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Urban Air Temperature Difference between Central Business District and Suburban Hill Footslope Village

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도시상업업무중심지구와 산기슭마을의 기온차

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국문요약

도시화로 인해 도심지와 도시외곽간의 기온차가 더욱 심해지는 열섬현상은 폭염과 더불어 도시민의 쾌적한 삶을 저해하는 요소로 작용하여 이를 저감하기 위한 노력이 시행되고 있다. 도시 기온은 도시의 지형적 특성, 도시 수체의 규모와 위치 등에 의해 영향을 받고 있는 것으로 알려져 있어 도시외곽에 산림이 존재하는 도시에서는 이들 지역과 도심지와의 기온차이를 측정하여 바람길을 이용한 기후응용도시계획에 활용할 필요가 있다. 허나, 아직 국내에서는 이들 기온 차에 대한 특성을 조사한 연구가 많지 않다. 이를 위해 본 연구에서는 서울시 강남 지역을 대상으로 도심지 상업업무중심지구 두 곳(GNS, SLS)과 도시외곽 산기슭 마을 두 곳(YGD, GPT) 간의 기온 차를 2008년 4월 14일부터 2009년 4월 13일까지 1년간 관측한 자료를 대상으로 일 변동, 계절별 변동을 비교, 분석하였다. 분석결과 관측 기간 동안 YGD는 연평균기온이 GNS보다 2.8℃ 낮았으며 열대야는 GNS, SLS가 16일인데 비해 GPT는 2일, YGD는 하루도 관측되지 않아 도시외곽의 산림이 도시기온 저감효과가 있음을 확인하였다.

Key Words：냉각 효과, 월간변동, 일변동, 열대야

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I. INTRODUCTION

The air temperature difference between urban and suburban area affected by the urbanization which forms an island in urban area is called urban heat island (UHI). In addition, global warming causes frequently observed heat wave and tropical night in summer. This leads to heat stress of people and a harmful effect on human health. In 1994 heat wave caused daily average death of about 70 from late July to early August in Seoul (Kim et al., 2006). Hence, it is necessary to mitigate the urban heat wave for better urban environment.

The high urban air temperature greatly depends on the synoptic conditions of weather, the topography and the presence of large bodies of water in urban area. In coastal cities, land and sea breezes have a profound influence, while in hilly areas nocturnal drainage and valley flows may decrease the air temperature (Arya, 1988). The nocturnal cold air flow in mountain areas can play a significant role in providing cooling effects which can save the money and keep urban people comfortable in summer. In Stuttgart city, nocturnal cold air flow into the city, which is a well known example of urban planning to decrease the urban air temperature using the nocturnal cold air flow.

Many studies have been carried out in other countries for the cooling effect of urban parks or green spaces as a urban cool-islands (Svensson and Eliasson, 2002; Chang et al., 2007). The cooling effect of green park is greater in urban arear than rural area (Upmanis et al., 1998; Correa et al., 2006). The cooling effects of city greens are remarkable not only on vegetated areas but surrounding built environments (Wong and Chen, 2004). Eliasson and Upmanis (2000) showed that nocturnal airflow in and around urban parks were generated during clear and calm weather conditions. In Korea, Kwon and Lee (2001) carried out a study on the cooling effects in fall contributed by Changdeok Royal Palace in Seoul. Lee et al., (2009) carried out the study on air temperature reducing effects by urban park in central business district area at Gangnam District, Seoul. Although there are many UHI studies which have increased our understanding, the basic measurement of temperatures across urban areas remains limited. Especially it results in extremely poor data coverage when linked with the complex heterogeneous urban morphology. There are few studies to investigate the air temperature measurement in Seoul. Therefore, the objective of this study was to investigate the air temperature reducing effects at suburban hill footslope area by comparing the air temperature with that of central business district (CBD) area, Seoul. The ultimate purpose of this study is to provide the basic air temperature observation data for UHI mitigation by urban planning using topoclimate data.

II. MATERIALS AND METHODS

1. Study site and observation position description

The study site is Gangnam-gu, Seoul, Korea. The study site is located between 37°30’16.80″N to 37°27′46.11″N and 127°1′45.67″E to 127°3′56.83″E. At the study site, four observing positions were selected. They are two from CBD area and two from suburban hill footslope area. For CBD area, Gangnam Station (GNS) and Seolleung Station (SLS) were selected and they are located at Gangnam-gu, Seoul (Figure 1, Table 1). The geographical characteristics of each site are as

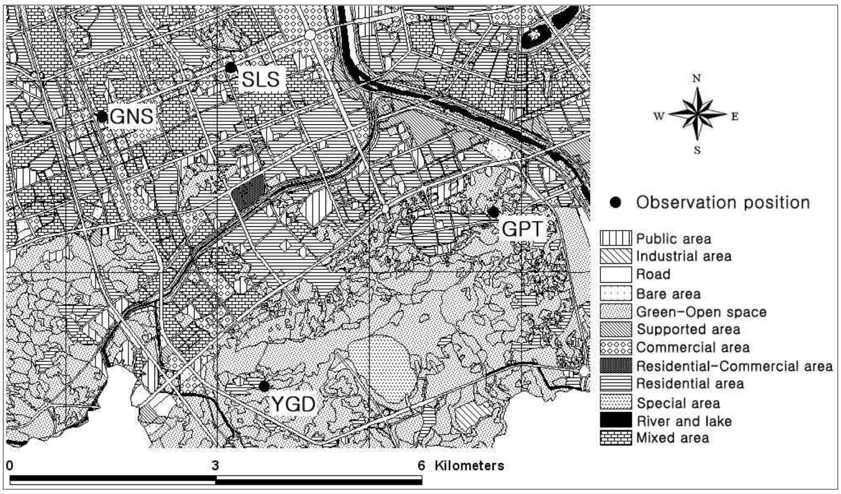

Figure 1. Study site.

follows (Figure 2). GNS is about 50m from the Gangnam Subway Station which is located at CBD with high rise buildings. SLS is 150m from the Seolleung Subway Station and also in CBD with high-rise buildings, heavy traffic and high air pollution. The land cover of both GNS and SLS is paved with impermeable land-cover materials such as asphalt and concrete. The sky view factor (SVF) at GNS and SLS is quite low due to high rise buildings in the study site.

For suburban hill footslope area, Yeomgok-dong (YGD) is located on southwest footslope of Guryong Mountain. Gwangpyeong Prince Tomb (GPT) is a green-open space located ar footslope of Daemo Mountain. YGD is located in greenbelt area. Fresh and cold air blows to the village from the hill at night. Southside of YGD is agricultural area and forest and north side of YGD is mountain forest. West side is residential area. GPT is covered with grass in an urban green space (Figure 2). The distance between GNS and YGD positions is 4.5km.

2. Methods

In order to determine air temperature difference, air temperature and humidity data were observed

Table 1. Observation positions.

No.	Initial	observation position	longitude and latitude	land use	elevation (m)
1	GNS	Gangnam Station	37°29′53.62″N 127° 1′45.67″E	Commercial area	24
2	YGD	Yeomgok-dong	37°27′46.11″N 127° 3′20.58″E	Residential area	40
3	SLS	Seolleung Station	37°30′16.02″N 127° 2′56.35″E	Commercial area	25
4	GPT	Gwangpyeong Prince Tomb	37°29′14″N 127° 5′31″E	Green-Open space	35

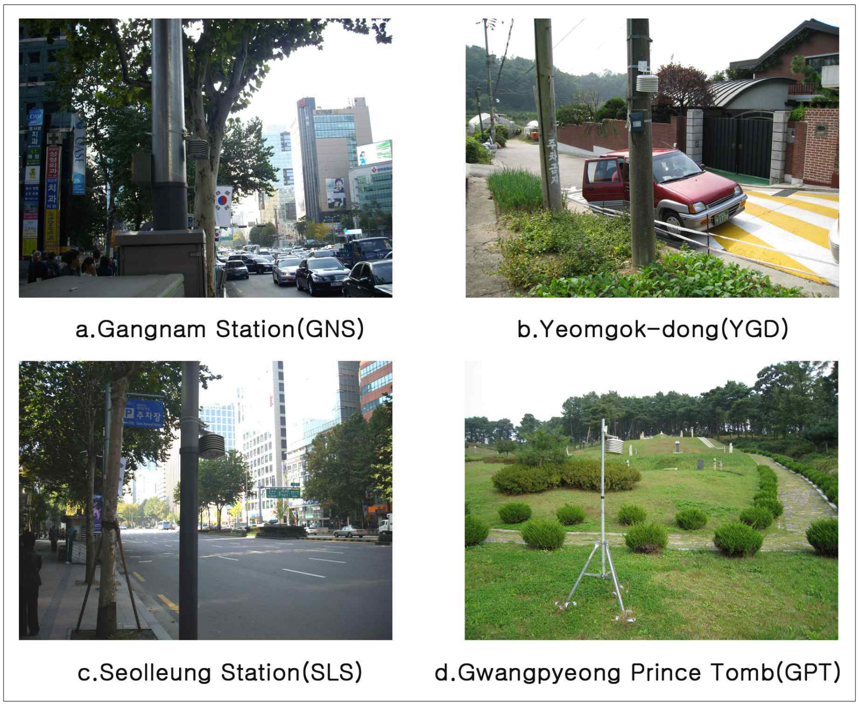

Figure 2. Photos of observation positions.

using Hioki-3641-20 digital temperature-humidity (T-H) sensors at both observation positions from April 14, 2008 to April 13, 2009. The sensor measurement range is -20.0℃ to 70℃ and its accuracy is ±0.5℃ (http : //www.tequipment.net/Hioki3641-20.html). T-H sensors were calibrated before installation to ensure data accuracy and the measurement interval was 10 minutes and installed at 2-2.5 m above ground level, to avoid radiation inversion and vandalism. The weather condition data (wind speed, precipitation and cloud cover) referred to Gangnam Automatic Weathering Station of Korea Meteorological Administration (KMA) at the same period (http : //www.kma.go.kr/weather/observation/currentweather.jsp?type=t24&mode=0&stn=108&auto_man=m&tm).

3. Data Analysis

The diurnal variations throughout the year and the number of tropical nights were derived to investigate the air temperature difference between CBD area and hill footslope village. In order to determine the air temperature difference between

Table 2. Numbers of free convection days used in analysis.

Month	Number of days
January	21
February	8
March	11
April	14
May	10
June	1
July	1
August	7
September	5
October	13
November	9
December	10
Total	110

four observation positions (GNS, YGD, SLS, YGD) weather data whose cloud cover is 3 or more, rainy day, and the wind speed is over 3.4m/sec were excluded in analysis because significant thermal differences cannot develop in these weather conditions. The number of free convection days used in analysis is shown in Table 2.

Air temperature data were also analyzed in terms of monthly variation. But a few date data were observed from May to August, so they were merged May to June and July to August.

Ⅲ. RESULTS AND DISCUSSION

1. The maximum, minimum and average air temperature

In the examination of observing air temperature results, the maximum, minimum, and average air temperatures were derived. Of all observation positions the maximum air temperature of 36.8℃ was observed at YGD. The recording time were 15 : 10 and 15 : 20 on August 08, 2008. At this time, the synoptic weather condition showed that no precipitation, wind speed was 0.9m/sec and cloud coverage was 2. The minimum air temperature of -14.6℃ was also observed at YGD at 7 : 20~8 : 10 on January 15, 2009. At this time the synoptic weather condition showed that no precipitation, average wind speed was 1.2m/sec and cloud coverage was 0.

The highest annual average air temperature of 14.8℃ was observed at GNS while the lowest one of 12.0℃ was observed at YGD (Table 3). The overall GNS shows the highest air temperature of all the observation sites. The average air temperature difference between GNS and YGD was observed by 2.8℃ and that between SLS and GPT was 2.1℃ during the observation period. The maximum air temperature difference was observed between GNS and YGD.

Table 3. The average, maximum and minimum air temperature for one year. (Unit : ℃)

	GNS	YGD	SLS	GPT
AVE	14.8	12.0	14.5	12.5
MAX	36.6	36.8	36.3	34.9
MIN	-10.6	-14.6	-11.1	-13

2. Number of tropical nights at observation positions

A twenty-four hour period with a minimum air temperature above 25℃ is termed a tropical night, according to the KMA (http : //web.kma.go.kr/notify/press/kma_list.jsp?bid=press&mode=view&num=1191120). Figure 3 shows the number of tropical nights of four observation positions. GNS and SLS show 16 as the number of tropical nights, GPT has two tropical nights while YGD has no tropical nights. This is explained by that solar radiation in mountain area is used for evapotranspiration and nocturnal cold air flow over hill footslope reduces nocturnal air temperature. However, in urban area the paved surfaces and

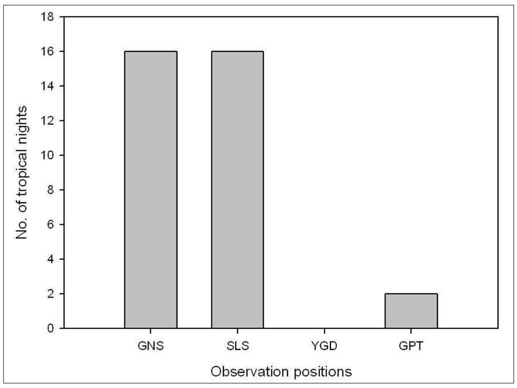

Figure 3. Number of tropical nights for all observation positions.

walls store some of the heat received during daytime and give it off after sunset to its air environment (Landsberg, 1981). Therefore, the daily temperature range of urban area is lower than mountain area and the clear conclusion is that urbanization increases nocturnal air temperature and decreases the daily range of temperature.

3. Diurnal variation between CBD and footslope village

The diurnal variation of air temperature at ten-minute intervals for all observation positions was compared (Figure 4). The highest value of 17.8℃ was observed at GNS (15 : 10-16 : 20) and the next one 17.7℃ was observed at SLS (16 : 00) while the minimum air temperature of 7.8℃ was observed at YGD (05 : 30-06 : 30). It suggests that the daily minimum air temperature was observed immediately before sunrise and the daily maximum air temperature was observed in mid-afternoon.

As we can see in Figure 4, the air temperature difference between urban area and mountain area are almost same during daytime but increases rapidly after sunset and keep staying throughout the night. Because the lower albedo of urban materials results in greater absorption of solar radiation during the daytime and the stored energy emits long-wave radiation at night. In addition, the SVF at GNS is low which blocks long-wave radiation emission, so the daily minimum air temperature difference between GNS and YGD is large.

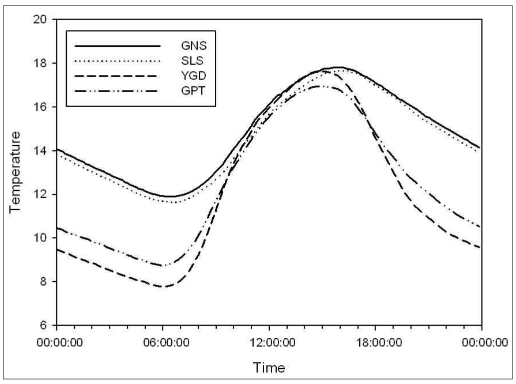

Figure 4. Diurnal variation of air temperature for all observation positions.

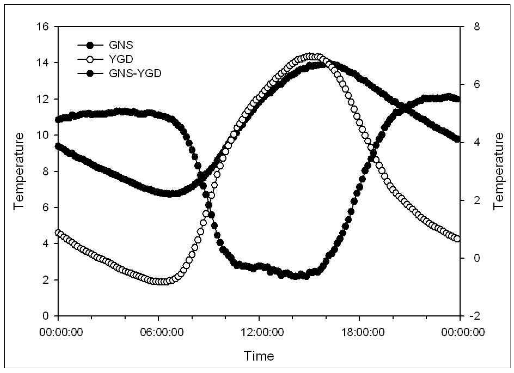

Figure 5. Diurnal variation of temperature difference between GNS and YGD sites.

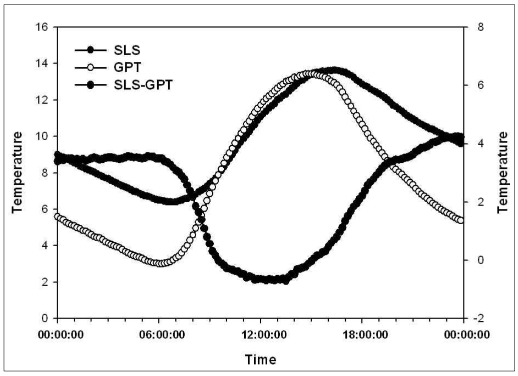

Figure 6. Diurnal variation of temperature difference between SLS and GPT sites.

The diurnal variation in UHI intensity using only free convection weather condition was derived to illustrate air temperature difference between GNS and YGD, SLS and GPT (Figure 5, 6). According to average temperature of the observation sites, the air temperature difference between GNS and YGD was 3.0℃ and that between SLS

Table 4. Synoptic weather conditions of maximum and minimum air temperature difference between GNS and YGD sites (DT_{MAX} : Maximum Temperature Difference, DT_{MIN} : Minimum Temperature Difference, PCP : Precipitation, WS : Wind Speed, CC : Cloud Cover).

	Observation time	Temperature difference (℃)	PCP (mm)	WS (m/sec)	CC
DTMAX	2008-09-18 19 : 40	11.1	0	1.3	1
DTMIN	2009-03-08 13 : 40 2009-03-19 14 : 30,14 : 40 2009-03-20 14 : 00	-3.1	0	1.2 3.2 1.4	0 2 0

and GPT was 2.1℃. It shows that the air temperature difference between GNS and YGD is larger than that of between SLS and GPT.

Considering the weather conditions, the maximum air temperature difference of 11.1℃ between GNS and YGD was observed at 19 : 40 on September 18, 2008. At this time, the synoptic weather condition showed that no precipitation, wind speed was 1.3m/sec and cloud coverage ratio was 1. The high air pressure covered the Korean Peninsula and the pressure gradient is gentle, so it was clear and calm weather according to the weather map (Figure 7). The reversed maximum air temperature difference was observed at 13 : 30 on March 08, 2009 and 14 : 30~14 : 40 on March 19, 208 and 14 : 00 on March 20, 2009 by -3.1℃. The synoptic weather condition at this time also showed no precipitation, wind speed was 1.2m/sec and 3.2m/sec and 1.4m/sec and cloud coverage ratio was 0, 2 and 0, respectively (Table 4). It is same as the former study that the UHI is developed with cloudless skies and light wind days (Landsberg, 1981; Oke, 1987; Lee et al., 2009).

The difference of daily maximum and minimum air temperature between GNS and YGD, SLS and GPT are shown in Figures 8 and 9, respectively. The daily maximum air temperature shows similar trends, but the average of daily

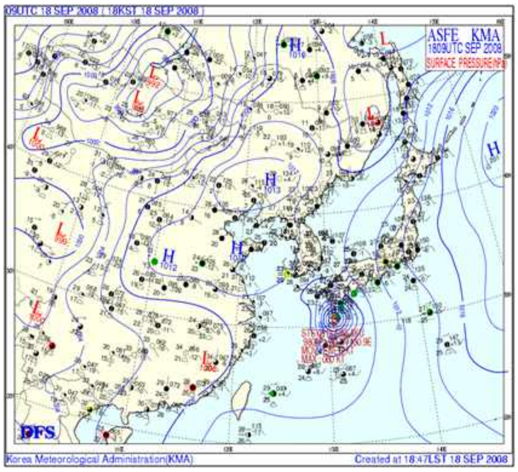

Figure 7. Weather conditions of the day that has the maximum air temperature difference between GNS and YGD.

minimum air temperature difference between GNS and YGD is about 5℃ while that between SLS and GPT is about 3℃. In terms of daily minimum air temperature YDG shows lower temperature than that of GPT. This can be explained by that some medium-density apartment residential areas are located nearby GPT, however, single family housing or town houses are located at YGD. Thus, the air temperature difference between GNS and YGD shows more representative characteristics than that between SLS and GPT. Another reason can be due to the nocturnal cold air drainage at YGD which creates cooling air pocket This needs to be investigated further by observing wind

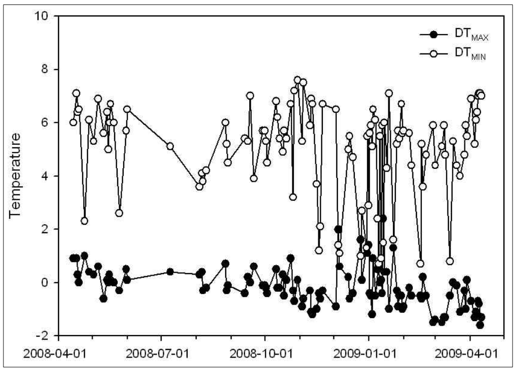

Figure 8. The difference of daily maximum and minimum air temperature between GNS and YGD.

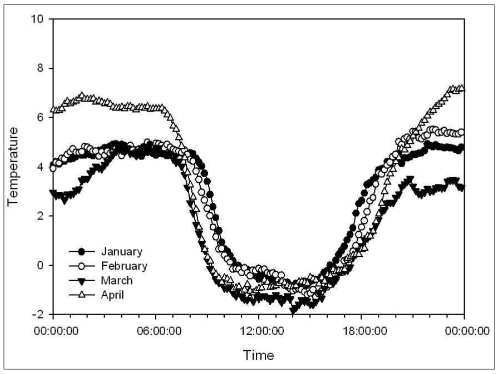

Figure 10. Air temperature difference between GNS and YGD sites from January to April.

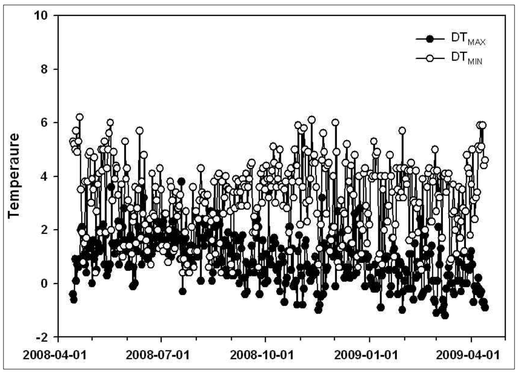

Figure 9. The difference of daily maximum and minimum air temperature between SLS and GPT.

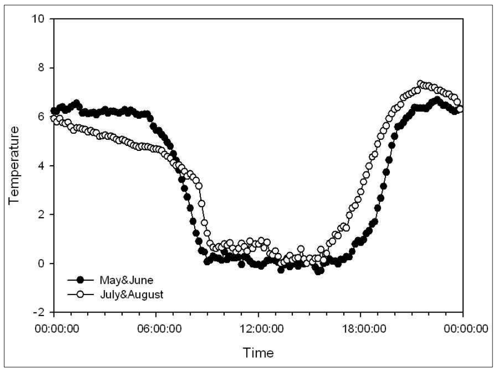

Figure 11. Air temperature difference between GNS and YGD sites from May to August.

speed and direction. Thus, the monthly variation of air temperature difference is confined to the data analysis between GNS and YGD. The higher nocturnal minimum temperature in urban area is the result of the reduced cooling effect in the late afternoon and evening (Oke, 1987).

4. Monthly variation between GNS and YGD

The monthly variation of air temperature difference between GNS and YGD is illustrated in Figure10~Figure12. In Figure 10, the period of January through March shows similar variations, however, April variation shows high nocturnal cooling. This could be due to more incoming solar radiation during the daytime because of the higher sun angle. Due to the low albedo characteristics of urban surface materials such as asphalt or concrete at GNS, more energy were stored during daytime and released as long wave emission at nighttime, which increases the air temperature. On the contrary, due to the high albedo at YGD area, more solar energy are reflected during daytime and less at nighttime.

Figure 11 shows the monthly variation of air temperature difference from May to August, which shows similar variations. The data for June and July, only one day meets these conditions. Therefore, May and June were combined, and July and August were combined in order to

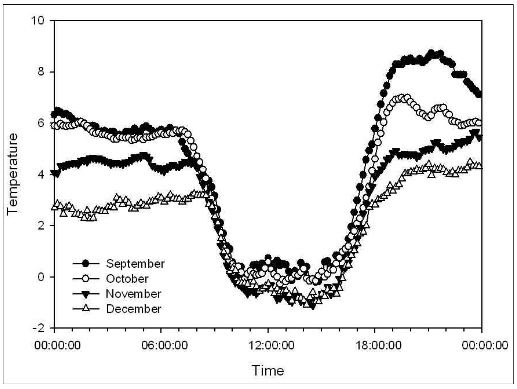

Figure 12. Air temperature difference between GNS and YGD sites from September to December.

illustrate the air temperature differences between GNS and YGD.

Figure 12 shows the monthly variation of air temperature difference from September to December. During the study period the maximum air temperature decreasing effect of 8.7℃ occurred at 21 : 10, 21 : 30 and 21 : 40 in September. At YGD, the active evapotranspiration and radiation energy exchange contributed to nighttime reducing effects. This is why UHI intensity is highest in September (Lee et al., 2009).

IV. CONCLUSIONS

In order to investigate the air temperature difference between CBD and suburban hill footslope village, air temperature was observed at four observation positions from April 14th, 2008 to April 13th, 2009. The air temperature difference data were analyzed and examined to illustrate diurnal and monthly variation. After investigation, the following conclusions were derived.

(1) Numbers of tropical nights were 16 at GNS and SLS, 2 at GPT, however, there was no tropical nights at YGD.

(2) The average air temperature difference between GNS and YGD is 2.8℃ while that between SLS and GPT is 2.1℃. It is a significant amount of UHI intensity considering the distance between GNS and YGD are 4.5km.

(3) The daily maximum air temperature differences are almost same, but the daily minimum air temperature difference is about 5℃ between GNS and YGD. It means that suburban hill footslope area shows lower nocturnal air temperature.

After carrying out this study, the topoclimate characteristic of YGD and GPT contributes to lower nocturnal air temperature. The meteorological characteristics, especially wind speed and direction need to be observed to understand better microclimate environment at the study site.

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