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FACTORS CONTRIBUTING TO URBAN HEAT ISLAND IN BANGKOK, THAILAND

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ABSTRACT

The study focuses on the characteristics of urban heat island (UHI) in Bangkok, Thailand. Hourly air temperature data from four weather stations -one in rural site and three in urban sites for the last five year are used to study the characteristics and intensities of UHI in Bangkok area. The results indicates the presence of urban heat island in Bangkok and it is increasing in terms of intensity. The study reveals the maximum intensity of around 6-7 °C is detected during dry season. The mean annual air temperature in Bangkok city is higher by 0.8 °C than outside the city. The weather conditions (wind, cloud, and precipitation), and different land cover types are the major factors governing the near surface urban heat island.

Keywords: urban heat island, urbanization, urban climate, energy consumption.

INTRODUCTION

Urban heat island (UHI) is defined as a phenomenon where temperatures of urban areas are higher than surrounding or rural areas (Oke, 1982). A measure to quantify urban heat island usually uses the term Urban Heat Island Intensity (UHII) (Kolokotroni, 2005), which is the maximum temperature difference between urban and rural air. Generally, the largest urban heat island effect, or maximum urban-rural area temperature difference occurs most at night, three to five hours after sunset, because the roads and other surfaces absorbing solar radiation in daytime release heat in night time. Thus, the rural areas cool off faster than urban areas at night. UHIs can provide both negative and positive impacts for cities. As cities grow, the urbanization causes less tree and vegetation displaced by buildings and roads, more skyscrapers and streets trap the wind path, and more heat is released from vehicles and air-conditioners. Besides, UHI increases human discomfort and air pollution concentration. Moreover, higher temperatures in urban heat island increase energy use especially for air-conditioning in buildings. This increases more air pollution and energy cost due to the use of more fuel. The UHI conditions increase the risk of climatic and biophysical hazards in the urban environments including heat stress and heighten acute and chronic exposure to air pollutants. Climate change, which is caused by increased anthropogenic emission of carbon dioxide and other greenhouse gases, is a long term effect with the potential to alter the intensity, temporal pattern, and spatial extent for the UHI in metropolitan regions (Cynthia *et al*, 2005). On the contrary, urban heat island may be beneficial for reducing heat loads as a result of reduced energy use for heating consumption reduces. However, this benefit does not count for developing countries (Arifwidodo, 2012). UHIs also have further impacts on global scale; it influences the long-term temperature record leading to difficulties to detect global climate changes.

The surface heat island refers to the relative warmth of surfaces. The surface temperature is easy to change, and thus it shows much greater difference in spatial variability and temporal variation between day and night than air temperature does. The main factors that cause the appearance of urban heat island include weather, geographic location, time of day and season, city form, and city functions (Voogt, 2004).

Weather: Calm and clear weather can lead to the largest magnitude of heat island. Increasing winds decrease heat island, and also increasing clouds at night.
Geographic location: The topography of the areas influences the weather such as wind. For instance, coastal urban cities come across with cooling temperatures in the summer due to the cooler sea surface temperatures. In warm humid climates, the wet surfaces can reduce the heat island magnitudes.

Time of day and season: In cities which are located in the mid latitudes have the strongest winter or summer seasons can lead to large magnitude of heat island in tropical cities.

City form: The materials in construction, the building dimensions and spacing, the green areas are all the example of city form. Some building materials can store a large amount of heat. The replacement of impervious or waterproofed surface lead to the higher heat island formation.

City functions: The urban pollutants come from energy use, and anthropogenic heat can generate heat island. For example, in densely building cities the high-energy use has a large influence to anthropogenic heating.

BANGKOK AND URBAN HEAT ISLAND

Development of Bangkok and Urban Heat Island

Bangkok is the capital city of Thailand located in the central part of the country. It is the center of industries, manufacture, economy, commerce, and construction. This draws a large amount of people from all over the country into the city, leading to the high growth of urbanization and industrialization. The population is about 10 million in daytime which is 16% of the total population of Thailand (the Bureau of Registration Department of Provincial Ministry of Interior, 2004). This rapid urbanization has led

ARPN Journal of Engineering and Applied Sciences

to several environmental problems such as air pollution, water pollution, land subsidence as well as the problems from the presence of urban heat island such as temperature rise, high energy consumption, and biophysical hazards etc. In 2012, the maximum temperature difference between urban and rural area of Bangkok was 7 °C, which higher than in the last 10 years.

Boonjawat et al (1998) initially showed the presence of heat island in Bangkok. The urban heat island intensity (UHII) between Chulalongkorn University (urban area) and Asian Institute Technology (rural area) was observed to be 3.5 °C during 6.00-7.00 a.m. This study also shows the substantial effect of sea breeze and solar radiation on UHI. Sea breeze decreases the air temperature in the southern part of Bangkok. Another study showed the effects of land cover on UHI in Bangkok. Komonveeraket (1998) conducted a study by using transformed vegetation index (TVI). The study showed inverse relationship among TVI, surface temperatures, and land applications. Green area had high TVI and low surface temperature, on the contrary the low TVI and high surface temperature corresponded to building area. This study also shows the substantial effect of sea breeze and solar radiation on UHI. Sea breeze decreases the air temperature in the southern part of Bangkok.

However, there are no further detail empirical evidences on the current status of UHIs effect to urban area in Bangkok, especially now that the city is in the process of implementing new master plan to guide its future development. Thus, to have a spatial distribution data and further update of magnitude of Bangkok heat island, more studies should be carried out to understand current UHIs characteristics and effects to urban area of Bangkok. Correspondingly, due to the appearance of urban heat island many problems arise, hence the impacts of urban heat island should be also taken into consideration. In case of Bangkok, the air conditioning load is considered to have the largest share (almost 60%) of electricity use (Arifwidodo, 2014). Therefore, it is important to assess the current status of UHI characteristics and its effects to urban area from the microclimate perspective.

Measuring Urban Heat Island

To identify urban heat island, the commonly used methods are the urban-rural weather stations, auto-traverse methods, computer modelling, and remote-sensing techniques (Henry et al, 1989). The urban-rural station is the simplest and most frequently used method which presents the air temperature below the urban canopy layer. Remote-sensing techniques offer high spatial resolution and easy repeatability (Henry et al, 1989), but the derived temperature may be different from the true surface temperature. The air temperature data are collected from The Meteorological Department in Bangkok (3 stations) and Pathumthani Province (1 station) to compare the urban-rural condition. Table-1 shows the type of station and data collected for the study.

Table-1. Weather station in the study.

Name of Station	Type of Station	Data Collected
Bangkok Metropolis	Urban	Hourly air temperature record from 2008-2012
Bangna	Urban	Hourly air temperature record from 2008-2012
Don Muang (airport)	Urban	Hourly air temperature record from 2008-2012
Pathumthani	Rural	Hourly air temperature record from 2008-2012

The air temperature from 2008-2012 from all four stations are collected to understand the temperature variation trend in Bangkok in 5 years moving average. These data are also used to understand the daily and annual course of UHI. Table-2 summarized the data and analysis done in the study.

Table 2. Type of Analysis and Data Source Used in the Study.

Analysis	Database Source	Finalized Data
Temperature trend	Monthly temperature records during 2008 -2012	Annual mean, maximum, and minimum during 2008-2012
Air temperature variation	Hourly air temperature record from 2008 to 20012 in April, August, December	Monthly mean air temperature data for April, August, December in 9 stations averaged for Bangkok city and Pathumthani station from 2008-2012
Daily variation of UHIs	Hourly air temperature record 5 from 2008 to 20012 in April, August, December	Monthly mean air temperature data for April, August, December averaged for the period 2008-20012
Urban heat island intensity	Hourly air temperature record 5 years from 2008 to 20012 in January, November, December	Mean monthly air temp differences in dry season during night time from 0.00-7.00a.m from 2008-2012 Maximum air temperature difference in dry season for each year from 2008 to 20012s
Maximum and minimum temperature	Hourly air temperature record 5 from 2008 to 20012 in April, August, December	Monthly maximum and minimum for April, August, December in from 2008 to 20012

Urbanization and UHI

Bangkok is the capital of Thailand situated in the central part of the country on the low-flat plain of the Chao Phraya River which extends to the Gulf of Thailand. Its latitude is 13° 45' north and longitude 100° 28' east. The elevation is about 2.31 m. MSL. The city is divided into 50 districts and 154 sub-districts. Total area of Bangkok is around 1568.737 square kilometers. Generally, the climate of Bangkok is tropical. The weather is warm

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and humid, and it is affected by monsoon season. The relative humidity is high throughout the year around 60 to 80 percent. There are three main seasons: Rainy (May-October), winter (November-January) and summer (February-April). The average wind velocity is 1.2 m/sec (4.3 km/hr). The average relative humidity is 73 % and the yearly average precipitation is 1,652 mm. The annual average ambient temperature is around 33-38 °C. The absolute minimum temperature is about 20° and the absolute maximum temperature is about 30 °C. The rainy season temperature is around 25-32 °C. The dry season temperature is around 20-25 °C and hot season temperature is around 40-42 °C.

The registered population in Bangkok increased from 1.6 million in 1958 to 5.4 million in 1986 and 5.6 million in 1999. The population of Bangkok is close to 5.78 million according to household registration in 2004. This is 10% of the total population of Thailand. The population density is 3,686 per square km with the increase of 0.98% per year (Arifwidodo and Chandrasiri, 2013).

The long-term annual air temperature record in Bangkok from 1980-2010 shows that the temperature had been cooler in cool season and warmer in hot season. For example, Bangkok Metropolis weather shows that the mean maximum and minimum annual air temperature from 1980-2012 was 33 °C and 24 °C respectively, and increasing linearly by 0.95 °C and 1.97 °C. One significant factor affecting this increase is probably the rapid urbanization in Bangkok. Using the data from the same weather station, the daily temperature from 2008-2012 is compared to Pathumthani weather station to understand the daily temperature variations between urban and non-urban area. The result shows that the temperature differences between each year are more obvious during winter. The temperature seems to be higher each year in the summer, and decrease during winter.

Table-3 shows temperature difference between urban and rural Bangkok. The result indicates that the daily variations of urban heat island in all different three seasons have similar trends. The UHI effect is high after sunset around 6-7 PM and begins to rise during the night time and reaches its maximum value at 2-4 °C depending on the seasons.

Table-3. Temperature difference between urban and rural Bangkok.

Time	Temperature difference between the hottest station in Bangkok and Pathumthani (averaged, 2008-2012)		
	Summer	Rainy	Winter
0.00-1.00	2.33	1.71	4.08
1.00-2.00	2.60	1.70	4.03
2.00-3.00	2.90	1.82	4.03
3.00-4.00	3.06	1.89	3.94
4.00-5.00	3.27	1.89	3.85
5.00-6.00	3.39	1.95	3.87
6.00-7.00	3.47	2.00	4.04
7.00-8.00	2.80	1.82	3.11
8.00-9.00	1.88	1.49	1.68
9.00-10.00	1.53	1.37	0.74
10.00-11.00	1.22	1.15	0.19
11.00-12.00	0.97	0.98	0.03
12.00-13.00	0.66	0.78	-0.16
13.00-14.00	0.38	0.48	-0.46
14.00-15.00	0.10	0.26	-0.60
15.0016.00	-0.09	0.13	-0.32
16.00-17.00	-0.34	0.06	0.39
17.00-18.00	-0.35	0.17	1.67
18.00-19.00	0.31	0.74	3.09
19.00-20.00	1.06	1.20	3.68
20.00-21.00	1.55	1.49	3.96
21.00-22.00	1.78	1.77	4.09
22.00-23.00	1.99	1.84	4.13
23.00-24.00	2.12	1.76	4.06

Precipitation and UHI

Figure-1 shows the effect of rainfall to UHI intensity in Bangkok. It is observed that the UHI intensity varies with precipitation. The increase of the precipitation which has the largest value in August at 230 mm causes a gradual decline of the UHI intensity to the lowest intensity of 2 °C. After that, as the rain decreases to minimum in December (0 mm), the magnitudes of heat island reach their maximum (5 °C) in December. Thus, the precipitation can be considered as one of the most significant factors governing UHI development, especially, in rainy season (from May to October). On the other hand, the UHI may create the precipitation in urban area. The rising warm air in urban area helps to create the clouds which results in more rainfall in urban area and area in downwind cities.

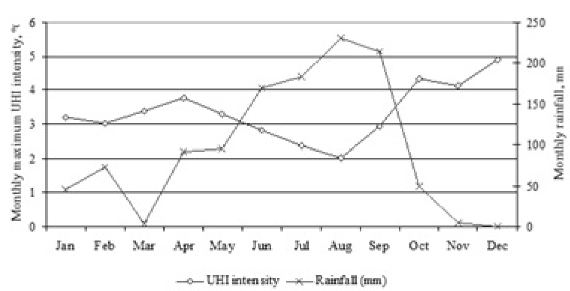

Figure-1. Monthly maximum UHI intensity between Bangkok Metropolis (urban) and Pathumthani (non-urban) station and monthly rainfall (mm) in 2012.

Population Density and UHI

In summer and in winter, 3 weather stations around the center is much warmer than its suburb (Pathumthani station). This is because they are located in the most densely build-up area which is surrounded by a number of buildings including hotels, hospitals, and government institutes while the Pathumthani station is situated away from the build-up area.

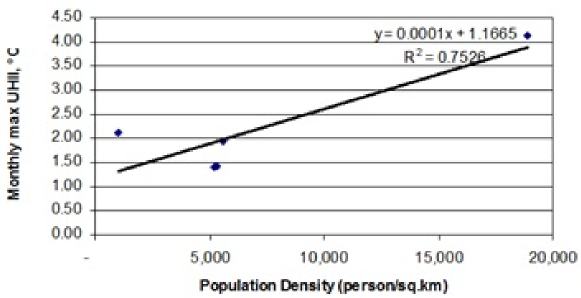

Figure-2. Relationship between population density and UHI variation.

To show the relationship between population density and UHI magnitude, the population density data in district of those stations are presented and plotted in Figure-2. The relationship between the population in city and the magnitude of heat island show the maximum urban heat island intensity in tropical hot and wet region is 4-9 °C when the population is around 1 million to 10 million. The total population in Bangkok according to household registration was 5.78 million about 10% of the total population in Thailand. However, this does not include those who commute and live in Bangkok without registration. These numbers are estimated at around 3.2 million (Department of City Planning, 2004). This makes the total population of Bangkok city to be almost 9 million. The Bangkok heat island magnitude should be approximately 6.5 °C.

Household Energy Consumption and UHI

A survey conducted by the National Statistical Office of Thailand (NSO, 2013) shows that the average energy expenditure is 2,084 THB or 10.9% of the total expenditure with the expenditure on electricity is 607 THB (29.1% of the total energy expenditure). The average electricity expenditure in Bangkok Metropolitan Area is 1,133 THB, higher than other region in the country. The number is slightly different with the result from the survey (854.35 THB for the electricity expenditure). 72% of households in the study has Air Conditioning (AC) equipment in their housing units. There is a positive correlation between income and the number of AC unit owned in the house (two-tailed *t-statistics*, $p < 0.0001$). This is because the higher the income, households tend to have bigger floor area in the house. The floor area of the house is also found to have a positive correlation with the frequency of AC use (two-tailed *t-statistics*, $p < 0.005$).

To understand the relationship between household energy consumption and UHI we measure a simple correlation between Cooling Degree Days (CDD) and the monthly energy consumption (in Thai Baht) from 400 household samples in Bangkok. As expected, there is a positive correlation between household energy consumption and CDD. Regressing monthly electricity consumption to generated CDD profiles resulting in high coefficients of R2 (adj.R2 = 0.840; S.E. = 1.216; F = 0.000017; p-value = 0.000017).

CONCLUSIONS

This study used hourly air temperature of Bangkok area (urban) and Pathumthani (non-urban) to estimate the urban heat island characteristics. The results from yearly data of air temperature shows the followings. During the last 30 year of air temperature observations (1980-2012), the mean, maximum, and minimum annual air temperature appear to have increased linearly by 1.74, 0.95, 1.97 °C respectively. This shows a slight increase in maximum temperatures and a significant increase in minimum temperature. The UHI severity in Bangkok is found to be higher compared to other major cities with UHI problems such as Shanghai, San Diego, and San Francisco, and is of similar range to Tokyo.

The UHI effect is most pronounced during the night time. It begins to rise after sunset and reaches its maximum at about sunrise during 6-7 am. It continues to decrease to the lowest magnitude or often become cool island phenomenon around 3-6 pm. This development of UHIs is observed in all seasons. For seasonal variation, the UHI effect is most intensive during the dry season, followed by hot and wet season. The highest intensity can be observed in December (mid of cool season) around 5 °C and in summer around 2-3 °C. Unlike in winter and summer, the UHI intensity between the night time (7 pm-7 am) and morning time (7-12 am) during rainy season are almost the same.

The study shows that many factors govern the UHI variations including city structures, population, and weather. Precipitation is found to be inversely proportional to the UHI magnitude. The area with the maximum UHI intensity is corresponds to the most densely build-up area with highest building and population density among other stations used in the study. The maximum intensity could range from 8-10 °C during the day time due to the surface materials such as road (concrete or asphalts), building walls, or paved surface warming faster than the surfaces in rural area, which normally are covered with green areas.

The study also examines the relationship between household energy consumption and UHI. The result shows that the higher the relationship is positive. It means that energy consumption is high in the area with high UHI variations and the other way around. This finding implies that if not UHI is not mitigated properly, Bangkok will experience a significant increase of household energy demand.

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