Urban Heat Island Phenomenon
A Look into the Metro Manila Setting

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Abstract

The microclimate phenomenon called Urban Heat Island (UHI) is fast becoming a worldwide concern. A description of the phenomenon, its history, the factors influencing it and its effects on the urban landscape is presented. It also discusses how UHI impinges on the regional and global environment. The paper would like to impart how an urban heat island is investigated in other countries and their mitigating measures to counteract or lessen its effects.

Lastly, the paper discusses the present status of Metro Manila and the possible presence of UHI. It also provides insights on how a study can be undertaken through the use of existing local data and resources and the experiences and knowledge of other countries.

Introduction

It is a common knowledge that cities and urbanized areas have higher temperature as compared to rural areas or countryside. This difference in temperature between the urban and rural areas is called the URBAN HEAT ISLAND (UHI) PHENOMENON or the Urban Heat Island Effect. The reason the city is warmer than its surrounding area comes down to a difference between the energy gains and losses of each region, meaning the amount of solar energy gained or stored and reflected by each area.

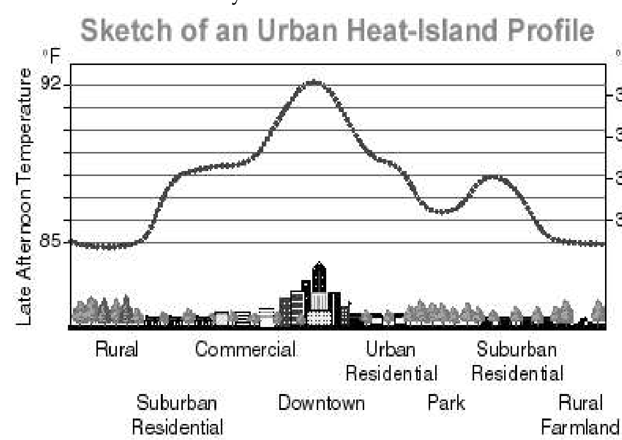

Figure 1 - Sketch of an Urban Heat-Island Profile
Source: US Environmental Protection Agency

In other parts of the world, there have been serious studies regarding the urban heat islands phenomenon. Their ultimate aim is to be able to come up with strategies to decrease the risk to public health during heat waves, reduction of city smog, reducing energy use and the emissions that contribute to global warming. Today, rapid urbanization has tremendous impact on climate and the environment which greatly affects the level of habitability of an area.

History of UHI Phenomenon

Ever since the first cities were established in antiquity, people have already observed that the air in urban areas was different from that in the rural setting. They have sensed a "persistent evil" of cities from the smell of it. It was the polluted air that assails the senses of a city dweller.

As early as 68 BC, people have already noticed that urban air was different from rural air. This can be read in the writings and odes of Horace. During this time Rome was heavily polluted due to burning of wood for fuel in cooking food as well as for metallurgy for the weapons of the empire. Another great source of air pollution is the burning of oil lamps for lighting of Rome's main avenues, palaces, establishments and private homes. Rome became the epitome of an urban area that is growing fast because it's the center of the Empire. Alongside with it is the defilement of the environment due to excessive waste and burning of fuel in maintaining a growing empire.

At the end of the middle ages, a European city, London, became the prototype of urban pollution. In fact, there were several instances when coal burning was banned[i]. A notable instance was Queen Elizabeth's banning of the act when the parliament was in session. Despite the issuance of decrees banning coal burning, air pollution persisted for the next 300 years. More than 4000 people died in a 1952 air pollution incident prompting England & other European cities to totally ban coal burning. As such this converted the English urban areas into "smokeless zones."

The roots of UHI studies can be traced to 1818 when Luke Howard, a chemist, published a paper dealing with the climate of the city and how air quality was found different from urban fringes. In 1820 he had deduced thru gathered data that the urban center of London was warmer than the rural peripheries. He attributed this to the extensive use of fossil fuel, specifically coal, such temperature difference. He also noted that nighttime, temperature were 3-4 deg F warmer and 1 deg F cooler in the city than in the country.

A few years after Howards' discovery, Emilien Renou, a meteorologist, published a paper stating that Paris is 1 deg C hotter compared to the countryside. He also noticed that wind speed in heavily built- up areas was lower than in the open countryside.

For the next 50 years, numerous monographic studies on climate of different cities were published and most of them on the urban-rural climatic differences. In 1917, Wilhem Schmidth started systematic research that relates to such temperature differences. He introduced the use of moving observation and survey posts such as bicycle, streetcars and horse-drawn carriages, on which instruments to gather data were installed. This started the micrometeorological observation of the urban landscape. The modern study of UHI was born.

With the addition of satellite as a means of investigating UHI phenomenon, the early years of the '70s started the wave for the serious and more in-depth study of UHI phenomenon and its effect. At present, the study of UHI has become more complex than ever. It involves factors such as rainfall statistics, population growth and density, vehicular traffic density, industrial particulates, urban vegetation and regional climate studies, among others.

Cause of Urban Heat Island Phenomenon

The main reason why urban heat island exists is ***urbanization.***

Urbanization of an area leads to the removal of existing vegetation, which in turn alters the moisture condition of the earth's surface. This alteration of soil moisture will greatly reduce the amount of humidity in an area. Consequently the ability of the soil to retain rainwater is altered because percolation of runoff is reduced due to paved areas.

The construction of more paved areas specifically roads and parking lots encourages more vehicles that burn more fossil fuels. And as such, they add up to the pollutants which will eventually turn into smog.

Erection of more buildings will add up further to the thermal gain of urban areas. The need to power up these new structures will require additional amounts of fossil fuel to be burnt. Furthermore, tall structures interfere with the natural wind flow patterns, thus, creating artificial wind pattern known also as wind tunneling.

Effects of Vegetation on UHI

Vegetation helps in the cooling process by absorbing and reflecting solar energy. Most of the absorbed thermal energy is used for food production through photosynthesis, thus reducing heat being convected to the surrounding areas.

Also, the absorption of thermal energy by the ground makes the water from the vegetation and soil evaporate producing an evaporative cooling. This evaporative cooling requires solar energy to change the water from liquid to vapor resulting in the cooling of the surrounding environment. Thus, the solar energy gained by the vegetation is compensated by the process of evaporative cooling. This is called evapotranspiration.

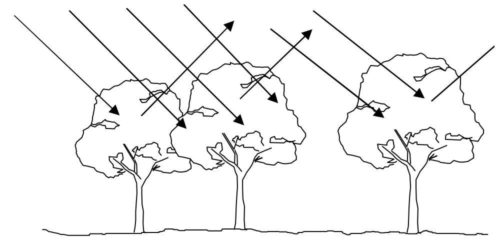

Figure 2 - The solar energy which hits a certain green area is greatly used by the vegetation for its transpiration and photosynthesis processes, causing a sensible reduction in temperature

Evapotranspiration of plants is a phenomenon tied to photosynthesis. Plants, in order to consume carbon dioxide from the atmosphere, keep their stomata open and in the process they loose water. A great quantity of water is pumped from the ground into the air under the shape of water vapor.[ii]

In urban areas, where vegetation is absent, the buildings, streets and sidewalks and cars absorb the majority of solar energy input. The pavements and buildings in the cities are largely non-porous so there is greater run-off; thus there is less water that can evaporate. This in turn result in evaporative cooling which contributes to the higher air temperatures.

A study confirms that a tree-lined open area 100x100 meters can reach a transpiration level of 50,000 liters of water a day. This is equivalent to the cooling capacity of five air conditioning units working 20 hours continuously. In another study in Germany, it has been observed that temperature difference between greenbelts and parks with dense vegetation and surrounding urban areas can be as high as 7 deg C.[7]

Effect of Paved Areas on UHI

Waste heat from city buildings, cars, trains and factories is another factor contributing to the warm cities. Heat generated by these objects eventually makes its way into the atmosphere. This heat contribution can be as much as one-third of that received from solar energy.

The thermal properties of buildings add heat to the air by conduction (transfer of heat from warm objects to cold ones; the rate of transfer is proportional to their temperature difference and their heat conductivity). The basic materials of building are tar, asphalt, brick and concrete are better conductors of heat than the vegetation of the rural area.

In a typical heat budget of a surface being exposed to solar radiation, 20% of thermal energy is lost by radiating it instantaneously, 10% is absorbed by the surface, 60% is lost thru convection and 10% is reflected by the surface. The ability of an object to reflect solar or thermal energy is determined by the albedo of the material.

Albedo is the reflective power of an object. It is also defined as the fraction or percentage that is reflected by a surface or a body. Different materials yield different albedo. Below is a list of common construction materials with its corresponding albedo wherein the range is 0-1. Zero albedo means 0% reflectivity while 1 means 100% reflectivity.

Materials	Albedo
Tar and Gravel	.03-.18
Asphalt	.05-.20
Concrete	.10-.35
Corrugated roof	.10-.15
Red/Brown Roof Tiles	.10-.35
Colored Paint	.15-.35
Bricks/Stone	.20-.40
Highly Reflective Roof	.60-.70
White Paint	.50-.90
Grass and shrubs	.25 -.30
Trees	.15-.18

Table 1 - Various Urban Albedo[8]

It can be observed from the table that plants have lower albedo compared to some construction materials, meaning they reflect less solar energy. Though this is true, it should be noted that plants do reflect less heat because it absorbs more. They absorb more heat in order for them to produce their own food through photosynthesis and at the same time a phenomenon called evapotranspiration takes place alongside.

Effect of Structures on UHI

In urban areas with high-rise structures, solar energy is reflected and absorbed by the vertical surfaces of buildings, increasing their thermal charge. Buildings themselves create micro-climates by shading the ground and changing wind flow patterns. Solar energy absorbed and re-emitted from building surfaces, pavements, roads, etc. creates a warming effect on the surrounding air. Also the large quantities of buildings break up the wind flow, reducing wind speeds and causing the warm air to remain stagnant in the city. This also causes increased pollution as well as temperatures. The presence of local high-rise buildings can degrade the local climate as wind speed at ground level can be significantly increased or reduced, while extensive shadows block access to sunlight. The canyon structure that tall buildings create enhances the warming. During the day, solar energy is trapped by multiple reflections of the buildings while the infrared heat losses are reduced by absorption. [iii]

Figure 3 - High rise structures create micro climate
CBD, Makati City

Impact of UHI

The urban heat island phenomenon adversely affects human health and the environment. It reduces the livability of an area by generating artificial heat and trapping polluted air due to decreased urban ventilation. This in turn causes smog to persist all day and even to the nighttime.

Poor Air Quality

Since air cannot move freely in highly urbanized areas, polluted air can not be "flushed." This results in the formation of smog wherein air pollutants such as nitrogen oxides and volatile organic compounds are mixed due to the presence of heat. It has been observed that the hotter an area is, the higher the probability of smog occurrence. Air quality studies in Los Angeles, California estimate that a 1 deg F increase in temperature can lead to smog formation of 3%.

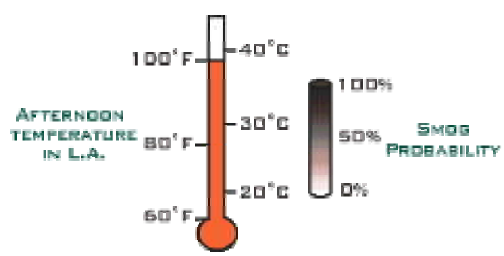

Figure 4 - Smog Probability due to Temperature Rise, L.A., California
(Source: US EPA)

Risks to Public Health

When smog persists, high concentration of ground level ozone aggravates respiratory problems such as asthma, lung diseases including cancer, and others. In some highly urbanized areas in the US and other countries the risk of heat waves has been an alarming trend. Heat exhaustion that results in lost productive manhours sometimes results in heat stroke. The UHI phenomenon puts children and the elderly greatly at risk to the health aftermath of it, increasing loss of productive manhours and medical expenses.

High Energy Use

Hotter temperatures subsequently increase the demand for artificial cooling. This in turn will result to higher demand for energy generation which means more burning of fossil fuel to meet such energy demand. An estimate of the US EPA states that almost 1/6th of the total electricity consumed in the US is used for artificial cooling due to intense heat. It is valued at around $40 billion yearly.

Global Warming

UHI phenomenon contributes to the global warming by increasing the demand for electricity. It has been learned that for every kilowatt hour of electricity consumed, 2.3 pounds or approximately 1 kilo of carbon dioxide (CO_2), the main greenhouse gas that contributes to global warming, is added to the atmosphere.[iv]

UHI Investigation

Identification of Target areas

In an urban setting, some places are hotter than some areas. After such areas are identified to be the subject to UHI Phenomenon studies, data gathering would be the next step.

Profiling of Target areas

- Topographic data of the area to determine the difference in elevations. It has been found out that an urban area with higher altitude or elevations tends to be cooler than lower lying urban areas.
- History of the urban area and its trend of urbanization will yield data that can be used to predict how large and fast an urban area can grow.
- Proposed Land Use Plans as opposed to the existing land use should be well studied.
- Population density has a great impact on UHI phenomena. People are generators of UHI and they are the ones directly affected by it.
- Vehicular density will determine the amount of particulates being released to the urban air space.
- Energy consumption data will help determine if an UHI Mitigation Program is effective or not.
- Types of building materials used will greatly determine the amount of heat being retained and reflected back into the surrounding areas.
- Vegetative inventory is essential so as to determine the plant species that survive in an area and to replace plant species that emit high volumes of Volatile Organic Compounds (VOCs).

Ground observation

- Collection of climatic data through ground observation. Figure 5 illustrates how data from ground observations are plotted two dimensionally to "map out" a potential heat island.
- Collection of past data to act as a benchmark of the present study.

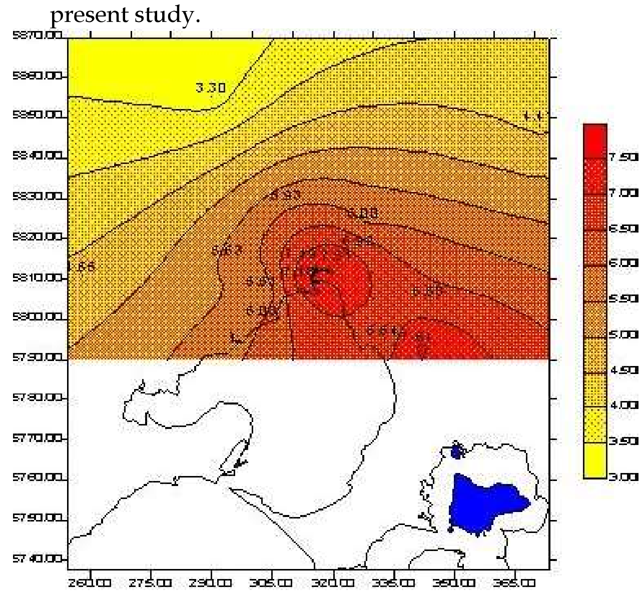

Figure 5 - UHI Mapping thru ground observation, London

- Data gathered either through ground observation or satellite and aerial photos can be processed by means of the Geographic Information System. Satellite images produce different thermal heat bands as shown in Figure 5.
- True images are superimposed on such thermal bands to produce images such as the one in Figure 6. The image below is the true image, the gray areas being urban centers or built up areas, while the image above is the thermal band image wherein the red regions are the built up and hotter areas.

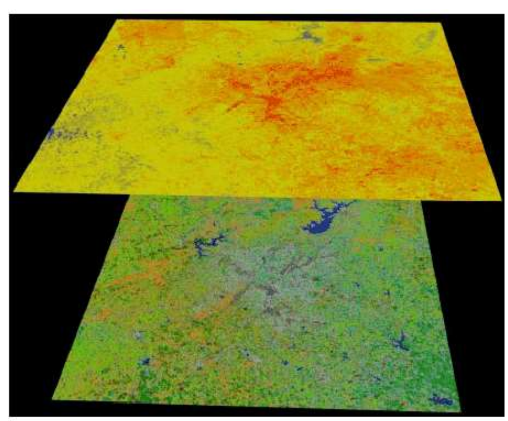

Figure 6 - Use of GIS in UHI study

(Source: http://www.ghcc.msfc.nasa.gov)

Correction by means of UHI Management Programs

After UHI investigations have been made, mitigation programs are outlined to reduce the impact of UHI in an area. Such programs would involve multi-disciplinary and multi-sectoral participation. In the US, UHI mitigation programs are being implemented at a grand scale over the initiatives of local government units. Community participation is also sought to ensure the success of the program.

The role of local government and communities is invaluable because they constitute the biggest contributors to mitigating the urban heat island effect. Local ordinances to ban, or minimize at least, the use of low albedo roofing or building materials can be passed. They can also regulate the alteration of vegetated areas or enhance it further. They can instruct shopping centers or building owners to provide vegetation in their parking lots and paved areas. They can also initiate tree planting programs along roadways and other public spaces. In the community level, planting of trees near homes to directly shield them from solar energy and reduce local air temperature and energy for cooling demand is highly suggested.

These mitigating programs to combat urban heat island effect can be applicable in the Philippines.

The Metro Manila Urban Heat Island

No systematic study has been made to date on the current UHI status of Metro Manila or in the Philippines in general. Cities and urban areas in Japan and Singapore to name a few are already instituting mitigating programs to reduce the effect of urban heat island phenomenon. The Japanese are greatly concerned about the effects of urban heating when they discovered after the war that fast rate of urbanization leads to increase in an urban area's temperature.

In the Philippines, data such as air quality, daily temperature, rainfall data, land use planning data, traffic data, and other data related to the study of Urban Heat Island phenomenon are readily available. Independent studies of the different government agencies have been undertaken or are being undertaken. However linking such data to Urban Heat Island has not been made. This can be attributed to the rationalism that the Philippines is in the tropics therefore temperature as high as 35 deg C is normal. This extreme heat is associated to the general absence of strong prevailing winds that ventilate an area. What aggravates this situation is the relentless rapid urbanization that leads to an urban heat island.

The Urbanization of Metro Manila

The founding of Manila as an urban area started just after the Spaniards took over the city. Its growth was more rapid compared to other areas in the Philippines colonized by Spain. It was a very important center for both trade and military functions due to the presence of a sheltered bay for ports that are ideal for the establishment of strong commerce and military supply line.

In 1872, it was documented that Manila cover an area of not less than 5 square kilometers and steadily rising yearly due to continuous influx of migrant traders, settlers, etc. When the Americans took over, a new era of urbanization took place. With the implements, tools, equipment and the planning expertise, Manila was put into "order." Roads were laid, Government Centers were established, open spaces were incorporated and more roads were being constructed. The grid iron planning of Metro Manila shaped the very foundation of what is now the present state of the metropolis.

Before World War II, Metro Manila roughly covered an area close to 50 square kilometers. After the war the rate of urban expansion slowed a bit. In 1972, urbanized area was close to 70 square kilometers and from thereon an unprecedented urban expansion took place. By the end of 1997 it increased almost 100 times from the 1972 figure totaling a staggering 700 square kilometers. At present, the fringes of Metro Manila are touching the fertile lands of Bulacan, Laguna and Cavite. An estimate states that by 2010, Tagaytay City would be part of urban Mega Manila.

Sources of Data for Metro Manila UHI Study

As mentioned earlier, critical data such as weather and climatic data, population, traffic volume etc. are readily available. Government and non-government agencies that can be tapped in the study of the Metro Manila urban heat island are the following:

- PAGASA- being the lead agency that is directly involved in the study of weather patterns and climatic trends in the country.
- DENR – being the head government agency that is involved in the welfare of the

country's environment and natural resources. It has several bureaus and agencies under it that can help in the study of UHI in Metro Manila. Among them is the EMB or Environmental Management Bureau.

- NAMRIA – GIS capable and has vast resources of landsat images and aerial photographs that can aid in the study of UHI.
- Manila Observatory – a Jesuit-funded institution that has climatic records that date as early as 1865. They also have vast resources of papers, articles and dissertations related to the study of UHI.
- Academe – papers, dissertations, published works and studies undertaken by the academe can be used.
  - Other government and non-government agencies:
    - NSO for population data;
    - LTO/LTFRB for vehicular data;
    - MMDA for traffic volume and air quality;
    - NEDA, WB, ADB for funded/assisted projects related to the UHI study;
    - Dept. of Science and Technology;
    - Dept. of Energy;
    - World Wildlife Foundation

The Metro Manila Urban Heat Island Discovered

"Climate Change due to the Urbanization of Metro Manila", published by Dr. Valeroso and Dr. Estoque of the Manila Observatory, was an early attempt to associate temperature and rainfall difference to urbanization. It presented through data gathered from different periods and different posts in and outside Metro Manila, that there exists a temperature difference in urban and rural areas. In brief it contains the basic nature of an UHI study.

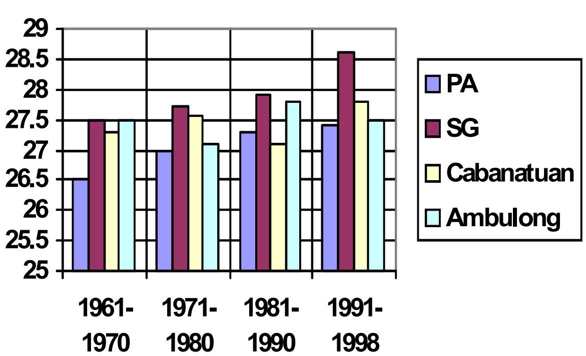

Figure 7 - Decadal Temperature Average
Source: Climate Change due to Urbanization of Metro Manila

Four stations were used, two being urban observation posts (Port Area, Manila and Science Garden, Quezon City) and the other two being rural observation posts (Cabanatuan, Nueva Ecija and Ambulong, Batangas City). The chart above outlines the observed data from the observation posts. It covers the years 1961-1998 and is grouped in a period of ten years or decadal temperature average.

The Manila Observatory paper concluded that there had been a gradual increase in temperatures associated with the urban expansion of Metro Manila.

The average temperature change in the two urban observation posts had been about 1 deg C higher for the past two decades. Meanwhile the two rural observation posts yielded erratic data which translates to a non-linear data change. What is significant in their paper is the temperature difference of the urban and rural observation posts. Urban posts recorded a 1 deg C higher temperature compared to its rural counterparts. This remained almost constant in the data gathered in the past forty years. The temperature difference show indeed urban Metro Manila is slightly hotter than the rural areas in its periphery. Thus an urban heat island of Metro Manila has been discovered.

Figure 8 - Metro Manila blanketed by smog (Source: klima.com.ph)

It was also noticed that the Port Area post recorded a slightly higher temperature compared to the Science Garden post. This can be attributed to the highly paved area with little vegetation wherein the Port Area post lies as compared to the other post located in Quezon City.

Dr. Estoque and Dr. Sta Maria also "estimate that the city temperatures in the afternoon could be as much as ten degrees warmer than those of the neighboring rural areas."[v]

Solutions to UHI in Metro Manila

Mitigating measures and strategies to counter urban heat island would include the replacement of the most important element that urbanization has removed- VEGETATION.

Reintroduction of vegetation

The reintroduction of vegetation to urban areas will modify the exchange of solar radiation. There would also be increased water vapor by means of evapotranspiration. Toxic gas, fumes and dust can be filtered by vegetation and thus improve the quality of urban air. Lastly, added vegetation will help reduce water run-off. Some techniques and design solutions employing vegetation would include:

- Planting of trees and other forms of vegetation on roadways, parking areas and other paved areas since 90% of urban heat comes from these sources.

Figure 9 - Trees and other forms of vegetation on paved areas

Figure 10 - Malls treated with vegetation, Arizona, USA
(Source: Landscape Architecture, Moorhead)

The Philippines is known for its malls and shopping centers. Along with these structures are huge parking lots and paved areas. The introduction of vegetation in shopping centers and malls is becoming a trend. This not only satisfies buyers visually but also comforts them by reducing heat in and around the complexes. The reduction of heat around the malls will also result in less artificial cooling effort.

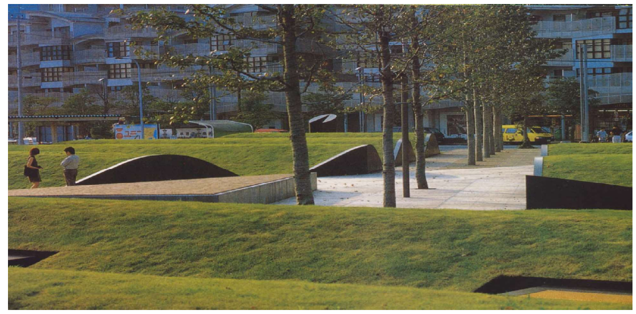

Figure 11 - Vegetation around building complexes
Source: Landscape Architecture, Moorhead

- This principle of vegetating malls and shopping centers can also be employed in other structures and complexes as well as in private homes. The presence of vegetation even though intermittent can greatly contribute to the lessening of impact of UHI.
- Designing and incorporating pocket parks in between buildings. The Makati Central Business district can be used as a model in the design of other highly built up areas such as the Ortigas Center, Araneta Center, and the emerging Global City in Fort Bonifacio, Taguig.

Figure 12 - Incorporating pocket parks in between buildings
(Source: Landscape Architecture, Moorhead)

Using Alternative Materials

The use of alternative materials that yield higher albedo or reflectivity are extremely encouraged to help in the overall reduction of urban heat. Some of the proposed design solutions are:

- Use of roofing materials with high reflectivity. If it is not possible due to some constraints, light colored roofing materials would be the best alternative. It is saddening to see temperate zone building materials being sold here in the tropics. Polycarbonate acrylic roofing is a classic example. Not only does it have low reflectivity. It also traps solar energy that results in localized heat build up.

Figure 13 - Grass pavers as an alternative to asphalt parking

- Use of porous paving materials such as concrete grass pavers and paving blocks which allow percolation of rain water into the soil.
- Employment of pavements that are high in albedo. Asphalt has a lower albedo compared to concrete but the latter is preferred due to its lower cost. Experimental paving materials that incorporates beads to open up asphalt porosity or lessen aggregate density are being tested on US roads. Also experimental asphalt paint and admixtures to change the usual gray or black color are also being tested for their efficiency in reflecting and reducing heat.
- The use of materials that are not easily thermally charged are also encouraged. Natural stones with low to medium porosity are suggested. Granite wall claddings, composite or not, are readily thermally charged and heat dispersion compared to other natural stones is poor.
- The employment of Green Architecture. Newer building materials and technology are being applied to help in the reduction of heat or thermal energy gained in structures. Moreover, these thermal energy gained by these building materials are translated into another form of energy – electricity, that is stored and later used. Example would be the use of photovoltaic cells in roof tops or glass walls that capture solar radiation rather than reflecting it then transforming it into electro-mechanical energy.

Legislation and Community Efforts

The mandatory imposition of the required 30% open space according to the building code should be followed. However in general the 30% open space being discussed in the NBC includes roads and other open spaces. With these, such roads and other open spaces should be tree lined or vegetated to reduce the impact of UHI. In the US and other European countries, the role of the community takes the center stage in their UHI mitigation programs.

In high rise structures and buildings a rooftop garden or the like is highly recommended. Such development will greatly reduce heat gained by exposed roofdecks.

Figure 14 – Rooftop garden
(Source: ZinCo International 3/98 Brochure)

Figure 15 – Landscaped Wall
Source: ZinCo International 3/98 Brochure

Conclusion

The study of urban heat island phenomenon has been taken seriously not only those in temperate zones but also in some tropical countries. The general notion that the tropics are generally hotter and that the need for UHI study is not needed should be repudiated. Urban areas such as Metro Manila are generally hotter than its surrounding rural areas. With urban areas growing at a very fast rate urban heat island study should be taken forthwith.

The very purpose is to mitigate or eliminate the undesirable climatic modifications that urbanization brings about. This is to prevent the "heat islands" from devouring the fertile rural edges of the metropolis. Models of UHI mitigating programs being undertaken by different countries can be studied and custom fitted to suit our own local conditions.

Mitigating or eliminating UHI effects benefits the urban metropolis. Energy savings of 10%-18% from artificial cooling can be achieved if proper mitigating programs are implemented. Air quality will be improved due to reduced amounts of emissions and reintroduction of vegetation. By achieving this, greenhouse gas reduction is consequently lowered. Health concerns addressed also by the reduced sicknesses related to heat stroke, heat exhaustion and respiratory illnesses.

There are many aspects and variables involved in mitigating urban heat island effect, hence the involvement of multi-disciplinary professionals as well as government and community efforts should be a coordinated effort. It is usually seen that diverse skills and talents often operates independently and sometimes in conflict with each other. Here the task of designers and urban planners would come into play, integrating and coordinating such individual works to come up with optimal design solutions and resolve conflicts.

Man created the Urban Heat Island effect; man must undo it in order to survive and achieve a more livable and energy efficient metropolis.

Endnotes

[i] The first instance of banning coal burning happened in 1200. This was again instituted by King Edward I in 1306 through a royal decree.

[ii] http://www.bestlife.com, Fabio Bertrand Elsa, Bio Architecture

[7] http://www.yosemite.epa.gov

[8] Ibid

[iii] http://cimss.ssec.wisc.edu/wxwise/heatisl.html

[iv] http://www.yosemite.epa.gov

[v] Climate Changes due to the Urbanization of Metro Manila.

References

http://www.bestlife.com

http://www.yosemite.epa.gov

http://cimss.ssec.wisc.edu/wxwise/heatisl

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