

Urban Spatial Development to Mitigate Urban Heat Island Effect in the Inner Area of Bangkok

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ABSTRACT

An urban heat island is one of the factors that cause a climate change to become more critical. Bangkok is one of the mega cities in the world in which urban areas have been affected by the urban heat island, especially the inner area of Bangkok and its CBD. The survey data from a satellite confirmed the hypothesis of the affected area in the inner zone of Bangkok. From the study it has been found that the urban heat island problem in the urban area of Bangkok was developed by the augmentation of its physical surroundings of all the man-made construction. The findings of the research show similar physical conditions and characteristics of the urban elements that caused the urban heat island in the area: the building masses, the building alignments, the street patterns, ground paving and its condition. It would be useful to find out if there are any suitable answers for the spatial development characteristics that would be possibly reduce or control the urban heat island problem in the inner area of Bangkok.

Keywords: *climate change, urban heat island, urban spatial characteristic, urban micro temperature, BKK inner area.*

THE CAUSES OF THE PROBLEM AND ITS IMPORTANCE

The urban heat island problem is currently growing in many large cities around the world, particularly in the metropolitan areas of Northern Europe, North America, Australia, South Africa and East Asia (WMO-UNEP¹). This urban heat island effect is one of the factors that cause a critical climate change. The urban heat island problem is becoming more severe as a result of growing populations

in cities. Increasing activities, energy usage, and the increasing congestion of buildings and construction lead to the rising temperatures in cities. The temperatures of the inner city areas and of rural areas where there is less construction were compared. It was found that the temperature varies about 1 to 2 degree Celsius during the day and 8 to 12 degree Celsius at night. The important factors causing this difference in temperatures that contribute to an urban heat islands are as follows:

¹ IPCC (Intergovernmental panel on climate change). (2007) IPCC WGII Fourth Assessment Report: Impacts, Adaptation, and Vulnerability. WMO-UNEP. 1329P.

Changes in the physical surroundings by the presence of a city

The presence of a city includes any construction covering natural surroundings, or landscapes, which affect and decrease the ability of the areas to release heat. The physical surrounding of a city is changed by the cumulative number of buildings and construction projects that decrease open or natural areas within the city. Since the buildings and construction have high properties of absorbing and restoring heat, they obstruct the effective process of natural water evaporation. The thermal property of the construction materials such as concrete is 2,000 times the heat capacity of the air at the same amount (H.-Y. Lee, 1993).² As a consequence, temperature balance in cities becomes unusual. As the heat is slowly released into the air, the higher temperature duration in the urban area is longer than that of the suburban or the countryside where fewer buildings and construction are found.

Human activities and energy usage in the city

The energy usage of a population in the city increases the urban heat island problem. Particularly, the use of fossil fuels in the forms of petroleum, gas, coal or fuel oil can generate greenhouse gases which are released back into the atmosphere. The greenhouse gases cause difficulty in thermal distribution and consistently increase the urban heat island effect. Other human activities that cause urban heat island problem include car transportation, fuels used in the industry, the activities occurring in big buildings or the density of the building placement.

From the causes of the urban heat island mentioned above, it was found that the widely acceptable solution is to increase the number of green areas by adding more public parks. The vegetation in public parks helps relieve the water evaporation problem and reduces the heat directly. Increasing the green areas or vegetation of rooftop gardens or on the

building walls is another popular way to help the urban heat island problem. However, although these solutions may relieve the urban heat island problem to some extent, they are less effective because of the following reasons. First, solving the problem by creating public parks is difficult because the inner city area is already fully developed and there are no available spaces. Also, the cost of land is very high; finding the large area to create a public park is very difficult. Second, maintenance costs for a park is very expensive involving pruning and care of plants, watering plants, adding fertilizers and pesticides, and controlling waste management (Spin A., 1984)³ If this is not well planned, the city will have to bear these enormous expenses.

THE BANGKOK INNER AREA

Bangkok is a city where the center area or the city core has a variety of functions; shopping malls, modern business districts, important historical areas, and traditional communities with crowded populations. It is one of the most densely populated cities in the world. These crowded areas are now facing environmental problems which severely affect their everyday life. One of the most critical of several urban issues includes the concern of the impact of climate change. Furthermore, the inner area of Bangkok is rapidly being developed by the property owners' desire or by the capital design trends in targeting this area to meet the need of a new generation's residences. Thus, constructing physical areas of the city and appropriately using these areas while facing environment problems is necessary. That is why it is very challenging to find the right solutions to city design and land use planning. The solution for urban heat island in Bangkok, especially the inner area, might be possible by intensively improving the city's physical surroundings. The proper answers to the urban spatial design can be used as a model to develop the future city design criteria. The design criteria may also be applied to solve the current urban heat island problem which is increasingly intense in the whole Bangkok metropolitan area.

² H.-Y. Lee. (1993). "An application of NOAA AVHRR thermal data to the study of urban heat islands". *Atmospheric Environment* 27B: 1–13.

³ Anne Whiston Spirn. (1984) *The Granite Garden: Urban Nature And Human Design*. [S.I.]: Basic Books.

THE RESEARCH QUESTION

What are the most appropriated solutions for urban spaces to reduce or solve the Urban Heat Island in the Bangkok Inner Area?

THE OBJECTIVE

This study is to find out the conditions of urban spaces that could help to reduce the Urban Heat Island in the Bangkok Inner Area.

THE HYPOTHESIS

The urban spatial characteristics of the Inner Area of Bangkok have elements which could be changed in the future to reduce or prevent the Urban Heat Island.

MATERIALS AND METHODS

The research methodology begins by using the surveyed data from the Meteorological Department on the impact of the urban heat islands on the surface of the earth by the remote sensing method from Landsat 5-TM Band 6 and Landsat T-8 TIRS, Band 10 Satellite of Geo-Informatics and Space Technology Development Agency (GISDA). It clearly shows images of the urban heat islands in Bangkok based on their locations and their urban form. Each zone in Bangkok has been differently affected. The overall spatial characteristics such as architectures, street patterns, open spaces, geography and climate of each area were studied to use as basic information for understanding its inner city area. The records of temperatures were also studied by using the data from the Meteorological Department. During the past four years the urban heat islands in Bangkok have been observed and analyzed. The temperatures at the macro level were collected at the study sites to observe the temperature changes and the situation of urban heat islands. Then conclusions were made based on the results of the temperature change in the study areas and then finding the correlation between the urban characteristics and the temperature changes.

THE URBAN HEAT ISLAND PHENOMENON IN THE CITY AREA

The urban heat island is a result of the differences temperature between the urban area and the rural or suburban areas. These differences have an influence on the city center which has a higher temperature than the rural areas. This high temperature of the city center area usually lasts significantly longer than the rural or suburban areas (Chart a).

Focusing on the physical characteristics of Bangkok's inner zone, it is shown that the area has denser sites of buildings and construction than the other areas of Bangkok. By observing the images from the satellites, it was found that the high density areas situated in the center are illustrated by a grey color. It is clearly shown that the high density area is continuously and widely expanded. Furthermore, it is found that the green areas are hardly seen. (Figure 1).

RESULTS OF THE SURVEYS' DATA COLLECTED FROM SATELLITES OF THE URBAN HEAT ISLAND IN BANGKOK

The data surveyed from Landsat-5 and 8 TM Band 6 and data from LANSAT-8 TIRS, Band 10 Satellite illustrate the bright value of the earth's surface which is measured by the reading scales that show a reflection of the infrared radiation on different surfaces. The surveyed data were used to evaluate the result by using the staining method which can be used to set the data from the survey and convert the data into a temperature (Celsius) unit. Since the results from this method shows the different temperatures on the image according to the spectrum from purple to red. The different spectrum colors can indicate the highest temperatures of the surveyed area and identify the locations of the highest temperatures.

After analyzing the data from the satellites and identifying the urban heat island's characteristics, it was found that it consistently occurs at the exact

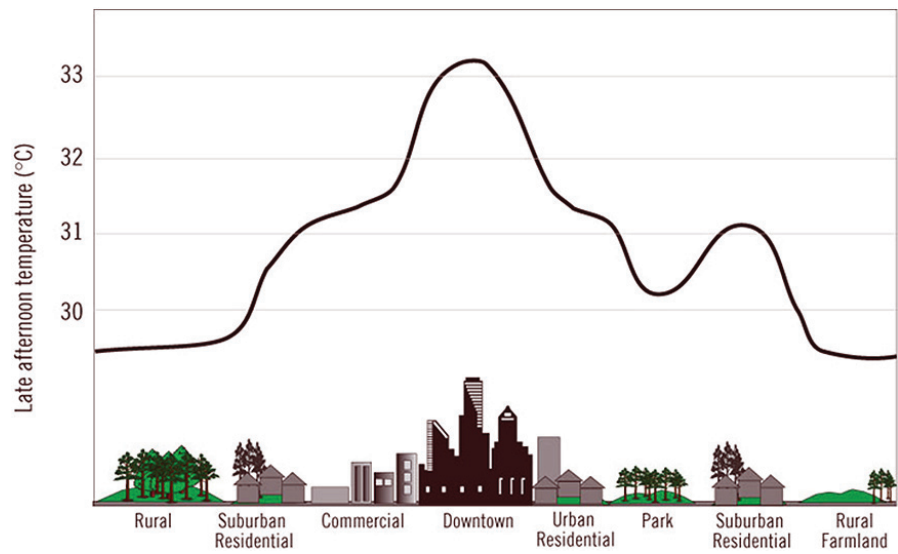
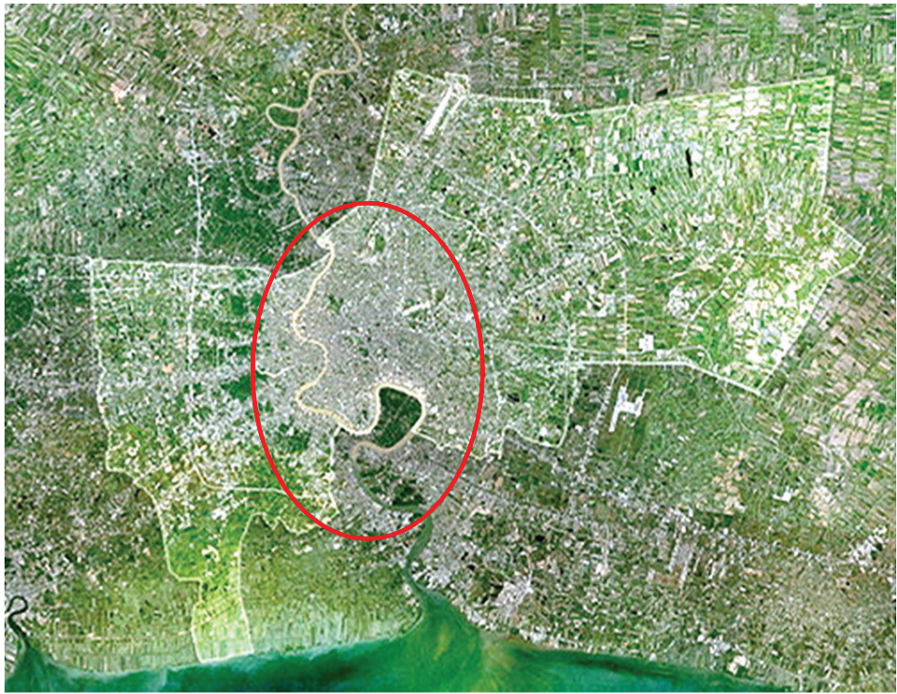


Chart 1:
The urban heat island in the city areas (Cuale, 2011)



 High Density Building Area

Figure 1:
The physical areas affected by the urban heat island in Bangkok
Resource: Geo-Informatics and Space Technology Development Agency (GISDA)

location and wide boundary of the city core area that has the most density of buildings and construction sites. It was also found that the temperature in that area during the night was around 29 degrees Celsius, which is two times higher than the Happiness Index or 4 degrees Celsius higher than the comfort condition of 25 Celsius.

Converting the color scale in order to analyze the urban heat island in Bangkok, the results show that the area that is most critically affected by the urban heat island is in the east coast of Bangkok. The affected area is two times bigger than the west coast. This finding is relevant to the fact that the Phra Na Khorn side or the east coast is more developed than the Thon Buri side or the west coast. Also, the urban heat island clearly occurs at the center area of the city which has more buildings and construction sites scattered around the Chao Phraya River.

Gathering the data from the satellite during three periods from all 22 districts of the inner city found that the average surface temperature in the area was rising from 28.64 degree Celsius in 1994 to 29.79 degree Celsius in 2003 and 31.20 degree Celsius in 2014. When the physical conditions of the areas were examined it is shown that the inner city area had notable increasing temperatures.

Apart from the data of the overall climate change in the inner area of Bangkok in 2014, it also shows that the inner city had an obviously high temperature. This reflects the impact of the urban heat island in Rama 3-Bangkorlaem district, Thon Buri-Chalearnnakorn district, Klongsan-Alley Nai Loy district, Issarapap-Alley No. 17 district, Dusit-Nakorn Chaisri district and Charan Sanit Wong-Thang Hua Seng district.

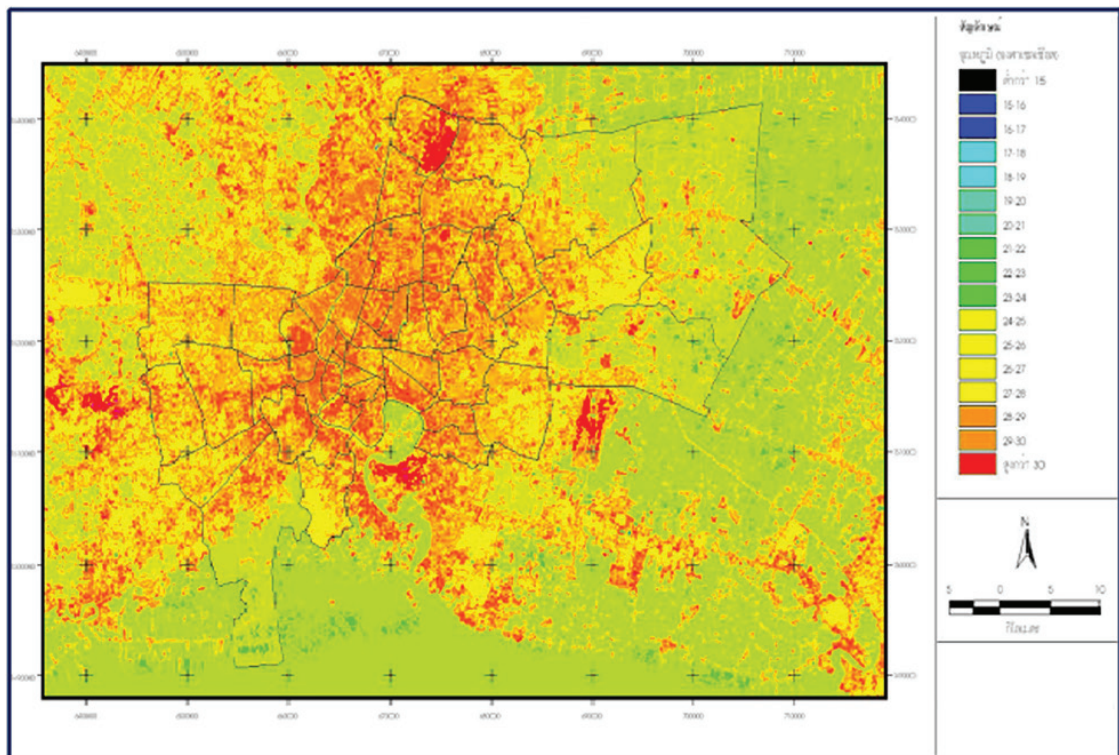


Figure 2:
The overall image of the temperature in Bangkok area by the remote sensing from Landsat 5-TM Band 6 Thermal infrared, Resource: The researcher

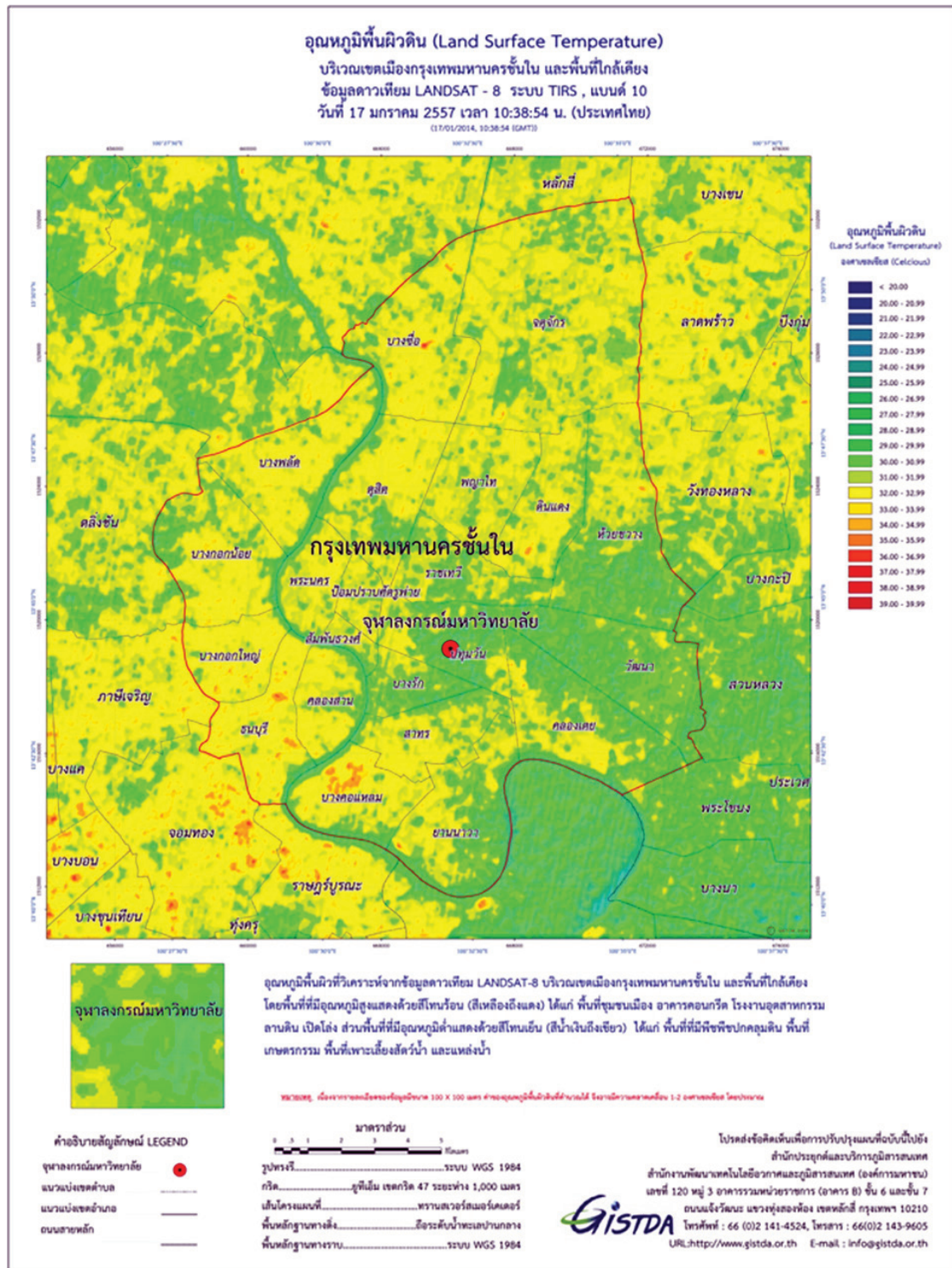


Figure 3:
 Land Surface Temperature in the inner city of Bangkok and the surrounding areas analyzed from Landsat-8 TIRS, band 10 recorded on 17 January 2014 at 10.39.

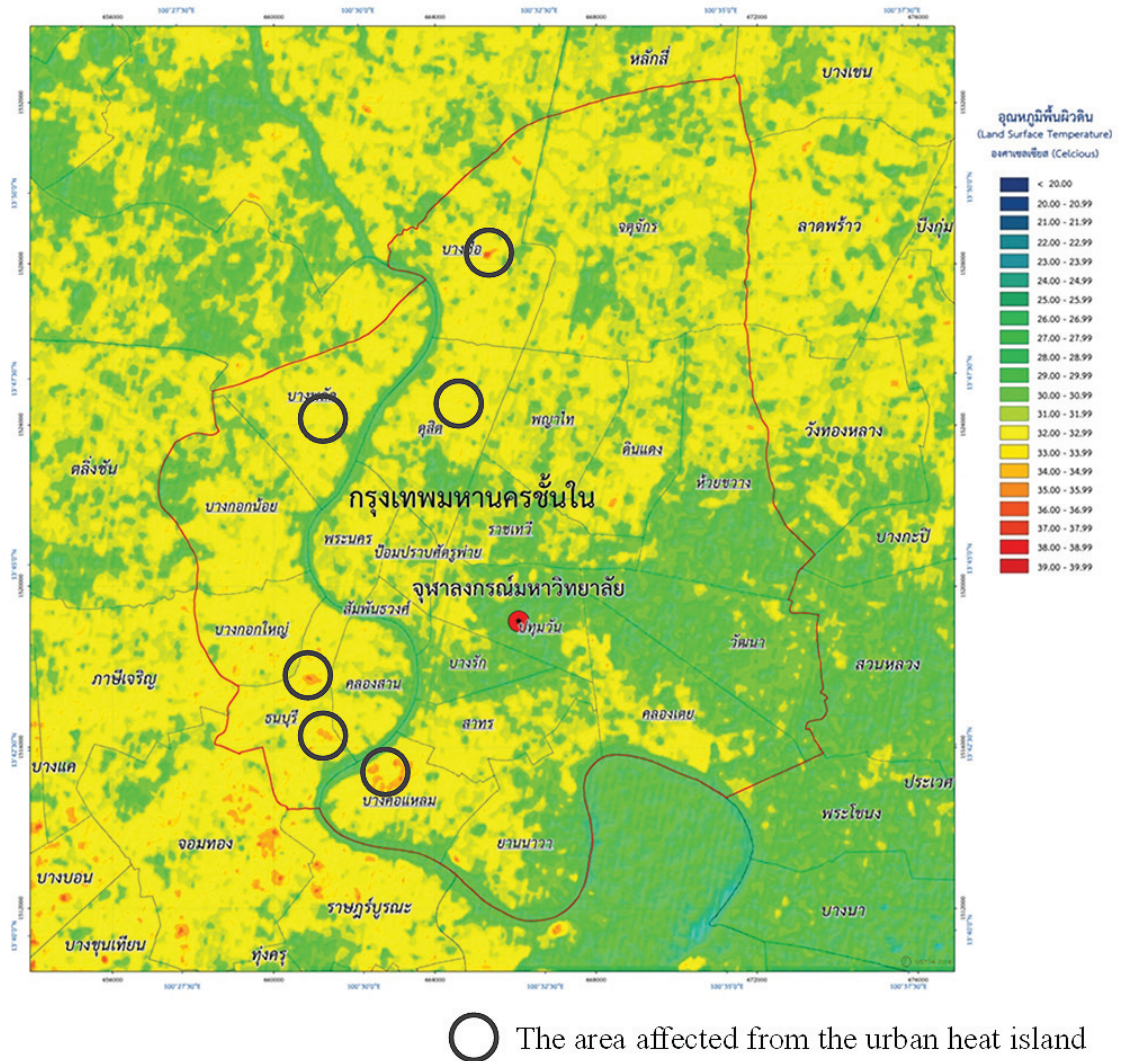


Figure 4:
Apart from the data of the overall climate change in the inner area of Bangkok in 2014

THE PHYSICAL CHARACTERISTICS OF THE URBAN HEAT ISLAND IN THE INNER AREA OF BANGKOK

The Bangkok inner area is an area of residential and commercial districts of small building types. Its urban pattern is a combined form which has various compositions starting with being a dispersed urban form to becoming a high density area.

The figure and ground pattern has a fine grain which is medium to low-rise buildings next to one another. Between each built up area is a disorganized building distribution pattern and varied spatial proportions. The buildings' footprints cover 40 to 70 percent of the land area. Most of the buildings in the area are concrete with galvanized iron roofs or tile roofs that are almost of the same height. Moreover, many residential buildings' roofs are adjacent to one another with the buildings' alignment parallel to the streets, which is common in Bangkok

It can be observed that in the six areas of study affected by the urban heat island there are few tall buildings situated inside and around the areas. The buildings in the areas receive solar radiation all day

and are not shaded by surrounding buildings. This differs from other areas in the city that have several tall buildings throughout their vicinity.



(a)



(b)



(c)



(d)



(e)



(f)

Figure 5:
The physical characteristics of the area affected from the urban heat island in the inner area of Bangkok. The Bangkorlaem area (a), The Chareon Na Korn area (b), The Klong San area (c), The Wong Sawang Road area (d), The Dusit area (e), The Charun Sanit Wong Road area (f).

Due to the urban spatial characteristics found in the six study areas, this study surveyed the areas and measured the ground temperatures at a micro-temperature level. The instruments were used to investigate the bulb temperature every five minutes in each of the studied areas after sunset during the entire winter season. The target areas, which are close to one another, were visited by vehicle each hour. The recorded data were used to compare a tendency of the decreased temperature in the first hour.

From the survey, it was found that the micro-temperature levels after sunset decreased very slowly and the same temperatures lasted for hours. When the temperatures of nearby districts were compared with the studied areas, it is shown that the micro-temperature level of the surrounding sectors in the same time frame dropped approximately 2.6-3.8 degree Celsius. Therefore, it could be concluded that the six studied areas are truly affected by an urban heat island.

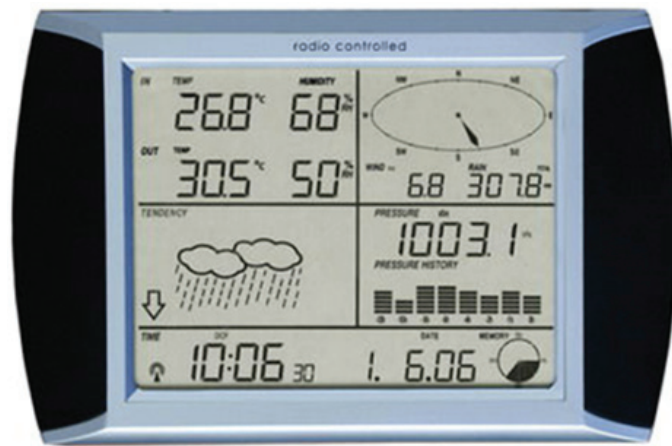


Figure 6:
The illustration of AW 002 Weather Station which has an ability to measure a temperature, humidity, wind speed and wind direction.

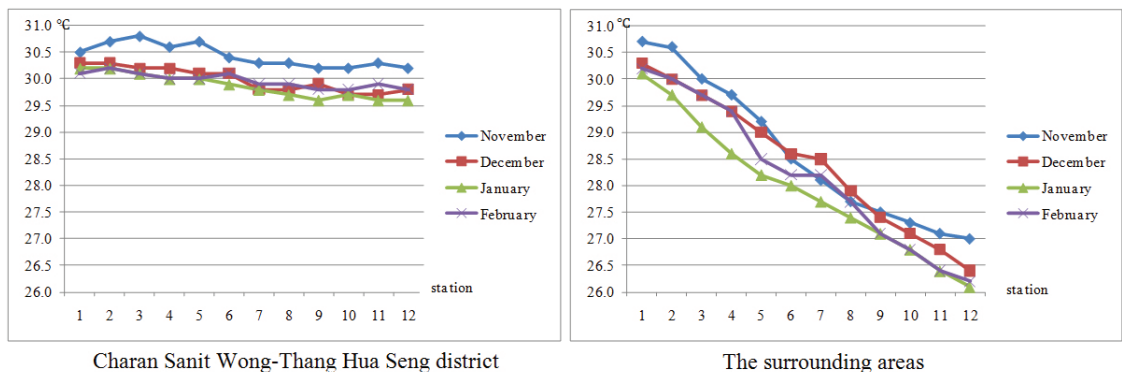


Chart 2:
The sample graph showing the changes of the temperatures in the surveyed areas in one hour at Charan Sanit Wong-Thang Hua Seng district comparing with the surrounding areas.

CONCLUSIONS AND SUGGESTIONS

By gathering data from the satellites and by surveying the six areas, it was found that the inner areas of Bangkok are truly affected by the urban heat island. The most affected areas are the areas where there are densely-populated communities with residential buildings or the densely-populated communities situated amongst the business districts. The Physical characteristics of these communities have similar conditions as follows:

1. The land plots are small in size and contain quite low buildings of one to four storeys. Situated in the residential communities, most of them are concrete buildings. There are also one storey houses whose roofs are adjacent. In the community areas, there are some medium height commercial buildings with 5-8 storeys amongst the houses. These characteristics make the buildings in these areas absorb heat from the sun evenly.

The areas that have the same height of the buildings are consistently heated and this easily leads to an accumulation of the volume of hot air. The release of hot air is also difficult because the patterns of building alignment are adjacent to one another. Both height and placement of buildings are factors that cause the hot air to circulate within the areas rather than being released into the sky.

This is different from areas with the several heights of the buildings with the smaller buildings being shaded by the taller ones. Thus heat masses change at different times at different positions.

2. Although building shapes vary but the buildings are evenly distributed, there are equal spaces around the buildings. This consistency of space allows the thermal mass to easily accumulate and to become a massive thermal volume.

In contrast, the areas having non-regimented spaces between the buildings allows the thermal mass to be released making it more difficult to accumulate and to become a massive thermal mass.

3. Many streets in the study area were found to be a dead-end and the streets are narrow, being between 4.00 to 6.00 meters. However the streets

do not create a consistent pattern, thus forming a non-regimented network of buildings that parallel the streets. Due to this chaotic street pattern characteristic, the wind flowing into these areas is impeded so the accumulated thermal mass cannot be distributed or dispersed.

4. There are few natural or 'green' pieces of land found in the areas studied. Due to the high density of use, paving in these areas makes it a hardscape. They were transformed into a flat landscape mortared by cement or asphalt. Because water evaporation from natural surfaces is a mechanism that greatly helps reduce temperatures, hardscaped areas impede water evaporation resulting in higher temperatures.

5. The big trees or trees in the area are very few. Hence, there is more shade from buildings rather than from trees. This indicates that there is a very little photosynthesis and transpiration of the trees to help reduce the temperature.

Analyzing the physical characteristics of the affected areas as a model to find the solutions can help to solve the urban heat island problem. Using the information mentioned above, suggestions to relieve this problem in Bangkok's inner areas are as follows:

1. Building and architectural constructions that have the same volume in an area should be avoided as it will cause the thermal heat released from the buildings to easily accumulate and to become a large thermal mass which is difficult to ventilate and flow out of the areas.

2. Tall buildings block the heat from the sun to the other buildings causing inconsistent solar heat radiation and exothermic process in urban areas. Therefore, the accumulation of the thermal mass in the areas is also reduced. This is the reason why there should be a new law indicating a clear control of the specific building heights in the inner area of Bangkok. Thus, if this environmental problem is solved some areas would be appreciably improved.

3. Street positioning and buildings' alignment can help air flow and ventilation. Thus, the design of the circulation network, including the control of the construction and placement of roads, would help the

city's air flow and ventilation. This control would also help to ventilate the air in the dense areas as well.

4. Moreover, the natural land control and maintenance in the city area is one of the main issues that should not be overlooked. Since natural soil helps absorb rainfall in the rainy season, evaporation from soil in the urban heat island condition also helps reduce the temperature in the city area.

5. Increasing the use of more vegetation and choosing proper construction materials, such as wood or light mass materials, will help to lower heat absorption better than using dense mass materials like bricks, cements and rocks. Choosing the right materials greatly help reduce a restoration of the heat during the day. This is similar to increasing vegetation to help reduce the heat through shade and photosynthesis. Some types of trees can be grown on buildings to reduce the sun's heat from inundating buildings

Solving the urban heat island problem is a very important issue to help the city's environment. In order to achieve this issue, the city has to face a new era of urban spatial aspects. The cooperation of all sectors focusing on the same target of environmental problems is needed. These are the keys to succeed in practically solving critical environmental problems and which can be adapted to fit with all cities around the world, especially in African and East Asian countries.

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