Doctoral Thesis

Thermal inequity in urban heat island
:Vulnerable class near the industrial area

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(Urban Infrastructure Engineering)

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ABSTRACT

Jong-Hwa Park

Thermal inequity in urban heat island : vulnerable class near the industrial area

(Under the direction of Gi-Hyoug Cho)

Many urban heat-related studies have focused primarily on the relationship between local heat risk level and the physical environment in the field of separate studies such as urban heat island, heat wave, and health.

My thesis suggests a different understanding of urban heat issues and emphasizes the recognition of social factors in urban structure. The purpose of my study is to analysis thermal inequity of the residential area according to proximity and heat environment difference of the industrial area in the urban heat island. Moreover, my thesis found that geographical conditions such as residential area adjacent to the old industrial area is associated with the social conditions as well as thermal inequity.

The findings indicated that (1) the existence of green buffers mitigated the thermal inequity between areas adjacent and non-adjacent to old industrial areas. However, the inequality construction of green buffers in adjacent areas caused thermal inequity between adjacent regions. (2) Very-small companies were found in vulnerable built environments of a higher LST than small and medium-sized companies in old industrial complexes, so there was a relationship between the size of the company and the vulnerability to heat of the environment. (3) green buffers were found to influence the air temperature reduction of old detached housing areas adjacent to old industrial areas.

From perspective of the study, thermal inequity is determined by the planning factor rather than simply being located close to the industrial area. My thesis suggests that the existence of green buffers played a role in reducing thermal inequity between the adjacent and the non-adjacent areas. The green buffers showed not only temperature reduction effect but also improvement of heat environment in adjacent residential areas. In addition, a plan which reduces the thermal inequity should be implemented through the link with the old industrial area rather than a single environmental improvement of the residential area adjacent to the old industrial area.

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CHAPTER 1

1.1 INTRODUCTION

The rise in urban air temperature has caused public concern about heat-related diseases and mortality in densely urban areas. In Korea, the average national heatwave days in 2018 were 31.5 days, which led to the heat island phenomenon centering on large cities. The Korea Meteorological Administration (KMA) estimated that the death rate from heatwaves will increase from 0.7 people per 100,000 population in 2006 to 1.5 in 2023~2040 (Korean Climate Change Assessment Report, 2014). Heatwaves have been shown to be a high risk for vulnerable populations such as the elderly, children, and the disabled (O'Neill 2003; Uejio et al. 2011; Vanos 2015).

However, as the duration of the heatwave became longer, the heat-related illnesses occurred according to class and place apart from the biological difference. According to the report of the Korea centers for disease control (2017), the workers who work in the outdoor space with high direct sunlight exposure had the highest number of heat illnesses (34.2%), followed that the heat illnesses occurred around the residential area (26.9%). The occurrence of a heatwave in workplaces and residential areas shows a different point of view in which older people in suburban mainly revealed as heat-related victims. The point of view in the workplaces and residential areas means that people in the city may differently exposure to heat according to their lifestyle and local conditions. Notably, vulnerable social classes were more easily damaged by a heatwave. For instance, among the heat-related illnesses, vulnerable social classes receiving medical care were 10.6% and simple worker and unemployed person were 16.6% and 16.7%, respectively.

Thus, the weighted influence of heatwave on the vulnerable social class is related to the uneven distribution of heat in the urban space. Some studies have shown that regional land cover composition is a significant determinant of spatial variation in land surface temperature (LST) (Connors et al., 2013; Zhou et al., 2014). The built environment, including buildings and roads, showed higher land surface temperature(LST) than natural surfaces (Zhou et al. 2014). Physical factors influence the spatial heterogeneity of heat, but residents of a particular area are exposed differently to heat by social conditions. Ethnic minorities, low-income, and low-educated people live in more environmentally disadvantaged neighborhoods with, for example, low-accessibility at parks and public transport service; thus they experience negative health problem due to relatively more exposed to heat(Bi et al., 2011). Therefore, socioeconomically vulnerable groups experience higher LST than other groups (Buyantuyev. & Wu. 2010; Jenerette et al. 2011; Huang et al. 2011).

Moreover, social conditions can determine people's ability to mitigate and adapt on heat(Uejio et al. 2010). As those with low-income levels, for instance, can have limited access to air conditioning, to mitigating and adapting to heat exposure can be challenging for certain classes. In other words, the combination of uneven distribution of urban heat and unequal social vulnerability creates a situation of thermal inequity (Mitchell & Chakraborty 2014).

These local differences and social conditions for differential heat exposure have received limited attention in environmental justice study. The intertwining of social difference with environmental exposure in different regions is considered as a fundamental element of environmental justice (Walker, 2012). The discussion of environmental justice has revealed a correlation between the location of factories with hazardous facilities and the racial and socioeconomic factors in the surrounding area. Most environmental justice studies suggest that socioeconomically vulnerable groups have higher levels of negative environmental exposure and health damage (Mohai, p. et al., 2009; Lee, S., & Mohai, P. 2011). Because, the burden of environmental pollution was imputed to vulnerable social classes while the distribution benefits from green area decreased(Jeong, H, 2003).

The industrial area which has factories and hazardous facilities was considered for discussing environmental justice issues. Neighborhoods around the industrial area are exposed to environmental problems such as noise, air pollution, water pollution, inconvenience with traffic congestion and landscape disturbance. Despite these problems, factories and hazardous facilities with environmental problems were located closer to residential areas of vulnerable social classes such as black people. In addition, the area adjacent to the industrial area is often regarded as a residential area for vulnerable social classes, due to the incorrect location plan of the residential area(Jeong, et al., 2011).

Thus, industrial areas may not differ significantly from environmental issues related to heat. In other words, the area adjacent to industrial areas was affected by relatively negative environmental impacts and the vulnerable social classes lived in the adjacent area were more damaged by a negative environmental influence such as air pollution. In addition, industrial areas have been founded to be urban space where a productive and built environment accelerated the urban heat island effect in addition to the existing environmental problems. For instance, many UHI studies have revealed that industrial areas have higher land surface temperatures and heat island effects (UHI) in the daytime than other land use characteristics (Dousset, B., & Gourmelon, F., 2003; Li, J. et al., 2011; Chakraborty, SD, Kant, Y., & Mitra, D., 2015).

Thus, the industrial area which had been an environmental influence in the environmental inequity may create inequity in the neighboring areas even in heat environment. In the city, built environment and anthropogenic heat of the industrial area have been revealed as major region to accelerate UHI effect. Nevertheless, the study on heat environment difference according to the internal environment of the industrial area was insufficient, and there was a lack of interest in terms of the relationship between the industrial area and the surrounding area in study related to heat environment.

From the perspective of environmental justice, the residential area adjacent to the industrial area showed an environmental inequity because of environmental influence from the industrial area in addition to the lack of responsiveness and poor housing environment of the vulnerable class. In other words, health damage caused by heatwaves was being aggravated to vulnerable class, but vulnerable class living in an area adjacent to industrial areas that raise the urban heat island can be in an additional heat influence compared to other areas. Thus, the purpose of my study is to analysis thermal inequity of the residential area according to proximity and heat environment difference of the industrial area in the urban heat island.

CHAPTER 2

2.1 LITERATURE REVIES

2.1.1 Urban heat island

The Urban Heat Island (UHI) phenomenon is a by-product of rapid population growth and urban development and is attracting attention as one of serious environmental problems that negatively impacts on urban activity of citizen. On the study of urban planning, the discussion of ‘urban heat islands’ has taken place among scholars since Oke (1982) first introduced the term. Changes in the physical environment such as landscape orientation, arrangement and the layout of buildings, and an increase in artificial land cover are the leading causes of UHI. Notably, the density of streets and buildings alters radiative flux and the flow of air. An increase in the use of automobiles and air conditioner and various industrial activities emit anthropogenic heat, creating a vicious cycle of rising urban temperatures.

UHI is affected by the relative ratio of urban impervious surface to natural vegetated land covers. Artificial materials by concrete and asphalt which have a high absorption of solar radiation increased heat accumulation of land surface(Kim et al, 2011). Unlike natural surface artificial materials, which increase sensible heat and interrupt circulation water, have little no evaporation effect. As urban area develops and density increases, impervious pavement and building pavements change pervious soils and vegetation. Dimoudi et al., (2003) studied that impervious pavement limits the presence of moisture, which plays a role in moderating local air temperature.

Impervious surfaces result in environmental problems related to UHI. Zhang et al., (2011) found that for every 10% increase in impervious surface area, average minimum temperature at 5 a.m. were 0.4℃ warmer. In contrast, the vegetation such as park, tree and grass contribute to cooling are through evaporation and shade. The parks and vegetation are lower than the Land surface temperatures of impervious pavement areas (Cao, X. et al., 2010).

The average land surface temperature(LST) of the urban area showed the highest in the industrial area (33.2°C) and the lowest in the green zone (24.9°C). In the residential area, the third general residential zone was over 1°C higher than the second general residential zone(An et al. 2016). In case of industrial areas, it has the characteristics of a building designed with flat concrete or iron roof. Moreover, it has the highest surface temperature because it lacks the green zone ratio and has the large land area. On the other hand, at night time, the ambient temperature appeared higher in urban core (Rinner, C., & Hussain, M., 2011).

Moreover, Industrial areas are a region generating high anthropogenic heat. Anthropogenic heat is one of contributor in urban heat island. Anthropogenic heat which is generated from traffic congestion areas and industrial areas can increase the temperature of UHIs by 1-5 ℃ and raise the temperature around industrial areas along the wind direction (Fan, H., & Sailor, D. J., 2005). Heat generated from industrial regions plays a significant role in contributing to the local climate. Paul Coseo & Larissa Larsen (2014) reported a decrease of 0.45 ℃ in neighboring areas when the more increased by one-kilometer from industrial sites, and the downwind from the industrial area during the day showed a tendency to raise the air temperature in the surrounding area.

2.1.2 Demographic and Social conditions to heat Vulnerability

The increasing urban temperature has a negative effect on people such as heat-related health problems. Especially, those who lack of the ability to use air conditioners are not able to respond an increased heat. Several studies have identified that extreme heat exacerbated mortality and morbidity of people and decreased performance in the workplace (Singh, S. et al., 2013, Humphreys, M., 2015, Kiefer, M.et al., 2016). The regional differences of heat vulnerability are determined by mixed physical, socioeconomic, and demographic factors (Uejio et al., 2011). They have emphasized the role of socio-demographic factors such as age, race, gender, education, health and economic status (Cutter 2009; Reid et al., 2009).

Age has considered as vulnerable variable for heat-related health. The people under 15 and over 65 years were vulnerable to heat and they contribute to high temperature vulnerability due to living in declined and high-density residential areas (Buscail, C. et al. 2012, Vargo, J. et al. 2016). In particular, groups of elderly people who are economically weak with health problems are vulnerable to heat, because elderly people have a high residence rate in urban heat island.

Maras, I. et al. (2014) analyzed the relationship between community and thermal vulnerability through a survey. His study showed that people who are socially independent and those who did not own a home were more exposed to heat because they have a high proportion of living in inner cities with higher building density. On the other hand, the number of retirement communities that represent the stability of the neighborhood has a role in protecting the old people from heat stress (Uejio et al. 2011). It means that Neighborhood stability is related to conditions such as crime risk, built year, and vacant households, which interrupt people`s behavior to cope with high temperature. For instance, high violent crime rate may interrupt heat behaviors like leaving a window open overnight (Palecki et al. 2001), and old buildings and vacancies cause urban decline and a lack of heat protection facilities(Smoyer, 1998).As a result, low neighborhood stability increases the risk of heat stress and death.

Among the socioeconomic conditions, income has an important correlation with heat vulnerability. Poor people experience negative effects of heatwave, and the area in which they live have relatively a low vegetation coverage. Low-income residents were more likely to be vulnerable to heat, because they lived in old buildings without wind plan in construction. In contrast, high-income residents showed a low heat vulnerability due to improved or increased green area (Chow, W. T. et al. 2012). Residents are likely to be exposed to high heat vulnerability because of low incomes and they are in short supply and cost to turn on the air conditioner. In addition, strategies to increase green area and albedo are not very effective when they applied to low density area with low income (Mushore, T. D. et al. 2017).

Uejio et al. (2011) showed that health inequality has been found by the relative importance of socio-economic vulnerability, and heat exposure in areas suffering from heat illness and mortality. On the other hand, the strategies to reduce air temperatures such as increasing green area or surface albedo, has also been used to assess the impact of indicators related to heat vulnerability and the distribution of health benefits (Vargo, J.et al. 2016) The health benefit was clearly different in regional demographic distribution, and land cover intervention indicated that there is a difference in mitigation effect about heat risk of age, race, and income depending on the regional location.

2.1.3 Thermal inequity

a. Inequity for environmental influence

In previous study of heat vulnerability, the uneven distribution of urban heat is associated with local residential environment and social conditions such as income of the vulnerable class. Thus, urban heat may unfairly affect to a certain region and class. Likewise, inequity for environmental influence such as urban heat has been mainly dealt with in environmental justice study.

The discussion of environmental justice focused on the correlation between the location of factories and hazardous facilities, racial and socioeconomic factors of the surrounding area. According to race, class and region, environmental justice on the effects of environmental pollution damage and the distribution of benefit is defined to environmental racism, environmental injustice, and environmental inequity.

In the early 1980s, the concept of environmental justice, which raised the issue of environmental justice in the United States, emerged by environmental racism where black people were concentrated in areas adjacent to hazardous facility. In other words, blacks have systematically excluded from community of an environmental opinion decision for exposure of harmful environments(Mohai, P., & Saha, R, 2007).

Environmental injustice refers the environmental damage which impact on vulnerable class of adjacent area as the location selection of factory and the hazardous facility was not properly reflected for the opinion of local residents. For instance, most factories moved to suburban areas by post-industry, while blacks residing in urban areas migrated back to the suburbs along the factory according to a residential discriminatory policy(Massey, D. S., & Denton, N. A., 1993).

Environmental inequity is a consequence of an environmental benefit reduction to the vulnerable class by environmental influence due to urban development. Bullard, R. D. (1994) defined that minority community was suffered from discriminative location decision by unfair policies and environmental risk. Because, socially vulnerable class who is likely to access low-priced real estate is relatively excluded from the market competition for the purchase of house of good environment condition.

Moreover, low-income households are difficult to be afforded the right to demand equal rights from the characteristics of public goods that are provided differently locally due to income inequality (Jeong, Hoi-Seong & Nam, Sang-Min, 2003). In other words, environmental problems more exposed to the vulnerable social class who has a relatively limited ability to cope with environmental influence such as air pollution showed that vulnerable class did not have an equality of environmental service from green space such as the responsibility of the environment improvement and the distribution of benefit. However, it is hard to find a study that approached the inequity associated with heat in perspective of environmental justice.

b. Thermal inequity for vulnerable class

Harlan, S. L et al. (2006) was the first to emphasize the unfair exposure to urban heat. To understand the relationship between the microclimate, demographic characteristics and the heat environment of eight urban residential areas, this study investigated the health inequalities on the heat in a city area. This study points out that socioeconomic and ethnic groups have been exposed to more heat stress and have difficulties in environmental improvement.

As the followed study, Jenerette et al. (2007) showed that urban temperature varies widely depending on the social characteristics of neighborhoods. The poor neighborhoods experienced higher temperatures, and as household income increased, the land surface temperature was lower by 0.28℃.

This result shows that the ratio of green areas in a poor neighborhood is insufficient compared to other areas.

Byrne, J. et al. (2016) found that vulnerable classes such as low-income earners and trade workers in suburban areas live in dense housing areas without dark roofs and insulation and have difficulty in climate adaptation. However, residents strongly demanded urban greening. Previous studies showed that their residential area was difficult to obtain environmental benefits with the challenge of responding to environmental problems by social conditions. He suggested that thermal inequality varies by place. Soja, E. W. (2010) argued that environmental impact and geographic space are unevenly distributed in socio-economic groups from injustice based on class and race.

The increase in the heat risk by location and social condition has focused on the correlation between LST and demographic and social conditions in the study of thermal inequity. Research has revealed that demographic and socioeconomic factors such as race, population density, and income have a significant correlation with the spatial variation of LST (Jenerette et al., 2007, 2011; Buyantuyev & Wu, 2010).

In the relationship between LST and social conditions, neighborhoods with minority residents, low-income residents, low-educated residents, and older people, experience higher LST than other regions (Healy, K. 2005). Thus, the correlation between LST and social conditions shows as the effect of land cover on LST because the land cover characteristics are related to the social conditions. For instance, a high rate of green areas is associated with high-income and white residents (Harlan et al., 2008; Schwarz et al. 2015)

Some studies showed that vulnerable social classes are located in the heat-risk area from a social condition and land cover relationship (Nichol, JE et al., 2009; Rinner, C. et al., 2010; Uejio et al., 2012). Maras et al. (2014) found a high correlation between economic resource and social inequality in health. In the case of an old city center, high temperatures at night time (20h-22h) are likely to be caused by high building density and heat load. This region is unevenly affected by heat because most of the vulnerable populations often live alone.

Mitchell, BC, & Chakraborty, J. (2015) found that vulnerable social residents related to household income, home ownership, and race were distributed in the UHRI (Urban heat risk index) region in three large cities with high population density and exposure to climate change risk. In the three cities, this study found a significant statistical association that socioeconomic and ethnic minority status is low and urban heat risk is high.

Furthermore, the relationship between the factors causing thermal inequity was analyzed. Huang. G.

et al. (2016) found that social conditions, particularly race and income, affected the spatial variation of LST independently from the land cover (Figure 2.1). The ratio of trees and buildings in the land use characteristics determines the race and income of the residents. Landscapes experiencing high LST were regions low in trees and high in buildings, low in revenue and high in ethnic minorities.

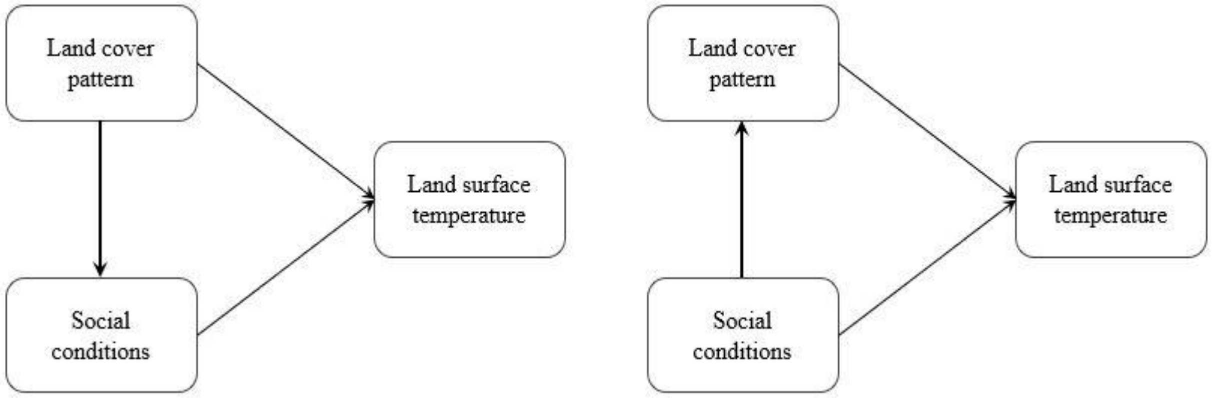


Figure 2.1 Conceptual models for the relationship between neighborhood social factors, land cover and land surface temperature from Huang. G. et al., (2016)

Areas with high house prices and high educational levels have more green areas and street trees, while regions of low income have fewer green areas and fewer street trees (N. Kabisch & D. Haase. 2014, Apparicio, P. et al., 2017). Economic factors such as income can directly affect the spatial variation of LST because they determine responsive capabilities such as utilizing and approaching air condition or performing lawn irrigation (Uejio et al., 2010). This study revealed that income and green areas were the main factors to explain of thermal inequity.

On the other hand, a few studies did not show any correlation between local characteristics and socioeconomic conditions. Jenerette, G. D., et al. (2016) showed that the symptom of heat-related illness was correlated with the daytime LST pattern in but with that of the night. Suburban areas had a relatively low intensity urban heat island compared to urban areas, but older people living in suburban areas showed higher mortality (Gabriel, K. M., & Endlicher, W. R., 2011; Madrigano, J., et al., 2015).

Studies have emphasized the need for measures to mitigate thermal inequity, and some have suggested that there is a need to reduce the inequality of access to public goods benefits through urban greening policies and planning. Policy-based research has suggested a framework for the need and strategic decision-making of green infrastructure to mitigate urban heat in relation to climate change (Gaffin, S. R., et al., 2012; Norton, B. A., et al.,2015). However, greening should be carried out in a way that avoids or exacerbates concerns about environmental inequity.

Like the previous study, the existence of green space has a positive effect on environmental improvement in many areas, but it is related to social conditions. If vegetation in the low-density area is different with income of neighborhood, the higher the income of the region, the more accumulated vegetation indices appeared (Jenerette, G. D., et al., 2013). In other words, high-income groups can reduce local heat exposure by selecting environmentally a high-quality location or by planting a green area. For instance, Lin, B. B., et al. (2017) found that built year and yard size correlated with green coverage. High-income groups better maintained green areas of yards and people with higher vegetation can benefit more from the yard through passive and active ways.

Moreover, in socio-economic conditions, urban residents perceived green areas as a factor in increased housing prices (Wolch, J. R. et al., 2014; Apparicio. P. et al. 2017) Thus, Wolch, J. et al., (2005) analyzed the differences in LA park where parks supplied by racial and income groups and found that high-income class over $ 40,000 lived in the region with 21.2% of the park per 1,000 people while under $ 20,000 was 0.5%. This result led to the establishment of park and a transportation plan and to avoid creating or accelerating concerns about environmental inequity.

However, urban greening can lead to paradoxical effects such as the local renovation of low-income housing (Wolch, Byrne, & Newell, 2014) because the public may not understand the benefits of street trees which provide environmental social and economic benefits to urban community(Jenniffer M. et al., 2014) which can trigger a negative and unexpected public reaction. Vulnerable areas can be worried about the cost of maintaining trees (Heynen et al. 2006). Agyeman, J. (2001) showed that low-income and minority group in the UK were neglected regarding living environment improvements and planning demands. As a result, construction of parks caused a rise in residential land prices and rental prices and the inevitable migration of low-income minorities.

In the domestic studies, Chu, J., (2008) found that low-income households in suburban areas have relatively high access to natural green spaces. Low-income households have been excluded from urban development projects, and moved out of suburban areas so that the proportion of low-income households has increased in areas with a high natural green space. However, it is difficult to see a natural environmental resource that is not parks or street trees according to urban planning as environmental benefit distribution. In other words, vulnerable groups have low access to ecosystem service, function, and interest of green area even though they live in the residential area with many natural green areas (Schwarz, K. et al., 2015).

Previous studies have shown that social conditions and a plan of green area are important factors in explaining thermal inequity. Because these variables are most frequently used in thermal inequity studies, this study uses demographic and resident characteristics identified as a vulnerable social class to describe neighboring social conditions.

Thermal inequity emphasizes that the relationship between land cover and social condition increases the heat risk. Since the land cover characteristics that influences the spatial distribution of heat differs according to residential areas of the social class, the residential area can be considered as mediation effect determining the relationship between land cover, social condition, and a plan of green area. Nevertheless, geographical location in existing studies of thermal inequity is focused on neighborhoods with high LST.

Perspective of environmental justice has found environmental inequity from the impact of external factors such as factories on surrounding areas. However, the study of thermal inequity has only explained the correlation between the physical environment and social conditions in a local area and has not sufficiently considered external factors in the local area.

The purpose of this study is to investigate the thermal inequity in the surrounding area and the industrial area, considered as the primary heat source in the UHI studies. My research reveals what the geographical conditions of areas proximate to industrial areas, which is a heat source in UHI, more increase the thermal inequity with the social conditions and built environment of the residential area. I extend the knowledge of thermal inequity by analyzing how a plan green existing in the local area affected the surrounding area and the thermal inequity. Also, this study evaluates difference on heat by industrial and built environment of old industrial complexes and analyzes the effect of urban planning for thermal mitigation in residential areas adjacent to old industrial areas using simulation.

To these ends, this dissertation presents three papers. The first paper (Chapter 3) examines whether the area adjacent to the old industrial complex shows thermal inequity or not and buffer green. The second paper (Chapter 4) analyzes LST difference by company size in old industrial complexes, considering the industrial and physical environment, and reveals the correlation between high LST of factory and adjacent area. The third paper (Chapter 5) evaluates the contribution of buffer green to improve the thermal environment in an old residential district adjacent to the old industrial district.

CHAPTER 3

Thermal inequity of the residential area adjacent to the old industrial area in nine cities

Keywords: *proximity of old industrial area, thermal inequity, green buffer facility, long-delayed green facility, land surface temperature*

3.1 INTRODUTION

Industrial area in urban space has been played a role as a major place for urban growth. However, industrial area provoked environmental problems such as air pollution and noise, which influence a negative effect on health of the residents. In addition, as the change of lands has extended the urbanized area, the industrial and the residential areas has near, and the range of negative impacts from industrial areas has more expanded. Previous studies on the thermal distribution of urban areas have suggested that areas with low vegetation and high building density are thermally vulnerable. In particular, industrial areas have the most vulnerable physical environment (Jusuf, S. K., et al., 2007; Radhi, H., Fikry, F., & Sharples, S., 2013).

Residential areas adjacent to industrial sites tend to have more environmental burden than other areas due to pollution, noise, harmful substances, odor, etc. coming from factories. The planned industrial area in the 1960s and 1970s was planned without the green space itself, and there was a lack of consideration of the negative impacts caused by the industrial area in the residential area planning process (Kim, J. Y. et al., 2013). As a result, various environmental problems such as noise, air pollution, landscape obstruction, and traffic congestion have occurred around the industrial area. Over time, as the infrastructure became obsolete and citizens began to recognize environmental issues as important, the value of housing around industrial areas fell. Previous studies have shown that the distance from the industrial complex has a negative impact on the value of residential real estate (Vor, F. D., & de Groot, H. L., 2011), and the decline of industrial complexes is related to the aging of neighboring areas (Son, Y. W., 2012, Jin, J. K. & Huh, J. W., 2014).

Thus, to mitigate the environmental problems occurred from industrial area, the Industrial Development Guideline established in 1991 requires that industrial areas have more than a certain amount of green buffers space around the industrial area adjacent to the residential area. As a result, from the noise, dust and air pollution generated by factories, the green buffers has mitigated the negative effect on residential areas(Cho, S. & Kim, H., 2009). However, some areas have left as long-delayed green facility for over 20 years because the green buffers was very late planned, after the industrial and residential areas have already been established. Long-delayed green facility is usually caused by lack of budget of local government which can`t carry out compensation for private property rights for a long time without a valid reason. The existence of long-delayed green facility restricts the development of the local area and decreases a land price of neighborhood.

Moreover, the neighboring area shows a poor residential environment due to no maintenance for a long time. For instance, the long-delayed urban planning facility area is illegally occupied by facilities such as junk shop and parking lots and they cause an environmental pollution with the hindrance of the urban landscape in the neighboring areas. Therefore, since socio-economically vulnerable people have no choice but to rent a cheap area in the same urban space, the area adjacent to the industrial area which has a high environmental burden is likely to be considered as one of the residential areas of vulnerable class. Besides, they may be exposed to higher heat than other areas because the area adjacent to the industrial area is located close to the negative heat effects of the industrial area. The presence of green buffers has mitigated the negative effects on the surrounding area of the industrial area, but the studies are inadequate in terms of the heat environment.

From the relationship among geographical characteristics, physical environment and vulnerable demographic and social characteristics, the purpose of this study is to examine the difference of heat environment according to the proximity and non-proximity in the old industrial area, and to reveal thermal inequity by the difference of urban planning factors such as green buffers and long-delayed green facility. The three main research questions guide thermal inequity for environmental justice. First, does the area adjacent to the industrial area have a higher heat environment than the other? Second, how do the vulnerable population and socio-economic factors affect relationship among geographic location, physical environment, and LST variation? Third, how does urban planning factors such as green buffers and long-delayed green facility adjacent to the industrial area make thermal inequity between the neighboring areas?

Figure 3.1 shows that a conceptual diagram with major hypotheses to analyze the thermal inequity according to area adjacent or non-adjacent to industrial area and presence of green buffers. The research hypotheses are based on the empirical inquiry on each research question and the contents of the previous research. Each research hypotheses summarize as Table 3.1.

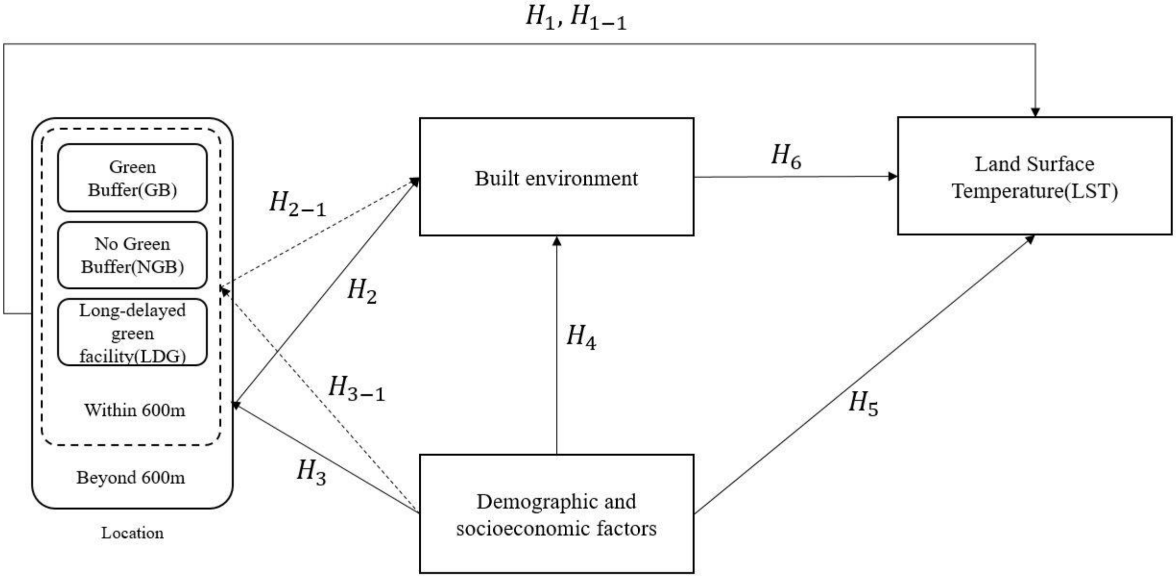


Figure 3.1 conceptual diagram to analyze the proposed research question

Table 3.1 Major hypotheses of the path model by research questions

Research questions
Hypotheses

Q1: Do areas adjacent to industrial sites contain higher heat environments?

H_1 *Areas within 600m of industrial sites contain higher LSTs.*
H_2 *Areas adjacent to industrial sites have higher vulnerable residential environment ratios.*

Q2: How do population vulnerability and other socioeconomic factors affect the relationships between geographical location, the physical environment, and LST variation?

H_3 *Vulnerable populations tend to live in areas adjacent to industrial sites.*
H_4 *Vulnerable populations tend to choose residential areas with lower housing prices that are also vulnerable to heat.*
H_5 *The higher the housing price, the lower the LST.*
H_6 *Vulnerable residential environments contain high LSTs.*

Q3: How do urban planning factors (e.g., the green buffer facility and long-delayed green facility) adjacent to industrial sites affect thermal inequity between neighboring areas?

H_{1-1} *Areas adjacent to green buffer facility have the lowest LSTs, while areas adjacent to the long-delayed green facility have the highest LSTs.*
H_{2-1} *Areas adjacent to the long-delayed green facility have high ratios of vulnerable residential characteristics, green areas, and housing prices.*
H_{3-1} *Vulnerable populations tend to reside in areas adjacent to the long-delayed green facility.*

3.2 METHODS

3.2.1 Study areas

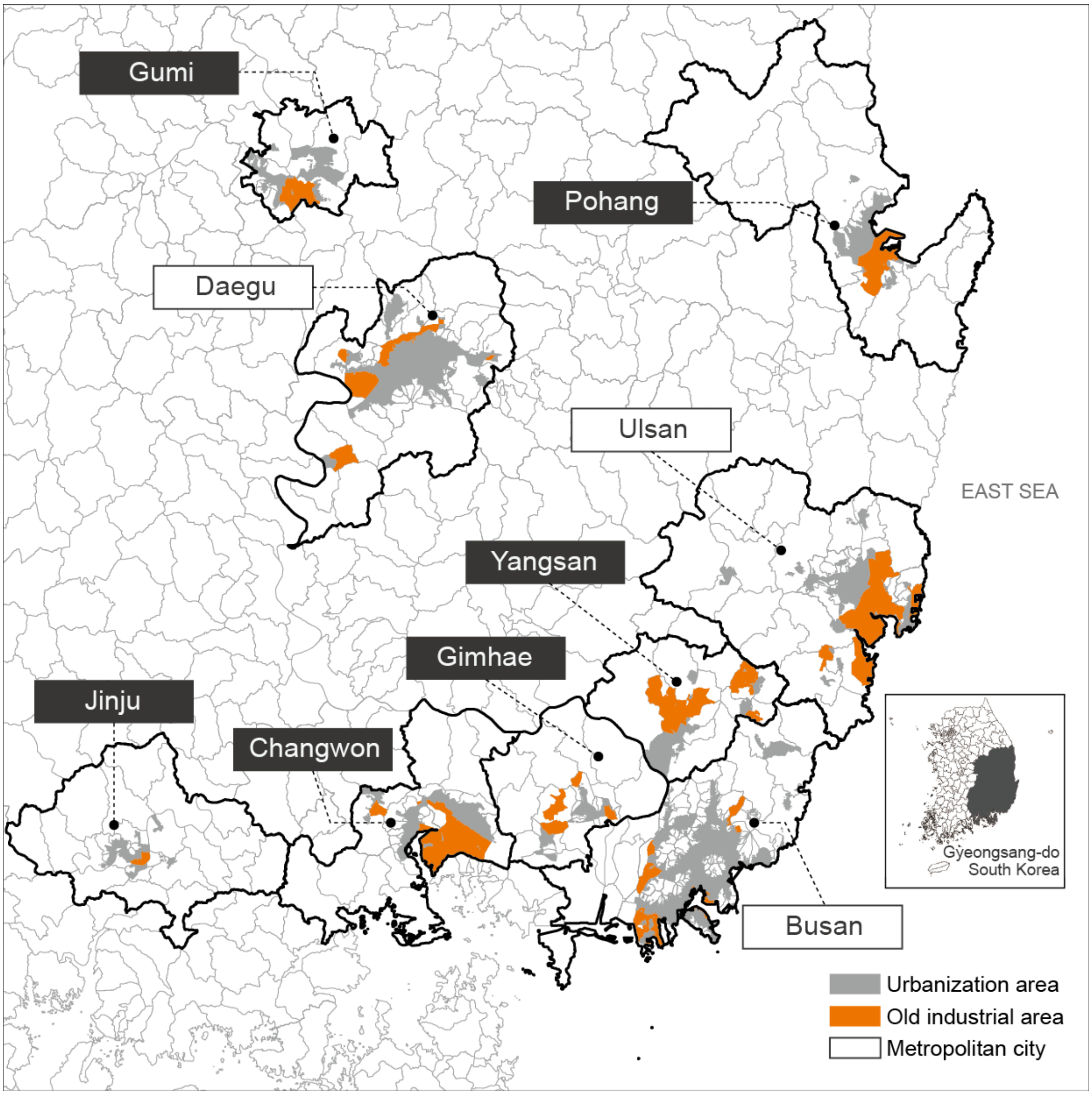


Figure 3.2 location of the old industrial complex and urbanized area in 9 cities.

The study area in this research contained three metropolitan areas and six cities located in GyungSang-do, South Korea (i.e., Pusan, Ulsan, Daegu, Gumi, Changwon, Gimhae, Yangsan, Jinju, and Pohang) (Figure 3.2). Each city has grown through the presence of major industrial developments and contains geographical characteristic similar to those seen in urbanized areas. Thus, this study focused on areas that were divided by the old national and general industrial complex built in

Gyungsang-do. The selection criteria were as follows:

First, residential areas needed to be adjacent to industrial sites. Second, cities were required to contain 300,000 or more residents. Third, cities in which old industrial complexes were built prior to 1980 were selected because local deterioration affected both internal and external factors in the surrounding areas. Areas adjacent to old industrial complexes tended to contain poor environments, low population densities, and high ratios of old buildings (Song, 2012; Jin and Huh, 2014).

The studied areas also had the following relationships between local residential zones and old industrial complexes. First, the industrial complexes were built prior to residences. However, settlements adjacent to the industrial complex were created through city expansion and the demand for residential areas near workplaces. Second, adjacent residential areas were created based on industrial complex designs. Here, the representative city is Changwon. Finally, industrial complexes were established by encroaching on existing residential areas. Here, the representative cities with general industrial complexes were Sa-sang, Shinpyeng, and Jang-lim in Busan. The industrial complexes were constructed with relatively little consideration of the residential areas, which were likely to be exposed to environmental pollution and noise.

Table 3.2 Geographical and meteorological information for the cities considered in this study

	City name	Area (km^2)	Urbanized area (km^2)	Population	Heatwave duration (days)	Avg. max. air temperature (℃)
Metropolitan City	Busan	765.82	183.89	3,440,484	5.4	29.7
	DaeGu	883.48	150.38	2,461,002	16.4	31.6
	Ulsan	1,061.18	92.89	1,166,033	10.1	30.4
City	ChangWon	743.77	79.29	1,053,551	9.1	30.6
	GuMi	615.49	33.02	422,237	12.9	30.9
	PoHang	1,129.86	47.06	510,360	9.9	29.6
	JinJu	712.95	17.69	352,807	9.9	30.7
	GimHae	463.36	24.54	532,912	14.9	30.1
	YangSan	485.45	22.95	310,731	15.3	29.6

Average Heatwave days (Aug. 2010-2017), Average Max Temperature (Aug. 2007-2017), Open weather data portal

Table 3.2 shows both geographical and meteorological information for the cities studied in this research. These cities experienced high environmental burdens during the summer. Average maximum temperatures reached approximately 30℃ (August) over a 10-year period. Heatwaves arrived at different times according to geographical location. For instance, heatwaves typically remained in Busan, Ulsan, Changwon, and Pohang (which are located in coastal areas) for approximately 10 days, while Daegu, Gumi, Jinju, Yangsan, and Gimhae typically experienced heatwaves lasting between 13-16 days. In Korea, Daegu metropolitan city experienced the highest air temperature and environmental burden during the summer. On the other hand, Busan (which had the most expansive urbanized area and the largest population among all studied cities) recorded the shortest heatwave (5.4 days).

a. *Spatial analysis unit*

The analysis unit used in this study was the census output area; the total count was 17,340. The census output area is 1/30 the size of the administrative district. This was the smallest statistical unit for which population numbers and social conditions were available. Industrial areas were used to analyze the sociodemographic characteristics and heat environments of neighboring areas. I thought this was more appropriate than the administrative district scale. Here, the considered factors were calculated as means values of census output area units.

Some census output areas were excluded from study because of location or data limitations. First, excluding urbanized areas, suburban areas had high ratios of elderly persons who were vulnerable to heat environments. This study thus only considered census output areas; these were urbanized areas remotely located from old industrial complexes. Urbanized areas were defined as zone units to represent actual urban areas that were separated from administrative areas based on population density and land use (SGIS, 2017). Second, areas without relevant data (i.e., if the value of the census output area was less than five, data were not counted) were excluded from study. Finally, census output areas within industrial areas were excluded because of concerns that they could produce overestimated adjacent characteristics.

3.2.2 Site classification according to regional conditions

a. *Neighborhoods classification according to proximity with old industrial complex*

This study used the Centroid containment method to combine (or average) a set of characteristics (e.g., population size, social demographics, and physical indicators) at specific distances from the census output area near the industrial sites (Mohai, P., & Saha, R. 2007; Lee, S. & Kwon, T., 2013). Census output areas extended 600m beyond industrial sites. any area overlapping the census output area exceeded 50% of the counting area, it was considered within 600m of the industrial area (= 1). However, if the distance exceeded 600m from the industrial area, it was regarded as non-adjacent (= 0) (Fig. 3.3, left).

b. Neighborhoods classifications within the 600m buffer zones

The studied areas were classified into three types to analyze the different heat environments among the areas adjacent to the industrial areas. These included the census output areas neighboring the green buffers (GBs), neighboring census output area to non-planned green buffer (NGB), and neighboring census output area to long-delayed green facility (LDG).

The selection process for neighboring areas of each type was the same as the method used to specify the spatial range of areas adjacent to industrial areas. For instance, after confirming a location of created or planned green buffers from land-cover data and the urban planning information system (UPIS) in Korea, the GB and LDG were selected by considering the census output area within a 600m range in a vertical direction from green buffer zone and long-delayed green facility, respectively (Fig. 3.3, right). Green areas such as parks, riversides, and small mountains were also considered as green buffers. These cases did not necessarily require green buffers because of an exception in the building code. The remaining census output areas within 600m were selected as the NGB.

Figure 3.3 Decision of adjacnet area by location condtion in the range within 600m. Proximity area on the old industrial area (left), Proximity area on Green buffers and Long-delayed green facility (right)

3.2.3 Variables

LST, physical environment, demographics, and social variables were considered when verifying thermal inequity. However, the LST data were difficult to use when explaining the influence of direct heat emanating from the industrial site to neighboring areas. This study therefore determined the physical characteristics that influenced LST to explain the different heat environments in areas adjacent to industrial sites.

a. *Land surface temperature (LST)*

This study examined five days of average LST in the census area to determine the level of thermal inequity between adjacent and non-adjacent areas to old industrial sites. The LST data were obtained from the TIRS (band 10 & 11) in the cloudless Landsat 8 image, which was suitable for analyzing the period from 18, September 2013 to 13, September 2017 (Table 3.3). The Landsat 8 satellite was launched by NASA and USGS in March 2013. It contains 11 bands consisting of nine operational intelligent sensor (OLI) bands and two thermal infrared sensor (TIRS) bands (10 & 11). The TIRS band has a suitable resolution up to 100m, but was provided as 30m pixels to match the OLI sensor data and resolution.

$$K_{\lambda n} = M_{Ln} Q_{caln} + A_L \qquad \textit{eq. 1}$$

$K_{\lambda n}$: TOA spectral Radiance (Watts /(m^2 *srad*um)

M_L: RADIANCE_MULT_BAND_n

Q_{cal}: DN(Digital Number)

A_L: RADIANCE_ADD_BAND_n

$$T_n = \frac{K_2}{ln(\frac{K_1}{K_{\lambda n}}+1)} - 273.15 \qquad \textit{eq. 2}$$

T_n : At-satellite brightness temperature(K)

K_2, K_1 : Band specific thermal conversion constant from the metadata.

K_λ : TOA spectral Radiance (Watts /(m^2 *srad*um)

I converted the TIRS band data from spectral radiance to brightness temperature using the thermal constants provided in the resulting metadata file (eq.1). The calculated surface temperature was converted to Celsius because it was measured as absolute temperature (K) (°C) (eq.2). Further information and the algorithms used during this process can be found on the US Geological Survey website. The LST data used in this study were calculated using Arc GIS 10.4 according to the following procedure.

Table 3.3 Descriptive statistics of Landsat 8 satellite image data

Date	20150604	20150807	20140905	20170913	20130918
Land cloud cover (%)	0.03	0.85	0.03	0.13	0.05
LST Max (℃)	41.3	36.4	33.9	33.5	30.8
LST Min (℃)	24.4	22.6	22.9	21.6	18.8
LST Mean (℃)	34.4	29.4	29.0	28.1	26.5

b. *Built environment in the census output area*

The physical environments of the census output area were classified into three types (Table 3.4). These included land surface characteristics, vulnerable housing environments, and housing type, which was used to control LST impact. First, land surface variables (e.g., roads, slopes, and greens) were obtained from the land cover data, while building density was provided by the national spatial data portal. Land cover variables were averaged according to the census output area units and then recalculated as a ratio by dividing them by the extent of the census output area. Green was an important indicator for reducing LST. This study therefore considered it as a major factor for explaining thermal inequality.

Second, the vulnerable housing environments were used to explain the relationship between the vulnerable social classes. As vulnerable housing environment variables, data on housing under 60m^2 or over 30 year of age were obtained from a statistic geographic information service. Houses over 30 years of age were considered old.

Third, housing types were classified into detached (including multi-family houses), multiplexes, and apartments. The Korea housing survey (2014) indicated that low-income residents usually lived in low-rise housing units containing less than five stories (e.g., detached and multi-family houses). More than half (57.6%) of all low-income residents lived in detached houses, but only 29.6% lived in apartments. On the other hand, high-income residents occupied 76.2% and 14.7% of apartments and detached houses, respectively. Apartments had lower LST than detached housing areas in the heat environment (Park. J & Cho, G., 2016). Vulnerable housing environments and housing types were determined using the statistic geographic information service (2015). The number of houses in each type was divided by the total number of houses in the census output area and calculated as a ratio.

Table3.4 Variables for census output area

Independent Variables		Descriptions	Source	Year
Vulnerable housing environment	under 60m^2 (%)	*Number of houses under 60m^2/ total number of houses in census output area*	*Statistical Geographic Information Service (SGIS)*	*2015*
	Over 30 years of age (%)	*Number of houses over 30 years of age/ total number of houses in census output area*		
Housing type	Detached housing (%)	*Percentage of detached and multi-family houses*		
	Apartment (%)	*Apartments*		
	Multiple houses	*Row houses, apartment units in private houses*		
Land cover	Building density	*Total floor area in census output area / total census output area*	*National spatial data portal*	*2015*
	Avg. Slope	*DEM data*	*Land cover (territory environmental spatial data)*	*2012-2013*
	Green area (%)	*Green area land cover / total census output area*		
	Road area (%)	*Road area land cover / total census output area*		
Population characteristics	Pop. over 65 (%)	*Population over the age of 65 (older people)*	*Statistical Geographic Information Service (SGIS)*	*2015*
	Pop. under 5 (%)	*Population under the age of 5*		
	Pop. 15 to 39 (%)	*Population aged between 15 and 39 years (the rising generation)*		
	Foreign pop. (%)		*KOSIS*	*2015*
Socioeconomic characteristics	Basic living (%)	*Recipient of national basic living ratio*	*KOSIS & government white paper*	*2013,2015*
	Single household (%)	*Single and non-family household ratio*	*Statistical Geographic Information Service (SGIS)*	*2015*
	Rented housing 2010 (%)	*Type of residence (monthly rent paid in advance, monthly rent with deposit in advance and without deposit)*		*2010*
	Housing price (10,000won/m^2)	*Average housing transaction by census area = detached housing transaction + public housing transaction*	*National spatial data portal*	*2012-2017*

c. *Demographic and socioeconomic characteristics*

Population and household characteristics for the census output area units were obtained from the Statistic geographic information service in 2010 and 2015.

Individual variables were selected from eight types to explain the different heat environments according to demographic and socioeconomic characteristics (Table 3.4). Persons over 65 or under 5 years of age were considered as part of the population vulnerable to heat. Basic living, single and rented households, and housing prices were considered vulnerable socioeconomic variables. Foreigners and persons aged over 15 and under 39 were considered workers.

The SGIS data were provided at five-year intervals. Rented household data were from 2010 because no information was available from 2015. Housing prices (2012-2017) were also provided in the SGIS data. Six-year housing price data were averaged according to census output area after the prices of detached houses and apartments were combined. Data on foreigners and basic living conditions were determined in Dong-units with larger areas than those in the census output data because census output areas did not provide them. To distribute population data according to Dong-units in the census output area, the total number of houses in the census output area were first divided by the total number of houses in Dong-units and then calculated as a ratio. The calculated value divided by the total population of the census output area was then reprocessed as a ratio.

3.3 ANALYTICAL METHODS

Figure 3.4 shows the method used to identify thermal inequity in proximity to the industrial area and green buffer.

A t-test was used to verify differences between groups according to physical, demographic, and socioeconomic variables, which were determined by geographical location and planning conditions. However, it was difficult to consider the correlation among other variables because the t-test analysis only measured the mean difference between groups. Moreover, it was necessary to analyze the impacts of physical characteristics on LST according to mediation variables (e.g., whether they were within 600m, GB, or LDG) (Figure 3.1). In addition, the demographic and social characteristics were located in high LST areas.

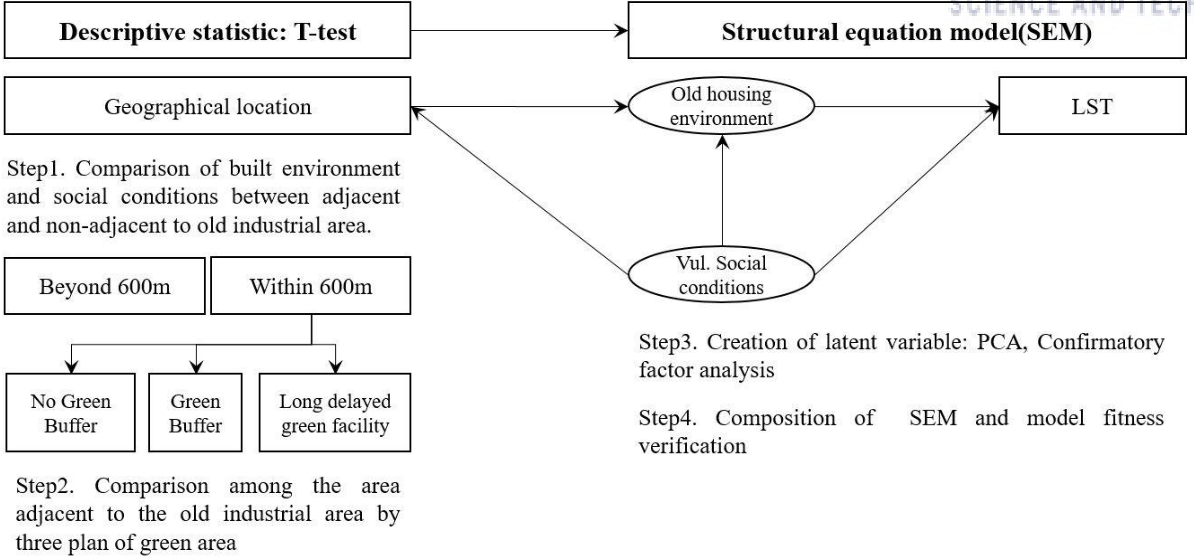


Figure 3.4. Conceptual diagram for study anaysis process

Thus, this study used structural equation modeling (SEM), which was conducted according to three mediation variables. The relationship between these variables and the proximity of the industrial areas revealed whether neighboring areas were thermally vulnerable. Thermal inequity was explained by comparing the proximity of the green buffer and long-delayed green facility.

a. *Structural Equation Modeling (SEM)*

Structural equation modeling (SEM) is an extension of general linear modeling. It allows researchers to test causal relationships between variables. These statistics cannot be used to theorize why one factor may cause another, but the effects of one factor can likely be determined (Lei and Wu, 2007). SEM was thus used to estimate complex causal relationships as well as the direct and indirect effects among the variables.

SEM was implemented using the lavaan function in the R-studio library. This was done to comprehensively explain the relationships between the individually analyzed built environments, social vulnerabilities, and LST differences. I examined the effects of the study variables on LST and found those causing thermal inequity. Model fitness was analysis through an exploratory factor analysis. Latent variables were then selected through a confirmatory factor analysis. The final model was constructed by determining the path between the variables according to the study hypothesis.

SEM fitness was also calculated. This was determined using the Goodness of Fit Index (GFI), Comparative Fit Index (CFI), Normally Fixed Index (NFI), Root Mean Square Residual (RMR), and RMSEA. The GFI, CFI, and NFI criteria were presented as good models with scores over 0.9. RMR and RMSEA were generally reported as model fitness indexes of less 0.1 (Steiger, 1990; Hu and Bentler, 1999; Genfen et al, 2000).

b. *Principal Component Analysis (PCA)*

An exploratory factor analysis includes a principal component analysis (PCA). Six variables were considered in this study's PCA, which was performed using varimax rotation (Table 3.5). If the Cronbach's alpha of the PCA is over 0.50, the model is considered fit; if it is over 0.70, it is considered reliable (Kim, K., et al., 2016). KMO test was conducted to confirm the fitness of the PCA (reliability was determined at 0.7874). Some variables were excluded from the PCA because they reduced the explanatory power of the model.

Table 3.5 PCA of vulnerable social and housing factors

Variable	Component1 (0.4825)	Component 2 (0.7874)
Pop. Over65		0.6294
Single household	0.5429	
Rented household	0.5903	
Detached house	0.3963	
APT	-0.4429	
Housing over 30 years		0.7005

Factors with eigenvalues over 1 were extracted. The two components showed an explanatory power of 78.7%. The first factor was determined according to whether the structure was a single household, rented household, detached house, or apartment (vulnerable households were detached). The second factor was determined according to the ratio of the population over 65 years old and the housing over 30 years (vulnerable populations lived in old houses).

c. *Confirmatory factor analysis*

The separate characteristics of the components were mixed as a result of the PCA. A confirmatory factor analysis was performed after the mixed factors were reclassified. Component 1 was reclassified as the population over 65 years old as well as single and rented households. Component 2 was reclassified as detached houses and houses over 30 years (apartments were excluded because they were contrary to other variables). Finally, non-latent variables were excluded and instead considered as observational variables used to explain thermal inequity.

The model was considered valid if the average variance extracted (AVE) was over 0.5 and conceptual reliability (Cronbach's alpha) was over 0.7 (Yoon, C. & Choi, G., 2015). Internal reliability was confirmed with an AVE of 0.57 and a Cronbach's alpha of 0.83. Consequently, the latent variables consisted of vulnerable social classes (populations over 65 years old and those living in single or rented houses) and descript detached housing (detached houses and houses over 30 years).

3.4 RESULTS

3.4.1 Descriptive statistics

a. Variations in land surface temperature by distance

LST was averaged over a five-day period and used to determine a proximity boundary from the industrial areas to find the heat difference between adjacent and non-adjacent areas. Arc GIS 10.4 was then used to create a buffer boundary of 1,200m at intervals of 100m from the outline of the census output area in the old industrial complexes. After the LST in each buffer area was calculated to mean value, the proximity boundary was first determined from the LST variations according to distance. As a result, Figure 2.4 shows that the average LST increased from a point measure at 200m and the highest mean LST was evident at boundaries of 400m to 500m. However, the average LST tended to decrease between 500m and 600m. I thus determined a boundary 600m as containing the area adjacent to the old industrial complexes based on results shown in Figure 3.5. Despite the proximity of the old industrial complexes, areas within 200m showed below average LST.

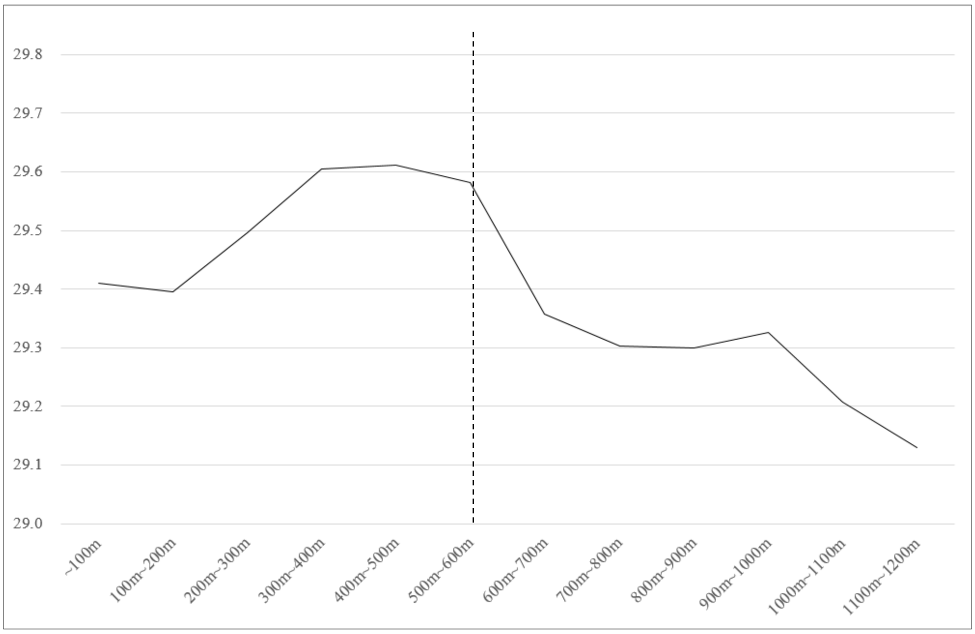


Figure 3.5 5-day average LST of the area adjacent to industrial area (100m intervals)

Table 3.6 Descriptive statistics for different built and social environments according to local conditions

	Beyond 600m buffer	Within 600m buffer			Within 600m buffer								
					GB	NGB			LDG			NGB-LDG	
Built Environment	Mean	Mean	Difference1		Mean	Mean	Difference2		Mean	Difference3		Difference4	
Physical Characteristics													
Under 60m^2	30.7	34.3	-3.6	***	35.0	33.5	1.5		22.3	12.7	*	11.2	*
Hover30Y	16.8	15.6	1.2	*	11.0	26.4	-15.4	***	29.0	-18.1	***	-2.7	
D_hou	23.9	23.0	0.9		17.5	35.2	-17.7	***	51.4	-33.9	***	-16.3	**
APT	61.9	65.1	-3.2	***	72.3	49.0	23.3	***	29.9	42.4	***	19.1	**
Multi_hou	10.7	9.2	1.5	***	7.9	12.3	-4.4	***	16.1	-8.2	***	-3.8	
Green	12.6	11.7	0.9	**	13.3	8.1	5.2	***	5.3	8.0	***	2.8	
Ave. Slope	3.6	4.1	-0.5	***	4.2	3.9	0.3		2.9	1.3		1.0	
Road	43.3	46.4	-3.1	***	48.6	41.2	7.4	***	40.2	8.4	**	1.0	
Social Environment													
Population characteristics													
Pop. over 65	11.4	9.9	1.5	***	8.6	12.9	-4.3	***	12.9	-4.3	***	0.0	
Pop. under 5	4.3	4.7	-0.5	***	5.0	4.0	1.0	***	3.5	1.5	***	0.5	
Pop. between 15 and 39	41.2	41.2	-0.0		40.9	42.0	-1.1	***	42.8	-1.9	*	-0.8	
Foreign pop.	1.1	2.1	-1.0	***	2.7	2.2	0.5	**	2.9	-0.2		-0.7	*
Vulnerable socioeconomic characteristics													
Basic living	3.2	4.1	-0.9	***	4.0	4.4	-0.4		3.5	3.1		0.9	
Single household	23.3	23.1	0.2		21.5	26.7	-5.2	***	30.0	-8.5	***	-3.3	*
Rented household	19.0	19.0	0.0		17.7	21.3	-3.6	***	32.4	-14.7	***	-11.1	***
Housing Price (10,000won/m^2)	162.1	143.2	18.9	***	149.5	130.7	18.8	***	101.3	48.3	***	29.5	***

Number of samples: n = 14,391 n = 3,039, GB(n = 2,145), NGB(n = 837), LDG(n = 57)

GB: neighborhood adjacent to green buffer facility. NGB: neighborhood adjacent to no green buffer facility. LDG : neighborhood adjacent to long-delayed green facility.

Difference 1 = *beyond 600m – within 600m.* Difference 2 = *GB-NGB.* Difference 3 = *GB-LDG.* Difference 4 = *NGB-LDG*

* $p<0.05$, ** $p<0.01$, ***$p<0.001$

b. Difference between built environments and sociodemographic characteristics according to local conditions

This study considered residential characteristics (e.g., housing aged over 30 years and housing under 60m^2) to explain thermal inequity and compared built environments between areas that were adjacent and non-adjacent to old industrial complexes using a t-test.

Table 3.6 shows the results for built environment, demographics, and socioeconomic characteristics according to local conditions. There were few differences between the built environments in areas adjacent and non-adjacent to old industrial complexes (only detached housing was not significant). For instance, the ratio of housing under 60m^2 was 34.3% in the adjacent area, while the non-adjacent area contained a ratio of 30.7%. There was a 3.6% difference between the two areas. The ratio of housing over 30 year of age was higher than 1.2% in non-adjacent area. On the other hand, the ratio of apartments was 65.1% and 61.9% in the adjacent and the non-adjacent area, respectively, while the adjacent area contained an additional 3.2%. The ratio of multi-family housing was 1.5% greater in the adjacent areas. The adjacent and non-adjacent areas showed 46.4% and 43.3% for ratios of road area, respectively (the adjacent area was about 3.1% greater). The green area ratios were 11.7% and 12.6% in the adjacent and the non-adjacent area, respectively (the adjacent area was about 1.0% less).

There were statistically significant differences between the populations over 65 and under 5 years of age, foreigners, basic living, and housing prices when looking at the demographic and socioeconomic characteristics. However, there were no differences in most of these characteristics (except for housing price) between areas. For instance, the population over 65 years of age comprised 11.4% of the total in the non-adjacent areas, while the adjacent areas showed 9.9%. There was thus a 1.5% difference between the two areas. The ratio of the population under 5 years of age, foreigners, and basic living in the adjacent areas was higher than in non-adjacent areas, but the differences were insignificant. Housing prices in the adjacent area were lower than 18.9 ten-thousand won per m^2 than in the non-adjacent areas. The adjacent and non-adjacent areas showed 143.2 ten-thousand won/m^2 and 162.1 ten-thousand won/m^2, respectively. The areas adjacent to old industrial complexes this contained higher LSTs than those in non-adjacent areas. However, it is difficult to explain why there was more vulnerability in built environments and within the demographic and socioeconomic characteristics seen in adjacent areas.

c. Differences between built environments and the demographic and socioeconomic characteristics according to the presence of green buffers, non-green buffer, and the long-delayed green facility

As shown in Figure 3.5, low LST in the adjacent areas within a 200m buffer was the result of green areas (e.g., green buffers). The presence of green buffers may reduce the vulnerable physical and social characteristics between adjacent and non-adjacent areas. Table 3.6 shows built environments and sociodemographic characteristic among the areas adjacent and non-adjacent to green buffers and the long-delayed green facility.

The ratio of green areas in the GB were 5.2% and 8.0%, respectively. This was greater than in NGB and LDG areas. The slope was not significant in all comparisons among these areas. The ratio of housing under 60m^2 showed that LDG was 12.7% lower than GB, but the difference between NGB and GB was not significant. For detached housing, LDG and NGB were 33.9% and 17.7% higher than in GB, respectively, while NGB was 16.3% lower than LDG. The ratio of APT showed that LDG was 42.4% and 19.1% less than GB and NDG, respectively; the multi-family house ratio of LDG was 8.2% and 4.4% higher than GB and NGB, respectively. The highest ratios of green areas were in GB zones, which were 5.2% and 8.0% higher than NGB and LDG, respectively. As shown in Table 3.6, the difference between NGB and LDG was not significant except for the ratio of housing under 60m^2, housing over 30 years of age, and detached housing.

The differences between demographic and socioeconomic characteristic indicated that LDG contained the lowest housing prices and the highest ratio of vulnerable social classes among all three areas. NGB and LDG showed a higher ratio of populations over 65 years of age, single households, rented households, and lower housing prices than GB zones. Populations over 65 years of age showed that GB was 4.3% lower than NGB and LDG, respectively. Foreigners, populations under 5 years of age, and populations over 15 and under 39 years of age showed few compositional differences between areas.

The single household ratio indicated that LDG was the highest (8.5% and 3.3% higher than GB and NGB, respectively). In addition, LDG was 14.7% and 11.1% higher than than GB and LDG, respectively, regarding the ratio of rented households. Housing prices showed that GBs were the most expensive areas, while LDGs were 29.5 and 48.3 ten thousand per m^2 more expensive than NGBs and GBs (the cheapest of the three areas), respectively. In comparing NGB and LDG, the ratio of populations over 65, under 5, over 15, and under 39 years of age were not significant.

3.4.2 Goodness-to-fit indices for Structural Equation Model

Figures. 3.6, 3.7 and 3.8 showed all the paths of the model with measured correlations for the area adjacent to industrial sites, buffered green and long-delayed green facility. All observed variables were shown in a square shape, while latent variables were expressed in an oval shape. Both latent variables were constructed with their observed indicator variables. The coefficient values of the models were normalized in order to be an easy comparison with each other. A positive coefficient sign implied that the independent variable was directly changed by the dependent variable. on the other hand, a negative coefficient sign was expressed using dotted lines and implied that independent variables vary inversely by dependent variables.

Table 3.7 Comparing five model fitness indices on three models

Fitness Indices	Criteria	**Model value**		
		Within600 model	*GB model*	*LDG model*
GFI	> 0.9	0.951	0.974	0.960
CFI	> 0.9	0.928	0.964	0.928
NFI	> 0.9	0.928	0.963	0.927
RMR	< 0.8	0.055	0.034	0.046

This SEM with standard estimates and significant level are provided in Figure 3.6-3.8. To verify the validity of the SEM model results and to show fitness of model, Table 3.7 showed the results of evaluating the model fit using five indices. The three models were found to meet the respective goodness-of-fit criterion. For instance, within 600m model had the power of explanatory that GFI was 0.951, CFI was 0.928, NFI was 0.928 and RMR was 0.055.

3.4.3 Results of Structural Equation Model

The SEM results showed our hypotheses and explained the relationship between multiple factors influencing LST. Moreover, green area and housing price were considered as variables to impact LST and explain thermal inequity, simultaneously.

Fig. 3.6 showed that the old detached house increased the LST and the areas within 600m showed higher LST than the areas beyond 600m. On the other hand, housing price and green area had a negative relationship with LST. In other words, high housing price and green area rate showed low LST. The housing price was considered as an intermediate variable to explain a local LST difference. The green area which reduced the LST increases the housing price, while the old detached house which increased the LST decreased the housing price. Thus, areas with high housing price had a better thermal condition and old detached house was vulnerable area on heat.

Moreover, the vulnerable social class mainly resided in the old detached house and vulnerable social class indirectly increased LST (Table 3.8). The vulnerable social class had a negative relationship with housing price and green area, which was located close to the thermal inequity condition.

However, the vulnerable social class located in areas within 600m was not in thermal inequity condition than areas beyond 600m. First, areas within 600 m had fewer old detached house, and vulnerable social classes were more resided in areas beyond 600m than areas within 600m. On the other hand, the area within 600m showed a negative relationship with housing price and green area. As a result, areas within 600 m have a relatively high LST, but vulnerable social classes indirectly had a negative relationship with LST (Table 3.8). As shown in Table 3.6, the areas adjacent to the green buffers within 600m played a role in decrease of the thermal inequity between areas within 600m and beyond 600m.

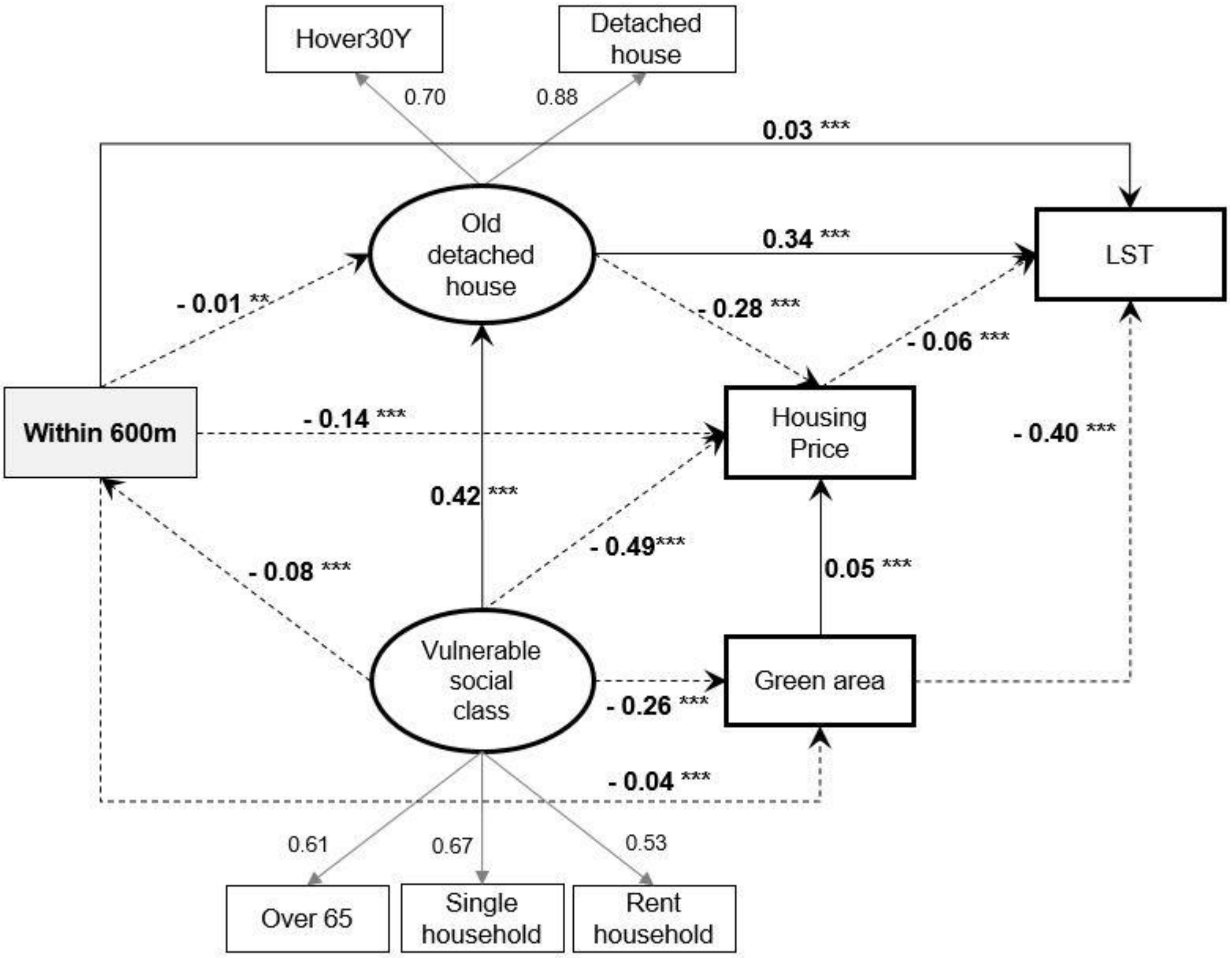


Figure 3.6 Estimates and significant level in the path diagram of Within 600m model

Table 3.8 Direct, indirect and total effect of within 600m model for LST

Within 600m Model	**LST**		
	Direct	Indirect	Total
Within 600 →(n) →	0.03	0.02	0.05
Vul.Social → Old → (n) →		0.15	0.15
Vul.social → Price → (n) →		0.03	0.03
Vul.social → Green → (n) →		0.11	0.11
Total			0.29
Vul.social → 600m→ (n) →		-0.01	-0.01

(n): old detached house or vulnerable social class or housing price or green area

a. Green buffers(GB)model and Long-delayed green facility(LDG) model results

Figure 3.7-3.8 showed the thermal inequity in areas within 600m by the planning conditions such as green buffers and long delayed green facility. Table 3.9 showed that in the GB model, the areas adjacent to the green buffers showed a directly negative LST, and vulnerable social class which do not live in GB showed a positive relationship to LST. Thus, the areas adjacent to the green buffers showed a low LST and a relatively better thermal environment under the thermal inequity condition. The areas adjacent to green buffers showed direct and indirect positive relationship with housing price and green area. On the other hand, the areas adjacent to the green buffers showed a negative relationship to the old detached house. In addition, the vulnerable social class lived more in areas non-adjacent to green buffers. In other words, the areas adjacent to the green buffers were not considered to be a residential area of the vulnerable social class, although the areas adjacent to green buffers had a relatively high housing price and green area. Therefore, the vulnerable social class lived in areas where there were no green buffers compared to the area adjacent to the green buffers.

Table 3.9 Direct, indirect and total effect of Vulnerable social class for LST, housing price, green area in GB and LDG model

Model	**LST**			**Housing price**			**Green area**		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
GB→	-0.06	-0.03	-0.09	0.01	0.02	0.03	0.16		0.16
Vul.social→GB→		0.02	0.02		-0.004	-0.004		-0.03	-0.03
LDG→	0.05	0.03	0.08	-0.03	-0.04	-0.07	-0.09		-0.09
Vul.social→LDG→		0.01	0.01		-0.003	-0.003		-0.01	-0.01

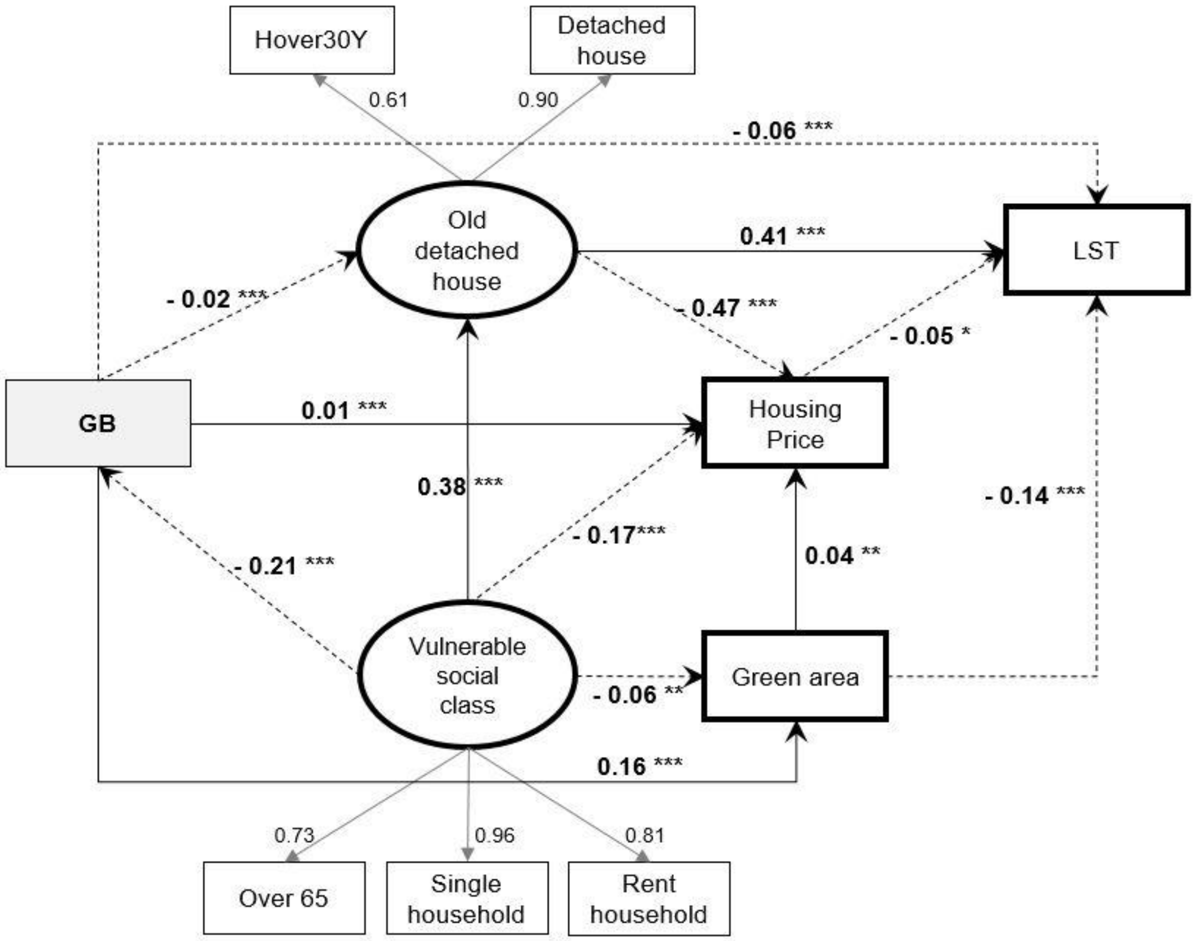


Figure 3.7 Estimates and significant level in the path diagram of GB model

The LDG model conflicted with the GB model. The areas adjacent to the long delayed green facility had a higher LST and the old detached house than the areas adjacent to the green buffers. In addition, the areas adjacent to the long-delayed green facility had a direct and indirect negative relationship with the hosing price and green area, and were considered as a residential area of the vulnerable social class (Table 3.9). As a result, the vulnerable social class was indirectly positive to LST in the areas adjacent to the long-delayed green facility(Table 3.9). In other words, the vulnerable social class who lived in the areas adjacent to the long-delated green facility was relatively affected to heat easily. Because the areas adjacent to the long-delayed green facility had a high LST but it was difficult to obtain the response ability on heat and the benefit effect of green area. Therefore, thermal inequity has occurred due to the difference of planning conditions although areas were equally adjacent to old industrial complex and showed a higher LST than areas beyond 600m.

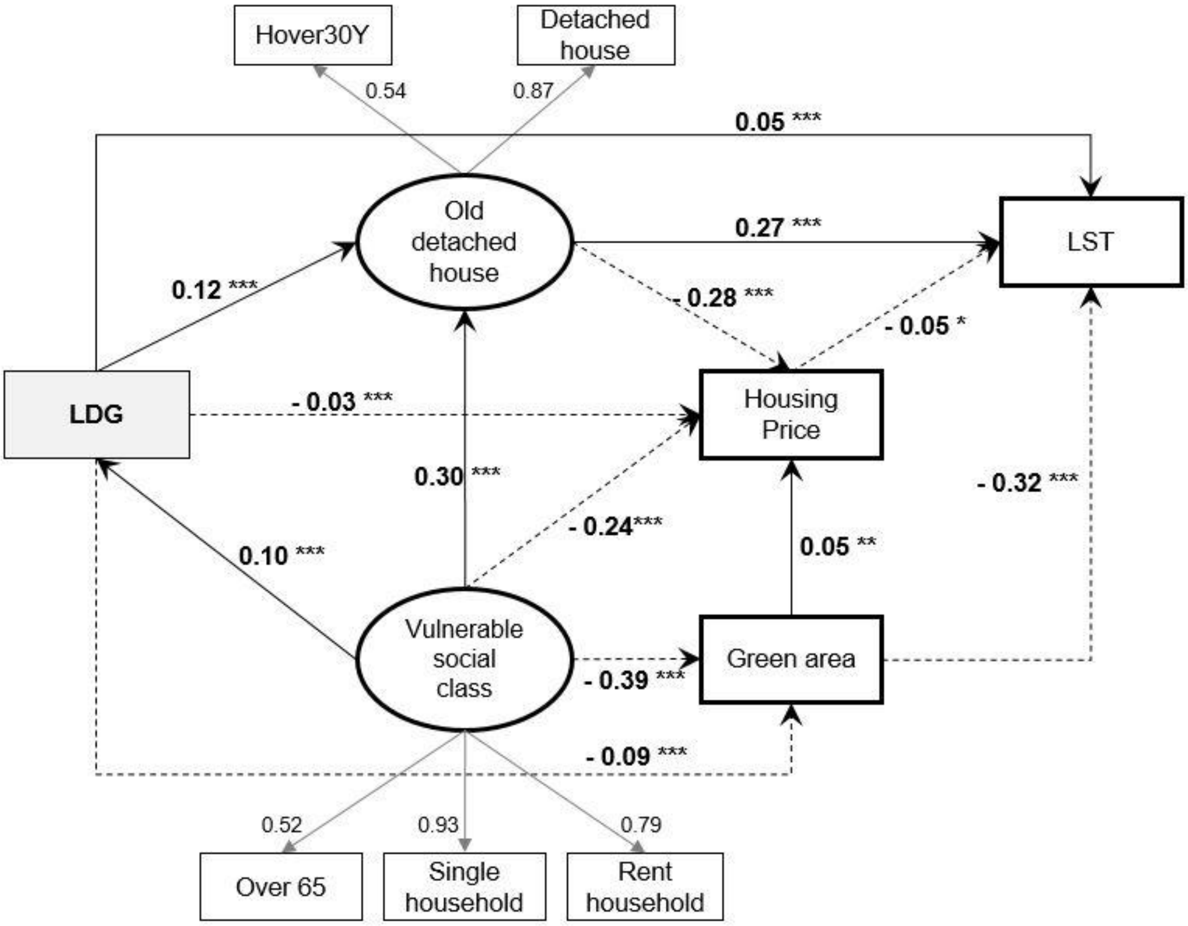


Figure 3.8 Estimates and significant level in the path diagram of LDG model

3.5 DISCUSSION

This study revealed inequity in terms of heat environments and existing environmental problems in the studied industrial urban spaces. Geographical proximity to the old industrial areas revealed an uneven distribution of LST. This enabled an analysis of whether vulnerable social classes were placed into high-heat environments. The different heat environments were also analyzed to determine whether urban green buffers and the long-delayed green facility in the areas adjacent to old industrial sites caused thermal inequity.

This study showed that local characteristics in areas adjacent to old industrial sites directly influenced LST. This explained conditions in areas adjacent to industrial sites. This also explained why areas adjacent to industrial sites contained poor residential environments. Vulnerable residential environmental factors (e.g., old detached and multi-family houses) increased LST because of high artificial surface rates, overcrowded spaces, and narrow distances between buildings (Wong, J. K. W., & Lau, L. S. K. 2013; Kim, M. & Moon, E., 2016).

Low-income classes in Korea mostly reside in residential areas containing small and old low-rise detached, public, and non-residential housing (e.g., flophouses and motels) (Hong, I., 2016). Except for public housing, vulnerable residential areas were generally of high density, lacked community spaces, and had poor parking environments. However, this study showed that the areas adjacent to industrial sites were not more vulnerable than the non-adjacent areas. This was unexpected. Nevertheless, the higher LST of the adjacent areas was a result of the relatively low ratio of green areas in the land cover.

Vulnerable social classes chose to live in residential areas adjacent to industrial sites, thus indirectly placing themselves in high LST areas. Some classes selected the areas adjacent to industrial sites due to environmental burdens. Many of these choices were made based on low housing prices and rent. The industrial areas caused a variety of discomforts (e.g., noise and environmental pollution problems, traffic congestion, and landscape obstructions) that hindered residential function in the surrounding areas (Jung, S. et al., 2011)

Although the results were relatively limited within a short distance from industrial areas, De Vor, F., & De Groot, H. L. (2011) showed a statistically significant negative impact on housing prices in the surrounding areas. Vulnerable social classes located in areas with low housing prices and a lack of green spaces experienced relative thermal inequity. In addition, housing prices independently influenced the spatial variations of LST (e.g., the range of trees and buildings). This supports the result of previous a study that showed how areas with low housing prices lacked reactional capacity, had limited air conditioning, and few green areas (G. Huang & M. L. Cadenasso, 2016). However, the areas with higher LST that were adjacent to industrial sites were not thermally unequal when compared to the non-adjacent areas.

This study found that green buffer zones created between industrial and residential areas reduced thermal inequity between the areas that were adjacent and non-adjacent to old industrial sites. After the industrial complex was established, a large-scale housing supply policy was implemented to focus on efficiency. This was supposed to solve housing problems for local workers. Many apartments were thus constructed in adjacent areas. However, green buffers were not initially planned because environmental issues were not considered during construction of the industrial complex. The buffer zones were implemented due to rising environmental interests beginning in the 1980s.

Jung, S. & Ko, S., (2010) asserted that, although the green buffers had little impact on neighborhoods when compared to parks, residents were generally satisfied with these buffers because they provided protection and helped them cope with environmental problems. Even though it is known that the adjacent areas contain bad environments, younger people considered them as places of residence due to relatively low housing prices and increased accessibility. Yang, G., (2013) showed that green areas improved residential comfort in a variety of ways (including the simplicity of greening and separation). The green buffer ratio did not appear to significantly increase housing prices. However, green buffers did contain higher prices than non-adjacent residential areas (Panduro, T. E., & Veie, K. L. 2013).

However, it is difficult to explain whether green buffers improved the physical environments of the adjacent areas or those considered relatively less vulnerable. For instance, planning and construction were not based on different social conditions. Nevertheless, areas adjacent to the green buffer had low vulnerable housing conditions, high apartment ratios, and low LST. As a result, areas within 600m and which were adjacent to the industrial area showed high LST. The environmental benefits of the green buffers thus appear to have reduced thermal inequity between the adjacent and nonadjacent areas.

Unfortunately, green areas were not constructed in all adjacent areas within 600m of the industrial sites. Some areas had already planned to implement green buffers, but development has been limited due to the long-delayed green facility. Even though all areas within 600m exhibited geographical characteristics similar to those adjacent to the industrial sites, the areas adjacent to the long-delayed green facility experienced thermal inequity.

The areas adjacent to the green buffers had lower LSTs than areas without green buffers. The areas adjacent to the green buffer had high ratios of green areas and APT, but housing prices were higher than in other areas. Such a housing environment makes it less likely for vulnerable social classes to reside in areas adjacent to green buffers. On the other hand, areas without green buffers or that are adjacent to the long-delayed green facility exhibited totally different environments. This indicated that vulnerable social classes lived in areas that were cheaper and contained backward residential environments when compared to those in areas adjacent to green buffers. It is difficult to empirically understand how the vulnerable social classes directly increased LST, but their residential areas were vulnerable to heat. Thus, vulnerable social classes who chose to live in areas adjacent to the long-delayed green facility could not receive environmental benefits despite the planned green buffer. The areas adjacent to the long-delayed green facility also exhibited the highest LST and experienced thermal inequity.

The long-delayed green facility was not discriminately created in consideration of local socioeconomic characteristics such as income or class. Areas not planned to contain green buffers were considered exceptions based on the following criteria: According to Article 18 of the Enforcement Rule of the Urban Parks and Greenery Act, the existence of other facilities similar to green buffers, areas adjacent to roads passing through city centers, and areas where the city had already been constructed [did not need such buffers].

On the other hand, areas containing the long-delayed green facility had the most significant cost problems, including land compensation. The industrial complex was planned during the 1960s and 1970s. The importance of the green area was not recognized at this time. Adjacent residential areas were then influenced by environmental problems due to plans that neglected local relationships to the settlement area. Green buffers were constructed to separate industrial complexes from adjacent areas with the later introduction of green installation criteria (Kim, J. et al., 2013). However, it was difficult to secure lands for green buffers because the existing industrial complex had already been urbanized. Despite the planned green buffer, the area containing the long-delayed green facility remained unestablished for over 20 years because of difficulties resulting from increased land prices.

This study has several limitations. First, it was difficult to use LST to explain the heat impact from old industrial areas. This is because anthropogenic heat is difficult to measure. This study therefore focused on whether the built environments in adjacent areas were vulnerable to heat caused by old nearby industrial areas. Even though the ratio of low-income classes and foreign factory workers lived close to old industrial areas, they were not considered due to limited census output data. Green buffer width was considered a major planning factor for mitigating environmental problems, but this study did not consider it. Finally, I do not know whether social conditions were considered during the green buffer planning stage.

Nevertheless, this study discovered thermal inequity within a 600m boundary of the old industrial areas and was thus able to explain the relationships between location, social conditions, and built environments. It is also important to note that the green buffers reduced thermal inequity between adjacent and non-adjacent areas and the discriminately constructed green plan. Although unintended, this was a significant step in discovering thermal inequity.

This study provides certain implications. First, it emphasizes that green buffers not only have the basic purpose of mitigating environmental problems, but can also help reduce urban heat. Green buffers placed next to heat sources can also mitigate thermal inequity. This study also found that close proximity to the industrial area indicated higher LST, but that adjacent areas may not be thermally unequal when compared to non-adjacent areas. Although not created according to local social conditions, green buffers should be prepared and supported through policy to ensure that residents in adjacent areas are not excluded from the environmental benefits. The long-delayed urban planning facility will be allowed in 2020 through the “sunset” law. This should be a priority because green buffers can reduce environmental problems not only in surrounding areas, but also throughout whole cities.

3.6 CONCLUSION

This study resulted in four major findings. First, areas adjacent to old industrial sites exhibited higher LST and were primarily occupied by vulnerable social classes, but the green buffers reduced the differences between the vulnerable residential environments in areas adjacent and non-adjacent to industrial sites. Second, areas that did not benefit from the green buffer contained poor heat environments. Third, neighboring areas without green buffers were occupied by vulnerable social classes because of low housing prices. Fourth, the long-delayed green facility resulted in the continued construction of a poor residential environment in the adjacent areas, which forced vulnerable social classes to live with thermal inequity.

These findings imply that the green buffers played a significant role within the 600m boundary. That is, they reduced thermal inequity between the areas that were adjacent and non-adjacent to the old industrial sites. In contrast, the long-delayed green facility reduced environmental benefits in the adjacent areas to the industrial sites when compared to the areas adjacent to green buffers. This contributed to thermal inequity.

CHAPTER 4

Evaluating heat environments according to company size in the old industrial complexes through a consideration of industrial and built environments

Keywords: old industrial complex, heat environment, company size, small land parcel, industrial environment

4.1 INTRODCUTION

The industrial complex was constructed during the 1970s and 1980s. It led to local economic growth in Korea and increased the growth rate of each city. Many residential areas were therefore needed, and thus expanded into the areas adjacent to the industrial complex. However, the industrial complex contained problems such as traffic congestion, environmental pollution, lack of infrastructure, and deterioration that negatively affected nearby cities. An urban heat island then resulted from climate change. Here, the industrial area was revealed as one of the contributing heat sources. People are deeply worried about these urban problems.

Young people and workers engaged in manufacturing and outdoor industries are suffering as a result of these changes. The Korean Centers for Disease Control & Prevention (KCDC) reported that a total of 4,526 people suffered heat-related illness in 2018. Of these incidents, 48 resulted in death. This is the highest rate since the surveillance system was introduced in 2012. High proportions of children and elderly live in these areas (30%), followed by the unemployed (18%), and manufacturing workers (16%).

Many studies have analyzed urban development activities that contribute to the rising urban heat island effect. Several studies have shown the diverse impacts of land use on urban temperature. Commercial and industrial areas with dense populations engaged in land use showed a high LST (43° C in summer) (Jusuf, S. K., et al, 2007). Industrial areas have especially poor physical environments with low NDVI and high building-coverage rates (Kim, J. et al., 2015). These areas also have high heat flux values due to large amounts of energy consumption (Chakraborty, S. D., et al., 2015). Industrial areas contain the highest LSTs where there is little vegetation in surrounding free space areas (1%), and the lowest LSTs in "green" areas (Rotem-Mindali, O., et al, 2015). Industrial areas also contribute to high temperatures and LST in urban areas because they generate significant heat.

Increased urban heat is aggravated by climate change. It has worsened the thermal environment in manufacturing workplaces and decreased productivity (Kjellstrom, T., & Crowe, J. 2011). The old industrial areas are more vulnerable to rising temperatures due to poor physical conditions. The old industrial complex exhibits deterioration due to the division of land parcels into smaller areas and changing occupancy types. Since the International Monetary Fund (IMF) has been active in Korea, industries requiring large-scale parcels have moved or gone bankrupt. Small and medium companies have thus begun to occupy large land parcels (Song, J. 2008; Kang, H. 2009). As a result, the proportion of small companies involved in Korea's manufacturing industry has steadily increased, moving from 86.7% in 2005 to 94% in 2017 (Bae, et al, 2017, Open data portal, 2017).

This increasing cluster of very small companies has led to several problems, such as a lack of parking spaces and increased demand for limited support facilities. Land prices have also risen because the old industrial complex is adjacent to the city center. Existing companies have thus begun to lease factories, thereby increasing the number of small businesses. The 2017 Survey of Small and Medium Business indicated that the lease ratio of medium companies was 16.7%, while the rate for small companies was 29.0%, and 50.3% for very small companies.

Unlike the general public, industrial workers are exposed to stronger heat for longer periods (Tawatsupa, B. et al., 2010). Even though workers are engaged in the same type of industrial work, the deterioration of the industrial environment and the rise of urban temperatures as a result of climate change may lead to different levels of high heat exposure depending on company size and physical environment. In Korea, the average wage level according to company size revealed big differences; very small companies registered at 242.8 thousand won, while small and medium companies registered at 319.5 thousand won, and large companies registered at 589.9 thousand won (Employment Labor Statistics, 2017). This led to different industrial accident rates (i.e., 1.24% for very small companies and 0.27% for large companies).

Industrial areas are major sources of urban heat. While many workers have engaged in such work for long periods of time, few studies have conducted micro-scale analyses of the thermal differences by considering the physical and industrial environments of the old industrial complex. Despite the relationship between the external and internal factors of these industrial areas, their characteristics were not considered during attempts to explain thermal inequality. It is therefore necessary to identify vulnerable heat environments within these industrial areas in addition to analyzing whether vulnerable social classes and vulnerable physical environments are located in the adjacent areas by considering the external factors.

This study analyzed different heat environments among equal buildings (EQB) according to company size. This was accomplished by considering the industrial and physical characteristics of EQBs to reveal thermal inequity in adjacent neighborhoods, where vulnerable characteristics seem to result in high LST.

I. Do equal buildings (EQBs) occupied by very small companies in vulnerable heat environments differ compared to EQBs occupied by companies of other sizes?

II. Are LST differences the result of EQB size (i.e., smaller EQBs exhibit higher LST)?

III. What relationship does high LST in EQBs located in the old industrial complex have with vulnerable physical and sociodemographic characteristics in neighboring areas?

4.2 METHODS

4.2.1 Study area

This study focused on old industrial complexes, which were selected according to the presence of structurally advanced and regenerative businesses among the study areas considered in Chapter 3. A structurally advanced and regenerative business indicates the need for environmental improvements to solve problems such as low productivity and high physical backwardness. The Korean government has promoted regenerative business to recover the functions of the industrial complex for approximately 20 years. It has designated four target cities since 2009.

Table 4.1 State of the old industrial complex in 2017

City	**Industrial complex name**	**Area (1,000m^2)**	**Worker**	**Major industry type**	**Very small/Small company (%)**	**Num. of operating / Moving companies**
DaeGu	*SeongSeo(1st~3rd)* *(1965)*	10,766	48,603	Machine metal, Textiles	40.6%/52.2%	2,574/2,595 (99.2%)
	West-DaeGu *(1975)*	2,662	14,670	Textiles, Machine metal	57.7%/37.8%	2,360/2,360 (100%)
	Dyeing *(1980)*	846	5,639	Textiles	15.3%/50.0%	123/125 (98.4%)
	DaeGu-3rd *(1967)*	1,679	12,693	Machine metal, Transportation equipment	58.9%/40.0%	2,535/2,535 (100%)
Busan	*SinPyeong·JangLim* *(1980)*	2,815	15,485	Machine metal, Textiles	22.8%/62.8%	569/630 (90.3%)
	SaSang *(1968)*	3,021	-	Machine metal	54.3%/42.4%	2,284/2,284 (100%)
Ulsan	*Ulsan·Mipo national* *(1962)*	48,444	95,818	Petrochemistry, Vehicle manufacturing, Other transport equipment	27.7%/48.6%	758/883 (85.8%)
Chang Won	*ChangWon national* *(1974)*	35,435	126,537	Machine metal, Electronics	35.9%/54.4%	2,603/2,855 (91.2%)
GuMi	*Gumi national 1rd* *(1973)*	10,223	91,360	Textiles, Electronics	23.9%/64.9%	1,889/2,224 (84.9%)
JinJu	*SangPyeong* *(1977)*	2,135	7,744	Machine metal	61.5%/35.1%	515/515 (100%)

※ Very-small /small company rate: Factory enrollment data(2017)

This study examined old industrial complexes that were adjacent to urbanized areas located in Daegu, Busan, Ulsan, Gumi, Jinju, and Changwon. Table 4.1 summarizes the current state of old industrial complexes according to study area. These target areas were built between the 1960s and 1980s. The Dyeing industrial complex in Daegu spans the smallest area (0.846km^2), while the Ulsan-Mipo industrial complex spans the largest (48.444km^2). The Dyeing industrial complex in Daegu had the smallest number of workers (5,639), while Changwon national industrial complex had the largest (126,537). The major industries were those engaged in machine metal, textiles, transportation equipment, vehicle manufacturing, electronics, and petrochemistry.

Among all companies located in the industrial complex, Gumi (84.9%) had the lowest operating rate, followed by Ulsan (85.8%) and Changwon (91.2%). The national industrial complex mainly exhibits low operating rates. Approximately 90% of all companies in the complex were small. Over 50% of all very small companies were located in Daegu (58.9%), followed by West-daegu (57.7%), Sasang (54.3%), and Sangpyeong (61.5%). Very small companies are present at high rates in the general industrial complex when compared to the national industrial complex.

4.2.2 Analysis method and spatial analysis unit

This study analyzed EQBs in the old industrial complex to determine the thermal environment on a micro scale. EQBs comprise two or more buildings. One EQB must provide a street address under article 8, section 3 (Road name address, 2017). An EQB is defined according to the following criteria:

I. The main building and wing are in one building group.
II. It is zoned as one group surrounded by a fence or wall.
III. It must be publicly registered as one building or building group.

This study investigated the EQB environment, industrial characteristics, and the built environment. Several factories that were obtained from the factory enrollment data used in this study were not classified as EQBs because they were not defined as belonging to one group. I thus complemented the dataset with land parcel data that were taken from the national spatial data portal. Some of these data had been excluded from the EQB list. Variable industry characteristics and information on built environments were obtained through the building register data and factory enrollment status data using the spatial join feature in Arc GIS 10.4. However, several EQB data were excluded because some built environment and industry characteristic data were omitted. Finally, 5,854 samples were used in this study.

4.2.3 Variables

a. Equal Building (EQB) Environment

Table 4.2 shows the variables used to examine the relationship between LST and the EQB environment (e.g., EQB characteristics, industrial characteristics, and the built environment). The industrial complexes were built in both coastal and interior regions. Geographical location was therefore considered a factor related to urban heat (Jusuf, S. K., et al., 2007; Kolokotroni, M., & Giridharan, R. 2008). Using Arc GIS 10.4, I thus calculated EQB distance to urbanized and coastal areas. EQB area was also used to examine this study's secondary hypothesis.

b. Industrial characteristics

The industrial characteristics of EQBs were obtained from factory enrollment data (2017) that was provided by the open data portal (Table 4.2). This included individual factory location, company size, and industrial environment characteristics. Company size was classified as small, medium, or large according to the number of workers. That is, large companies contained more than 300, medium companies contained between 50 and 300, and small companies contained less than 50.

A very small company is generally defined as employing less than five workers, but this was raised to 10 for the manufacturing industry (SME statistics, 2017). Thus, very small companies were considered for examination in EQBs when they contained less than 10 workers. In addition, the considered industrial characteristics included air pollution and number of workers.

Workers engaged in the manufacturing industry are exposed to a variety of dangerous environments and hazards, including high temperatures, steam, and chemicals. There are different exposure intensities according to the manufacturing process and industry type. For instance, workers in a steel manufacturing plant are likely exposed to high temperatures and steam.

This study therefore considered high temperature exposure as part of the physical working environment factors included in the Korea Working Condition Survey (KWCS) data (2014). These data have been obtained from the overall working environment according to occupation and business type for employees over 15 years of age every three years since 2006. Manufacturing workers in indoor and outdoor facilities are also exposed to different work intensities depending on occupation (e.g., manager or simple laborer).

Table 4.2 The environmental variables of equal buildings (EQBs)

Variables	Unit	Calculation	Source
Equal buildings (EQB) characteristics			
EQB area	km^2		*Road name portal & National spatial data portal, 2017*
Distance to urban area	*km*		*National spatial data portal, 2017*
Distance to sea	*km*		*Territory environmental spatial data,* 2012-2013
Industry Characteristics			
Number of workers	*people*		*Open data portal, 2017: Factory enrollment data*
Company size	*dummy*	1: Very small, 2: Small, 3: Middle, 4: Big	
Air pollution exhaust	*dummy*	Total amount of air pollution emission = 0: None, 1: under 2ton, 2: 2~10ton, 3: 10~20ton, 4: 20~80ton, 5: Over 80ton	
Avg. high temperature exposure score	*score*	Throughout working hours: 6, Almost all working hours: 5, Working hours 3/4: 4, Half of working hours: 3, working hours 1/4: 2, Almost no exposure: 1, Never exposure: 0	*the Korea working condition survey, 2014*
Built Environment			
Floor area ratio	*%*	Total floor area / EQB area * 100	*Private open system of building data, 2017*
Built coverage ratio	*%*	Built coverage area / EQB area * 100	
Avg. building Height	*m*		
Avg. built year	*year*	2017 – built year	
Green area	*%*	Green area / EQB area * 100	*Territory environmental spatial data,* 2012-2013

The high temperature score was calculated based on a middle industry classification. This was done to compare high temperature differences among EQBs. According to KWCS data, high temperature exposure levels are classified according to the level of exposure experienced during all working hours, half of all working hours, and no exposure. In this study, high temperature exposure levels were assigned on a scale ranging from 0 to 6. For instance, exposure during all working hours scored 6 points, while no exposure scored 0 points. This study thus identified that higher LST was present in EQBs with higher temperature exposure scores.

c. Built environment

Building characteristics were obtained from the building register data provided by the private open system for building data. The building register data contained information on individual buildings, including area, structure, and location. This study used building coverage ratio, average height, and average built year for examination. Building coverage and floor area were calculated into ratios by dividing EQB area. Building height was an average of all buildings in a given EQB. Built year indicated old level factories and was calculated as an average value of all buildings present in 2017 minus the built year of a given building.

Green area ratio was calculated by dividing the green area created in the EQB by the EQB area. There were certain criteria for green areas in industrial complexes. Integration guidelines suggested that green area size should be determined according to the size of the industrial complex (a minimum of 5% to a maximum of 13%; the minimum area of any public green should be over 500m^2) (The national low information center, 2017). There were also building codes. Landscaping was required if the land parcel area was over 5,000m^2. Thus, EQB green area data were extracted from areas where greens were included in the EQB land cover as provided by the Environmental spatial information system.

d. Housing, demographics, and neighborhood social characteristics of areas adjacent to EQBs

The neighborhood characteristics of areas adjacent to industrial complexes included the variables listed in Chapter 3. These variables explain the relationship among EQBs with high LSTs and the vulnerable physical, demographic, and social characteristics of neighboring areas. However, these characteristics were calculated into averages based on individual EQBs because many neighborhoods typically surrounded one EQB.

Moreover, if values were calculated into usual averages, they were very likely to be underestimates.

For this reason, the neighborhood characteristics of adjacent areas to individual EQBs were calculated into weighted average values in consideration of their distance from a given individual EQB using Excel.

Weighted values were allocated to each neighborhood at 100m intervals based on EQB location. For instance, areas within a 100m distance were assigned the number 5, while areas more than 400m away were assigned to Areas that were extracted to within a 500m buffer of each EQB using Arc GIS 10.4. Any EQB that was not adjacent to a neighboring area within a 500m buffer boundary was excluded. A total of 3,393 EQBs were finally extracted.

Demographic and social factors included populations over 65 and under 5 years of age, foreigners, basic living, rented households, single and unrelated households, and housing transaction prices. Physical factors were also considered for housing of less than 60m^2 or over 30 years of age to determine the existence of poor residential environments. Detached housing and APT were included as housing types. All factors were calculated by ratio except housing transaction price data.

4.3 RESULTS

4.3.1 Descriptive statistics

Table 4.3 shows the results of the descriptive EQB statistics according to company size. EQB environments as determined according to company size were divided into 3 categories (i.e., EQB characteristics, industry characteristics, and built environment).

Number of workers was used to determine company size. Very small companies contained an average of 4.9 workers, but could contain up to 9. Small companies contained a maximum of 99 workers (22.4 on average), while medium companies contained a maximum of 298 workers (108 on average). Large companies contained a maximum of 4,100 workers (1,438.9 on average). However, the minimum number of workers in large companies was similar to that seen in small companies. Some large companies contained other small factories within the industrial complex.

For EQB characteristics, EQBs with extensive areas indicated that the contained company was larger. Large companies used a maximum of 4.255km^2 (an average of 0.249km^2), while medium companies used a maximum of 0.161km^2 (an average of 0.021km^2). On the other hand, small companies used a maximum of 0.161km^2 (an average of 0.004km^2), while small companies used0 a maximum of 0.009km^2 (an average of 0.001km^2).

Table 4.3 Descriptive statistics according to company size, equal building (EQB) environment, industry characteristics, and built environment

	Company Size															
	Very Small (n= 2,121)				*Small (n= 2,756)*				*Medium (n=861)*				*Large (n=116)*			
Variable	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Equal building (EQB) characteristics																
Equal building area (km^2)	0.001	0.001	0.0001	0.009	0.004	0.007	0.0001	0.161	0.021	0.046	0.0001	0.613	0.249	0.583	0.0021	4.255
Distance to urbanized area (km)	0.5	0.5	0	3.2	0.6	0.6	0	4.2	0.7	0.6	0	3.9	0.7	0.9	0	3.7
Distance to sea (km)	16.6	28.4	0.02	90.9	24.2	33.7	0.02	90.9	28.6	35.6	0.01	90.9	29.9	38.0	0.01	90.3
Industry characteristics																
Number of workers (people)	4.9	2.6	0	9	22.4	11.1	1	99	108.0	58.8	2	298	1438.9	4507.2	5	41059
Air pollution exhaust	0.11	0.5	0	5	0.17	0.6	0	5	0.54	1.2	0	5	1.13	1.8	0	5
Heat exposure score	1.48	0.3	0.8	2.2	1.45	0.3	0.8	2.2	1.40	0.3	0.8	2.2	1.30	0.3	0.8	2.2
Built environment																
Built coverage (%)	65.3	13.8	7.9	99.2	63.7	16.1	3.2	99.7	60.9	18.7	3.7	98.6	50.6	22.1	1.9	89.0
Total floor area (%)																
Avg. built year	20.1	11.4	0	49.0	19.6	10.7	0	61.3	19.2	9.5	0	45.0	18.9	8.4	0	42.0
Green area (%)	0.1	1.4	0	37.2	1.1	4.7	0	58.8	4.0	8.2	0	71.6	13.2	15.7	0	72.0

For geographical location, old industrial complexes in Korea are typically located adjacent to urbanized or coastal regions. There was almost no difference in distance related to company size because most old industrial complexes considered in this study were close to urbanized regions.

On the other hand, distance from the coast revealed differences depending on company size. These differences were based on the city in which the industrial complex was built. The average distance of a very small company was 16.6km, which was closer than other company size. The average distances of medium and large companies to coastal areas was 28.6km and 29.9km, respectively; they were 12.0km and 13.3km further from coastal areas than very small companies, respectively.

The smaller the company size, the higher the built coverage ratio of the built environment in the EQB. Very small and small companies had averages of 65.3% and 63.7%, respectively. The medium company average was 60.9%, while large companies revealed the lowest average of 50.6%. Total floor area ratio was highest at 101.4% for medium companies, and lowest at 84% for large companies. Very small and small companies revealed averages of 93.1% and 95.7%, respectively. The floor area ratio was higher when apartment-type factories contained several companies. The average building height was 8.6m to 9.8m when factory work was performed indoors; factory heights were meticulously planned. Very small companies had the highest average age (20.1 years), while large firms had the lowest average age (18.9 years).

The smaller company size, the lower ratio of green area. Large companies had an average green area ratio of 13.2%, while very small companies had an average of 0.1% (a difference of 13.1%). Medium and small companies showed averages of 4% and 1.1%, respectively. Compared with large companies, green areas seemed to be 9.2% and 12.1% smaller, respectively. Even when considering maximum green area ratio, very small companies showed 37.2%, while large companies showed 72%. This was a significant difference.

4.3.2 Result of Multiple Regression Model

Table 4.4 showed the results of relationship between the LST and the EQB environment of the industrial complex. The r-squared value in multiple regression of model was 0.7274. The LST was lower as the EQB area was larger. The LST decreased by 0.7 °C as the building area increased by 1 km^2. The LST increased as distance from the urbanized and the coastal areas. In the industrial characteristic, the temperature exposure score showed a positive relationship with the LST and the exhaust of air pollution was not significant.

Table 4.4 Multiple regression model result

	Model 1(n=29,265)			
Land Surface Temperature	Estimate	Std.Err	t	sig.
EQB Environment				
EQB_Area	-0.732	0.133	-5.5***	
Distance to urbanized area	0.118	0.020	5.9***	
Distance to sea	0.014	0.000	38.4***	
Industry Characteristics				
Heat exposure score	0.293	0.048	6.2***	
Air pollution	-0.014	0.015	-0.9	
Built Environment in the EQB				
Total floor area	-0.005	0.000	-20.7***	
Building coverage	0.023	0.001	28.3***	
Ave. Built Year	0.006	0.001	5.7***	
Green space in EQB	-0.025	0.002	-11.1***	
Company Size				
Very small				
Small	-0.222	0.025	-9.0***	
Medium	-0.255	0.036	-7.1***	
Large	-0.023	0.090	-0.3	
Industry type				
Petrochemistry & textile	-0.418	0.046	-9.0***	
Electrical & electronic				
Machine & transportation & metal	-0.056	0.046	-1.2	
Etc.	-0.488	0.049	-9.9***	
Day				
Jun.4, 2015	8.633	0.035	250.2***	
Aug.7, 2015	1.605	0.035	46.5***	
Sept.5, 2014	2.934	0.035	85.0***	
Sept.13, 2017	1.841	0.035	53.4***	
Sept.18, 2013				
*Cons_*	29.101	0.083	350.8***	
R-square		0.7274		

** p<0.05, ** p<0.01, ***p<0.001*

In the industrial characteristic, the higher the high temperature exposure score, the higher the LST, but the air pollution emission was not significant. As the high temperature exposure score increased by 1 point, the LST increased by 1℃. In other words, the positive relationship between the high-temperature exposure score and the LST indicated that the working environment of the worker was in a poor heat environment, internally and externally. In the building environment, as the building coverage and built year were increased, the LST was decreased, while as the total floor area and green space increased, the LST decreased. Petrochemistry & textile and etc. in industrial types were lower than electrical & electronic by about 0.4℃. On the other hand, machine & transportation & metal industry was not significant.

By controlling previous variables, the LST difference by company size was founded. Very small company which have the most vulnerable working environment showed the highest LST. Compared to the very small company, the small company was lower about 0.2℃ and the medium company was lower about 0.3℃. Large company did not significant.

4.3.3 Correlation between the LST of the EQB and adjacent areas.

Table 4.5 showed the correlation between the LST of the EQB and the demographic and social characteristics of the area adjacent to the old industrial complex. In terms of population and social characteristic, foreigner, basic livelihood recipient, single and rent household showed a positive correlation with the LST. In the housing environment, housing under 60m^2 and housing over 30 years showed a positive correlation with the LST. In particular, rent household showed a strong correlation coefficient of 0.35. However, population over 65 and under 5, detached house, and APT were not significant. Green area and housing price showed negative correlation with LST.

As a result, areas adjacent to the high LST of the EQB relatively presented vulnerable housing types and vulnerable social classes who except for the population over 65 and under 5 located close to areas adjacent to the high LST of EQB. In addition, the respectively negative correlation between the LST of EQB and green area and housing price showed that the adjacent to the old industrial complex had a thermal inequity condition.

Table 4.5 Correlation between the LST of the EQB and housing environment, demographic and social characteristics of areas adjacent to old industrial complex

	LST	Over65	Under5	Forg	Basic	H_price	Single	Rent	Under60m^2	Over30Y	Green	D_hou	APT
LST	1												
Demographic and social characteristics													
over65	-0.03	1											
under5	-0.01	-0.68 ***	1										
Forg	0.17 ***	-0.20 ***	0.15 ***	1									
Basic	0.07 ***	0.38 ***	-0.32 ***	-0.12 ***	1								
H_price	-0.25 ***	-0.28 ***	0.28 ***	-0.10 ***	0.09 ***	1							
Single	0.08 ***	0.12 ***	-0.41 ***	0.36 ***	0.05 **	-0.18 ***	1						
Rent	0.35 ***	-0.02	-0.17 ***	0.16 ***	-0.05 **	-0.71 ***	0.09 ***	1					
Housing environment													
under60m^2	0.13 ***	-0.01	0.02	0.31 ***	0.01	-0.26 ***	0.08 ***	0.21 ***	1				
over30Y	0.13 ***	0.57 ***	-0.40 ***	0.29 ***	0.20 ***	-0.11 ***	0.43 ***	-0.05 **	0.05 **	1			
Green	-0.11 ***	-0.21 ***	0.12 ***	-0.15 ***	-0.29 ***	0.01	-0.03 *	0.06 ***	0.09 ***	-0.34 ***	1		
D_hou	-0.01	0.52 ***	-0.52 ***	-0.07 ***	0.10 ***	-0.20 ***	0.47 ***	0.03	-0.43 ***	0.47 ***	-0.12 ***	1	
APT	0.03	-0.57 ***	0.60 ***	0.15 ***	-0.15 ***	0.23 ***	-0.48 ***	-0.06 ***	0.38 ***	-0.46 ***	0.12 ***	-0.84 ***	1

4.4 DISCUSSION

This study did not consider occupation or industry type. However, different heat environments were found in different working environments. Very small companies had poorer heat environments than small and medium companies located in old industrial complexes, but large companies exhibited the highest LST. This was unexpected.

This study found that very small companies were exposed to high heat not only in working areas, but also in outdoor environments. In terms of the built environment, very small companies showed physical characteristics that were likely to result in poor thermal conditions. Very small companies occupied factory buildings at high rates due to less than average EQB areas (1,000m^2). Factory buildings between very small companies were of close proximity. This design exploits narrow EQB areas to their maximum capacity. Narrowly divided land parcels were used for the planned blocks. Building layouts thus resulted in high LST through a widening of the building area across the land space.

The very small and small companies divided land parcels in old industrial complexes to build factories, thus making the best use of limited space. This included straight building configurations along adjoining roads, while factory buildings on different land parcels were built in mostly facing configurations (Bae, et al., 2003). Buildings should generally be constructed at least 1m off the property and under 6m according to building code-related criteria concerning property and building lines. However, the building code does not apply to factory buildings in industrial complexes (The national low information center, 2018). In other words, very small companies could easily be situated in higher LST environments compared to other company types.

I did not consider working conditions according to company size, but some previous studies have pointed out that small companies contain poor heat environments. Unlike the general public, manufacturing workers are exposed to strong heat for long periods of time. These workers usually operate indoors. Although they are not exposed to direct solar radiation, they experience very high thermal stress due to insufficient air conditioning and high heat levels (Lundgren, K., et al., 2013). Lee. J and Ahn. J, (2016) examined the Korea working conditions survey. They revealed that the smaller the company, the higher the exposure risk. Thus, small companies find it difficult to pay attention to safety and health improvements because of long working hours. Low-wage workers are more likely to experience heat stress (Srivastava, A., et al., 2000; Bhanarkar, A. D., et al., 2005; Tawatsupa. B. et al., 2010). These studies support my results. That is, very small companies tend to contain poor built environments for heat.

4.4.1 Different heat environments according to EQB area

Large company factories are typically built on large parcels of land. Large EQBs can thus be constructed to contain relatively low LST. For instance, although this study did not consider a detailed industry types, the petrochemical industry is typified by low coverage rates due to storage tanks and pipelines. This industry type has tended to contain wide open spaces and a high ratio of green areas, thus exhibiting the lowest LST among all industries. On the other hand, electronic, automobile, and metal-related industries located in large EQB areas tend to contain huge factories alongside relatively large green spaces.

While there was no significance difference, large companies exhibited higher LST than small companies. This was because large companies had huge factories to accommodate production and workforce needs. Some companies had relatively high or low LSTs because they occupied relatively wide or narrow building areas. For instance, several very small companies exhibited relatively low LST because they occupied larger EQB areas. The reasons for this are as follows.

First, several very small companies shared factories within the same EQB area. Very small companies rented factories at high rates because they could not afford their own (Song, J.. 2008). Apartment-type factories have recently appeared. Very small and small companies are thus able to perform industrial activities in better environments. The second reason involves downsizing. That is, companies downsize as economic conditions worsen; this is done by reducing the number of employees (Jeon, K, 2018). Consequently, physical EQB areas are major variables in explaining different heat environments. This is because larger EQB areas enable companies to use building components that result in lower LST.

Although large companies exhibit high LST, they do not seem to contain vulnerable heat environments. The larger the company, the higher the number of workers. However, large companies tend to employ safety supervisors; longer breaks are thus ensured during heatwave warnings (HanKyoReh, 2018). In addition, small and medium companies cannot afford to cope with heat under the current system, in which the demand for labor is high and high-risk jobs are transferred to subcontractors.

Regarding the industrial characteristics, this study did not consider occupation (e.g. administrative position or simple laborer) or working environment (e.g. indoor or outdoor). However, high temperature exposure exhibited a positive relationship to EQBs with high LST. This indicates that companies experiencing high temperatures may have poor thermal conditions. High temperature exposure is mainly the result of production activities involving hot machines, furnaces, and molten metals. This varies depending on industry type and occupation (Lee, J. & Ahn, J., 2016). Thus, manufacturing workers in factories with high temperature exposure rates are positioned in very vulnerable heat environments due to high LST, which is also a problem in outdoor spaces.

4.4.2 Green space affects on company size

This study showed that larger companies were more easily affected by the positive aspects of green spaces. Very small and small companies with land parcels of less than 1,500m^2 and 5,000m^2, respectively, had green area rates of less than 1%. The smaller the company, the less likely they can afford to secure green spaces. This is the result inefficient expenses and development spaces. Consequently, workers at large companies are easily influenced based on green areas, which are not typically present at very small and small companies.

Furthermore, very small and small companies located in old industrial complexes receive little influence from green areas. Industrial complexes built prior to the 1970s and 1980s were not required to secure green areas. They thus operated below current criteria that necessitate green space creation (Kim, et al., 2013). Large companies are likely situated in better thermal environments because they have secured sufficient green spaces. Article 27 of the building code indicates that, if the land parcel area is more than 5,000m^2 or the total floor area of building is more than 1,500m^2, landscaping should be secured in the factory area (The national low information center, 2018a). Since the land parcel and total floor areas of very small companies are below these criteria, they are not obligated to secure landscaping, and can likely not afford it.

A high demand for factory expansion and limited industrial complex space in Korea resulted in the "Article 26 Special Act on Deregulation for Business Activities" in 2011. This was designed to mitigate problems associated with obligatory landscaping (The national low information center, 2018b). Green areas are thus rarely secured within factory areas. Although green areas are important aspects for improving urban heat environments, industrial areas tend to place less emphasis on them compared to residential areas.

4.4.3 Thermal inequity in neighborhoods adjacent to EQBs with high LSTs

Vulnerable social classes tend to live in output areas that are adjacent to old industrial complexes. They thus live near high heat sources. This study showed that several vulnerable social classes lived in poor thermal environments even when outside (the exceptions where persons over 65 years of age living in single households).

Vulnerable social classes lived near heat sources related to the residential environment. Areas adjacent to EQBs with high LSTs tended to contain old or detached houses that were vulnerable to heat. Detached and old housing is insufficient compared to APT. They were adjacent to high heat sources but showed high LST due to the difficulty involved in creating green areas in narrow outside spaces. On the other hand, houses under 60m^2 contained some of the poorest environments. These were adjacent to EQBs with low LST (similar to APT). This indicates that old detached housing in areas adjacent to old industrial complexes had poor external heat environments. This was also discussed in Chapter 3.

High ratios of green space were established adjacent to EQBs with high LST. As mentioned in other studies, green buffers are placed between industrial and residential areas to mitigate the air pollution generated by factories. Among the sites considered in this study, national industrial complexes containing large companies in Daegu, Ulsan, and Gumi had high green buffer ratios.

This study has several limitations. Various types of industries exist within the manufacturing industry, but these were not considered. Since most industries (except the petrochemical) have similar plant layouts and shapes, LST is difficult to use when explaining heat differences. I could also not explain anthropogenically generated factory heat. Because it was difficult to obtain asset information based on company size, this study only classified companies according to the number of workers. It was difficult to explain why vulnerable social classes chose to live in areas adjacent to EQBs (e.g., factories) with high LSTs. I could not explain thermal inequity in the industrial areas because industry and occupation types were not considered due to insufficient data.

This study has two implications. LST differences were analyzed according to company size. This was done by considering the built environment and industrial characteristics. Many UHI studies have focused on land-use characteristics as causes. This indicates that company size is related to higher heat exposure based on different built environments and existing working conditions that tend to produce high levels of heat.

4.5 CONCLUSION

This study analyzed different heat environments according to company size by examining industrial characteristics and building environments in EQBs located in old industrial complexes. Very small companies exhibited higher LSTs than small or medium companies. Different heat environments throughout old industrial complexes can be explained by examining the presence of green spaces, EQB area, and proximity between buildings. Results indicated that smaller EQB areas and company sizes contained concentrated buildings and lacked green spaces. EQB area was the main factor in explaining different heat environments according to company size. While this did not apply to persons over 65 years of age who lived in single households, areas adjacent to factories with high LSTs tended to contain vulnerable social classes.

CHAPTER 5

Effect of the green buffer zone to improve thermal environment in the residential area adjacent to the old industrial area: A case study in Busan, South Korea

Keyword: ENVI-met v4.0, buffer green zone, thermal environment, street canyon, old residential and industrial areas

5.1 INTRODUCTION

Changes in the thermal environment due to heat and urban heat island primarily threaten the health of vulnerable populations (Patz et al., 2000; Jeon, H., 2011). According to the 2018 thermal disease surveillance system, the number of patients suffering from fever was high in the elderly living alone and the elderly population was high, and the incidence of fever was high in the low- income population receiving medical care. Among the total 4,526 patients, the elderly accounted for about 30.6% (1,386). In the case of low-income households, the risk of death from heatwave was 19.4% higher than that of the general population (Kim, E., & Kim, H, 2017).

Most of the housing types in the aged residential area are composed of single-family houses, and the spaces and fences within 50cm width are formed in the narrow side space. These conditions act as factors that exacerbate the thermal environment in residential areas. Moreover, residential areas where vulnerable groups live are often lacking in greenery and hydroponics facilities, which makes it impossible to eliminate the thermal stress of residents. In the residential area already formed, it is difficult for the urban environment to be improved immediately, such as a large-scale spatial structure change or expansion of the infrastructure. Therefore, in the case of the aged housing area, the housing environment becomes worse due to the change of the thermal environment. In particular, the area adjacent to the aged industrial complex is a region with generally vulnerable surroundings in urban space and is in a region of higher thermal stress than other regions because it is close to the effects of anthropogenic heat generated by factories (Shashua-Bar & Hoffman, 2000; Britter & Hanna, 2003; Fan & Sailor, 2005).

Considering the additional influences (e.g. noise, dust, etc.) from the factory, areas near the old industrial complex are often equipped with buffered green unlike other residential areas. Most green bufferss are linearly formed between residential and industrial areas. Basically, the green buffers is intended to mitigate the influence of the main pollution such as noise and dust generated in the industrial area on the residential area. For this reason, it is difficult to find a study on the thermal reduction effect of green buffers on the area adjacent to old industrial complex

On the other hand, the research on the thermal reduction effect of the green space itself has been carried out variously. The results of previous studies clearly show the effect of green space on the thermal side. Cao, X. et al., (2010) showed that linear greenhouse can improve the microclimate by preventing the formation of high-temperature air masses in the street. Cao, X. et al., (2010) & Feyisa, G. L., et al., (2014) revealed that the thermal effect of the green area is affected by the area and shape of the area. Greenbelt significantly reduced the UHI effect compared to round, rectangular or other forms of green space. In addition, J. Park, & Cho, (2016) study focused on the distribution of urban heat island and the range of influence of greenery. Using land use and satellite data, they suggest that linear green space can have a clear impact on urban thermal conditions up to 150 m.

Previous studies used LST data to analyze the effect of green space, so the spatial unit is wide. In terms of microclimate, roadside trees can contribute to people's thermal stress relief through cooling effect by shading and evapotranspiration (Oliveira, S., et al., 2011). However, it is difficult to find a study on the thermal mitigation effects of green spaces at the microclimate level. Considering microclimate is important to analyze the thermal effect in the buffered green area which is not large scale. In other words, evaluation of microclimate scale is needed for the effect of temperature reduction and thermal stress relaxation of green buffers.

The purpose of this study is to evaluate the thermal reduction effect of green buffers in the adjacent area of old industrial complex at micro level. Considering that the area adjacent to the industrial area has a poor residential environment and the occupancy rate of vulnerable groups is high, we will look at how green buffers space can be utilized as a way to mitigate thermal inequality. The case study area was selected as the residential districts adjacent to the Sasang-gu complex in Busan Metropolitan City and the simulation is used to analyze how the green buffers space contributes differently to the atmospheric temperature and comfort of the suburban settlements. This study has three research questions as follows.

First, does the green buffers have a positive effect on the thermal environment (temperature, comfort) of the industrial area and the adjacent residential area?

Second, what is the difference of heat reduction in residential area according to the width of green buffers?

Third, how does the thermal mitigation effect of green buffers change over time?

5.2 METHODS

5.2.1 Study site and measurement days

Location of this study area is Sam-rakdong (6,651 residents in 2018) of Sa-sanggu, mid-west of Busan metropolitan city, in south Korea. Sam-rakdong is a residential area with high of basic living recipients (1,280 residents in 2015). The residential district is adjacent to Sa-sang industrial complex and old area where most of houses are built in the late 1970`s. The study area is a low cost detached housing area with a housing price of 915 thousand won. Demographic and social characteristics lived in the study area are as follows: 17% for elderly people, 39% for single households, 40% for rent households.

The study area consists of one or two-stories detached house with flat roofs and street canyon with concrete of grey color, asphalt and no trees (Figure 5.1). Buildings of the factory district have planned to be average 11m of building height with slide roofs of blue color. There are very small companies of mechanic and metal manufacture.

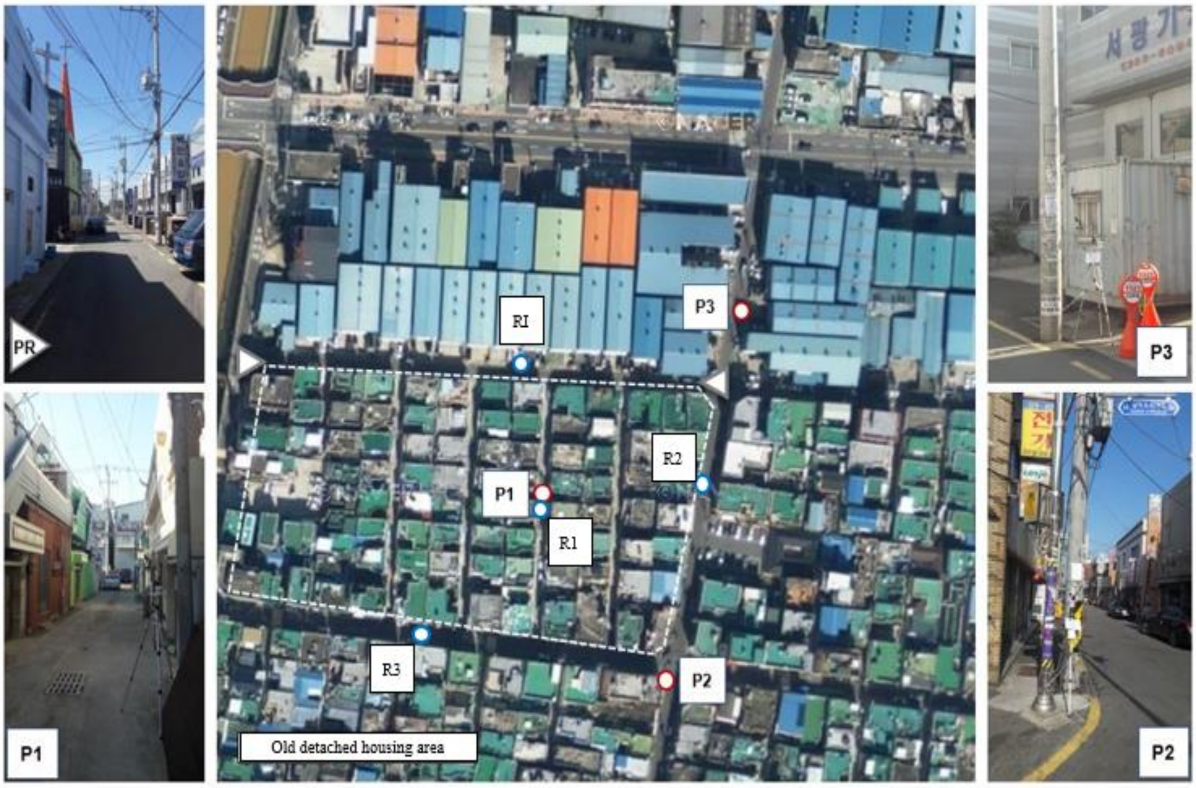


Figure 5.1 Study area and locations of field measuring point (P1 to P3) on 3 August 2018 (Old detached housing area: white dot-outline).

The study area is a detached residential area with a low housing price of 91.5 thousand won/m^2. In Busan in 2018, it was the heat wave days of 19th from July 20 to August 15, and the heat wave days had been continued for 11 days until the measurement day(open weather data portal, 2018). Thus, the simulation was conducted for 3-4 August 2018 using the ENVI-met v4.0.

5.2.2 ENVI-met v4.0 model

ENVI-met is a micro-climate analysis program that divides urban space into grids and predicts the results of the meteorological phenomena in a 2·3-dimensional form through the physical processes for a precise simulation. The ENVI-met has been applied to simulate urban green space, building and landscape planning for microclimate and human biometeorological impact. ENVI-met support a detailed representative of CDF model and the modeling of 3-demensional vegetation and surface cover property. this simulation has the advantage that numerical information for evaluating the contribution of the atmospheric environment can be compared and analyzed and describes to the changes in the atmospheric environment caused by change of vegetation in microscale(Huttner et. Al., 2009).

a. Thermal comfort

Mean radiant temperature(Tmrt)

The study site allows for validation of the human-biometeorological performance of the applied model in terms of Tmrt and PET. It was based on thermal comfort, which were conducted at 4 measurement points on 3, 4 August 2018.

The Mean radiant temperature(Tmrt), which combines atmospheric shortwave and longwave radiation flux, is one of the important weather parameters that determine human energy balance and human thermal comfort(Lindberg, F., et al., 2008). Mean radiant temperature(Tmrt) was calculated from the value of the field measurements using the equation as followed (Thorsson, S., et al., 2007):

$$T_{mrt} = [\left(T_g + 273.15\right)^4 \frac{1.335 \times 10^8 WS^{0.71}}{\varepsilon D^{0.4}} \times T_g - T_a]^{0.25} - 273.15$$

where Ta is the air temperature (℃), Tg is the globe temperature (℃), D is the globe diameter (m), WS is the wind speed(ms-1) and ε is the globe emissivity ($\varepsilon = 0.95$).

Physiologically equivalent temperature(PET)

This study used the BioMet (v1.0), a sub-model provided in the ENVI-met v4.0 model, to estimate

PET. BioMet (v1.0) calculates PET according to the method described by Höppe (1999). PET refers to pedestrian sensory perception index proposed in Germany for urban and regional planners. This index is useful for assessing climate change. The PET better describes the effect of thermal condition on pedestrians than temperature only. The thermal comfort for PET index is evaluated according to the criteria given in Table 5.1.

Table 5.1 Ranges of the physiological equivalent temperature (*PET*) for different grades of thermal perception by human beings and physiological stress on human beings;(According to Matzarakis & Mayer, 1999)

PET(℃)	Thermal perception	Grade of physiological stress
	Very cold	Extreme cold stress
4		
	Cold	Strong cold stress
8		
	Cool	Moderate cold stress
13		
	Slightly cool	Slight cold stress
18		
	Comfortable	No thermal stress
23		
	Slightly warm	Slight heat stress
29		
	Warm	Moderate heat stress
35		
	Hot	Strong heat stress
41		
	Very Hot	Extreme heat stress

Additionally, the human metabolic heat rate and other personal parameters need to be considered (e.g. age, gender, clothing, weight and height). For this study, using the BioMet(1.0v), PET was calculated with standardized data (i.e. age: 35 years, height: 1.75; metabolic rate: 80w/ m^2; clothing: 0.9; weight: 75 kg; sex: man) as a default setting value.

5.2.3 Simulation configuration

The meteorological data and model parameter used in configuration file of ENVI-met are summarized in Table 5.2. The simulation area was subdivided into a 3-D grid. Its horizontal area consisted of 130 by 130 grids of 2m resolution. The vertical grid size was also 2 m. The horizontal area considered a total area of 6.76ha in this simulation. In the model, the boundary of domain shows a large variation according to the wind speed and wind direction. This influences the correct interpretation on the results. Therefore, the simulation domain is additionally secured by 20 m at each boundary. The configuration file value is initial modeling timing data. The analysis date is from 4:00 am on 3, August, 2018 to 8:00 am on 4, August, 2018, and the weather data is simulated for 28 hours at 1-h interval. In order to increase the accuracy of the model, the simulation was performed at 4:00 am, which is 4 hours before the actual measurement time. The results of the modeling were obtained at 1.4m agl.

Table 5.2 Description of the meteorological boundary and input parameter for model

Model parameter	**Run time: 28h**
Main model area(x,y,z)	130, 130, 30
Grid size(d_x, d_y, d_z)	2, 2, 2
Soil profiles	Concrete & Asphalt pavement
Building profiles	Default(concrete) / factory: Steel sandwich panel (Blue & gray)
Position on earth	Busan/south Korea, 37.17, 128.98
Model rotation out of north	4°
Meteorological data	Date: 3.August. 2018
Wind speed (10 m .agl)	2.8m/s
Wind direction	340
Specific humidity (2,500m a.g.l)	7.0g/kg
Roughness length	0.1
Material emissivity	Buildings: 0.90, concrete & asphalt: 0.90, grasslands: 0.95 trees: 0.95

a. Meteorological data

The meteorological data had been measured at three points(P1-P3) for two days of a clear sky (Figure 5.1). The field measurement was carried out for a total of 31 hours from 8 am on August 3 to 4 pm on August 4. All sensors recorded data every 1-min in each site and data were averaged hourly to use in simulation. The meteorological data of the simulation was taken from the P1 point measurement data. Using weather devices, the following meteorological variables were measured: air temperature(Ta), Relative humidity(RH), Wind speed(WS), Wind direction(WD) and globe temperature(Tg). Sensors at each station were installed at height 1.5m from the ground.

Ta and RH were recorded from HOBO temperature RH smart sensor with solar radiation shield. Tg measurement was conducted using a 40mm table tennis ball painted with grey color (RAL 7001) with a T-type copper-thermocouple sensor inside the middle of the ball(Thorsson et al. 2007). WS and WD were measured with other variables, but ENVI-met is used wind speed at 10m above ground. In this study, WS at 10m above ground and WD are derived from the Sa-sang AWS(Automatic weather station). This station is located in about 4 km south-west away from the study area. The accuracy of each sensor for the measurements is as follows: ± 0.21℃ and ±1.0 for Ta and Tg, ± 2.5% for RH, and ± 1.1m/sec and ±7degrees for WS and WD, respectively.

b. Buildings material data

ENVI-met can describe specific building characteristic using 3-D input data. To consider the thermal effects on the building skin, the default value of concrete was applied to the residential buildings and the sandwich panel was applied to the factory buildings. The sandwich panel is a combination of stainless steel or aluminum on both sides of the insulation. In this study, reflectance, emissivity and thickness of sandwich panels were considered.

Emissivity and reflectance are major factors affecting surface temperature. The higher the emissivity and reflectivity, the lower the surface temperature. Emissivity and reflectivity of sandwich panels were obtained from the American Society for Testing and Materials (ASTM) (Lee, U., et al., 2012). In this study, stainless steel was considered as the material of the factory building, and light gray and blue color were applied to the wall and roof color. The emissivity was 0.9 and the reflectance was 0.33 (light gray) and 0.28 (blue) depending on the color. The wall and roof thicknesses were considered 100T and 150T, respectively. Materials were added to the material properties for the factory building in the Manage database of ENVI-met.

c. Green buffers planning

This study is applied to the scenarios based on the status of the green buffers surveyed in the previous study. Main planting species of buffered green area are composed of evergreen trees such as strobus pine, pine, zelkova, cherry, pine and acacia. Plant density is suggested to be 0.22 tree/m^2 for arbor, 0.15 tree/m^2 for arborescent and 0.67 tree/m^{2}for bush(Han, B. H., et al. 2010). Na, Y., et al. (2015) presents the required planning criteria for construction of the green buffers. Green buffers should be secured height at least 4 m and the ratio of evergreen to deciduous tree is 8:2. However, this study did not consider tree density.

Plant name	Pine	Pinus Pinea	Robin pseudoacacia	Koelreuteria paniculate
Height	15m	15m	12m	10m
Crown width	7m	11m	7m	13m

Figure 5.2 The basic species in ENVI-met; Plant name and geometry(Image: VAN DEN BERK, 2018)

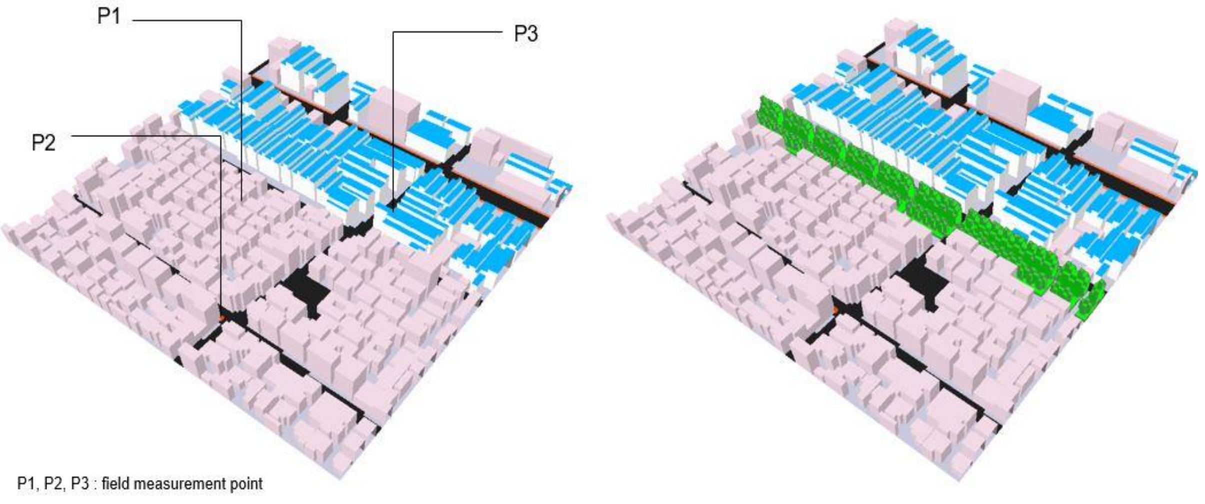
This study area creates a buffered green zone with grassland and tree after removing the existing buildings, because there is no free space to create green buffers. In order to evaluate the effect of green buffers space, the width of 10m and 20m of green buffers are simulated. Vegetation species of green buffers considered the basic species provided in ENVI-met(Figure 5.2); pine, pinus pinea, robin pseudoacacia, Koelreuteria paniculate. The plant height is 10-15m and the crown diameter is 7-13m.

4.3.4 Simulation scenarios

The study area is a typical residential area adjacent to small businesses in the old industrial area. Three scenarios are simulated on August 3, 2018 to assess the impact of current spatial structure on heat and thermal comfort and to quantify the thermal contribution of green buffers (Figure 5.3). Case 1 simulates the configuration of the current residential area and evaluates the thermal environment in the backward residential environment adjacent to the factory. Case 2a evaluates domain applying a green buffers of 10m width by removing detached housings within 10m of a residential area adjacent to the factory. CASE 2b extends the buffer area to 20m and simulates to find the effect of the buffered greenhouse compared to CASE 2a.

The difference of Ta, Tmrt, and PET between Case 1 and Case 2 show the thermal mitigation effect of the green buffers. The difference between Case 2a and 2b explains the impact of green buffers width.

Finally, the between Case 1 and Case 2 shows the difference of effect on the thermal comfort in outdoor space by green buffers. A wind direction of 340 degrees, which is the windward from the industrial district, is applied to the model to analyze the thermal effects of the factory. The thermal comfort is compared to the four points of the street considering the street orientation and width, the distance to the green buffers, and the land use characteristic (Table 5.3).



CASE 1 (current)

CASE 2 (Buffer green zone)

Figure 5.3 Visualization of the area input file for the ENVI-met simulations related to CASE 1 (current site configuration), CASE 2(a: green buffers 10m, b: green buffers 20m).

Table 5.3 Characteristics of street canyons within the simulation domain for examining thermal comfort

	R1-NS	R2-NS	R3-WE	RI-WE
Length(m)	88	100	150	160
Width(m)	4	8	8	12
Distance from Green buffers(m)	14	14	82	4
Road materials	Concrete	Asphalt	Asphalt	Asphalt &Concrete

5.3 RESULTS

5.3.1 ENV-met model validation

The results of ENVI-met model on 3 to 4 August 2018 for case 1 is carried out validation compared with field measurement data. To validity each variable between simulated and measured values, this study considered 1-hour values of Ta and Tmrt at height of 1.4m agl based on 75 pairs collected at 3 points in site. In case of Tmrt, globe temperature was limited to 25 pairs collected at p1 point as a limit of equipment and the time between 8 am and 8 am was considered.

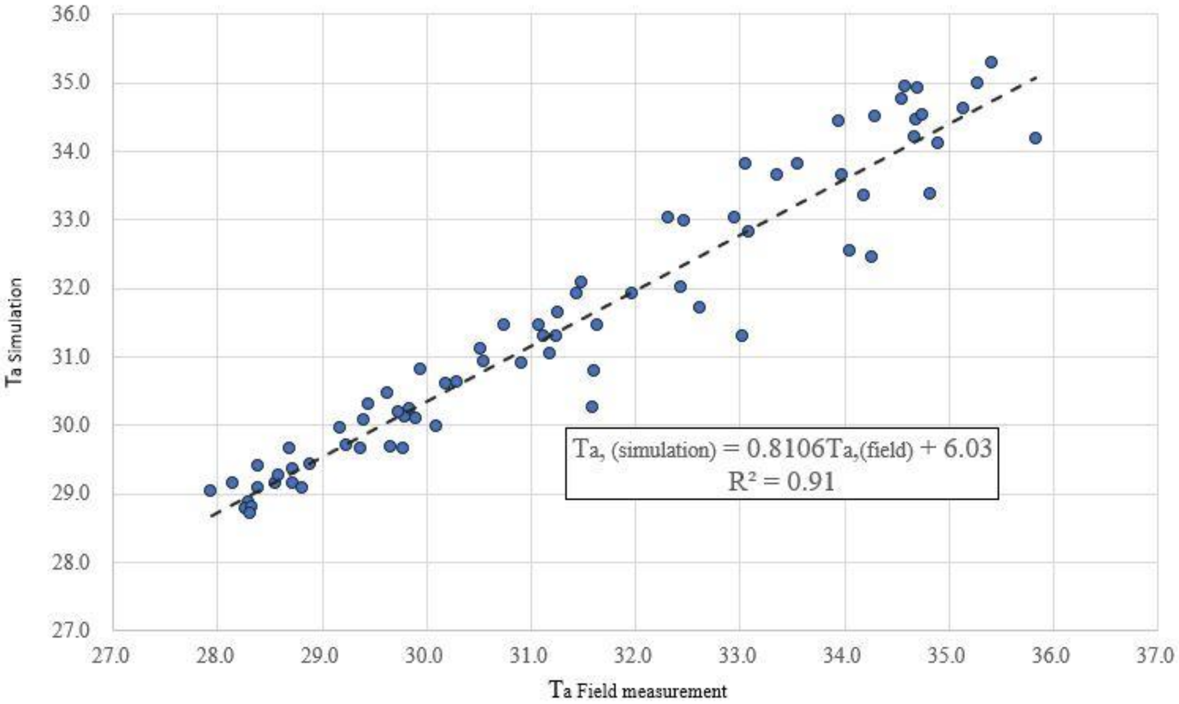
The accuracy of the simulation performance in the ENVI-met model was tested using the error measurement of model evaluation (Yang, X., et al., 2013; Lee, H. et al., 2016): Root mean square error (RMSE), mean absolute error (MAE), mean bias error (MBE), and coefficient of determination (R^2). The verification value of each RMSE, MAE and MBE are closer to 0, which means that the results of measured and simulated value are similar to each other.

Table 5.4 showed that RMSE showed a 6.0℃ and 0.7℃ difference in Tmrt and Ta, respectively. MAE was relatively low for Ta (0.2℃) and high for Tmrt (5.6℃). On the other hand, MBE showed 4.2℃ underestimated for Ta and 0.1℃ overestimated for Tmrt.

Table 5.4 Validation of quantitative measures between the ENVI-met model and field for Ta and Tmrt values (sample pairs: Ta= 75, Tmrt= 25);

	RMSE(℃)	MAE(℃)	MBE(℃)	R^2
Simulation - Field				
T_a	0.7	0.2	0.1	0.91
T_{mrt}	6.0	5.6	- 4.2	0.93

Figure 5.4 showed the linear regressions between 1-h simulated and measured values were derived for Ta. The R2 values were strongly correlated between simulated and measured Ta (0.91) and Tmrt (0.93). The regression showed a concentrated scatter patterns on linear. Evaluation results of the performance of ENVI-met model explains to be suited to simulate in complex environment of residential area on heat wave days.



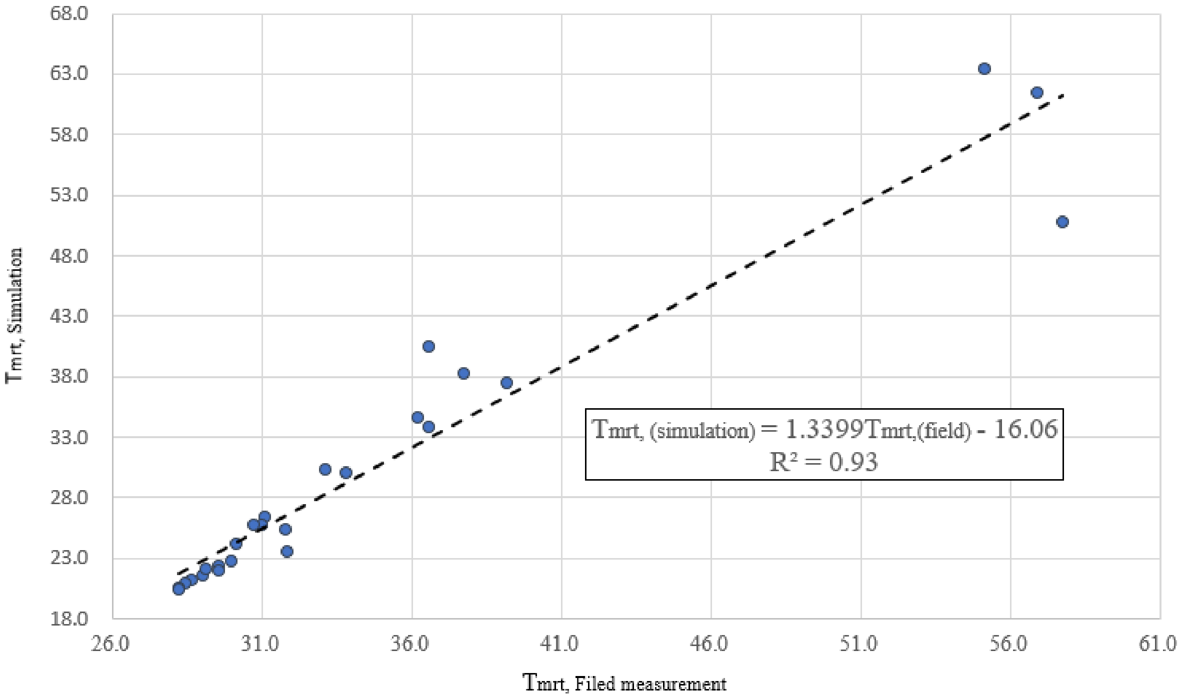


Figure 5.4 Comparison between 1hour simulated and measured values of Ta and Tmrt (at a height of 1.4m agl) on 3 to 4 August 2018 in am.8-am.8 (25h)

5.3.2 Microclimate of current site configuration

In this study, Ta, Tmrt, and PET values of 1.4m height were extracted from the model results in order to evaluate microclimate changes in green buffers composition. Figure 5.6-5.13 were created by LEONARDO software in ENVI-met model. The spatial maps show spatial variations for each scenario based on the hottest time of day (14h). The results of the simulation values represent by color-coded ranges and the white color means buildings. To analyze the differences between the scenarios, Ta, Tmrt and PET values were compared (Table 5.5-6). Also, to compare the difference between day and night, the time zone was divided into 14-16h and 22-00h.

As the results of CASE1, Figure 5.6-5.8 show the spatial variation of Ta, Tmrt and PET at 14h. The range for Ta was 26.7℃-37.5℃, the range for Tmrt was 39.1℃- 68.9℃ and the range for PET was 36.8℃- 62.0℃. The building condition was more influential on Tmrt and PET than Ta. This means that various forms of shading and sunlight resulting from physical condition can affect ventilation in the outdoor space.

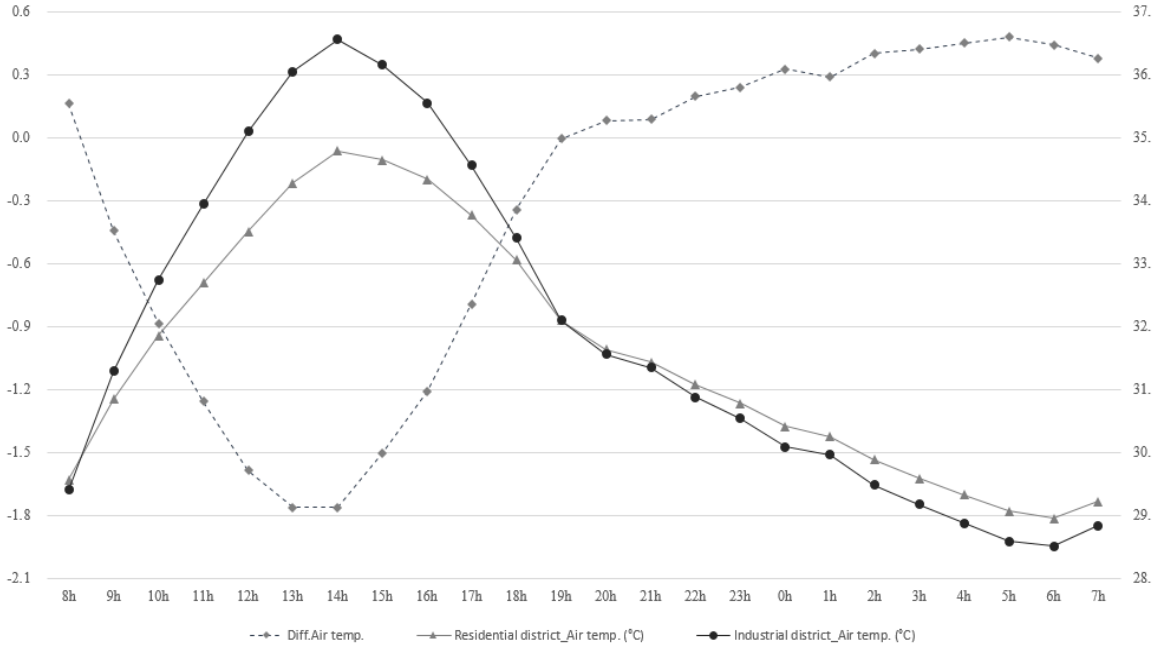


Figure 5.5 Difference of air temperature between residential and industrial district

Figure 5.5 shows the temperature changes over time in the industrial and residential districts. As shown in Figure 5.5, the maximum temperature was around 14:00. The temperature in the factory area was 36.6 ℃ and the temperature in the residential area was 34.8 ℃. On the other hand, the lowest temperature appeared around 6:00. The temperature in the residential area was 29.0 ℃ and the temperature in the factory area was 28.5 ℃. During the daytime the factory area was higher than the residential area, but at night it was reversed. Daytime factory area was 1.5 ° C higher than that in residential area. The difference began to appear at 9 o'clock, and the largest difference was observed at 1.8℃ at 14 o'clock. The residential area was 0.1℃ higher than the factory site at 20 o'clock, and 0.3℃ higher at night time (22h-00h).

The mean daytime Ta of the N-S street canyon and the W-E street canyon did not differ by 34.5 ℃ and 34.6 ℃. However, the average W-E street canyon between the plant and the residence is 34.8°C, which is slightly higher than the streets in the residential area. The difference in Ta values between the street canyons is due not only to the direction of the street but also to the surface material and the height of the surrounding buildings. The Ta value of the N-S street canyon in the residential district at night was analyzed to be 30.7 ° C, indicating that the tropical night phenomenon occurred.

Tmrt shows the thermal change of the space according to the pattern of the shade area and the sun exposure area formed by the buildings. As a result, Tmrt shows a great difference in the direction of street canyons. The average Tmrt of the W-E street canyon is 58.8 ℃ which is significantly higher than the N-S street canyon (average 40.9℃). The average Tmrt of the W-E street canyon located between factories and houses was 67.7 ℃. Within the same street canyon (W-E), the mean Tmrt of the sidewalk facing north was 65.7°C, while the mean Tmrt of the sidewalk facing south was 51.9°C.

PET refers to the level of sensible temperature felt by a person in the external space. The weekly average PET of the W-E street canyon is 44.6 ℃, which represents a "very hot" grade thermal perception by PET classification. On the other hand, the weekly average PET of the N-S street canyon is 37.5 ℃, which belongs to the "hot" grade thermal perception by the PET classification standard. For the W-E street canyon located between factories and homes, the average PET is 51.6 ℃. At night, mean PET in W-E and N-S street canyons were 27.3 ℃ and 26.6 ℃, respectively.

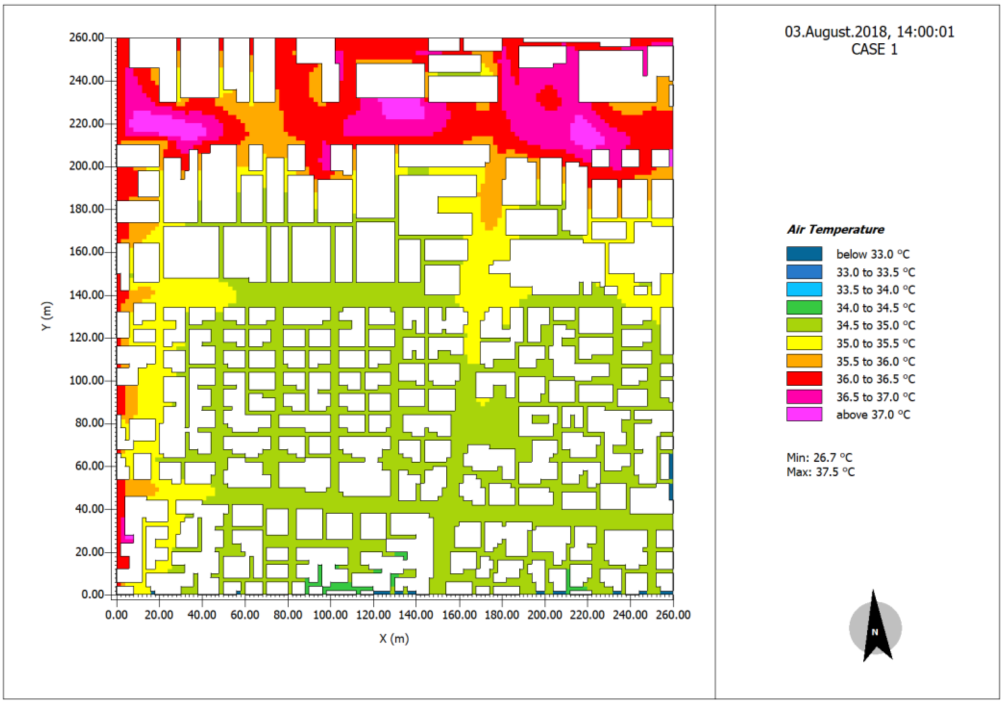


Figure 5.6 Simulated Ta values at a height of 1.4 m agl for case 1 (current site configuration) at 14h on the heat wave day of 3 August 2018 (white areas: buildings).

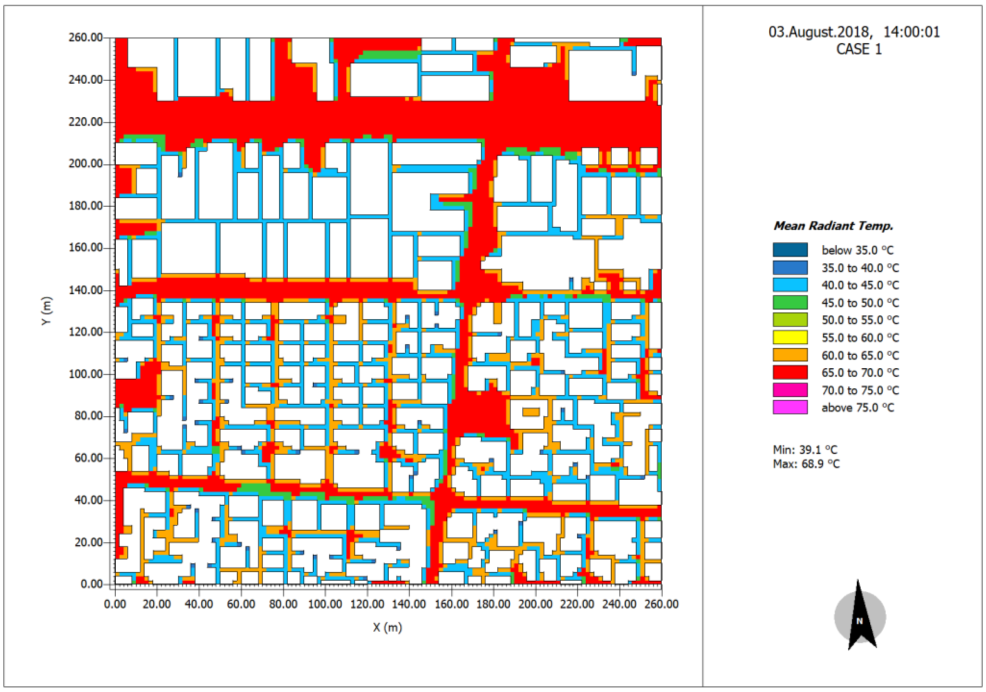


Figure 5.7 Simulated T_{mrt} values at a height of 1.4 m agl for case 1 (current site configuration) at 14h on the heat wave day of 3 August 2018 (white areas: buildings).

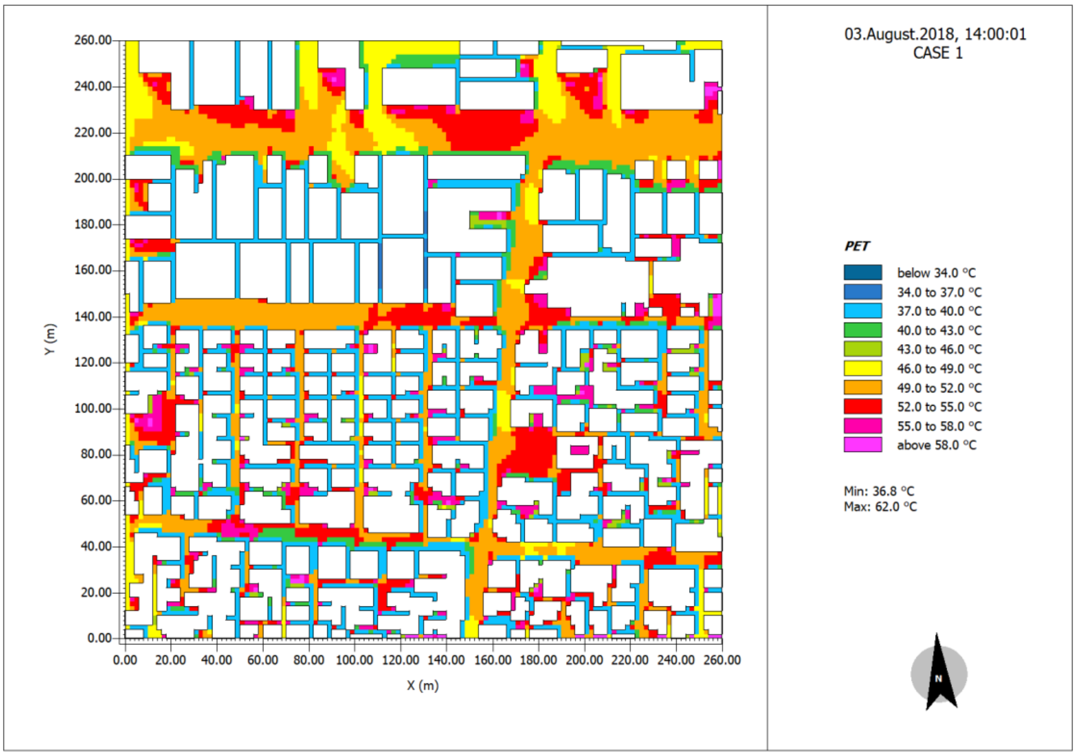
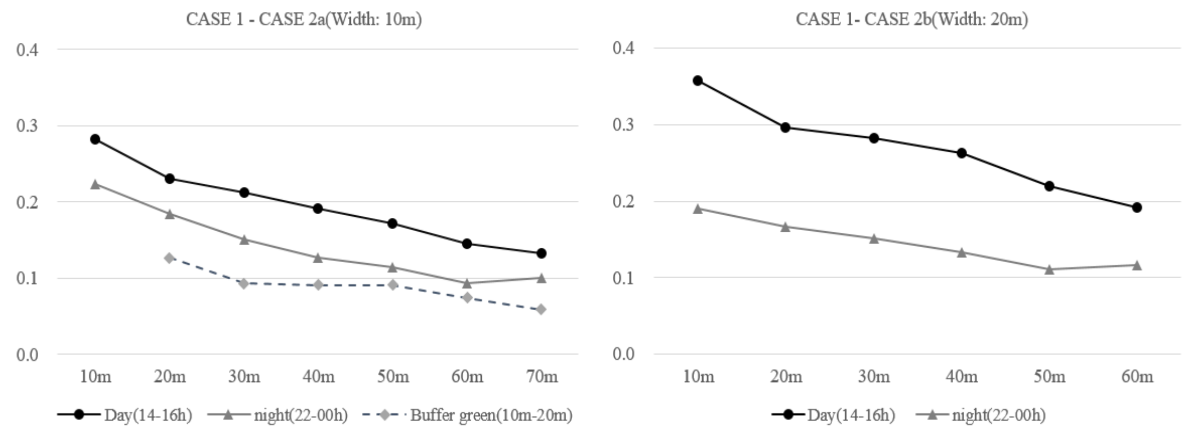


Figure 5.8 Simulated PET values at a height of 1.4 m agl for case 1 (current site configuration) at 14h on the heat wave day of 3 August 2018 (white areas: buildings).

5.3.3 Green buffer zone effect

The existence of green buffers influenced the temperature reduction of adjacent residential areas. Table 5.4 illustrates the temperature reduction in streets measured every 10m from Green buffers. As shown in Table 5.4, the closer to the green buffers, the greater the temperature reduction effect. In the case of Green buffers formed by 10 m width in the daytime, the maximum decrease of 0.3°C from the point 10m away from the green buffers and 0.1°C decrease from the point 60m away from the green buffers. Green buffers formed at a width of 20m decreased 0.4°C at 10m from Green buffers and 0.3°C at 20m from Green buffers. Compared with 10m interval, Green buffers formed with 20m width showed 0.1°C lower temperature than Green buffers formed with 10m width. Regardless of the width of the green buffers, at night, the temperature decreased 0.2°C from the point 30m away from the green buffers and decreased 0.1°C from the point 40m away.

Table 5.5 Difference of air temperature by distance in old detached housing district with graph



CASE 1-2a (Width: 10m)	Day(14-16h)	night(22-00h)	Green buffers (10m-20m)	CASE 1-2b (Width: 20m)	Day(14-16h)	Night(22-00h)
10m	0.3	0.2	-		-	-
20m	0.2	0.2	0.1	10m	0.4	0.2
30m	0.2	0.2	0.1	20m	0.3	0.2
40m	0.2	0.1	0.1	30m	0.3	0.2
50m	0.2	0.1	0.1	40m	0.3	0.1
60m	0.1	0.1	0.1	50m	0.2	0.1
70m	0.1	0.1	0.1	60m	0.2	0.1

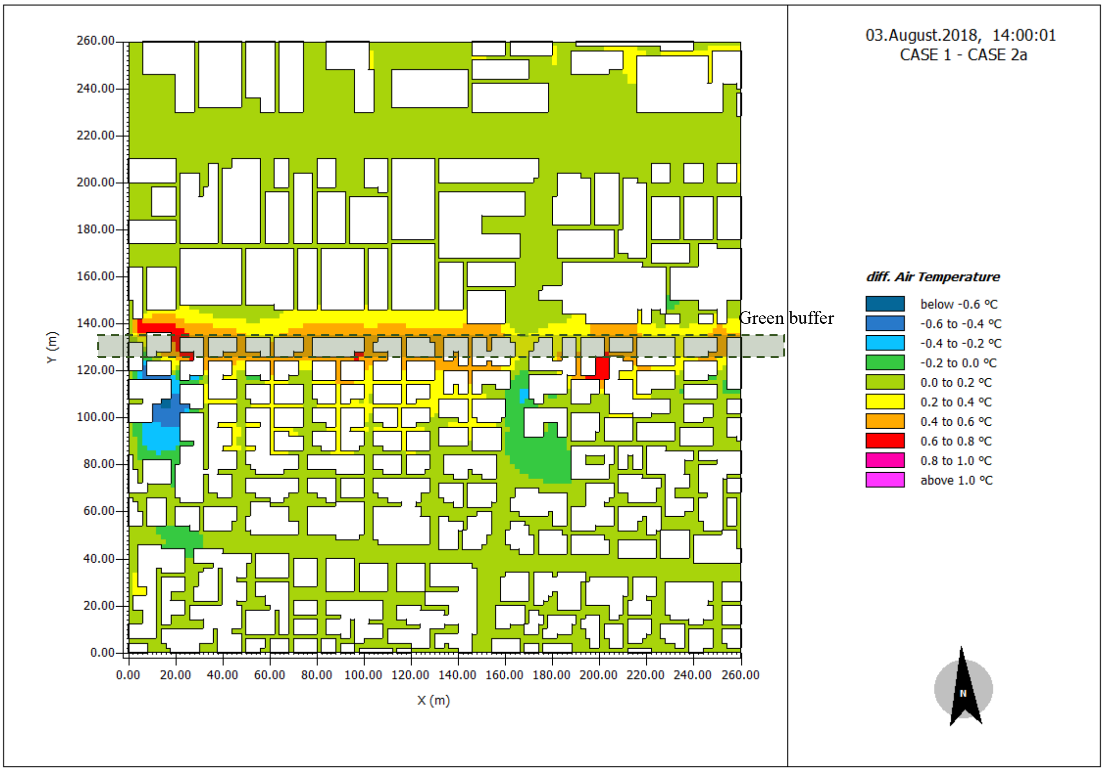


Figure 5.9 Differences in simulated Ta values at a height of 1.4 m agl at 14h between cases 1 and 2a (effect of green buffers, width: 10m).

a. Thermal comfort by an oriented street canyon

Simulation results of CASE1 and CASE2a show that the thermal comfort is changed due to increase of wind speed and interception of heat transfer caused by the formation of green buffers between residential area and industrial area. Table 5.5 shows the Tmrt and PET values for the thermal reduction effect of green buffers in oriented street canyon. Changes in Tmrt and PET show more spatial differences than Ta. The pattern of PET was similar with the Tmrt pattern and showed the greatest temperature reduction effect at the point near the green buffers. Figure 5.10-13 showed spatial change in Tmrt and PET with the existence of green buffers.

Table 5.6 Mean values of T_{mrt} and PET (each in ◦C) at a height of 1.4 m agl for case 1 and the differences between case 1 and 2a (effect of green buffers 10m), 2a and 2b (green buffers 20m)

		14-16h			22-00h		
		CASE1	1-2a(10m)	2a-2b(20m)	CASE1	1-2a(10m)	2a-2b(20m)
R1_N-S	T_{mrt}	40.6	1.2	0.2	22.9	0.0	0.0
	PET	37.2	0.5	0.1	26.6	-0.1	0.0
R2_N-S	T_{mrt}	41.9	1.2	0.1	23.1	-0.1	-0.1
	PET	37.9	0.5	0.2	26.7	0.0	0.0
R3_W-E	T_{mrt}	52.0	1.3	0.2	23.5	0.0	0.0
	PET	44.9	0.6	0.2	27.5	0.0	0.0
RI_W-E	T_{mrt}	67.4	24.3	0.1	23.5	-2.0	-0.3
	PET	52.3	13.8	0.0	27.2	-0.7	-0.1

The R1_W-E oriented street canyon showed the greatest temperature reduction effect due to the canopy effect caused by the formation of green buffers. The mean daily Tmrt decreased by 24.3℃ and the mean PET decreased by 13.8℃ (Table 5.5). In contrast, the temperature reductions in R1_N-S oriented street canyon and R2_N-S oriented street canyon were very low. The average weekly Tmrt decreased by 1.2℃ and the average PET decreased by 0.5℃. Although the floor material is different, it does not show much difference in thermal comfort.

In the R3_W-E oriented street canyon, the decreased mean Tmrt and PET were 1.3℃ and 0.6℃, respectively. This street was relatively far away from the green buffers compared to the R1_W-E oriented street canyon, so the effect of temperature reduction was minimal. The R3_W-E oriented street canyon had an average higher Tmrt and PET value than the N-S street canyon, but the temperature reduction was similar.

As a result of the comparison between CASE 2a and CASE 2b, when the green buffers of 10m width was formed, the temperature decreased about 0.1-0.2 ℃ during daytime. However, the effect of temperature reduction was not observed at night, and the temperature was rather increased. For the R1_W-E oriented street canyon closest to the green buffers, the average Tmrt increased by 2.0 ° C and the average PET increased by 0.7 ° C. This negative effect did not differ even when compared to the case of Green buffers with a width of 20 m.

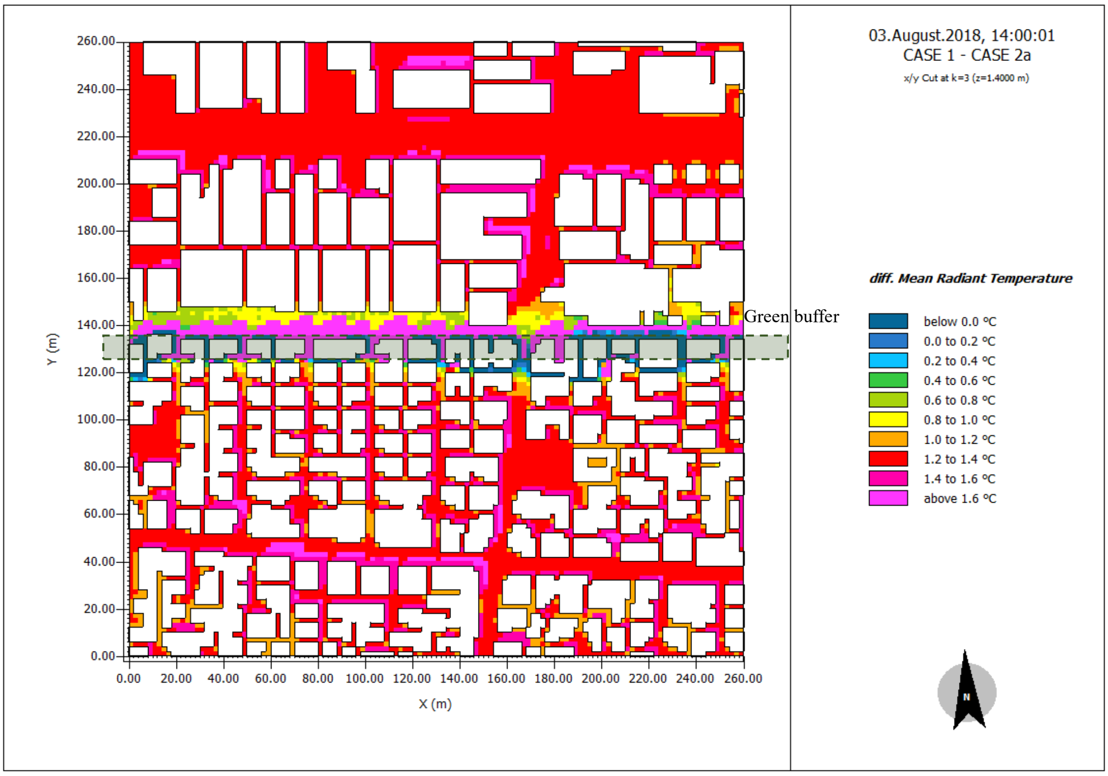


Figure 5.10 Differences in simulated Tmrt values at a height of 1.4 m agl at 14h between cases 1 and 2a (effect of green buffers, width: 10m).

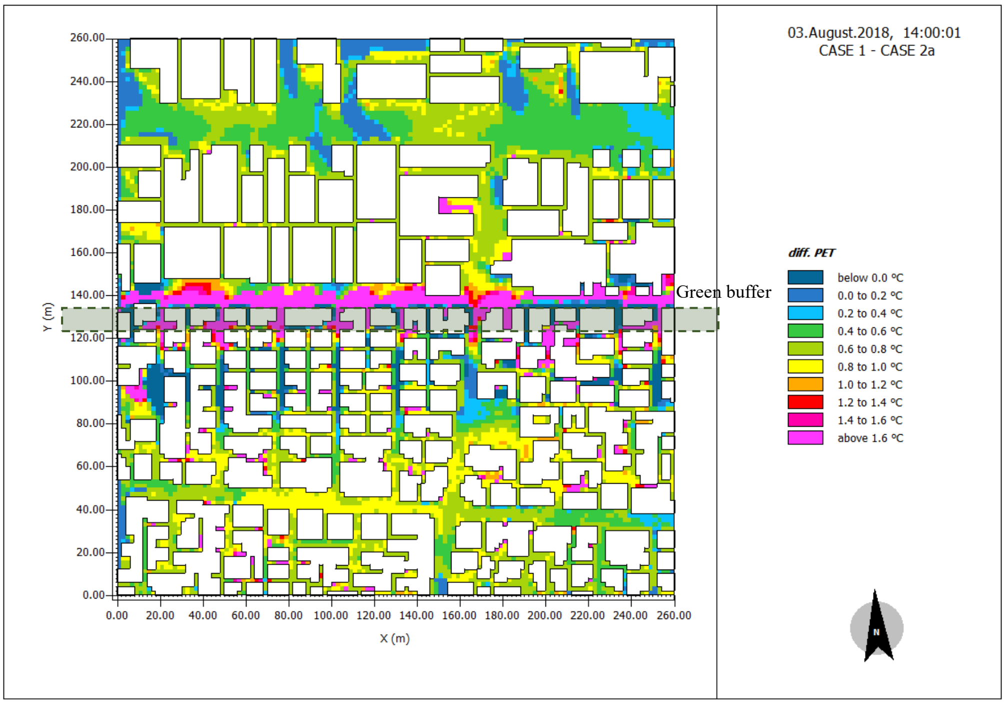


Figure 5.11 Differences in simulated PET values at a height of 1.4 m agl at 14h between cases 1 and 2a (effect of green buffers, width: 10m).

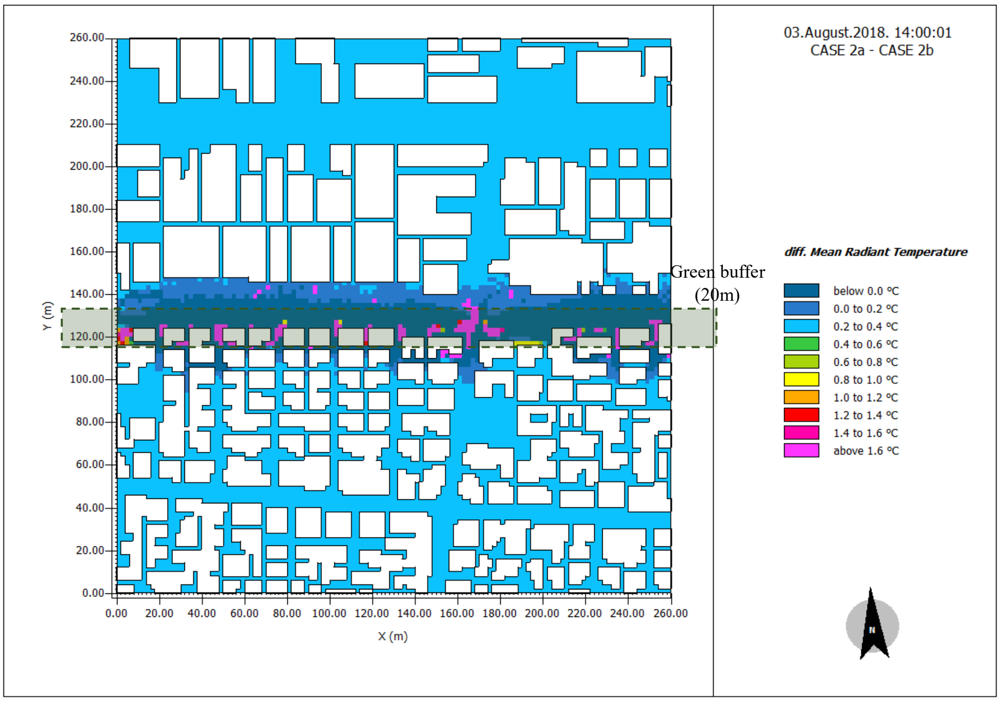


Figure 5.12 Differences in simulated Tmrt values at a height of 1.4 m agl at 14h between cases 2a and 2b (effect of green buffers, width: 20m).

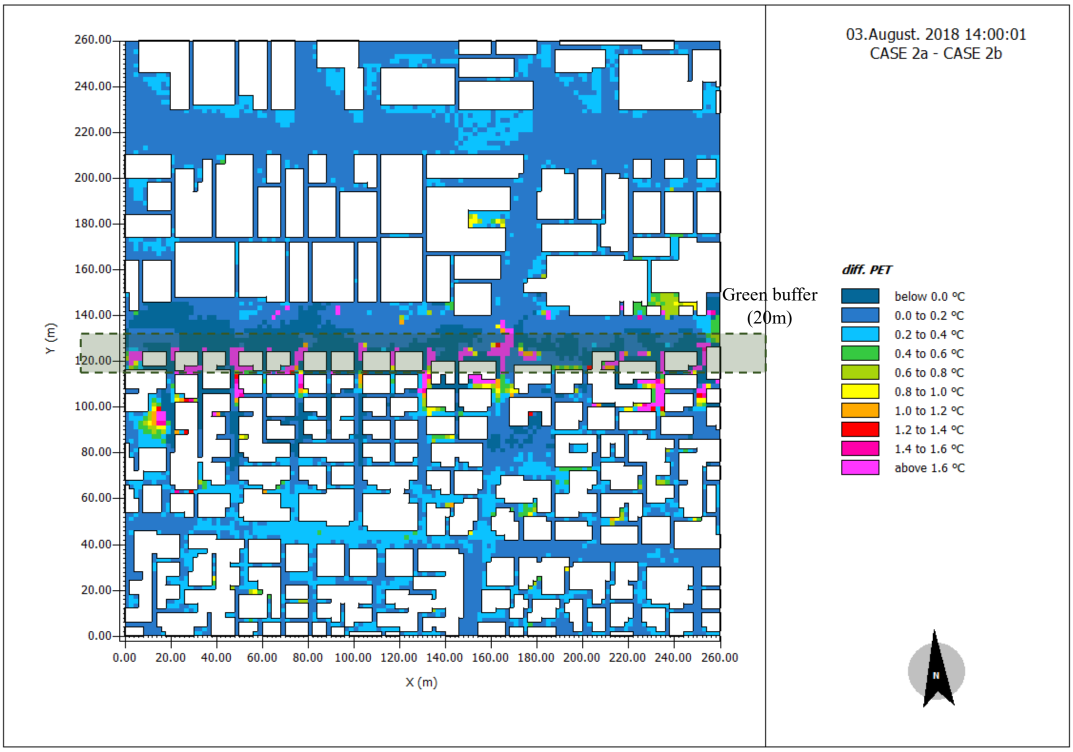


Figure 5.13 Differences in simulated PET values at a height of 1.4 m agl at 14h between cases 2a and 2b (effect of green buffers, width: 20m).

5.4 DISCUSSION

Simulation results in the heatwave condition showed the effect of green buffers on thermal reduction in the poor housing area adjacent to the old industrial area. In general, urban greening has proven to be an effective way to mitigate local heat stress (Santamouris, M. 2014; Norton, B. A., et al., 2015). This study extended existing knowledge on improvement of the thermal environment in urban areas, in addition to the existing role of green buffers established between industrial and residential areas including Tmrt and PET. A typical street canyon in study area was selected in the simulation area to examine the heat reduction effect of the green buffers space by distance and orientation.

Prior to the green buffers scenario, the air temperature between the old residential and industrial district on the current scenario varied by time of day. The high air temperature in daytime in industrial areas is due to factories of steel material and wide road of asphalt, which are easily heated by solar radiation. Because anthropogenic heat generated in a factory could not be implemented in simulation, the effect of heat flux on the building material was considered (Yang, X., et al., 2013). On the other hand, the air temperature of the residential district was reversed at night time. The streel material of the industrial district was cooled rapidly, while the concrete material of the residential district released heat flux more slowly. Another reason is the windward from the industrial district. The windward from the north priorly cooled the industrial district, and the residential district reduced the cooling effect due to the slow wind speed by the dense buildings and the narrow side. In other words, the outdoor space plan was not enough.

Green buffers zone scenarios shown that green buffers contributed to local cooling. The size of spatial and temporal variation simulated by Ta, Tmrt, and PET varied greatly depending on the building environment, green area, and time due to the difference in energy budget. Thus, the spatial variation of Ta, Tmrt, and PET was greater in daytime than nighttime (Lee, H., et al., 2016). In the daytime, the spatial variation in the simulation domain could be explained by the shade and the evaporation effect by the green buffers zone (Georgi, J. N., & Dimitriou, D., 2010; Oliveira et al 2011).

Notably, the point value for Ta closer to the buffer zone showed a strong reduction effect and the further away from the its effect decreased. As a result of this study, the reduction effect of Ta shown up to 70m from green buffers zone. As the width of the green buffers zone extended, the reduction effect intensity increased slightly due to the overall weather condition change on the site. Unlike CASE 1, the green buffers increased the wind velocity by 0.1m /s in the street between the residential and industrial district and the relatively low Ta and RH within green buffers zone influenced the cooling effect of surrounding area. The closer to the green buffers zone, the difference of RH by point was increased. However, due to the narrow width of 3m, there was no increase in the wind speed in the single residential area due to buffered greenery. On the other hand, in the R2 N-S oriented street canyon of asphalt, the green buffers scenario showed a higher air temperature at a certain time(13-14h). Unfortunately, the reason for this is difficult to explain in this study.

The difference of simulation results between CASE 1 and 2a showed overall mitigation effect of green buffers on human heat stress. In general, the W-E oriented street is exposed to solar radiation for a longer time than the N-S oriented street, and it showed higher temperature and heat stress. However, except for the street of green buffers, the typical width considered in this study showed a similar mitigation effect for heat stress regardless of orientation. RI W-E oriented canyon showed the largest cooling effect during the day because of high trees and canopies than existing buildings. The heat stress in a north-facing sidewalk was mitigated due to shadows created from the existence of green buffers located on the south facing the factory. This is the most effective mitigation strategy by shading the direct solar radiation. This reversed result of the nighttime pattern in the local scale implied that trees trap a heat and the building released a heat more quickly at night (Myint, S. W., et al. 2015).

The extended width of the green buffers zone slightly increased the thermal cooling effect on the adjacent residential district and the heat stress mitigation did not show greater effect compared with the 10m green buffers zone. As the width increased, the amount of tree and grassland increased, and the evaporation effect was risen by an increased RH (C.Zhu et al., 2017). However, the result of this study revealed that the green buffers zone of 20m width was not more stable to get over the influence of the long-wavelength surface radiation than 10m width. Construction of green buffers contributed to local reduction for Ta but it was limited to mitigate local heat stress except for the very near area. Although the criteria for the width of the buffer zone is provided by the size of the industrial complex, where the residential district has already been constructed was limited to expand the buffer zone in the area due to compensation or private property infringement. Nevertheless, this study showed that green buffers contributed to the reduction for Ta in the backward residential district.

This study has the following limitations. ENVI-met is relatively simple and easy to express such as green area and land cover in program characteristic. However, since the expression of the material related to the building skin is limited, ENVI-met is difficult to implement such as a real environment. In addition, although the skin material of the factory was used in this study, the anthropogenic heat generated by the factory was not considered. Finally, we did not consider density and species of trees when designing green buffers zone.

In general, two implications such as the shading and ventilation are proposed to improve thermal environment of the microclimate. Shading has been considered as an important strategy for mitigation of heat stress and created by building and green area (Lee, H., et al., 2013). In order to improve the thermal environment, a street tree should be considered at a specific point exposed to the sun in addition to the construction of green buffers. Furthermore, the green buffers need to be evaluated considering various width and empirical evaluation should be done through the field measurement in the area adjacent to green buffer. If the green buffers are difficult to construct in the region such as this study area according to the legal exception criteria, the surface temperature of the region should be reduced by increasing the number of small parks or street trees. Moreover, since the green buffers created to the linear, it is required to play an important role in forming a network of urban green.

5.5 CONCLUSION

This study evaluated the potential of green buffers zone to improve the thermal environment of old residential areas adjacent to the Sa-sang industrial complex. Ta and Tmrt and PET were examined in terms of spatial and temporal changes. Scenarios were tested in different width to investigate the cooling effect of green buffers zone. The results showed that the green buffers zone affected the reduction of air temperature in the adjacent old detached housing area and the increase of width slightly raised the effectiveness of reduction. In addition, the green buffers zone showed the effect in mitigating human heat stress next to area.

CHAPTER 6

SUMMARY AND CONCLUSION

The studies in this paper were based on the assumption that old industrial complexes increase the urban heat island and may influence the physical and social condition of the adjacent areas. My thesis found that geographical conditions and green buffers play a role in the thermal inequity of adjacent areas.

The main results of each paper can be summarized as follows. The first paper (Chapter 3) shows that the existence of green buffers mitigated the thermal inequity between areas adjacent and non-adjacent to old industrial areas. However, the inequality construction of green buffers in adjacent areas caused thermal inequity between adjacent regions. According to the results of the second paper (Chapter 4), very-small companies were found in vulnerable built environments of a higher LST than small and medium-sized companies in old industrial complexes, so there was a relationship between the size of the company and the vulnerability to heat of the environment. In the third paper (Chapter 5), green buffers was found to influence the air temperature reduction of old detached housing areas adjacent to old industrial areas, and the extended width of green buffers was slightly reduced on the effect of green buffers.

My thesis found several significant results through its three studies. First, existing urban planning, which lacked the consideration for environmental issues between residential and industrial areas, established inequality in residential settlement patterns. Cities selected for the study areas have changed while growing around the industrial areas. Areas adjacent to industrial areas naturally developed as worker-residential areas due to their geographical proximity, but environmental problems, and aging of the industrial areas led to aging of the adjacent residential areas. In Chapter 3, the existence of green buffers was found to reduce the thermal inequity between the adjacent and the non-adjacent regions, but in the aging areas which are not adjacent to the green buffers of the adjacent areas lived mainly vulnerable classes. Thus, a lack of consideration for the environmental impact on surrounding residential areas in the planning phases of the industrial complexes, and an imbalanced construction of green buffers affected to vulnerable residential area on the heat in the adjacent area.

Second, the increase of very small and small companies due to the deterioration of the industrial areas led to the rise of the LST. In general, industrial areas are presented as a significant heat source in studies on UHI, but detailed considerations of the physical environment in the industrial area was lacking in the research. Chapter 3 analyzed the heat differences in the old industrial complex based on the company size. The result showed that workers in very small companies were exposed to high heat not only in indoor working conditions but also outdoor. Small companies with the smallest building areas have high LST compared to other sizes of company, due to insufficient green areas and high coverage rate. Small companies that occupied divided land parcels have poor working environments because of the very narrow distance between buildings.

Third, the areas adjacent to old industrial complexes are placed in thermal inequity due not only to the inside but also the outside conditions. Chapter 3 described the thermal inequity of an adjacent area with a focus on the locational characteristics of the old industrial complex. Therefore, Chapter 4 evaluated the heat environment in old industrial complexes and found a correlation between factories with high LST and residential areas of the weak class. The characteristics of old and detached houses in areas adjacent to old industrial complexes was found to have a higher heat environment of inside and outside condition. Jin, J. & Hun, J., (2014) showed that the decline by the aging of the industrial complex was related to the old buildings in the adjacent residential area. While old industrial complexes have not necessarily seen a decline of industry, the relatively poor inside industry environment led to the aging of surrounding areas, and residential areas could be created to vulnerable heat environment. As a result, although there is a difference depending on the planning condition in the adjacent area, the vulnerable classes were placed in thermal inequity both inside and outside.

Lastly, green buffers were analyzed as an essential factor in the mitigation of thermal inequity in the areas adjacent to old industrial areas, and the thermal inequity and the heat reduction effects of the green buffers were a different range of explanatory benefits. In the second chapter, areas adjacent to old industrial areas is considered as 600m, and the buffer zone plays a vital role in reducing the thermal inequality. On the other hand, in Chapter 5, the green buffers showed a slight reduction effect of air temperature within a range of about 100 m. It is not surprising that the range of impacts in the two studies is not consistent because the spatial scale and the measurement data for the heat of the two studies were different. However, the green buffers have a positive effect in addition to the heat reduction effect. Green buffers which was initially planned to block environmental pollution solved some other environmental problems such as noise, and provides a visual barrier and psychological relief from harmful facilities.

Moreover, according to the results of Chapter 3, the area adjacent to the green buffers showed relatively affordable housing prices, and there were a high rate of apartments and multi-family housing. Therefore, it was understood that the inequity was decreased because the surrounding area was adjacent to the industrial area and the type of the house and the class change. However, there is no evidence to suggest that the construction of green areas has led to the increase of less vulnerable apartments on heat or green area in the region. Thus, it is inadequate to generalize the range of influence of green buffers. Nevertheless, this study expanded the knowledge of thermal inequity by discovering the role of green buffers.

Finally, my study suggests that the existence of green buffers played a role in reducing thermal inequity between the adjacent and the non-adjacent areas. The green buffers showed not only temperature reduction effect but also improvement of heat environment in adjacent residential areas.

Second, thermal inequity is determined by the planning factor rather than simply being located close to the industrial area. In other words, the green buffers played a role in reducing the thermal inequity of between adjacent and non-adjacent areas, but green buffers areas were unevenly distributed in the actual plan. In addition, areas adjacent to the long-delayed green facility which has most poor heat environment have been not received the environment benefit in spite of green planning area.

Lastly, both the industrial and adjacent areas should simultaneously be considered to effectively reduce thermal inequity by proximity. My study found that factories with a high LST in the old industrial area were associated with the vulnerable physical and social characteristics of the adjacent areas. For instance, in terms of the relationship between industrial and adjacent area, the declined the industrial area related to old houses of surrounding areas(Jin, JK & Hur, JW, 2014). In other words, the physical environment which is related to a poor heat environment showed a correlation between neighboring land use characteristics. Therefore, a plan which reduces the thermal inequity should be implemented through the link with the old industrial area rather than a single environmental improvement of the residential area adjacent to the old industrial area.

My thesis has some common limitations. First, it is not known whether the areas adjacent to old industrial complexes have a high rate of heat-related illness or mortality. Health problems are related to a wide variety of factors apart from the thermal condition. If the proximity to the old industrial complex is related to the occurrence of heat-related illnesses, the explanation of heat exposure for areas adjacent to the heat source may become evident. Second, because income data is not available for each resident, the residential area of the vulnerable class by the socioeconomic condition is decided by the housing price. If income and housing price information are complementarily considered, the reason why vulnerable socioeconomic groups choose areas adjacent to old industrial complexes and areas without green buffers can be supplemented. Third, as with previous studies, the effect of anthropogenic heat in industrial areas cannot be explained since the LST is challenging to describe the heat transfer due to the surface temperature data indicated by the land cover characteristic. Therefore, my study tried to explain the influence relationship considering the locational condition close to the region with high heat because the industrial area is a significant area for enhancing UHIs. Finally, whether the green buffers are unevenly constructed according to the specific conditions is difficult to explain. The inequality of distribution in environmental justice means that public benefits are not evenly distributed to social conditions such as race, class, and income. In this study, however, is it is difficult to explain whether the existence of green buffers and long-delayed green facilities are the result of policies that are socially discriminative. Therefore, this is inevitable to infer from the present result. For now, the enforcement of the plan is merely related to the financial limitations of the local government.

Despite the limitations described above, this study explored the inequity of urban heat. The previous studies have focused primarily on the relationship between local heat risk level and the physical environment in the field of separate studies such as urban heat island, heat wave, and health. However, this study suggests a different understanding of urban heat issues and emphasizes the recognition of social factors in urban structure. Moreover, my thesis found that geographical conditions such as proximity to the old industrial complex is associated with the social conditions as well as thermal inequity. In my thesis, it is difficult to ascertain whether social conditions cause distribution inequality, but the unequal construction of green buffers is a significant factor in generating thermal inequity in the areas adjacent to old industrial complexes.

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