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UHI and Thermal Performance of Office Buildings in Bangkok

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Abstract

Urbanization has an impact on thermal environment of Bangkok. Besides receiving a great deal of solar radiation like other hot-humid cities, the effect of urban heat island (UHI) further adds to discomfort as well as increases the cooling loads of buildings in Bangkok. In order to keep building occupants thermally comfortable, most buildings in Bangkok rely primarily on air-conditioning systems which consume enormous amount of energy. Office buildings, in particular, are the major energy consumers of the city. Therefore, it is important to study the impact of UHI on thermal performance of office buildings and find ways to improve their conditions. Moreover, UHI intensity (UHII) in each area is influenced by local height-to-width ratio (H/W ratio). In order to study UHII of areas representing different densities and H/W ratios and their effect on thermal performance of office buildings, the research is divided into 2 parts. The first part is aimed to investigate UHII in relation to H/W ratio of medium and high density areas. The second part is aimed to investigate thermal performance of office buildings in such areas. Results from field measurement including indoor and outdoor air temperatures, surface temperatures and mean radiant temperatures (MRT) were analyzed along with energy consumption and cooling degree hours (CDH). Results show that H/W ratio has an influence on UHII. However, it is not always the case that higher H/W ratios yield higher UHI intensities. UHI intensities from the medium-density area with low H/W ratios tend to be higher than those from the high-density area with high H/W ratio as the maximum UHII difference between the two areas is 2.57 K. Even though energy consumption of each building does not show a direct relationship with UHII and H/W ratio due to incomparable building sizes, operational time, energy management, and design factors, the increase of CDH tends to follow the increase of UHI intensity.

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Keywords: Urban Heat Island; Thermal performance; Height-to-width ratio; Office building; Bangkok

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1. Introduction

Impacts of urbanization are profound in Bangkok. The city is located in the central region of Thailand and is home for an approximately registered population of 5.7 million and a hidden population of 2.6 million (in 2010) [1]. The number of population continues to grow and there have been new development projects recently especially in business areas to serve the purpose of working and living in the city. Consequently, the urban area has become a concern of high density and its environmental impact. The densely built-up areas trap the heat within urban canopy causing urban environments to be warmer than their surroundings especially during the night time. This phenomenon is known as Urban Heat Island (UHI) [2].

Thermal conditions of urban areas of a hot-humid city like Bangkok are intensified by UHI. A study based on five-year meteorological data indicates the presence of urban heat island in Bangkok and it is increasing in terms of intensity [3]. The results show that the maximum intensity of around 6-7 °C is detected during the dry season. The mean annual air temperature in Bangkok city is 0.8 °C higher than outside the city.

The conventional way for climate-responsive design relies on weather data provided by meteorological station. The measurement points in Bangkok, however, are situated in open areas and record data at 30 meters above ground. Therefore, it is unlikely that the collected values are influenced by urban heat. It was found that there are discrepancies between weather data and those from field measurement. Air temperatures measured in medium and high density or central business areas of Bangkok are always higher than those obtained from the meteorological stations. In order to provide more precise data for the purpose of climatic building design, correction factors have been proposed to add to the values from the meteorological station. For the hottest month, April, the correction factors are 0.2 K, 0.5 K, and 1.4 K for the low dense, the moderate dense, and the central business area, respectively [4].

The increased temperatures in the city are a contribution of UHI factors including street canyon geometry, thermal properties of materials, anthropogenic heat released from combustion and metabolism, and lack of green spaces. Among these factors, the street canyon geometry has an impact on the type and magnitude of urban airflow as well as the short and long wave radiation balance in the canyon [5]. The canyon geometrical characteristics are defined by height-to-width ratio, (H/W ratio) or aspect ratio which has been found to correlate significantly and directly with the UHI effect [6]. For Bangkok, a recent study reveals the effect of H/W ratios on nocturnal UHI intensities during wet and cool seasons [7].

By considering that heat islands affect both outdoor and indoor environments resulting in the increase of energy demand for air-conditioning, it is crucial to understand the UHI conditions and find countermeasures. Whilst many studies on UHI effect have been conducted extensively in many cities especially in temperate climates, studies are lacking in the tropics. In the case of Bangkok, there are only a few. Moreover, most research works are carried out at macro-scale level using LANDSAT data while there is a missing link to building level.

This current research focuses on investigating thermal performance of building and the existence of UHI of Bangkok in relation to H/W ratios. Since office buildings are the major energy consumers in the city by sharing 37% of total electricity consumption for building sectors [8], the study selects four office buildings to represent medium and high density areas.

2. Climate and Characteristics of Bangkok

Bangkok is located at approximately 13.44^o North, 100.5^o East and covers total area of 1,568.74 sq.km. It has a diurnal temperature range of minimum 22.5 ^{o}C to 26.9 ^{o}C and maximum 32.1 ^{o}C to 36.3 ^{o}C. A mean annual temperature is 27.8 ^{o}C and a mean annual RH is 79.9%. The minimum RH is 74% in January and the maximum RH is 85% in September. Bangkok experiences moderate wind speed. The average wind velocity at 10 meters above ground is 1.7 m/s. The street canyons in densely built up areas of Bangkok are blocked by tall buildings, thus calm periods and stagnant conditions possibly occur.

3. Building and area selection

Areas of Bangkok can be catagorised by considering urban density, transportation, and surface temperature [9]. The current study selected 4 areas to represent medium and high densities, medium and high traffic while surface temperatures vary from low to medium as shown in Table 1. The previous study nonetheless focuses on macro scale using satellite data while the current research is aimed at micro-scaled study. Due to the insufficient GIS data on height of land use provided by Bangkok Metropolitan Authority (BMA) and a discrepancy in road widths recorded in different official documents, a field investigation was inevitably conducted in the 4 selected areas to find the actual building heights and widths of main road and side road of each area.

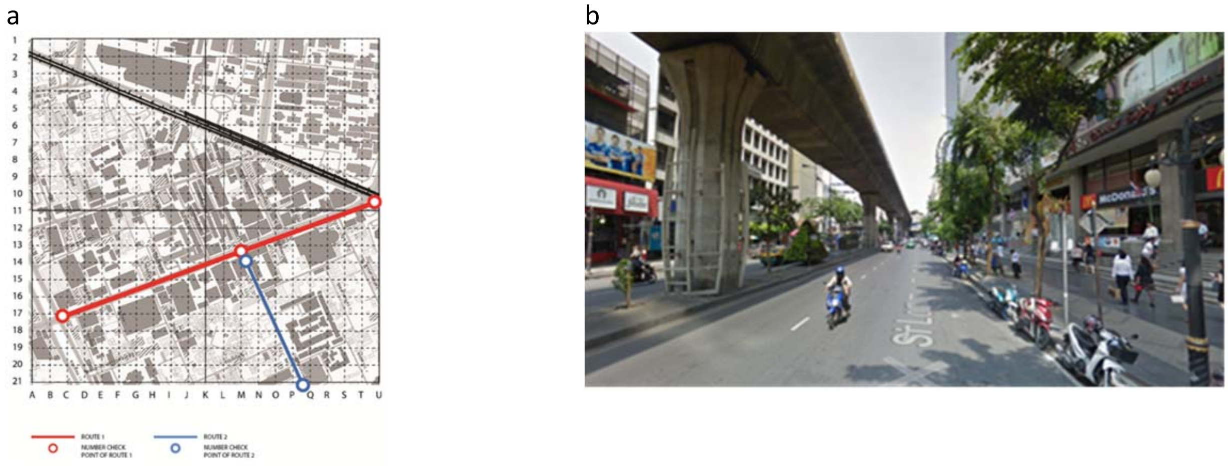


Fig. 1. (a) Silom Road in Sala Deang; (b) Street view of Silom Road.

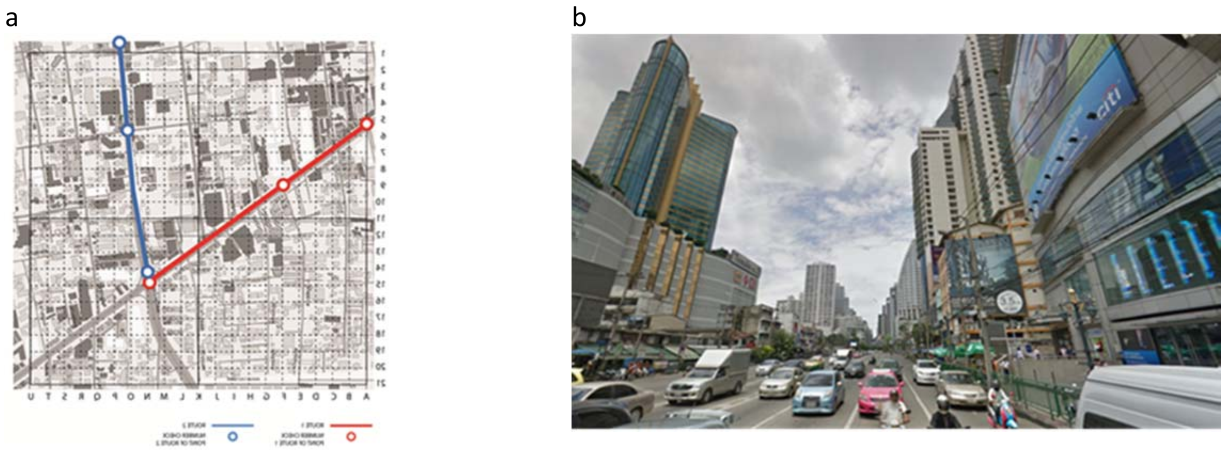


Fig. 2. (a) Asoke Montri Road in Asoke; (b) Street view of Asoke Montri Road.

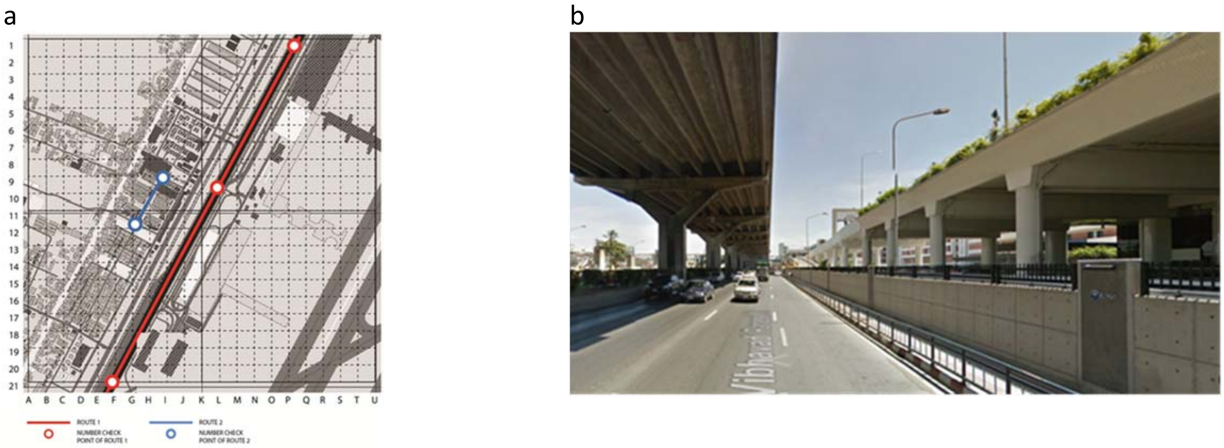


Fig. 3. (a) Vibhavadi Rangsit Road in Don Mueang; (b) Street view of Vibhavadi Rangsit Road.

Fig. 4. (a) Chuchart Kumphu Road in Kasetsart University; (b) Street view of Chuchart Kumphu Road.

Table 1. List of studied areas.

No.	Area	Urban Density	Transportation	Surface Temperature
1	Sala Deang	High	High	Low
2	Asoke	High	Medium	Low
3	Don Mueang	Medium	Medium	Medium
4	Kasetsart University	Medium	Medium	Low

4. Methodology

The study adopted a field measurement method. The work was divided into 2 parts. First, it was to investigate UHII in relation to H/W ratios of selected areas in which case study buildings are situated. Second, it was to conduct a field measurement to investigate thermal performance of the selected buildings. Weather stations were also used to collect outdoor condition data simultaneously. Data collected included indoor and outdoor air temperatures, surface temperatures, mean radiant temperatures (MRT), energy consumption and cooling degree hours (CDH) during the measurement period, wet and cool seasons.

4.1. The study of height-to-width ratios and UHI intensities

Urban geometry effects on UHI are commonly studied through Sky View Factor (SVF) and H/W ratio concepts. While SVF is used to determine to what extent the sky vault can be seen from a point in the middle of the street [10], H/W ratio helps transforming the three-dimensional spaces to two-dimensional sections. In cases of uniform building cluster, H/W ratio can be expressed as shown in Figure 5. However, in real situations, urban geometries are generally non-uniform due to various building heights. Thus, the calculation for H/W ratio has to be adjusted as shown in Fig.6.

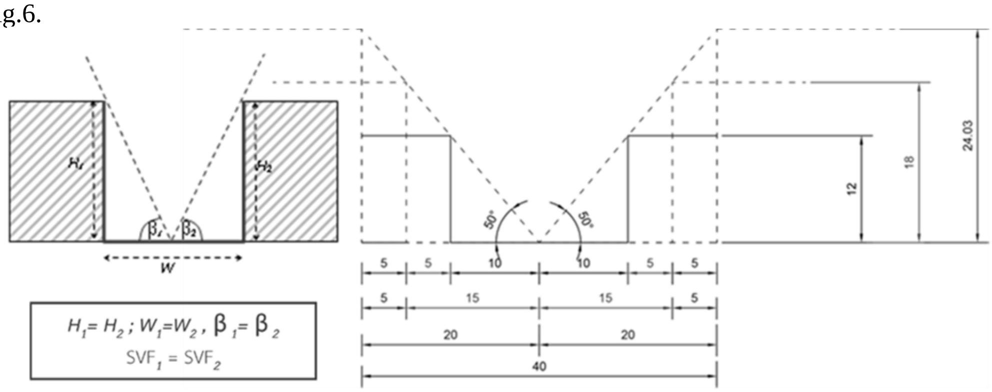


Fig. 5. H/W ratio calculation for uniform buildings.

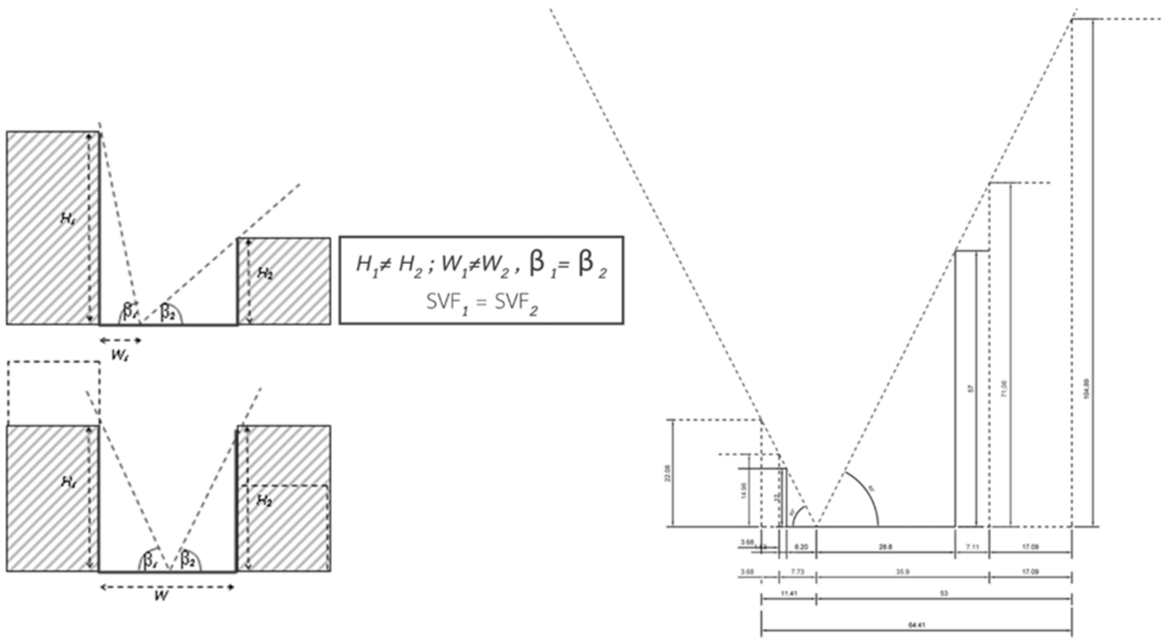


Fig. 6. H/W ratio calculation for non-uniform buildings.

Each selected area was studied within 100 sq.km. using a grid of 1000 m x 1000 m. The maximum H/W ratio permitted by law is 2 while road widths vary from 6 to 16 meters. By sectionalizing urban canyons into rectangular sections, a weighted percentage of the different sections' H/W can be calculated. After adjusting building heights using the method shown in sectional view of Figure 6, road widths which were varied in plan depending on setback distance of each buildings were also weighted in percentage of 1000 m road length. The average H/W ratios were then calculated by using adjusted building heights divided by weighted road widths. Figure 7 shows an example of how cross-sections of each road were provided to find weighted H/W ratios along the street grid.

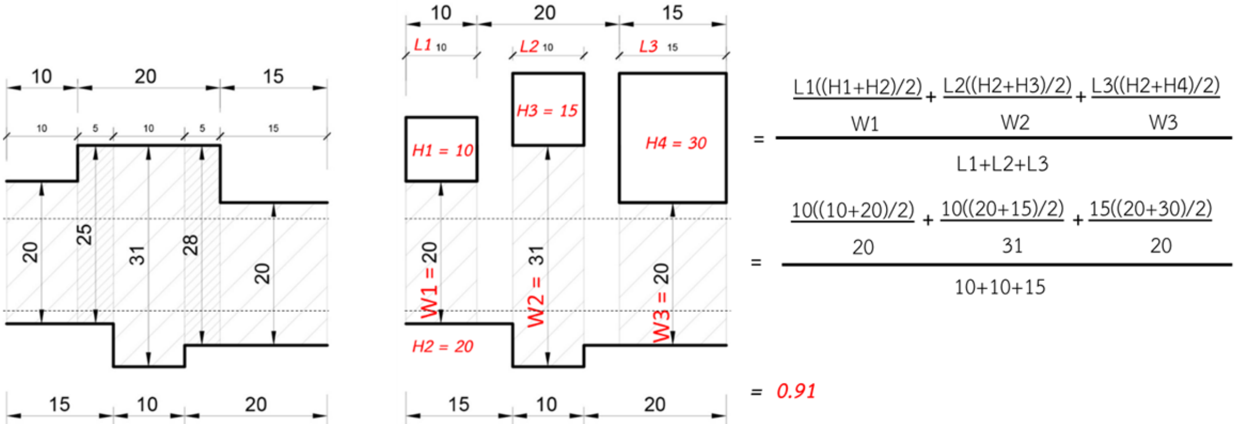
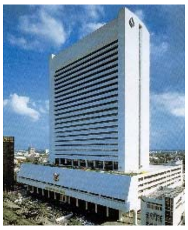
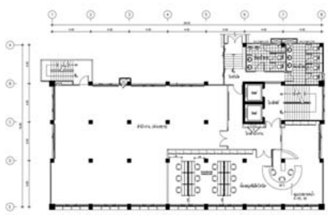


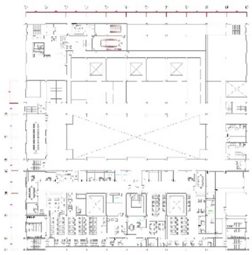
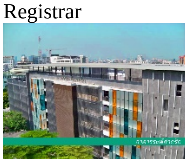
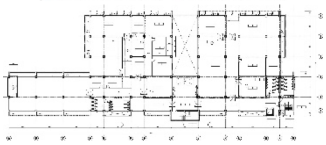
Fig. 7. An example of cross-sectional lines for finding H/W ratios on main road of Sala Deang

4.2. The investigation of thermal performance of buildings

There are four office buildings selected as case studies to represent medium and high density areas. All buildings are air-conditioned during office hours. The thermoset is set at 25 °C. The areas for measurement are open-plan offices on intermediate floors to avoid effect of heat transferred from roof and floor. Main building enclosure materials of all buildings are brick walls and sliding glass windows. Normal office hours are from 8:00 am to 5:00 pm. The investigation days range from minimum 3 to 10 day cycles depending on permission to enter each office. Parameters for indoor measurement during non-air-conditioned and air-conditioned hours include air temperature, mean radiant temperature (MRT), wall and window surface temperatures, and relative humidity. Outdoor thermal conditions were also observed with a mobile weather station to record air temperature, relative humidity, wind speed and direction. Each sensor records measurements at 5 minute intervals. Annual energy consumption was reported along with CDH during the period of observation. Table 2 gives the summary of building data and measurement arrangement.

Table 2. Summary of building data and measurement arrangement.

No.	Area	Building's name and characteristics	Floor plan	Selected area for investigation	Measurement schedule	
					Date	Time
1	Sala Daeng	Bangkok Bank Head Office 		332 sq.m.	August 2015	11:45 am-1:35 pm
2	Asoke	FAP Office		126 sq.m.	February 2016	11:40 am-12:35 pm

No.	Area	Building's name and characteristics	Floor plan	Selected area for investigation	Measurement schedule	
					Date	Time
						
3	Don Mueang	Don Mueang Airport office 		270 sq.m.	August 2015	4:45 pm-8:10 am
4	Kasetsart University	KU Office of The Registrar 		240 sq.m.	February 2016	4:00 pm-10:10 am

5. Results and discussion

5.1 Results from the study of H/W ratios and UHII

Results from the study of H/W ratios and indoor thermal conditions are combined in Table 3 for analysis. The results indicate temperature differences between indoor and outdoor ranging from -7.59 K to 21.03 K. The outdoor temperatures from on-site measurements are generally higher than the indoor temperatures except for the cases of Federation of Accounting Professions (FAP) Office and Don Mueang Airport office. This is due to some rainy days during the time of measurement at the two buildings making outdoor temperatures lower than the controlled indoor temperatures.

Table 3. H/W Ratios and results from the field investigation

Building and H/W Ratio of the area		Indoor Measurement											Outdoor Measurement		UHII (K)
		Air Temp	RH,	Globe	NORTH TEMP		SOUTH TEMP		EAST TEMP		WEST TEMP		WEATHER STATION		
		(°C)	(%)	MRT	Window	Wall	Window	Wall	Window	Wall	Window	Wall	Temp, °C	RH, %	
Bangkok Bank Head Office	MIN	22.47	57.49	22.40	26.86	26.18	26.71	27.27	26.76	25.90	28.01	27.90	26.34	30.75	-1.10
	MAX	27.44	72.24	27.50	47.29	32.81	57.92	34.76	34.95	31.06	37.77	32.64	43.91	88.75	1.09
0.95	AVG	25.09	65.00	25.08	31.30	29.22	32.22	30.06	29.55	28.15	31.05	29.85	31.66	61.96	0.38
FAP	MIN	21.18	32.55	21.80	18.89	20.93	19.29	21.65	17.93	20.19	19.38	21.29	16.38	25.25	-0.73
0.91	MAX	36.13	80.47	34.60	35.37	35.01	42.05	34.40	45.95	34.96	35.19	35.85	43.91	91.25	2.72
	AVG	26.00	59.58	26.50	26.37	25.40	27.12	25.98	26.38	25.67	26.15	25.62	27.35	60.25	0.51
Don Mueang	MIN	19.13	68.34	19.00	27.14	28.55	25.76	29.55		22.52	23.52	22.17	23.24	38.25	-0.31

Building and H/W Ratio of the area		Indoor Measurement											Outdoor Measurement		UHII (K)
		Air Temp	RH,	Globe	NORTH TEMP		SOUTH TEMP		EAST TEMP		WEST TEMP		WEATHER STATION		
		(°C)	(%)	MRT	Window	Wall	Window	Wall	Window	Wall	Window	Wall	Temp, °C	RH, %	
Airport Office	MAX	24.71	78.34	24.70	37.53	30.74	41.80	33.25		25.26	51.19	31.32	41.05	100.00	3.66
0.47	AVG	21.66	72.57	21.67	30.85	29.87	31.50	31.62		23.85	28.11	25.49	30.98	62.28	1.34
KU Office of Registrar	MIN	24.06	35.53	21.80	27.41	26.68		27.03	24.97	27.08	25.25	26.29	23.24	32.75	0.59
0.29	MAX	29.40	65.23	29.90	29.34	29.41		34.35	42.40	29.76	49.01	31.36	39.22	88.75	0.88
	AVG	27.53	54.63	27.66	28.42	28.00		30.11	29.54	28.39	29.34	28.59	29.08	60.52	0.78

The influence of high density area and H/W ratio is found by comparing results from the same measurement period of buildings in high H/W ratio area with ones in low H/W ratio area. There can then be 2 pairs of them.

- During the wet season, August 2015, Bangkok Bank Head Office in Sala Deang representing the area with high H/W ratio is compared with Don Mueang Airport office representing the area with low H/W ratio.
- During the cool season, February 2016, Federation of Accounting Professions (FAP) Office representing Asoke, the area with high H/W ratio is compared with KU Office of the Registrar in Kasetsart University representing the area with low H/W ratio.

In terms of H/W ratio effect on outdoor climate, the results from the filed investigation show that during the wet season in Sala Deang area, outdoor temperatures range from 26.34 ^{o}C to 43.91 ^{o}C, the average temperature is 31.66 ^{o}C, and relative humidities range from 30.75 % to 88.75 %. In Don Mueang area, outdoor temperatures range from 23.24 ^{o}C to 41.05 ^{o}C, the average temperature is 30.98 ^{o}C, and relative humidities range from 38.25 % to 100 %. By considering air temperatures 3-5 hours after sunset, there exists UHI. The temperatures of the areas with high H/W ratio and those with low H/W ratios were compared with simultaneous air temperatures obtained from the station outside Bangkok to find UHI intensities of each area. It was expected that higher H/W ratios would result in higher UHII but it was not the case for selected areas. It is found that UHI intensities from the medium-density area with low H/W ratios tend to be higher than those from the high-density area with high H/W ratio as the average UHII difference between the two areas is 0.96 K and the maximum UHII difference is 2.57 K.

For the cool season, the results from Asoke area show that outdoor temperatures range from 16.83 ^{o}C to 43.91 ^{o}C, the average temperature is 27.35 ^{o}C, and relative humidities range from 25.25 % to 91.25 %. In Kasetsart University area, outdoor temperatures range from 23.24 ^{o}C to 39.22 ^{o}C, the average temperature is 29.08 ^{o}C, and relative humidities range from 32.75 % to 88.75 %. The temperature differences between Asoke and Kasetsart University are from -2.88 K to 6.73 K. These indicate that the temperature from the urban area with higher H/W ratio can be slightly lower than the area with low H/W ratio. However, it should be noted that during the measurement duration, the high H/W ratio area in Asoke experienced monsoon rain.

Due to the controlled indoor conditions, MRT results are about the same as indoor air temperatures. Nevertheless, results from comparing surface temperatures of opaque brick walls and glass windows show the differences depending on season and building side that faces the sun.

- During the wet season, north-facing side show surface temperatures of brick wall ranging from 26.18 ^{o}C to 32.81 ^{o}C while the surface temperatures of glass window are from 26.86 ^{o}C to 47.29 ^{o}C. For south-facing side, surface temperatures of brick wall are from 27.27 ^{o}C to 34.76 ^{o}C while the surface temperatures of glass window are from 25.76 ^{o}C to 57.92 ^{o}C. For east-facing side, surface temperatures of brick wall are from 25.52 ^{o}C to 31.06 ^{o}C while the surface temperatures of glass window are from 26.76 ^{o}C to 34.95 ^{o}C. Bangkok Bank Head Office always gave the highest values.

- During the cool season, north-facing side show surface temperatures of brick wall ranging from 20.93 ^{o}C to 35.01 ^{o}C while the surface temperatures of glass window are from 18.89 ^{o}C to 35.37 ^{o}C. For south-facing side, surface temperatures of brick wall are from 21.65 ^{o}C to 34.40 ^{o}C while the surface temperatures of glass window are from 19.29 ^{o}C to 42.05 ^{o}C. For east-facing side, surface temperatures of brick wall are from 20.19 ^{o}C to 34.96 ^{o}C while the surface temperatures of glass window are from 17.93 ^{o}C to 45.95 ^{o}C. For west-facing side, surface temperatures of brick wall are from 21.29 ^{o}C to 35.85 ^{o}C while the surface temperatures of glass window are from 19.38 ^{o}C to 49.01 ^{o}C.

The biggest difference between wall temperature and glass window temperature is 23.16 K in case of the south-facing wall of Bangkok Bank Head Office. The discrepancies between on-site measurement data and the values obtained from meteorological station are found. The temperature differences range from minimum -1.56 K to maximum 8.71 K and the average temperature difference is 0.76 K.

5.2 Results from the investigation of thermal performance of buildings

The wet season shows UHII higher than the cool season. UHII results in increased cooling load as shown in Figure 8.

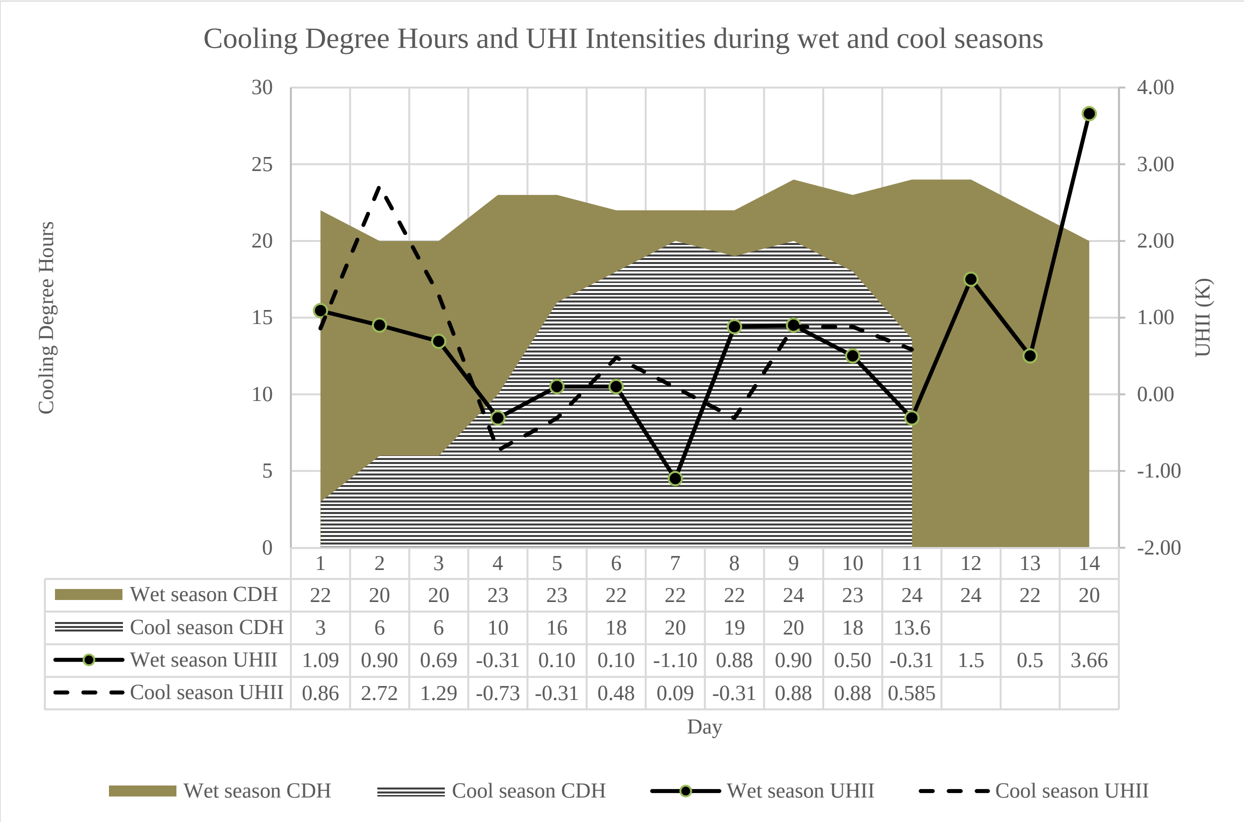


Fig. 8. Cooling degree hours and UHII during wet and cool seasons

Table 4. UHI Intensities and cooling degree hours

H/W Ratio of the area	Min UHII	Max UHII	Average UHII	Min CDH	Max CDH	Average CDH	BUILDING	Energy consumption (kWh/sqm.yr)	Based line for Bangkok Office

									Buildings
0.95	-1.10	1.09	0.38	20.00	24.00	22	Bangkok Bank Head Office	165	218.5
0.91	-0.73	2.72	0.51	3.00	20.00	12	FAP	243	215.8
0.47	-0.31	3.66	1.34	20.00	24.00	23	Don Mueang Airport Office	255	199.9
0.29	0.59	0.88	0.78	13.60	20.00	17	KU Office of Registrar	196	215.8
Diff	0.79-1.32	1.84-2.57	0.27-0.96						

Report from each building shows the amount of energy consumed in comparison with baseline for offices in Bangkok. Cooling load accounts for approximately 60% of total energy consumption. However, some buildings are good at managing energy demand while others are not. Bangkok Bank Head Office is the best out of 4 buildings as it consumes around 13 kWh/sqm per month. FAP Office and Don Mueang Airport office do not seem to be energy-efficient and exceed the baseline. KU Office of the Registrar can keep the consumption rate under the baseline due to less demand during semester breaks. Therefore, direct relationship between energy consumption of buildings in medium and high H/W ratio areas and UHII cannot be established because of incomparable building sizes, operational time, energy management, and design factors. Nonetheless, the increase of CDH tends to follow the increase of UHI intensity. It indicates the influence of UHII on cooling demand.

6. Conclusion

The existence of UHI of Bangkok has a great impact on outdoor environment and thermal performance of buildings. While most buildings try to maintain indoor air temperature at 25 ^{o}C, the outdoor air temperature can be 21.03 K higher than the indoor. UHI intensity also adds more effect on building performance by increasing outdoor temperature influencing the incoming heat and cooling load of buildings. H/W ratio has an effect on UHI intensity as, based on the selected cases, UHI intensities from the medium-density area with low H/W ratios tend to be higher than those from the high-density area with high H/W ratio. The average UHII difference between the two areas is 0.96 K and the maximum UHII difference is 2.57 K. The wet season shows UHII higher than the cool season and UHII results in increased cooling load. Even though energy consumption of each building does not show direct relationship with UHII and H/W ratio due to incomparable building sizes, operational time, energy management, and design factors, the increase of CDH tends to follow the increase of UHI intensity. There are discrepancies between on-site measurement data and the values obtained from meteorological station. The local measured values are by average 0.76 K higher than those from the meteorological record. Building enclosure materials are crucial for protecting the building from the incoming heat. Transparent element like glass windows let the heat come through far more than the opaque one as the maximum temperature difference between the brick wall and glass window is 23.16 K. In order to design buildings responsive to urban climatic condition these days, UHI effects and factors such as H/W ratio and building materials should be taken into consideration.

Acknowledgements

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