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Influences of Urban Land Use and Land Cover Types on Temperatures Changes in Tropical Areas, Bangkok Thailand

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Abstract

The current globalized era has led to the continuous expansion of urban areas worldwide, resulting in significant changes to land cover and land use as green spaces are converted into urban environments to accommodate human habitation and socio-economic activities. This urbanization has caused an increase in average temperatures, though the rise is not uniform across all areas. This study employed a traversing methodology using motorcycles equipped with temperature measurement instruments across Bangkok and its surrounding areas. The research routes were divided into two main mobile measurement routes to represent different land uses in urban zones: 1) South to North and 2) West to East. The mobile temperature measurements were compared with data from a fixed sensor located on the Kasetsart University campus. Overall, the results collected for both day and night traverses indicated that temperature increases correlate with urban characteristics such as street canyons (building aspect ratios), land cover heat capacity, traffic density, overcrowded communities in slums, central business districts, and heightened anthropogenic activities. Conversely, certain urban areas also exhibited temperature decreases, attributed to the presence of green spaces and open areas. It was concluded that green spaces significantly affect temperature through the evapotranspiration of plants, which increases the energy used for evaporation and subsequently reduces the energy required for air heating, leading to lower temperatures in green areas and their surroundings. Therefore, future studies will focus on the structural components of green areas within urban neighborhoods.

Keywords: Land Use and Land Cover Change; Street Canyon; Green Areas; Urban Heat Island

1. Introduction

The increase in globalization has led to the rapid growth of cities to meet demographic and economic demands. Advancements in technology have enabled the human population to drive urbanization. Over the past 100 years, the emergence of cities around the world has been evident, and as of 2024, 56% of the global population now resides in urban areas (Murakami, 2022). This growth has also contributed to the expansion of cities. In particular, these impacts are visible in tropical regions, where dense populations exacerbate heat stress caused by the urban heat island (UHI) effect. (Chakraborty & Qian, 2024)

The heat island effect is defined as the increase in air and surface temperatures in urban areas compared to their rural surroundings, commonly referred to as urban heat island (UHI). This phenomenon is primarily attributed to land use, land cover changes, and the structure of urban fabrics, which alter the radiative properties of cities (Iamtrakul *et al.,* 2024). While the types, amounts, proportions, and densities of urban elements vary from one city to another, each city presents unique and diverse characteristics due to its specific urban structure and physical features (Thinh *et al.,* 2002).

The rapid expansion of urban areas, many cities worldwide have experienced the urban heat island (UHI) effect, a phenomenon where the ambient temperatures within cities are higher than those in surrounding rural areas. On average, surface temperatures in cities are typically 1.5 °C higher than their rural counterparts.

As cities are built and developed at varying spatial scales, urban building materials contribute to increased heat storage on surfaces. This effect is compounded by anthropogenic heat sources, such as combustion engines and pollution emissions, which intensify the local greenhouse effect, leading to higher air temperatures.

In response to current trends, urban areas are increasingly implementing mitigation strategies, such as expanding green spaces. Vegetation enhances latent heat exchange, which can effectively lower ambient temperatures.

Cities, viewed as complex structures, often exhibit fluctuations in temperature hotspots. These variations are not confined to a single area but occur as clusters scattered throughout the urban landscape. This creates distinct zones with differing temperature gradients. (Oke *et al.,* 2017) According to Zhang *et al.* (2015), these hotspots are influenced by both the spatial and temporal expansion and development of urban areas.

As cities expand and grow more complex and heterogeneity within the urban surface, they encompass mixed-use spaces, including low-rise residential neighborhoods and high-density districts with commercial and industrial zones. These variations in land use and land cover contribute to differences in temperature gradients, which can be observed across various parts of the city. With patches of different proportions of urban area, green area, water bodies, these radiative properties of various height, aspect ratio and density of built-up structures often alters wind direction, and wind speed often resulted in the correlation with the average urban surface temperature. Particularly in areas far from water sources, with limited air circulation, and where urban area coverage exceeds green space and water body coverage (Ngamsiriudom & Tanaka, 2023)

Given the diverse land cover characteristics in urban areas such as built-up areas, forests, water bodies, agricultural lands, and miscellaneous spaces distributed across cities with various land-use purposes (residential areas, economic centers, transportation zones, or public spaces), the areas surrounding roads affect surface temperatures differently (Adulkongkaew *et al.,* 2020).

While some cities are well planned, many cities especially in tropical areas are often shaped by different political and social demographic changes as thus the expanding city are seen without a strict growth pattern. Such, case can be applied with Bangkok, Thailand in which over the years have seen rapid expansion it the city's urban land cover making for a complexity in surface emission and heat changes.

This research applies in Bangkok, a topical city in South East Asia in which the temperature mobile measurements in comparison with fix mobile sensors in different land use areas together with remote sensing analysis were made covering different land use and cover of the city showing the impacts in the changes of land use patterns toward surface temperature as this would allow for the spatial analysis the heat hotspots as well as identifying different land use patterns, urban structure and cover to their influence on the urban heat island impacts.

2. Methodology

2.1 Study Area

The study area is Bangkok, the capital of Thailand is located along the lower regions of the Chao Phraya River delta on the central plain of Thailand. In evaluation, the urban area is predominantly flat, with a mean elevation of 1.5 meters above sea level. Being the most populated city in Thailand, the areas of Bangkok cover approximately 16,000 km² and has a population of 8.2 million, with 6.3 million residing within the municipality, while the rest of the population lives within the urban extension. (National Statistical Office, 2023)

2.2 Mobile Temperature sensors

This research applied the use of the mobile sensor for the measurement of ambient temperature, as this measurement technique would provide the spatial changes with continuous measurement within the urban areas (Brent & Anthony, 2006). In mobile measurement of the temperature, the Smart-T unit was attached to a motorcycle that is set to traverse on the design route of the city. With the sensor measuring temperature and humidity. This sensor can meet the research-grade requirements (Cao *et al.,* 2020)

2.3 The Fix measurement

For the fix measurement the used of the HOBO sensor was used and installed at Kasetsart University Garden (UTM: P47 E668920 N1531448). The data collected from the fix sensor was then used to compare in temporal sync with the mobile sensor. The placement is shown in Figure 1 at the Height of 1.50 meters from to ground, with the measurement interval were computed every 20-seconds.

2.4 Route and Path

Temperature measurements of road surface temperatures were conducted along routes passing through urban areas in Bangkok, covering a total distance of 77 kilometers (Figure 1). The route was designed to include different land-use areas of Bangkok. To minimize the influence of solar radiation variations due to the time of day, the route was divided into two paths: one running South to North and the other West to East. These two routes allowed the study to assess factors associated with solar radiation during the day, identifying hotspots influenced by radiative properties, and to evaluate the effects of anthropogenic heat during the nighttime period.

The planning of each route considered the overall framework of Oke's land-use classification, ensuring that the traverses covered all land-use types (Stewart & Oke, 2012). The data collection on the roads was carried out during two specific time periods to represent both day and night conditions: 12:00 – 14:00 and 21:00 – 23:00. The data collection spanned three days, with the traverse speed limited to a maximum of 40 km/hour. Temperature measurements were recorded at 1-second intervals during the traverse.

2.5 Spatial variations in Air Temperature and digital elevation model (DEM)

This research also used Landsat-9 OLI/TIRS images acquired on May 11 2024.

Figure 1. The Fix Station (HOBO) Temperature Sensor at the Kasetsart University, Bangkok

The satellite images, downloaded from the US Geological Survey webpage (https://earthexplorer.usgs.gov/). The Landsat-9 data have been georeferenced to the WGS84/ 48S projection system, which was then used to investigate the Land surface Temperature (LST). The LST tool was developed using the NDVI-based LSE (Land Surface Emissivity), Acquiring the data information from Band 10, Band rescaling factor to compute for brightness, Normalized Vegetation Index, Emissivity, digital elevation model and lastly Land surface Temperature. For the digital elevation model (DEM), the use of DEM image were downloaded from US Geological Survey webpage (https://earthexplorer.usgs.gov/) and analyzed using the ArcGIS Program.

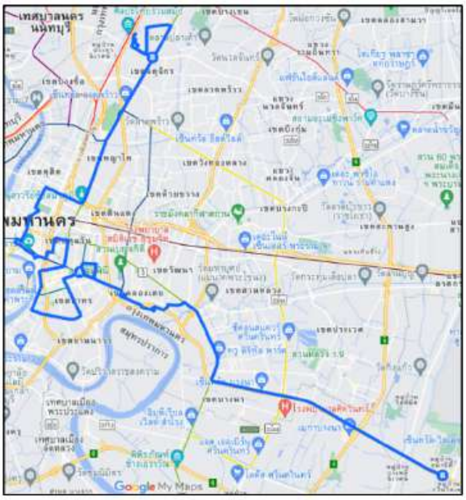
2.6 Mobile Traverse Route

The study area was surveyed using Landsat 9 satellite images with a resolution of 30m x 30m to identify hotspots and cool spots in the urban areas of Bangkok and Samut Prakan. Based on this analysis, road routes were determined to pass through these identified hotspots and cool spots, covering a total distance of 77 kilometers.

The routes were designed to start at the same point, Lumpini Park, but end at different locations. Two routes were specified:

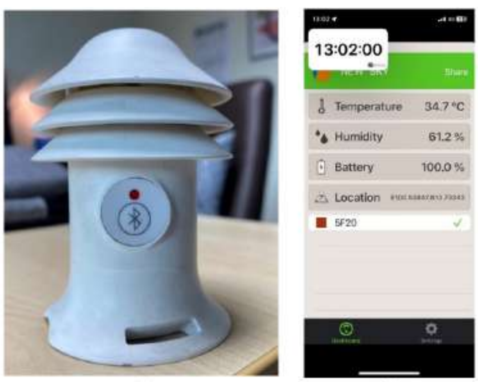
1. North – South Route: From Lumpini Park to Kasetsart University.

2. West – East Route: From Lumpini Park to the PTT gas station on Bangna-Trad Road, covering a distance of 33 kilometers.



Source: Google My Maps (2024)

Figure 2. Mobile/Traverse Temperature Measurement Route



(a)
Smart-T Traverse/
Mobile Temperature Sensor

(b)
Mobile Application

Figure 3. Setup of Sensor and Equipment in Study Area

2.7 Data analysis

In comparing both data set between the traverse routes, the stationary HOBO temperature data from Kasetsart University (KU site) was used to compared the average with the smart-T Temperature sensor and with the ensemble 3 days average (3rd - 6th June 2024) used and the temperature differences mapped out according to the GPS coordinates of the Traverse.

3. Results and Discussion

The comparison between mobile and fixed-station temperature measurements revealed that the average ambient temperature at the fixed station was lower than in the mobile experiment. This increase can be attributed to roadside heat sources, whereas the HOBO fixed station is located in green areas within the Kasetsart University, Bang Khen Campus. From the fixed site, it was seen that the higher temperatures in the mobile experiment can be as depicted throughout each of the 2 routes (South-North and West-East), together with many different hot spots within the city, especially in the cluster district of the densed center (Figure 4). Where the patterns for these hot spots are often related to several urban structures differing in the types of 1) Buildings material or Urban fabrics as different buildings/ anthropogenic material process different radiative properties. 2) Building Density or the ratio of building footprint area to the urban site area and 3) Building Aspect Ratio describing as the vertical-to-horizontal ratio of buildings. (Kong *et al.,* 2022)

Referring to Figure 4, it was seen that within the urban center, there are also areas with lower temperature differences or cool spots within the influence of urban Green Areas: the cooling effects of green spaces in their increase in the latent heat flux (Maskulrath *et al.,* 2023).

The timing of the recordings, whether during the daytime or nighttime, also impacted the results. The daytime measurements showed the greatest temperature differences between mobile and fixed stations with some hot spots being higher than the range of 2.22 to 3.66 °C. While during the nighttime, the average increase of temperature difference was 1.95 to 1.0 °C. However, not all locations exhibited have consistent temperature increases, as hot spots were specifically identified along the 2 routes.

3.1 Hotspots and Urban Heat Factors

The Higher temperature hotspots were linked to variations in land use, cover, and activities. Such that it was also seen with Satellite data to contributing to support these findings, and all together identifying eight hot and cool spots across two routes. (Figure 5 and 6)

3.2 China Town and Silom Road

Along the south-to-north route, both during the day and night time, the areas of Chinatown (Figure 5 Image 4) exhibited the largest temperature difference, having the night time temperature differences from 1.79 to 3.66 °C and the day time from 1.0 to 1.95 °C respectively. One of the factors contributing to the large temperature difference was suggested for traffic flow and anthropogenic activities. Describing the Chinatown area, it is a bustling commercial area with high tourist activities and street food vendors. This reflects the impact of urban human activities such as crowed roads, high commercial processes, and extensive use of air-conditioning and heating systems both for buildings and local food stalls. These activities consume vast amounts of energy and generate anthropogenic heat, intensifying surface temperatures (Wang & Chew, 2023). In addition, positive feedback of rising temperature can also be amplifies with the increase in anthropogenic heat production that further raises temperatures, contributing to a UHI that forms a warm air canopy over the city. This, in turn, increases energy consumption for heating and cooling buildings (Kloss *et al.,* 2011) promoting even higher temperature to be clustered within the area. As described in Khamchiangta & Dhakal (2019), the location of Chinatown in Bangkok was described to have a high building aspect ratio as the relation was highly correlated to the increase in land surface temperatures in which the radiative

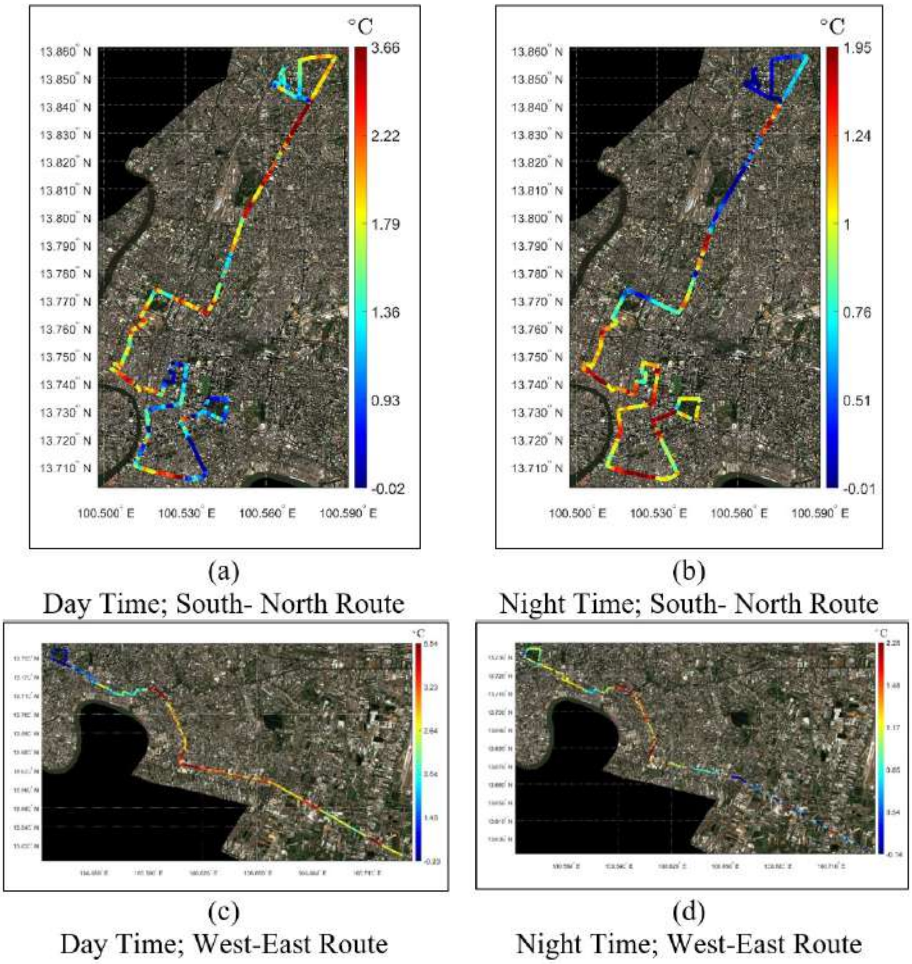


Figure 4. Day and Night Mobile Traverse Temperature Differences in Bangkok; avaged from 3rd - 6th June 2024

interactions with heat is trapped within the urban canopy. Thus, the higher aspect ratio prevent circulation of airflows. Memon *et al.* (2010) suggested that air temperatures increase by 1.3 °C when ambient wind speed decreased from 4 m/s to 0.5 m/s. A similar pattern is observed in tropical cities like Singapore, where heat contributions from anthropogenic sources are significant, where Quah & Roth (2012) and Wang *et al.* (2023) suggested that dense building structures and the radiative properties have an increase by 1.44 °C and the traffic have an increase by 1.35 °C.

Extrapolating on the vehicle speed and density, data from the Office of Transport and Traffic Policy and Planning (OTP) (2021) Showed that in Chinatown, the average vehicle speed was 10 – 15 km/h. This was based on the heavy traffic within the city. The speed is, therefore, significantly lower than on outer roads like Bangna-Trat (West to East Route) (Figure 5 Image 6) where the vehicle speeds are 30 – 35 km/h on average. Thus, in relation to the vehicle speeds, it was also found that the vehicle heat increases with urban area fraction and mean building height as decrease in vehicle speed and increase in the building height amplifies with the 90% confidence level in Hong Kong (Chen *et al.,* 2021). Additionally, it was also supported that the lower building aspect ratio in outer areas allowed for better air circulation and cooling as this was also reflected in the west to east route.

Similarly, the Silom Road, leading from Lumphini Park, represented another hot spot. Its high building aspect ratio restricted wind movement, creating a wind-captivity zone and reducing natural cooling. Studies indicate that higher aspect ratios can increase air temperatures, with rises up to 1.3 K when ambient wind speeds decrease from 4 m/s to 0.5 m/s. Suggested by Takkanon (2016), it was reported that Silom Road (Saladaeng District) had the highest height-to-width ratio (0.95), associated with high urban density and population. In contrast, areas like Don Mueng and Kasetsart University, with lower height-to-width ratios (0.06 – 0.09), showed correspondingly lower temperatures. This was also seen with the Digital Evulation Model (DEM) in Figure 6 where in the central business district, the areas was cluster with average buildings height reaching 50m or higher. These results align with findings from Kotharkar *et al.* (2019). In tropical Nagpur, India, their measurement of surface temperature showed that every 500 m away from the building cluster have an increase in the ambient temperature of 0.13 - 0.14 °C, respectively. However, in newly developed areas where integration of green spaces are cooperated into the urban center, it was seen that an increase of 10% in vegetation density ratio supported to the decrease of surface temperature by 0.17 °C. Conversely, a 10% increase in the aspect ratio (AR) led to increases in temperature.

The heat measured by the mobile experiment aligned with the Land Surface Temperature (LST) derived from Landsat 9 imagery. These findings were correlated with the building height analysis to identify urban hotspots. The analysis revealed that during daytime, the emissivity and radiative properties of urban structures, particularly taller and denser buildings, contributed to greater heat retention. Statically applying, Figure 7 indicated a slightly positive correlation between the land surface temperatures and the average building height (R^2 = 0.159).

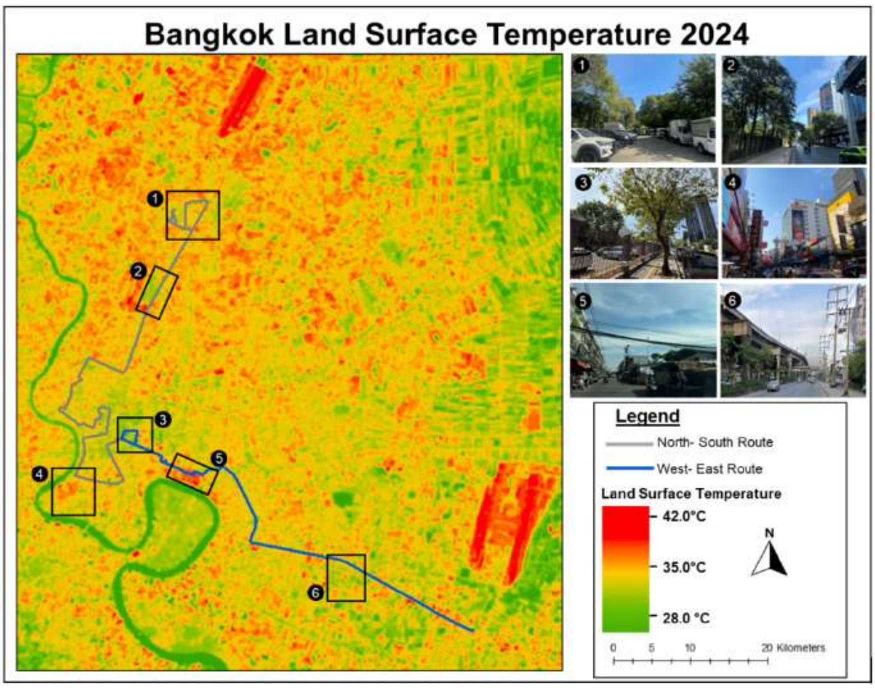


Figure 5. Bangkok Land Surface Temperature and Hotspot from Landsat 9

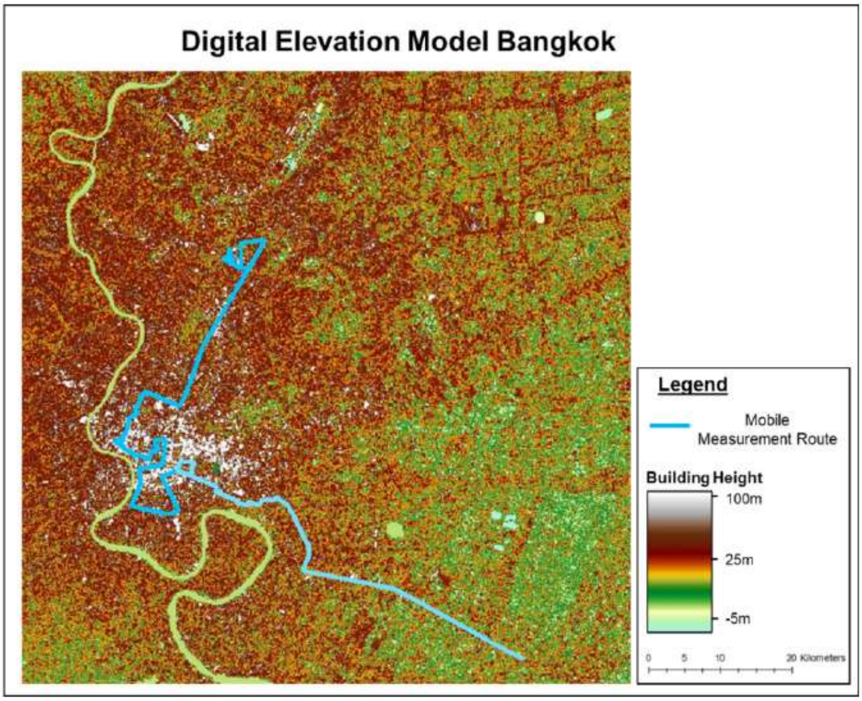


Figure 6. Digital Evaluation Model

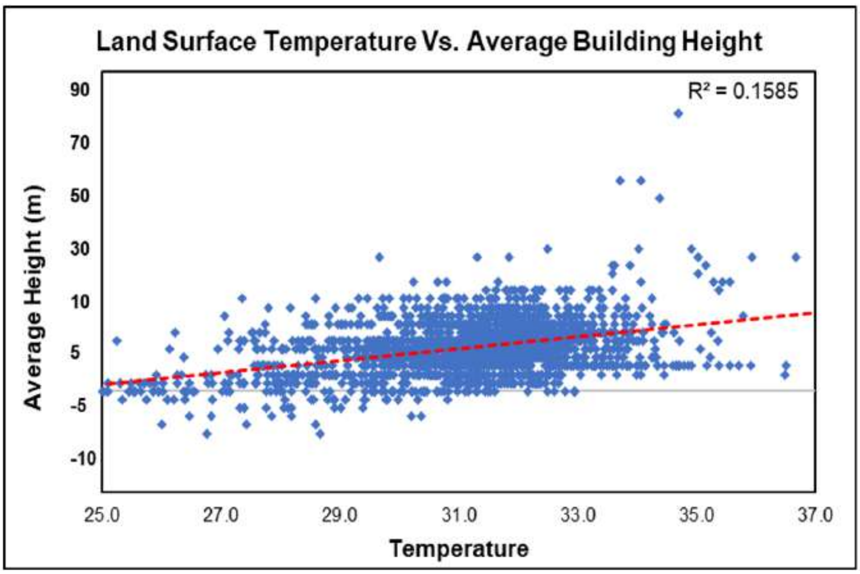


Figure 7. Linner Relationship of Building height and Land Surface Temperature, Bangkok

3.3 Slums Impacts

Another significant hotspot identified during the experiment was the Klong Toey slum (Figure 5 Image 5), observed along the west-to-east route traversing on the Rama 4 Road. This, again, was described to be a high-commercial area. The temperature in this area showed a notably higher number, at 2.04 - 2.64 °C which was 0.85 - 1.17 °C higher than the KU average for the day and night time, respectively. This increase was similar to patterns observed in the Silom area. Focusing on the hotspot which is the Klong Toey Cluster, the building aspect ratio in Klong Toey was recorded at 0.45, contributing to its higher temperatures. The traverse measurements revealed temperature increases ranging between 0.5 and 2.0 °C within this area.

Having mentioned that the higher surface ambient temperature can be attributed to several factors, particularly the building materials and their density. The materials used in Klong Toey, such as cement and other high-thermal-conductivity materials, directly absorb solar radiation, leading to increased heat retention and reradiation. This phenomenon is evident in slum areas like Kolkata, which have densely packed dwellings, narrow streets, and low or absent vegetation exacerbate heat accumulation. Similar conditions have been reported in Mumbai, where nighttime radiant temperatures are in compact. Low-rise slum areas were 2 – 3 °C higher than those in other building forms (Mehrotra *et al.,* 2020). In addition, the high daytime heat storage of compact, low-rise dwellings, primarily constructed of cement, also adds up to the heat island effects. The heat capacity of metal sheets and concrete amplifies this issue, indicating that densely populated areas with high building density and limited green spaces, such as Klong Toey, are more prone to elevated temperatures.

While the impacts of the building height and aspect may not be the contributing factors, building materials are the main drivers for the higher heat measured. This was based on the impacts of the urban fabric which contributes significantly over 70% to the formation the hotspot within developing cities (Chen *et al.,* 2017). Controllable urban design parameters, such as vegetation coverage and building design, play a more critical role in modulating temperatures than uncontrollable factors like meteorological or topographic conditions (Cheval *et al.,* 2024). The land cover materials are impacting the absorption and radiation properties, highlighting the complex interplay of material characteristics in urban heat dynamics within the slums area.

3.4 Green Areas and Cooler Temperatures

In the north-to-south route, cooler temperatures were observed in areas with urban green spaces, such as Lumpini Park (Figure 5 Image 3), Chatuchak Park (Figure 5 Image 2) and the Kasetsart University, Bang Khen Campus (Figure 5 Image 1). These areas promote cooling through the process of evapotranspiration, which increases latent heat and reduces sensible heat.

The lower traverse temperatures observed in Lumpini Park and Chatuchak Park confirm the cooling benefits of urban green spaces with the mobile data at -0.5 to 0.5 °C for both the day and night measurements. During the depicting the mobile measurement, it can be seen that the mobile measurement may be higher, as this was based on the fact that the mobile measurement was recorded on the road side, while the ambient temperature was placed within the green area of the Kasetsart University, Bang Khen campus.

The impacts caused by the green area have an influence on surrounding temperature, aligning with studies by Doick *et al.* (2014) where the average nighttime cooling effect distance (CED) of Kensington Gardens in London, reported that this park reduced summer nighttime temperatures by an average of 1.1 °C, with a maximum reduction of 4 °C. In the effects of the greening areas, the findings underscore the importance of increasing vegetation coverage and optimizing urban design to mitigate urban heat island effects. For instance, increasing vegetation density can reduce urban temperatures by 0.2 – 4.7 °C (Wu *et al.,* 2024), depending on factors like plant species, coverage area, and urban configuration. The increase in latent heat promotes the net radiation to subsidence from the sensible heat fluxes promoted by the evapotranspiration process. As the result, this reduces the ambient temperatures (Maskulrath *et al.,* 2023; Tamaskani *et al.,* 2021).

The vegetation coverage and density showed a negative correlation with heat island variations, playing a crucial role in mitigating surface temperatures. As such, increasing urban vegetation density can decrease temperatures through mechanisms like enhanced shading and evapotranspiration. Studies by Kleerekoper *et al.* (2011) and Gunawardena *et al.* (2017) have shown temperature reductions ranging from 0.2 °C to 4.7 °C in urban environments with increased vegetation density. Regarding this situation of Bangkok, further studies on the green area distribution, density and proportion to their urban surroundings would have to be carried out.

3.5 Day and Night time Influence:

The recording of temperatures during both day and night revealed notable differences. Daytime measurements showed the greatest temperature variations between the mobile and fixed stations. However, these variations were not uniform across all locations, as certain hotspots were identified along the route.

Nighttime measurements exhibited a similar pattern to daytime observations, albeit with reduced intensity. For example, in the east-to-south-to-north route, hotspots were detected near Yaowarat in Chinatown, where temperatures increased. Contributing factors to these elevated temperatures are believed to include anthropogenic activities such as high traffic density, commercial activities, and the dense urban fabric in the area.

Influence of green spaces at night demonstrated a more pronounced cooling effect during the evening compared to daytime, as supported by findings from Yang *et al.* (2017) suggesting that the temperature difference between green spaces and urban areas was greater in the evening than in the morning or afternoon. With the temperature difference was −1.44 °C and −0.71 °C in the evening, compared to −0.61 °C and −0.64 °C in the afternoon. This highlights the importance of urban green spaces in mitigating nighttime temperatures. Their enhanced cooling effect during the evening can be attributed to processes such as evapotranspiration, reduced solar radiation absorption, and the slower release of stored heat compared to surrounding urban materials.

4. Conclusion

Changes in land cover, particularly in urban areas, have direct impacts on ambient temperatures. This study highlights the amplifying temperature effects of urbanization in a tropical city. During the mobile measurements, a notable increase in temperature was observed across urban areas. However, not all areas exhibited the same level of temperature rise. The regulation of thermal heat was heavily influenced by building height and density, as represented by the aspect ratio. Areas with a higher aspect ratio (taller and denser buildings) showed increased thermal retention. Additionally, urban clusters, central business districts (CBDs), areas with dense traffic, street-level construction, and human activities significantly contributed to elevated temperatures. These findings were corroborated by Land Surface Temperature (LST) data, which revealed similar temperature trends in these hotspots.

As urban development continues to expand, integrating green patches into cities will play a vital role in mitigating temperature increases. Green areas have demonstrated their ability to reduce urban temperatures by enhancing latent heat via evapotranspiration. This process underscores the importance of green spaces in regulating the urban thermal environment. Lastly, this study's limitations include its focus on measurements taken during Bangkok's monsoon season, specifically during a period without precipitation. Additional measurements during the dry season are recommended to compare seasonal data. Such comparisons would provide a more comprehensive understanding of urban land use's effects on temperature and the intensity of urban heat islands.

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