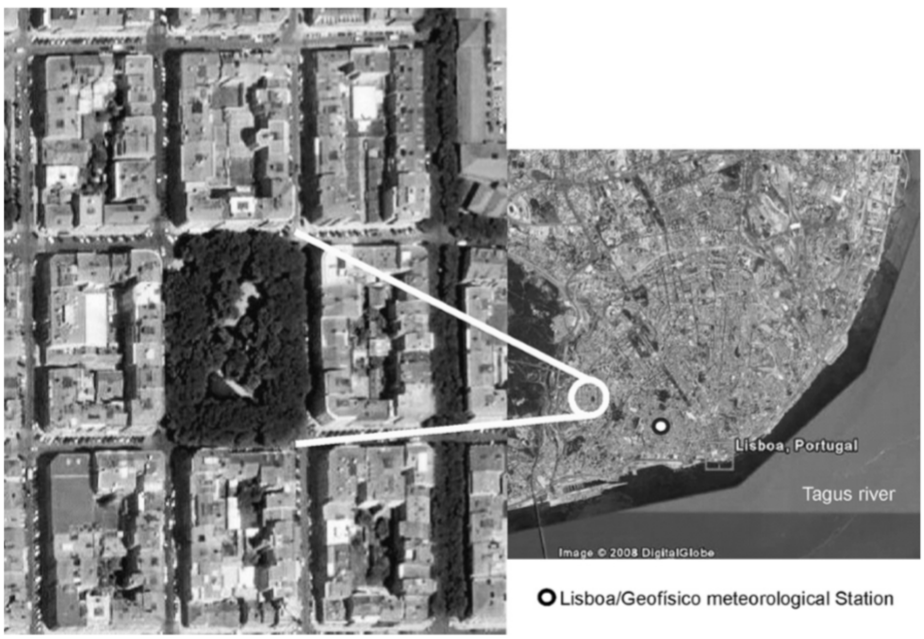

Figure 14: Location of the Garden Teófilo de Braga in the city of Lisbon. Source: Oliveira, et al., 2011

During the 6-day period of this study, measurements of air temperature, relative humidity, wind speed, solar irradiance and infrared radiation were taken. Measurements were carried out at 8 different locations along a path approximately 750 meters in length. The locations were chosen to assess the effect of the proximity of the garden, the street orientation and the presence of vegetation within the weather parameters of the area. To assess the influence of solar exposure in the microclimatic conditions, two sets of measurements were recorded in each site, one in the sun and one in the shade. The measurements were taken in the early afternoon around the time of maximum temperature during the daytime.

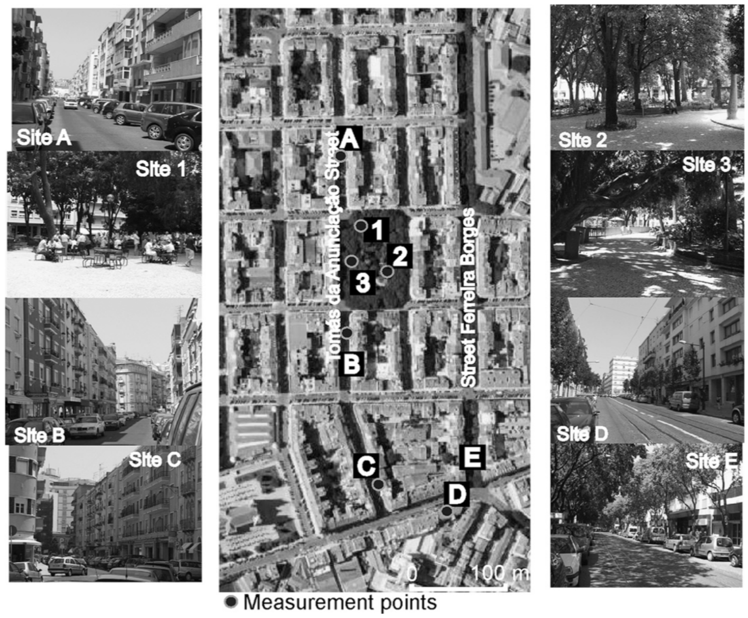

Figure 15: Location of the 8 measurement points used in the study Source: Oliveira, et al., 2011

The results of the study were discussed through three aspects: the variation in the intensity of the "park cool island" (PCI) between the different days when observations were made, the influence of solar exposure, and the influence of the distance to the garden and urban features. The term "park cool island" is used to explain the difference between the measured values inside and outside the garden. The PCI reached maximum values of 6.9 °C, meaning the green area has a cooling effect in the surrounding atmospheric environment. Results show that with clear and calm weather conditions, the thermal differences between the park and its surroundings were higher. While the results of this study do show that there is a cooling effect given as a result of a small green space, different characteristics of urban areas, different meteorological conditions of a particular area, and the characteristics of the green space itself all determine how effective the cooling effect will be. In addition, the study results how that the garden was cooler both in sunny and shaded areas, even on warmer days. The presence of trees on the street, however, did not make much of an impact as far as the cooling effect. This is probably due to the importance of irrigation that takes place in the garden, allowing for more intense and concentrated evapotranspiration.

7.2 Green Roofs: *Analysis of the green roof thermal properties and investigation of its energy performance.*

This study analyzes the thermal properties of green roofs and provides the results of the effect

of green roofs on energy performance. This study was completed in two phases. The first phase involved taking surface and air temperature measurements both indoors and outdoors at the site of the buildings where the green roof had been installed. The second phase of the study involved using a mathematical approach to test the thermal properties and the energy savings achieved through a green roof.

The temperature range of the results varied from 26 to 40°C depending on what type of vegetation covered each spot where a measurement was taken. The lowest temperatures taken on the surface of the green roof ranging between 26 and 29°C and were measured in places dominated by thick and dark green vegetation. The highest temperatures measured were between 36 and 38°C and were taken in places covered by sparse red vegetation. Measurements taken on the bare soil showed a value of 40°C.

The mathematical analysis used to measure heating and cooling rates and energy savings estimated that the heating and cooling loads are lower in the building with the green roof, regardless of the kind of roof insulation. The greatest energy savings during a year-long period for a non-insulated building were calculated and found to be about 37%, however, this value increased to 48% when natural ventilation was applied to the model. The impact of the green roof on the energy savings of the well-insulated buildings was found to be almost less than 2%. This estimate shows that energy consumption in buildings with green roofs can be lower than those without green roofs and can even be improved by natural ventilation during the summer.

The study concluded that during the summer, green roofs helped to keep air temperatures low during the day and higher at night. However, they found that night-time ventilation kept temperatures low during the day as well as at night.

7.3 Albedo: *Mitigation of urban heat islands: materials, utility programs, updates.*

To analyze the reduction in energy consumption for cooling by increasing the albedo, Rosenfeld et al. monitored the cooling energy use of a house and two school bungalows. The house was monitored in its original condition to obtain control data and it was found that the albedo of the roof in its original, un-modified condition was 0.18. The next year, after the roof had been modified to be white, the albedo had increased to 0.73. The seasonal cooling energy savings at the site of the

house post-modification were estimated to be about 40% or 33 kWh/yr.

At the school site, one of the two school bungalows was used as a control site and remained white roofed and walled all summer. The second school bungalow was simultaneously monitored in three conditions: unpainted metal roof and yellow walls, brown roof and brown walls, and white roof and white walls. The results showed that a higher albedo in a single building produced 20–40% direct energy savings, and that the indirect effects of wide-scale albedo changes could nearly double the direct savings.

7.4 Pavements: *Passive cooling of outdoor urban spaces. The role of materials.*

In this study, Doulous et al. measured 93 commonly used outdoor pavement materials to see which materials would achieve lower ambient temperatures and thus fight the heat island effect. The pavements used in this study were made up of various colors (white, black, green, gray, etc.), materials (mosaic, concrete, granite, marble, pebble) and textures (smooth and rough). An infrared camera was used to measure surface temperatures, which were taken on an hourly basis. In addition, the ambient meteorological conditions were measured to account for any anomalies. The meteorological conditions were characterized by high air temperatures, low relative humidity and clear sky. Wind speed was measured at less than 2 m/s during the experimental period, thus, the effect of wind speed on the temperature of the materials did not make much of a difference.

Figure 16: The site of the experimental campaign with the modulated platform.
Source: Doulous et al., 2004

In general, the smooth surfaced materials presented lower surface temperatures than the ones with rough surface. The black colored materials had the largest surface temperatures out of all of the

material tiles. The results showed that rough and dark-colored surfaces (made of “hot materials”) tended to absorb more solar radiation than the smooth, light-colored and flat surfaces (made of “cold materials”). The study concluded that cold materials are preferable in urban environments with a hot climate whereas hot materials should be used in areas with a cold climate.

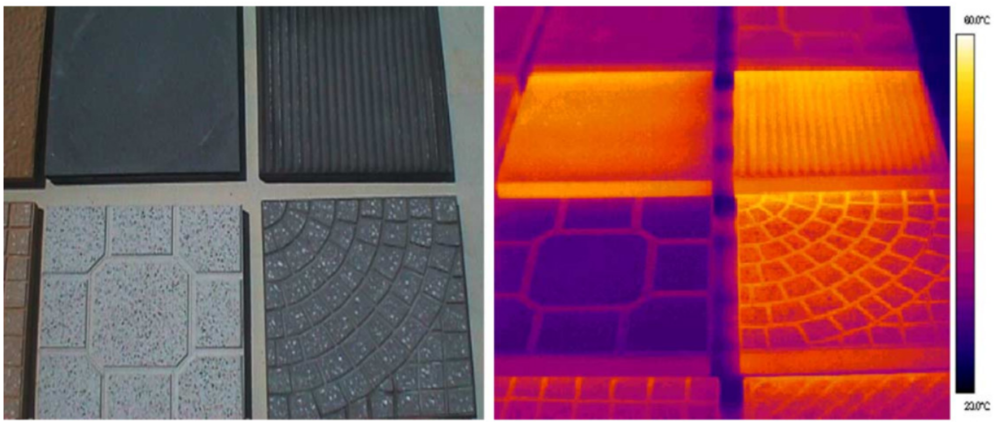

Figure 17: Visible and infrared image of selected building materials. Source: Doulous et al., 2004

8. Recommendations

Local governments, universities, and other organizations are in a great position to raise public awareness of the benefit of urban heat island reduction strategies. Through demonstration projects such as creating a green roof in a public space or documenting how a cool roof can reduce temperatures, these organizations can help spark community dialogue and get people involved. Another effective way to get a community involved in heat island reduction actions is to create incentive and or rewards programs. For example, local governments can promote cool roofs through incentive programs, such as grants, which offset initial costs of cool roof installations, or rebates, which offset ongoing energy costs. Incentives encourage community members, but do not require specific behavior from them. Local governments, utilities, and private organizations can work together or separately to create incentive and award programs that will encourage positive community behavior and help to reduce heat islands.

Urban forestry programs or tree planting programs currently exist in most large cities and counties in the United States. The United States Forest Service has an Urban and Community Forestry Program that aims to support forest health for all of our Nation's forests, create jobs, contribute to vibrant regional wood economies, enhance community resilience and preserve the unique sense of place in cities and towns of all sizes (U.S. Forest Service, 2008). Through this program, the U.S. Forest Service has been able to work with communities all across the United States to maintain, restore and improve more than 140 million acres of community forest land (U.S. Forest Service, 2008). Local governments can work with local nurseries to create tree donation programs to encourage community members to plant more trees.

The existing conditions of a given urban area will determine the type of heat island mitigation strategies that will be most effective relative to the area. In most cases, widespread change of the urban fabric by changing the spacing of buildings and the layout of the city is usually not feasible. This is why other strategies such as using light-colored roofs and pavement and planting more vegetation are easier for cities to promote. In addition, while trees and vegetation can be beneficial in a warm urban climate, research has demonstrated that trees and vegetation can have a negative effect on the urban microclimate in cold climates (McPherson, Herrington, & Heisley, 1988). For this reason, it is necessary for cities and their community members to have an in-depth knowledge of the plant species as well as of the local climate conditions when trying to reduce urban heat islands. Outreach and public awareness programs are a great way to inform the public on ways to help and get involved.

Educational programs can be brought into local schools and local governments can support community events that focus on bringing awareness to urban heat islands and urban heat reduction strategies. Education programs aim to teach the public, either by providing information or by offering examples and demonstrating results. Cities can use educational programs to encourage their community members to increase shading around their homes, install green and cool roofs, and use energy-efficient appliances and equipment.

In addition to the voluntary efforts used to combat urban heat islands, policy measures can also be an effective way to help the cause. For example, zoning codes can be used to require parking lots to be shaded or to allow density bonus for construction that adopts heat island mitigation strategies. Green building standards such as the building requirements of the U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) Rating System. Building codes are another way to mandate that new construction projects be more environmentally friendly. In January of 2003, the City of Chicago amended its energy code to require all new roof installations to meet a minimum solar reflectance of 25 percent (U.S. EPA, 2008).

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