The Urban Heat Island: Causes and Effects

Focusing on Urban Forestry as a Key Mitigation Strategy

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Executive Summary

The Urban Heat Island Effect has become one of the world's leading urban environmental issues of this century. Urbanization has increased concerns about the UHIE, especially in terms of human health and a healthy functioning urban environment. The UHIE results in significant and sometimes dramatic increase in air temperature change between the urban environment and its surrounding areas. The most dramatic change to be seen is the alteration of the landscape, causing multiple interactions with people, different surface materials, atmospheric anomalies and the urban ecology. Mostly important is the heat island structure which extends from the ground to certain levels above ground, and the atmospheric interactions which in turn causes different thermal projections throughout the city. Thus the heat island effect is a contributing factor to a larger list of health problems which will only increase with the explosive growth of the population and the increasing impact of climate change. The only viable solution to this alteration of our environment is to implement better urban planning and for the ultimate expansion of green spaces that are made possible through new materials, technology and urban forestry. Urban forestry has come from being valued for its aesthetic quality, to being valued as an essential urban ecosystem. There is much more to our natural green spaces than imagined: they ameliorate our environment by giving us many resources that we need in any city. Maintaining urban forests and addressing changes to urban planning will become valuable steps in mitigating the UHIE problems for future generations; making natural environments a valuable component of any urban city should be a priority for the sustainability and future developments in an urban environment.

Keywords: Urban Ecosystem, Climate Change, Sustainable practices

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In understanding the urban heat island effect we must first remind ourselves that we live in on a planet that is dynamic and interactive; heat fluctuations occur on the earth by the 1) heating of the sun on soil or rough materials, 2) atmospheric changes that impact surface temperature and 3) terrestrial ecosystem and aquatic ecosystem interactions (Bromley et al., 2004). Population growth and expansion is the precursor for urbanizing an area, which inadvertently creates the urban heat island effect (McPherson, 1993). The urban heat island effect can be best defined as a metropolitan area which is significantly warmer than its surrounding regions (McPherson 1993). This occurs mostly through the generation of heat by its structures and effect on man-made materials and heat created by human activity; the modification of land surface by urban development (Ritter, 2006). Generally it is mostly described as being cooler in rural vegetated areas as opposed to the warmer inner city climate; this difference in temperature is what creates an urban heat island. In a city with one million or more people, the annual mean air temperature can be 1 to 3 degrees warmer than its surroundings, and on a calm, clear night (with minimal cloud cover) the temperature difference can be up to 12 degrees (United States Environmental Protection Agency, 2008). As population centers increases within a city, they tend to modify a larger area of land and have a direct increasing correlation in average temperature (USEPA, 2008). There are two types of urban heat islands that differ in the ways they are formed, and their impacts (USEPA, 2008) on the city.

a) Surface heat Islands

The main mechanism that makes up this heat island is based on the amount of surface heating created by impervious material in a city (USEPA, 2008). On hot sunny days, the sun can heat urban surfaces to temperatures 27-50 degrees hotter than air, while the shaded moist surfaces remain close to air temperatures (USEPA, 2008). The surface heat island is present at all times of the day and night, but tend to be the strongest during the day, when the sun is shining, and on summer days (McPherson, 1993). On average during peak urban heat conditions the difference between urban and rural areas is 10 to 15 degrees and at night time the difference in surface temperature is usually smaller from 5 to 10 degrees (McPherson, 1993). The heat capacity of surface urban heat islands varies from season to season due to the changes in the sun's intensity along with ground cover and weather. They can only be seen through remote sensing which takes thermal images of the areas to see where heat induced areas and cool areas exist (USEPA, 2008).

b) Atmospheric Heat Islands

The second type of urban heat island is called an atmospheric urban heat island; warmer air in urban centers compared to cooler air in nearby rural areas (USEPA, 2008). This heat island can be further divided into two atmospheric urban heat islands the canopy layer urban heat islands and the boundary layer urban heat islands.

i. Canopy Layer Heat Island

The canopy layer urban heat island is found in the layer of air where people reside, from the ground to below the tops of roofs and trees (USEPA, 2008).

ii. Boundary layer Heat Island

The boundary layer urban heat island begins from the roof top and treetop level and ends up and above to a point where urban landscape does not influence the atmosphere; this area is about 1.5 km from the surface (USEPA, 2008).

These are the most observed urban heat islands, and thus scientist use a more general term such as atmospheric urban heat island. The weakest part of an urban heat island is during the late morning, throughout the day, and become more significant after sunset; due to the slow discharge of heat from urban infrastructure (USEPA, 2008). Atmospheric heat islands are also dependent on the properties of the urban surfaces, seasons and weather conditions, yet the variety in intensity is much less than surface heat islands. Annually, and on a mean basis, air temperature in bigger cities might be 1 to 3 degrees warmer than those in rural areas (USEPA, 2008). The difference in cooling rates between the two areas are most notable on clear and calm nights and days where rural areas can cool more quickly than urban areas.

c) Surface and air temperature relationships

There is a definite relationship between surface and air temperatures when it comes to the changes in the canopy boundary layer, for example, parks and well vegetated areas, have cooler surface temperatures and contribute to cool air temperatures, while denser, structured urban areas often lead to warmer air temperatures (McPherson, 1993). The Urban heat island effect can be seen as a relatively small example of localized climate change. The warming that results from the changes in radiation and thermal properties of the urbanized structure such as buildings can influence the local microclimate (USEPA, 2008). Heat islands are also influenced by a city's geographical location and by local weather patterns, and their intensity on daily and seasonal basis. Thus with this in mind, the warming that results from urban heat islands differs from global climate change in that the effects are limited to the local area (scale) and may decrease with distance from the source (USEPA, 2008).

d) UHI and Climate Change (Global Warming)

Global warming and climate change are closely related concepts: climate change results in changes such as temperature, precipitation, and wind that may last for a long period of time also global warming refers to the warming that occurs as a result of greenhouse gases which come from human activities (USEPA, 2008). The impact from urban heat island and global climate change may in fact be similar and cumulative, for example some cities may experience longer growing seasons due to the urban heat island effect, which is extended by climate change. Both have the capacity to increase energy demands, especially in the summer, as air conditioning demands peak, both are associated with air pollution and green house emissions depending on the amount of energy consumed and the fuel that is used in air conditioning (USEPA, 2008). Since urbanization is something that can't be halted at anytime, the least that can be done is to conduct strategic planning for urban issues so that they will not be contributing to global warming; thus finding strategic ways to mitigate the urban heat islands will be the challenge.

II. Formation of Urban Heat Islands

The urban heat island effect can be manifested in various locations around the city with different scales or intensities which depend on the city, building patterns, its surface properties and the amount of green space and trees in the city (USEPA, 2008). We can describe the structure of the heat island affect as being a "cliff" like heat plume that arises over the hottest part of the city (McPherson, 1993) that is trapped under atmospheric conditions of the city like clouds, down ward-wind -warm air and city geometry. Usually at night the calming night breeze from the rural areas will sweep in towards the urban areas and creates a dome which traps hot air that is still present. This trapped hot air is not diffused through latent heat therefore, as the cool air rushes (along the ground) into the area, it creates a "bubble" pocket effect which can extend several stories high (McPherson 1993).

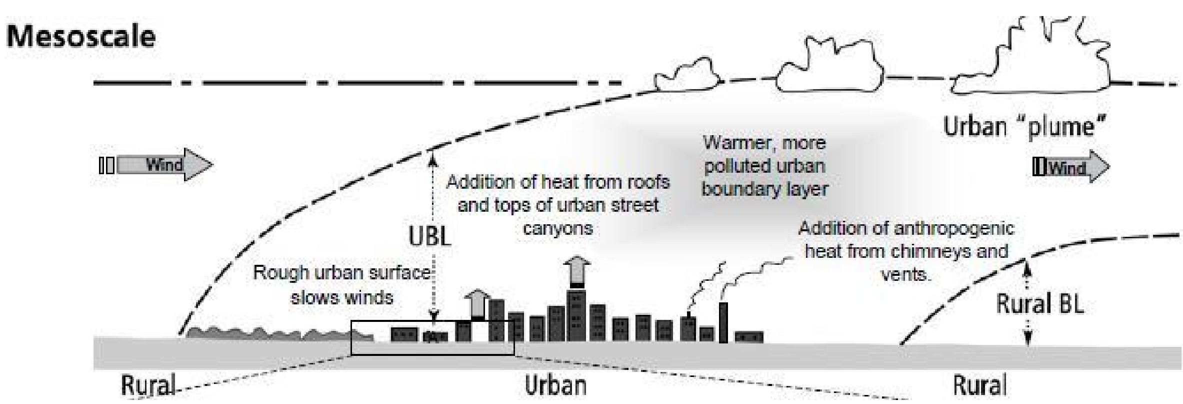

Figure 1. Urban Heat Island Process: Heat Dome

Source: USEPA, 2008, Pg 6.

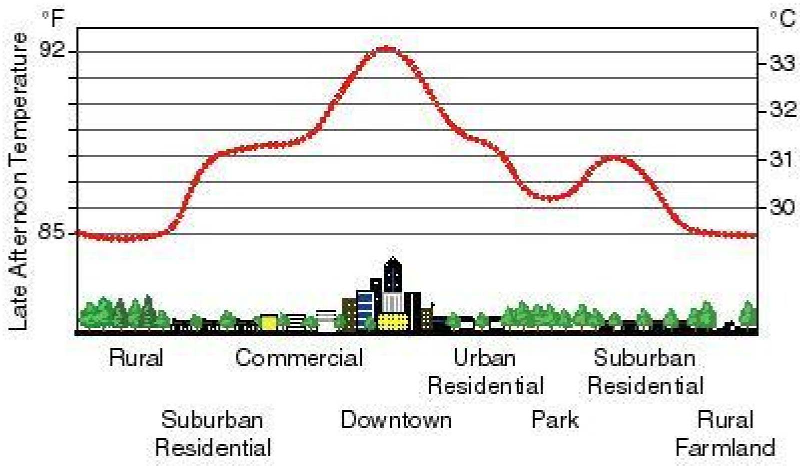

Figure 2. Temperature Displacement of UHI

Source: USEPA, 2008 Title Page

By day break of the next day there is an increase in the mixing of warm air and the trapped air from the previous night so a heat island is still present. The micro-scale climate that is created can also occur in the areas where buildings are closer to the ground, without shading from other building, can further cause mixture of hot air from that arises from the latent heat off the ground and the warm air in the atmosphere, thus further trapping smoke or dirt particles in the air (McPherson 1993). The containment of air within a city area is caused by both the energy of the heat island system and the boundary layer of the urban atmosphere but can also happen due to the lack of vegetation (USEPA, 2008). Areas that are not urbanized usually contain open landscape, trees and vegetation which provide shade, which help lower surface temperatures. These features help decrease the air temperature through a process called evapotranspiration; this is a process in which plants release water to the surrounding air, and dissipates ambient heat (The United States Geological Survey, 2009).

a) Reduction in vegetation

As a comparison, urban areas are defined by dry impervious material such as roofs, side-walks, roads and parking lots. Thus as a city grows bigger, an increase of paved material and buildings develops, which means that vegetation is reduced. This change in land cover produces less shade and moisture to aid in keeping urban areas warm; areas that are dry and built up evaporate less water which contributes to increased surface and air temperatures (USEPA, 2008). The loss of evapotranspiration to impervious material in an urban setting is as follows: 20-30% of precipitation is returned to the atmosphere though evapotranspiration (based on a 60-80% reduction of vegetation), thus 30-70% of rainfall becomes runoff, with 5 % deep infiltration (USEPA, 2008). By contrast, in a rural area where there is more than 50% natural surface and forests, 40% of precipitation is returned to the atmosphere through evapotranspiration produced by trees, and only 10% runoff is found on the surface and 50% is infiltrated into the soil (The Capital District, 1998).

The amount of heat transferred from the surface of impervious material to running surface water also causes an increase in temperature in the surrounding area, it is not a large change, but there would have to be other factors involved to make such a significant temperature change; factors such as surface weather conditions, air temperature, humidity, solar radiation before and after precipitation, rainfall intensity and temperature of rainfall (The Capital District, 1998). Thus there is less evaporative cooling and transpiration cooling from concrete, metal, and buildings.

b) Urban materials and their thermal properties

Urban material properties such as thermal emissivity, heat capacity and solar reflectance can influence the urban heat island process as they are indicators of how the sun’s energy is emitted, absorbed and reflected (USEPA, 2008).

i. One of the characteristics of solar energy is also solar reflectance, or albedo, which is the percentage of solar energy that is reflected by a surface (Ritter, 2006). Solar reflectance is correlated to a material's colour, the darker the colour the lower the solar reflectance and the opposite is true for light colours. So how does this hinder or help with the formation of the heat island effect? Urban areas around the world have similar roofing and pavement material that are made from substances that usually have lower albedo properties (dark colour) than those in rural areas; thus cities and larger towns absorb more and reflect less of the sun's energy. A substance with high albedo reflects a significant amount of radiation (Ritter, 2006), an example of this would be clouds and surface snow cover. In comparison a substance with low albedo reflects very little incoming radiation such that most of the energy is absorbed by the object. An example of this would be forests, corn fields, concrete and dirt (Ritter, 2006). The urban heat island effect is caused by this difference in albedo because concrete, metal and buildings over all have a lower albedo than rural areas with trees and vegetation (Beardmore, 2010); thus absorb all the heat energy from the sun. This absorbed heat, will not only raise the surface temperature but also contribute to the creation of surface and atmospheric urban heat islands.

ii. Thermal emissivity is also another important property that contributes to an urban heat island; emissivity is a measure of a materials ability to emit or release thermal energy which it has absorbed. With most of the material constraints being the same for buildings, the amount of surfaces with low emissivity ratios will stay cool, because they dissipate heat more easily; for example glass and highly reflective material, will have lower emissivity due to release of heat (Industrial Measurement Guide, 2010) . Most building materials have high thermal emissivity due to their material and surface properties, such as concrete and asphalt.

iii. Lastly, the property that gives rise to a heat island is an object's heat capacity. Heat capacity is the measurement of the substance's ability to store heat (Ritter, 2006). Different types of materials have different heat storing capabilities; materials such as stone and steel have higher heat capacities than rural material, which normally consist of sand and dry soil (Beardmore, 2010). This property has a major influence in maintaining the heat in downtown areas and since the city buildings are efficient at storing the sun's energy as heat; there is a larger area where heat can be absorbed almost twice as much as a rural area.

c) Urban Geometry

When we look at a city we can also suspect that there is an additional factor that contributes to the urban heat island in terms of dimensions and spacing of buildings. The urban geometry within a city changes the amount of energy absorbed, the wind flow, and the energy budget of the city especially the ability of a surface to emit radiation (emissivity) (USEPA, 2008). Because there are many obstructive buildings and structures around a city, the surface areas of many of these structures are blocked by other structures and thus results in a large thermal bubble (mass) that is hard to remove, because of the stored heat throughout the day (USEPA, 2008). Cooling or moving through convection or heat dispersion may be ideal, but since the surface area is so small and confined due to the buildings and lack of space, it is usually hard to do.

Another urban geometrical feature that adds to the heat island phenomenon is an urban canyon. An urban canyon is the way that buildings are arranged in a city, mostly composed of tall buildings in a narrow street line (McPherson 1993). The effects that this canyon has on the urban heat island is two-fold; one, the tall buildings can act as a shield, and create shade thereby reducing surface and air temperature, and two, when the sun rays hits the surface of the canyons, it is first reflected and then absorbed by buildings walls. During the night, urban canyons usually stop cooling down as the buildings and structures can block the heat that would otherwise become air borne and move away from the urban areas (McPherson 1993). Another way to measure or describe the effects of urban geometry is through something called "sky view factor". This is the visibility of the sky from a given point on the surface; for example an open field would have a larger visibility range than an urban downtown space that is surrounded by walls and large buildings (McPherson 1993). An urban area that contains tall buildings would have lower sky view factor since there would be only a limited area of sky visible and thus help propagate heat islands.

d) Urban Surfaces and the Heat Budget

Every day, the earth absorbs and redirects energy from the exchange of heat between it and the atmosphere. This heat comes from radiant energy that is largely absorbed through solar radiation. When studying something like the urban heat islands or the radiation balance of the earth, there are specific energy ‘equations’ or budgets that accounts for the incoming and outgoing components of radiation (Ritter, 2006). The components of the budget are as follows: short-wave radiation, long-wave radiation, latent heat, sensible heat, thermal storage and anthropogenic heat.

i. Shortwave radiation is radiation that has many wavelength band widths such as ultraviolet light, visible light, and near infrared which originally come from the sun, and then through the atmosphere when it reaches the earth (Ritter, 2006). This type of energy reflects less radiation back into the atmosphere than when it arrives (due various particles being absorption or reflection); the portion that is absorbed, increases the surrounding temperature due to the absorbed heat by the surface of the object (Ritter, 2006). This type of radiation is another driver of the urban heat island effect as urban surfaces reflect less than other natural vegetated surfaces.

ii. Long-wave radiation, which is radiation that is found only in the infrared wavelength spectrum, is energy that has been absorbed by the earth’s surface and radiates from its surface (Ritter, 2006). The amount of energy that is emitted depends on the temperature of the object’s surface; the hotter the surface the more radiant energy it will emit (Ritter, 2006).

Iii. Latent heat can be represented through the way evapotranspiration cools evaporation of water into air. Areas that are rural and vegetated retain more moisture and thus become cooler when the water is evaporated into the air (The United States Geological Survey, 2009). Urban areas are often dry and impervious with little moisture is found in the infrastructure, which makes it harder to for material to cool and thus contributing to higher air temperatures.

iv. Thermal storage, which is heat storage from a storage system such as solid thermal mass, is also increased in a city partly because of the lower solar reflectance of urban surface, thermal properties of construction materials, and by the urban geometry (USEPA, 2008)).

v. Sensible heat can be found through convection especially when there is a temperature difference between air and the earth's surface (Ritter, 2006). Since urban surface temperatures are made of several layers of air (hot, warm, cool), there is often circulation of air which keeps adding to the warmth via convection (movement of heat through wind, land mass and atmospheric elements).

vi. Lastly anthropogenic heat is heat that is created by humans though excess heat released from cars, air conditioners, factories, and other man made sources; this heat accumulates with more intensive uses in the city (USEPA, 2008).

vii. There may also be additional factors that contribute to the urban heat island effect, which are part of the natural world's ambience. Weather and location are not in our control and thus they play a significant role in influencing the heat island effect. The peak times of an urban heat island occur during calm winds and clear to cloudy skies; this is the most ideal condition for a heat island to form since the amount of solar energy that reaches the urban surfaces is increased and heat can be trapped if it is clear with a few cloud cover (USEPA, 2008).

Another added factor to the formation of the urban heat island effect is a city's geographical location. There are many topographical features that aid in decreasing or increasing the effect of a heat island. For example, areas with a larger surface area and a mountainous range, have the ability to increase larger wind patterns that may occur throughout the city, thus mitigating heat, and yet mountains also create a shield for winds which does not help the heat accumulation in the city (USEPA, 2008).

Large bodies of water are also a good topographical feature to have around a city as water, naturally, helps regulate temperature and create breezes that whisk heat away from the city's core (USEPA, 2008). In essence there are several factors that lead to the urban heat island effect, and thus by monitoring the energy balances and the areas where urban cities are being built, we will be better equipped for heat island mitigation in the future.

III. Why do we care about the impact of the Urban Heat Island on an Urban Ecosystem?

Critical problems that the heat island effect creates are the following: elevated temperatures throughout the city along with associated problems such as an increase in energy consumption (due to increase air conditioning), increase emissions of air pollutants (lack of air movement and trapping dust particles), greenhouse gases (trapping heat), and decreasing water quality (higher runoff material/heating of storm water) (USEPA, 2008). These are the severe consequences of what an urban heat island can bring to an urban ecosystem.

a) Urban Ecosystem

An urban ecosystem is composed of man-made elements as well as natural elements, whose interactions are not only affected by the natural environment (such as a heat island) but also by culture, personal behaviour, governing policies, local economy and social activities (USEPA, 2008). The urban ecosystem is a life supporting system for the natural and human environment, it provide services such as water supplies, resource of aggregates, landfill areas, recreation zones, watershed protection green house uptakes and biodiversity of plants and animal species (USEPA, 2008). The interactions of these services, city life, concrete infrastructure (buildings, pavements, roads), and the internal city climate creates many environmental problem such as global warming, water and air pollution. Thus the heat island is the most prevalent problem that a city faces today, as it affects the urban ecosystem on many levels mostly in terms of quality of city living, air quality and water quality.

b) Air Quality and Extreme Heat

With increased day time temperatures and lack of night time cooling creates an all around higher air pollution level, which can affect human health. Most of the symptoms that are felt by the public are general discomfort, respiratory difficulties, heat cramps, exhaustion, heat stroke, and heat related mortality (USEPA, 2008). Heat islands can also provoke more intense weather conditions such as making heat waves extremely hot or leading to abnormally humid weather. The risks that are associated with this kind of weather mainly apply to a portion of the population which is the highly sensitive such as the elderly or children and especially anyone with existing health conditions. The severity of the problem can be seen in cases where the intensity of a heat wave caused more than 1000 deaths, as in an extreme heat wave in the Midwest during the summer of 1995. In addition, the Centre for Disease and Central and Prevention estimated that between the years of 1979-2003, heat exposure contributed to more than 8,000 premature deaths in the USA (USEPA, 2008).

Due to the urban heat island effect, the elevated air temperature conditions may increase from 27-50 degrees during the summer, and it has been noted that electricity consumed (for a community close to Chicago as a sample size) increased 2% for every .6% increase in air temperature (20-25) due to increase use of air conditioning (USEPA, 2008). This suggests that there was a community wide increase in the electricity consumed to compensate for the heat island effect. Sometimes this electricity usage, resulting from a cooling demand, can be elevated during excessive heat waves (in some cities) and cause power surges and temporary black outs. The increased temperature changes that the urban heat island creates compounds the problem as our reliance on air conditioning increases. This is dangerous since, every time we use air conditioning, it takes a toll on the environment by burning more fossil fuel, resulting in further carbon dioxide and other greenhouse gases.

Presently, most of the cities in many parts of North America use electricity that is produced via combustible fossil fuels (USEPA, 2008). Most of the pollutants that are released from power plants are sulphur dioxide, nitrogen oxides, particulate matter, carbon monoxide and mercury; these pollutants are hazardous to human health and to air quality as they are the main elements found in acid raid (USEPA, 2008). Also as hot air rises in the cities, the frequency and intensity of low level ozone is produced, thus accelerating the rate of photo-chemicals and pollutants (nitrogen oxides and organic compounds) that create air quality problems.

c) Water Quality

Not only does the heat island cause a lack of clean air and health issues, but also causes water thermal pollution. The heated water becomes runoff and it drains into storm water sewers and raises the temperature as it is released into streams, rivers, ponds and lakes (USEPA, 2008). Effects of this are devastating to the natural surroundings, such as affecting the local aquatic life, especially the metabolism and reproduction habits of many fish. Studies show that the runoff from urban areas is about 11-19 degrees hotter than rural areas; thus this is a drastic change in temperature, but even a slight change can cause stress on the aquatic life (USEPA, 2008). For example, Brook trout were found to have thermal stress when there was a small change in temperature (1-2 degrees) per hour (USEPA, 2008). What can be done to help the population and the surrounding ecosystem regain stability in times of anthropogenic stress?

IV. Strategies for reducing the Urban Heat Island Effect

The urban heat island effect has been a part of our cities for many centuries, and with the change in climate things could be exacerbated. There are some mitigation strategies that have been researched in the development process, yet there needs to be a push in city planning for these strategies to become a reality in the coming years as cities will have to adapt to their changing environment.

a) Change in geometry city structure

One of the drivers of the heat island effect, which is urban geometry, was designed for efficiency and space and yet there are a lot of factors that could not have been avoided to prevent the urban heat island from occurring. Four rules of placement for building urban cities are typically as follows 1) maximize shelter from wind for pedestrian comfort 2) maximize dispersion of air pollutants, 3) maximize urban warmth to reduce the need for space heating 4) and maximizing solar access (Golany, 1995) . Due to the overlapping needs of the urban geometry objectives, such as conserving heat and dispersing pollutants at the same time, some of these objectives could not be emphasized and thus only a portion of the objectives were accepted. Although these rules of building placement worked in the past, in terms of urban lifestyle, they have made the heat island worse throughout the decades.

Within the several designs for urban lay outs, there have been studies that show how some of these, may reduce the urban heat island effect. For example, in hotter regions, where cities are built in a north-south street section, it has been noted that the urban heat island effect was weaker than in cities with east-west streets (USEPA, 2008). Also there has been analysis conducted on how increasing the canyon height ratio to width ratios may in fact create stronger day time “cool islands” and less of a night time heat island effect (USEPA, 2008). Many of the observed examples that would help reduce the heat island effect such as aspect ratio, building density, and street orientation would be a viable solution, however there may be building restrictions in some cities and different planning projects, so that the chances of a drastic change in the cities is slim; a major change in the urban geometry would not be cost effective as every major city has already been established.

b) Cool Roof surfaces

Even though cities have been built with structure and function in mind for the growing population, they now are incorporating other ways to reduce the urban heat island such as the use of light colour surfaces. Most of the materials used for construction are dark coloured surfaces. This decreases the albedo potential which means that more heat is absorbed and thus temperature rises. If a lighter coloured surface is applied, there is at least a temperature drop -between 1-4 percent lower than what is originated (USEPA, 2008); thus, it would not only be beneficial to the temperature difference in cities but also in the reduction of energy needed through air conditioning. This means that a city would have to figure out the largest surface areas where darker material is located and change that colour through paint or any other material available.

c) Urban Forests and vegetation

The most effective energy reducing and cooling tool that urban cities can rely on are trees, largely urban forests, and green spaces. In several studies, it was reported that there were significant changes in surface temperature after the introduction of vegetation to the area; the vegetated surfaces repeatedly lowered surface temperature by at least seventeen degrees and there was a 20-80% reduction in air conditioning cost (USEPA, 2008). Other experiments such as modeling simulations of trees around suburban homes in California show that the shading of trees is more than effective in times where peak hours require more cooling energy (USEPA, 2008). Also evaporative cooling from grass turf can also provide certain advantages to the microclimate such as cooling walls and rooftops, where grass turf is placed on walls and roofs to provide maximum cooling. This is known to be a very good design for density populated areas, where trees may not be easily planted in some of the urban areas (USEPA, 2008).

Some issues with introducing vegetation to an urban area are cost of re-planning, re-designing the urban areas, not to mention the cost of continual maintenance and vegetation material. These problems can be avoided by having good clear designs that are suited for species selection, their ecological needs, and the city space (USEPA, 2008). Design examples that would aid in the urban heat island mitigation are in adjusting vegetation for urban canyons, parking lots, parks and residential housing.

For example trees along the street canyons can reduce radiant heat loss to the sky through convection and advection; in parking lots they shade the ground surface, which in most cities is black asphalt (McPherson, 1993). Most large cities may have lost some of their green space but there can still be a significant change done through urban forestry. Trees, grasses and shrubs provide much cooling for an urban environment and thus urban planning must take them into account when building or redesigning and urban space.

V. How have urban forests evolved within a city and why is it important to the UHI

Urban forestry differs from traditional forest management in that the objectives are slightly broader in that urban forestry has to deal with the changing needs of the urban ecosystem infrastructure. The urban forest objective is to cultivate and manage trees for their present and potential contribution to their environment which includes the social and economic well being of urban society (Kuchelmeister & Braatz, 1993). Today, it includes the merging of arboriculture, ornamental horticulture and forest management (Agro-forestry); it is also related to landscape architecture and park management. Due to the many demands of a growing urban ecosystem, it also includes managing municipal watersheds, wildlife habitats, outdoor recreation opportunities, landscape design, recycling of municipal wastes, tree care and in some cases the production of wood as raw materials (Kuchelmeister & Braatz, 1993).

a) Forested city areas

Urban forestry has been side by side in human settlement throughout the ages; it is a requisite part of landscape architecture. Most of the ancient cities of Europe and Asia used developed parks, gardens and other green spaces (Kuchelmeister & Braatz, 1993). In eighteenth century Europe municipal and crown forests were managed for recreation and hunting. Throughout history aesthetic and amenities of forests has also been a common trend in urban communities.

b) Present locations and management

Most of the urban forestry areas are carried out in the city centers, suburban areas and the "urban limits" where the forested area meets the rural lands. Each area is managed according to each zone's needs; forestry activity can be extremely different in each zone for example wood lot management to recreation use (Kuchelmeister & Braatz, 1993). In city cores, the potential of urban forests are significantly lower and limited due to the larger population and reduced area size; mostly in this area it is a matter of light routine maintenance work such as re-planting trees as they are needed (Kuchelmeister & Braatz, 1993). In the suburban areas, there is room for more of tree-planting, forestry planning uses as the availability of land is extended. This area is most likely to be privately owned or have people that are more settled into their surroundings and thus have an invested value and interest in tree protection and care (Girling et al., 2000).

For most of the larger metropolitan cities, trees may be a minor part of the landscape, especially closer to the city core. In these areas there are many harsh conditions which limit the health and productivity of trees.   Conditions such as root damage, soil compaction, and location are difficult for a single tree to grow. In areas where there is more tree canopy, management may be complicated due to its fragmentation of green space within the city core (Girling et al., 2000). Consistency between tree-planting, location, configuration of planting and management of the trees in an urban setting proves to be difficult compared to the rural areas where there is room for growth and trees have a more consistent environment. There may be different objective in rural versus urban setting for forests/trees which are conditioned by the socioeconomic requirements of both areas.

c) Urban forests and climate change

In the onset of climate change, where it has become a global problem, the urban heat island event may increase in the years to come due to the interconnected global issue of rising temperatures, thus investing in urban forests now, would essentially aid in fighting climate change.

Forests play a major role in reducing the levels of CO_2 and other greenhouse gases in the atmosphere, which inadvertently aids in the conservation of energy that is mostly needed for space heating and cooling (USEPA, 2008). The storage process of carbon happens when CO_2 is transferred into the tree and stored as carbon in materials that can be fixed as wood, branches, roots and leaves. The tree utilizes carbon dioxide into its system, and oxygen is produced as the process of photosynthesis is carried out; this further helps filter the air by obtaining carbon dioxide in the tree itself (USEPA, 2008).

Shade is created as the leaves and branches of trees reduce solar radiation, only letting a limited amount of light through to the ground. The amount of shading that occurs relates to the canopy variability for specific trees. For example in summer time there is generally about 10-30% (for deciduous forest) of sunlight that reaches the area underneath the tree; the rest of the sunlight has either been reflected or absorbed (USEPA, 2008). Research has shown that there are many potential ways that trees and vegetation cool their surroundings, for example, peak air temperatures in tree groves are 5 degrees cooler than in open terrain, air temperature over irrigated fields are 3 degrees cooler than air over bare ground, suburban areas with mature trees are 2-4 degrees cooler than new suburbs without trees, and temperatures over grassy fields (for sports) are 2 degrees cooler than over bordering areas (USEPA, 2008). These slight changes in temperature may not be astronomical figures, however over a long period of time and with increase in vegetation, there will be a significant change in the air temperature. The many capabilities of urban forests will not only be beneficial on a local level but also on a global scale.

VI. Urban forests Benefits on urban ecosystems (co-benefits of urban forestry)

a) Air

Ground level ozone is another “air quality” issue that is being researched, and urban forests may help with this matter. Research in New York City shows that by increasing the urban canopy cover by 10% would in fact decrease ground level ozone by 4 percent (USEPA, 2008). Studies show that forests can reduce pollutants up to 784,000 tons per year (USEPA, 2008); this study used the effect on ground ozone, particulate matter that was less than 10 micrometers in diameter, and that contained mostly nitrogen dioxide, and carbon dioxide. Among these emissions other emission that can be reduced by trees are the evaporative emissions of volatile organic compounds which are one of the main components in the creation of ground level ozone (USEPA, 2008).

Lastly the removal of carbon from the air is another benefit that trees and vegetation can provide for an urban environment. A study suggests that in late 2006 the net rate of carbon sequestered by the United States was around 24 million tons per year, and that the national average urban forest storage density was just over 25 tons per hectare. So with that in mind there are many ways for carbon to be taken out of the environment only by making slight changes to the amount of vegetation that can be placed within a city. A study in the United States in 2006 suggests that about 15,000 inventoried trees in South Carolina were responsible for an annual net reduction of over 1,500 tons of carbon dioxide (USEPA, 2008).

b) Hydrology

Cities are not a closed system, they interact with everything in their urban ecosystem, thus when water flows over an impervious surface, it also picks up other urban elements such as oil, gasoline, fertilizers and industrial chemicals(The Capital District, 1998) . Since there is usually lack of vegetation in larger cities, these substances are washed into water bodies where they harm aquatic organisms and in turn harm us. Also the large amounts of impervious material (surfaces) can cause excess rainwater to pool in streets and on properties faster than the sewer system can absorb it. Thus trees help reduce storm water runoff and improve water quality (The Capital District, 1998). Trees can capture large amounts of rain through their root system and canopies which can aid in filtering some of the pollutants thus results in redirection of rainwater into the ground water supply and thus improving water quality. Healthy urban forests aid in stabilizing watersheds, by absorption through roots and air pockets within in soil which retain the rainwater, to slowly be released through time (The Capital District, 1998).

c) Biodiversity

Green areas have an essential role in urban biodiversity. Bogs and suburban wetlands can be some of the most productive natural ecosystems and can provide habitat for regional fauna. By incorporating green areas in all city zones will not only serve in biology conservation and biodiversity of plants and wildlife but also provide green belts (linear parks) that can serve as biological corridors (Kuchelmeister & Braatz, 1993).

d) Urban forest use

Developing countries use forests for timber and food sources. The timber used in urban areas comes from plantations, street trees, shelter belts, parks and gardens. In many cities timber harvesting while intensive outdoor recreation is commonly used. To offset the cost of tree care, harvesting trees is mandatory (Kuchelmeister & Braatz, 1993).

e) Aesthetic and Recreational Qualities

Trees are valuable for the needs of city dwellers; they fulfill psychological, social, and cultural needs. Trees maintain important roles in aiding to ease dwellers' stress levels and improving psychological health (Kuchelmeister & Braatz, 1993). When trees are located in an appropriate area, trees are effective in screening unsightly views and provide privacy while still maintain holistic visual of landscapes. Parks allow for recreational and social activities for people in the city. One study showed that hospital patients placed in a room with a window facing trees, would often heal faster and stayed at the hospital within a shorter time frame than patients without (Kuchelmeister & Braatz, 1993).

f) Community Building

With urban forests, local parks and gardens in city zones, there is always public involvement when it comes to improvement of a healthy environment; opportunities to work together and strengthen the local environment aid in the amenities that people desire (Kuchelmeister & Braatz, 1993).

VII. Developing sustainable urban forest management strategies for the UHIE (and eventually climate change)

a) Current problems with urban forests

Currently, urban forests have many stressors and challenges that make it difficult to maintain and mange multi-aged, multi-species, healthy forests. Trees that are planted in the city such as alongside streets, buildings, and sidewalks, barely have room for their root system to grow (Clean Air Partnership, 2010). They do not receive enough water and are susceptible to other stressors like extreme heat, road salt and hard surfaces. Their soil material is usually compacted with poor nutrients and usually unable to properly drain excess water. With all of these inhospitable elements, city developers continue to plant trees which not only limits the survival rate and maturity of the tree but also fails to promote social and environmental benefits (Clean Air Partnership, 2010).

Sometimes there is a lack of public understanding of how to properly provide for these trees (Clean Air Partnership, 2010). Urban trees in such a stressful environment need to be constantly maintained; for example pruning, watering and monitoring for pests and pollution should be a priority. Even though contractors are forced to care for these trees for at least two years after they have been planted, trees in the city environment need a longer time frame to grow properly (Clean Air Partnership, 2010). Maintenance budgets may also not be adequately funded due to costly water and other tree necessities. For example in a case of a severe rainstorm, it cost Urban Forests Services $600,000 for clean up after all the trees had fallen , and there was a hole in the budget city budget because of this (Clean Air Partnership, 2010); if there was proper funding and contingency plans this money could have been saved and used elsewhere.

Another problem with the lack of knowledge of how urban trees function and urban tree funding is that there is no inventory of how many trees there actually is on certain city areas for both private and government owned trees (Clean Air Partnership, 2010). Lack of communication between city official and residents who have private property causes inadequate observation and appreciation of the actual value of urban trees (Clean Air Partnership, 2010). A few homeowners are tempted to remove large trees for misconstrued fears of trees being a nuisance; the challenge lies in convincing landowners to keep their trees for the well being of urban forest and their environment. There is no regulation that regulates the minimum requirement for neither green space nor further protection of the existing trees in developing areas (construction of new buildings); thus the building departments have no authority over protecting existing trees (Clean Air Partnership, 2010).

Although there is variety of tree species within the city area as a whole, there is a gap where similar tree species tend to make up the larger portions of an urban forest (better adaption to the city); thus some urban forests lack biodiversity. In some cities, like in Toronto, a tree (maple) may be the most commonly used tree (Clean Air Partnership, 2010). This is a problem when there is a low level of species diversity within a small area due to that it leaves the urban forest susceptible to invasive plants and pests.

b) Example of current action plan

With the issues that the heat island brings, increasing heat is the most prevalent. Urban forests aid in cooling their surroundings especially if leaf areas is increased. The larger the tree canopy cover, the greater the benefits for the urban ecosystem as a whole. This is the sole reason for increasing the number of large, healthy trees in urban areas. One example of what percentage would have to be increased (for the mitigation to work) is in increasing tree canopy coverage to 40% of what is originally there; this projection is based on Toronto's current urban cover which is only 17 % coverage, and thus the increase of 40% was calculated through their finding and urban tree needs (Clean Air Partnership, 2010). For future planning to be effective, such as that in the example above, there are some things that urban planners still need to consider.

c) Protection of Existing Urban trees

Protection may be the hardest thing to implement as making codes and ordinances for trees may be challenging for city developers. Tree ordinances provide the community with regulations for planting or preserving trees. Specifically, ordinances can protect trees during building construction and with conservation of tree groves in a situation where trees may be seen as disjointed individual (Girling et al., 2000). For example in Atlanta, Georgia, tree ordinances states that no more than 50% of existing trees are to be removed, damaged or destroyed and that all trees 30 feet of a construction zone be protected, thus no excavation should occur within 10 feet of a tree (Girling et al., 2000).

With new residential development, limiting construction impacts through the design of "clustering homes" to a particular site, can aid in retaining natural forest. Furthermore, by redesigning and making changes to planning lot sizes there can be equal amounts of homes that are needed but occupying smaller amount of land (Girling et al., 2000). Also by designing sites that not only protects but adds to the community, as a unique landmark would, may be beneficial to everyone as a whole; for example by retaining large, old and rare trees would increases heritage values of the area as they are considered to be specimen species (Girling et al., 2000).

d) Managing for effects under the UHI

Heat is a major stressor to trees, and with UHI in the city it requires a lot more for the forests/trees to survive let alone to aid in the mitigation. Planting heat tolerant trees in sites where heat is the most prevalent (along road sides, parking lots, near buildings) can increase survival rates (Clean Air Partnership, 2010). Species tolerant of heat and drought conditions include hedge maple, the London planet-tree and the silver linden (Clean Air Partnership, 2010). Selection of tree species would largely depend on what grows best in a specific city and a tree species that grows in the southern most part of that area; this is so that conditions of heat stress would be simulated in the new area when temperatures are higher (due to change in city climate) (Clean Air Partnership, 2010).

As an aid to improving air quality, to counteract the pollution basin that UHI creates, planting pollution resisting trees is another option. Trees that have higher levels of carbon sequestration include Silver linden and Carolina basswood, blue spruce and hybrids such as Robusta and Siouxland (Clean Air Partnership, 2010). To increase effectiveness they should be planted near the pollutant source and efforts should be made in keeping the older mature trees alive. Research as to which tree is well suited for the designated city is still required.

Programs for tree watering and maintenance should be implemented. Various cities have urban forest departments which have budgets for tree maintenance, however, budgets should always be revised and new programs should be created in cases of any future environmental disasters. For example water maintenance during the summer is important for trees, yet how does the distribution and quantity of water impact the rest of the water city usage?

Some alternatives to continuous water usage may be water gators (Clean Air Partnership, 2010). Water gators are bags that are zipped around the base of the tree and filled with 20 gallons of water that slowly drip out over a 6 to 10 hour period (Clean Air Partnership, 2010). Support from the entire community would help with the burden of water needs on the city and increase the survival rates of trees. Programs like 'adopt a tree' where residents take care of a tree's needs, are most helpful and if everyone did this there would be more money saved for times where it was really needed (Clean Air Partnership, 2010).

Another management technique would be to plant trees around buildings to save energy. In winter evergreens are used to block wind, from the north and deciduous trees can be planted on the south and west sides of buildings to provide cooling shade in the summer (letting enough sunlight to enter in winter) (Clean Air Partnership, 2010).

Finally consistent monitoring tree health is necessary to check for stress levels on the trees from pollution, diseases and other stressors such as pests (Clean Air Partnership, 2010). Monitoring will allow for complete information to be obtained for future use and how particular species composition of an urban forest many need to be changed so that there is a decrease in mortality rates.

VIII. Conclusions

The urban heat island effect is something that was inadvertently created through man's creation of urban areas. Future predictions suggest that by the end of this century there will be more people moving to urban cities due to population growth and expansion, thus with an increase in population an increase in other health related issues occurs, such as increasing heat islands. For a city to sustain a healthy environment and aid in the mitigation of UHIs, it must know how it can provide assistance for its growing population. Thus by maintaining urban forests and increasing green spaces within the urban ecosystem there is hope that something such as the UHI will not create ecological and biological disasters, even at times of global warming. The tools that will allow for future policies to be implemented for adaption to climate change and issues such as UHI are:

1) Education and
2) Thorough strategic urban planning that incorporates natural, social and ma- made objectives into city living; such as planning for better urban forests as their multiple functions are beneficial to the common wealth (environmentally and economically) of a city.

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