ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

Final Technical Report
CAF2016-RR12-CMY-Arifwidodo

Understanding Urban Heat Island Effect and Its Implications to Climate Change Adaptation Strategies in Major Southeast Asian Cities

The following collaborators worked on this project:

1. Sigit D. Arifwidodo, Department of Landscape Architecture, Kasetsart University, Bangkok, Thailand, sigit.d@ku.ac.th
2. Rizqi Abdulharis, Centre for Agrarian Researches, Institut Teknologi Bandung, Bandung, Indonesia, kiki.gis@gmail.com
3. Tetsu Kubota, Graduate School for International Development and Cooperation, Hiroshima University, Hiroshima, Japan, tetsu@hiroshima-u.ac.jp

Table of Contents

Project Overview

Project Duration	**:**	2 years
Funding Awarded	**:**	US$40,000 (Year 1); US$40,000 (Year 2)
Key organisations involved	**:**	Kasetsart University, Bangkok, Thailand – Dr. Sigit D. Arifwidodo Hiroshima University, Hiroshima, Japan – Dr. Tetsu Kubota Institut Teknologi Bandung, Bandung, Indonesia – Dr. Rizqi Abdulharis

Project Summary

The project is a regional research project aimed to understand the Urban Heat Island (UHI) effects to daily lives of urban residents and their implications to microclimate adaptation and mitigation strategies for planning policy in major Southeast Asian cities. Its purpose is to mainstream microclimate considerations in urban planning policy in Southeast Asian cities. The case studies selected for the project are Bangkok (population: 7 million) and Bandung, Indonesia (2.4 million). The proposed project will be divided into 3 parts. First, the project will assess the consequences of UHI to urban area in the selected cities through meso-scale urban climate modelling. Second part of the project will examine the existing UHI mitigation and adaptation measures and the perceptions and preferences of urban stakeholders on microclimate considerations in urban planning policy. The third part of the project will propose the alternative scenarios and appropriate adaptation and mitigation responses to reduce UHI intensity and improve urban sustainability. The project is relevant because it directly corresponds to a number of high priority focused area of interest activities under APN's climate adaptation framework as follows. First, the project deals with the downscaling datasets of climate modelling at the urban level, which corresponds to thematic area of interest no. 1 and no.7. Second, as the project aims to mainstream microclimate adaptation and mitigation strategies in urban planning policy, it relates to thematic area of interest no.4. Third, the project also intends to build capacity for urban policy makers to implement master plan that are in line with the UNFCC adaptation activities (thematic area of interest no.5 and no. 6).

Keywords: Urban Heat Island, Climate Change Adaptation, Health Effects, Meso-Climate Modelling, South-East Asian CIties

Project outputs and outcomes

Project Outputs:

- A comparison of UHI effect in three sectors: health, energy consumption, urban planning
- Finished urban stakeholders analysis on current climate adaptation measures
- Academes from Thailand and Indonesia contribute to the regional symposium on UHI, climate change adaptation and resilient city
- 2 working papers, 3 papers for international conferences, 1 paper for international journal

Key facts/figures

- Urban Heat Island in Bangkok is found to be high during the night and can make up 4.5^0 C difference.
- In Bandung, the average and maximum LST between 1995 and 2015 had risen from 18 to 22^0 C, as well as 24 to 37^0 C, respectively.

Potential for further work

One of the project limitations is the cross sectional nature of the data used in the analysis, which limits interpretation of impacts in the future. Although the study collect time-series data for the weather condition, the analysis conducted is mainly based on the cross sectional data. Hence, it would be interesting to see the further work based on the longitudinal data, which will improve the analysis especially the modeling part. Other potential for further study includes the application of the method to other cities in South-East Asia with similar socioeconomic and geographical condition. This type of study will improve the reliability of generalization of the result while enriching body of knowledge on the topic of urban heat island and urban climate resilience.

Publications

Arifwidodo, S.D. & Chandrasiri, O. (2015). Urban Heat Island and Household Energy Consumption in Bangkok, Thailand, *Energy Procedia*, 79 (2015), 189-1194

Arifwidodo, S.D. (2015). Factors Contributing to Urban Heat Island in Bangkok, Thailand, *ARPN Journal of Engineering and Applied Sciences 10 (15), 6435-6439*

Arifwidodo, S.D., and Chandrasiri, O. (2016). Urban Heat Island and Health Effects in Bangkok, Thailand. Proceeding of the *International Conference on Humanities and Technology, Melaka, Malaysia*

Arifwidodo, S.D., and Nilkamheang, N. 2018. Perceived Health Effects and Urban Heat Island in Bangkok, Thailand. *Proceeding of the 14th International Urbanization Conference, Bangkok, Thailand*

Awards and honours

-

Pull quote

"My involvement in the project has provided me a better capacity in understanding of the effects of urban heat island and the importance of designing for resilience, which I will continue to develop in my professional life after my graduation" – Nutkritta Nilkhamheang, former student assistant in the project, currently working at Shma Design Company in Bangkok, Thailand.

Acknowledgments

The project would like to acknowledge the Kasetsart University, Institute Teknologi Bandung, and Hiroshima University for their financial and in-kind contributions. The project would also acknowledge the International Health Policy Programme, Ministry of Public Health Thailand for their assistance in analyzing the health effects of urban heat island in Bangkok.

1. Introduction

1.1. Background

Urban heat island (UHI) is defined as a phenomenon where temperatures of urban areas are higher than surrounding or rural areas (Oke, 1982). An illustration of urban heat island profile and its relationship with land application is presented in Figure 1. The figure shows urban areas create more heat than rural areas because transportation, industrial and other human activities are higher in urban areas.

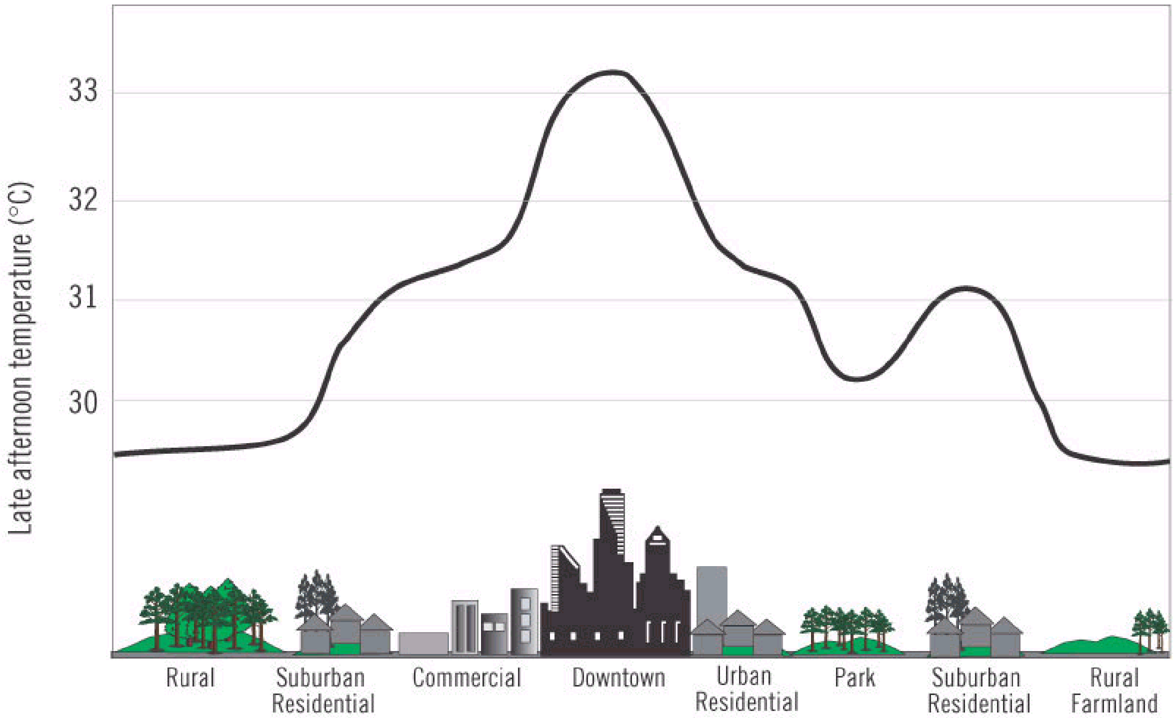


Figure 1. The urban heat island profile.
Source: http://adaptation.nrcan.gc.ca/perspective/health-03_e.asp

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 nighttime. Thus, the rural areas cool off faster than urban areas at night.

To identify urban heat island phenomenon, several methods are available, and the most commonly used methods are the urban-rural weather stations, auto-traverse methods, computer modeling, 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.

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. UHIs also have further impacts on global scale; it influences the long-term temperature record leading to difficulties to detect global climate changes.

Several factors cause the UHI include the size of city measured by population, thermal properties of materials increasing heat storage in the city, anthropogenic heat released from combustion of fuels and metabolism, greenhouse effect, canyon irradiative geometry reducing the albedo of the system, less evaporating surfaces, and reduction of heat transfer (Oke, 1973; Oke, 1991; Givoni, 1998; Santamouris, 2001). In summer, heat islands can have an enormous effect on air-conditioning load by increasing energy demand due to the higher temperature in urban areas caused by heat island. This can lead to power shortages and also raises the energy cost. UHIs, moreover, have direct effects on human health by creating heat stress and spreading the vector-bone diseases (Voogt, 2002). The UHI has significant impact on human comfort and health, urban air pollution, energy management, and urban planning. The urban heat island has a direct effect on air conditioning load. Many studies have been done to strengthen this effect especially in the United States and European cities. For example, a study in Los Angeles revealed that the electricity demand rises 2% for every degree Fahrenheit daily maximum temperature increase. Peak power demand also rises 3% for every 0.5 °F rises in daily maximum temperature. Consequently, it was estimated that 1-1.5 GW of power was used due to the UHI effect. This large amount of energy can be compared with around $100,000 per hour or $100 million of electricity costs per year (Akbari et al., 1992). However, the studies on the consequences of UHI in urban areas in Southeast Asian cities are scarce, especially on its impacts and implications to climate change adaptation policies. Therefore, it is necessary to conduct such studies in order to prepare appropriate adaptation and mitigation measures.

1.2. Description of the Project and Its Policy Relevance

The project is a regional research project aimed to understand the Urban Heat Island (UHI) effects to urban energy consumption and their implications to microclimate adaptation and mitigation strategies for planning policy in major Southeast Asian cities using Bangkok and Bandung as the case studies. It aims to mainstream microclimate considerations in urban planning policy in Southeast Asian cities. The study elaborates three main research questions. First question is concerned with the pattern and characteristics of Urban Heat Island (UHI) in Southeast Asian Cities. Second question explores the association between UHI and the current policy mitigation and adaptation. The third question is related to the effects of UHI to the daily lives of urban residents.

The project will be divided into 3 parts. First, the project will assess the consequences of UHI to urban energy consumption in the selected cities through meso-scale urban climate modelling. Second part of the project will examine the existing UHI mitigation and adaptation measures and the perceptions and preferences of urban stakeholders on microclimate considerations in urban planning policy. The third part of the project will propose the alternative scenarios and appropriate adaptation and mitigation responses to reduce UHI intensity and improve urban energy efficiency through workshop and capacity building program for policy makers.

In urban regions, 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 create an Urban Heat Island (UHI) phenomenon, which will then increase energy consumption especially for air-conditioning in buildings. In many cities, urban planning policy has broadened its aim to also to contribute to adapt and mitigate the effect of climate change. However, there has been lack of empirical evidences to support the microclimate considerations in urban planning policy.

Therefore, it is necessary to conduct a research project on how the Southeast Asian cities cope with the effects of UHI especially in relation with climate change adaptation strategies in urban area. The project will provide better input for local government to develop suitable mitigation adaptation measures for the future.

1.3. Summary of Proposed Activity and Its Relevance to Focus Activity

The project is a regional research project aimed to understand the Urban Heat Island (UHI) effects to urban energy consumption and their implications to microclimate adaptation and mitigation strategies for planning policy in major Southeast Asian cities. Its purpose is to mainstream microclimate considerations in urban planning policy in Southeast Asian cities. The case studies selected for the project are Bangkok (population: 7 million) and Bandung, Indonesia (2.4 million).

The proposed project will be divided into 3 parts. First, the project will assess the consequences of UHI to urban area in the selected cities through meso-scale urban climate modelling. Second part of the project will examine the existing UHI mitigation and adaptation measures and the perceptions and preferences of urban stakeholders on microclimate considerations in urban planning policy. The third part of the project will propose the alternative scenarios and appropriate adaptation and mitigation responses to reduce UHI intensity and improve urban sustainability through workshop and capacity building program for policy makers.

The project is relevant because it directly corresponds to a number of high priority focused area of interest activities under APN's climate adaptation framework as follows. First, the project deals with the downscaling datasets of climate modelling at the urban level, which corresponds to thematic area of interest no. 1 and no.7. Second, as the project aims to mainstream microclimate adaptation and mitigation strategies in urban planning policy, it relates to thematic area of interest no.4. Third, the project also intends to build capacity for urban policy makers to implement master plan that are in line with the UNFCC adaptation activities (thematic area of interest no.5 and no. 6).

2. Methodology

2.1 Operational Definition

The study uses constructs that can have different meanings. The conceptual definitions of these constructs are discussed in the previous chapter. However, in order to identify more specific conditions and how to measure them, they need operational definitions. The operational definitions chosen have to have an immediate impact on the course of the study, especially the findings. The study will use previous researches as a foundation to construct operational definitions. The operational definition of each construct and how to measure is explained as follows.

2.1.1 Urban Heat Island

Urban Heat Island in this project is defined as the yearly maximum temperature difference in the city (the single hottest day in 2013). To identify urban heat island, the most 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 a*l, 1989), but the derived temperature may be different from the true surface temperature. The project uses the WRF-ARM (Weather Research and Forecasting) developed by the US meteorological institute for urban climate simulations. Due to the limitation of computing resources, instead of simulating the whole year, the project will select a typical day as a representation of average climatic condition in both case studies, Bangkok and Bandung.

2.1.2 Health Effects of Urban Heat Island

Health effect in this project is measured as (a) heat stress and (b) health and well-being outcomes.

a. Measuring heat stress

   Heat stress is identified as the uncomfortable feeling when doing daily activities and measured using the following proxy questions: 'How often did the hot period of this year interfere with the following activities? Sleeping; Housework; daily travel; work; and exercise.

b. Measuring health and well-being outcomes

   Health in this project is defined following WHO as 'a complete state of physical, mental and social well-being and not merely the absence of diseases or infirmity'. We measure health and well-being outcomes using three health effect variables: (1) physical health effect; (2) mental health effect; (3) well-being. The variables of health effects and their proxy questions can be found in table 2.1.

Table 2.1 Variables Used to Measure Health Effect

Health Effect Variable	Proxy Question	Measurement
Physical Health Effect (standard Medical Outcomes Short From Instrument (SF8))	During past weeks, how much energy did you have?	5 level likert scale
Mental Health Effect (standard Medical Outcomes Short From Instrument (SF8))	During the past four weeks, how much have you been bothered by emotional problems?	5 level likert scale
Well-being	Thinking about your life and personal circumstances, how satisfied are you with your life as a whole?	10 level likert scale

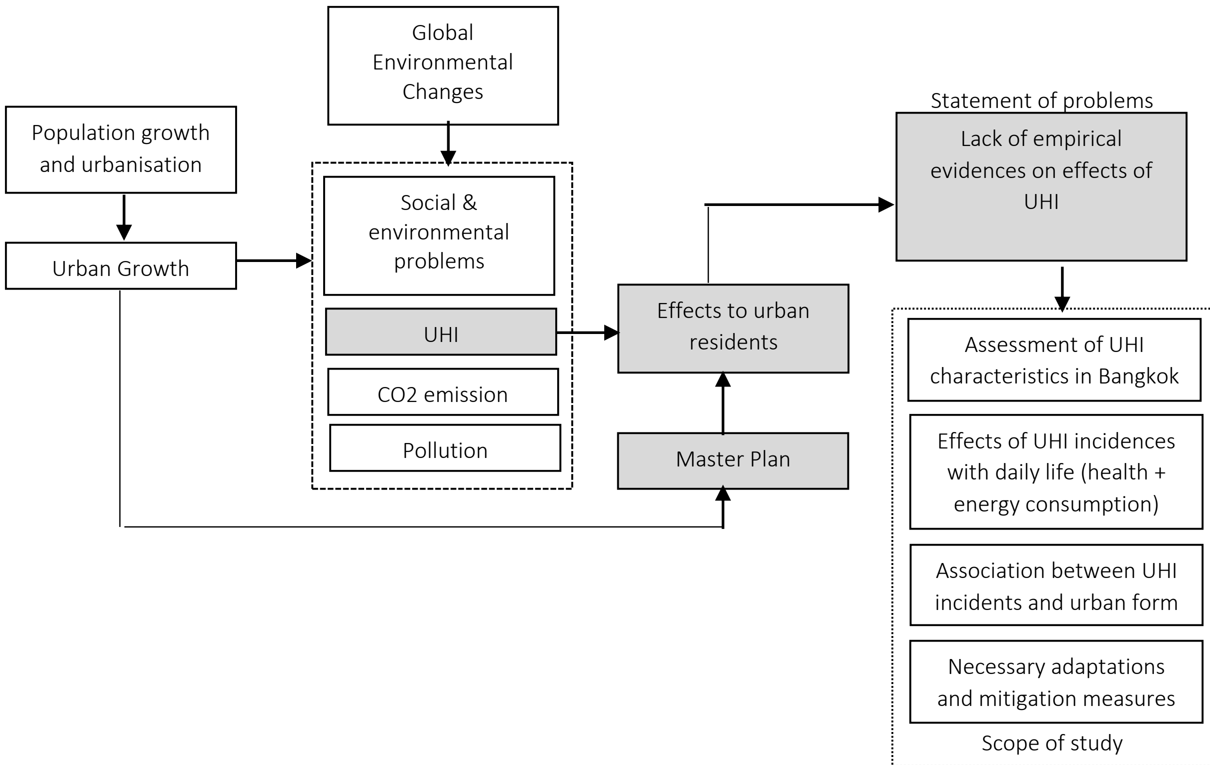
2.1.3 Household Energy Consumption

The study defines household energy consumption as the per-square meter of floor electricity consumption assuming that different types of house have the same amount of lighting, appliances and usage pattern. The benefit of the approach is that it is easier to give a simple and easy estimate of expected electricity consumption for different kind of housing types. However, the estimation will be very rough because in Bangkok, there are different typologies of housing that need to be considered.

2.2 Research Stage and Framework

As it focuses to investigate the intensity of UHI incidence and its effects to everyday lives, the study is divided into four parts. First, the study will examine the characteristics of UHI (daily and seasonal variations, magnitude and spatial pattern). Second, it will examine the direct effects of the urban development in the city and the magnitude of UHI including its effects to household energy consumption. Fourth, we will also examine the perceived health effects of UHI to everyday lives of urban residents. Lastly, we will examine the necessary adaptation measures at the city and household level. The research stages and framework are summarized in figure 2.1. Each stage of research requires different data and analysis. The following section explains the data collection and analysis used in the study.

Figure 2.1. Research Framework



2.3 Data Collection and Analysis

Data collection and analysis of this study use different method following the research objectives. In general, the study requires primary and secondary data. Secondary data were obtained by gathering previous studies about UHI and relevant climatic data. The study also obtains relevant urban planning documents including reports, master plan, and planning related regulations. Primary data were collected through interviews, field observation, and questionnaire. The study employed qualitative and quantitative data analysis. Qualitative analysis was used to produce descriptions, especially in determining the current mitigation efforts of UHI, and understanding the perception of urban planning practitioners and their characteristics. Quantitative analysis was used to deal with numbers and figure to produce justification about the phenomena found in the research and to produce description, especially the characteristic of UHI and its impacts to urban population. The similar method was also used to establish association between factors of UHI and determining the emerging patterns and trends of UHI in case study cities. The following section describes in detail how the data were collected and analyzed in the study.

2.3.1 Measuring Urban Heat Island

In measuring UHI, the study employs two methods which are commonly used: the urban-rural weather station (air temperature) method and land surface temperature method, depending on the available data. Table 2.2 summarizes the method used for measuring UHI in both case studies.

Table 2.2. Method used to measure UHI in Bandung and Bangkok

Case Study	**Method**	
	Air temperature	**Land surface temperature**
Bangkok	The hourly air temperature data for the weather stations are collected from The Meteorological Department in Bangkok (3 stations) and Pathumthani Province (1 station) to compare the urban-rural condition.	LANDSAT 5 and 8 data for Bangkok on the year of 1995, 2005, and 2015.
Bandung	We did not use the air temperature data for Bandung, since the city only have one weather station that collects hourly air temperature data, which makes the comparison between urban and rural air temperature is not possible.	LANDSAT 5 and 8 data for Bandung on the year of 1995, 2007, and 2015.

2.3.2. Measuring Association between Land Cover and Urban Heat Island

One of the activities in the study is to understand the direct relationship between urbanization, urban development and land use changes and their impacts on the increasing UHI magnitude. Hence, a proper method to measure the association between land cover and UHI is required.

Table 2.3. Method of measuring association between land cover and UHI

Case Study	**Method of Measuring Association**	
	LST and land cover	**WRF-ARW**
Bangkok	Chi-square correlation	Calculation condition based on WRF-ARW version 3.21. The 1 way nesting method is done for the model. The grid of 120 x 120 with the resolution of 3 km is used as the Domain-1 of the model and Domain-2 is determined using grid of 103 x103 with 11km resolution. It should be noted that the

		analysis is limited to Domain-2 only (Bangkok metropolitan region).
Bandung	Chi-square correlation	We did not calculate the WRF-ARW model on Bandung due to data unavailability.

In this study, measuring association is done in two parts. The first part is using the association between land surface temperature (LST) and the land cover. The second part is using the WRF-ARW model to establish the spatial pattern of UHI. We did not calculate the WRF-ARW model for Bandung due to data unavailability. Further detailed on the WRF-ARW model can be found in the discussion part on the Bangkok case study. Table 2.3 summarizes the type of association measurement.

This study uses the WRF-ARW model to establish the spatial pattern of UHI and its effect to future urban development in Bangkok. The model is divided into 2 parts. The first part is modeling the existing condition of UHI using the current weather data and land use. The second part includes the model to forecast the effect of UHI using the forecasting weather data and future land use based on the master plan.
In this study, WRF-ARW version 3.21 software is used. Calculation conditions are shown in table 2.4, and the calculated area is shown in figure 2.2.

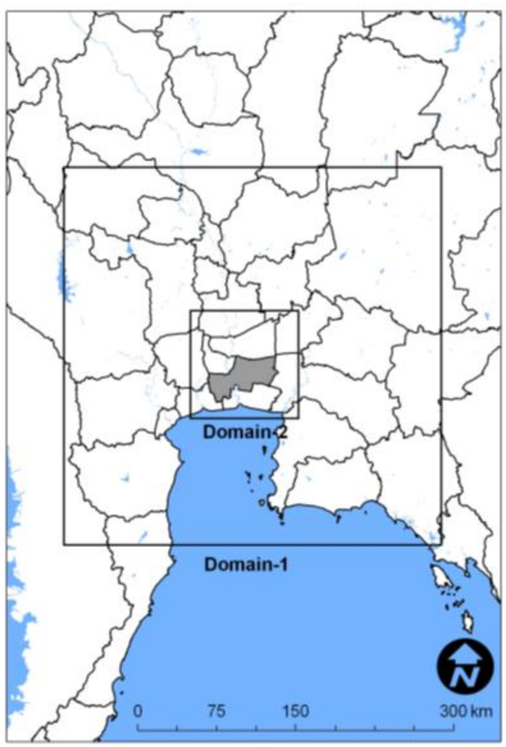


Figure 2.2 Domain of the WRF-ARW model

The one-way nesting method is done for the model. The grid of 120 x 120 with the resolution of 3 km is used as the Domain-1 of the model and Domain-2 is determined using grid of 103 x103 with 11km resolution. It should be noted that the analysis is limited to Domain-2 only (Bangkok metropolitan region). The land use data used for the calculation is shown in figure 2.3. The land use data is derived from the Landsat 5 TM satellite remote sensing data (spatial resolution 30m) acquired on 19 January 2014. The land use classification in the model is based on the USGS land use/ land cover classification.

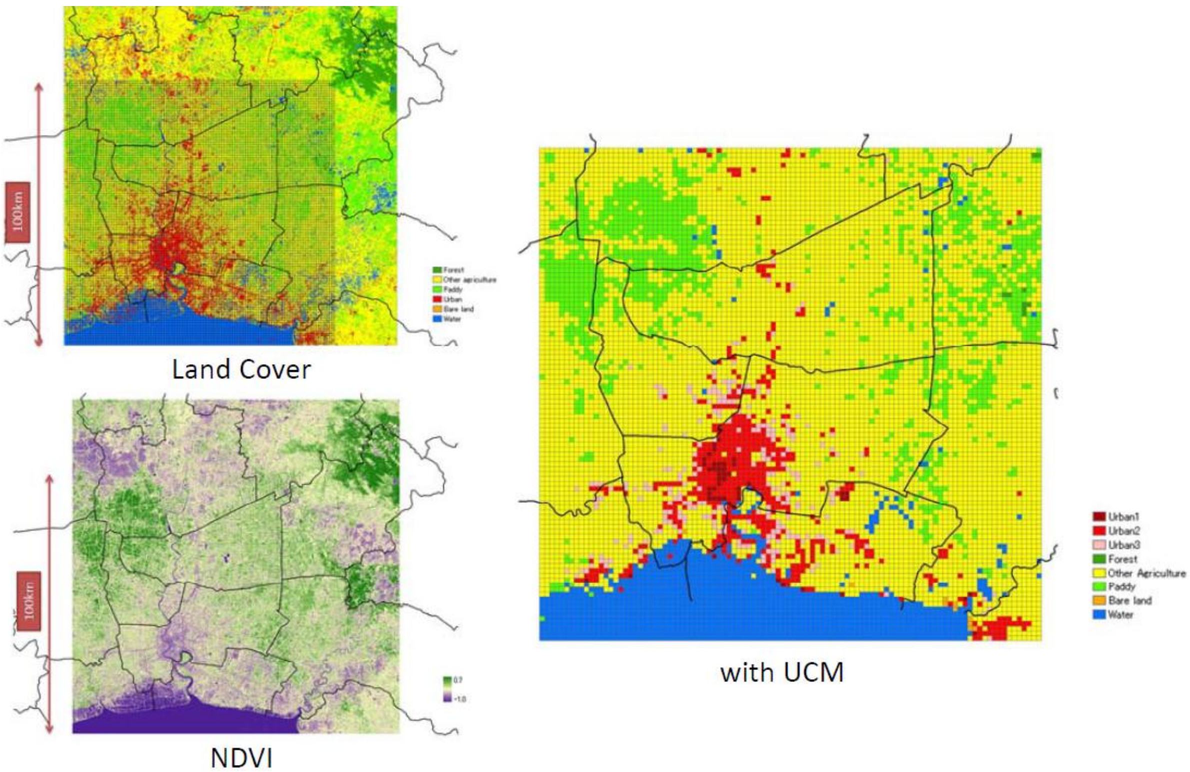


Figure 2.3. Land Use data used for the model.

Table 2.4. Calculation condition of WRF-ARW model

Calculation period		5 – 8 August 2012
Vertical grid		28 layers (surface ~ 100hPa)
Horizontal grid		Domain-1: 3km (120x120 grid), Domain-2: 1km (105x105 grid)
Meteorological data		NCEP global objective analysis (6-hour intervals, 1^0 grid, 17 layers)
Land Data	**Elevation data**	GTOPO30
	Land use data	LANDSAT 5 TM (acquired 19 January 2009)
Cloud Physics		Purdue Lin scheme

Radiation Process	**Long wave**	Rapid Radiative Transfer Model (RRTM) Long wave
	Short wave	MM5 (Dudhia) short wave
Atmospheric Boundary Layer		Mellor-Yamada-Janjic PBL
Land Surface Cover	**Urban**	Noah LSM
	Non-urban	Noah LSM
Cumulus Parameterization		None
4-dimensional Assimilation		None

In order to understand the impact of master plan of Bangkok to the UHI magnitude, the study conducts two different models. The first model is based on the existing condition of Bangkok, using the current land use based on the previous master plan. The second model is based on the new master plan of Bangkok 2556. The study compares the magnitude of UHI between the present and future scenario. The comparison method includes a map overlay and a CDD cross tabulation. To measure the direct and indirect effects of UHI magnitude, we use CDD from the present and future scenario as a proxy variable for a probit model with dependent variable of energy consumption or health outcomes.

2.3.3 Measuring Health Effect of Urban Heat Island

The study collects survey questionnaire of urban residents to understand the effect of UHI to their everyday lives. The questionnaire covers three subjects: the effect of UHI to health condition, household energy consumption, and the household adaptation measures for UHI. As mentioned in the previous section, the health effect is measured by well-being, physical and mental health related questions.

The urban resident in the project is defined as the residents of urban area of Bangkok or Bandung. It means the UHI assessment in the project is not limited to administrative boundaries and it will cover the whole urban area. In fact, the analysis considers the metropolitan region as a boundary for spatial analysis. However, in establishing policy recommendations we will focus our scope into urban level policy and how the city government can collaborate with other institutions beyond their administrative boundaries. We believe this approach will result in better and more executable UHI mitigation and adaptation strategies.

The main reason in determining sample size is the budget limitation. Using an advanced stratified random sampling and precise number of population; the project will require a very big number of samples. Therefore, we decide to use a simple random area sampling method with the confidence level 95%, confidence interval 5, and assumed that the number of population for urban area in Bangkok and Hanoi is very large or unknown using the following formula (Israel, 2003):

Where n = sample size

N = number of population

$$n = \frac{N}{1 + N(e)^2}$$

e = error

The minimum number of sample required for both case studies is 384. We decided to increase the number of sample into 500 to mitigate the error in data collection and the possibility of low return rate. The variable used in measuring health effects of UHI is summarized in table 2.4.

Table 2.4. Health related variables used in the study

Health	PHYSIC	Physical health effect of UHI in last 4 weeks / Energy during the past 4 weeks
	MENTAL	Mental effect of UHI; emotional problems last 4 weeks
	WELLBEING	Overall life satisfaction
	HEAT	Heat interference in daily life: sleeping; housework; daily travel; working; exercise

The data is the analyzed using descriptive statistics and logit/probit model for each health outcome (physical, mental and well-being). To assist the interpretation, a linear regression OLS model is also used. Individuals with missing data are excluded.

2.3.4 Measuring Association between Urban Heat Island and Household Energy Consumption

Cooling Degree Days (CDD) index is used to establish the correlation between UHI and energy consumption. The study also uses Cooling Degree Days (CDD) to investigate the effect of higher temperature on cooling energy consumption in Bangkok and Bandung. The CDD profiles were derived from weather stations, in addition to providing an energy audit database, are used in the OLS regression to examine the sensitivity of electricity consumption. These data are also used to understand the daily and annual course of UHI, as mentioned in section 2.3.1.

CDD is calculated from the following equation:

$$CDD,i,d = \sum_{m-1}^{24} \frac{(Tm-Tb)(Tm-Tb)>0}{24} \qquad (1)$$

Where CDDi is the cooling degree days for particular day (d), Tb is the base temperature 24°C and Tm is the mean air temperature, considering only the positive values.

Using the same survey in 2.3.3, we can also estimate the household energy consumption. The variables used in the study are summarized in table 2.5.

Table 2.5. Variables used in analyzing space cooling energy consumption

Category	Variable	Description
Climate	CDD18	Cooling degree days using 18° as the base temperature
Building	TOTAREA	Total floor area of the house in sq.m

	HOUSETYPE	Type of housing unit, with 1 = detached house; 2 = row house/town house; 3 = shop house
Energy consumption	ELECTAPP	Type of electricity appliances owned in the house using a category: AC unit; fan; microwave; TV; refrigerator; PC/laptop; others
	AC	Number of Air conditioner unit own
	TYPEAC	Type of AC unit with 1 = split unit; 2 = central unit
	USEAC	Frequency of using AC unit during last month, with 1 = not using at all; 2 = only few days or night; 3 = almost every day or night; 4 = always turn on every day and night
	ENRGYSAVE	Energy saving products owned in the house: electrical saving label products; LED light bulbs; EER refrigerator; LED/LCD TV; EER AC unit; others
Household	HHMEMBER	No. of household member
	INCOME	Average monthly income
	AVAGE	Average age of household
	EDUCATION	education of the head of household
	STAY	Length of stay in the household
	TENURE	Housing tenure of the respondents with 1 = own; 2 =
Energy	ENERGY	Total energy consumption (electricity bill) in the last month
	COOLING	Total energy consumption for cooling
Health	PHYSIC	Physical health effect of UHI in last 4 weeks / Energy during the past 4 weeks
	MENTAL	Mental effect of UHI; emotional problems last 4 weeks
	WELLBEING	Overall life satisfaction
	HEAT	Heat interference in daily life: sleeping; housework; daily travel; working; exercise

The data is analyzed with descriptive statistics and OLS linear regression to understand the effect of UHI (measured with CDD) to the monthly electricity consumption for cooling (measured with total energy consumption for cooling and per square meter cooling energy consumption) after controlling socioeconomic variables.

3.4. Limitation of Method

The study uses cross-sectional data which limits the interpretation of impacts in the future. Although we collect time-series data for the weather condition, the analysis conducted in this study is mainly based on the cross-sectional data. The followings are recognized as method limitation in the study.

1. The number of sample. The number of sample in this study is limited to 400 respondents for each case studies. For example, Bangkok has the population of more than 6.3 million. Using a proper stratified random sampling, it will require more than 10,000 samples, which is not feasible for the budget of the study.

2. The number of days modeled in WRF-ARW. The study only models one day representing the typical day for each scenario. Ideally it will require a whole year model or a seasonal model to observe the changes of weather pattern for each scenario. However, due to the limitation of modeling equipment, we are only able to estimate the one day weather model for each present and future condition scenario.
3. Data unavailability. The survey questionnaire is unable to collect many necessary data to establish robust estimate and reliable generalization. For example, we could not collect the monthly electricity bill for a whole year. The data is important to understand the complete relationship been weather condition and household energy consumption. To overcome such drawback, the study collects the monthly electricity bill during April, the hottest month in Thailand. The data then is compared to the monthly national average in the whole year to understand the increase in the electricity bill.

3.5. Description of Selected Case Study Areas

The project selected two case study areas: Bangkok, Thailand and Bandung, Indonesia because these cities represents two completely different geographical conditions of rapid-growing city in Southeast Asia. Bangkok is a coastal city with maximum elevation of 4 m above sea level, while Bandung is a mountainous city with elevation of 768 m above sea level and surrounded by up to 2,400 m high late tertiary and quaternary volcanic terrain. The difference in geographical condition makes the cities experience different UHI effect. Using two case studies it is expected that the result can be generalized and the method used in the project can be applied to other Southeast Asian cities with similar characteristics.

3.5.1. Bangkok, Thailand

The climate of Thailand is under the influence of monsoon winds of seasonal character i.e. southwest monsoon and northeast monsoon. The southwest monsoon which starts in May brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially the windward side of the mountains. Rainfall during this period is not only caused by the southwest monsoon but also by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones which produce a large amount of rainfall. May is the period of first arrival of the ITCZ to the Southern Part. It moves northwards rapidly and lies across southern China around June to early July that is the reason of dry spell over upper Thailand. The ITCZ then moves southerly direction to lie over the Northern and Northeastern Parts of Thailand in August and later over the Central and Southern Part in September and October, respectively. The northeast monsoon which starts in October brings the cold and dry air from the anticyclone in China mainland over major parts of Thailand, especially the Northern and Northeastern Parts which is higher latitude areas. In the Southern Part, this monsoon causes mild weather and abundant rain along the eastern coast of the part. The onset of monsoons varies to some extent. Southwest monsoon usually starts in mid-May and ends in mid-October while northeast monsoon normally starts in mid-October and ends in mid-February. From the meteorological point of view, the climate of Thailand can be divided into three seasons as follows.

- Rainy or southwest monsoon season (mid-May to mid-October). The southwest monsoon prevails over Thailand and abundant rain occurs over the country. The wettest period of the year is August to September. The exception is found in the Southern Thailand East Coast where abundant rain remains until the end of the year that is the beginning period of the northeast monsoon and November is the wettest month.
- Winter or northeast monsoon season (mid-October to mid-February). This is the mild period of the year with quite cold in December and January in upper Thailand but there is a great amount of rainfall in Southern Thailand East Coast, especially during October to November.
- Summer or pre-monsoon season, mid-February to mid-May. This is the transitional period from the northeast to southwest monsoons. The weather becomes warmer, especially in upper Thailand. April is the hottest month.

3.5.2. Bandung, Indonesia

The empirical part of the study is conducted in Bandung Bandung, Indonesia, which is a mountainous city with elevation of 768 m above sea level and surrounded by up to 2,400 m high late tertiary and quaternary volcanic terrain. The city is divided into 26 kecamatan (sub-district) and 136 kelurahan (village). The city is located in Western Java Province, Indonesia. According to socioeconomic census in 2007, the total population of Bandung is 2,296,548 with population density around 138 persons per hectare (Bandung CSA, 2008). Presently, Bandung is one of the biggest growth centers in Indonesia with mixed land use and a concentric urban structure. Being one of the national and regional centers of economic, social, political and administrative activities, Bandung has been experiencing dramatic changes in its landscape. Many critical urban issues relating to urbanization such as urban infrastructure and basic service provision, decent housing and settlements, land for housing, are the few things that urban planning in the city needs to tackle. That is why in 1990s, the city implemented planning policies directed to strengthen the city center, focusing the inner development of the city.

In general, climate in Bandung is tropical with significant rainfall throughout the year with short dry season. The average annual temperature is 26.8^{0}C and the annual rainfall is 2120 mm. The warmest month is October with average temperature of 27.9^{0}C, while the coldest month is July with the average temperature of 25.7^{0}C, which represent the lowest temperature in the whole year.

3. Results & Discussion

3.1. Bangkok, Thailand

The following section describes the result of the study in Bangkok, Thailand. Bangkok is the capital city of Thailand located in the central part of the country. Bangkok is 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. 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 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.

3.1.1. Urban Heat Island Characteristics in Bangkok, Thailand

To analyze the characteristics of UHI in Bangkok, we compare the urban and non-urban weather stations. We also investigate factors contributing to the UHI characteristics such as the relationship between UHI and precipitation, land use, population density, and other factors acknowledged in the literature. The following sections explains the characteristics of UHI in Bangkok.

Generally, the climate of Bangkok is tropical. The weather is warm 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. In 2012, the maximum temperature difference between urban and rural area of Bangkok was 7°C, which higher than in the last 10 years.

The temperature trend in Bangkok during 1951 – 2012 shows a significant increase. It can be noted that during the past decades Bangkok is cooler during the cool or winter seasons and warmer in hot or summer seasons. Figure 3.1 shows the annual mean maximum temperature in Bangkok during 1951 – 2012. In 2013, Bangkok recorded a new record of maximum temperature of 40.1o compared to 39.8^{o} in 2012. The same also can be said to the minimum temperature, and average temperature in Bangkok.

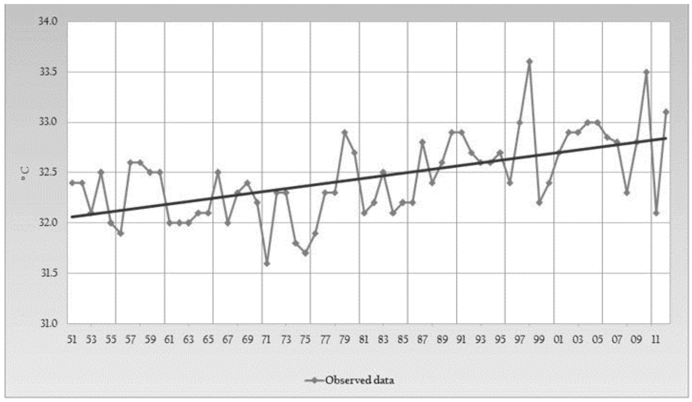


Figure 3.1. Annual Mean Maximum Temperature from 1951 – 2012 in Bangkok
(Source: Thai Meteorological Department, 2014)

The data from Heat Island Group present the increases in urban temperature in many cities as shown in Figure 3.2. The figure shows that the temperatures in cities all over the world have been warming up from 0.1-0.4 °C during 1990-2000. For Bangkok city, the rate was around 0.32°C per decade which was similar to the growth rate in Tokyo city. However, many other cities observed much lower rate such as Shanghai, San Diego, and San Francisco as well as in New Jersey. The warming rates in two cities, Newark and Camden are around 0.1°C and 0.2°C per decade, respectively (Cynthia et al, 2005). Thus, it can be implied that there is a significant difference of temperature rising rate in a period of 1951 to 2012 for Bangkok heat island. These differences among cities may vary from location due to several factors such as climate, topography, urbanization pattern in each area.

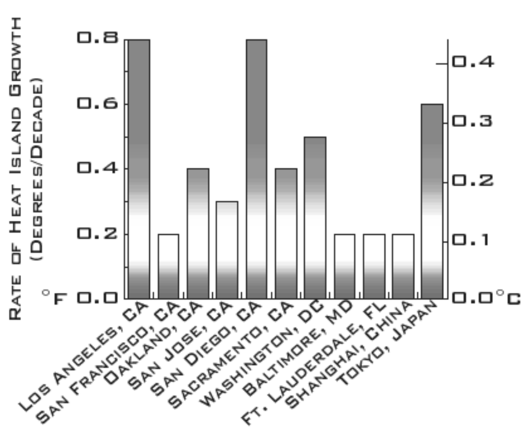


Figure 3.2: The rate of heat island growth in many cities per decade.
(Source:http://eetd.lbl.gov/HeatIsland/)

a. Urban and non-Urban Air Temperature Difference in Bangkok

To analyze the air temperature difference in urban and non-urban area, 5 years temperature records from Bangkok Metropolis weather station and Pathumthani Agromet station are compared. The long-term annual air temperature record in Bangkok from 1980-2012 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.

Using the data from the same weather station, the daily temperature from 2008-2015 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 3.1. Daily temperature difference between urban and rural Bangkok

Time	Temperature difference between the hottest station in Bangkok and Pathumthani (averaged, 2008-2015)		
	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

Table 4.1 shows the daily 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.

b. ***Daily and Seasonal Variations of UHI in Bangkok***

The variation of UHI is analyzed using two methods: daily and seasonal variation. The daily variation explains the daily temperature differences in any typical days in different seasons, while seasonal variation explains the monthly temperature differences in any typical seasons in a whole year. The following section describe daily and seasonal variation of UHI.

Daily Variation of UHI

To understand the daily variations of UHI, the air temperature from three weather stations in three different seasons in Bangkok are used. The result then is compared with the data from Pathumthani station. Figure 3.3 to 3.4 show the result. In summer (figure 3.1), the high degree of temperature difference between Bangkok and Pathumthani occurs during night time to 08.00 with the maximum temperature difference of 3.5 °C. Then, temperature difference decreases gradually and there is no difference during 12.00 to 14.00. After sunset, the temperature differences begin to rise again. The similar pattern happens to other weather stations. One interesting finding is that the temperature in Bangna station is found to be lower compared to other station in Bangkok and Pathumthani. This is probably because the number of green space in Bangna is higher than in other area in Bangkok and Pathumthani.

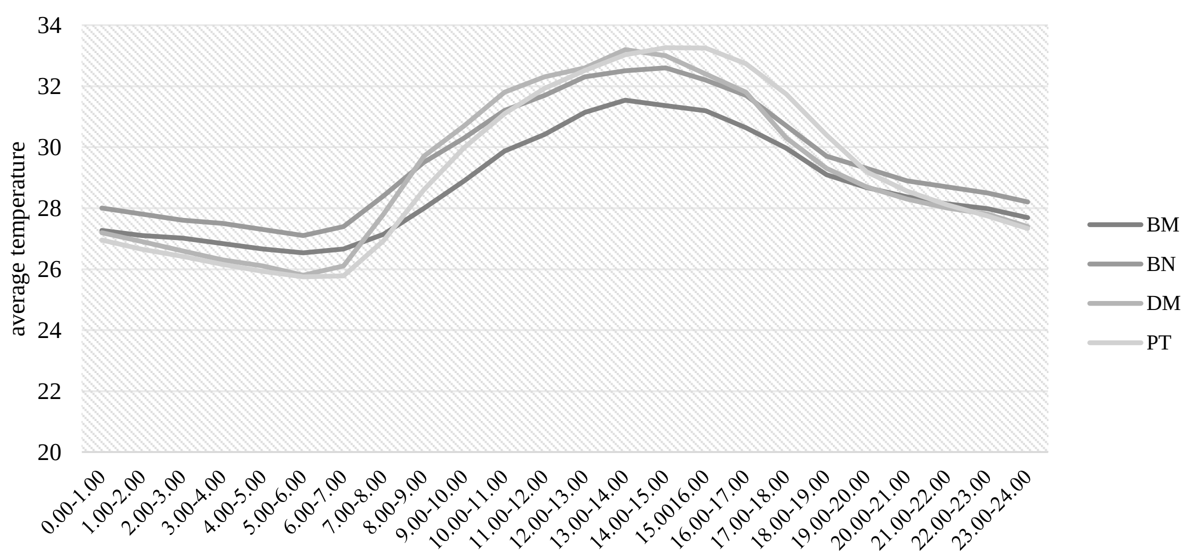


Figure 3.3. Mean air temperature in summer season (April 2015)

Figure 3.4 summarizes the temperature difference in rainy season. It shows the similar trend as in summer, but the maximum temperature differences between urban and rural station is 2 °C during 06.00 – 07.00.

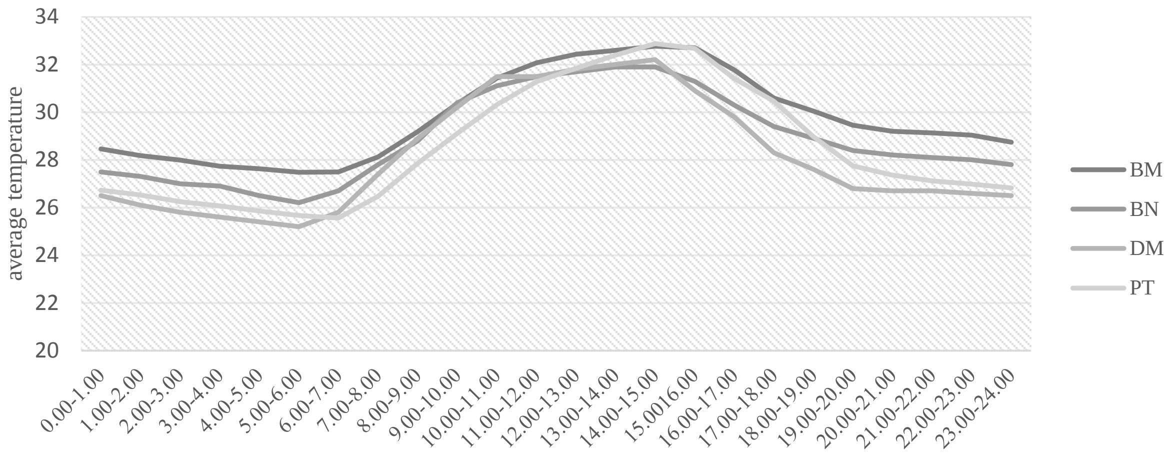


Figure 3.4. Mean air temperature in rainy season (August 2014)

Figure 3.5 shows the temperature difference in winter season. It can be seen that the differences between urban and non-urban area are much larger than in the summer. The monthly maximum temperature differences of 4°C are found from 20.00 to 04.00. The differences decreases and become nearly the same temperature from 10.00 to 12.00. In the afternoon, during 14.00-15.00, the temperature at the urban area is slightly lower than in the sub-urban area. This is probably because the tall buildings around the meteorological station provide a proper shading to lower the temperature. Another reason is probably because the lack of green space and permeable surfaces in the urban area create the lag of heat release.

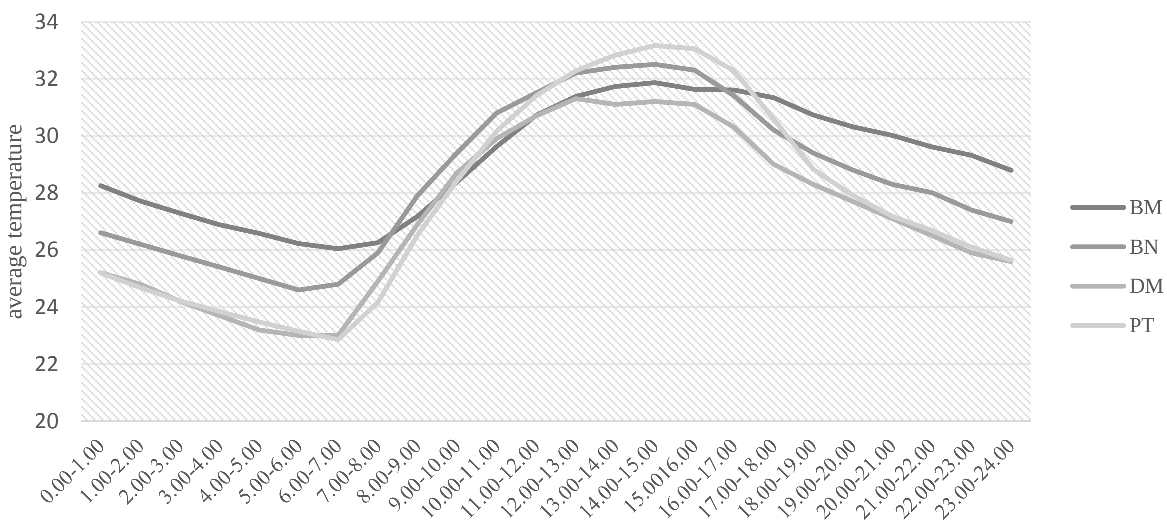


Figure 3.5. Mean air temperature in winter season (December 2014)

The above results show that the daily variations of UHI in three different seasons in Bangkok have similar trend. The UHI effect is high after sunset around 18.00-19.00 and the temperature difference reaches maximum value of 2°C - 4°C during the night depending on the season. The magnitude of UHI is low in the morning and it the temperature difference continue to decrease in the afternoon. After the sunset, temperature difference begins to rise again.

Seasonal Variation of UHI

To understand the seasonal variation of UHI, a yearlong observation during January to December 2012 was observed. The monthly average UHI intensity is illustrated in figure 3.6. From the figure, it is evident that the nocturnal heat island during 7 p.m. to 7 a.m. is the most prevailing case as the maximum intensity can be detected during 6-7 a.m. from the previous section, and followed by the morning time during 7 a.m. to noon, and then by the afternoon and evening time during noon to 7 p.m. After 7 a.m. the UHI intensity began to reduce gradually to a minimum value in the afternoon as observed in the previous section. Thus, the developments of UHI during the day or diurnal variation can be found throughout the year. Except in August the nocturnal UHI seem to be about the same as in the morning time. During the wet months of May to October the nocturnal and day heat island intensity have less intense especially during August to September reaching its minimum around 1.6°C. This development is contrary to what is observed in winter and summer.

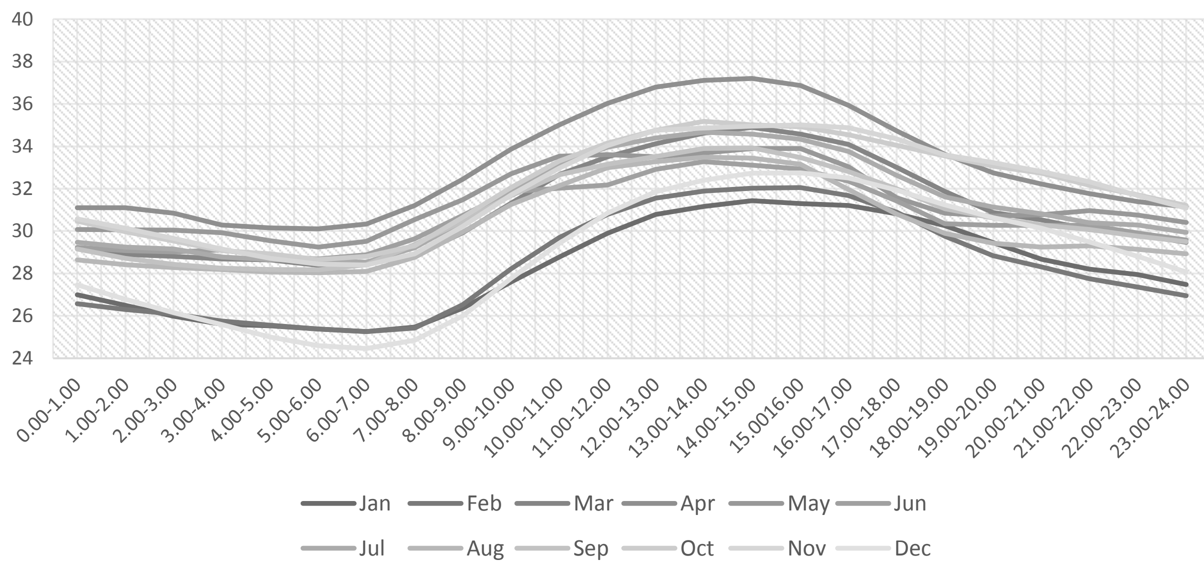


Figure 3.6. Seasonal Variation of UHI in Bangkok 2014

In winter, the rapid rise of UHI intensity can be clearly observed. The highest intensity of nocturnal time reaches in the middle of winter in December (4.4°C). The mean monthly largest intensity of 5°C is found in December during 9-10 p.m. In summer, while the nocturnal heat island reaches its maximum, the declining daytime heat islands in cool season are observed during October to December. After the end of winter, the cool island occurs during the afternoon and evening. Therefore, it can be said that during summer and winter the more nocturnal heat island, the less daytime heat island can be found. Therefore, from the 1 year data, it is evident that the heat island phenomena occurs throughout the year especially during the night time, and the UHI intensity ranges from 4-5°C in winter, 2-3°C in summer, and 1.5-2.5°C in rainy season.

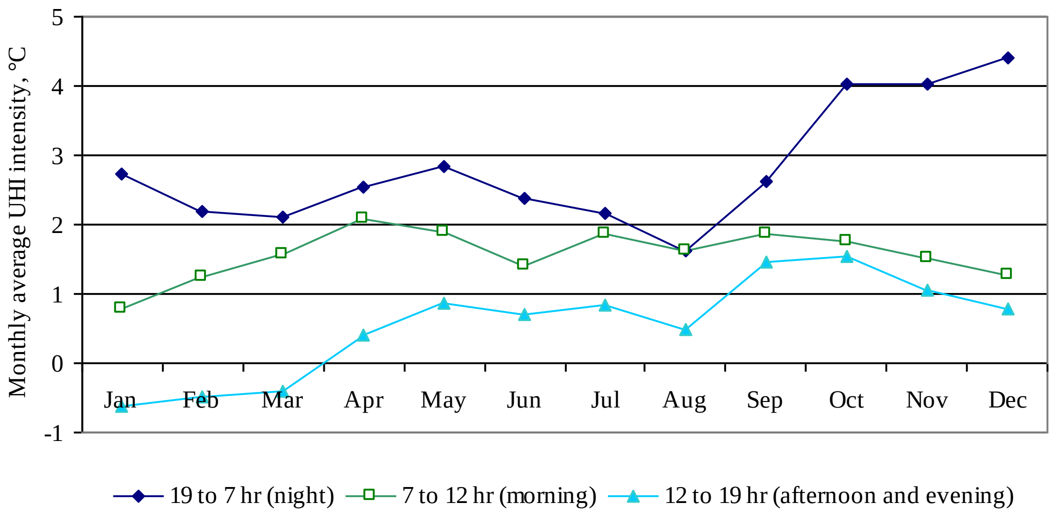


Figure 3.7. Seasonal Variation of Monthly Average UHI Intensity between Urban and Non-Urban Station in 2014

Figure 3.7 summarizes the seasonal variation of monthly average UHI intensity between urban and non-urban stations. It is obvious that the Bangkok heat island is much more intense at night both in summer (2-3°C) and particularly in winter (4-5°C). The lowest intensity of UHI is observed in rainy season. The monthly average maximum heat island intensity of 5 °C is found during 9-10 p.m. in December. Except in rainy season, no variation between nighttime and morning time are found. However, heat island development can be observed (1.5-2.5°C).

c. Factors Influencing UHI Magnitude in Bangkok

The following section analyzes the factors influencing UHI magnitude in Bangkok based on the above discussion on the UHI characteristics.

Weather Condition

It is been recognized in literature that different weather condition creates different UHI formation and magnitude. In this study we use rainfall, wind speed, and cloud data from Department meteorology to understand the influence of weather condition to the UHI magnitude in Bangkok.

Winds and Clouds

From the above data, it can be observed that UHI in winter is higher compared to other seasons, and this is probably because of the change of wind velocity, the cloud cover and which are associated with unstable turbulent weather. To further understand this, we select one typical day in the winter season (29 December 2014) to analyze the daily UHI intensity, cloudiness factor, and wind speed. The cloudiness factor data was obtained from Department of Meteorology of Thailand and divided into 10 scales, with 1 is low-level clouds and 10 is high-level clouds). During the day, the wind speeds increase to around 6-8 km/hr and the magnitudes of UHI decreases to -2 to -3°C. The greater wind speed lowers the UHI magnitude. Figure 4.6 summarizes the association between UHI intensity, wind speed, and cloudiness factor.

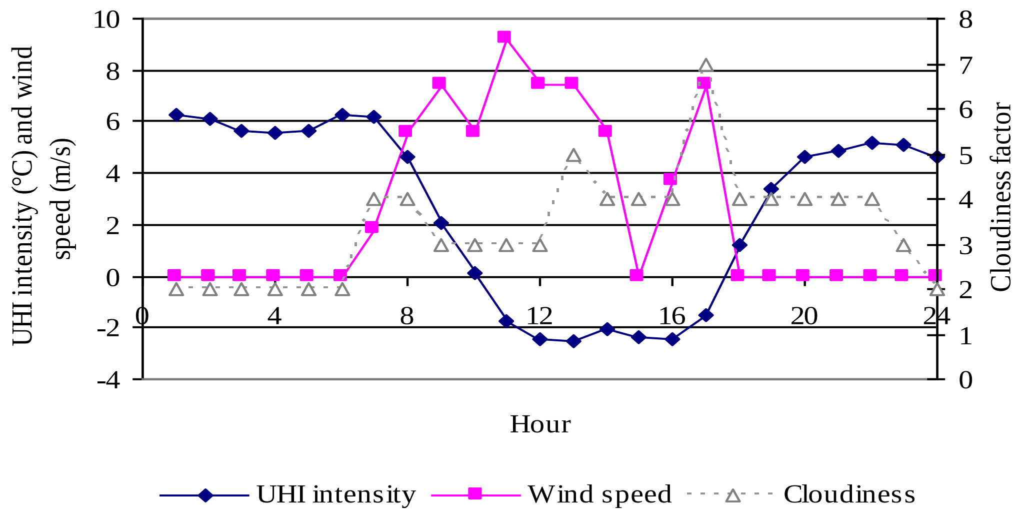


Figure 3.8. UHI intensity, wind speed and cloudiness factor on 29 December 2014

Similar to wind speed, UHI magnitude is inversely associated with cloud cover. The high-level cloud amount is found during the day time leading to the lower UHI intensity while little or no cloud is found during the nighttime causing the larger UHI intensity. This is probably because clouds reflect solar radiation which results in surface cooling during the day time.

Precipitation

To understand the association between precipitation and UHI magnitude, we examined data from Bangkok Metropolis weather station in 2014. 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). Figure 4.7 summarizes the result.

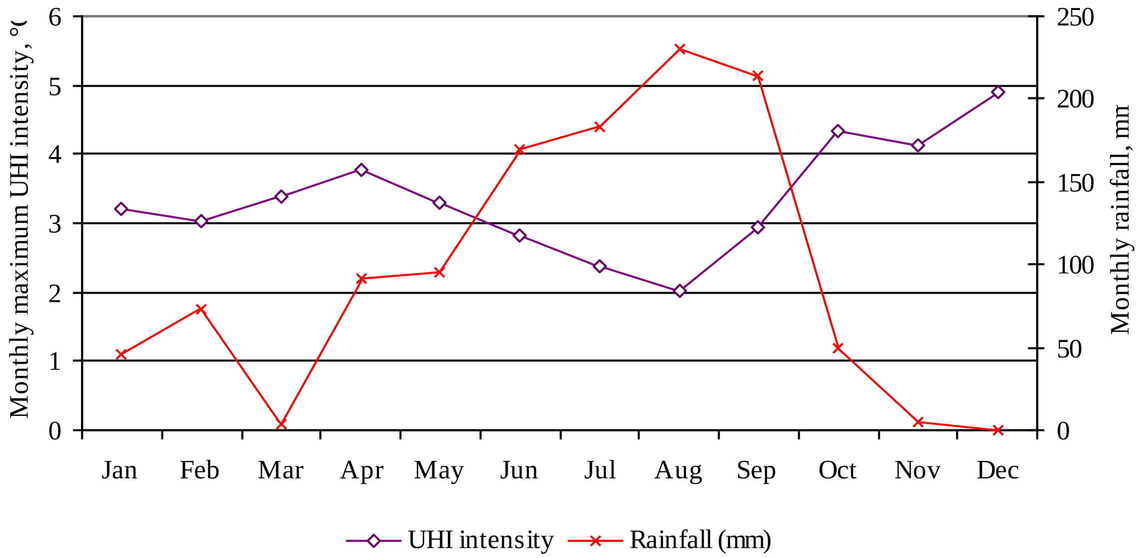


Figure 3.9. Monthly maximum UHI intensity and monthly rainfall in Bangkok Metropolis station in 2014.

Land use and population density

From the abovementioned discussion, it was found out that all weather station in urban Bangkok were warmer than in sub-urban Pathumthani, especially at night. We cross-tabbed the district density (house/sq.km) of all weather stations in the study and average yearly temperature. It was found out that the association was positive and statistically significant ($p<0.05$). Figure 3.10 shows the relationship between district population density and UHI intensity in Bangkok. The pattern shows similar result with the housing density.

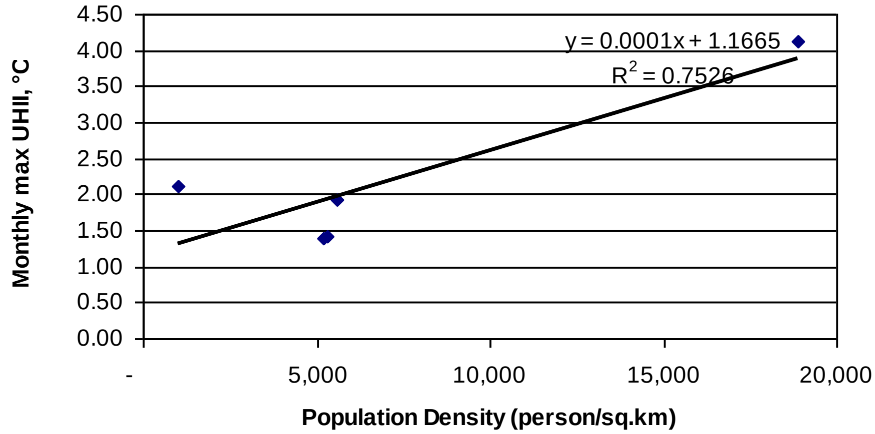


Figure 3.10. The relationship between district population density and monthly UHI intensity

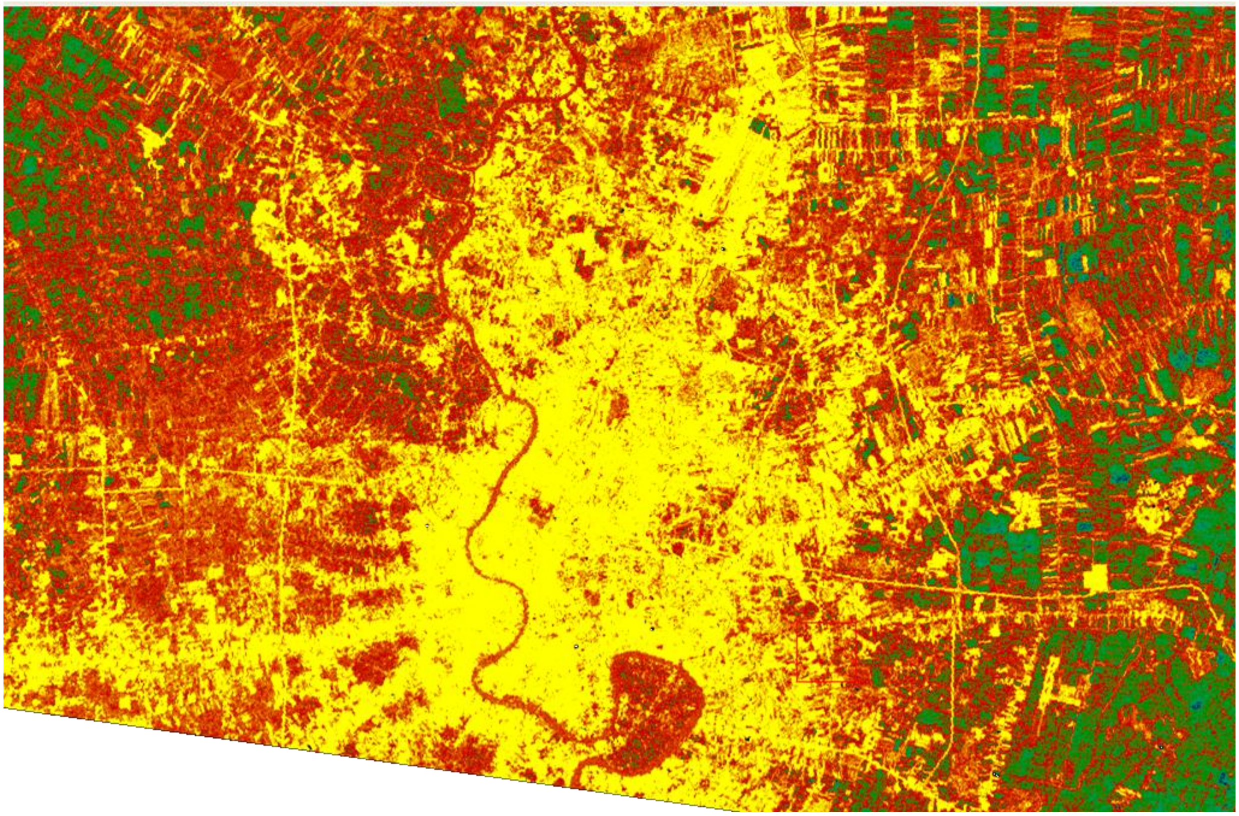


Figure 3.11. The surface temperature pattern for Bangkok city in dry season (acquisition date: 8 November 2014).

Note: the effective at-satellite temperature is grouped into four color, with yellow (the warmest), orange (warm), red (cool), and green (coolest)

Figure 3.11 shows the surface temperature patter for Bangkok in summer. The figure confirms that the association between housing and population density with UHI intensity. The red zone covers the middle and outer areas. The decrease of surface temperature results from land use and land cover change. The high surface temperature presents the lack of vegetation area, where as low surface temperatures are found in large green areas. The surface temperature differences between conservative vegetation areas (green zone) and very densely build-up areas (high density of high-rise buildings and residences) could be as high as 8-10 °C.

3.1.2. Effects of Urban Heat Island in Bangkok, Thailand

In Bangkok, the higher magnitude of UHI has created health and environmental problems. The following section discusses the effects of UHI in Bangkok in three particular domains: urban planning, energy consumption, and public health.

a. The Effect of UHI to Future Urban Development and Planning Practices in Bangkok

To understand the effect of UHI to the future urban development of Bangkok, we uses the WRF-ARW to model the spatial pattern of UHI. We conducts two models. First is the current climate of Bangkok based on the current land use and the second model is the future climate of Bangkok based on the land use in the Bangkok Comprehensive Plan 2013. The detailed methodology on how we create meso-climate modeling can be found in the methodology section.

Meso-climate modeling on current condition

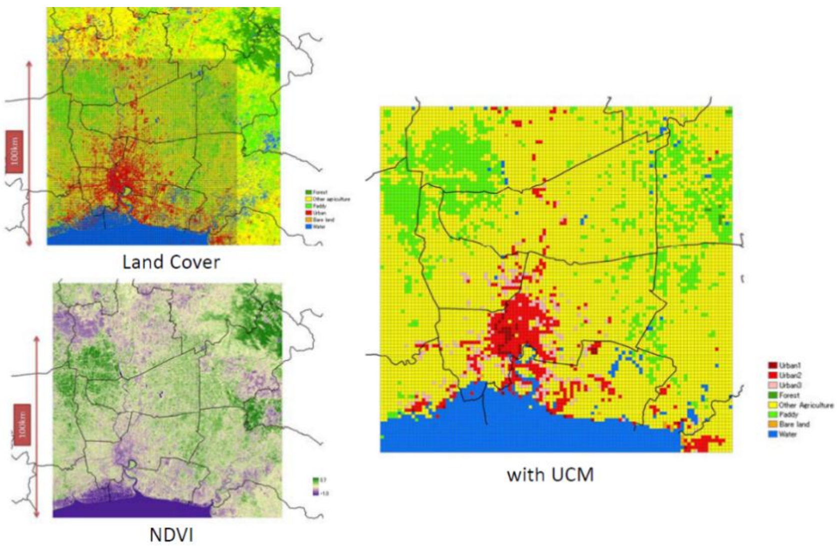


Figure 3.12. The Mesh Data of the Present Land Use

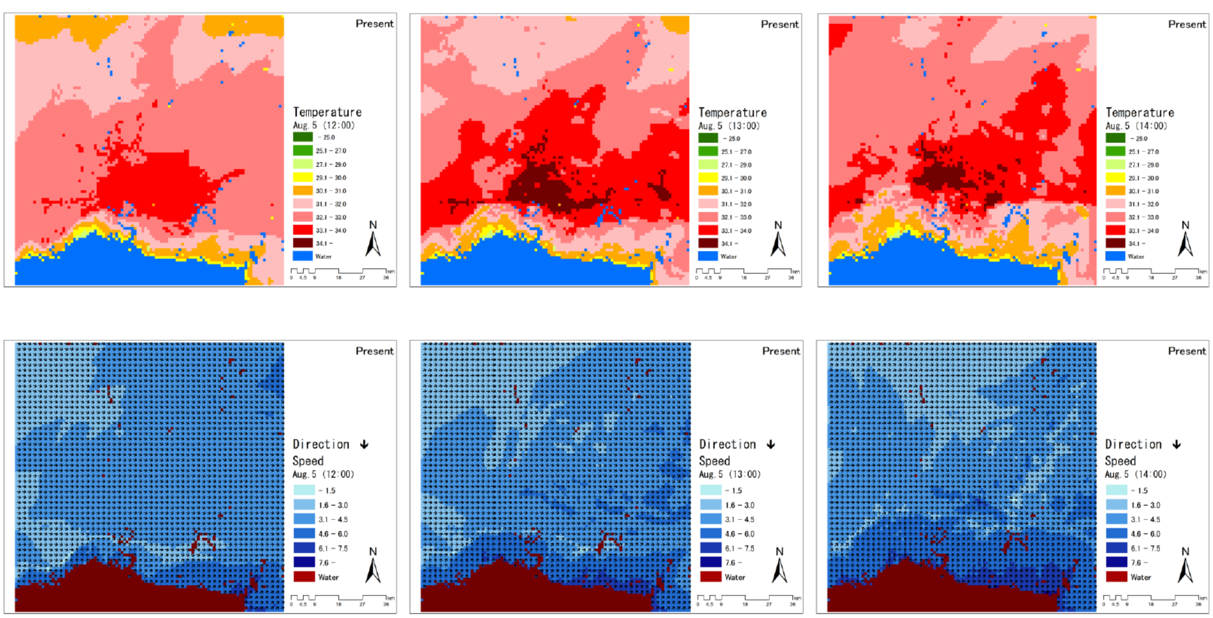


Figure 3.13. Temperature Data on 5 August 2014, 12.00-14.00

Figure 3.12 shows the mesh data of the current condition of land use in the domain 2 of the model. We select one typical day which is 5 August 2014, and run the WRF model. We export the result into ARCGIS ver.10. Figure 3.13 shows that the calculated temperature in the afternoon is around 25 - 36^{0}C. The wind speed is around 1.0 – 8.0 km/s. Wind direction is mostly static in the afternoon blowing from the west and weak sea breeze blowing northeast before it turns to east in the Samutprakan province. At 14.00 the sea breeze blows stronger towards Bangkok and cool down the temperature.

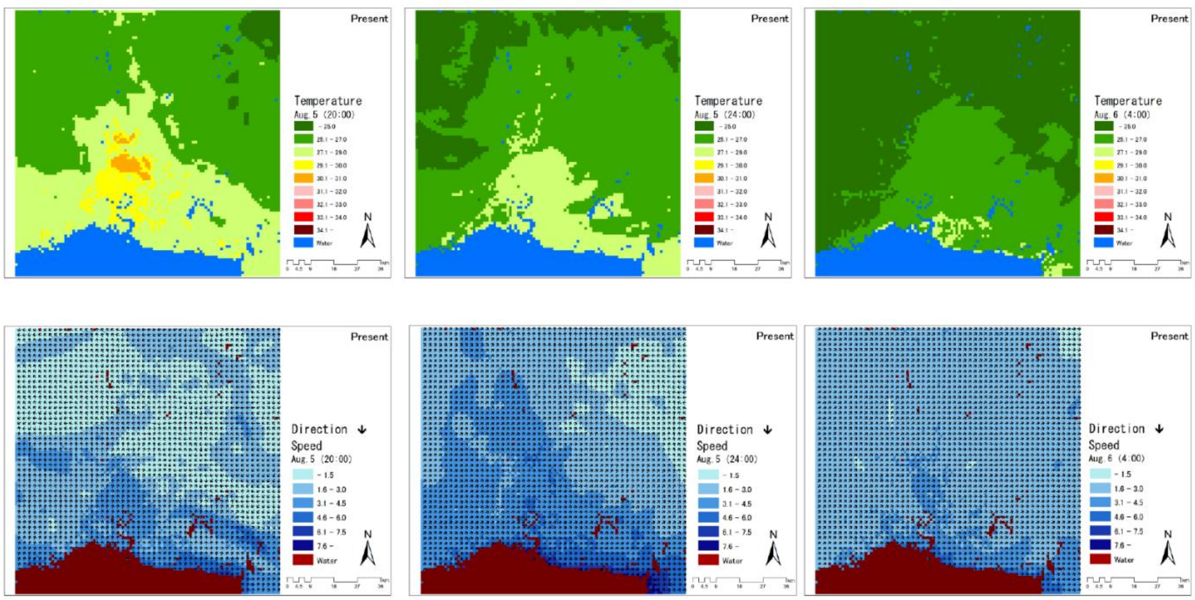


Figure 3.14. Temperature Data on 5 August 2012, 20.00-04.00

Figure 3.14 shows that the calculated temperature ranged from 23 - 30^{0}C. Temperature is cooler during the evening until 04.00 and continue to rise in the morning of 6 August 2014. Wind speed is low in the evening (3 – 4.5 km/s) but the wind direction towards the city cools down the temperature.

To construct a model for future land use, the current model is validated using the comparison between the calculated weather data and observed data obtained from Department of Meteorology of Thailand.

Figure 3.15 shows that in general, there are similarities between observed and calculated data. It can be concluded that the model is valid and can be used to predict the future weather condition. The model prediction for the future weather condition is explained in the following section.

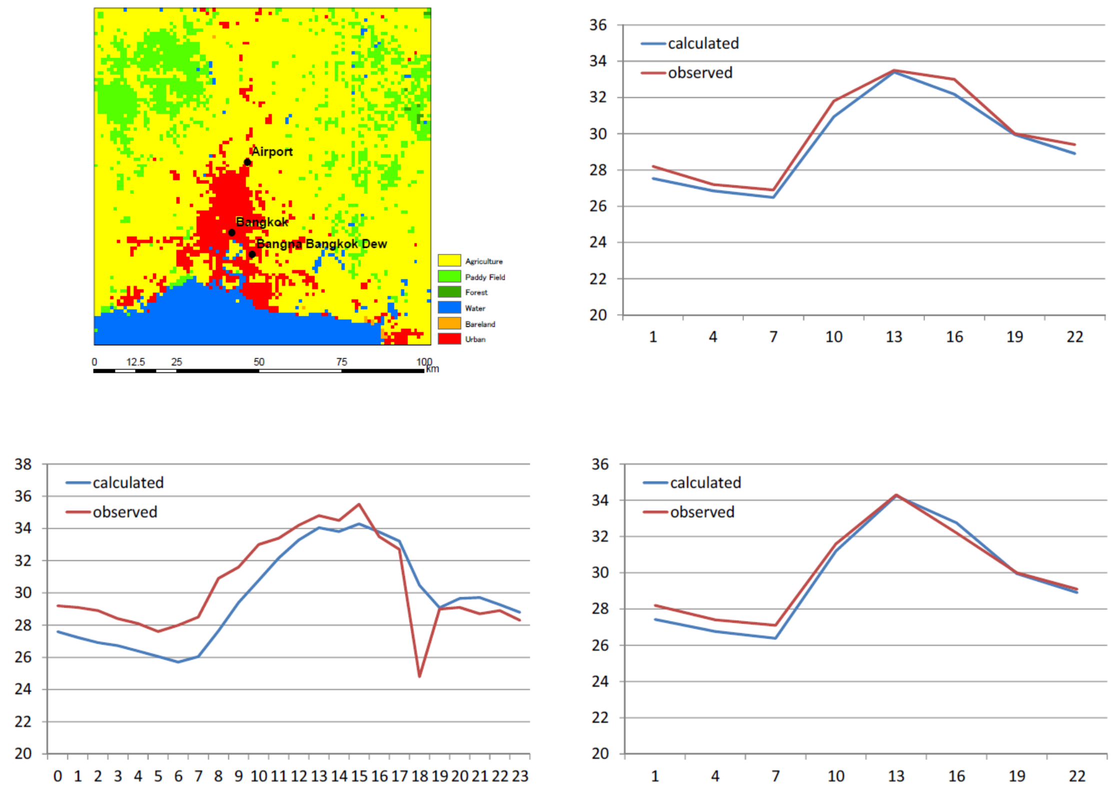


Figure 3.15. The Comparison of Result between Model and Observation Data on 5 August 2014

Note: figures in clockwise: the current land use, weather data comparison from Bangkok metropolis station, Bangna station, and airport station

Meso-climate modeling under the Future Master Plan Scenario

We run the model with similar condition and parameters with the current land use model. The only change is the land use is based on the new master plan of Bangkok. We also select the 5 August 2014, as an example of typical day to present the result so it is comparable to the current land use model. We export the result into ARCGIS ver.10.

Figure 5.8 shows that the calculated temperature in the afternoon range from 32-38 ^{0}C, which is higher than the model with current land use. The urban Bangkok will get very hot in the afternoon. The sea breeze cools down the urban area with the speed around 3-5 km/s in the morning. In the afternoon (13.00), high temperature (more than 35 ^{0}C) occurs in almost all area in Bangkok and even expanding in neighboring provinces. At 14.00, the temperature is lower because of increasing wind speed from the south.

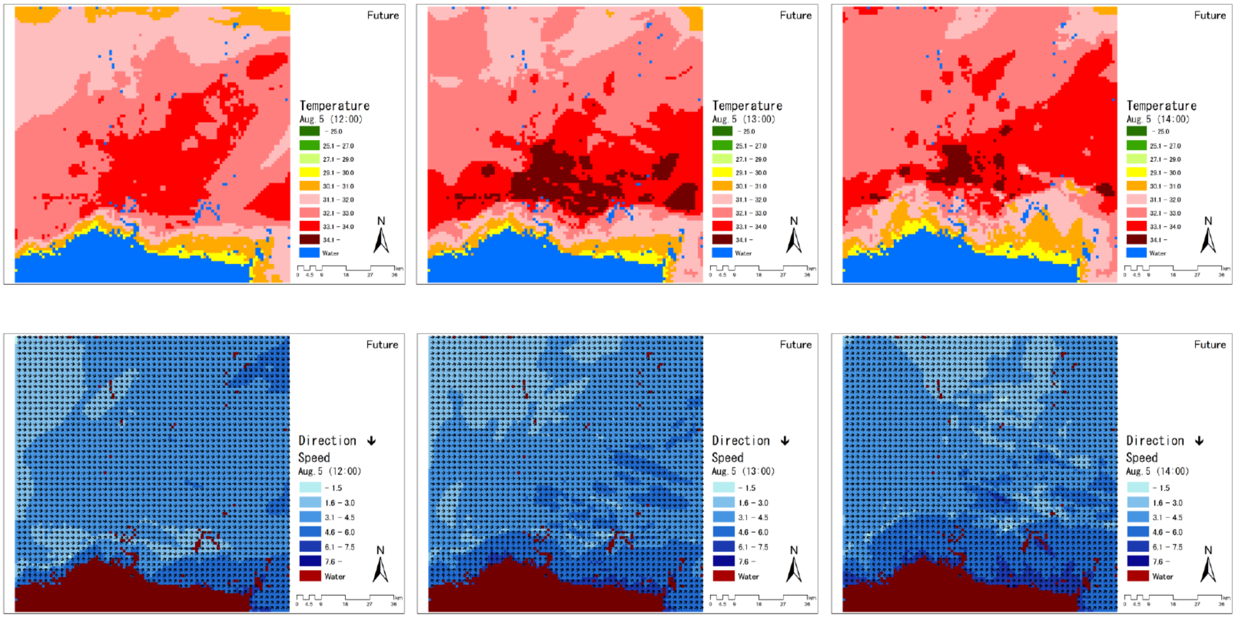


Figure 3.16. Temperature Data on 5 August 2014, 12.00-14.00

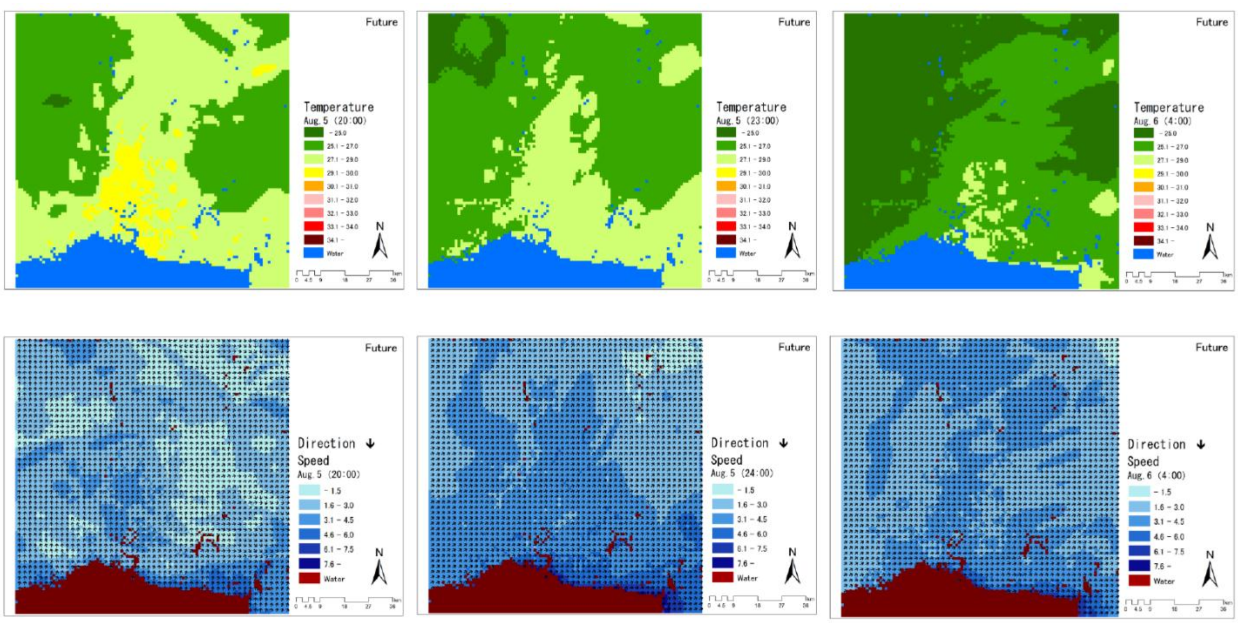


Figure 3.17. Temperature Data on 5 August 2014, 20.00-04.00

Figure 3.17 shows that the calculated temperature in the evening is ranged from 27 – 30 ^{0}C and the wind speed is from 1.0 – 4.5 km/s. Wind speed increases at midnight cooling the temperature in the city even more. At 04.00, almost all part of Bangkok has the temperature of 25 – 30 ^{0}C, even though the wind speed is low (1.5 – 3 km/s).

Comparing the current and future land use, it can be summarized that the magnitude of UHI is even bigger. The temperature in Bangkok and its surrounding provinces is higher during the day and becomes very low at night. The temperature difference between the current and future condition range from 2 – 7 ^{0}C, which is very high. On the other hand, at night time, the temperature difference between two scenarios range from 0 – 4 ^{0}C. It means that the UHI magnitude is 1.5 – 2 times of the current condition (62.5% increase). Table 3.2 summarizes the result.

Table 3.2. Temperature Difference between Current and Future Scenarios on 5 August 2014

Scenario	Average Temperature Difference in daytime	Average Temperature Difference in Nighttime	UHI Magnitude
Current Land Use	30.5 ^{0}C	26.5 ^{0}C	4 ^{0}C
Future Land Use	35 ^{0}C	28.5 ^{0}C	6.5 ^{0}C

From table 3.2, it is found that the new master plan will increase the magnitude of UHI. It will increase the temperature of Bangkok. Using one typical day example on 5 August 2012, the new master plan increase the UHI magnitude 62.5% from the current condition. In daytime, the increase can reach 4.5 ^{0}C, and at night is around 2 ^{0}C. The UHI magnitude under the current condition is 4 ^{0}C and under the new master plan is 6.5 ^{0}C.

b. ***The Effect of UHI to Household Energy Consumption in Bangkok***

Another important effect that needs to be investigated is the effect of UHI to household energy consumption, especially in the form of using air conditioning device to cool the house. In Bangkok, the air conditioning load is considered to have the largest share (almost 60%) of electricity use. Therefore, it is important to assess the impact of UHI to household energy consumption from the microclimate perspective.

Cooling Degree Days (CDD) index was used to establish the correlation between UHI and energy consumption. The study also uses Cooling Degree Days (CDD) to investigate the effect of higher temperature on cooling energy consumption in Bangkok. The CDD profiles from 4 weather stations from 2013-2014, in addition to providing an energy audit database, are used in the OLS regression to examine the sensitivity of electricity consumption. The air temperature from 2008-2014 from all four stations are collected to understand the temperature variation trend in Bangkok in 7 years moving average. These data are also used to understand the daily and annual course of UHI.

Table 3.3. Variables used to understand the effect of UHI to household energy consumption

Variable	Description	Range
CDD	Monthly cooling degree days with base temperature 24°C in 2014	M = 152.68; SD = 32.11
Electricity	Monthly electricity bill in 2014 in THB	M = 854.35; SD = 431.178
Number of AC	Number of air conditioning unit owned in the house	Min = 0; max = 2

AC use	Frequency of using AC equipment in last month	0= no use; 1= just a few hours; 3 = few day and night; 4 = almost every day and night
Energy	monthly energy use for space cooling in 2014 (kWh/m2)	M = 2,136.04; SD = 2,103.65

Table 3.3 summarizes the variables used in the study. Variables that have not been found significant association with the household energy consumption are not included in the study. All variables in the study are analyzed whether they follow the normal distribution pattern. To model the relationship between CDD and the household energy consumption, we use the linear regression following the equation below.

$$E = a + bCD \qquad (2)$$

Where E is the dependent variable of monthly energy use for space cooling per square meter, a represents the intercept and b is the slope and CDD is the predictor variable. We also use t-statistics to establish the simple association between two variables.

Monthly CDD profile for 4 weather station areas in 2014 is summarized in table 3.4. The highest number of CDD occurs in April and the lowest in January in the urban area. However, using the 24°C it seems that CDD occurs very little in sub-urban area (Pathumthani). The finding shows that UHI effect in Bangkok is higher compared to the sub-urban area.

Table 3.4. CDD profiles for four weather stations

	Jan	**Feb**	**March**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Avg**
BM	69	107	176	222	231	190	178	159	154	135	154	110	148.57
BN	106	156	115	230	122	220	234	181	169	149	148	136	151.92
DM	68	106	183	205	217	184	174	148	150	132	142	98	143.07
PT	46	5	0	0	0	0	0	0	0	0	0	10	6.57

Note: BM = Bangkok Metropolis Station, BN = Bangna Station, DM = Don Meuang Station, PT = Pathumthani Station

A survey conducted by the National Statistical Office of Thailand 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, $p < 0.005$). Air Conditioning (AC) equipment ownership is the most fundamental factor in household space cooling consumption [8]. More than

80% of the respondents have AC equipment in their housing units. There is a positive relationship between the ownership of AC equipment and CDD ($F = 81.569$, $p < 0.001$). As expected, there is a positive correlation between household energy consumption and CDD. Regressing monthly energy use for space cooling per square meter (E) to CDD resulting in high coefficients of R2 (adj R2 = 0.881; std error = 1.046; p-value < 0.001). This finding implies that CDD and E values experience change in the same direction.

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.

c. Health and Well-Being

The section explores the health effects of UHI in Bangkok. Using 400 randomly selected respondents, the study focuses on three health effects, physical activity, daily activities, and health outcomes. Table 3.5 summarizes the characteristics of respondents.

Table 3.5. Respondent's Characteristics of the Survey

Variable	Description	Mean (std. dev)	% of 1
Age	Age of the respondent	39.6 (14.08)	
Gender	Gender of the respondent, 0 = female, 1 = male	-	38.2
Marital status	Marital status of respondent, 0 = single, 1 = married	-	48.3
Education	Education level, 1 = no formal education, 2 = elementary, 3 = secondary, 4 = undergraduate, 5 = post graduate	-	1
Household status	Status in the household, 0 = head of the household, 1 = other	-	31.3
Number of Household members	Number of household members	4.0 (1.82)	-
Monthly income	Monthly income of the head of household, 1 = less than 5,000 THB, 2 = 5,000-10,000 THB, 3 = 10,001-30,000 THB, 4 = 30,001-50,000 THB, 5 = more than 50,000 THB	-	8.8
Type of workplace	Type of workplace of respondent, 1 = work in air conditioned room, 2 = work without air conditioned room, 3 = housekeeper, 4 = student,	-	54
Smoking	The respondents smoking addiction, 0 = yes, 1 = no	-	88.7
Alcohol	The respondents alcohol addiction, 0 = yes, 1 = no	-	90.5
Cardiopulmonary	Does the respondent have a cardiopulmonary disease, 0 = yes, 1 = no	-	93.7
Ischemic	Does the respondent have a ischemic heart disease, 0 = yes, 1 = no	-	99.8
Cerebrovascular	Does the respondent have a cerebrovascular disease, 0 = yes, 1 = no	-	98.6
Respiratory	Does the respondent have a respiratory disease, 0 = yes, 1 = no	-	90.9

The average age of respondents is 39.6 years old with mostly are single (51.7%) and head of household (69.7%). The average income is between 10,000-30,000 THB. Most respondents do not have chronic diseases such as cardiopulmonary, ischemic, cerebrovascular, and respiratory diseases. The following section explores the perceived health effects of UHI.

Perceived Health Effects of UHI

The UHI related health effects in the study is defined as the heat stress effects. Empirical evidences show that heat stress in tropical cities is increasing due to urban heat island and urbanization, especially in developing countries. Increasing heat stress has substantial adverse effects on population mortality and morbidity. Health impacts from heat stress in this study are categorized as physical health impacts, mental health impacts, and well-being.

Daily Activities and Heat Interferences

Daily activities and heat interferences are summarized in table 3.6. The variables for are constructed by asking the respondents to rank the agreement on statements in the questionnaire, with 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

Table 3.6. Descriptive Statistics on Daily Activities and Heat Interferences

Variable	Description	% of 5	Mean (mode)	% of agreement
Sleeping 1	I have trouble sleeping because of summer heat	32.7	3.9 (4)	88.3
Sleeping 2	I need to turn the fan/AC on during sleeping at night	56.2	4.51 (5)	98.8
Housework 1	I do less housework in the afternoon because it is too hot	20.4	3.64 (4)	86.1
Housework 2	I turn the fan/AC on while doing housework	21.0	3.55 (4)	78.4
Daily travel	I have difficulties going to work because of the heat	25.5	3.77 (4)	88.7
Work	I have problem at work because of the hot weather	22.4	3.68 (4)	87.3
Exercise	I do less exercise because of the hot weather	14.1	3.0 (3)	76.9

Note: % of agreement is constructed by combining the 1-2 answer into “no” and 3-5 into “yes”

Table 3.6 shows that most respondents have problems on daily activities because of heat interferences. More than 80% of respondents have trouble sleeping at night and almost 100% respondents require AC or fan to help them sleep at night because it is too hot. Respondents reported that they do less housework in the afternoon and need to turn on AC or fan while doing the chores. More than 80% of respondents have heat interferences problem at work, and more than 70% of respondents doing less exercise because it is too hot.

Health and well-being outcomes

Health and well-being outcomes in the study is summarized in table 6.3. Health and well-being outcomes in this study is defined by three aspects: physical health, mental health and life satisfaction. All aspects are measured by self-reported survey questionnaire using proxy variables.

Table 3.7. Health and well-being outcomes

Outcomes	Percentage
Overall life satisfaction (score ranged from 0-10)	
9-10 (very satisfied) high	13.2
8 (high)	23.6
6-7 (medium)	41.7
0-5 not very satisfied (low)	21.4
Energy level in the past 4 weeks	
Very much	5.6
Quite a lot	22.2
some	58.9
A little or none	13.4
Emotional problems in the past weeks	
Not at all	12.0
Slightly	32.1
Moderate	39.4
Quite a lot	16.5

The table shows that during the survey, more than 50% respondents reported that they have low-medium level life satisfaction. More than 70% have less energy to do everyday activities than usual, and more than 80% experience slight emotional problems during the time of survey. Table 3.8 provides a cross tabulation and spearman correlation result among health outcomes, age, and gender.

Table 3.8. Association among health outcomes, age and gender (spearman correlation)

	Age	Gender
Overall life satisfaction	-0.01 (ns)	-0.03 (ns)
Energy levels	0.95 ($p<0.05$)	0.14 (ns)
Emotional problems	-0.207 ($p<0.001$)	1.77 ($p<0.001$)

Note: gender variable is constructed using a dummy variable where 1 = female. Age variable is constructed by grouping the original age variable of respondents into three groups: adolescents, adults, and elderly.

Table 3.8 shows that there is no association between life satisfaction and age and gender. There is a positive association between energy levels and age meaning that the older respondents have less energy than the younger ones. The data also show that the younger respondents tend to have more emotional problems in the last four weeks, and female respondents are also reported to have more emotional problems compared to male ones.

Association between Health Outcomes and Heat Stress

To understand the association between health outcomes and UHI, first we need to establish correlation between UHI and the heat interferences with daily activities. The argument is that UHI will disrupt the daily activities through heat interferences. The disruption of daily activities will eventually affect the health outcomes.

Table 3.9. Association between heat stress and health well-being outcomes is measured using spearman correlation and checked using chi-square tests.

	Life satisfaction	Energy level	Emotional problem
Sleeping 1	-2.03***	-0.078	0.196***
Sleeping 2	-0.49*	-0.49	0.93
Housework 1	-0.198***	-0.193***	0.215***
Housework 2	-0.157***	-0.125*	0.046
Daily travel	-0.83**	-0.118*	0.136**
Work	-0.153**	-0.190***	0.174***
Exercise	-0.191***	-0.162***	0.183***

Note: *** p<0.001, ** p<0.05, *p<0.01

Table 3.9 shows the association between heat stress, measured by heat interferences with daily activities and health well-being outcomes. The data suggest that heat interferences with daily activities are associated with health and well-being outcomes, especially life satisfaction. Energy level variables have negative association with housework activities, daily travel, work and exercise. Emotional problem variable has positive association with sleeping, housework, daily travel, work, and exercise. Heat interferences to housework 1 is found to have highest correlation value with all health and well-being outcomes. From table 6.2 and 6.5 we understand that the level of physical activity (PA) of Bangkok residents is affected by UHI. The spearman correlation coefficient shows that heat interferences to physical activity (measured by exercise level) is significant.

The data suggest that respondents with heat interferences problem will have lower life satisfaction lower energy level, and experience more frequent emotional problems. This findings share similar result with the literature which found that heat stress significantly reduce health outcomes and well-being. For example, Lan et al (2010) found that people working in hot environment had lower motivation to work and experience negative mood during working. Guo et al (2012) found that there is an effect of increasing temperature on mortality in Chiang Mai city in Thailand. This study found out that heat stress is not only affecting the working life, but also interfere with other aspect of daily life such as sleeping, daily travel, and exercise.

The analysis found that there is a significant association between these variables when we established bivariate correlation (spearman rank). It can be inferred that UHI affects the health indirectly through the heat interferences with daily activities. However, there are limitations to the study. First, it cannot establish a direct causality between heat interference and health. Second, the respondents mostly answered the questionnaire during April-May period, which is the hottest period of the year. It will be interesting to see the time series data of the response so we can compare between summer and winter season.

3.1.3. Policies and Adaptation Measures to Urban Heat Island in Bangkok, Thailand

The following section presents the existing policies and measures related to UHI. Policy documents, especially related to urban development are examined to understand the gaps in the existing measures.

a. <u>Bangkok Urban Development</u>

Bangkok is the most heavily populated city in Thailand. The registered population is around 6 million, however, the real population is closer to 10 million. Since 2000, the Bangkok region has experienced annual population growth 2.5 times the rate of growth from 1980 to 2000. By 2010, the Bangkok region – which includes the provincial level city of Bangkok and the provinces of Samat Prakan, Samut Sakhon, Pathum Thani, Nonthaburi and Nakhon Pathom – was nearing a population of 15 million. As is characteristic of urbanization in both developing and developed countries, much of Bangkok's recent growth has occurred outside the city, in suburban (and exurban) areas. Between 2000 and 2010, the city grew by 30%, while the suburban provinces grew more than twice as quickly, at 66%. The city's population growth was 1.9 million, while the suburban provinces added 2.5 million population.

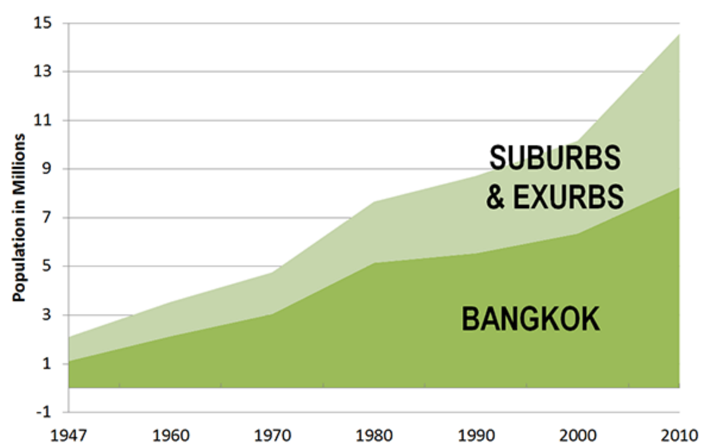


Figure 3.18. Bangkok Population Growth 1947-2010
(Source: http://www.newgeography.com/files/cox-bangkok-1.png)

Urban Bangkok has been classified into three zones; the inner city, the urban fringe and the suburb. The inner city is the main concentration area for governmental offices, commercial activities, educational establishments, historical conservation areas and living quarters. The urban fringe is the new central business district accommodating outward increase in the numbers of business and commercial activities. Suburban is the outer part of Bangkok link to the inner city by radial roads. Bangkok and its surrounding is Thailand's economic engine. In 2009, BMA produced a GDP of about 3,770 billion of Baht (42% of the country's total GDP). It benefits from agglomeration and scale economies and the scope for further diversification inherent in a broad base of industry and services.

Beside its large population size, the city also have a large area more than 1500 sq.km, sprawling over and encroaching into nearby provinces. Bangkok is not only the political, administrative, economic and cultural capital of Thailand, but it is also the focal point for the national road, railway, aviation and communications services. In a very real sense, all roads do seem to lead to Bangkok. Employment opportunities in government, industry and commerce exceed those offered elsewhere in the country, as do the educational opportunities available.

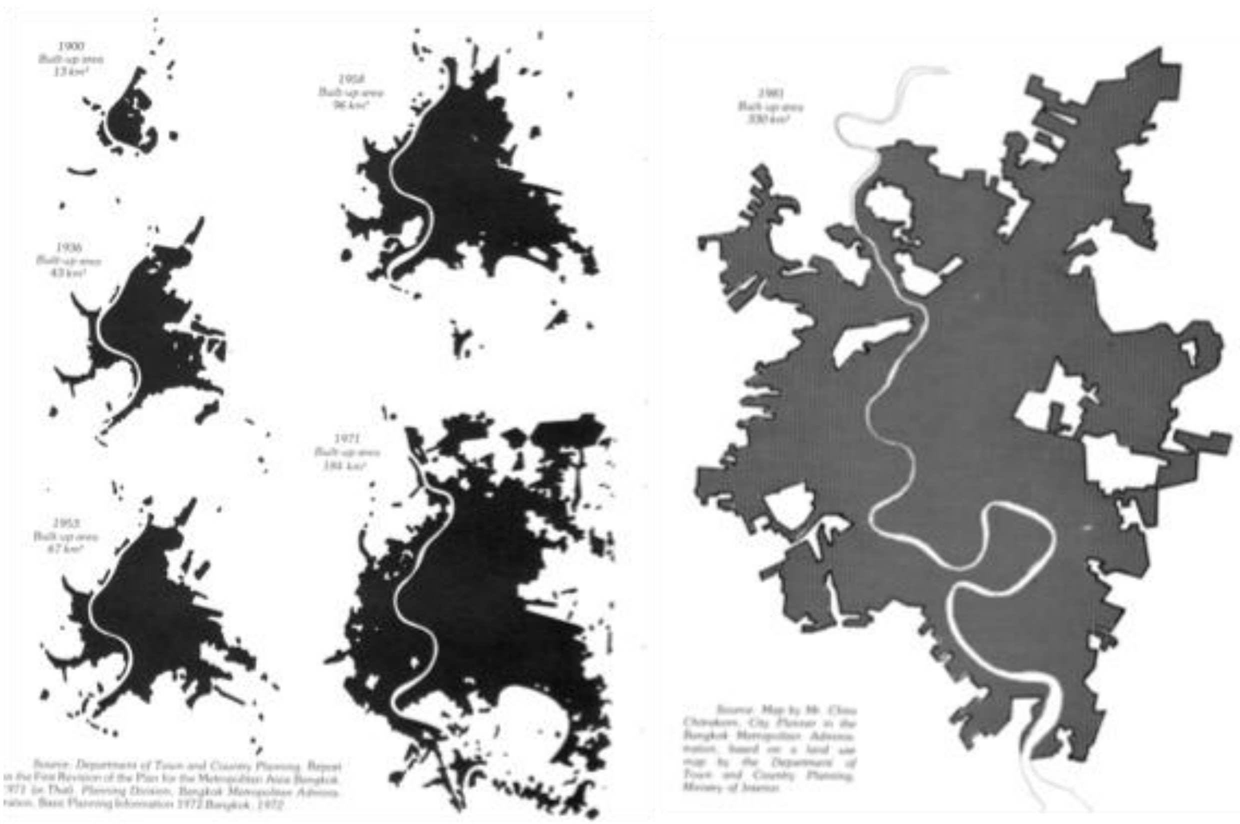


Figure 3.19. Expansion of Bangkok 1900 - 1990

Since Bangkok has expanded in every direction and links closely to the neighboring provinces in the context of a regional area, many people who live in the vicinities around the BMA daily commute to work there. Therefore new economic clusters are developed outside the city, like the high technology industry research center in the north of Bangkok, changing the type of industry of Bangkok from manufacturing to more high-tech oriented. Furthermore new transportation infrastructure (boats, busses, and railway) was developed, especially to the facilities laying outside the BMA, making it easier for people to commute to Bangkok. This has resulted in a further densification of Bangkok instead of further spreading the program over the region.

The BMA is a special province with a special administration area and an elected governor. Due to the importance of Bangkok for Thailand, every important development project (regional facility) in and around BMA has to be approved by the ministerial cabinet. The BMA council approves the developments in BMA. These developments have to go together with the Bangkok Metropolitan Regional plan. The BMA plan was made by the National Economic and Social Development Board (NESDB), responsible for economic and social development), the Ministry of Interior and the Department of Public Works and Town and Country Planning (DPWTCP, responsible for spatial planning of BMA). At the district level has it own administration and they have a representative in the BMA council. The district makes a plan and the representative brings the plan into the BMA council where it is checked according the Regional Plan and then approved.

b. Bangkok Planning System

Bangkok planning practice is part of Thailand Planning System. It follows the national development plan established by the National Economic and Social Development Board (NESDB). In Thailand, provincial regional plan is prepared by the Department of Public Works, Town and Country Planning, Ministry of Interior. However, Bangkok master plan is developed by the Department of City Planning of Bangkok Metropolitan Administration (BMA) because Bangkok is considered as a special provincial region. The first master plan of Bangkok was established in 1960, called "The Litchfield Plan: The Greater Bangkok Plan 1990". Since then, the urban planning law of Thailand was established in 1975 and Bangkok follows the 5-year urban comprehensive plan cycle. The first comprehensive plan of Bangkok is established in 1992 as a 5-year development plan. Currently Bangkok master plan in use is the fourth revision in 2013.

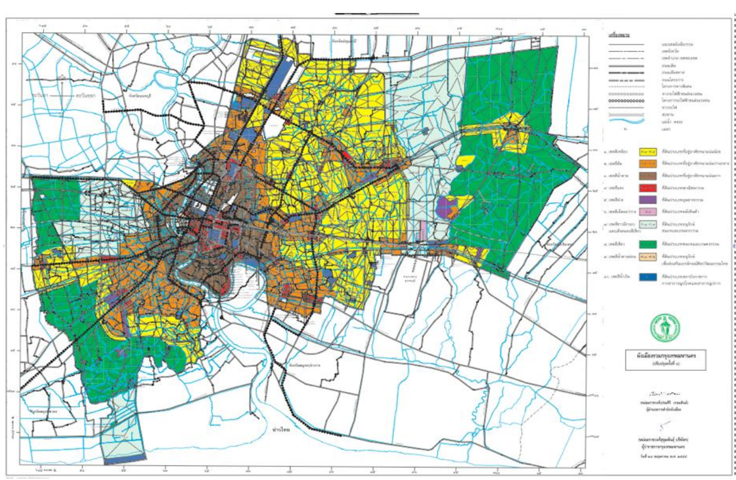


Figure 3.20. Bangkok Land Use Comprehensive Plan 2013

To control the rapid land use change in Bangkok, Ministry of Interior develops the Bangkok Structure Plan in 2006. The plan limits the expansion of urban area in Bangkok and the surrounding area which known as Bangkok Metropolitan Region (Figure 3.21).

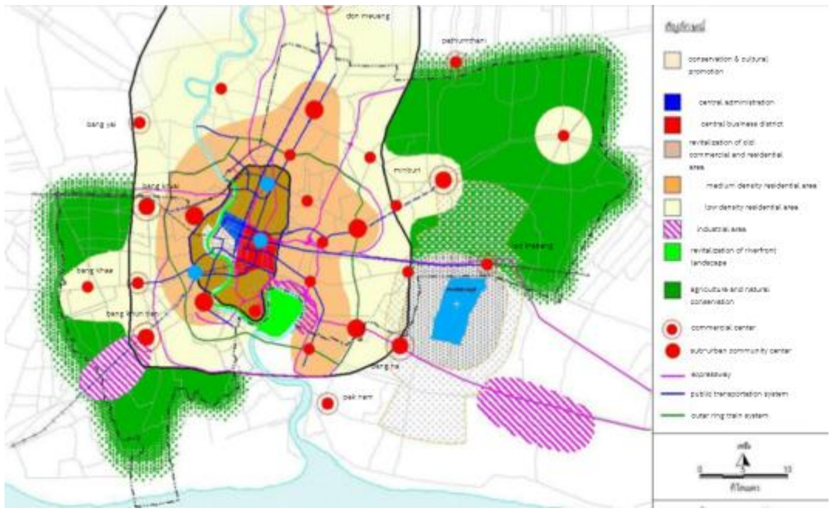


Figure 3.21. Bangkok Structure Plan 2006

Both plans are the main documents in guiding the development of Bangkok. The latest iterations and revision of the plan will guide the development of the city until 2057.

c. *Existing Policy on UHI Mitigation and Adaptation in Bangkok*

Policies directed to UHI mitigation are non-existent in Bangkok. However, the current efforts in mitigating and adapting to UHI are scattered in different development plans. Table 3.10 summarizes the related policies and efforts in UHI mitigation and adaptation.

Table 3.10. Policies related to UHI Mitigation and Adaptation in Bangkok

Documents	Year	Policy related to UHI
Green Area Master Plan	2007	• The plan aims to increase the ratio of green space in Bangkok to be 5 sq.m./person in next 25 years •
Bangkok GHGs Emission Mitigation Plan	2009	• Initiative 3 of the plan, which seeks to improve electricity consumption efficiency • Initiative 5, which tries to expand the park areas inside BMA and neighboring provinces
Bangkok Comprehensive Plan 2013	2013	• The new revision of the plan in 2012 include the plan to add more 50 city parks in Bangkok.

Green Area Master Plan 2007 is a complementary document to Bangkok Comprehensive Plan 2009 which aims to overseeing the green area development and increase the ratio of green space in Bangkok. In 2004, the ratio of green space is 2.98 sq.m/ person. The plan has been successfully increased the number into 3.33 sq.m/person in 2011. The number is still low compared to other major Southeast Asian Cities, such as Singapore (66.2) and Kuala Lumpur (43.9). The plan also proposes new locations of urban park, conducting street trees inventory and replanting, and greening the canals.

Table 3.11. Action Plan for Initiative 3 and 5 in Bangkok GHGs Emission Mitigation Plan 2009

Initiative	Action Plan	Remark
Initiative 3	• Improve Energy Efficiency in all BMA buildings • Promote and support the implementation of energy conservation scheme in privately owned buildings	The plan is followed up by the implementation of TREES certificate for green building in 2012 and giving FAR bonus to medium-high rise buildings which include green roof and open space in their design.
Initiative 5	• Plant trees in area under the jurisdiction of the Bangkok Metropolitan Administration • Campaign and support tree planting on private land in Bangkok • Plant trees in neighboring province areas	The plan corresponds to green area master plan 2007 and Bangkok Comprehensive Plan 2012.

Policies related to UHI can also be identified in Bangkok GHGs Emission Mitigation Plan 2009. From total five initiatives stated in the plan, two initiatives are directly related to UHI mitigation: initiative 3 of the plan, which seeks to improve electricity consumption efficiency and initiative 5, which tries to expand the park areas inside BMA and neighboring provinces. Table 5.2 summarizes action plan from each initiative. The above table shows that although there is no direct policies on related to UHI in Bangkok, there are already some measures to combat UHI as part of climate change mitigation plan in Bangkok.

3.2. Bandung, Indonesia

The following section describes the findings from Bandung case study. Center for Agrarian Studies of Institut Teknologi Bandung (CAS-ITB) was responsible to perform the research in Bandung Basin. Surrounded by a number of mountains, Bandung Basin is a sub-ecoregion of Cidurian-Citarum Ecoregion. Bandung Basin is located in five municipalities with a total extent of 343,087 hectares. Most importantly, climate of Bandung Basin is considerably milder compared to its surrounding.

In 2009, Bandung was still considered among the top four of most livable cities in Indonesia, particularly due to its pleasant urban design and environment. Nonetheless, while flooding has been annually occurred in some parts of Bandung Basin since the 19th century, a high rain intensity, which has been increasing since 2011, has caused a higher number of landslides, typhoons, and falling trees in Bandung in 2016 than it of 2015. While vulnerability to landslide increases at the beginning of rainy season after a long dry season, it has been reported that thypoons caused falling trees, other damages, and even fatal casualties. Although typhoon may normally happen during seasonal transition, the potential of typhoon occurrence has increased twice since 1998 due to climate change.

3.2.1. Characteristics of Urban Heat Island in Bandung, Indonesia

To acquire evidences, causes, and impacts of climate change in Bandung Basin, several data was required, namely land use/cover, LST, energy consumption, and public health, as well as perception on climate change. Such data was acquired from Landsat imageries and household survey. Furthermore, policy on climate change adaptation was also collected to be utilized as of inputs on recommendation-making process.

Landsat imageries were collected to obtain data concerning land use/cover and LST of Bandung Basin. The imageries were acquired from The National Satellite Land Remote Sensing Data Archive (NSLRSDA) at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center.

Land use/cover data of 1995, 2007, and 2015 was acquired from spectral bands of Landsat 5 TM of 1995 and 2007 and Landsat 8 OLI/TIRS of 2015, each was taken at a pointof time of the years. Spatial resolution of spectral bands of the mentioned imageries was 30 m. Furthermore, the average of annual LST of 1995, 2007, and 2015 was detected from thermal band of Landsat 5 Thematic Mapper (TM) of August, July, June, May, October, and September 1995 and August and September 2007, as well as thermal infrared band of Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRRS) of March, April, June, July, and October 2015, which representing different seasons in Indonesia. Spatial resolutions of the mentioned thermal bands were 120 and 100 m respectively.

To acquire land use/cover data, atmospheric correction was performed to increase accuracy of spectral reflectance of surface, which was followed by land use/cover classification after removing watershed areas, as well as areas covered by cloud and cloud shadow. The coverage of watershed areas in 1995, 2007, and 2015 was 3,739; 3,942; and 3,861 hectares respectively, while the extent of areas covered by cloud and cloud shadow in the mentioned years was 17,997 hectares or 3.8% of Bandung Basin area; 39,986 or 8.3% of extent of Bandung Basin; and 2,065 hectares or 0.4% of Bandung Basin extent respectively. Land use/cover classification was done by means of hybrid method, which combined unsupervised and supervised classification. Unsupervised classification employed minimum 10 and maximum 25 spectral classes, which the latter classes were defined by means of supervised classification using offical land use/cover data as its reference. The mentioned output was reclassified based on USGS land use/cover classification system. See Table 3.12 for USGS land/use cover classification system. In order to assess accuracy of land use/cover classification output, a confusion matrix was calculated. The matrix has been used mainly to provide a basic description of thematic map accuracy and for the comparison of accuracies, particularly as it provides more fully measures of accuracy that uses the information content compared to other thematic map accuracy assessment such as kappa coefficient of agreement.

Table 3.12. USGS land/use cover classification system (Hutajulu, 2016)

Class	Sub-class
Forest	Evergreen Broadleaf
	Evergreen Needleleaf
	Mixed Forest
Agriculture	Dryland Cropland and Pasture
	Irrigated Cropland and Pasture
	Mixed Dryland/Irrigated Cropland and Pasture
Residential	Commercial Area
	High Intensity Residential
	Medium Intensity Residential
	Low Intensity Residential
Water Bodies	-
Barren or Sparsely Vegetated	-

Having calculated omission and commission of classification of satellite imageries of 1995, 2007, and 2015, it was concluded that the accuracy of land use/cover classification was considerably adequate to be utilised. The overall accuracy of land use/cover data of 1995, 2007, and 2015 was 71%, 74%, and 81% respectively.

To acquire a correct land use/cover classification, a further consistency assessment was performed by comparing land use/cover classification outputs of 1996 and 2007, as well as 2007 and 2015. Such an assessment resulted in especially an inconsistent residential class of 2007 (Hutajulu, 2016). Such an inconsistency was identified as the mentioned class was classified under rice field in 1995 and 2015.

While acquisition of Landsat imagery was done during dry season of 2007, several rice fields that were located near settlement areas were classified as barren land, which, due to reclassification of residential areas into low, medium, and high-intensity residential types, were merged into low or medium-intensity residential areas. Therefore, the inconsistency was corrected by assigning parts of low or medium-intensity residential areas into rice fields, which were classified under irrigated cropland and pasture. See Figure 3.22 for land use/cover classification of Bandung Basin of 1995, 2007, and 2015.

To assess relationship between land use/cover and climate change, the produced land use/cover map, which spatial resolution was 30 m, was resampled to it of 120 m spatial resolution. The method of resampling was nearest neighbor.

LST can be acquired by converting At-Satellite Brightness Temperature data of thermal bands of Landsat. Having obtained LST from various points of 1995, 2007, and 2015, averages of annual LSTs of the mentioned years were calculated. See Figure 2.3 for LST of Bandung Basin of 1995, 2007, and 2015.

On the use of LST, such data was firstly validated by means of official near surface air temperature data. Such a process revealed that LST and near surface air temperature data were highly correlated.

		Actual Change Status	
		Changed	**No Change**
Modeled Change Status	**Changed**	Correctly Classified	Commission Errors
	No Change	Omission Errors	Correctly Classified

Figure 3.22 Confusion matrix for mapping land use/cover change (Pierce Jr., 2015)

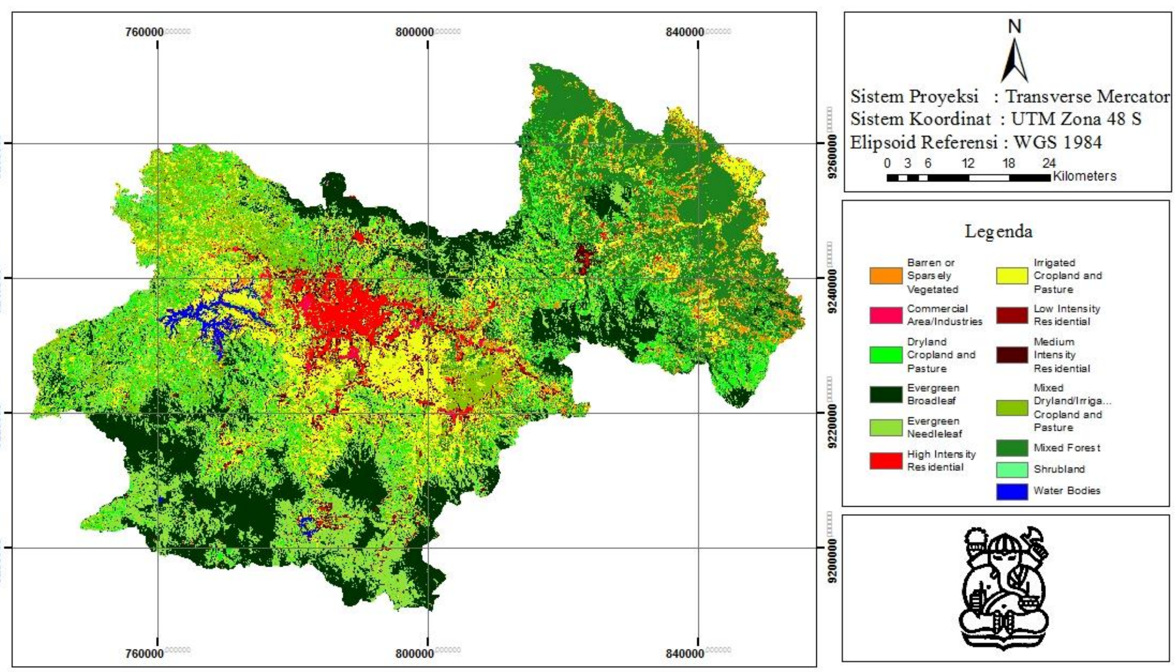


Figure 3.23a. Land use/cover classification of Bandung Basin in 1995

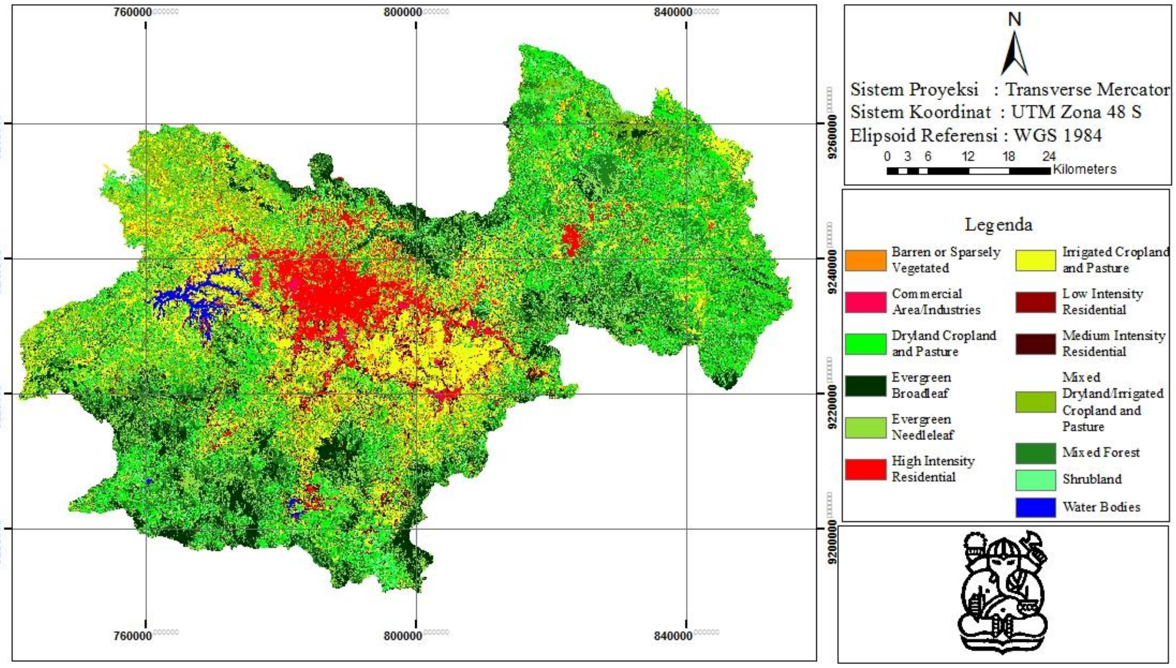


Figure 3.23b. Land use/cover classification of Bandung Basin in 2007

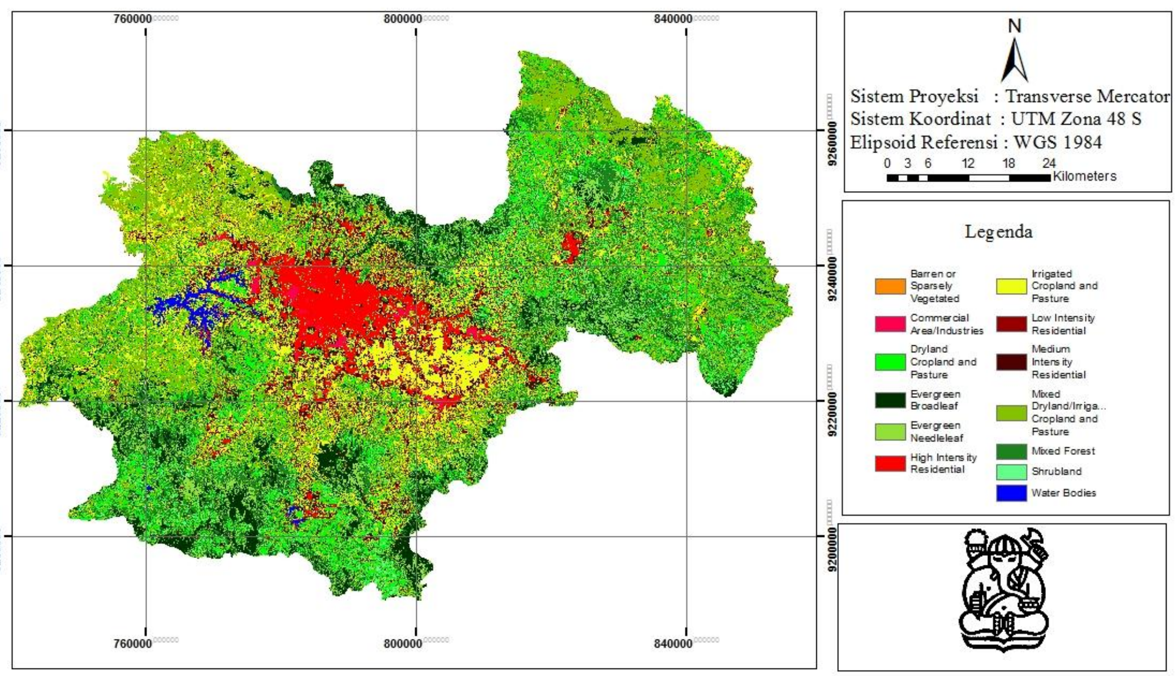


Figure 3.23c. Land use/cover classification of Bandung Basin in 2015

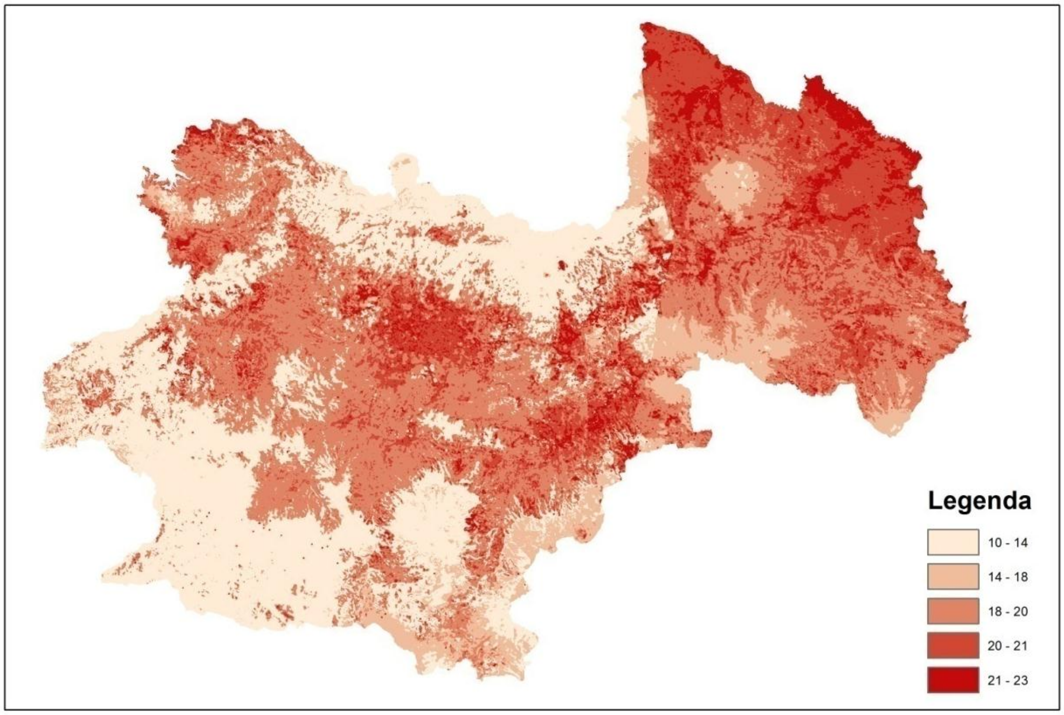


Figure 3.24a Land Surface Temperature of Bandung Basin in 1995

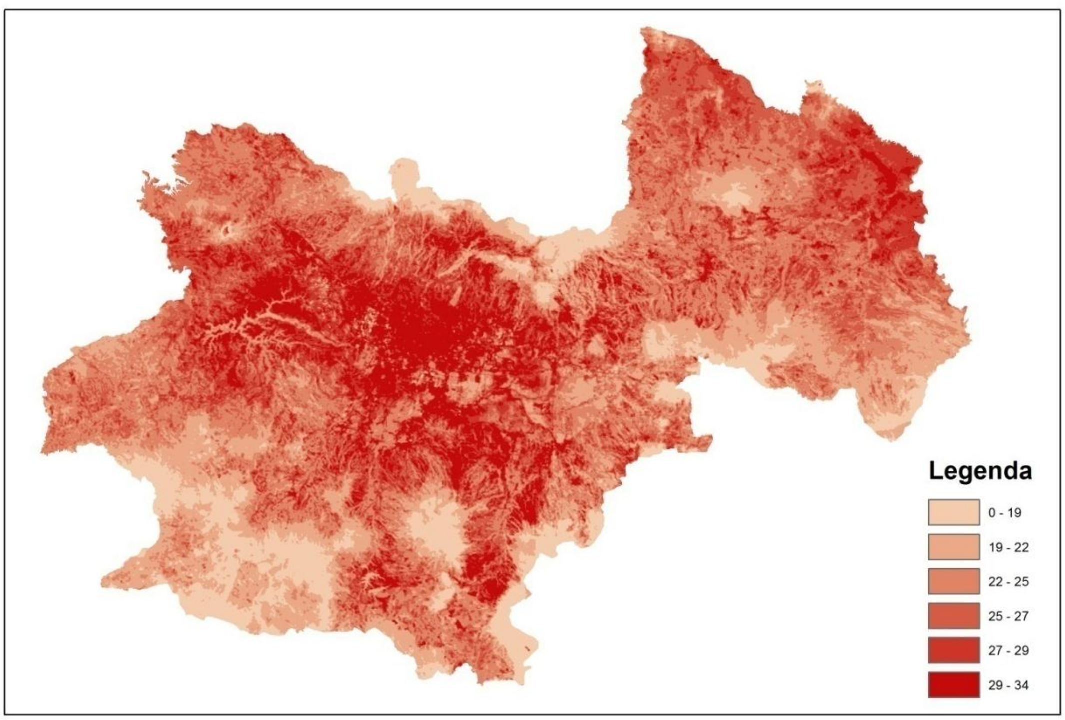


Figure 3.24b. Land Surface Temperature of Bandung Basin in 2007

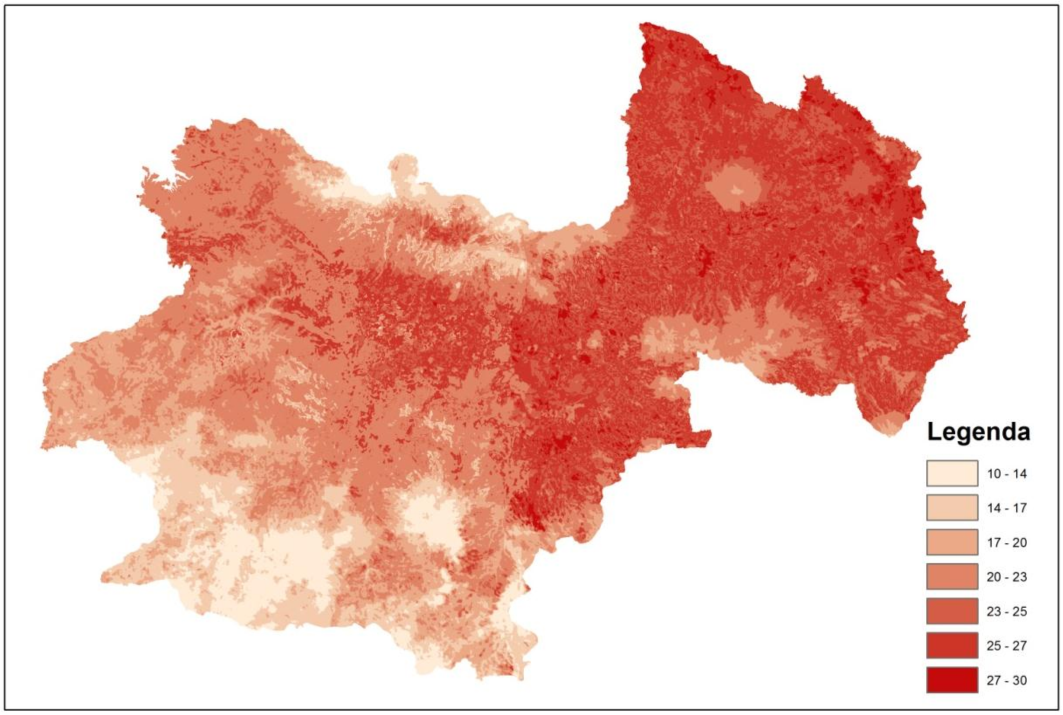


Figure 3.24c. Land Surface Temperature of Bandung Basin in 2015

LST change was analyzed by a combination of spatial analysis method of raster data overlay and basic statistical method. Averages of annual LST of 1995, 2007, and 2015 were overlaid to acquire LST changes on each 120 x 120 m2 pixel. 120 meter spatial resolution was utilized as the analysis was performed using satellite imageries with different spatial resolution, namely LST of 1995 and 2007 with 120 meter spatial resolution and LST of 2015 with 100 meter spatial resolution. The lower spatial resolution was chosen because image with lower spatial resolution that is resampled to a higher resolution without adding depth to data does not provide a same level of detail compared to image that originally has the targeted spatial resolution. Having overlaid the mentioned LSTs, value of minimum, maximum, and average of each LST, as well as LST changes between 1995 and 2007, between 2007 and 2015, and minimum, maximum, and average of LST change, were identified.

Having analysed LST of 1995, 2007, and 2015, climate in Bandung Basin had changed. The maximum value of LST had risen 60 C from 240 C in 1995 to 300 C in 2015 (Hutajulu, 2016). The average of LST had increased 40 C from 180 C in 1995 to 220 C in 2015, while the minimum value of LST in 1995 and 2015 was 100 C (Hutajulu, 2016). Moreover, in 1995, Bandung Basin was dominated by areas with LST of 200 C, which was as large as 147,116 hectares or 31%, while, in 2015, the mode of LST was 260 C as it was occurred in 14% of Bandung Basin area or 66,922 hectares (Hutajulu, 2016).

Especially in 2007, as the imageries were taken on August and September, in which particularly Bandung Basin and Province of West Java in general were experiencing an intense dry season, the maximum, minimum, and average value of LST were considerably higher compared to them of 1995 and 2015 (Hutajulu, 2016). Furthermore, the mode of LST of 2007 was equal to it of 2015, which was occurred in 17% of Bandung Basin area or 83,139 hectares. Such facts reveal an incidence of extreme climate in Bandung Basin. This is in accordance with climate data of the mentioned months, as August 2007 was completely dry (BPS Jawa Barat, 2008). Also, maximum temperature of August and September 2007 was 30^0 and 31^0 C, which was the third and highest maximum temperature in Bandung Basin in 2007 (BPS Jawa Barat, 2008). See Table 3.13 for an overview of LST of Bandung Basin in 1995, 2007, and 2015.

Table 3.13 LST of Bandung Basin in 1995, 2007, and 2015

Year	**Land Surface Temperature**		
	Maximum (^{0}C)	**Minimum (^{0}C)**	**Average (^{0}C)**
1995	24	10	18
2007	34	12	25
2015	37	10	22

Evidence of UHI in Bandung Basin can be identified from LST. High LST was identified at Municipality of City of Bandung, as well as urban areas of other municipalities in Bandung Basin, such as District of Soreang, which is the governance center of Municipality of Bandung; District of Majalaya, an industrial area at Municipality of Bandung; and District of Lembang, an agricultural center at Municipality of Western Bandung. Especially at Municipality of Bandung, LST of 49.08% of the area in 2015 was between 25^0 and 29^0 C, while LST of 48.92% of Municipality of Bandung at the same year was between 20^0 and 25^0 C.

Land use and land cover change in Bandung

Bandung Basin has been experiencing a population boom, especially between 1995 and 2007. During the mentioned period, population of Bandung Basin increased 46% from 5,854,449 to 8,526,896 (BPS Jawa Barat, 1995; BPS Jawa Barat, 2008). Although the population only increased 2% between 2007 and 2015, the population number between 1995 and 2015 increased 2,864,030 or 49% compared to it of 1995 (BPS Jawa Barat, 1995; BPS Jawa Barat, 2007; BPS Jawa Barat, 2015).

Impact of such a growth was severe. Forest coverage of Bandung Basin between 1995 and 2007 was declining 54,012 hectares or 24% of it of 1995, while the extent of barren or sparsely vegetated areas at the same period was decreasing 4,550 hectares or 19% of it of 1995. On the other hand, extent of agricultural, residential, and commercial areas between 1995 and 2007 was increasing 31,945 hectares or 16%; 3,916 hectares or 10%; and 509 hectares or 24% of it of 1995 respectively. The same trend of land use/cover change between 2007 and 2015 occurred, although it was dominated by the increasing of coverage of residential areas of 21,213 hectares or 36% of it of 2007. See Figure 3.25 for land use/cover change in Bandung Basin in 1995, 2007, and 2015.

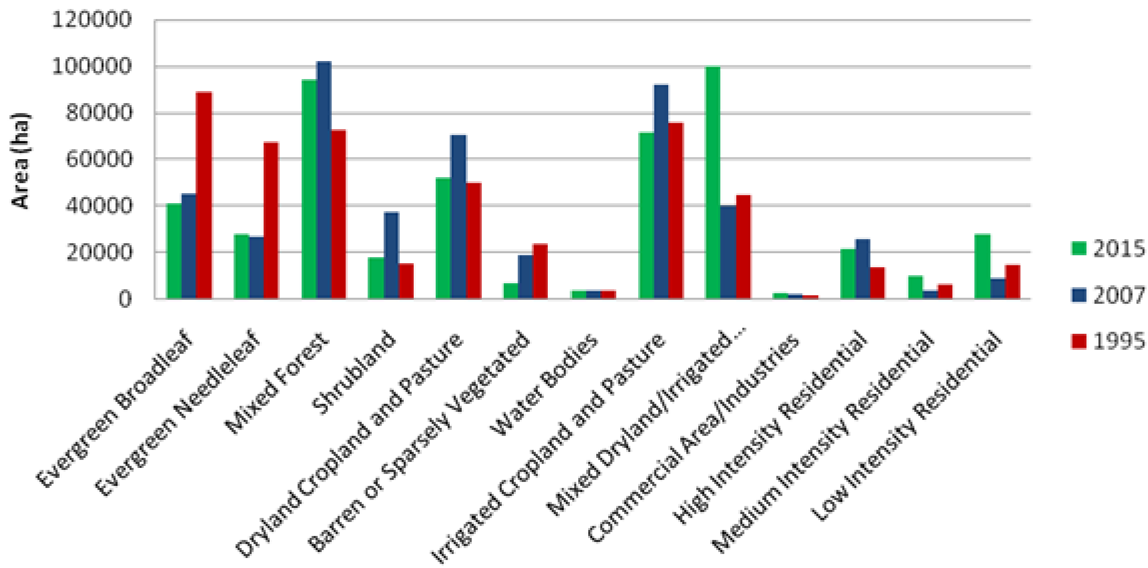


Figure 3.25. Land use/cover change in Bandung Basin in 1995, 2007, and 2015

Land use/cover and land surface temperature

We analyzed the relationship between land use/cover change and land surface temperature using overlay analysis and Pearson's Chi-square test of independence. Land use/cover and LST of the corresponding year of 1995, 2007, and 2015 were overlaid. Moreover, relationship of each corresponding pixels was analyzed using Chi-square test of independence with null hypothesis that there is no relationship between land use/cover and LST of Bandung Basin. We found that land use/cover and LST of 1995, 2007, and 2015 are significantly related. This is because the output of such a test was 0, which is less than 0.05. Therefore, null hypothesis was rejected. See Table 3.14 for output of Pearson's Chi-square test of independence of land use/cover and LST of 1995, 2007, and 2015.

Table 3.14. Output of Pearson's Chi-square test of independence of land use/cover and LST of 1995, 2007, and 2015

Chi-Square Tests			
	Value	**Df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	1.173E5	308	0
Likelihood Ratio	118,300	308	0
N of Valid Cases	1,338,688		

Having understood the relationship between land use/cover and LST in Bandung Basin in 1995, 2007, and 2015, the further analysis was to identify relationship between land use/cover and LST change. Average of LST of forest, which covered 228,260 hectares or 49% of Bandung Basin area in 1995, was 17^0 C, and 20 years later in 2015, average of LST of 163,338 hectares of forest area was 21^0 C. The increasing of agricultural area extent from 170,477 hectares in 1995 to 241,552 hectares in 2015 had contributed to the raise of average of LST of such a land use/cover type as many as 5^0 C.

Furthermore, the largest raise of LST average was detected on commercial areas. Although the extent of such areas was only increased 1,016 hectares from 1,593 hectares in 1995 to 2,609 hectares in 2015, the land use/cover type contributed to the raise of average of LST as many as 8^0 C. The second largest LST average raise of 70 C was contributed by residential areas, which extent raised from 34,477 in 1995 to 59,606 in 2015.

As aforementioned, due to a limited availability of clear satellite imagery in 2007, land use/cover and LST of 2007 were affected by an extreme dry season. Among its consequences was higher LST average of all types of land use/cover in Bandung Basin. Although, in 2007, residential areas only covered 38,393 hectares or 9% of Bandung Basin area, it produced the highest LST average among other land use/cover types, which was 28^0 C. The second highest LST average was emitted by barren or sparsely vegetated land use/cover type that was 27^0 C, which was followed by LST average of agricultural areas that was 26^0 C. Moreover, commercial areas only produced LST average of 25^0 C, while forest emitted the lowest LST average of 240 C. See Table 3.15 for land use/cover extent and LST average of land use/cover type in 1995, 2007, and 2015.

Table 3.15. Land use/cover extent and LST average of land use/cover type in 1995, 2007, and 2015

Land use/cover Type	**1995**			**2007**			**2015**		
	Extent (ha)	**Extent (%)**	**LST Average**	**Extent (ha)**	**Extent (%)**	**LST Average**	**Extent (ha)**	**Extent (%)**	**LST Average**
Forest	228,260	49.4%	17	174,247	39.6%	24	163,338	34.2%	21
Agriculture	170,477	36.9%	18	202,423	46.0%	26	241,552	50.5%	23
Residential	34,477	7.5%	18	38,393	8.7%	28	59,606	12.5%	24
Commercial	1,593	0.3%	17	2,102	0.5%	25	2,609	0.5%	25
Barren or Sparsely Vegetated	23,522	5.1%	18	18,972	4.3%	27	7,035	1.5%	22

Having compared LST average of 2007, which data source was acquired during a dry season of 1995 and 2015 that was acquired at dry and rainy season, dry season tended to amplify LST of barren or sparsely vegetated and agricultural areas. While in 1995 LST averages of 5 main land use/cover class were between 17^0 and 18^0 C, the highest LST average in 2015 was recorded to be produced by commercial areas. Moreover, in 2015, barren or sparsely vegetated and agricultural areas produced second and third lowest LST averages, which were 22^0 and 23^0 C respectively.

Relationship between sub-classes of agricultural areas and LST average change in 1995, 2007, and 2015 was also vary. While dry land and irrigated cropland and pasture emitted higher LST average along enlargement of such land use/cover types, LST average of mixed dry land/irrigated cropland and pasture were significantly reduced along enlargement of extent of the latter land use/cover type.

Concerning relationship between residential areas and LST average change in 1995, 2007, and 2015, high intensity residential and commercial areas produced a higher LST average along extension of the mentioned land use/cover types. On the other hand, LST average of medium and low intensity residential areas reduced along additional extent of such land use/cover types.

We also calculate the correlation between types of land use in the Municipality of Sumedang to understand the effect of land use change to the temperature change. Table 3.16 summarizes the result of correlation between different types of agricultural land and land surface temperature.

Table 3.16. Correlation model between land use and land surface temperature

Type of Land Use/ Cover	Correlation Model	Adjusted R2	P- value
Agricultural land			
Mixed dry land/ irrigated cropland and pasture	y = -0.0001x + 7.962	0.505	p<0.05
Irrigated cropland and pasture	y = 0.0001x + 4.679	0.877	p<0.05
Dry land cropland and pasture	y = 0.0001x + 2.435	0.954	p<0.05
Forest cover			
Mixed forest	y = 0.0001x + 0.273	0.999	p<0.05
Evergreen needleaf	y = 0.0001x + 1.901	0.951	p<0.05
Evergreen broadleaf	y = 0.0001x + 3.254	0.885	p<0.05
Built area			
High intensity residential	y = 0.0001x + 0.043	0.999	p<0.05
Medium intensity residential	y = 0.0001x + 6.704	0.802	p<0.05
Low intensity residential	y = 0.0001x + 7.943	0.684	p<0.05
Commercial and industries	y = 0.0001x + 0.030	0.239	p<0.05

The table revealed the correlation between land use/cover and LST change between 1995 and 2015. Agricultural types of land use/cover change, except mixed dryland, were contributing on increasing LST. See Figure 3.3 for details. Moreover, the change of extent of mixed forest was also contributing to increase LST, while evergreen needleleaf and evergreen broadleaf were significantly decreasing LST. See Figure 3.4 for details. While the extent of built environment was increasing as many as 26,104 hectares, it was only high intensity residential type of land use/cover that was correlated to the increasing of LST.

Additionally, architecture of houses that had AC installed in them was also contributing on releasing anthropogenic heat. Architecture of 55.26% of houses that had AC installed in them was minimalist.

Perceived temperature change

Pre-household survey in 2015 also revealed that citizens of Bandung Basin had experienced climate change in various degrees. 250 respondents, or 82% of total respondents, agreed that climate of Bandung Basin had considerably changed. 217 respondents, or 87% of respondents who stated that the climate of Bandung Basin had changed, mentioned that temperature of Bandung Basin had become hotter, while only 7 respondents stated that temperature of the research area had been cooler than before. Additionally, 3 respondents stated that the climate of Bandung Basin had been unpredictable.

On the distribution of respondents, 94 of 217 respondents who stated that the climate of Bandung Basin had become hotter, or 38%, live at Municipality of City of Bandung; while number of respondent stated that the climate of Bandung Basin had become hotter at Municipality of City of Cimahi, Bandung, Western Bandung, and Sumedang was 17, 27, 53, and 26 respectively. Therefore, 71% respondents agreed that Bandung Basin had become hotter.

Especially at Municipality of Sumedang, respondents mentioned that the municipality has become hotter since Jatigede Dam was activated in 2015. LST of 2015 of such a municipality confirmed the statement. LST of 52.55% of municipality area in 2015 was between 25 and 30^0 C, while LST of 43.97% of the area at the same year was between 20 and 25^0 C. Moreover, LST of 0.04% of the area in 2015 was between 30 and 35^0 C, although there were 3.44% of the area with LST between 16 and 20^0 C. See Figure 3.26 for LST of Municipality of Sumedang.

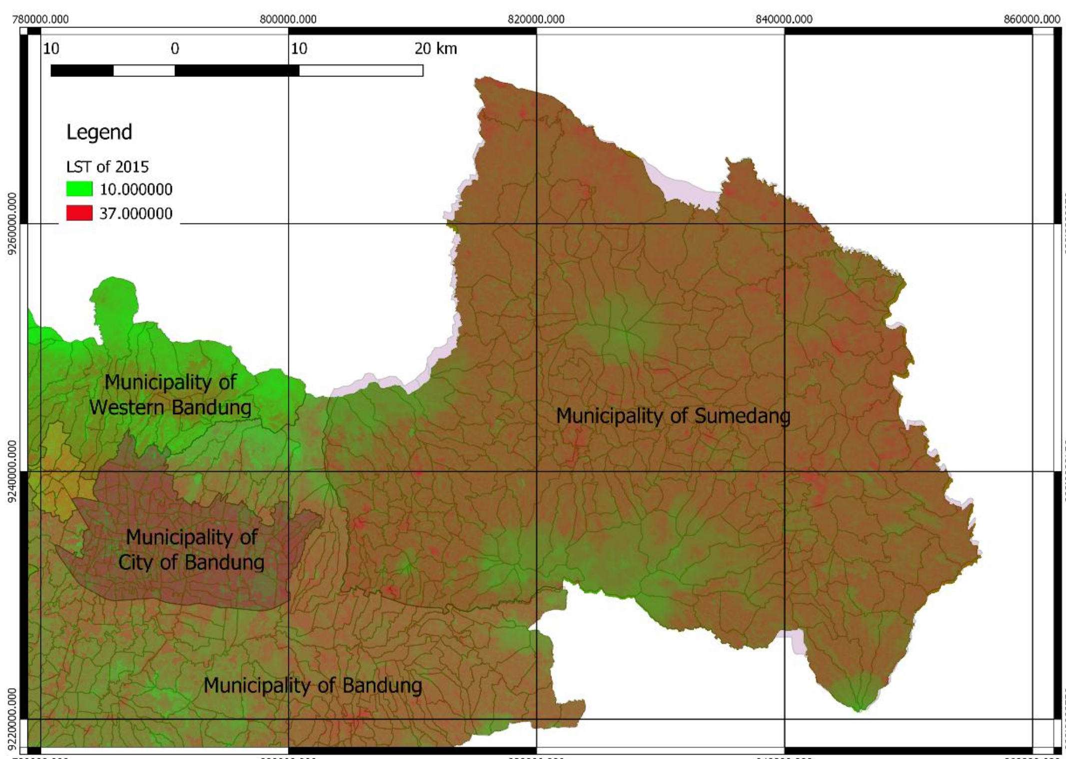


Figure 3.26. LST of Municipality of Sumedang Shows the Temperature Difference in 2015

On the other hand, respondents live in rural areas of Bandung Basin stated that the climate had not changed much. There were only 17, 32, and 27 respondents live at Municipality of City of Cimahi, Western Bandung, and Sumedang stated that climate in their areas had become hotter. Percentages of the above number of respondent were less than 11% of total respondents. Land use of the mentioned municipalities was dominated by rural areas.

3.2.2. The Effects of Urban Heat Island in Bandung, Indonesia

The following section describes the effects of urban heat island in Bandung, Indonesia. The study manages to identify two important effects of UHI in Bandung, which is household energy consumption and health and well-being.

a. The effect of UHI in Bandung to household energy consumption

One of the biggest effect of UHI in Bandung is the rising amount of household energy consumption. The Household energy consumption identified using expenditure approach on the average component of monthly electricity bills, expenditure on private vehicles usage, expenditure on public transportation, and expenditure on cooking fuel.

This study selected four locations in Bandung as research areas. Every location represents different characteristic of urban form. These four locations are Astana Anyar, Braga, Sarijadi and Margahayu. Astana Anyar and Braga represent the urban form with the characteristics of unorganized settlement, close proximity to the city center, and the surrounding land use is dominated by mixed-use (commercial and residential). The average lot size in Astana Anyar is 70.62 m2. That amount is considerably large for the housing size in the city center. In contrast to Astana Anyar, the average of lot size in Braga is smaller, that is 16.65 m2. Sarijadi represents the urban form with the characteristics of vertical housing and located in sub-center of the city. The housing type in Vertical House Sarijadi is type 36 or 36 m2. Margahayu represents the urban form with the characteristics of organized settlement, located in sub-urban area designated for residential use, and far from the downtown or mixed-use area. The average lot size in Margahayu is 173m2.

One of the components seen in the formation of urban form is the community layout or street orientation. The community layout in Astana Anyar and Braga is difficult to be identified because the housing type is unorganized. In contrast to the cases in Margahayu and Sarijadi where the type of housing is organized. Most of the community layout in Margahayu and Sarijadi has north-south street orientation, whereas the good street orientation is the east-west street orientation because that kind of street orientation allows the solar access so can reduce the using of household electricity.

Table 3.17 Characteristics of Urban Forms in the Study Area

Urban Forms	Distance to City Center	Average Lot Size	Average Density	Housing Type	Road Networks	Street Orientation	Land Configuration	Socio-Economic Condition
Astana Anyar	Close to city center	$70.62m^2$	142 houses/ha	Landed-Unorganized Settlement	Irregular	Unidentified	Surrounded by mixed-use; Close to facilities	Low – Middle
Braga	Close to city center	$16.65m^2$	600 houses/ha	Landed-Unorganized Settlement	Irregular	Unidentified	Surrounded by mixed-use; Close to facilities	Low – Middle
Sarijadi	Quite far from the city center	$36m^2$	278 houses/ha	Vertical – Organized Settlement	Grid	North-South	Not surrounded by mixed-use; Close to residential facilities	Middle
Margaha yu	Far from the city center	$173m^2$	38 houses/ha	Landed – Organized Settlement	Grid	North-South	Part of housing is surrounded by mixed us; Close to residential facilities	Middle – High

The number of respondents surveyed in each location is the same. For the case of Astana Anyar – Braga the number of respondents is 100 which is divided into two locations, so each location consists of 50 respondents. For the case of Sarijadi Flat, the number of respondents is 100 and for Margahayu, the number of respondents is 200 because we aim to see the difference between the neighborhood which has close proximity to the mixed-use and the one which far from the mixed-use. Table 3.18 summarizes some important characteristics of the respondents.

Table 3.18. Socioeconomic Characteristics of the Respondents for the Survey

Variable	Sub-District			
	Astana Anyar	Braga	Sarijadi	Margahayu
Household member	79% less than 4 members; 21% more than 4 members	97% less than 4 members; 3% more than 4 members	92% less than 4 members; 7% more than 4 members	80% less than 4 members; 20% more than 4 members
Length of stay	9% less than or 10 years;91% more than 10 years	72% less than or 10 years; 28% more than 10 years	26% less than or 10 years;74% more than 10 years	22% less than or 10 years; 78% more than 10 years
Housing status	76% house owner; 16% rental, 8% other	82% house owner; 14% rental, 4% other	78% house owner; 18% rental, 4% other	86% house owner; 6% rental, 8% other
Income (in IDR)	40 % less than 2.5 million; 52% 2.5-5 million; 8% more than 5 million	10 % less than 2.5 million; 88% 2.5-5 million; 2% more than 5 million	21 % less than 2.5 million; 74% 2.5-5 million; 5% more than 5 million	12 % less than 2.5 million; 40% 2.5-5 million; 48% more than 5 million

Table 3.18 the majority of respondents' income in Astana Anyar is 2.5-10 million per month. And then, 40% of respondents have income less than 2.5 million per month. In the case in Braga, 90% of respondents have income 2.5-6 million per month. Then another 10% earn less than 2.5 million per month. The case in Sarijadi is similar to the case in Braga, where the majority of respondents have monthly income for about 2.5-10 million. While the other 21% earn less than 2.5 million per month. Cases in Margahayu are more varied, 40% of respondents have income of 2.5-5 million per month, 38% of respondents earn 5.1-10 million per month, 12% others earn less than 2.5 million per month and 10% of respondents have income more than 10 million per month.

Astana Anyar - Braga

Monthly electricity bill in Braga and Astana Anyar is considerably low. The majority of respondents or about 42% have electricity bills less than equal to 100,000 per month. The second majority (27%) respondents have electricity bill more than 100.000 to 200.000 per month.

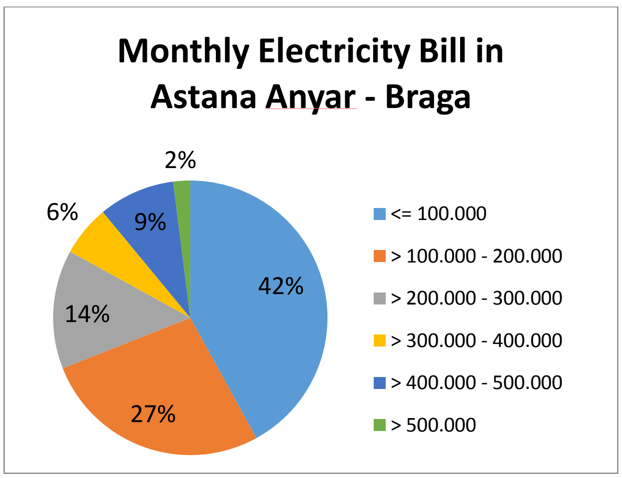


Figure 3.27. Monthly Electricity Bill in Astana Anyar - Braga

These amounts in line with the low ownership of electrical appliances in both places. In Braga, only 36 respondents who have a fan, and no one has exhaust fan. In Astana Anyar, fewer respondents have a fan that is 23 out of 50 respondents and only 4 respondents who have an exhaust fan. In both places, no one has AC. The frequency of fan use is also thought to affect the monthly electricity bill. In Astana Anyar and Braga, the frequency of fan use at most is several times during the day and night. Based on survey, the use of a fan in the last three years remains the same, but there are also respondents who answered more often. Some respondents who answered more often revealed that the reason for using the fan more often because Bandung is getting hotter.

Sarijadi

Monthly electricity bill in Sarijadi is a little higher than those in Astana Anyar and Braga. There are 39% of respondents whose electricity bills is more than 100.000 to 200.000 per month. Even though, the majority of respondents or about 60% respondents have electricity bills less than equal to 100,000 per month. The monthly electricity bill in Sarijadi almost homogeneous, there is only 1% whose electricity bills is more than 200.000 to 300.000. It is probably due to the same type of house that is type 36 so that the power provided for electricity is the same.

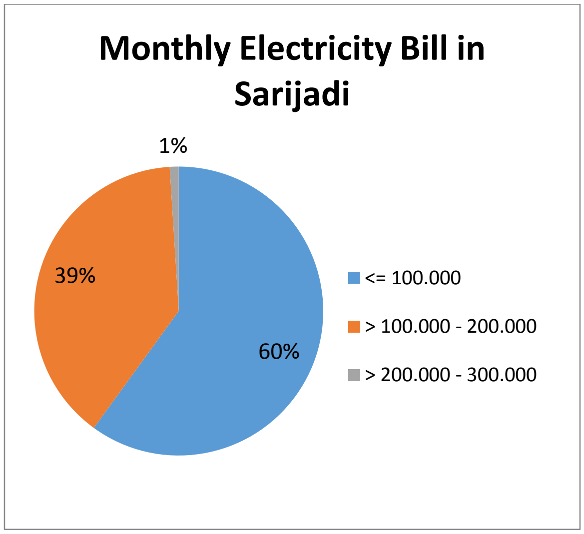


Figure 3.28. Monthly Electricity Bill in Sarijadi

Electronic appliances ownership in Sarijadi is quite high. There are 60 families who have fan, 27 families who have exhaust fan, and 91 families who have refrigerator. But no one has AC. Although the electronic appliances ownership is high, but the frequency of usage is quite rare. There are only 4 respondents who use the fan almost every day and night. Most of them use it in a few hours in a day or several times during the day and night. The frequency of fan or exhaust fan usage is also thought to affect the monthly electricity bill. Based on survey, the use of a fan in the last three years remains the same, but there are also respondents who answered less often and more often. There are 19 respondents answered less often in using fan and there are only 13 respondents answered more often in using fan.

Margahayu

Monthly electricity bill in Margahayu is relatively high, that is more than 300.000 to 600.000. This is due to the ownership of electronic appliances especially AC. There are 49 respondents who have AC, 142 respondents who have fan, 46 who have exhaust fan, and 191 respondents who have refrigerator. Although there are only 49 out of 200 respondents who have AC, but the frequency of AC use in Margahayu is quite high. From 49 respondents who have AC, there are 19 respondents who use AC several times during the day and night and there are 15 respondents who use AC almost every day and night. The lot size is also thought to affect the monthly electricity bill, because the bigger the house the more space it requires the lights, thus affecting the use of electricity.

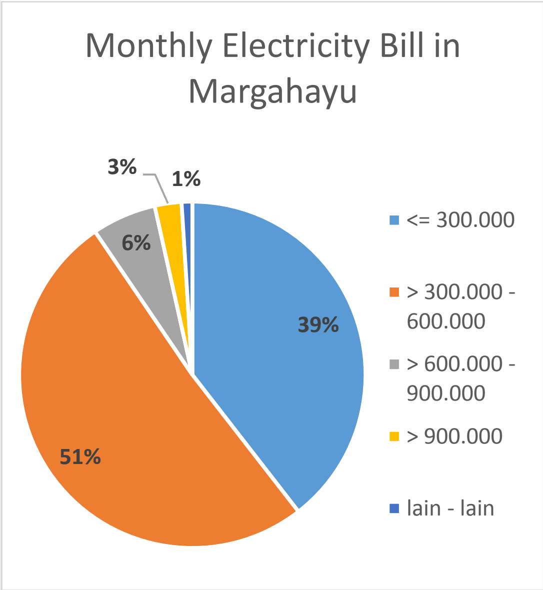


Figure 3.29. Monthly Electricity Bill in Margahayu

Analysis of Energy Consumption Pattern Based on Average Income

To understand the relationship between the income levels with the amount of household energy consumption each month we analyzed household energy consumption identified using expenditure approach on the average component of monthly electricity bills, expenditure on private vehicles usage, expenditure on public transportation, and expenditure on cooking fuel.

There are four income levels, those are:

1. Average income less than 2.5 million per month
2. Average income ranging from 2.5 to 5 million per month
3. Average income ranging from 5.1 to 10 million per month
4. Average income more than 10 million per month

As for the average income of less than 2.5 million per month (group 1), the majority of respondents have to pay for electricity bill, public transportation, private vehicle use, and cooking fuel of 100,000 per month for each of these expenses.

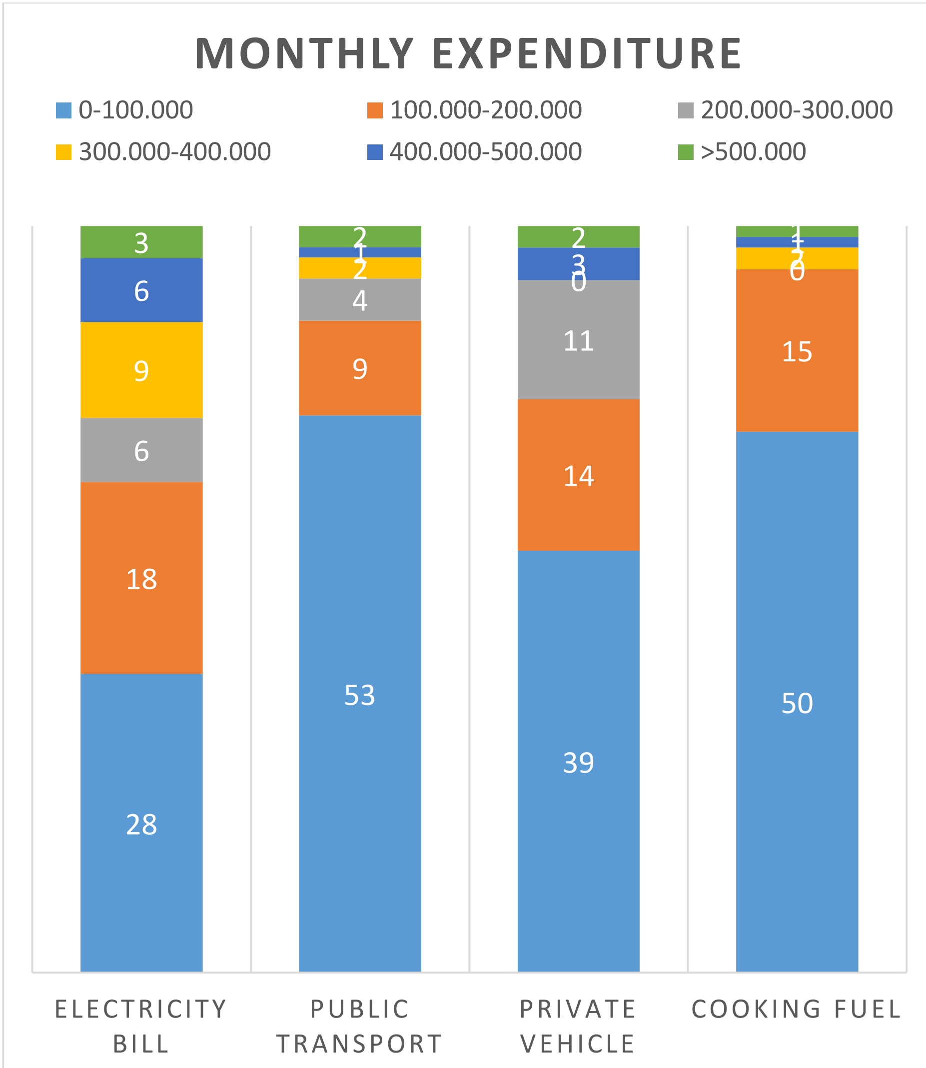


Figure 3.29. Monthly Energy Consumption Pattern for Income Group 1

As for the respondents with average income of 2.5 to 5 million per month (group 2), the majority of respondents have to pay for electricity bill, public transportation, private vehicle use, and cooking fuel of 100,000 per month for each of these expenses. This amount is equal to respondents who have income less than 2.5 million per month. And then, the proportion of the use of public transport is also greater than the use of private vehicles.

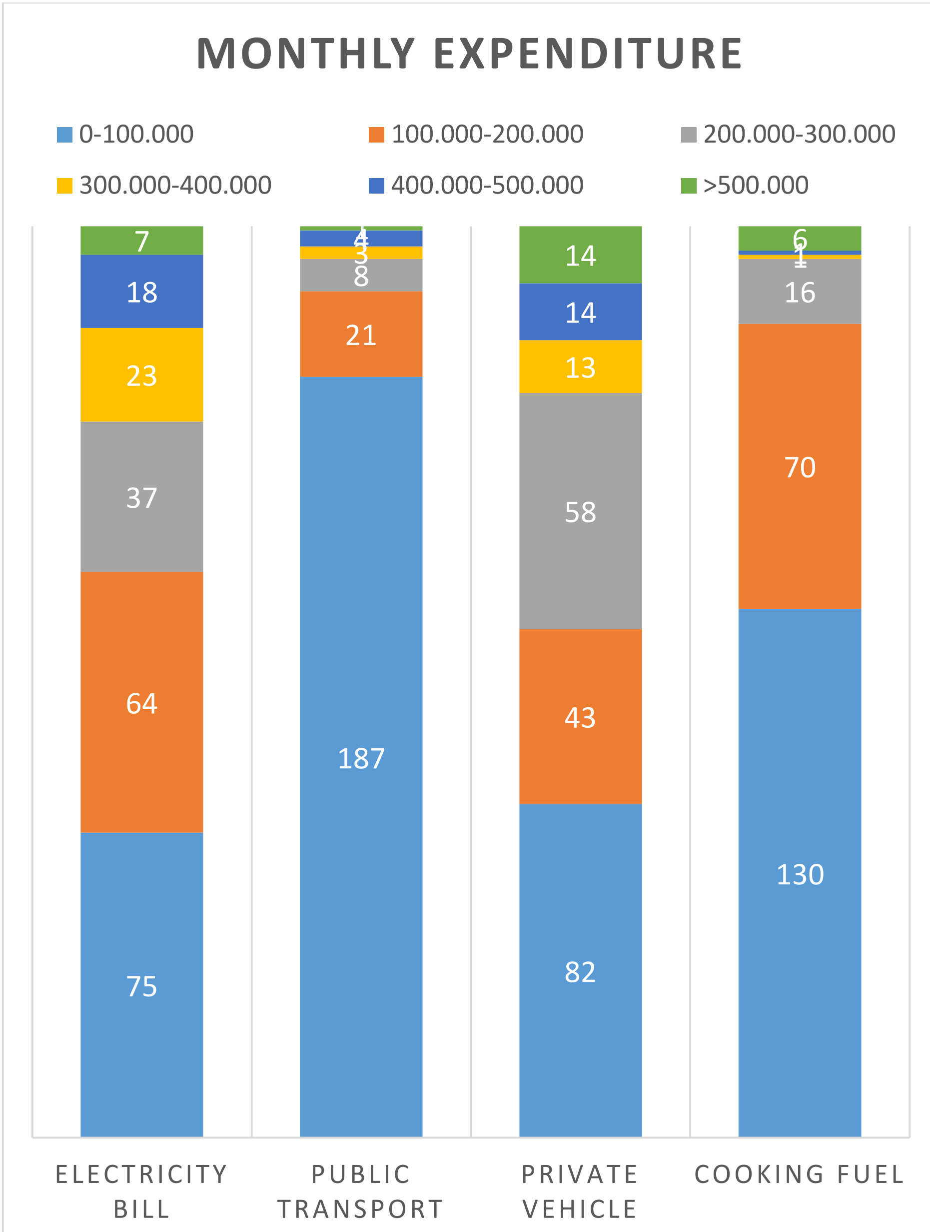


Figure 3.30. Monthly Energy Consumption Pattern for Income Group 2

As for the respondents with average income 5.1 to 10 million rupiahs per month (group 3), the expenditure on electricity, public transportation, private vehicle use, and cooking fuel are varied. For the electricity bill, the majority of respondents have to pay 300.000 to 400.000 per month. For public transport use, most of them have to expense less than 200.000 per month. Then for private vehicle use, majority of respondents have to spend more than 500.000 per month. Lastly, for the expenditure of cooking fuel, it cost 0-200.000 per month.

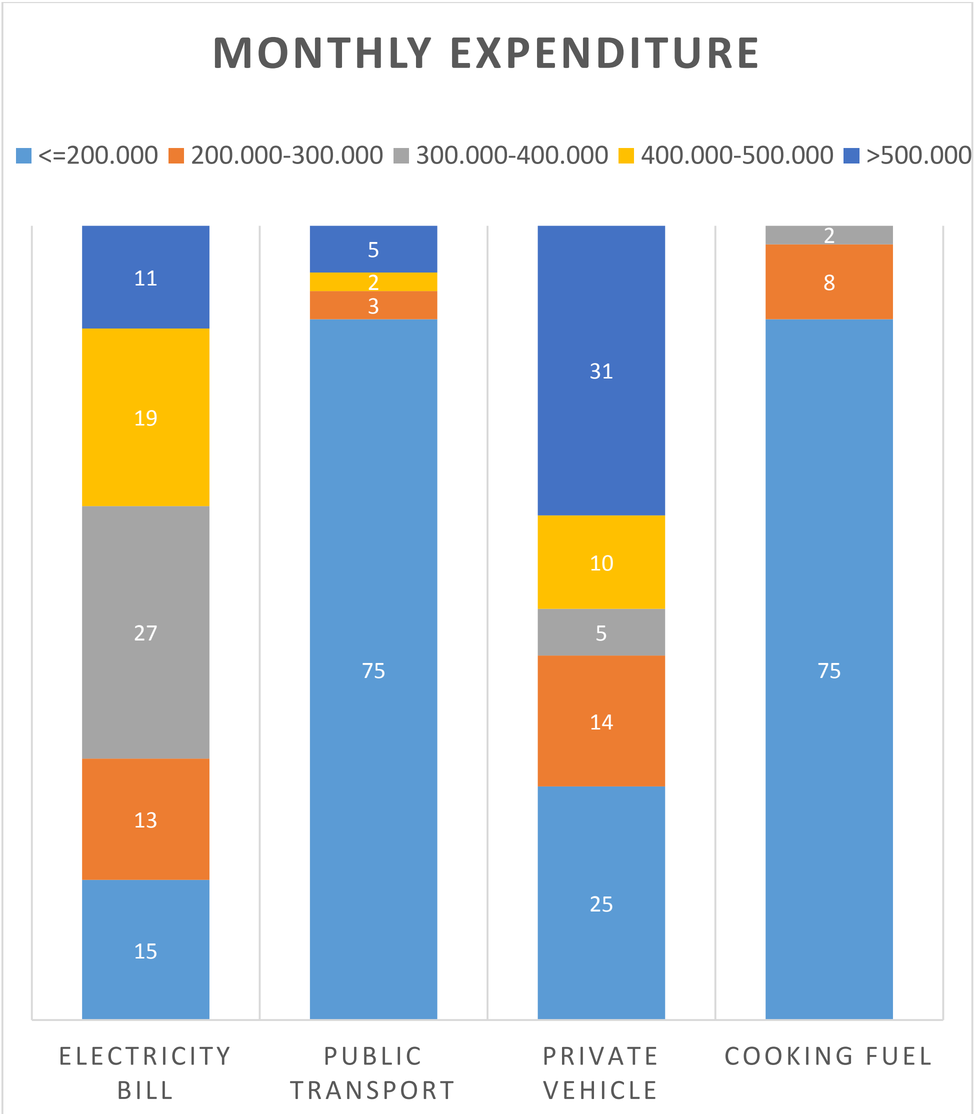


Figure 3.31. Monthly Energy Consumption Pattern for Income Group 3

As for the respondents with average income more than 10 million per month (group 4), the expenditure on electricity, public transportation, private vehicle use, and cooking fuel are also varied. For the electricity bill, the majority of respondents have to pay more than 400.000 per month. For public transport use, most of them have to expense less than 200.000 per month. Then for private vehicle use, majority of respondents have to spend more than 500.000 per month. Lastly, for the expenditure of cooking fuel, it cost 0-200.000 per month. Differences in energy consumption look very significant on expenditure for electricity and the use of private vehicles.

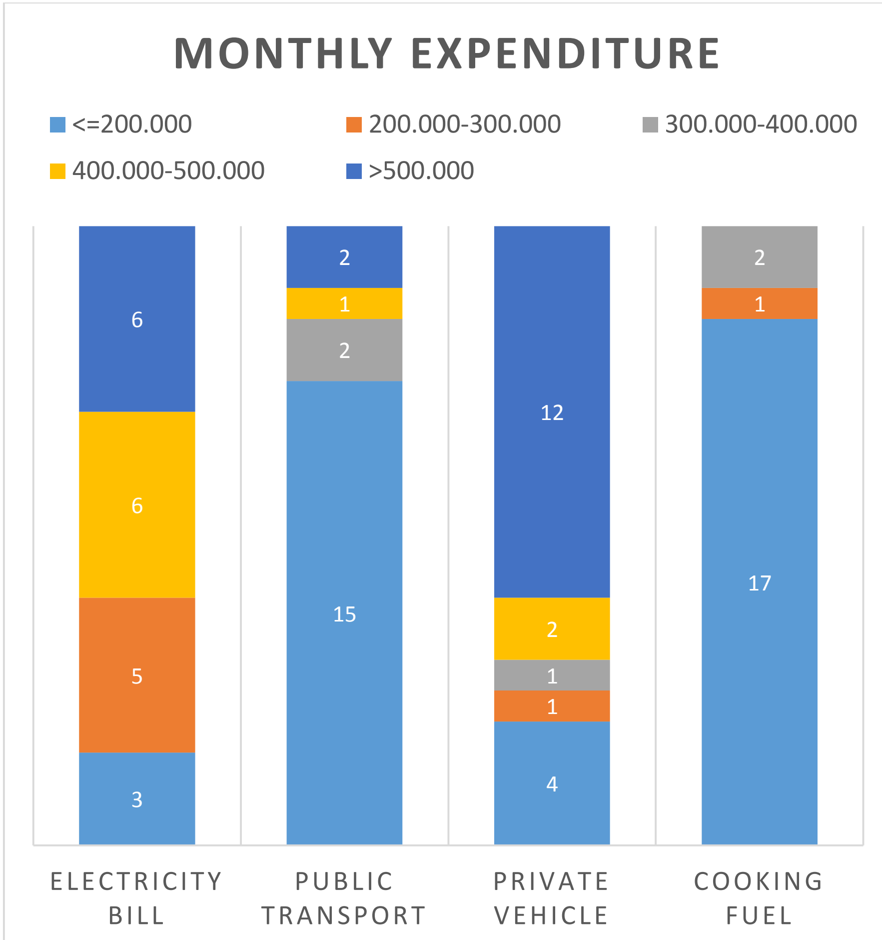


Figure 3.32. Monthly Energy Consumption Pattern for Income Group 4

b. The effect of UHI in Bandung to health and well-being

Using the similar questionnaire in Bangkok, we also aim to know the effect of heat interference on respondents' daily activities. There are seven variables that will show how much heat will interfere the daily activities of respondents.

Table 3.19. Heat Interference Variables

Variable	Description
Sleeping 1	Have trouble sleeping because of the heat
Sleeping 2	Need to turn the fan/AC on during sleeping at night
Housework 1	Do less housework in the afternoon because it is too hot
Housework 2	Turn the fan/AC on while doing housework
Daily travel	Have difficulties going to work because of the heat
Work	Have problem to concentrate at work because of the hot weather
Exercise	Do less exercise because of the hot weather

Sleeping 1 – Have trouble sleeping because of the heat

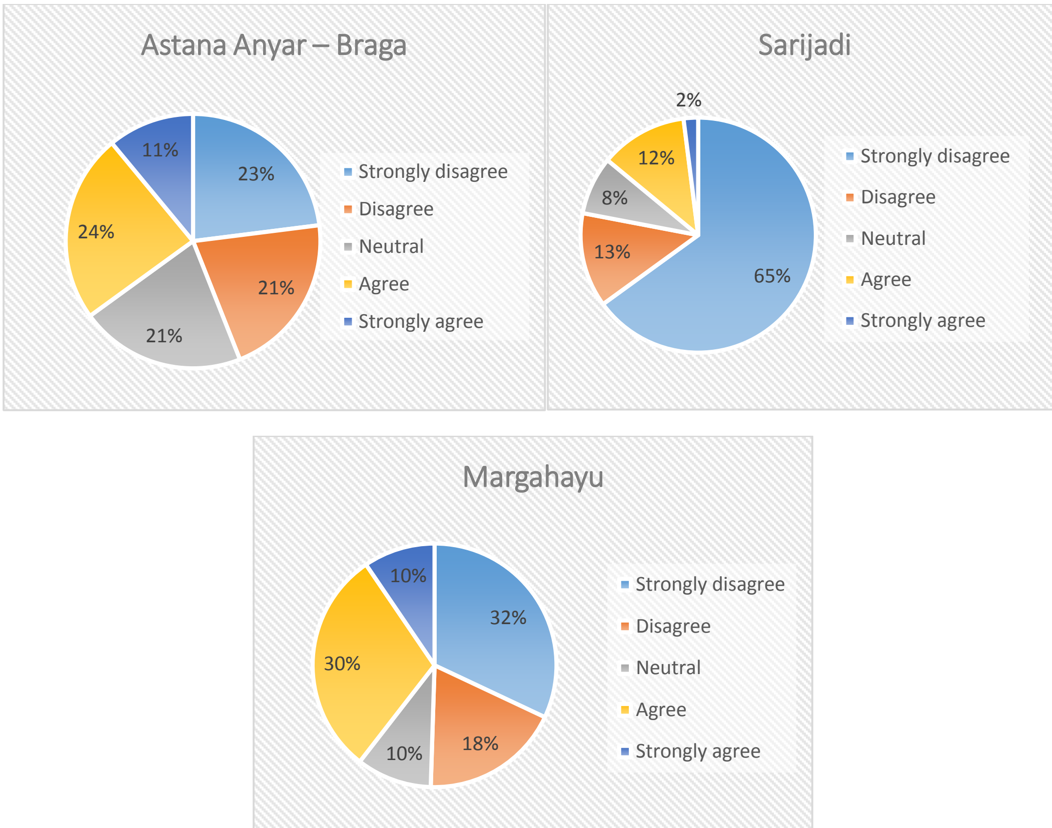


Figure 3.33. Sleeping Disruption Because of Heat in Bandung

The majority of respondents in Astana Anyar and Braga or about 24% feel that they have trouble sleeping caused by the heat. But, the majority of respondents in Sarijadi (65%) and Margahayu (32%) are strongly disagree, they don't feel that their sleep is disrupted due to heat.

Sleeping 2 – Need to turn the fan/AC on during sleeping at night

The majority of respondents in Astana Anyar and Braga or about 40% feel no need to turn on the fan during sleeping at night. However, this statement is contradictory with the previous statement that they feel they have trouble sleeping caused by the heat. The majority of respondents in Sarijadi (64%) and Margahayu (49%) feel they don't need to turn on the fan while sleeping at night. It probably because they don't have any trouble sleeping.

Housework 1 – Do less housework in the afternoon because it is too hot

The majority of respondents in Astana Anyar and Braga (27%), Sarijadi (63%) and Margahayu (44%) feel not disturbed by the heat when having to work during the day.

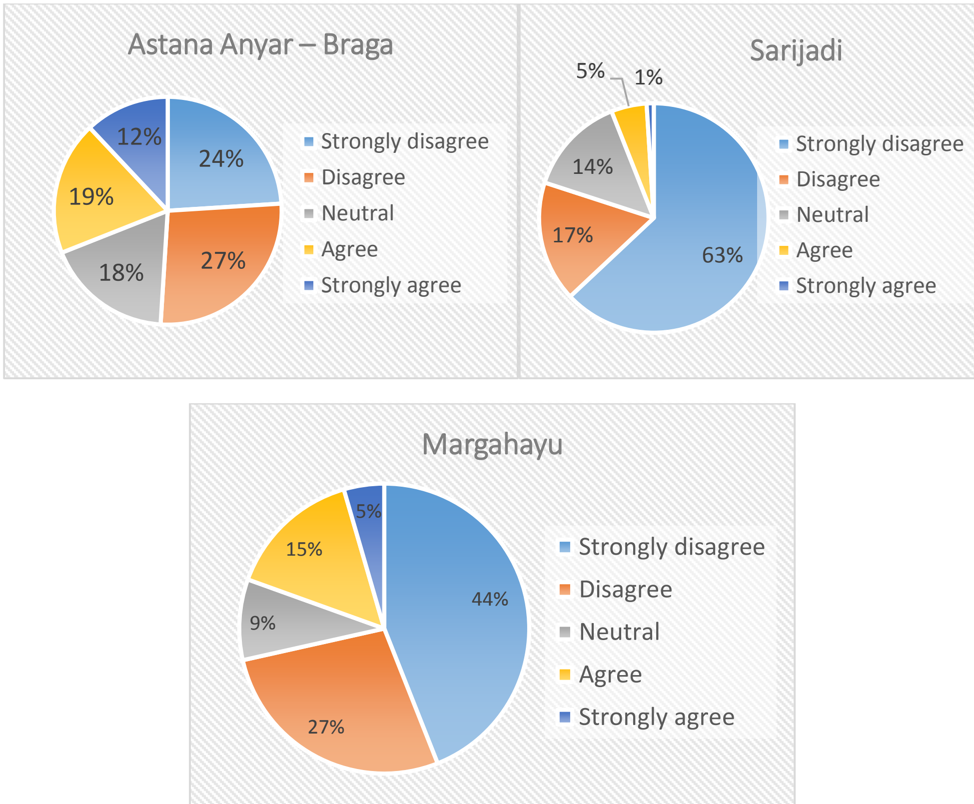
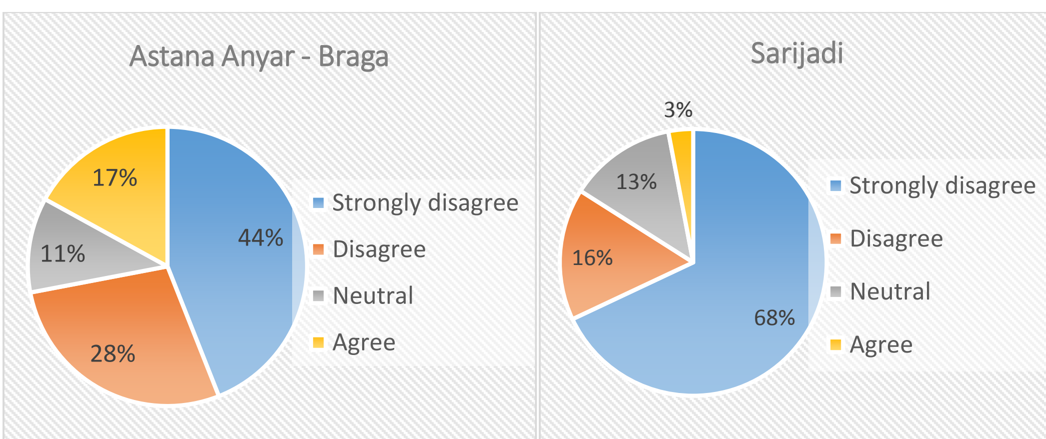


Figure 3.34. Housework Disruption Because of Heat in Bandung

Housework 2 – Turn the fan/AC on while doing housework

The majority of respondents in Astana Anyar and Braga (44%), Sarijadi (68%), and Margahayu (51%) feel they don't have to turn in the fan or AC while working.



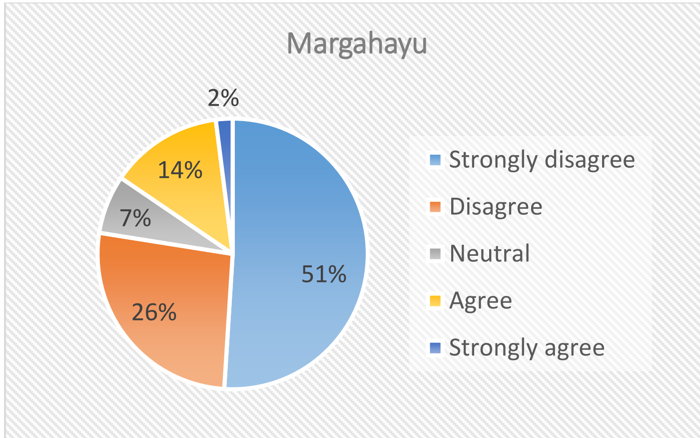


Figure 3.35. Housework Needs Cooling Because of Heat in Bandung

Daily travel – Have difficulties going to work because of the heat

The majority of respondents in Astana Anyar and Braga (28%), Sarijadi (44%), and Margahayu (41%) feel they don't have any difficulties going to work because of the heat.

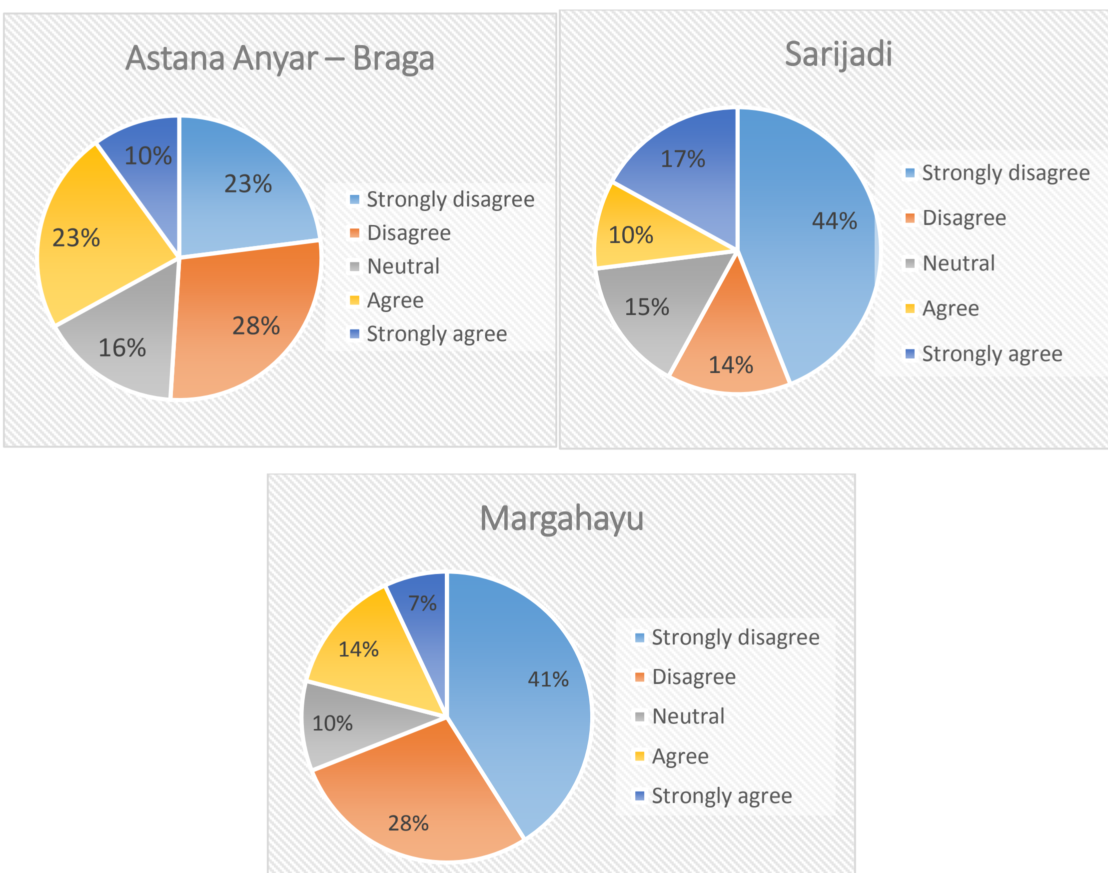


Figure 3.36. Problem in Going to Work Because of Heat in Bandung

Work – Have problem to concentrate at work because of the hot weather

The majority of respondents in Astana Anyar and Braga (26%), Sarijadi (58%), and Margahayu (41%) feel they don't have any problem to concentrate at work because if the hot weather.

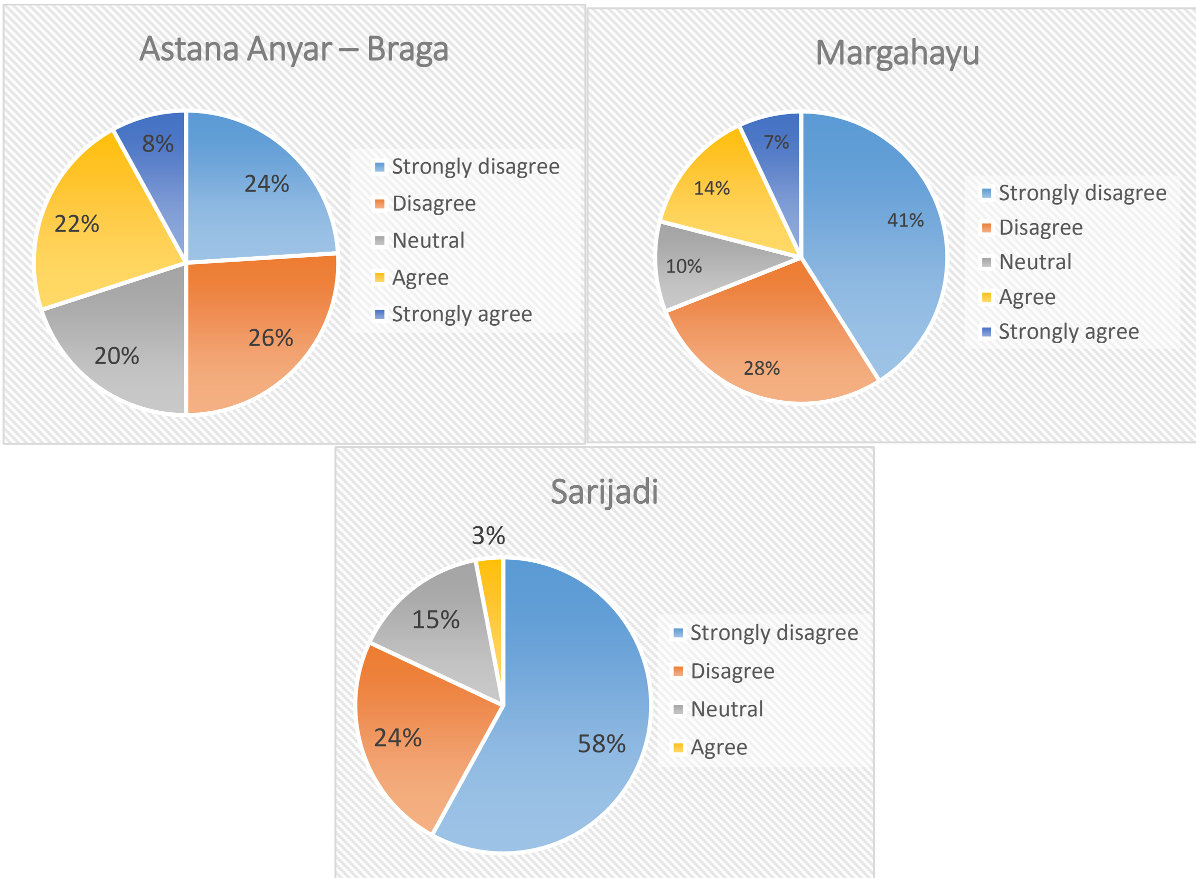
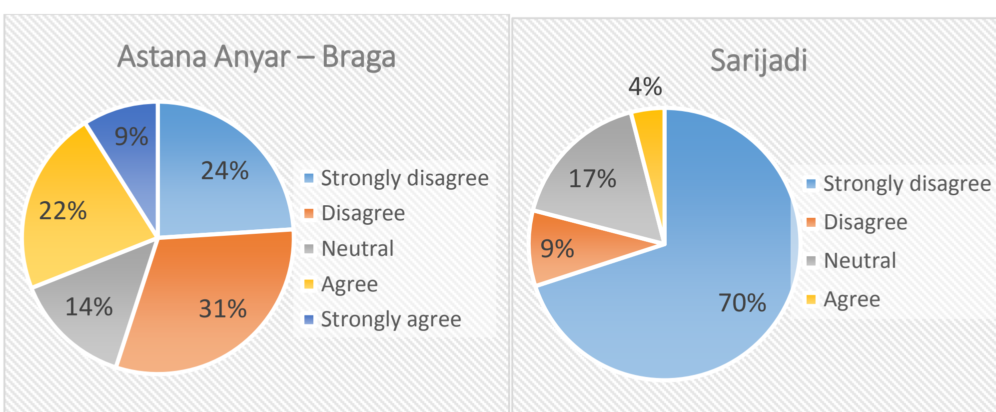


Figure 3.37. Problem in Concentrating in Work Because of Heat in Bandung

Exercise – Do less exercise because of the hot weather

The majority of respondents in Astana Anyar and Braga (31%), Sarijadi (70%), and Margahayu (38%) feel they are not disturbed by the hot weather so have to do less exercise.



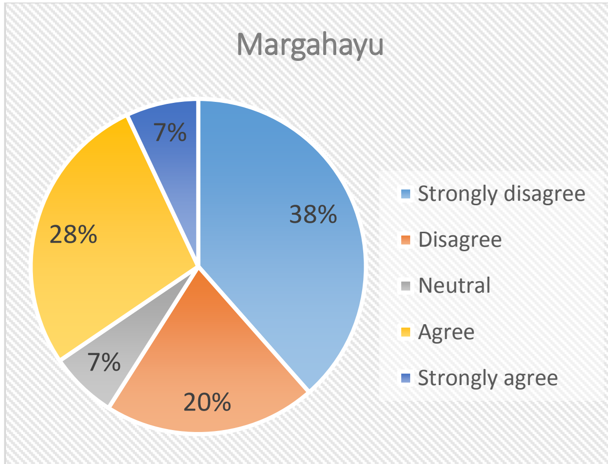


Figure 3.38. Problem in Exercise Because of Heat in Bandung

Mental health effects and well-being

This study also aims to know the effect of heat interference on respondents' mental health. There are two variables that will show how much heat will interfere the mental health of respondents.

Table 3.20. Measuring Mental Health Effects of Urban Heat Island

Health Effect Variable	Proxy Question	Measurement
Mental Health Effect	During the past four weeks, how much have you been bothered by emotional problems?	5 level likert scale
Well-being	Thinking about your life and personal circumstances, how satisfied are you with your life as a whole?	10 level likert scale

Based on the survey results, related to the mental health effect, majority of the respondent in Braga (66%), Sarijadi (79%), and Margahayu (80%), feel that they are not bothered by emotional problems. There are 36% respondents in Braga and Astana Anyar who feel bothered by emotional problems. At most 22% of respondents feel they are bothered by emotional problems once a month. In Sarijadi, there are 16% of respondents who also feel they are bothered by emotional problems once a month. In Margahayu, there are only 9% who feel they are bothered by emotional problems once a month (figure 3.39)

As for the well-being variable, based on the survey results, majority of the respondent in Braga (39%) and Margahayu (72%) feel that they are satisfied with their life as a whole. But, for the case in Sarijadi, majority of the respondent (61%) have a medium level of well-being. It means they don't feel that they are not very satisfied or very satisfied with their life.

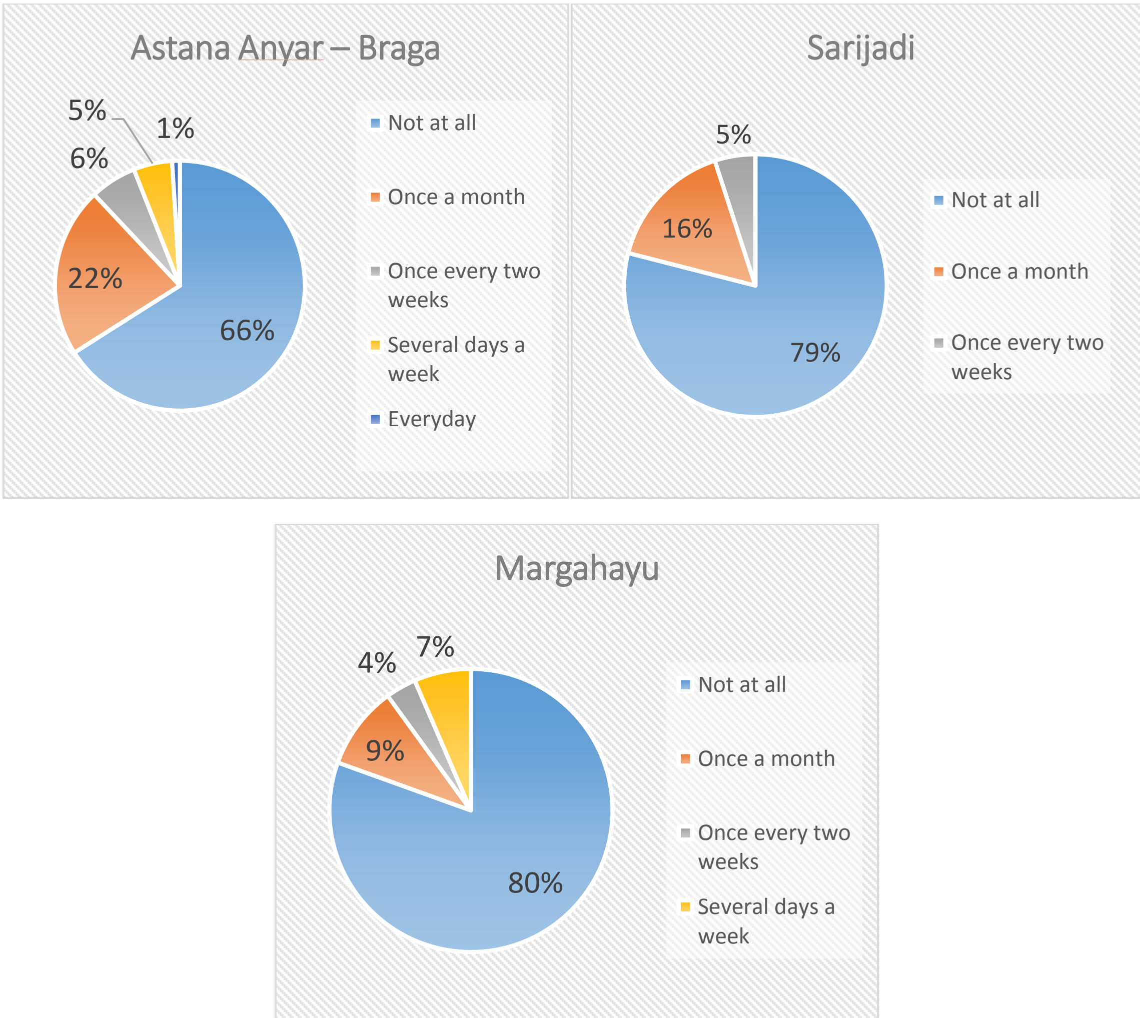
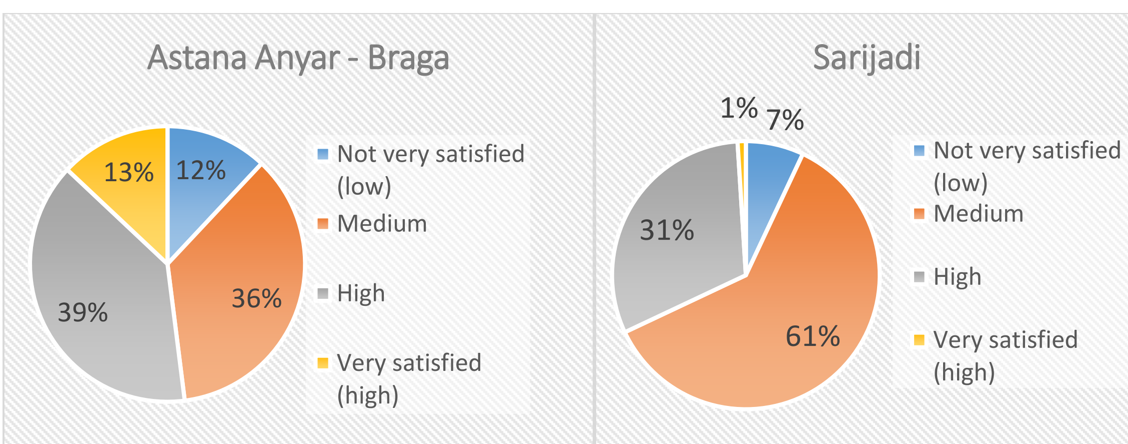


Figure 3.39. Emotional Problem Because of Heat in Bandung



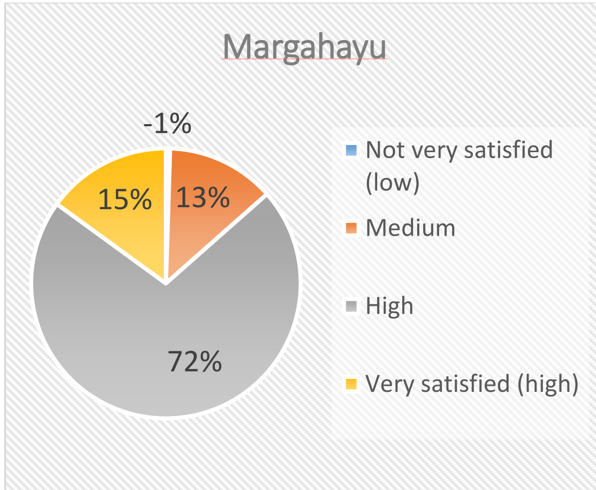


Figure 3.40. Well-being Problem Because of Heat in Bandung

In summary, it seems that there have been little interference of UHI to daily activities of urban residents in Bandung. This is because the heat interference is very small and the UHI magnitude is also very small.

3.2.3. Policies and Adaptation Measures to Combat Urban Heat Island in Bandung, Indonesia

There is no direct policy onto reducing the UHI effect in Bandung City according to the information given during Focus Group Discussion with the officials from Bandung City Agency for Environment Protection. However, after reviewing several policies regarding physical and spatial planning, building codes, environmental management, etc., there are several implicit policies that can be seen as an effort to mitigate and adapt with the UHI effect. Although these policies are not purposively focused on combatting the UHI effect, the implementation of these policies can give positive contribution to mitigate and adapt to the city's increase of temperature. Explanations on each policy are discussed as follows.

a. Greening program

Provision of more vegetation in the city is one of mitigation and adaptation measures that can be done to cope with global warming and UHI effect. This is because trees can absorb excessive heat from buildings and other sources (Yow, 2003). The vegetation can be provided through urban parks, rooftop gardens, green walls, and urban forests. In Indonesia, the green and open spaces in the cities are regulated by the National Act No 26/2007 on Spatial Planning.

The policy stated that every city/regency should provide a minimum of 30% open spaces of the total area in the city/regency. From the total ⅔ of the open spaces should be accessible by the public and the remaining ⅓ can be in the form of private spaces. In line with this policy, the Government of BandungCity tries to increase the amount of parks and open spaces. The most prominent greening program was conducted during 2005-2007 period, when several open spaces and parks rehabilitated into its original function after being occupied by gas-stations for some years; and during 2013-2016 period when the Bandung City government established more than 10 thematic parks for greening and leisure purposes. This program hopefully can increase the percentage of open green spaces in Bandung City from 13% to 16% in 2030. However, this measure still seemed difficult to attain the 20% of public open space requirement.

b. Energy saving program

Saving the energy can be included as a mitigation measure against global warming and UHI effect. The increase of temperature in urban areas leads to the increase of cooling load which is provided by electricity. More electricity consumption means more energy wasted as heat to the urban atmosphere and more GHG released to the global atmosphere (Dhakal, 2002). Therefore, reducing the energy consumption can decrease the heat and GHG emission.

The save energy program is not clearly adopted in any policies formulated by Government of Bandung City or even in upper level administration such as provincial level. This program is usually found in the national level policies, especially under the Ministry of Resources and Energy. Therefore, the role of local government is to support the National Energy Saving Program.

One of the most recent strategies under this policy that has already undergone is the switch from kerosene use to LPG. This program is targeted especially for the low-income people who mostly use kerosene for their cooking stove. The community and neighborhood organization is playing important roles in implementing this program, because they are the lowest level of organizations that identify and distribute subsidised-LPG to the targeted households. However, the initiatives on saving energy always come from the higher level, especially from the government. The initiatives on saving the energy among individuals or households level are almost never been heard before.

c. Air pollution control

Control on air pollution can benefit in mitigating the global warming effect. However, this strategy is not effective to reduce UHI intensity. In fact, it is the UHI effect that can influence the level of air pollution. The increase of temperature due to UHI effect is acting as a catalyst and increase the formation of smog (ozone) which is very harmful for human health (Dhakal, 2002; Gorsevski, undated).

The pollution control in Bandung City is handled mostly by the EPA. In this case, the most related policies with UHI effect are mentioned in the Environmental Strategy of the Provincial EPA, under the section of Air Quality Management. However, this program is focused more on air pollution abatement such as controlling emissions from vehicles and industries.

d. Mass transportation and reduction of private vehicles

The provision of mass transportation is geared towards reducing the number of private vehicles on the street. Less vehicles means less fossil fuel burned which lead to decrease of heat and GHG emissions. Therefore, this measures is applicable both to mitigate global warming and UHI effect. In Indonesia, the mass transportation provision has become a popular topic since the establishment of TransJakarta Busway Project in Jakarta. The Government of Bandung City's program to establish a bus lane called the Trans Metro Bandung has not been successful. Through this project, the local government hopes that it can reduce the number of vehicles on the street which lead to less traffic and less emission of heat and also pollutants. Thus, the provision of mass transportation can reduce heat emission from the vehicles, but only if it successfully reduce the number of private vehicles on the road. This project was introduced at the end of 2006, and relaunched again in 2014, however it has not been effectively reducing the number of private vehicle used until present time. The other mass transportation program is the development of Light Rail Transit (LRT), which up until 2018 still has not been started yet.

e. Urban planning policies

Urban planning policies and strategies can also play important role in reducing the city's temperature (Yamamoto, 2006). The city's plan is formulated under the Spatial Plan of Bandung City 2011-2031. This plan was promulgated into Local Act no 18/2011. Several strategies contained in this Act that can be effective to reduce the city's temperature have already mentioned before, such as the establishment of more green open spaces and establishment of new parks throughout the city.

The other program mentioned in this policy is the provision of green spaces along the river banks which has long been occupied by tenants. The tenants will then be relocated to a vertical housing which can start the development of a more compact city.

f. Urban design policies (building codes/regulations)

Most of the measures for UHI effect is done through urban design and retrofitting the buildings in urban areas (Yow, 2003). This measure is one way to adapt with the temperature condition in the city. The arrangement of new buildings can be designed to give shades to the pedestrians and provide a 'wind-path' that can cool down the ground temperature (Yamamoto, 2006). The material used in the building and ground can also reduce the effect of UHI. There are several building and ground material that can reflect the sun radiation and have good water permeability (Greater London Authority, 2006). This adaptation measures on building can also decrease the cooling load of buildings and leads to less energy consumption.

In term of urban design policies, there is Act number 28/2002 on Buildings that was promulgated by the National Government. At the city level, Government of Bandung City has also formulated several building regulations. The building code for Bandung City has been formulated since 2005. This regulation is a guideline for building development as well as applying for building permit. This regulation is only bonding the institutions related with buildings, mainly the Building Agency. Therefore, the rule is not strictly bonding the citizens or developers in building their properties. The code also does not regulate things that could reduce the UHI effect such as supporting vegetation on roof tops of high-rise buildings, the usage of reflective building material in combination with heat absorbing landscape features, creation of wind-path, and so on.

3.3. Discussion of Major Findings

The following section discusses the findings from Bangkok and Bandung case study and generalize them into new knowledge to inform policies and measures to adverse the effect of UHI in Asian cities.

3.3.1. Case Study of Bangkok, Thailand

The daily variations of UHI in Bangkok in three different seasons have similar trend. The UHI effect is high after sunset around 18.00-19.00 and the temperature difference reaches maximum value of 2°C - 4°C during the night depending on the season. The magnitude of UHI is low in the morning and it the temperature difference continue to decrease in the afternoon. After the sunset, temperature difference begins to rise again. The seasonal variation of UHI shows that from the 1 year data, it is evident that the heat island phenomena occurs throughout the year especially during the night time, and the UHI intensity ranges from 4-5°C in winter, 2-3°C in summer, and 1.5-2.5°C in rainy season. These characteristics of UHI in Bangkok have similarities with other tropical cities such as Mexico City and Singapore. It can be said that cities with similar climate will experience similar pattern and characteristics of UHI.

The higher magnitude of heat island in Bangkok especially at night is found due to two reasons. First, the buildings, roads, pavement surface in the built up areas absorb more heat during the daytime and release it slowly after sunset than in rural area. Second, is due to the artificial heat release into the urban atmosphere by anthropogenic heat, heat released by human activities such as from fuel combustion, space cooling, transportation, running appliances, and vehicle exhausts. Other contributing factor is the weather condition, which includes precipitation, wind speed and direction, and cloudiness patterns.

There is a positive association between UHI and the current master plan of Bangkok that aim to increase the density of Bangkok Metropolitan Area. Using one typical day example on 5 August 2012, the new master plan increase the UHI magnitude 62.5% from the current condition. In daytime, the increase can reach 4.5 0C, and at night is around 2 ^{0}C. The UHI magnitude under the current condition is 4 ^{0}C and under the new master plan is 6.5 0C. It can be inferred that the implementation of new master plan to guide Bangkok development will increase the severance of UHI impacts to both the environment and the residents.

The study finds that respondents with heat interferences problem from UHI will have lower life satisfaction lower energy level, and experience more frequent emotional problems. This findings share similar result with the literature which found that heat stress significantly reduce health outcomes and well-being. It was found that there is a significant association between these variables when we established bivariate correlation (spearman rank). It can be inferred that UHI affects the health indirectly through the heat interferences with daily activities. However, there are limitations to the study. First, it cannot establish a direct causality between heat interference and health. Second, the respondents mostly answered the questionnaire during April-May period, which is the hottest period of the year. It will be interesting to see the time series data of the response so we can compare between summer and winter season.

3.3.2. Case Study of Bandung, Indonesia

The policy review showed that there is no direct policies to reduce the UHI effect in Bandung City. There are, however, several indirect policies that can be seen as mitigating the UHI effect such as expressed in the City Master plan and also as part of the national policies conducted by the city government.

Analysis from urban climate model using the surface temperature did not yield a significant result. Model of UHI was generated mainly by means of satellite imageries of 1995, 2007, and 2015, particularly by utilising LST. As describe at Section 2, UHI model can be developed using LST. Moreover, as described at Section 2.2, LST of Bandung Basin was highly correlated with air temperature, which allowed LST to be utilised to model UHI. As data on air temperature in Bandung Basin was not comprehensively available, employment of LST allowed not only modeling of UHI but also climate change in general.

Evidences of UHI were also identified in Bandung Basin. As depicted at Section 3.1, LST of urban areas in Bandung Basin, such as Municipality of City of Bandung, District of Soreang in which governance center of Municipality of Bandung is located, and District of Majalaya in which the industrial area of Municipality of Bandung is located, was considerably higher compared to their surroundings. Additionally, as described at Section 3.1, LST of District of Lembang in which the agriculture center of Municipality of Western Bandung is located was also higher compared to its surrounding.

The employment of LST on this research also provided evidences of climate change in Bandung Basin in general. As described at Section 3.1, the average and maximum LST between 1995 and 2015 had risen from 18 to 22^0 C, as well as 24 to 37^0 C, respectively.

For the analysis of effect of UHI, the sample location was finally selected based on the urban forms, namely the organized and unorganized urban form, and vertical housing. The analysis based on household's income is also conducted. Based on the urban forms, the electricity bill in unorganized urban form (kampung) and vertical housing are lower than those living in the organized housing. The lot or house size might be the cause of this result. The cooling appliances ownership is also affected the amount of electricity bill, however, the appliances ownership is affected by the household income which related with the installed capacity of the house. The low group of installed capacity (450 VA and 900 VA) is subsidized, which explained the reason why the small and old houses in the unorganized settlements are having a small amount of electricity bill. On the contrary, the transportation expenditure between different urban forms seems to be similar. This is because the high number of private vehicles use in all types of urban form. Households that live in proximity to the city center or daily activity places are also using private vehicles instead of public transportation. Anthropogenic heat released by utilisation of cooling equipments was only slightly contributing to LST rise. Although the average of monthly electricity usage of AC was 262 kilo Watt, or 85.34% of the average of total monthly electricity usage of household, there were only 12.42% of respondents whom had AC installed in their houses or offices. Moreover, as described at section on energy consumption at Section 3.3, percentage of electricity usage of fan and refrigerator compared to total monthly electricity usage of household was only 0.22% and 1.34% respectively.

Based on the household's income, the result showed that the higher the household income leads to higher energy consumption and transportation expenditure. This is well within the predicted results. Higher income households own more vehicle and electronic appliances, which lead to the higher energy consumption. This occurred even to those who live within the range of 1-5 km to their daily activity places. The expenditures that do not increase when the income is higher are cooking fuel and public transportation expenditure.

On the perceived urban heat island effect to the daily activities and mental health, the respondent in all types of urban form and income felt that the warm temperature does not have significant influence to their daily activities, mental health, and their overall quality of life. This result is rather unexpected as some of the households cooling appliances ownership and the frequency of utilizing cooling appliances are increase in the last three years.

4. Conclusion

4.1. Synthesizing Major Findings from the Project

The following sections summarize major findings from the analysis. Major findings are presented based on the corresponding research questions. Each section describes thee research question and its corresponding findings.

a. There are different patterns and characteristics of UHI in Southeast Asian cities

The case studies represent two different cities with different characteristics. The project selects Bangkok and Bandung as the case study because these cities represents two completely different geographical conditions of rapid-growing city in Southeast Asia. Bangkok is a coastal city with maximum elevation of 4 m above sea level, while Bandung is a mountainous city with elevation of 768 m above sea level and surrounded by up to 2,400 m high late tertiary and quaternary volcanic terrain. The difference in geographical condition makes the cities experience different UHI effect. Using two case studies it is expected that the result can be generalized and the method used in the project can be applied to other Southeast Asian cities with similar characteristics.

These characteristics of UHI in Bangkok have similarities with other tropical cities such as Mexico City, Singapore, and Jakarta. This characteristics represents the megacities in tropical climate where urban land use largely covers the urban area. On the other hand, in Bandung case, although the study found out that there is a significant change in temperature rise and worsen UHI magnitude, the geographical condition of Bandung makes the temperature change is not really felt by the residents. However, the higher number penetration of air conditioning equipment ownership and higher shares of energy consumption for cooling confirms the trend. The UHI characteristics in Bandung is found to be similar of Hanoi in Vietnam and Chiang Mai in Thailand, where they share similar geographical and socioeconomic characteristics.

b. The built environment is found to intensify UHI magnitude

In both case studies, it is found that built environment amplifies the magnitude of UHI. It means that the higher number of non-permeable surface of land use such as buildings and roads the higher the magnitude of UHI. This finding is in agreement with what have been established in literature on UHI. The long-term annual air temperature record in Bangkok from 1980-2012 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.

The higher magnitude of heat island in Bangkok and Bandung especially at night is probably due to two reasons. First, the buildings, roads, pavement surface in the built up areas absorb more heat during the daytime and release it slowly after sunset than in rural area. Second, is due to the artificial heat release into the urban atmosphere by anthropogenic heat, heat released by human activities such as from fuel combustion, space cooling, transportation, running appliances, and vehicle exhausts. Other contributing factor is the weather condition, which includes precipitation, wind speed and direction, and cloudiness patterns.

c. There is a significant association between health outcomes and UHI

The study in both case studies finds that respondents with heat interferences problem from UHI will have lower life satisfaction lower energy level, and experience more frequent emotional problems. This findings share similar result with the literature which found that heat stress significantly reduce health outcomes and well-being. For example, Lan et al (2010) found that people working in hot environment had lower motivation to work and experience negative mood during working. Guo et al (2012) found that there is an effect of increasing temperature on mortality in Chiang Mai city in Thailand. This study found out that heat stress is not only affecting the working life, but also interfere with other aspect of daily life such as sleeping, daily travel, and exercise.

It was found that there is a significant association between these variables when we established bivariate correlation (spearman rank). It can be inferred that UHI affects the health indirectly through the heat interferences with daily activities. However, there are limitations to the study. First, it cannot establish a direct causality between heat interference and health. Second, the respondents mostly answered the questionnaire during April-May period, which is the hottest period of the year. It will be interesting to see the time series data of the response so we can compare between summer and winter season.

d. There is a positive association between UHI magnitude and household energy consumption

The study found out that UHI magnitude has positive association with the household energy consumption in two ways. First, energy consumption for cooling is higher when the UHI magnitude is higher, corresponds to seasonal variations. Second, energy consumption for cooling is higher in the area that suffers high UHI magnitude. It means in downtown area, where the magnitude of UHI is higher, household energy consumption is also higher compared to the sub-urban area. However in Bandung, although the average of monthly electricity usage of AC was 262 kilo Watt, or 85.34% of the average of total monthly electricity usage of household, there were only 12.42% of respondents whom had AC installed in their houses or offices, and percentage of electricity usage of fan and refrigerator compared to total monthly electricity usage of household was only 0.22% and 1.34% respectively.

e. Integrated policy measures to mitigate UHI are still scarce at the city level

The findings of the study indicate that sectoral approach to urban management has led the local government to inadequately address the UHI. In Bangkok, BMA, the responsible agency of the development of Bangkok has failed to integrate UHI in their planning practices. There are three different planning documents drafted by three different agencies under the BMA that mentions UHI adaptation. However, the implementation has not been very successful. This is because of two reasons. First, there are no specific plan to adapt to UHI. All planning documents related to UHI are part of efforts to solve the urban problem in different sector. For example, UHI adaptation are part of the document to increase the number of green space in Bangkok or a part of the climate mitigation and adaptation plan. There has not been a specific plan aiming to reduce the severity of UHI in Bangkok. Second, the existing plan are under three different implementing office. This has caused lack of coordinated efforts between policies.

In the case of Bandung, there is no direct policy onto reducing the UHI effect according to the information given during Focus Group Discussion with the officials from Bandung City Agency for Environment Protection. However, after reviewing several policies regarding physical and spatial planning, building codes, environmental management, etc., there are several implicit policies that can be seen as an effort to mitigate and adapt with the UHI effect. Although these policies are not purposively focused on combatting the UHI effect, the implementation of these policies can give positive contribution to mitigate and adapt to the city's increase of temperature.

4.2. Answering Research Questions and Objective of the Study

The study elaborates three main research questions. First question is concerned with the pattern and characteristics of Urban Heat Island (UHI) in Southeast Asian Cities. Second question explores the association between UHI and the current policy mitigation and adaptation. The third question is related to the effects of UHI to the daily lives of urban residents. The following section summarizes the research questions and objective of the study.

Q1. What are the patterns and characteristics of UHI in Southeast Asian Cities?

Using case study from Bandung and Bangkok, it is found out that two different characteristics of UHI emerged. The first one is the character of Bangkok which represents the character of megacities in Southeast Asia, where the higher magnitude of UHI happens because the high proportion of built up areas (buildings, roads, pavement surface) and anthropomorphic activities (anthropogenic heat, heat released by human activities such as from fuel combustion, space cooling, transportation, running appliances, and vehicle exhaust). In this type of cities, UHI is found to be high during the night and can make up 4.5^0 C difference.

The second pattern is found in Bandung, which represents typical cities in the mountainous area, where there are less built-up area and anthropogenic heat. With increasing urbanization and built up areas, the study found that the temperature is rising in Bandung, and UHI magnitude is higher in the last 15 years. However, perceived effect of UHI is still not felt by the urban residents. This is because the temperature trend is still considered at the comfort zone. The highest temperature recorded was 37^0C, and the average and maximum LST between 1995 and 2015 had risen from 18 to 22^0 C, as well as 24 to 37^0 C, respectively.

Both patterns and characteristics of UHI are commonly found in Southeast Asian cities. The first pattern is similar to what can be found in Bangkok (Thailand), Johor Bahru (Malaysia), Singapore, Jakarta, and Metro Manila. The second pattern is commonly found in secondary cities such as Bandung (Indonesia), Hanoi, Da Nang (Vietnam), Chiang Mai (Thailand) or city with urban containment policies such as Kuala Lumpur (Malaysia). In both patterns, we notice that there are also contributing factors such as the weather condition, which includes precipitation, wind speed and direction, and cloudiness patterns.

Q2. What are the association between UHI and the current policy mitigation and adaptation?

Study in both cities found that there is no direct policy aiming to adverse the effects of UHI. However, there are policies in different sectors that are indirectly aims to alleviate the magnitude of UHI in urban area. In Bangkok, policy measures in adapting and mitigating UHI are scattered in different development plans. Policies related to UHI can also be identified in Bangkok GHGs Emission Mitigation Plan 2009. From total five initiatives stated in the plan, two initiatives are directly related to UHI mitigation: initiative 3 of the plan, which seeks to improve electricity consumption efficiency and initiative 5, which tries to expand the park areas inside BMA and neighboring provinces. Similar situation happens in Bandung. Many policies are scattered in different sectors such as urban planning master plan, building code, environmental management and public health. Hence, policy measures indirectly aim at reducing the effects of UHI are already in place. However, further study is required to analyze the success of the implementation of such polciies.

Q3. What are the effects of UHI to the daily lives of urban residents?

The study explores the effects of UHI to daily lives of urban residents, focusing on two aspects: household energy consumption for cooling and health and well-being. Regarding the household energy consumption for cooling, study in both cities found out a similar pattern. First, energy consumption for cooling is higher when the UHI magnitude is higher, corresponds to seasonal variations. Second, energy consumption for cooling is higher in the area that suffers high UHI magnitude. Even in Bandung, where the seasonal temperature variation is lower, higher energy consumption for cooling is recorded especially in the Central Business District (CBD) area.

The second aspect is perceived health and well-being. Different perception on health effects are recorded in Bandung and Bangkok. In Bangkok, the analysis found that there is a significant association between these variables when we established bivariate correlation (spearman rank). It can be inferred that UHI affects the health indirectly through the heat interferences with daily activities. However in Bandung, many respondents stated that there is no health effects from warming temperature in the city.

In concluding the discussion on the result, it can be said that the study has achieved the objective of understanding the effects of UHI in Southeast Asian cities by answering the aforementioned research questions.

5. Future Directions

5.1. Limitations of the Study and Suggestions for Future Research

Despite the study accomplishment in achieving the research objective and answering all research questions, the study also suffers from limitations. First one is the use of the meso-climate model in the study requires more data and computing power. Hence, we were not able to produce a complete future scenario for Bangkok and Bandung. In Bandung, meso-climate modeling was not used in analyzing the magnitude of UHI because there were not enough data. However, using Land Surface Temperature (LST), we were able to understand the micro-climate condition of the urban rea and comparing it to the rural area. Second, perceived health effect of UHI requires more respondents. We were only able to collect few respondents due to time and budget constraints. Future research should address this issue. Third, the policy analysis in both case studies are limited into development plans and related sector to urban development, such as master plans. Hence, future research should also include the policy of non-environment sector such as health, education, and transportation. There is also a need to assess the implementation of policies since having policy documents is not the same with implementing the policies, which requires more resources. Fourth, future research should be able to expand the case studies based on different characteristics of typical Asian cities. Case studies done in this study cover only two major characteristics of megacities and secondary cities. There is a need to expand the characteristics into more complicated ones such as industrial cities, port cities, tourism cities, or cultural landscape cities where there are many heritage that needs to be protected.

One of the project limitations is the cross sectional nature of the data used in the analysis, which limits interpretation of impacts in the future. Although the study collect time-series data for the weather condition, the analysis conducted is mainly based on the cross sectional data. Hence, it would be interesting to see the further work based on the longitudinal data, which will improve the analysis especially the modeling part. Other potential for further study includes the application of the method to other cities in South-East Asia with similar socioeconomic and geographical condition. This type of study will improve the reliability of generalization of the result while enriching body of knowledge on the topic of urban heat island and urban climate resilience.

5.2. Policy Implication: Integrating UHI Adaptation into Decision-making Processes

Integrating UHI adaptation into decision-making process seems to be the logical implications of the finding. In the cities of developing countries where resources are scarce, a better understanding the effect of UHI to urban area can help local government to make a better judgment on allocating resources and amenities, and knowing better when to promote growth or to contain it, while minimizing externalities that may occur.

Following our findings, integration of UHI adapatation into urban planning process can be achieved in the form of concurrent assessment. It refers to tailor-made adaptation measures based on assessment procedure that developed simultaneously with the decision making process (Partidario and Voogd, 1999). Through the integration approach, externalities of the effects can be minimized once (1) a policy that promotes the integration of UHI adaptation is adopted in planning related documents under different agencies; (2) an integrated master plan on UHI adaptation linking all sectoral plans is prepared; (3) and guidelines for managing the urban improvement in the city are formulated according the improved master plan.

Since UHI adaptation activities are complex and involve broad context stakeholders, government agencies, and other interest groups, cooperative management and inter-sectoral coordination are indispensable. This effort requires the full involvement of all the various stakeholders. However, attempts to develop an integrated system may cause conflicts and rivalry especially between local government agencies when delegation of authority and allocation of resources are not specified. Therefore, it is important to select one coordinating agency that can perform the integrated UHI adaptation efforts.

Awareness building and improving understanding for all stakeholders involved in the urban planning practices in cities is also important. Integrating UHI adaptation measures in urban planning practices demands both the similar perspective of all stakeholders and strong level of capabilities of policy makers. Through the improved understanding, collaboration efforts and efficient actions on reducing UHI effects can be established and maintained.

6. Reference

Arifwidodo, S.D. (2012). Exploring the Effect of Compact Development Policy to Urban Quality of Life in Bandung, Indonesia, City, Culture and Society (3)4, 303-311

Arifwidodo, S.D. & Chandrasiri, O. (2013). The Relationship between Housing Tenure, Sense of Place and Environmental Management Practices: A Case Study of Two Private Land Rental Communities in Bangkok, Thailand, Sustainable Cities and Society, 8(1), 16-23

Arifwidodo, S.D. (2014). Urban Form and Household Energy Use in Bandung, Indonesia. In Sridhar K.S. and Wan G. eds. Urbanization in Asia: Governance, Infrastructure and the Environment, India: Springer

Arifwidodo S.D. and Tanaka, T. (2015). The Characteristics of Urban Heat Island in Bangkok, Thailand, Procedia Social and behavioral Sciences 195 (1), 423-428

Arifwidodo, S.D. (2015). Factors Contributing to Urban heat Island in Bangkok, Thailand, ARPN Journal of Engineering and Applied Sciences 10 (15), 6435-6439

Arifwidodo, S.D. & Chandrasiri, O. (2015). Urban Heat Island and Household Energy Consumption in Bangkok, Thailand, Energy Procedia, 79 (2012), 189-1194

Boonjawat, J., Niitsu, K., Kubo, S. (2000). Urban heat island: Thermal pollution and climate change in Bangkok. Journal of Health Science, 9,1, January-March 2000, 49-55.

Cynthia Rosenzweig, William D. Solecki, Lily Parshall, Mark Chopping, Gregory Pope & Richard Goldberg. (2005). Characterizing the urbanheat island in current and future climate. Global Environmental Change Part B: Environmental Hazards, 6 (1), 2005, 51-62

Givoni, B. (1998). Climate Considerations in Building and Urban Design, Wiley, USA,

Henry, James A., Dicks, Steven E., Wetterquist, Orjan F. & Roguski, Stephen J. (1989). Comparison of satellite, ground-based and monitoring techniques for analyzing the urban heat island. Photogrammetric Engineering and Remote Sensing. 55(1), 69-76.

Jauregui, E. (1997). Heat island development in Mexico City, 1997 Atmospheric Environment, 31, 22, 3821-3831

Kolokotroni, M., I. Giannitsaris & R. Watkins. (2005). the effect of the London urban heat island on building summer cooling demand and night ventilation strategies. Solar Energy, In Press, Available online 17 May 2005.

Mikhail, A.L., & Anatoly A.I. (2002). Influence of Moscow City on the air temperature in central Russia. M.V. Lomonosov Moscow State University, Moscow, Russia.

Nyuk Hien Wong & Chen Yu. (2003). Study of green areas and urban heat island in a tropical city. Habitat International, 29, 3, September, 547-558

Oke, T.R. (1982). The energetic basis of urban heat island,. Journal of the Royal Meteorological Society 108 (455), 1–24.

Oke, T.R. (1995). The heat island of the urban boundary layer: characteristic causes and effects. Wind Climate in Cities. Kluwer Academic Publishers, Dordrecht, 81-107.

Appendix

Appendix A1. Workshop, Symposium, and Meeting

Synthesis Workshop and Symposium: Planning and Designing Urban Landscape in the Time of Climate Change (Year 2)

KU Home, Kasetsart University, 20-21 June 2018

As a part of dissemination of the research result, the project conducted a 2-days synthesis workshop and symposium in Bangkok. The workshop aimed to synthesize the result of the project and the possibility to formulate suggestions, recommendations, and lesson learned from the project. The workshop was conducted on 20 June 2018. The next day, 21 June 2018, the project conducted a symposium to disseminate the project result to all interested parties in Bangkok and Thailand.

Name	Institution
Dr. Sigit Arifwidodo	Department of Landscape Architecture, Faculty of Architecture, Kasetsart University
Dr. Sani Limthongsakul	Department of Landscape Architecture, Faculty of Architecture, Kasetsart University
Orana Chandrasiri	International Health Policy Pogramme, Ministry of Public Health, Thailand
Nutkritta Nilkhamheang	Department of Landscape Architecture, Faculty of Architecture, Kasetsart University
Dr. Phakamas Thinpanga	Thailand Environment Institute Foundation
Predapond Bandityanod	L49 Landscape Design Office, Bangkok
นายปัญวิษฐ์ อินทร์เอี่ยม	Kasetsart University
นายพิงค์พัชร ศิริชัย	Kasetsart University
นางสาวประภาทิพย์ เกษมสว่างสุข	Kasetsart University
นายพสธร ชมพูชาติ	Kasetsart University
นายกัมปนาท ปานถาวร	Kasetsart University
นายศุภโชค โล่ห์บุญทรัพย์	Kasetsart University
นายสกนธ์ เจริญภักดี	Kasetsart University
นายนวมินทร์ เฉลิมเกียรติ	Kasetsart University
นางสาวชณิกานต์ พิชญ์พิศาล	Kasetsart University
นางสาวศตานันท์ วังทิพย์	Kasetsart University
นายอาทิตย์ แก้วละเอียด	Kasetsart University
นายพีระยุทธ กรุดสอน	Kasetsart University
นายพงศ์ปณต วรปทุม	Kasetsart University
นายภูดิท วิชัยดิษฐ	Kasetsart University

Synthesis Workshop and Symposium: Urban Heat Island and Urban Planning in Bandung, Indonesia

Institut Teknologi Bandung, 12-13 July 2018

As a part of dissemination of the research result in Bandung, Indonesia, the project conducted a 2-days synthesis workshop and symposium at the Institut Teknologi Candung campus, Indonesia.. The workshop aimed to synthesize the result of the project and the possibility to formulate suggestions, recommendations, and lesson learned from the project. The workshop was conducted on 12 July 2018. The next day, 13 July 2018, the project conducted a symposium to disseminate the project result to all interested parties in Bandung and Indonesia.

Name	Institution
Dr. Sigit Arifwidodo	Department of Landscape Architecture, Faculty of Architecture, Kasetsart University
Dr. Petrus Natalivan	Department of City and Regional Planning, Institut Teknologi Bandung
Dr. Niken Prilandita	Department of City and Regional Planning, Institut Teknologi Bandung
Orana Chandrasiri	International Health Policy Pogramme, Ministry of Public Health, Thailand
Dr. Rizqi Abdulharis	Centre for Agrarian Researches, Institut Teknologi Bandung
Alfita Puspa Handayani	Centre for Agrarian Researches, Institut Teknologi Bandung
Hasanuddin ZA	Institut Teknologi Bandung
M.S. Fitrianto	Institut Teknologi Bandung
Navila K.S	Institut Teknologi Bandung
Alifiya	Institut Teknologi Bandung
Novi Kartika Sari	Institut Teknologi Bandung
Alfiyah Nur F	Institut Teknologi Bandung
Puni. S.	Bappeda Kab. Bandung
Ani W	Bappeda Jabar
Lina Y	Bappeda Jabar
Cindra Tri Y	Institut Teknologi Bandung
Siti Farah R	Institut Teknologi Bandung
Stevan Sarajar	Institut Teknologi Bandung
Adang Sahwad	Institut Teknologi Bandung
M. Faruk	Institut Teknologi Bandung
Dewi F	Office of Public Health, Bandung City
dr. Henny R	Office of Public Health, Bandung City
A. Wahyu	Office of Public Health, Bandung City
M. Dwiki R	Institut Teknologi Bandung
Rachmilda P.D	PT PLN (Persero) DJB
Murni Elfrida	Institut Teknologi Bandung
Simangunson, G.A.	Institut Teknologi Bandung
Sudjaja, M.I.T.	Institut Teknologi Bandung
Hutajulu, D. A.	Institut Teknologi Bandung

Appendix A2. Funding Sources outside APN

Budget Secured from Other Sources (Cash and In-kind Contribution)		In-Kind (US$)	Cash (US$)
Activity	**Organization**		
Field Survey Design and Modeling Preparation	Hiroshima University	1000	0
Tools for modeling (GIS, WRF-ARM, UCM)	Hiroshima University	4,000	0
Time series Weather data and spatial data	Hiroshima University	1,000	0
Administration Support	Kasetsart University	1,000	1000
	Institut Teknologi Bandung	1,000	1000
Focus Group Discussion	Kasetsart University	1,000	0
	Institut Teknologi Bandung	1,000	0
Country Workshop	Kasetsart University	1,000	1000
	Institut Teknologi Bandung	1,000	1000
Total		**27,000**	**4,000**

Appendix A3. List of Young Scientist Involved in the Project

With the support of APN and institutions of project collaborators, we tried to involve as many young scientists as possible to join the research project and involve them in many of project activities. The following table provide the list of young scientists in the projects and their involvements.

Name	Institution	Involvement in the Project
1. Students conducted thesis/research related to APN project		
Andhang Tri Hamdani	PhD Thesis, Hiroshima University, Japan	Mr. Andhang conducted PhD thesis under one of the project collaborators, Dr. Kubota. His topic is related to using meso-climate modeling for UHI using case study of Bandung, Indonesia and Hanoi, Vietnam. Mr. Andhang graduated in end of 2017.
Masaki Ida	Master Thesis, Hiroshima University, Japan	Mr. Ida conducted master thesis under one of the project collaborators, Dr. Kubota. His topic is related to exploring health effects of UHI using case study of Bandung, Indonesia.
Hutajulu, D. A.	Bachelor thesis, Institut Teknologi Bandung, Indonesia	Ms. Hutajulu conducted bachelor thesis on the topic of study on Correlation between Land use/cover and Land Surface Temperature Change in Bandung Basin. She is under supervision of one of the project collaborators, Dr. Abdulharis.
Sudjaja, M.I.T.	Bachelor thesis, Institut Teknologi Bandung, Indonesia	Mr. Sudjaja conducted bachelor thesis on the topic of study on Correlation between Land use/cover and Land Surface Temperature Change in Bangkok Metropolitan Area under the supervision from Dr. Abdulharis.
Simangunson, G.A.	Bachelor thesis, Institut Teknologi Bandung, Indonesia	Mr. Simangunson conducted bachelor thesis on the topic of Analysis on Correlation between Land Surface Temperature and Heat-related Illness in Bangkok Metropolitan Area, under supervision from Dr. Abdulharis and Dr. Sigit Arifwidodo
Murni Elfrida	Bachelor thesis, Institut Teknologi Bandung, Indonesia	Ms. Elfrida conducted bachelor thesis study on the topic of urban form, urban heat island and household energy use in Bandung under the supervision of Dr. Sigit Arifwidodo.
Nutkritta Nilkhamheang	Bachelor thesis, Kasetsat University, Bangkok, Thailand	Miss Nilkhamheang assisted the project on the topic related to health effects of UHI in Bangkok under the supervision of Dr. Sigit. The result of her study was presented at the international conference early 2018.
2. Research Assistant/ Student Assistant		
Orana Chandrasiri	International Health Policy Pogramme, Ministry of Public Health, Thailand	Miss Chandrasiri was the research assistant of the project. Her involvement include identifying the urban-rural temperature difference and assisting the project leader in meso-climate modeling in Bangkok.

Alfita Puspa Handayani	Institut Teknologi Bandung, Indonesia	Ms. Alfita assisted the project as the research assistant. Her main task is to provide the LST data and other related GIS for the Bandung case study.
Dr. Sani Limthongsakul	Asian Institute of Technology, Thailand and Kasetsat University, Bangkok, Thailand	Dr. Sani assisted the project on the policy related to UHI in Bangkok, since it is also her PhD Thesis topic. She graduated in 2017 and now teaching at the Faculty of Architecture of Kasetsart University, Bangkok, Thailand.

"My involvement in the project has provided me a better capacity in understanding of the effects of urban heat island and the importance of designing for resilience, which I will continue to develop in my professional life after my graduation" – Nutkritta Nilkhamheang, former student assistant in the project, currently working at Shma Design Company in Bangkok, Thailand

"From the project I learned to expand my perspective of public health to environmental health. I learned that environment holds a very important role in determining the health and well-being of an individual. Hence, policies aimed to improve health and well-being should also integrate environmental considerations" – Orana Chandrasiri, Research Assistant of the project, currently a researcher at the Ministry of Public Health of Thailand

"*The project helped me in enriching the topic of my PhD thesis not only into meso-climate modeling but also the implications of the modeling scenario into decision making processes especially related to the future effects of UHI"* – Andhang Tri Hamdani, former student assistant in the project, currently working as a researcher in Hiroshima University, Japan

Appendix A4. Working Papers, Conference Papers, and Journal Article

Arifwidodo, S.D. & Chandrasiri, O. (2015). Urban Heat Island and Household Energy Consumption in Bangkok, Thailand, *Energy Procedia*, 79 (2015), 189-1194

Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 79 (2015) 189 – 194
Energy Procedia

2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies

Urban Heat Island and Household Energy Consumption in Bangkok, Thailand

Sigit Arifwidodo[a*], Orana Chandrasiri[b]

[a]*Department of Landscape Architecture, Faculty of Architecture, Kasetsart University, Thailand*
[b]*International Health Policy Program, Ministry of Public Health, Thailand*

Abstract

This study focuses on the urban heat island (UHI) development and its impact on household energy consumption. Hourly air temperature data were used to study the characteristics and intensities of UHI in Bangkok area. A survey questionnaire of 400 randomly selected respondents is conducted to explain the relationship between UHI intensity and household energy consumption. Cooling Degree Days (CDD) index was used to establish the correlation between UHI and energy consumption. The result indicates that the presence of UHI in Bangkok plays a significant role in residential energy use, directly and indirectly. UHI is found to have association with the air conditioning equipment in Bangkok and increase the monthly electricity bill. Energy consumption is found to have positive association with CDD, which implies that UHI have significant influence on the household energy consumption. The study concludes that combining the concept of UHI mitigation and adaptation planning and energy-efficient housing design will contribute to better solutions for creating a more energy-efficient city.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE

Keywords: household energy consumption; urban heat island; urban planning; sustainable urban development; cooling degree day

1. Introduction

Urban heat island (UHI) is defined as a phenomenon where temperatures of urban areas are higher than surrounding or rural areas [1]. A measure to quantify urban heat island usually uses the term Urban Heat Island Intensity (UHII), which is the maximum temperature difference between urban and rural air [2].

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

* Corresponding author. Tel.: +66-294-289-60 ext 314; fax: +66-294054-13.
E-mail address: sigit.d@ku.ac.th.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE
doi:10.1016/j.egypro.2015.11.461

Arifwidodo, S.D. (2015). Factors Contributing to Urban Heat Island in Bangkok, Thailand, *ARPN Journal of Engineering and Applied Sciences 10 (15), 6435-6439*

VOL. 10, NO. 15, AUGUST 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

FACTORS CONTRIBUTING TO URBAN HEAT ISLAND IN BANGKOK, THAILAND

Sigit D. Arifwidodo
Department of Landscape Architecture, Faculty of Architecture, Kasetsart University, Bangkok, Thailand
E-Mail: sigit.d@ku.ac.th

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

Arifwidodo, S.D., and Chandrasiri, O. (2016). Urban Heat Island and Health Effects in Bangkok, Thailand. Proceeding of the *International Conference on Humanities and Technology*, *Melaka, Malaysia*

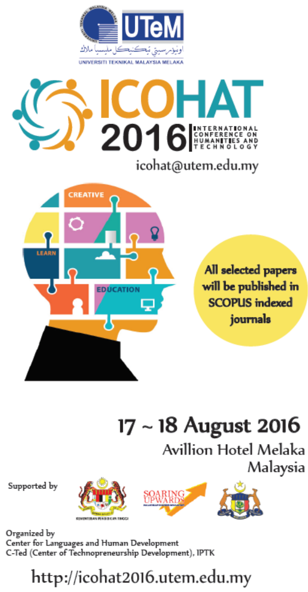
Urban Heat Island and Health Effects in Bangkok, Thailand

Sigit Arifwidodo
Department of Landscape Architecture,
Faculty of Architecture, Kasetsart University, Thailand
50 Paholyothin Road, Jatujak, Bangkok 10900 Thailand
Tel.+662 942 8960 ext 314 Fax. +662 940 5413
Email: sigit.d@ku.ac.th, dwiananto@gmail.com

Orana Chandrasiri
International Health Policy Program, Ministry of Public Health, Thailand
Ministry of Public Health, Tiwanon Rd. Nonthaburi 11000, Thailand
Tel: +66(0) 2590-2366-7 Fax: +66(0) 2590-2385
Email: orana@ihpp.thaigov.net, orana.chandrasiri@gmail.com

Abstract
Urban heat island (UHI), a phenomena happens when the temperature in urban area are warmer than sub-urban, is widely acknowledged to have significant impact on human comfort and health. The study explores the health effects of urban heat island (UHI) in Bangkok. Using 400 randomly selected respondents, the study focuses on three health effects namely, physical health impacts, mental health impacts and health outcomes. The temperature data are obtained from urban and non-urban weather stations in Bangkok and its vicinity. Descriptive statistics are used to establish associations between UHI and health effects. It is found that there is a significant association between these variables when we established bivariate correlation (spearman rank). It can be inferred that UHI affects the health indirectly through the heat interferences with daily activities.
Keywords: urban heat island, health outcomes, urban development, temperature, sustainable development

Introduction
The urban heat island (UHI) phenomenon generally refers to the higher temperature in cities or urban areas than the temperature in surrounding areas. The UHI is used to describe a characteristic warmth of surfaces and atmosphere in urban areas. Meteorologists initially observed the UHI more than a century ago. The UHI phenomenon occurs most at night because the roads and other surfaces absorbing solar radiation in daytime release heat in nighttime. The anthropogenic heat, heat aroused by human activities, can be an important factor causing UHI especially in winter. Urban areas create more heat than rural areas because transportation, population, industrial and some other activities are higher in urban areas. Rosenfeld (1997) cites that on hot summer days, the air in cities can be 4.4°C hotter than the surroundings. The cause of this phenomenon is mainly from urban development results in large amounts of dark colored surfaces such as roofs, road, and parking lots. These surfaces absorb heat more than reflecting it raising high temperature in cities.



Arifwidodo, S.D., and Nilkamheang, N. 2018. Perceived Health Effects and Urban Heat Island in Bangkok, Thailand. *Proceeding of the 14th International Urbanization Conference, Bangkok, Thailand*

Perceived Health Effects and Urban Heat Island in Bangkok, Thailand

Sigit Arifwidodo[a]*, Orana Chandrasiri[b], Nuttkritta Nilkamheang[a]

[a]*Department of Landscape Architecture, Faculty of Architecture, Kasetsart University, 50 Ngamwongwan Rd, Bangkok 10900, Thailand*
[b]*International Health Policy Program, Ministry of Public Health, 88/20 Satharanasuk 6 Alley, Nonthaburi 11000, Thailand*

Abstract — Sub-Theme: (4)

The study explores the health effects of urban heat island (UHI) in Bangkok. Using 400 randomly selected respondents, the study focuses on three health effects namely, physical health impacts, mental health impacts and health outcomes. The temperature data are obtained from urban and non-urban weather stations in Bangkok and its vicinity. Descriptive statistics are used to establish associations between UHI and health effects. It is found that there is a significant association between these variables when we established bivariate correlation (spearman rank). It can be inferred that UHI affects the health indirectly through the heat interferences with daily activities.

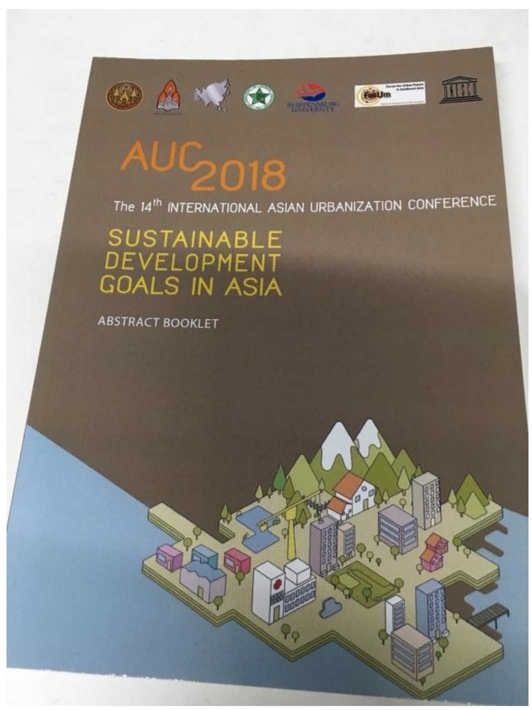
Keywords
Urban heat island; health outcomes; urban development; temperature; sustainable development

1. Introduction

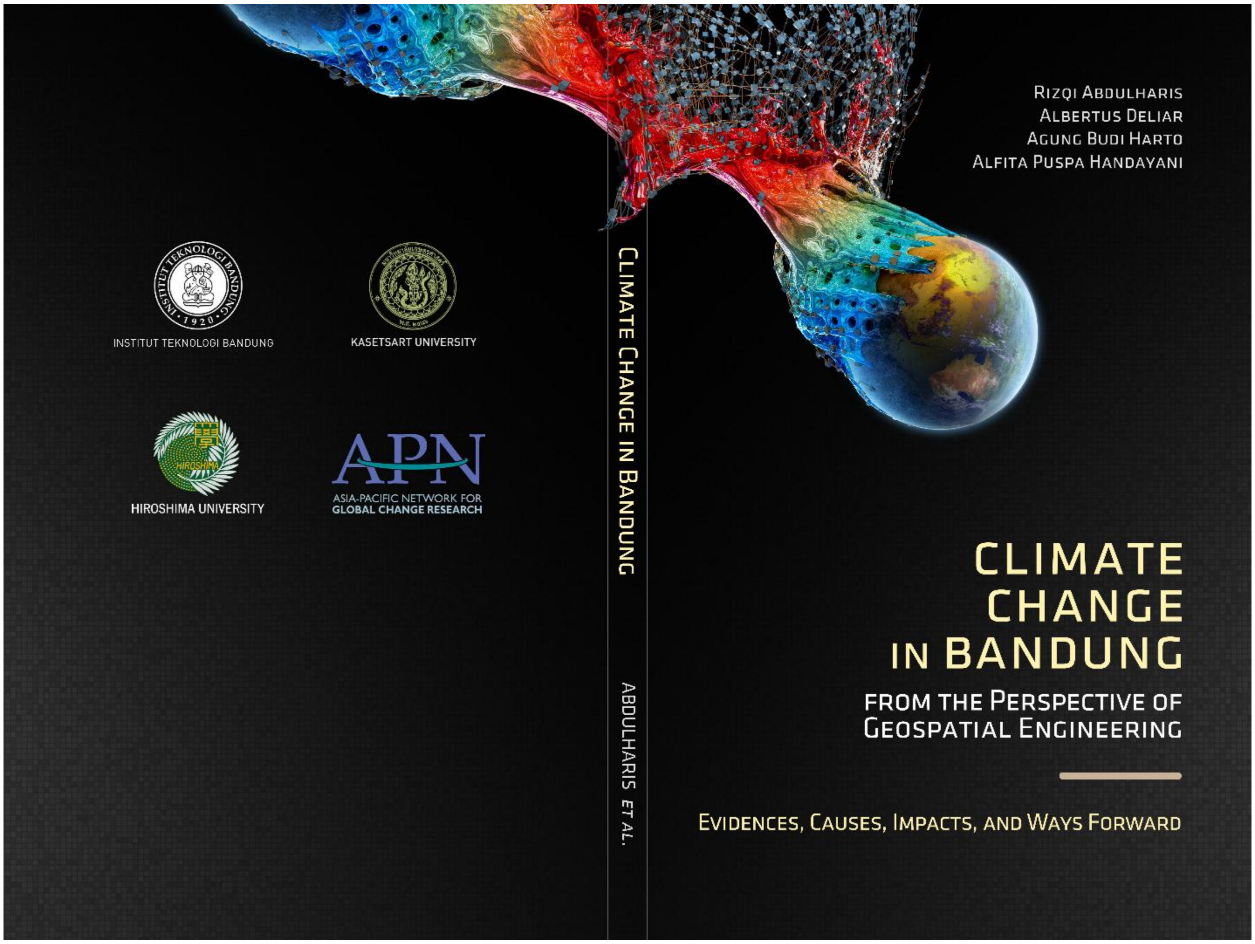
The urban heat island (UHI) phenomenon generally refers to the higher temperature in cities or urban areas than the temperature in surrounding areas. The UHI is used to describe a characteristic warmth of surfaces and atmosphere in urban areas. Meteorologists initially observed the UHI more than a century ago. The UHI phenomenon occurs most at night because the roads and other surfaces absorbing solar radiation in daytime release heat in nighttime. The anthropogenic heat, heat aroused by human activities, can be an important factor causing UHI especially in winter. Urban areas create more heat than rural areas because transportation, population, industrial and some other activities are higher in urban areas. The cause of this phenomenon is mainly from urban development results in large amounts of dark colored surfaces such as roofs, road, and parking lots. These surfaces absorb heat more than reflecting it raising high temperature in cities.

UHI can have both negative and positive effects for cities. The UHI developments alter the atmospheric characteristics of a region. The transformation of radiation, thermal, moisture, and aerodynamics are all affected by this change. This has an effect on the natural energy and hydrological balances (Oke, 1995). In summer, heat islands can have an enormous effect on air-conditioning load by increasing energy demand due to the higher temperature in urban areas caused by heat island. This can lead to power shortages and also raises the energy cost. This high temperature also has a consequence in higher smog due to more photochemical reaction rate. UHIs, moreover, have direct effects on human health by creating heat stress and spreading the vector-bone diseases (Arifwidodo, 2015).

* Corresponding author. Tel.: +662 942 8960; fax: +662 940 5413.
E-mail address: sigit.d@ku.ac.th



Working Paper (in English). Abdulharis, R. Deliar, A. Harto, A. B. and Handayani, A. P. (2018). Climate Change in Bandung from the Perspective of Geospatial Engineering: Evidences, Causes, Impacts, and Ways Forward. Penerbit ITB: Bandung



Working paper (in thai). Arifwidodo, S.D. Integrating Micro-Climate Mitigation Strategies into Urban Planning Practices: Assessment of the Urban Heat Island Effect of Bangkok Master Plan 2013. Kaestsart University: Bangkok.