INFLUENCES OF POPULATION, BUILDING, AND TRAFFIC DENSITIES ON URBAN HEAT ISLAND INTENSITY IN CHIANG MAI CITY, THAILAND

by

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This research aims to evaluate the urban heat island intensity (UHII) and study the influences of population density, building density, and traffic density on the UHII in Chiang Mai city on each season and time. The surrounding air temperature was measured by thermocouples at a constant height of 2 m above the road by mobile surveying approach. The surveyed routes were divided into urban routes and rural routes. The UHII was calculated from the average surrounding air temperature difference between the urban and the rural areas. Experimental investigations were carried out in two seasons, consisting of summer (March-May, 2014) and winter (December 2013-February 2014). Experimental investigations were carried out in two periods, which were a daytime period (01.00-03.00 p. m.) and a nighttime period (10.00 p. m.-00.00 a. m.) on Mondays, Wednesdays, and Sundays. The results show that the UHII in summer day, summer night, winter day, and winter night were 1.07 °C, 1.27 °C, 0.58 °C, and 1.34 °C, respectively. This implies that the temperature in Chiang Mai city's urban area is higher than that in the rural area the entire year. Moreover, it was found that the UHII in summer day, winter day, and winter night were primarily affected by the traffic density with the sensitivity percentage of 87.50%, 72.73%, and 63.33%, respectively. In contrast, the UHII in summer night was mainly affected by the building density with the sensitivity percentage of 50.00%.

Key words: *urban heat island intensity, Chiang Mai city, population density, building density, traffic density*

Introduction

Chiang Mai city is located in the north of the Kingdom of Thailand (latitude 18°47' N and longitude 98°59' E). It is one of the largest cities in Thailand, located 696 km north of Bangkok. The topography of Chiang Mai city is mountain-rimmed basin. The major businesses in Chiang Mai city are trade, services, agriculture, and tourism [1, 2]. The population of the city in 2010 was 1,737,041 [3]. In recent times, Chiang Mai city's economy and society have witnessed dramatic growth. Migration of population from the rural area to the urban area is the leading cause of the significant increase in the city's population density. Aside from the increase in the population of the city, the migration not only causes an increase in the quanti-

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ties of vehicles on the city's roads, but also an increase in the activities that require the use of very high energy, such as government offices, business offices, commercial shops, tourist attractions, hotels, entertainment places, department stores, *etc*. Since urban areas have higher number of components that release tremendous amounts of heat to the surroundings than rural areas, the surrounding temperature in the urban area is significantly higher than that in the rural area. This phenomenon of the temperature difference between urban and rural areas is defined as *urban heat island* or, in short, *UHI*. The occurrence of the urban heat island is because of accumulation of the heat radiation from the Sun in buildings, which is then directly released into the surrounding air [4]. The quantitative value that refers to the level of the UHI is defined as the average temperature difference between urban and rural areas, and is defined as *urban heat island intensity* or *UHII* in short [5]. The UHII can be either a positive or a negative value, depending on the local situation of the city. A positive value for the UHII implies that the ambient temperature of the urban area is higher than that of the rural area, and *vice versa* for a negative value for the UHII. Sometimes, the latter case is called the *urban cool island*. The urban heat island is now an important issue for various capital cities or major cities, like Chiang Mai city, especially in the rapidly developing countries. An increase in the UHII causes an increase in the local temperature, the air pollution, and the required energy for air-conditioning systems [6]. A number of past studies have reported that almost all of the major cities in the world have to face the urban heat island phenomenon: for example, the UHII in New York City, USA, was found to be 5.0 °C [7]; that in Shanghai, China, was 7.0 °C; the same in Seoul, South Korea, was 8.0 °C; the UHII in Bangkok, Thailand, was 8.0 °C; that in Tokyo, Japan, was 12.0 °C [8]; the UHII in Budapest, Hungary, was 1.0 °C [9]; the same in Petra, Greece, was 3.0 °C; the UHII in Athens, Greece, was 3.3 °C [10]; and the UHII in Hong Kong, China, was 10.5 °C [5].

Based on the obvious difference in the social appearances between the urban and rural areas in Chiang Mai city, accompanied with the influences on the environment due to the UHI phenomenon, as mentioned above, there is concern regarding whether Chiang Mai city is now facing the UHI problem or not, and if it is, at what level of the UHII. Until now, reports on UHII in Chiang Mai city have been very limited. Moreover, since the characteristics of the activities happening in Chiang Mai city are totally different for each season and time, the assumption that the UHII in Chiang Mai city may be different for each of the season and time is proposed. In order to be relieved of the concern regarding the UHII situation in Chiang Mai city and to verify the assumption, these became the background and significance of this study, with the objectives of evaluating UHII and studying the influence of population density, building density, and traffic density on the UHII in Chiang Mai city in each season and time. The mobile approach was chosen to be the experimental method to collect the temperature distribution along the surveyed routes between the urban and the rural areas around Chiang Mai city, because of the convenience, promptitude, and inexpensiveness of this approach. In addition, the temperature collected by following this approach is the surface temperature, which can be naturally sensed by people. This method is different from the methods used in various past studies on UHII: a weather station data approach, a simulation approach, and a thermal remote sensing approach [5, 11-14]. The benefits of this study are that the UHII and the level of severity based on the UHI phenomenon in Chiang Mai city is clearly reported, as well as the quantitative factors affecting the difference in the UHII in each season and time are investigated. The experimental data are also useful to government officials who respond to the city's development plan to control increases in the factor that consequently affects an increase in the UHII to be as little as possible.

Temperature measurement methodology and UHII assessment

In order to assess the UHII in Chiang Mai city, the average surrounding temperatures in the urban and the rural areas were firstly experimentally investigated, and the UHII was calculated from the temperature difference between these areas. In this study, the Chiang Mai city area was divided into urban area and rural area, as shown in fig. 1. It can be seen from the map of Chiang Mai city in fig. 1 that there were four surveyed routes in the urban area (route no. 1-4) and four surveyed routes connecting the urban area to the rural area (route no. 5-8). The route no. 1-4 pass through the dense commercial area where the densities of people, buildings, vehicles, and activities were very high. As for route no. 5-8, although they begin and follow some part of the routes located in the urban area, which is the same as route no. 1-4, they connect to the rural area adjacent to the Chiang Mai city. Thus, route no. 5-8 could be divided into two parts, that is, one part as being located in the urban area and the other part as belonging to the rural area, which passes through loose commercial area, private houses and accommodations, tree gardens, paddy fields, and meadows. The details of each surveyed route are presented in tab. 1.

The mobile temperature measurement system consisted of four polyvinyl chloride (PVC) tubes with the diameter and length of which were 0.075 m and 0.30 m, respectively. The tubes were secured on the roof of the car used for surveying. One Chromel-Alumel thermocouple (Omega, Type K, accuracy ±0.5 °C) was installed inside each PVC tube in order to force the tip of the thermocouple into the exact place and to prevent the movement of the thermocouple when the car was driven along the surveyed routes. This technique of measurement ensures that the temperature recorded is the real temperature of the surrounding air in the area that the surveying car is passing through. Moreover, the PCV tube obstructs the thermocouple from heat ra-

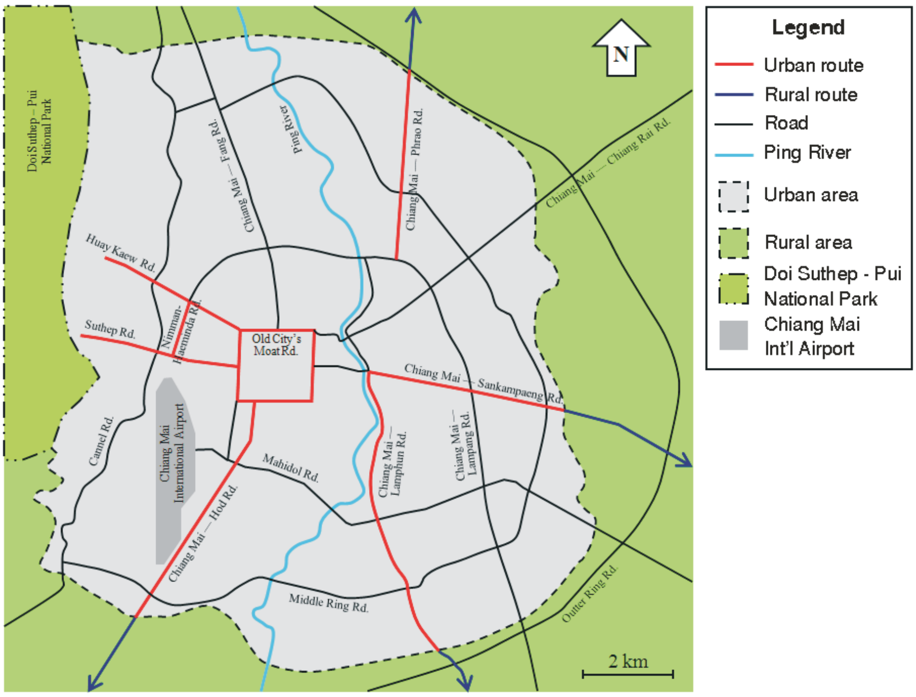

Figure 1. The urban area, rural area, and surveyed routes

diation from anywhere in addition to other uncontrolled factors. Therefore, these were the advantages obtained from this technique of measurement. It should be noted that this temperature measurement technique could be found in a past study, as well [12]. The tip of the thermocouple was located above the route's surface at a height of 2.0 m and above the roof of the car at a distance of 0.15 m, as illustrated in fig. 2. As far as the position of the thermocouple above the roof at this height is concerned, it has been verified that the thermocouple was located beyond the boundary layer of the air passing over the surface of the roof. Since the solar heat accumulated on the roof affected only the air in the boundary layer for it to have a temperature higher than the surrounding air temperature, it can be confidently considered that the measured temperature was the actual surrounding air temperature. After that, the thermocouples were connected to the temperature recorder (Lutron, TM-947SD, accuracy ±0.1 °C) used for recording the temperature variation every second. In addition to the temperature measurement, a video camcorder (Speed, HD-10Z, resolution 1,080 p at 30 fps) was installed in the car in order to record the appearance of places along the surveyed route simultaneously with the temperature measurement. Visualizing analysis on the recorded video could be used to confirm that each particular recorded temperature belonged to that particular location along the surveyed route by comparing the timestamp in the temperature and video data.

Table 1. Details of surveyed routes

Route no.	Route's name	Length [km]	Area
1	Nimmanhaeminda Rd.	1.3	Urban
2	Old City's Moat Rd.	6.0	Urban
3	Huay Kaew Rd.	3.3	Urban
4	Suthep Rd.	3.0	Urban
5	Chiang Mai – Hod Rd.	6.0	Urban
		14.0	Rural
6	Chiang Mai – Lamphun Rd.	6.7	Urban
		5.3	Rural
7	Chiang Mai – Phrao Rd.	4.1	Urban
		11.9	Rural
8	Chiang Mai – Sankampaeng Rd.	4.3	Urban
		11.7	Rural

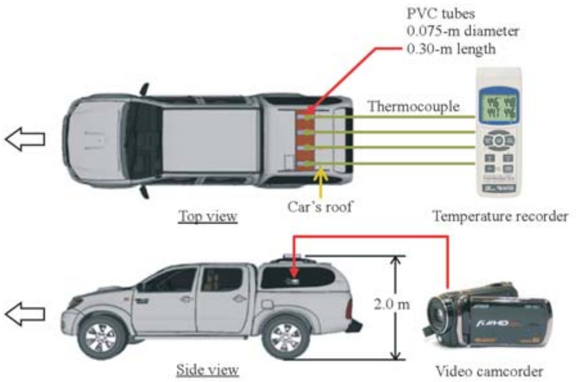

Figure 2. The mobile temperature measurement set-up

The surveying procedure started from the heading to the beginning of the surveyed route. Consequently, the temperature recorder and the video camcorder were started to record the temperature variation and the moving picture of the places along the roadside. It should be noted that the time settings in the temperature recorder and the video camcorder must be identical. Then, the car was driven along the surveyed route with an average velocity of 50 ± 10 km/h, depending on the local traffic density. The measurement was completed after the car reached the defined end of the surveyed route. This procedure was conducted for individual routes; therefore, all the procedures were repeatedly done for each route. Based on the assumption that the UHII in Chiang Mai city may be different, depending on season and time during the day, as previously discussed, it is understood that the surveying procedure must be done in summer and winter, and in the daytime and nighttime, for each season. For the daytime, the surveying time was between 01.00-03.00 p.m. since the radiation from the sun was the highest during this time. The structure of buildings, road surfaces and others fully absorbed the heat radiation. In the nighttime, the surveying was conducted between 10.00 p. m.-00.00 a. m. since the heat radiation in the building's structures fully released to the ambient during this time. The temperature collected in this duration was the continuous result which was directly affected from the absorbed heat radiation since the daytime. The surveying procedure was also repeatedly done on Mondays, Wednesdays, and Sundays. Monday was the representative for the first day of the weekday. The activities in the urban area were dramatically active compared to the previous weekend. Wednesday was the representative for the day being on the middle of the weekday where the activities were less active compared to the one on Monday. For Sunday, it was the representative for the weekend. While working activities in the urban area were calm, the commuting of people from the rural area to the urban area was leisurely observed. In the light of this reason, the data measured on these chosen days could be implied to data measured entire the week. Therefore, it was unnecessary to conduct the measurement on everyday of the week. The scope and detail of the measured seasons and times are shown in tab. 2.

Table 2. Scope and detail of measured seasons and times

Season	Surveying month	Time	Surveying time
Summer	March-May 2014	Daytime	01.00 p. m. – 03.00 p. m.
Summer	March-May 2014	Nighttime	10.00 p. m. – 00.00 a. m.
Winter	December 2013 – February 2014	Daytime	01.00 p. m. – 03.00 p. m.
Winter	December 2013 – February 2014	Nighttime	10.00 p. m. – 00.00 a. m.

The temperature variations along every route in each area within the same season and time were averaged to figure out the representative temperature of each area. For the urban area, the representative temperature was defined as the average temperature of the urban area (T_u), and for the rural area, the representative temperature was the average temperature of rural area (T_r). Subsequently, the UHII values of Chiang Mai city in each season and time were calculated from the temperature difference, as UHII = $T_u - T_r$. Finally, the quantitative factor affecting the difference in the UHII in each season and time would be analyzed by taking into consideration the sensitivity percentage of each factor.

UHII of Chiang Mai city

The UHII values of Chiang Mai city in each season and time assessed by following the mobile approach are presented in tab. 3.

Table 3. UHII of Chiang Mai city

Season	Time	T_u [°C]	T_r [°C]	UHII [°C]
Summer	Daytime	36.36	35.29	1.07
Summer	Nighttime	28.65	27.38	1.27
Winter	Daytime	28.05	27.47	0.58
Winter	Nighttime	21.09	19.75	1.34

It can be seen from the overview of the UHII values obtained of Chiang Mai city in each season and time that they are all positive. These values imply that Chiang Mai city faced the urban heat island phenomenon. The maximum UHII was 1.34 °C obtained on a winter night, while the minimum UHII was 0.58 °C achieved on a winter day. Upon taking into consideration, in detail, the temperature variation along the surveying routes, it was found that the temperature distribution depended on the characteristics of the different places. The temperature was high in areas with high traffic and building densities, while the temperature was low in natural areas. This is because shade and moisture from trees contribute significantly to the decrease in the surrounding temperature. Thus, an increase in areas of plantation and green areas is accepted to be the best policy to relieve the severity of the UHI phenomenon of the city [15]. Although the year-round UHII of Chiang Mai city was not in the critical level since severe UHI phenomenon manifests itself observably only when the UHII exceeds the boundary range of 2-5 °C, the sign that Chiang Mai city has begun facing the UHI phenomenon was more noticeable. It is, therefore, necessary to intentionally monitor any changes in the UHII of Chiang Mai city and keep the level of UHII to be not higher than the recent level.

Quantitative factors affecting UHII of Chiang Mai city in each season and time

In addition to the results discussed in the previous topic, since it was established that the UHI phenomenon was present in Chiang Mai city, this could be taken as evidence to support the view that the difference in social factors between the urban and the rural areas was the cause of the UHI phenomenon. However, it can also be noticed from the results of the UHII of Chiang Mai city that seasons and times had an effect on the UHII, causing its values to be slightly different. This additionally supports the theory that there was a primary social factor that had a strong influence on the difference in the UHII of Chiang Mai city in each season and time. In the light of these reasons, the quantitative social factor in Chiang Mai city during 2013-2014 was successfully studied and collected. Therefore, it can be concluded that there are three main factors that contribute to the UHII values between the urban and the rural areas being significantly different. The main factors are population density, building density, and traffic density.

In order to analyze which social factor had the strongest influence on the UHII of Chiang Mai city in each season and time, relationship between the individual factor and the average surrounding temperature measured from each sub-district that all the surveying routes passed through was plotted on the horizontal axis and the vertical axis, respectively. The rela-

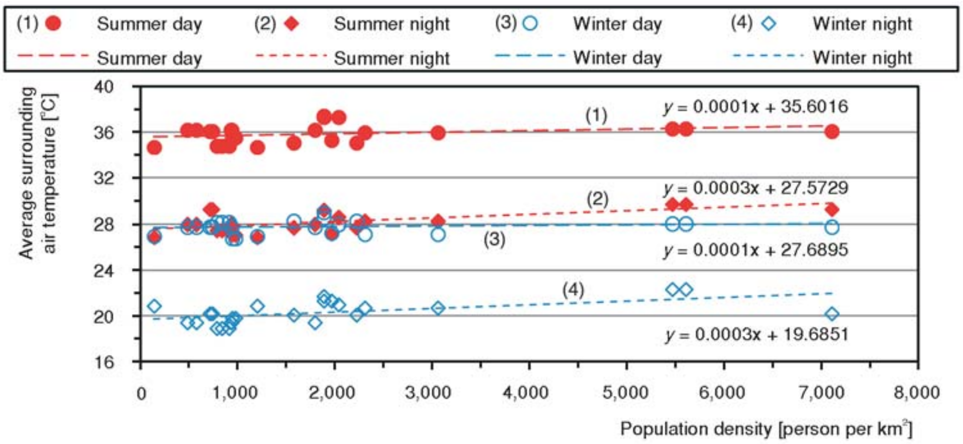

Figure 3. The relationship between the population density and the average surrounding temperature

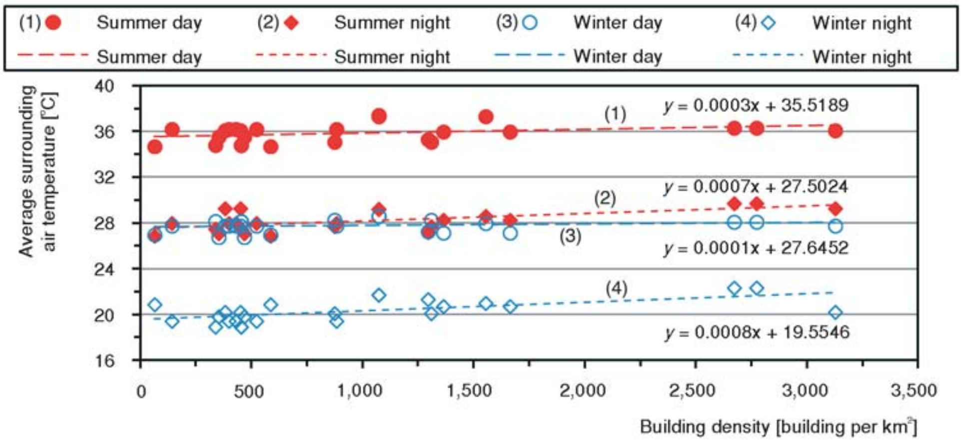

Figure 4. The relationship between the building density and the average surrounding temperature

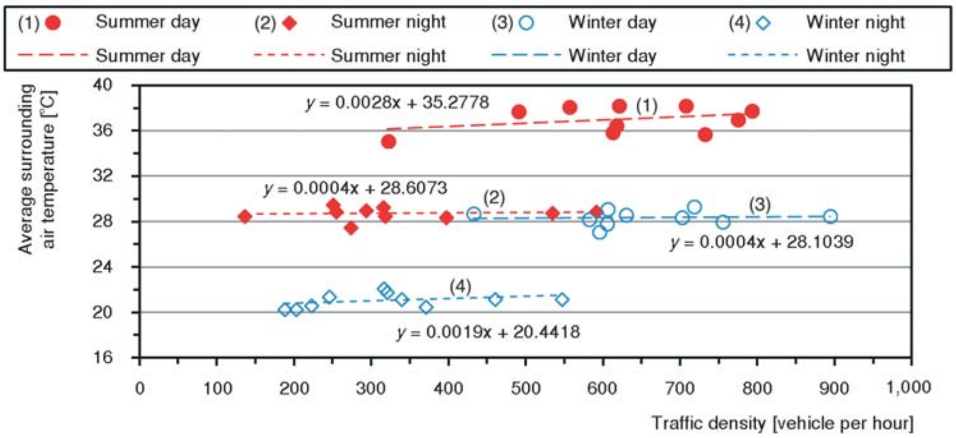

Figure 5. The relationship between the traffic density and the average surrounding temperature

tionships of population density, building density, and traffic density with the average surrounding temperature are shown in figs. 3-5, respectively.

Based on the nature of the relationships, as shown in figs. 3-5, it was clear that the slopes of all the trend-lines had positive values. This could be considered as implying that all the selected social factors – population density, building density, and traffic density – individually had direct influence on the surrounding air temperature; that is, when each of these factors increased, the surrounding air temperature consequently increased. Although an increase in each factor would cause a change in the surrounding air temperature in the same direction, the factor due to which the relationship would have a steeper slope of the trend-line was deduced to be the factor that had stronger influence on the UHII in each season and time, and the opposite would be the case for the factor due to which the relationship would have a less steep slope of the trend-line. From this interpretation, the slope of the trend-line or the rate of change in the average surrounding air temperature over each factor could be analogously defined as the *sensitivity* of the factor. *Sensitivity* was used as a quantitative indicator to determine the level of influence of each factor on the UHII of Chiang Mai city in each season and time. However, since the UHII is simultaneously affected by all the factors, the use of *sensitivity* which is the absolute value, to determine the level of influence would be misleading. In order to compare the levels of influence of the different factors, each of the sensitivity indicators was calculated to be the ratio of its sensitivity to the sum of all the sensitivities in each season and time which was defined as the *sensitivity percentage*. From this point, the social factor that had the highest sensitivity percentage was defined to be the primary cause of the UHII of Chiang Mai city in each season and time. The sensitivities and the sensitivity percentages are shown in tab. 4. The primary social factor and the physical reason describing how the primary factor had the strongest influence on the UHII in Chiang Mai city in each season and day were analyzed as follows.

Table 4. Sensitivities and sensitivity percentages of social factors

Season	Time	Sensitivity [°C/unit of factor]			Sensitivity percentage [%]		
		Population	Building	Traffic	Population	Building	Traffic
Summer	Daytime	0.0001	0.0003	0.0028	3.13	9.38	87.50
Summer	Nighttime	0.0003	0.0007	0.0004	21.43	50.00	28.57
Winter	Daytime	0.00005	0.0001	0.0004	9.09	18.18	72.73
Winter	Nighttime	0.0003	0.0008	0.0019	10.00	26.67	63.33

Primary factor affecting UHII of Chiang Mai city on summer days

The primary social factor that had the strongest influence on the UHII of Chiang Mai city on summer days was traffic density, with a sensitivity percentage of 87.50%. As for the remaining factors, the sensitivity percentages of the building and the population densities were 9.38% and 3.13%, respectively. This is because the traffic density in the daytime in urban areas is significantly greater than that in rural areas. Therefore, an increase in the surrounding air temperature in the daytime in urban areas is directly affected by the huge quantity of heat released from vehicles. In addition to this reason, there is a correspondence to the result reported in a past study that an increase in the concentration of air pollution, consisting of CO, CO_2, and NO_2, which are released into the atmosphere together with a vehicle's exhaust gas, has a strong influence on the increase in the UHII [16]. The ambient temperature in Chiang Mai city, in addition to the heat from the traffic, is very high, about 36-40 °C in summer. This naturally causes the surrounding air temperature in urban areas in summer to be obviously higher than that in rural areas which have significantly more greenery.

Primary factor affecting UHII of Chiang Mai city on summer nights

The primary social factor that had the strongest influence on the UHII of Chiang Mai city on summer nights was building density, with a sensitivity percentage of 50.00%. As for the remaining factors, the sensitivity percentages of the traffic and the population densities were 28.57% and 21.43%, respectively. The UHII at night time is affected by the thermal occurrence at daytime. Upon taking into consideration the physical reason for the UHII on summer days, as previously discussed, it can be observed that the heat released from vehicles as well as solar heat have not only a direct effect by causing an increase in the surrounding air temperature in the daytime, but also an indirect effect by getting accumulated in the structure of buildings, the density of which is higher in urban areas. Although the accumulated heat in the buildings does not directly cause an increase in the surrounding air temperature in the daytime, the heat gets released into the atmosphere at nighttime and consequently causes an increase in the UHII in the nighttime. Moreover, since in the nighttime, the traffic density obviously decreases from that in the daytime, the influence of traffic density on the UHII consequently decreases. The physical reason agrees very well with the result obtained in some of the past studies which found that the heat accumulated in buildings during the daytime is released into the environment of the urban area more significantly than the environment of the rural area in the nighttime. This is the reason why there is no report on the negative UHII in the nighttime [5]. In addition, another past study stated that the physical appearance of an area directly affects the UHII of the area in the nighttime. The surrounding temperature in an area where buildings are densely located would be higher than that in an open area. Moreover, a difference in the density of buildings also causes a difference in the surrounding temperature although the buildings may be located in the same urban area [17].

Primary factor affecting UHII of Chiang Mai city on winter days

The primary social factor that had the strongest influence on the UHII of Chiang Mai city on winter days was traffic density, with a sensitivity percentage of 72.73%. As for the remaining factors, the sensitivity percentages of the building and the population densities were 18.18% and 9.09%, respectively. The physical reason and the explanation for how traffic density affects the UHII on winter days are the same as for summer days, as previously discussed, that is, the main cause being the heat from vehicles.

Primary factor affecting UHII of Chiang Mai city on winter nights

The primary social factor that had the strongest influence on the UHII of Chiang Mai city on winter days was traffic density, with a sensitivity percentage of 63.33%. As for the remaining factors, the sensitivity percentages of the building and the population densities were 26.67% and 10.00%, respectively. It can be seen that the primary factor on winter nights is traffic density, which is different from the case on summer nights where the primary factor is building density. Although the heat accumulated in building structures gets released into the environment in the nighttime on winter nights the same way as on summer nights, the solar heat radiating from the Sun on winter days is significantly lower than that on summer days. This is because the Sun's rays are not perpendicular to Chiang Mai city in winter. This obviously causes the intensity of solar heat radiation on winter days to be less than the intensity on summer days. This statement has been verified in this study by collecting the global radiation intensity – a combination of direct and scattering radiations – during an entire year by using a pyranometer (EKO, MS-802, accuracy ±10 W/m^2). In the light of this reason, the quantities of heat accumulated in and released from the buildings are insignificant. The traffic density, therefore, is the alternative choice remaining to be the primary factor on winter nights. Moreover, upon taking into consideration the activities in Chiang Mai city, it was also found that the amount of domestic and international tourists traveling to Chiang Mai city is generally the highest in winter compared to other seasons. This could be seen from the Tourism Statistics Report of Chiang Mai in 2012 that the amount of tourists travelling to Chiang Mai city during October-March in which the winter took part was 2,917,279, while the amount of tourists during the remaining summer and rainy seasons was 2,221,092 [18]. Moreover, the tourism activities in the urban area are apparently dense during the nighttime, since there are many places of restaurants, nightclubs, and bars located in the main city, as well as the famous walking street on saturday and sunday nights [19]. Thus, this, expectedly, causes unusual traffic jams in the urban area on winter nights and causes a great quantity of heat to be released into the atmosphere from vehicles. This point can be considered as evidence to support the view that the traffic density due to the activities of tourists during winter nights in Chiang Mai city mainly stimulates the level of the UHII in Chiang Mai city to increase on winter nights. This finding corresponds to the results of the comparison of the UHII values on winter days and winter nights, which is that the UHII values on winter days are lower than the UHII values on winter nights. This can also be explained by taking into consideration the activities of the tourists in winter. Since most places of tourist attraction are in the rural areas of Chiang Mai city; for example, there are 14 national parks and also 24 neighborhood cities located in the rural area around Chiang Mai city where the tourists are mostly attracted [20], the activities of the tourists are denser in the rural areas than in the urban areas during winter days. As a result, the surrounding air temperature in the rural areas increases unusually, and this causes the UHII of Chiang Mai city on winter days to be unexpectedly low.

Conclusions

The UHII and the influence of population density, building density, and traffic density on the UHII in Chiang Mai city in each season and time have been thoroughly assessed and investigated by following the mobile approach. The UHII was the difference between the average surrounding temperatures in the urban and the rural areas which were experimentally investigated along eight different routes located on the urban area and rural area. The measurements were carried out in two seasons, consisting of summer and winter. The experiments were carried out in two periods, which were a daytime and a nighttime on Mondays, Wednesdays, and Sundays. It can be found that the UHII on summer days, summer nights, winter days, and winter nights were 1.07 °C, 1.27 °C, 0.58 °C, and 1.34 °C, respectively. This implies that the surrounding air temperature in Chiang Mai city's urban areas is higher than that in rural areas during an entire year. Additionally, it was found that the UHII on summer days, winter days, and winter nights were primarily affected by the factor, traffic density with the sensitivity percentage of 87.50%, 72.73%, and 63.33%, respectively. In contrast, the UHII on summer nights was mainly affected by the factor, building density with the sensitivity percentage of 50.00%.

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