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Exploring the effects of urban heat island: A case study of two cities in Thailand and Indonesia

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ABSTRACT

This study is part of a regional research project aimed at understanding the effects of Urban Heat Island (UHI) on urban residents. Using two case studies in Bangkok, Thailand and Bandung, Indonesia, the study focuses on the effects of UHI on household energy consumption and health and well-being. A survey questionnaire of 400 respondents from each city was employed. Household energy consumption is measured using a proxy variable of average monthly electricity consumption. UHI intensity is measured using a cooling degree days (CDD) variable constructed from the temperature difference between urban and suburban weather stations. The perceived health effect is measured by heat stress, physical health impacts, mental health impacts and health and well-being outcomes. The data are then analyzed through descriptive and inferential statistics. The result indicates that the presence of UHI in Bangkok plays a significant role in household energy consumption. UHI is found to have a positive association with the ownership of air conditioning equipment in Bangkok and Bandung and is found to increase the monthly electricity bill. In terms of health effects, it is found that UHI affects health directly through heat stress and indirectly through lowering the health and well-being outcomes. Results from the two case studies indicate that UHI has affected the daily lives of urban residents in terms of increasing household energy consumption for cooling and disruption of activities such as working, sleeping, and general health and well-being.

HIGHLIGHTS

» UHI increases the household energy consumption for cooling.

» UHI indirectly affects health through heat interferences which caused disruption of daily activities such as working, sleeping, and general health and well-being.

» Local government needs to pay more attention to UHI mitigation strategies at the city level.

1. INTRODUCTION

The urban heat island (UHI) phenomenon generally refers to the higher temperature in cities or urban areas than in surrounding areas (Oke, 1995). UHI conditions increase the risk of climatic and biophysical hazards in urban environments including heat stress and heighten acute and chronic exposure to air pollutants (United States Environmental Protection Agency [US EPA], 2013). 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 of UHI in metropolitan regions (US EPA, 2012). The UHI phenomenon occurs mostly at night because the roads and other surfaces absorbing solar radiation in the daytime release heat during the night (Oke, 1982). Anthropogenic heat, or heat caused by human activities, can be an important causal factor of UHI, especially in winter. Urban areas create more heat than rural areas because rates of transportation, population, industrial and some other activities are higher in urban areas (Kolokotroni, Zhang, & Watkins, 2007).

UHI can have both negative and positive effects on cities, and UHI developments alter the atmospheric characteristics of a region. The transformation of radiation, thermal, moisture, and aerodynamic factors are all affected by this change, which affects 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 temperatures in such areas, which can lead to power shortages and hikes in energy cost. A study conducted by Miner, Taylor, Jones, and Phelan (2017) that examined the economic cost of UHI found that the maintenance cost of air conditioning devices in major cities in the world is around 0.1–0.2% of a city's gross domestic product (GDP). Another study by Arifwidodo (2014) in Bandung city, Indonesia found a significant relationship between household energy consumption for cooling and increase in local temperature. Ewing and Rong (2008) also found a similar result—i.e., household energy consumption is associated with the incidence of UHI and the spatial pattern of the metropolitan region. The study finds that high-density areas with less green space experience higher UHI intensity, which results in higher household energy consumption for cooling in the summer. Household energy consumption for cooling is also found to be higher in tropical countries, where winter does not reduce the UHI intensity (Voogt, 2004).

UHI can also cause negative health impacts and human discomfort. It directly affects human health by creating heat waves, heat stress and spreading vector-borne diseases (Voogt, 2004), and can also cause heightened acute and chronic exposure to air pollutants and reduced physical health and well-being. 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 of UHI in metropolitan regions (Arifwidodo, 2015). Table 1 summarizes the common health effects of UHI compiled from the literature.

Indirect Health Effect	*Direct Health Effect*
Increased mortality and morbidity rate in population	Cardiopulmonary disease: chronic bronchitis, pneumonia
	Ischemic heart disease
	Cerebrovascular disease
	Respiratory disease: influenza, common cold
Lower life satisfaction	Heat stress
	Sleep deprivation
	Less daily travel
	Higher sedentary behaviour
	Less activity during the hot period

TABLE 1. Major species in the field plots and their maximum height and DBH. Source: Oke, 1995; Tawatsupa et al., 2014; Guo et al., 2012; Tan et al., 2010.

Despite interest in the topic, empirical studies on the effects of UHI on household energy consumption and health are still limited, mainly because there are different methods of measuring UHI and its effects on daily lives of urban residents – for example, use of both air temperature or surface temperature to understand the microclimate conditions of an area (Henry, Wetterqvist, Roguski, & Dicks, 1989). Most studies on the effect of UHI on household energy consumption were mainly conducted in sub-tropical countries where the effects of UHI during winter were also pronounced, which presented a different situation compared to cities in tropical contexts (see Ewing & Rong, 2008; Arifwidodo, 2014). Prior research suggests that space heating and cooling and lighting are the most important determinants of household electricity consumption (see Randolph & Masters, 2008; Steemers, 2003); however, their associations with UHI and other climatic variability are still sparse (Sailor & Vasireddy, 2006).

Similarly, although the impact of UHI in the form of heat waves are well-documented in developed countries, few studies cover cities in the tropics (Tan et al., 2010). Studies conducted by Thawillarp, Thammawijaya, Praekunnatham, and Siriruttanapruk (2015) and Tawatsupa, Dear, Kjellstrom, Sleigh, and Samakkeekarom (2014) examined heat stress and heat-related illnesses in Thailand and found that there is an increasing prevalence of illnesses associated with rising temperatures. Therefore, it is important to understand these issues using case studies in tropical countries. The present study is based on the two case study areas of Bangkok, Thailand and Bandung, Indonesia because these cities represent two different geographical conditions of rapidly growing cities in Southeast Asia. Bangkok is a coastal city with maximum elevation of 4 m above sea level, while Bandung is a mountainous city 768 m above sea level and surrounded late tertiary and quaternary volcanic terrain rising to 2,400 m. These differences in geographical conditions means the cities experience different UHI effects. By using these two case studies, it is expected that the results can be generalized and the method used in the study be applied to other cities with similar characteristics.

2. METHODOLOGY

The study argues that UHI has significant effects on household energy consumption and public health. In measuring UHI, the study follows Tan et al. (2010) in measuring UHI intensity as the temperature difference (ΔT) between urban area (u) and suburban area (s). In both cities, the yearly average temperatures from three weather urban stations and one suburban station in Bangkok and Bandung were calculated. In linking household energy consumption with UHI, we calculated the cooling degree days (CDD) to investigate the effect of higher temperature on cooling energy consumption in Bangkok and Bandung. The CDD method is a common technique to investigate the effect of higher temperature on cooling energy consumption (Giannakopoulos et al., 2009).

The CDD profile for the model is derived from weather stations for each city, and used as one of the independent variables in the OLS regression to examine the electricity consumption and the direct effect of UHI on perceived health. CDD is calculated from the following equation,

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

where CDDi is the cooling degree days for a particular day (d), Tb is the base temperature 24°C and Tm is the mean air temperature, considering only the positive values. The study follows Radhi and Sharples (2013) by using 24°C as the base temperature, since it is more appropriate for tropical countries than 18°C which is usually used in European and American cities. The study also collected the monthly average of electricity consumption as a proxy for household energy consumption. The data were then analyzed using the ordinary least square (OLS) regression model to understand the effect of UHI intensity (measured by CDD) on household energy consumption (measured with average monthly electricity consumption for year 2015) as the dependent variable.

In exploring the health effects of UHI, the study obtained survey data on perceived health stress and health outcomes. Previous studies such as Tan et al. (2010) and Thawillarp et al. (2015) have identified that UHI affects health through heat waves and heat stress, causing heat-related illnesses. Since Thailand has never experienced heat waves, the study uses heat stress as a measure of the health effect of UHI. Heat stress is identified as the uncomfortable feeling when doing daily activities and is 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. The health outcomes were measured by three variables: physical health, mental health, and well-being. The data from the survey questionnaire were then analyzed using descriptive and inferential statistics to understand the patterns and characteristics of the perceived health effects.

The empirical analysis in this study is based on two data sets, which differ with respect to aggregation. The first data set is the monthly average temperature which was collected from three urban and one suburban weather stations. The second data set was obtained from the survey questionnaire for 400 households from each city. The study employed a stratified random sampling technique with each district as the unit of analysis. The study obtained a list of registered households and their addresses from the district office as a sample frame, and randomly selected the respondents proportionally based on the population in each district. The data used in the analysis are weighted to account for different probabilities and survey response. The study also geocoded the respondents home address to incorporate the temperature data into their responses and create a proxy variable for the UHI intensity. Table 2 summarizes the variables and definitions used in the analysis.

3. RESULTS AND DISCUSSION

3.1 Urban heat island in Bangkok and Bandung

Bangkok is the capital city of Thailand, and is located 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 is 100°28' East, with an elevation of about 2.31 m above sea level. The city is divided into 50 districts and 154 sub-districts, with total area of around 1,568.737 square kilometres. As the centre of industry, manufacturing, economy, commerce, and construction, a large number of people are drawn to it from all over the country, leading to high growth of urbanization and industrialization. The population is about 10 million in the daytime, which is 16% of the total population of Thailand (NSOT, 2013). This rapid urbanization has led to several environmental problems such as air pollution, water pollution, land subsidence as well as problems from the presence of UHI, high energy consumption, and biophysical hazards (Arifwidodo, 2012). Generally, the climate of Bangkok is tropical (warm and humid), and the city is affected by the monsoon season. The relative humidity is high throughout the year at around 60–80%. 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, with absolute minimum of about 20°C and absolute maximum temperature of about 30°C. The rainy season temperature is around 25–32°C, the dry season temperature is around 20–25°C and the hot season temperature is around 40–42°C. In 2015, the maximum temperature difference between urban and rural areas of Bangkok was 7°C, which is the highest in the last 10 years.

Category	*Variable*	*Definition*	*Bangkok*		*Bandung*	
			Mean (stddev)	*% of 1*	*Mean (stddev)*	*% of 1*
UHI intensity	CDD24	Cooling degree days using 24°C as the base temperature	152.68 (32.11)	-	12.1 (6.57)	-
	TEMP	Average monthly temperature difference between urban and suburban stations	1.95 (1.97)	-	2.8 (1.8)	
Housing	HOUSETYPE	Type of housing unit, with 1 = detached house; 0 = other	-	46.8		
	AC	Number of Air conditioner units owned	1.8 (1.2)	-	1.52 (0.56)	-
	TYPEAC	Type of AC unit with 1 = split unit; 0 = other	-	78.3	-	98.4
Energy Consumption	USEAC	Frequency of using AC unit in the past year, with 1 = almost every day, 0 = rarely used	-	84.2	-	23.4
	ENRGYSAVE	Energy saving products owned in the house, with 1 = own; 0 = not own	-	76.3	-	65.4
	ENERGY	Total energy consumption, measured with the monthly average of electricity bill for this year in USD	26.69 (13.47)	-	14.45 (12.67)	-
Household	HHMEMBER	No. of household members	4.0 (1.82)	-	5 (2)	-
	INCOME	Average monthly income in the last year (in USD)	627.63 (266.87)	-	197.8 (142.96)	-
	AVAGE	Average age of respondent	39.6 (14.08)	-	46.15 (22.4)	
	EDUCATION	Education of the head of household, with = 1 if respondent has graduated from high school, 0 otherwise	-	70.8	-	54.2
	GENDER	Gender of the respondent, 0 = female, 1 = male	-	38.2	-	65.3
	MARITAL	Marital status of respondent, 0 = single, 1 = married	-	48.3		69.3
	HHSTAT	Status in the household, 0 = head of the household, 1 = other	-	46.7	-	54.8
	TENURE	Housing tenure of the respondents with 1 = own; 0 = rent/other	-	87.4	-	83.5
Health	PHYSICAL	Physical health effect of UHI measured by perceived energy level during the past 4 weeks, with 1 = very low, 5 = very high	-	13.4	-	10.1
	MENTAL	Emotional problems the last 4 weeks experienced by respondents, with 1 = very rarely, 5 = very frequently	-	16.5	-	13.6
	WELLBEING	Life satisfaction for the last four weeks, with 1 = very unsatisfied, 10 = very satisfied	-	11.4	-	9.8
	SMOKE	The respondent’s smoking addiction, 0 = yes, 1 = no	-	88.7	-	56.4
	ALCOHOL	The respondent’s alcohol addiction, 0 = yes, 1 = no	-	90.5	-	99.5
	ISCHEMIC	Does the respondent have an ischemic heart disease, 0 = yes, 1 = no	-	99.8	-	98.7
	CEREBROVAS	Does the respondent have a cerebrovascular disease, 0 = yes, 1 = no	-	98.6	-	96.4
	RESPIRATORY	Does the respondent have a respiratory disease, 0 = yes, 1 = no	-	90.9	-	95.9
	CARDIO	Does the respondent have a cardiopulmonary disease, 0 = yes, 1 = no	-	93.7	-	95.9

TABLE 2. Variable used in the analysis.

Bandung is the capital of West Java Province in Indonesia. It is considered the fourth most populous city in the country. The city is located on a river basin surrounded by volcanic mountains, and this topography provides a cooler year-round temperature than most cities in Indonesia, which makes Bandung famous for tourism. The annual temperature in Bandung is 24.72°C with relative humidity around 70%. Presently, Bandung is one of the biggest growth centres in Indonesia with mixed land use and a concentric urban structure. Being one of the national and regional centres 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 issues that urban planning in the city needs to tackle (Arifwidodo, 2014). Nonetheless, while flooding has annually occurred in some parts of Bandung Basin since the 19th century, the high rain intensity, which has been increasing since 2011, has caused a higher number of landslides, typhoons, and falling trees in Bandung in 2016 compared with 2015. While vulnerability to landslides increases at the beginning of the rainy season after a long dry season, it has been reported that typhoons caused falling trees, other damages, and even fatalities. Although typhoons may normally occur during the seasonal transition, their likelihood of occurrence has doubled since 1998 due to climate change. Urbanization in Bandung has caused a change in the microclimate. In 1995, the average temperature in the city was 18°C, which rose to 22°C in 2007 and 25°C in 2015, with a maximum temperature difference between urban and rural areas of Bandung of 6°C, which is the highest in the last 10 years.

Although the magnitude of UHI is increasing, policies and measures to tackle UHI and its impacts are still scarce in Bangkok and Bandung. Bangkok Metropolitan Administration (BMA), the institution responsible for the city development, has three different planning documents drafted by three different agencies related to UHI adaptation. Moreover, the implementation of each sector has only met with limited success, due to two reasons. First, there is no integrated plan to adapt and mitigate UHI. All planning documents related to UHI are part of efforts to solve the urban problem in different sectors. For example, UHI adaptation is included in a document to increase the number of green spaces in Bangkok as well as a document on the climate mitigation and adaptation plan. Second, the plans exist under three different implementing offices, which resulted in a lack of coordinated efforts between policies. In the case of Bandung, there is no direct policy for reducing UHI effects. The local government does not perceive mitigating UHI as important since Bandung's temperature is considered colder compared to other major cities in Indonesia. While several implicit policies aimed at mitigating and adapting to UHI effect exist, which can be found in the master plan, zoning regulations, building codes, and environmental policies, these policies are not purposively focused on combating the UHI effect despite their potential, if implemented, to positively contribute to mitigating and adapting to the city's increase in temperature.

Variable	*Bangkok*	*Bandung*
	Coeff (std.error)	***Coeff (std.error)***
CDD	0.0049 (0.0012)***	0.0007 (0.0003)**
AC	0.0738 (0.0311)***	0.0738 (0.0256)**
USEAC	0.1316 (0.0409)**	0.1264 (0.0373)
ENRGYSAVE	-0.1014 (0.0988)	-0.0400 (0.0788)
HOUSETYPE	-0.0260 (0.0610)**	-0.0271 (0.0274)**

TABLE 3. Result of OLS Regression model on the Effect of UHI on Household Energy Consumption. Note: *** = $p<0.001$, ** $p<0.05$. Adjusted R2 for Bangkok = 0.23 ($p<0.001$), adjusted R2 for Bandung = 0.21 ($p<0.001$). The model is adjusted for control variables HHMEMBER, INCOME, AVAGE, EDUCATION, GENDER, MARITAL, HHSTAT, TENURE. Dependent variable is ENERGY. Source: Author's analysis.

3.2 Urban heat island and household energy consumption

In Bangkok, a survey conducted by the National Statistical Office of Thailand in 2013 shows that the average energy expenditure is 2,084 THB (or 10.9% of total expenditure), among which 607 THB (29.1% of the total energy expenditure) is spent on electricity. The average electricity expenditure in Bangkok Metropolitan Area is 1,133 THB, higher than other regions in the country. This figure is slightly different from the result from the survey (854.35 THB for electricity expenditure). Seventy-two percent of households in the study area had air conditioning (AC) equipment in their housing units, and a positive correlation between income and number of AC units owned in the house exists (two-tailed t-statistics, $p < 0.0001$). This is because the higher the income, generally the bigger the floor area of households. The floor area of the house is also found to have a positive correlation with the frequency of AC use (two-tailed t-statistics, $p < 0.005$).

In Bandung, the sample appears biased towards the relatively higher income group. The average income of the sample is above that of the average socio-economic survey in 2007 conducted by Bandung Statistical Agency (Bandung Statistical Agency [BSA], 2007). The average income from our survey is 2,868,267.9 IDR, while it is 711,138 IDR from the socio-economic survey.

On average, households in the study area spend 163,455 IDR per month for electricity expenditure. Most of the respondents live in detached housing with permanent structures (76.3%). Table 3 summarizes the effect of UHI on household energy consumption in Bangkok and Bandung.

After controlling for other variables, the result shows that there is a statistically significant relationship between UHI intensity (measured by CDD) and household energy consumption both in Bangkok and Bandung. The result confirms that UHI magnitude has a positive association with the household energy consumption in two ways. First, energy consumption for cooling is higher when the UHI magnitude is higher, corresponding to seasonal variations. Second, energy consumption for cooling is higher in the area that suffers high UHI magnitude. This means that in the urban area, where the UHI is high, household energy consumption is higher compared to the suburban area. This finding is similar to that of Arifwidodo (2014) and Zhou, Zhuang, Yang, Yu, and Xie (2017), which suggests that household energy for cooling in the urban area is associated with higher volume of anthropocentric activities and microclimate. However, in Bandung, although the average monthly electricity usage for cooling was 262 kilowatt-hours or 85.34% of the average of total monthly household electricity usage, there were only 12.42% of respondents who had AC installed in their house. The fact that variable AC usage is not significant reflects the low percentage of AC equipment and usage compared to total monthly electricity usage of households, which was only 0.22% and 1.34% respectively.

3.3 Urban heat Island and perceived health effect

The UHI-related health effects in this study are defined as 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. Although not as severe compared to other countries, Thailand has experienced an increased prevalence of heat-related illnesses (Langkulsen, Vichit-Vadakan, & Taptagaporn, 2010). A study on heat stress in the country has revealed that heat stress is a very serious problem (Tawatsupa et al., 2014), and the Thai Meteorological Department (2009) has predicted that the average temperature will increase by 4°C by 2100, which will contribute to excess mortality.

Table 4 summarizes the variables of heat stress from Bangkok and Bandung. The variables are constructed by

Variable	*Description*	*% of 5*		*% of agreement*	
		BKK	*BDG*	*BKK*	*BDG*
Sleeping 1	I have trouble sleeping because of summer heat	32.7	11.2	88.3	50.3
Sleeping 2	I need to turn the fan/AC on during sleeping at night	56.2	10.2	98.8	22.1
Housework 1	I do less housework in the afternoon because it is too hot	20.4	12.1	86.1	28.9
Housework 2	I turn the fan/AC on while doing housework	21.0	2.8	78.4	16.3
Daily travel	I have difficulty going to work because of the heat	25.5	10.1	88.7	46.1
Work	I have problems at work because of the hot weather	22.4	8.7	87.3	50.7
Exercise	I do less exercise because of the hot weather	14.1	9.4	76.9	58.4

TABLE 4. Heat stress category in Bangkok and Bandung. Note: % of agreement is arrived at by combining the 1–2 answer into meaning "no" and 3–5 into meaning "yes". Source: author's analysis.

Health Outcomes	*Percentage*	
	BKK	*BDG*
Overall life satisfaction (score ranged from 0–10)		
9–10 (very satisfied) high	13.2	11.3
8 (high)	23.6	22.1
6–7 (medium)	41.7	34.5
0–5 not very satisfied (low)	21.4	32.1
Energy level in the past 4 weeks		
Very much	5.6	66.5
Quite a lot	22.2	22.2
Some	58.9	66.3
A little or none	13.4	5.1
Emotional problems in the past weeks		
Not at all	12.0	70.2
Slightly	32.1	18.4
Moderate	39.4	4.2
Quite a lot	16.5	7.2

TABLE 5. Health and well-being outcomes. Note: the Likert scale for the overall life satisfaction is 1–10 with 1 = very unsatisfied and 10 = very satisfied. The scale for energy level is 1–5 with 1 = very rarely, 5 = very frequently. The scale for the emotional problem is 1–5 with 1 = very low, 5 = very high. The adjustment of the language did not change the grouping of data. Source: author's analysis.

Variable	*CDD*	
	BKK	*BDG*
Sleeping 1	0.077**	0.031*
Sleeping 2	0.099**	0.045*
Housework 1	0.135***	0.063***
Housework 2	0.047**	0.064**
Daily travel	0.001**	0.001**
Work	0.006**	0.007**
Exercise	0.119**	0.125**

TABLE 6. Association between UHI intensity and heat stress. Note: *** = p<0.001, ** p<0.05, * = p<0.01. Adjusted R2 for Bangkok = 0.11 (p<0.001), adjusted R2 for Bandung = 0.08 (p<0.001). BKK = Bangkok, BDG = Bandung. The dependent variables are Sleeping 1, Sleeping 2, Housework 1, Housework 2, Daily travel, work, and exercise. Source: author's analysis.

asking respondents to rank their agreement with statements in the questionnaire, where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. The table shows that most respondents have problems with daily activities because of heat interferences. More than 80% of respondents have trouble sleeping at night and almost 100% of respondents require use of an 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 the AC or fan while doing such chores. More than 80% of respondents have heat interference problems at work, and more than 70% of respondents exercise less because it is too hot.

In Bandung, due to relatively colder weather conditions, the result is slightly different from Bangkok. Only half of the respondents report that they have trouble sleeping because of heat and 22% of respondents need AC equipment to sleep at night. Contrary to Bangkok, only 29% of respondents in Bandung experience problems during their housework and only 16% need to use their AC. Another different result is revealed in daily travel, with only 46% of respondents in Bandung experiencing difficulties going to work compared to 88.7% in Bangkok. In terms of work and exercise, more than half of the respondents in Bandung report that they experience problems due to hot weather.

Table 5 describes the health and well-being outcomes in Bangkok and Bandung. Health outcomes are relatively similar, except for emotional problems. Respondents in both cities report that their overall life satisfaction is mostly at the medium level (6–7 on a 10 Likert-scale). More than half of the respondents in both cities also report that they have experienced a low level of energy in the past month. On the other hand, more than 70% of respondents in Bandung feel that they do not have emotional problems, while in Bangkok more than 87% suffer emotional problems during the past weeks.

To understand the association between health outcomes, heat stress, and UHI, two models of ordinary least squares OLS regression model are established. The argument is that UHI will disrupt daily activities through heat stress, and heat stress then eventually affects health outcomes. The first model is used to understand the association between UHI intensity (measured with CDD) and heat stress. The second model is to understand the association between heat stress and health and well-being outcomes.

Table 6 summarizes the association between heat stress and UHI intensity, measured with CDD. The data suggest that UHI intensity is significantly associated with all heat stress variables. The positive association means that the higher the UHI intensity, the higher the disruption of daily activities and cause of heat stress. It can be inferred that UHI directly disrupts daily activities of the respondents and causes heat stress. Only sleeping 1 and sleeping 2 variables show less significance (p<0.01) in Bandung, probably because of the weather conditions during the night, which is much cooler than Bangkok.

	Life satisfaction		*Energy level*		*Emotional problem*	
	BKK	*BDG*	*BKK*	*BDG*	*BKK*	*BDG*
Sleeping 1	-0.03***	-0.05**	-0.078	-0.045	0.196***	0.164**
Sleeping 2	-0.49*	-0.27*	-0.49	-0.23	0.93	0.73
Housework 1	-0.198***	-0.112***	-0.193***	-0.096***	0.215***	0.176***
Housework 2	-0.157***	-0.092***	-0.125*	-0.096*	0.046	0.022
Daily travel	-0.83**	-0.74**	-0.118*	-0.102*	0.136**	0.094**
Work	-0.153**	-0.113**	-0.190***	-0.128***	0.174***	0.153***
Exercise	-0.191***	-0.082***	-0.162***	-0.118***	0.183***	0.098***

TABLE 7. Association between heat stress and well-being outcomes. Note: *** = p<0.001, ** p<0.05, * = p<0.01. Adjusted R2 for Bangkok = 0.121 (p<0.001), adjusted R2 for Bandung = 0.115 (p<0.001). BKK = Bangkok, BDG = Bandung. The model is adjusted with control variables HHMEMBER, INCOME, AVAGE, EDUCATION, GENDER, MARITAL STATUS, HHSTAT, TENURE, SMOKE, ALCOHOL, ISCHEMIC, CEREBROVAS, RESPIRATORY, CARDIO. The dependent variables are life satisfaction, energy level, and emotional problems. Source: author's analysis.

The association between heat stress and health and well-being outcomes is summarized in Table 7. The data suggest that heat stress is 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 the highest correlation value with all health and well-being outcomes in Bangkok and Bandung. The data suggest that respondents with heat stress problems will have lower life satisfaction, lower energy level, and experience more frequent emotional problems. These findings are similar to the results in the literature, i.e., that heat stress significantly reduces health outcomes and well-being. For example, Lan, Lian, and Pan (2010) found that people working in hot environments had lower motivation to work and experience negative moods during work. Guo, Punnasiri, and Tong (2012) found that there is an effect of increasing temperature on mortality in Bangkok, Thailand. This study found that heat stress not only affects their working life, but also interferes with other aspects of daily life such as sleep, daily travel, and exercise.

4. CONCLUSION

The study explores the effects of UHI on the household energy consumption and perceived health effects in Bangkok, Thailand, and Bandung, Indonesia. The effects on household energy consumption are examined using monthly electricity. The results show that UHI is associated with increasing AC equipment ownership and increase in household energy for cooling in both cities. The perceived health effect of UHI is examined using heat stress variables and health outcomes. Analysis of the data suggests that UHI increases heat stress and lowers health outcomes. The study indicates that UHI affects the daily lives of urban residents and that local governments need to pay more attention to it. Integrating UHI adaptation into decision-making processes is the logical implication of this finding. In the cities of developing countries where resources are scarce, a better understanding of the effect of UHI on urban areas can help local governments make better decisions in allocating resources and amenities and be more aware of when to promote growth or contain it, while minimizing any externalities that may occur.

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