ORIGINAL ARTICLE

Heat Island Intensity in Seongseo, Daegu, South Korea - a Rural Suburb Containing Large Areas of Water

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Abstract

We examined urban heat island intensity in Seongseo, Dae gu, South Korea, where a large area of water is located within the suburb. We found a maximum urban heat island intensity of 4.2℃, which occurred around 7 PM in the summer season. Throughout the remainder of the year, we observed the largest heat island intensity levels during late night hours. In contrast, the winter season displayed the smallest values for heat island intensity. Our results conflicted with heat island intensity values for cities where suburbs did not contain water areas. Generally, cities with suburbs lacking water displayed the largest heat island intensity levels before sunrise in the winter season. We also observed negative urban heat island intensity levels at midday in all seasons except for the summer, which is also in contrast with studies examining suburbs lacking water areas. The heat island intensity value observed in this study (4.2℃) was relatively large and fell between the averages for, Asia and Europe according to the relationship between urban population and heat island intensity.

Key words : Heat island, Heat island intensity, Rural area, Urban area, Air-temperature difference

1. Introduction

Cities typically have higher temperatures compared to rural areas. This is referred to as the urban heat island effect and, has been detected in a number of cities irrespective of city size.

Urban climate has been studied extensively since the 1970s, and Landsberg (1981) published a book summarizing results of those studies up to the publication date. Many of these studies have focused on cities in Japan (e.g., Kawamura, 1979; Yamashita, 1990). Sakakibara (1994) conducted mobile observations in Koshigaya City, which was surrounded by rice fields and had a population of 300,000 at that time and found that the maximum heat island intensity

was around 5.5℃ in the winter season. This result was consistent with cities to the west.

In Korea, a number of studies have been conducted on the formation and properties of urban heat islands in cities varying in size and characteristics. Kim (1976) studied the spatial distribution of temperature in the summer season in Daegu and concluded that the heat island phenomenon was distinctive on sunny versus cloudy days in the summer season. Ahn et al. (2006) also examined changes in urban heat island intensity as a function of the seasons and weather conditions in the Daegu region. They found that urban heat island intensity was larger in the morning compared to the afternoon. Moreover, they observed that the maximum heat island intensity occurred

around 8 AM throughout all seasons. However, Mikami et al. (2005) who found that cities on a plain ground reached their maximum heat island intensity within a few hours after sunset. Furthermore, Lee et al. (2008) evaluated the effect of urban heat islands on the weakness of local wind circulation patterns in Daegu using a numerical simulation technique. Koo et al. (2010) also studied changes in land use in Daegu over the last 100 years and evaluated the effect of these changes on the urban heat island.

Kim (1984) studied the seasonal characteristics of the horizontal distribution of urban temperature in Busan using a local bus. He concluded that the heat island phenomenon was distinctive around the suburbs (e.g., Seomyun and Nampodong) and that heat islands were more prominent in the winter compared to the summer. Han et al. (1993) found a seasonal spatial distribution of the urban heat island in Busan and compared their results to the concentration and distribution of CO and CO_2. They found that the heat island intensity in Busan was strongest at night in the winter season but varied through time, concluding that heat island intensity was influenced by to the density of buildings (which impacted radiation levels), sea water temperature, and artificial waste heat generated from household heat and vehicle fuels. Lee et al. (2010) examined a process of heating the cooling air current generated at night from Seongjigok water area as it flowed up to Seomyun suburb, absorbing the sensible heat from the ground using numerical simulation techniques and data analysis on the specially observed data. Do et al. (2012) analyzed the Korea Meteorological Administration's AWS(Auto Weather System) data for the most recent five years (2006 to 2010) and determined the frequency of the urban heat island in Busan. They also studied the correlation between the urban heat island and meteorological factors, including air pollution. Others verified the presence of urban heat islands in Chuncheon (Lee et al., 1993) and Jeonju (Lee and Ban, 2004)

Korea. Jang and Kim (1991) analyzed the correlations between meteorological factors, air pollution, and temperature differences in the city-proper and suburbs of Seoul.

Although a number of studies on urban heat islands have been conducted, contradictory results regarding the characteristics of urban heat islands have been reported depending on the unique properties of the cities and their geographical features. These contradictory results include the following:

① Daily variance: Some studies reported that urban heat islands were largest in the early morning, while others reported maximums from sunset to midnight. Sekiguchi (1972) reported that the urban heat island in Nagano, a basin-type city, did not have noticeable temperature differences between the day and night hours for downtown and suburban areas. Another study showed that suburbs had higher average values for the maximum temperatures in summer during clear days (Yamashita, 1990).

② Seasonal differences: Kawamura (1977) demonstrated that temperature differences between downtown and suburban areas in a city in Japan were larger during the winter compared to the summer. On the contrary, cities in the United States tended to have greater temperature differences in the summer compared to the winter (Mitchell, 1961).

③ City size and urban heat island intensity: Urban temperature can change with increased urbanization. In addition, a ratio was observed between the maximum difference in temperatures in the downtown and suburban areas of a city and its population size, which can be used to represent city size (Oke, 1973).

Hukuoka (1983) conducted a study of cities in Japan, while Park (1987) conducted studies on cities in Japan and Korea. They reported that cities in Korea and Japan had smaller heat island intensity levels compared to equal-sized cities in Europe, in particular, showing two straight lines distinguished by criteria of 300,000 population.

However, many cities around the Kanto Plain in Japan had no such two straight lines as they claimed and the heat island intensity in a similar sized city was similar as shown in the western type one (Sakakibara, 1994).

In addition, there has been no consensus on the correlation between city size and heat island intensity to date. Oke et al. (1991) hypothesized that differences in heat island intensity levels between Western and Asian cities ware due to surrounding land cover types (e.g., fields, rice paddies, water areas).

Given the varied properties of urban heat islands throughout the world, we analyzed the properties of the urban heat island in Seongseo, Dalseo-gu, South Korea. This area has a population of 600,000, contains the largest industrial complex in Daegu, South Korea, and is surrounded by the Nakdong and Kumho Rivers.

2. Materials and methods

In order to analyze the temperature difference between the Seongseo Industrial Complex in Daegu and the suburban water area, we used the automatic weather observation system (AWS) run by Keimyung University (Gamsam Middle School) and the KMA (at the Gangjeong (Goryung) Weir). Changes in heat island intensity were studied compared yearly and seasonally and over different weather conditions (e.g., rainy/cloudy days versus sunny days, days with strong versus weak winds). To compare the properties of the urban heat island for rainy, overcast days versus sunny days, we used the Daegu KMA dataset.

Fig. 1 shows the observatory location at the Gamsam Middle School and the Gangjeong (Goryung) Weir as well as land use cover in Daegu. The study area included the largest industrial complex in Daegu which supported a dense population living in a high-rise apartment complex. The Gangjeong (Goryung) Weir is located on the northern side of the Nakdong River, which flows along the western border of the Seongseo Industrial Complex.

We analyzed the urban heat island properties from January 2012 to December 2012. Recently, temperatures have been high during the summer season and low during the winter season in this region. The heat island intensity level was analyzed, which has been
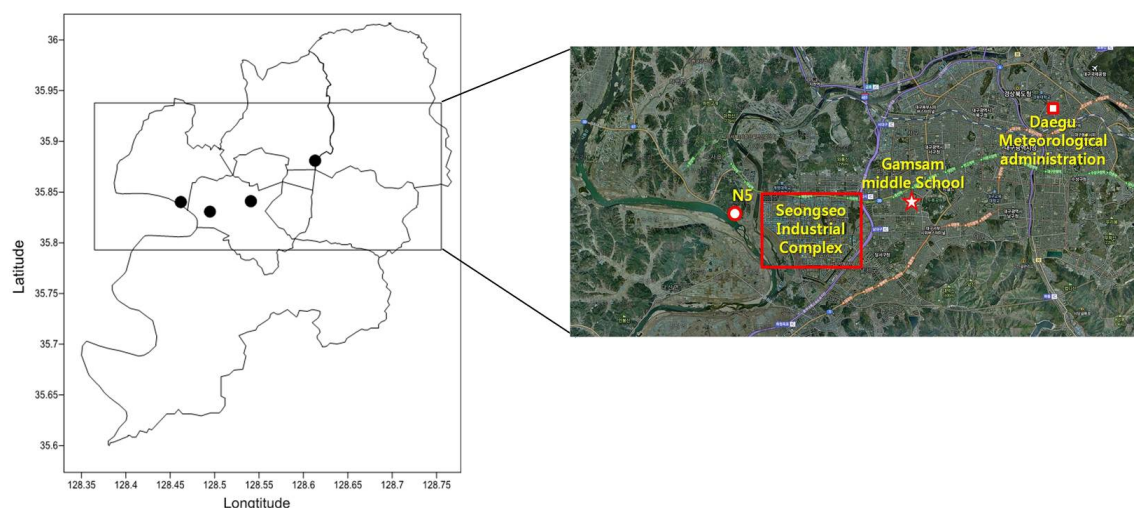

Fig. 1. Land use in Daegu and the locations of the AWSs, which included the Gamsam Middle School (★), Gangjeong Reservoir (●), and the Daegu Meteorological Administaration (■).

widely used in the study of urban heat islands (Do et al., 2012; Ahn et.al, 2006). The heat island intensity ($\triangle T_{u-r}$) can be represented in the following equation:

$$\triangle T_{u-r} = T_{u(max)} - T_{r(min)}, \tag{1}$$

where $T_{u(max)}$ and $T_{r(min)}$ refer to the maximum and minimum temperature values, respectively, observed in urban and suburban regions. Here, temperature data collected at the Gamsam Middle School, located at the western edge of the Seongseo Industrial Complex were used for $T_{u(max)}$ while data collected from the Gangjeong(Goryung) Weir were used for $T_{r(min)}$.

3. Result and discussion

Fig. 2 shows the yearly average temperature distribution at the Gamsam Middle School and the Gangjeong (Goryung) Weir in the Nakdong River. The daily maximum temperature observed at the Gamsam Middle School was reached around 4 PM, while that observed at the Gangjeong (Goryung) Weir was observed around 3 PM. The temperatures observed at the Gamsam Middle School were higher than those observed at the Gangjeong (Goryung) Weir for all time ranges. Temperature differences tended to decline after 7 AM and then increase in the afternoon.
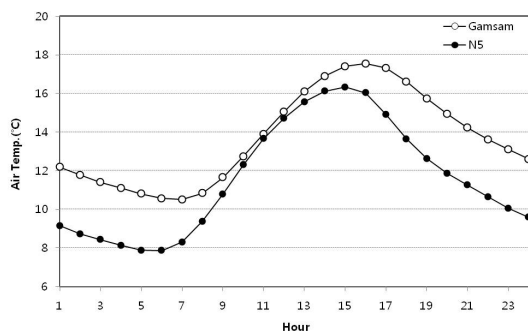

Fig. 2. Variation in air temperature through time at two positions, Gamsam Middle School (urban area) and Gangjeong Weir (rural area).

We also compared the seasonal characteristics of urban heat island intensity (Fig. 3). Urban heat island intensity levels were clearly different in the summer compared to other seasons; heat island intensity was higher in the summer (June to August) and autumn (September to November) while spring and winter showed a similar pattern. In the summer, a positive heat island intensity was observed from 9 AM to 16 PM, while a negative intensity was observed during this time for the other seasons. The seasonal negative heat island intensity shown here supported the previous results of Ahn et al. (2006), although their negative intensity was more distinctive in the study region. Moreover, Ahn et al. (2006) found that heat island intensity was highest at night in the winter, whereas we found that the intensity was highest at night in the summer. Our study results also supported those of Sakakibara (1994), who reported high temperatures in the summer for suburban areas near water.
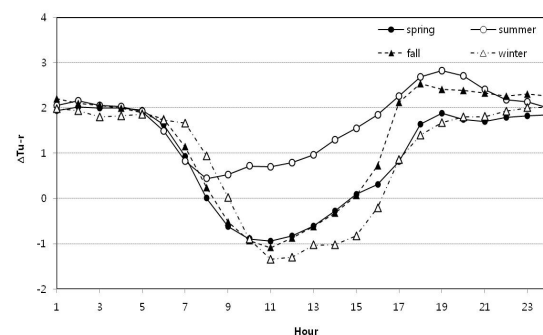

Fig. 3. Seasonal variation in heat island intensity. Here, heat island intensity ($\triangle T_{u-r}$) was defined as the difference in air temperature two positions, Gamsam Middle School (urban area) and Gangjeong Weir (rural area).

In order to evaluate the yearly difference in heat island intensity in more detail, we evaluated the yearly average temperature difference (heat island intensity) for all time ranges between the two regions using the method adopted by Ahn et al (2006) and

Kuttler et al. (1998) (Fig. 4). Heat island intensity was highest in the late afternoon in the summer while showing a similar trend from midnight to the next day morning in seasons other than summer. Moreover, negative values of heat island intensity were observed from 9 AM to 4 PM in all seasons except for summer. This observation conflicted with that of Ahn et al. (2006), where a negative heat island intensity was reported from 9 AM to 7 PM throughout the middle of June to the middle of August.
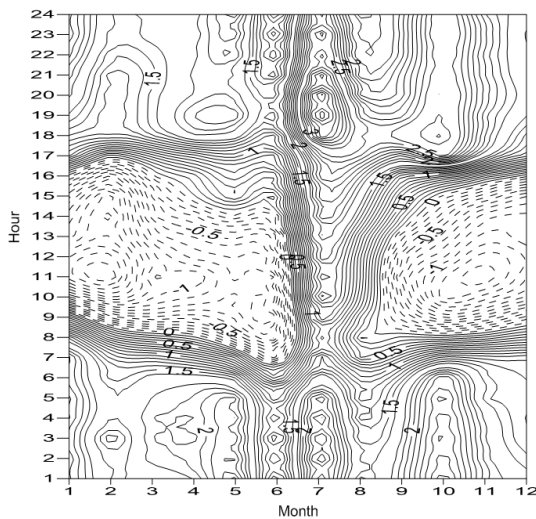

Fig. 4. Diurnal and annual variation in heat island intensity in Seongseo, Daegu, South Korea (contour interval is 0.1℃).

Fig. 5 presents the seasonal variation in heat island intensity as a function of weather condition (i.e., cloudy versus clear days), which was determined by the ground solar radiation level. We defined a cloudy day as having less than 3 hours of sunlight and a clear day as having more than 8 hours of sunlight accroding to the sun-hour data observed at the KMA in Daegu (Sakakibara et al., 2002; and Ahn et al., 2006).

On cloudy days (Fig. 5(a)), we observed a large difference in seasonal heat island intensity, particularly

before 10 AM. The largest difference during that time range occurred in the winter followed by autumn, spring and summer. From 10 AM to sunset, we did no observe a distinctive seasonal difference. For all seasons, heat island intensity on a cloudy day was weaker than that on a clear day. However, for suburban rural areas, the largest seasonal variance between clear and cloudy days occurred in the summer. We hypothesize that the difference between the urban and rural area occurred because of the presence of water, which has a large heat capacity. Thus, the evaporation effect of the suburban water area likely significantly influenced the heat island intensity.
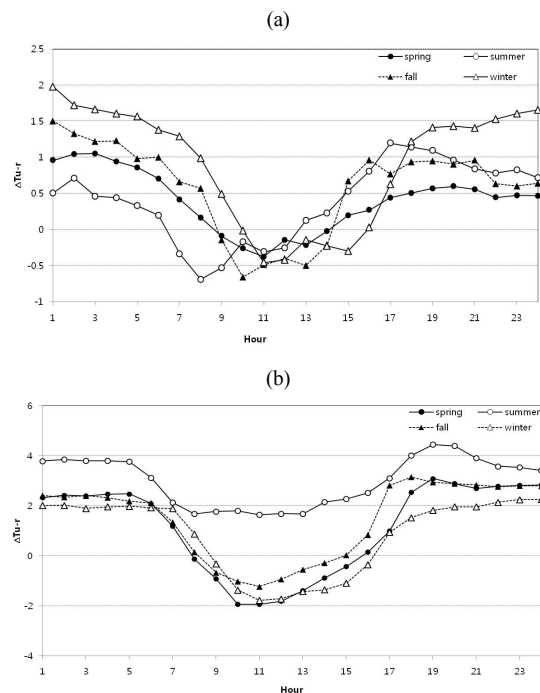

Fig. 5. Seasonal variation in heat island intensity ($\triangle T_{u-r}$) as a function of weather condition on. (a)cloudy and (b)clear days.

Fig. 6 presents heat island intensity levels as a funcgion of daily mean wind speed. As established by Ahn et al. (2006) and Sakakibara et al. (2002), we

assumed a weak wind when wind speed was less than 3.5 m/s, and a strong wind when the speed was more than 3.5 m/s. We found that heat island intensity was two times higher during periods with weak winds (Fig. 6(a)) compared to periods with strong winds (Fig. 6(b)) in all seasons except for the summer. On the contrary, weak winds were associated with a higher heat island intensity in all time ranges during the summer season. This result indicated that a higher level of heat island intensity occurred during the summer in a city with a suburban area that was surrounded by water in part due, to the strong evaporation effect in the suburban areas. In other words, as wind speed became stronger, the evaporation effect in the water area also became stronger and consumed the surrounding heat into the latent heat of vaporization. Note that Fig. 6(b) does not contain a graph bar for the autumn because a strong wind did not occur during the study period.
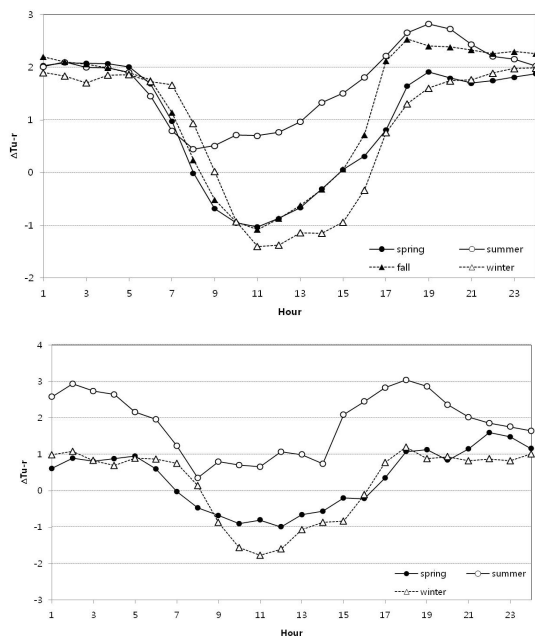
Fig. 7 shows the highest monthly heat island intensity levels observed during the day (before or after the daily maximum temperature occurred), at midnight (12AM), and around sunrise (6AM). As shown in this figure, the daytime heat island intensity was positive during warmer seasons(May to October) and negative during colder seasons. July and August experienced the largest while January and February had the smallest. In contrast, the heat island intensity at night was shown strongly in all seasons, with October having the strongest and June having the weakest. In addition, heat island intensity levels at night were comparatively stronger than at sunrise, likely because the suburban area was surrounded by water (Sakakibara, 1994). Moreover, we observed larger values of heat island intensity during the day in August and July. Sakakibara (1994) hypothesized that heat island intensity was larger during the day in a city where the suburbs were surrounded by water because the evaporation effect was strongest during the summer. In other words, summer days in this type of city generated the largest difference in heating rate on the ground due to the difference in land cover types between downtown and suburban areas.
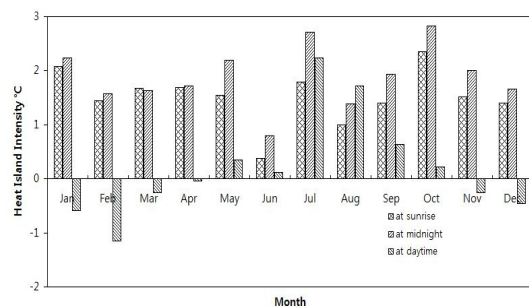

Fig. 6. Seasonal variation in heat island intensity (△Tu-r) as a function of wind strength on days with (a) strong and (b) weak winds.

Fig. 7. Monthly heat island intensity in Seongse City, Daegu

4. Conclusion

We made the following conclusions after analyzing the meteorological data from downtown and suburban areas in Seongseo City in Daegu, a densely populated

area with a large industrial complex .

(1) Heat island intensity was largest in the evening during the summer and in the early morning during the winter. This result was consistent with that of Sakkibara (1994).

(2) A heat island intensity of about 3℃ was observed in the evening during the summer (or about 4.2℃ if cloudy days were not considered). This result was in contrast with other studies, which reported the largest heat island intensity levels in the early morning hours during the winter. However, our results were consistent with those of Kimura et al. (1991), Sakakibara (1994), and Hujibe (2011), who found that heat island intensity was highest during the summer for cities with suburban areas surrounded by water.

(3) Seasonally, we observed the largest and the smallest levels of heat island intensity in the summer and winter, respectively. This was consistent with the results of other studies examining suburban areas surrounded by water. However, these results were also different from those of Ahn et al. (2006), who found that the maximum heat island intensity levels were found in the early morning during the winter.

(4) The heat island intensity in Seongseo in Daegu was approximately 4.2℃ during the evening on clear summer days. This value fell between heat island intensities observed in Asia and Europe according to the classification by Park (1987) and Oke (1973).

Our study examined the heat island intensity of a city with a large suburban area surrounded by water. In the future, we recommend that heat island intensity during the night and day be examined as a function of the surrounding water's heat capacity. In addition, we also recommend that heat island intensity be examined for multiple cities with various populations sizes, which could inform the relationship between urban population and heat island intensity.

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