환경영향평가 Vol. 32, No. 3(2023), pp.176~186 J. Environ. Impact Assess. 32(3): 176~186(2023) ISSN 1225-7184
https://doi.org/10.14249/eia.2023.32.3.176

Research Paper

Variation of Green Space Cooling Effect Influenced by Its Composition and Surroundings in Suwon City

Seung Yeon Lee*, · Seong Woo Jeon****

Environmental Assessment Group, Korea Environment Institute*
Environmental Science & Ecological Engineering, Korea University**

수원시 녹지 조성 및 주변 환경에 따른 녹지 냉각 효과의 변화

이승연*, · 전성우****

한국환경연구원 환경평가본부*, 고려대학교 환경생태공학과**

요약 : 도시열섬(Urban Heat Island; UHI)은 도시가 인근 지역에 비해 뜨거운 현상을 의미하며 도시 내부의 건물의 구성, 토지피복의 종류 등이 변화하기 때문에 발생한다. 도시열섬을 완화하기 위한 방법으로 녹지공간의 조성인데, 녹지가 제공하는 냉각효과의 경우 녹지의 내부 구성 요소 및 녹지의 크기에 따라 변화한다. 본 연구는 다양한 토지피복으로 구성된 수원시를 대상으로 녹지의 크기와 녹지를 구성하는 요소들에 따른 냉각효과의 차이를 확인하고, 녹지의 인근 토지피복에 따라 녹지로부터 제공되는 냉각효과의 차이를 고찰하고자 한다. 연구 결과, 녹지의 초기 온도는 산림의 비율이 높을수록, 그리고 호수가 존재할수록 낮아졌다. 냉각효과 중 하나인 냉각강도는 숲의 비율이 높을수록 강해졌지만, 초기 온도가 더 큰 영향을 미쳤다. 다만 냉각 거리는 녹지의 크기나 구성에 따라 달라지지 않음을 확인했다. 본 연구의 결과는 도시의 계획 시 열섬을 완화하기 위한 녹지 설계 방안을 제시한 다는 점에 의의를 가진다.

주요어 : 도시열섬, 녹지 공간, 냉각 효과, 초기 온도, 수원시

Abstract : Urban Heat Island (UHI) is caused by an energy imbalance in urban areas, where building design and land cover contribute to its amplification. To mitigate UHI, increasing green space is one of the well known and the most effective approach. This study aims aimed to identify specific components of green spaces that lower temperatures and demonstrate the cooling effects based on their size and composition. Forests within green spaces have had a greater impact on temperature reduction due to shading and blocking solar radiation. Although lakes also contributed to temperature reduction, the effect to cooling intensity was not significant. The cooling distance does not depended on green space size or composition. The study emphasizes that initial temperature has a stronger influence on cooling intensity than green space size, highlighting the importance of vegetation type within green spaces to achieve a cooling effect. These findings provide valuable insights for urban planning and the design of green spaces to mitigate the effects of the urban heat island.

Keywords : Urban Heat Island, Green Space, Cooling Effect, Initial Temperature, Suwon City

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First Author: Seung Yeon Lee, Tel: +82-44-415-7474, E-mail: syl9005@gmail.com, ORCID: 0009-0004-2777-1275
Corresponding Author: Seong Woo Jeon, Tel: +82-2-3290-3043, E-mail: eepps_korea@korea.ac.kr, ORCID: 0000-0001-5928-8510

Received: 21 June, 2023. Revised: 26 June, 2023. Accepted: 27 June, 2023.

I. Introduction

Urban Heat Island (UHI) is a phenomenon where urban areas are noticeably warmer than the nearby rural areas (Kim 1992). The change in thermal patterns alters habitat conditions for species, consequently affecting their life cycles and distributions. For instance, Melass (2016) showed that the growing season (e.g., from the beginning of spring to the end of autumn) increased by 18-20 days when the temperature rose by 7°C in the Boston metropolitan region. In addition, hot weather or overheated temperatures could escalate energy expenditure by stimulating metabolism in organisms. While a higher metabolic rate requires more energy resources (e.g., food), foraging in extreme thermal conditions would not be easy for species such as lizards (see Ackley 2015). It is also well-documented that climate change influences humans, particularly those living in urban areas. Surprisingly, Huang et al. (2020) reported that heat exposure might be related to diseases or even the death rate. Therefore, it is important to understand how to mitigate urban thermal conditions.

UHI is one of the results of the environmental balance in the energy budget between thermal absorption and release, with factors such as the urban climate system, city structure, as well as the structural materials configuring the urban area (Montavez et al. 2000). Although the initial amount of solar radiation exposed, in combination with wind and cloud thickness (e.g., climate characteristics of the city), determines UHI intensity, building geometry and land cover types play a major role in magnifying or weakening this urban-specific thermal condition. In the perspective of urban design, the lower the aspect ratio (e.g. the height and width ratio of buildings), the more street canyons are exposed to solar radiation, meaning a higher chance for urban space to absorb heat energy (Priyadarsini et al. 2008; Bakarman et al. 2015). Urban surface cover influences the thermal behavior of urban landscapes. Specifically, impervious surfaces change the radiation flux (by decreasing albedo; Taha 1997) and block evapotranspiration generated by vegetation (Yang et al. 2019). In addition, UHI could be intensified by human activities such as air pollution or traffic intensity (Taha 1997; Niu et al. 2021).

The most promising way to mitigate UHI is to increase vegetation cover in urban areas. Vegetation cools down the surrounding environment through shadowing, evaporative cooling, rainwater interception, and storage (Gill 2007), as well as lowering albedo (Aflaki et al. 2017). The strength of cooling services differs among different vegetation types. For example, if water is not sufficient for continued evaporation, grass may dry out and lose its cooling power (Watkins et al. 2007). By strategically designing urban green areas, the thermal mitigation value of vegetation can be effectively harnessed. According to Alexandri and Jones (2008), changing the roof color to green can decrease the temperature by up to 11.3°C at canyon level. Additionally, Gioia et al. (2014) suggests that parks under 3 ha do not show any cooling effects, however, Lin et al. (2017) showed that even parks even 0.1 ha can mitigate the surrounding thermal conditions. Bao et al. (2016) also declared that evenly distributed green areas have a greater effect on decreasing surface temperature.

The urban landscape is highly diverse, and the thermal conditions in urban areas are complex, highlighting the importance of considering both the driving and balancing forces of the urban heat island (UHI) phenomenon in order to comprehensively understand the cooling effects of green areas. These cooling effects can be influenced by various factors, such as the land use type and structural characteristics of the surrounding environment. The interactions between different elements of the city structure can amplify the intensity of the UHI, making the size of green areas a crucial factor in mitigating the UHI and enhancing the cooling effects. However, determining the optimal size of green areas for these effects remains a topic of debate. It is evident that the size of the green area should be considered in conjunction with the specific composition of vegetation types and the accumulated heating effects of the surrounding areas (Jaganmohan et al. 2016). Therefore, the objectives of this study are as follows: 1) to identify which specific components of green spaces contribute to lower temperatures in these areas, 2) to demonstrate the cooling effects based on the size and composition of green spaces, and 3) to explore how these effects may differ depending on the heterogeneity of urban structures.

II. Study Area and Method

1. Study area

Suwon City is located in the dry-wet continental climate zone. However, Suwon City recently exposed to extremely hot days in increased from 10.2 days (mean of 30 years from 2013) to a total of 38 days (the Korean Meteorological Administration, data acquired in 2023.06.01). In the same year, hot weather in Suwon City lasted for 30 days, and the highest temperature reached 39.3°C, which alerted Suwon City to prepare for the heatwave (Kim 2017). Accordingly, Suwon City has established policies to adapt to climate change and is actively creating green space with diverse size and composition to mitigate heatwave (Kim 2017). In addition to these policy decisions, Suwon City has highly heterogeneous land cover. Although buildings are densely located in the center, the northern part of Suwon City is covered with Gwanggyo mountains, and the eastern part is utilized for agricultural purposes. Additionally, recently developed residential buildings are designed to be high-rise with low impervious land cover to deliberately cool down the living surroundings. Due to this heterogeneity, green areas of Suwon City will reveal different cooling effect despite of their characteristic similarity. The goal of this study is to find out the variation of cooling effect by green space's composition and its neighboring land cover. Therefore Suwon City is reasonable to be studied since this city has diverse characteristics of green space that surrounded by different land cover (Figure 1. (a) and (b)).

The Green space (GS) was separated from a biotope map created in 2019 by Suwon City. Among 7 calsses of "Green Biotope", 3 classes (Forests, Grasslands, Parks, and green spaces) were chosen for the GS, and if the filtered GS enclosed a lake, that particular lake was also included in the GS. Areas under 1000m² were deleted from the initially collected GS due to the resolution limitation of the data. Additionally, GS areas that had the same or higher temperature as the surrounding areas were also removed (Chang et al. 2007). Suwon City strategically placed GS to enhance ecological connectivity and provide accessible parks for citizens. As a result of these policies, GSs in Suwon City are distributed throughout the city at short distances (Kim 2018), which complicates the determination of the exact origin of the cooling effects. Given the aim of this paper to examine the cooling effects of GS, we aggregated green areas within a 300m radius (Upmanis et al. 1998).

2. Cooling effects

This paper targeted June to August when extreme thermal conditions frequently occur. The thermal condition of the city was represented by Land Surface Temperature (LST), which was calculated using Landsat-8 following the methodology of Jee et al. (2016). Due to the monsoon and frequent squalls, only June was used to calculate LST.

The Cooling Effect (CE) was measured by the temperature difference between the green space (GS) and its surroundings (Chang et al. 2007). The maximum cooling distance and the intensity of the cooling effect were used to demonstrate the cooling effect of each selected GS. Initially, buffer zones with a 30m interval were set around each GS (Figure 2 (a)) to analyze the temperature change curve. Since the cooling effect of GS is influenced by the urban landscape (e.g., land use, Cheng et al. 2015), the trend of the change will eventually follow the surrounding temperature and show several peaks in the represented curve. Therefore, the first peak of the temperature change curve was chosen to determine the maximum distance that the GS affects (i.e., Cooling Distance; CD). Cooling Intensity (CI) was calculated as the temperature difference between the temperature of the GS (i.e., initial temperature; IT) and CD (Figure 2 (b)). Specifically, CD indicates the maximum distance that the GS's cooling effect reaches, and CI represents the total cooling temperature provided by the GS. Each buffer zone and the GS's mean temperature were derived using Zonal Statistics (ArcGIS 10.1).

3. Statistical analysis

The initial temperature and cooling effect are both affected by the complex and dynamic interaction between urban landscape, climate, and the characteristics of the GS. In this paper, the size and composition of the GS were chosen to represent characteristics of GS. The composition of the GS was further divided into the Majority of Green

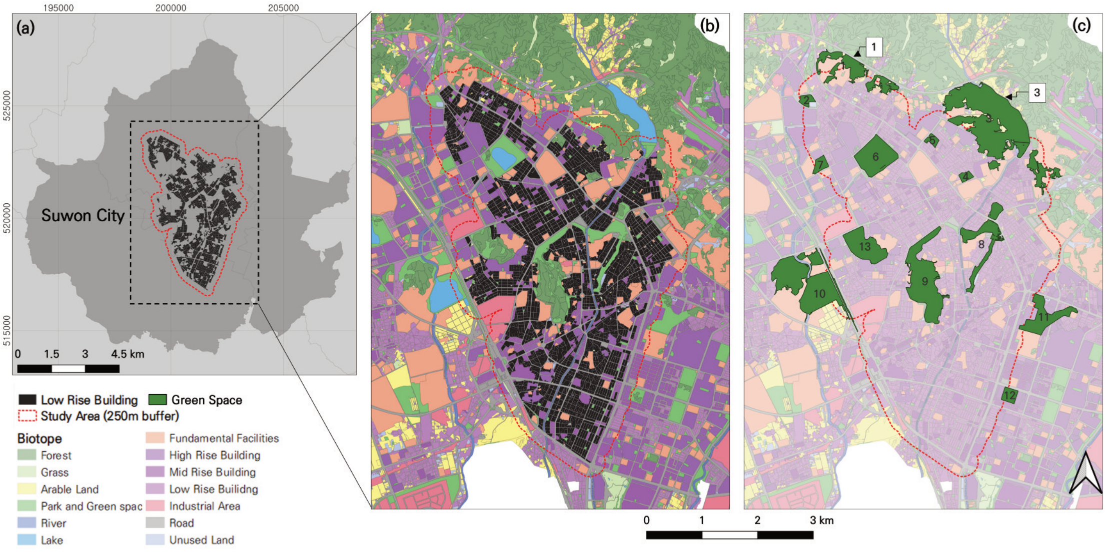

Figure 1. Location of Suwon City, the study area, and biotope types near study area. (a) Dark grey indicates the realm of Suwon City, black indicates low rise building, red dotted line indicates the boundary of study area (i.e. 250m buffer from area where low rise building locates) (b) Biotope types near low rise buildings. (c) Green spaces(GSs) that this study investigate. Note that each number labeled on GSs is the unique ID assigned for the study.

Space (MajGrn) and Lake Existence (LakeEx). The Majority of Green Space refers to the vegetation type (vegetation type: forest, grass, park and green space) that occupies more than 50% of each GS. If none of the vegetation types has a percentage higher than 50%, the particular green space is labeled as "complex". The Lake Existence variable is labeled as 1 if the GS contains a lake and 0 if not.

Simple regression was first used to find out baseline relationship between area and IT (Table 2, Model 1). Also, multiple regression with Majority of Green and Lake Assistance as independent variable was applied to find out the characteristic of GS that lowering the temperature (Table 2, model 2). Two multiple regression model was build to discover cause of cooling effect variation. For the relationship between characteristics of GS and cooling effect, the size and initial temperature was used as independent variables (Table 2, model 3). To determine whether the effect of the component of green space on the cooling effect is different form IT, multiple regression with Majority of Green and Lake Assistance was also analyzed (Table 2, model 4). The model was chosen using step-wise selection. Before applying linear regression, effective sample size was examined by power test. The All means were reported with standard deviation.

III. Result

1. Temperature of green space

A total of 13 GSs were selected for this study and each GS assigned unique number for the further analysis(Green Space ID). The size ranged from 3.06 to 127.94 hectares, and all GSs except ID 2 and 7 comprised more than two vegetation types (Table 1). The vegetation type that occupied the most in each GS was park and green space (maximum 100%, mean ± SD: 46.93 ± 35.87%), followed by forest (94.43%, 44.92 ± 35.59%). Only four GSs (ID 1, 3, 6, 10) included a lake as a component, and except for ID 1, the lake's ratio ranged from 24.76% to 33.74%.

The average initial temperature was 26.78°C (±1.92), with a minimum of 23.50°C and a maximum of 29.94°C (Figure 3(a)). This was almost

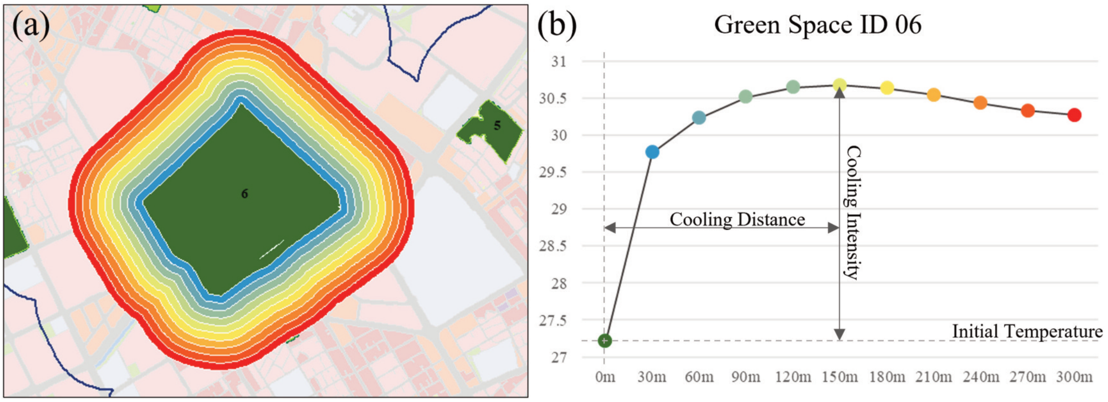

Figure 2. Methodology of calculating cooling effects (a) Buffer zones with 30m interval were set around green area (b) Graphical explanation of cooling distance (CD) and cooling intensity (CI). Each color of dots in (b) corresponds to the buffer zones in (a). Green dots located on 0m is the initial temperature (i.e., mean temperature of green area) and the yellow dot located on 150m is the first peak of the temperature curve. In this case (Green Space ID 06), CD is 150m and CI is 3.46°C

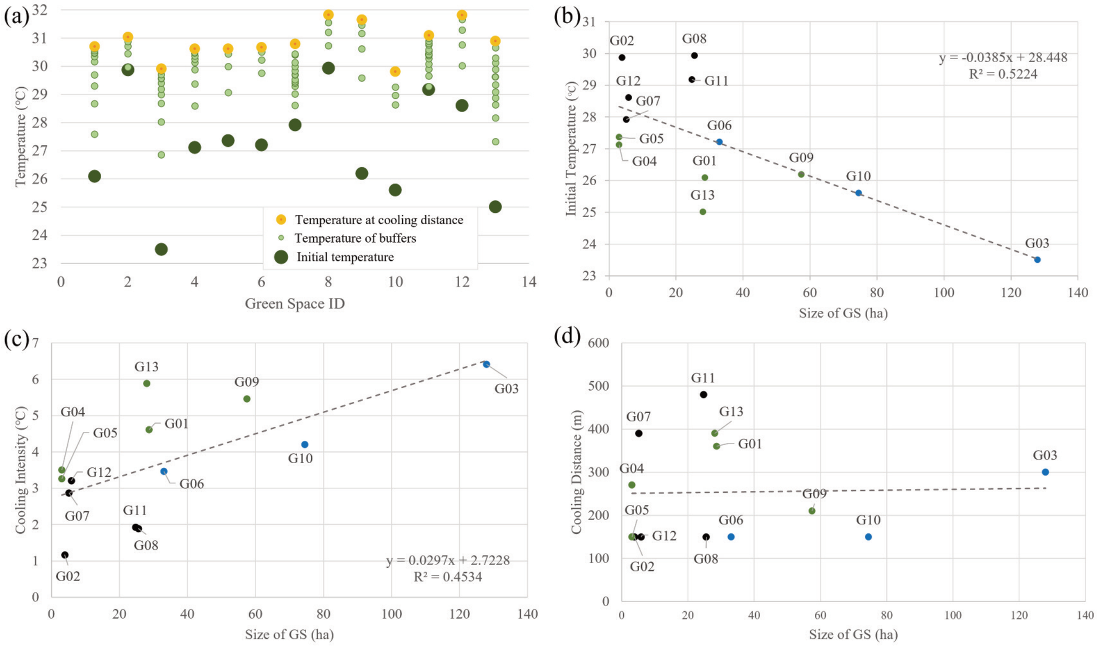

Figure 3. (a) Temperature of all GSs and their surrounding buffer zones. Dark green large dots represent initial temperature of GS and green small dots with dark green perimeter indicates temperature of buffer zones. Yellow dots are the temperature at cooling distance. Note that Green Space ID indicates the unique number of each green space corresponding to Figure 1 (c). (b) Simple regression result between initial temperature and size of GS in ha. (c) and (d) depict the simple regression result between CE variables and size of GS in ha. Note that Black dots for all simple regression results indicate park and green space, dark green dot shows forest, and blue dots represents GS including lake.

8~13°C lower than the maximum temperature of the study area (37.03°C). The simple regression results showed that the initial temperature had a significantly negative coefficient with the size of the GS ($F_{1,11}$=1.387, *p*=0.005, R^2=0.479; Table 2, Model 1). In the multiple regression model with GS characteristics, the initial temperature was highly influenced by a high percentage of forest and the existence of a lake. However, GSs covered with park and green space or a complex vegetation type had no significant effect on the initial temperature ($F_{4,8}$=1.387, *p*=0.002, R^2=0.783; Table 2, Model 2).

2. Cooling effect of green space

The average Cooling Distance (CD) of the 13 GSs was 253.85m (±118.50), with a minimum of 150m and a maximum of 480m. Almost half of the GSs had a cooling distance of 150m, regardless of the size or major coverage type of the GS. The size of the GS did not explain the change in CD ([simple regression] R^2<0.001, *p*=0.923), nor did the GS characteristics (R^2= 0.158, *p*=0.820).

The average CI of all GSs was 3.68°C (±1.59), with a minimum of 1.17°C and a maximum of 6.41°C. The results of multiple regression on CI showed that the size of the GS was not significantly associated with CI, while the IT had a significant impact on CI ($F_{3,9}$=32.19, R^2=0.886, *p*<0.001, Table 2, Model 3). In the model developed to examine the relationship between GS characteristics and CI, only forest significantly influenced CI ([multiple regression] $F_{4,8}$=5.514, R^2=0.601, *p*=0.020, Table 2, Model 4).

Table 1. Area and composition of Green Space by ID

Green Area ID	Area (ha)	% of Biotope in Green Area			
		Lake	Grass	Forest	Park and Green space
1	28.66	0.32	1.81	83.46	14.41
2	3.9	-	-	-	100
3	127.94	24.76	1.74	66.6	6.91
4	3.06	-	0.57	82.19	17.24
5	3.06	-	-	94.43	5.57
6	33.03	33.74	-	3.89	62.36
7	5.13	-	-	-	100
8	25.52	-	0.04	7.35	92.61
9	57.48	-	0.33	62.15	37.52
10	74.52	33.35	0.63	27.08	38.94
11	24.71	-	0.04	20.32	79.64
12	5.84	-	-	25.74	74.26
13	28.06	-	0.53	73.14	26.33

Table 2. Simple and multiple regression result

	Estimate	Std.Error	t	p
Model 1: IT ~ Area				
Intercept	28.448	0.526	54.07	< 0.001 ***
Area	-0.038	0.011	-3.469	0.005 ***
Model 2: IT ~ MajGrn + LakeEx + MajGrn:LakeEx				
Intercept	29.104	0.4	72.643	<0.001 ***
MajGrn(Complex)	-1.603	1.267	-1.265	0.241
MajGrn(Forest)	-2.746	0.567	-4.847	0.001 ***
LakeEx	-1.892	0.981	-1.928	0.090**
MajGrn(Forest):LakeEx	-0.964	1.388	-0.695	0.507
Model 3: CI ~ Area+IT+ Area:IT				
Intercept	26.903	3.674	7.322	<0.001 ***
Area	-0.053	0.069	-0.766	0.463
IT	-0.855	0.132	-6.489	<0.001 ***
Area:IT	0.002	0.003	0.748	0.474
Model 4: CI ~ MajGrn+LakeEx+ MajGrn:LakeEx				
Intercept	2.215	0.449	4.928	<0.001***
MajGrn(Complex)	0.742	1.421	0.522	0.616
MajGrn(Forest)	2.33	0.636	3.666	0.006***
LakeEx	1.248	1.101	1.134	0.29
MajGrn(Forest):LakeEx	0.622	1.557	0.399	0.7

IV. Discussion and Conclusion

This study showed that the initial temperature of GS and the cooling effect it provides differed based on its complex composition. The GS was found to be 8~13°C cooler than the study area. This lower temperature was influenced by factors such as size, a high percentage of forest, and the presence of a lake. Among the indices of cooling effect, CI increased as the size of GS increased. CI was also influenced by the initial temperature as well as a high percentage of forest. CD, on the other hand, was found to have no relationship with the size of GS or the GS composition.

The low temperature of GS could be caused by various mechanisms of GS components. The well-known mechanisms include shadowing and evapotranspiration by vegetation, as well as evaporation by water bodies. This study also confirmed that forest ratio and the existence of a lake were key factors in reducing local temperature. Specifically, the forest ratio had a greater impact on temperature reduction compared to the lake. In comparison to GS ID 6, where a lake existed, ID 8 and ID 11 were mainly covered by grass and were 1.6°C hotter than ID 6. On the other hand, ID 1 and ID 13, which had a high ratio of forest, were 1.2°C cooler than ID 6 (Figure 3). The reason why forests exert a more intense cooling effect compared to lakes may be attributed to the exposure rate of heat waves. Forests create shade, which initially blocks solar radiation and prevents the surface from warming up. This is a key factor that differentiates forests from grass (Armson et al. 2012). On the other hand, lakes absorb solar radiation to some extent, which may reduce temperature compared to urban surroundings, but not as much as trees. However, further study is necessary to clearly understand this mechanism.

CD is strongly influenced by the geometry of the city and the topography of the land. Most parts of the study area were filled with low-rise buildings; however, high-rise buildings, which are considered cooling urban structures, are also scattered in the same area. Interestingly, except for ID 8, GS with a CD of 150m was surrounded by high-rise buildings and showed different patterns in reaching the cooling distance. Those GS that have a high percentage of forest or a lake exhibit a noticeably large temperature jump between the initial temperature and the first buffer zone (Figure 3(a)). This means that the cooling effect was influenced by the surrounding area until its effects accumulated with other cooling urban factors. The effects of the surrounding area can also be observed in ID 3, which was expected to have the highest cooling distance based on its size and composition of the biotope type. ID 3 is the largest among all GS and includes a lake with a high percentage of forest. However, because it is surrounded by another forest, the distance of the cooling effect was shorter compared to other GS with a smaller size.

Noticeable fact in this research is that the initial temperature impacts CI more than the size of the GS. The effective size required to cool down the surroundings has been a subject of debate. Chang et al. (2007) argue that the park size should be at least 3 ha to provide cooling effects, while Gao et al. (2022) suggest a minimum of 29.8 ha or more strategically. In this study, the key factor in cooling effect was found to be the vegetation type within the green space, rather than its size. When comparing GS ID 4, 5, 6, and 12, which have similar CI values, ID 6 was almost 11 times larger (33 ha) than ID 4 and 5 (3 ha), and 6 times larger than ID 12 (6 ha). However, the main composition of ID 4 and 5 was forest, while ID 6 consisted of a lake. As mentioned in previous paragraphs, water has the capacity to retain solar radiation, which may lead to a slight increase in air temperatures. On the other hand, forests block or reflect solar radiation, resulting in a cooler environment. It is important to note that this result should not be oversimplified to imply that lakes have no ability to cool down their surroundings, as the temperature gap between the initial temperature and the first buffer zone was largest for the GS that included a water body (Figure 3(a)).

This study demonstrated that the cooling effect of green spaces is influenced by various factors such as composition, size, and surrounding environment. The size of GS played a role in the cooling effect, with the cooling intensity increasing as the size of GS increased. The presence of a high percentage of forest within GS had a greater impact on temperature reduction compared to the presence of a lake. Forests provided shade and blocked solar radiation, leading to a more intense cooling effect. However, lakes also contributed to a reduction in temperature, although not as significantly as forests. The cooling distance was not found to have a relationship with GS size or composition. The study highlights that the initial temperature has a stronger influence on cooling intensity than the size of GS, emphasizing the importance of vegetation type within the GS for achieving a cooling effect.

Although the power test result with p-value of 0.05 showed that effective sample size for this study should be more than 18, effective sample size with p-value of 0.1 was at least 13. Therefore, the statistical result of this paper may maintain the significance, but it is necessary to obtain additional samples with various characteristics of green space and conduct further study. The findings of this paper provide valuable insights for urban planning and the design of green spaces to mitigate urban heat island effects and enhance local climate conditions in dry-wet climate zone. However noted that the study result could not represent overall relationship between thermal condition of surroundings and green space, since the thermal variation may higly altered by climate that location of the green space. In consequence, further studies are necessary for incorporate the effects of interactions between climate condition and the neighboring land cover.

Acknowledgement

This work was supported by Korea Environment Industry &Technology Institute (KEITI) through "Climate Change R&D Project for New Climate Regime.", funded by Korea Ministry of Environment (MOE) (2022003570003). We thank to Who-Seung Lee, No Ol Lim, Hyo-jin Cho, Ji-yeon Lee ,Yoojin Shin who gave advice and useful comments to improve the manuscript.

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