DOCTORAL DISSERTATION

Study on Outdoor Thermal Comfort in Urban Parks in Indonesia and Japan

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DEDICATION

This dissertation is dedicated to my parents

Siti Saroh, B.A.

and

Khoiruddin Thoif, B.Ed.

Who have given me invaluable educational opportunities through their hard work and sincere prayers.

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ABSTRACT

Urban population has rapidly increased along with the growth of economy and industrialization all over the world. Many cities prepare city development plans by incorporating elements of open space in order to regulate space density and maintain stability for the comfort of its citizens, both in terms of physical (spatial comfort) and non-physical (psychological comfort). For this reason, the city regulates urban park development planning as one of the vital environmental components, helping to supply leisure and recreational activities and social interaction spots for the community. In order to create a comfortable urban park for the community, there are many ways to evaluate its performance. Urban park comfort can be measured by the level of visits (frequency), the level of satisfaction, the level of activity, the level of crowds, the level of environmental comfort, the level of citizen participation, and so on. A level of environmental comfort can be measured by outdoor thermal comfort. The outdoor thermal comfort (OTC) has a complexity which would be influenced by the climate's performance, human factors, and urban structures, such as vegetation ratio or Green Plot Ratio (GnPR), Building Plot Ratio, sky view factors, and so on. Meanwhile, urban parks provide facilities for visitors to gain environmental benefit such as relaxation or urban healing, family entertainment, child's play, and many other similar things but sometimes it has problems with its thermal comfortability. Therefore, a computational simulation should be done to evaluate outdoor thermal comfort and determine significant factors to increase the quality of urban environment. This dissertation was conducted in Kitakyushu (Japan). While the preliminary study was conducted in Bandung (Indonesia) which provided methods and results as a sample for this dissertation study.

Chapter 1, introduction, consists of background, problem statement, research objectives, scopes and limitations, structure of research and research framework. The method to develop this idea is viewing current trend related to urban parks development. Urban problems in Indonesia and Japan are shown as the background of this study. The topic leads to the outdoor thermal comfort studies in urban parks as an important strategy and effective way to solve the environmental problems. This part of study justified the aim to investigate to what extend the outdoor thermal comfort can be used to evaluate the quality of urban parks in Indonesia and Japan.

Chapter 2, literature review, aims at conducting a literature review for identifying the classification of urban parks, influencing factors, motives, and barriers to outdoor thermal

comfort, and the relationship between outdoor thermal comfort and vegetation in urban green open spaces based on literature.

Chapter 3, research methods, shows the way of data collection, data analysis, and the target of results. There are two types of data, the primary and the secondary data. The field measurement data such as air temperature (Ta), relative humidity (RH), and wind speed (v) are categorized by the primer along with questionnaire data. Meanwhile, the secondary data are including weather station, urban policies, published journal papers, conference papers, and so on. The data analysis methods used in this study are descriptive, distribution, correlation, numerical and computational simulation, and systematic review.

Chapter 4, outdoor thermal comfort in three urban parks in Indonesia. This section focused on the preliminary study which is used as a sample for research methodology, such as preparing data collection and analysis for the study. It aims to determine the quality of thermal comfort which can be adopted by the city of Bandung, Indonesia. This study uses a quantitative approach method that is a method that uses measurable analysis and can be calculated using certain formulas. Sampling type used for this study is a non-random sampling with purposive sampling technique. The result found that: 1) A hypothesis that the greater the ratio of vegetation an urban park, the greater the thermal comfort value is correct; 2) People adaptation to the thermal quality of the urban park's environment as a whole is quite good. Most respondents were able to accept thermal performances and want to get cooler than the actual performances. Satisfaction of the performance of shading, sunlight, and wind within the area is quite good; 3) Average value of PET on urban parks in Bandung is in the range of 22.9 ^{o}C to 25.1 ^{o}C with slightly cooler thermal sensation, with a slight cold stress. This PET values is lower than the cities in other tropical countries; and 4) Environmental thermal factor that most influences the TSV value in the three urban parks in Bandung is RH (Relative Humidity). This means that the higher the humidity in an urban park, the lower the thermal comfort value.

Chapter 5, visitor perception and expectation in urban park. The study analyzes several variables based on answers to field survey questionnaires using 425 respondents. Furthermore, Green Park, located in Kitakyushu, Japan, serves as the case study. The result found six essential variables: 1) "Playing with children" is the most popular reason for visiting this park; 2) Tourists living closer to the area frequently visit; 3) The existence is necessary; 4) The relationship between the importance and the origins of the tourists is related to a sense of place;

5) Tourist preferences are affected by seasonality; 6) The most favorite expectation is the availability of water facilities.

Chapter 6, relationship of age, gender, and body proportion to outdoor thermal comfort. The study analyzes relationship between the age, gender, and body proportion and the outdoor thermal comfort based on Thermal Sensation Vote (TSV) value. The hypothesis are: 1) the older a person is, the lower the standard of comfort will be, and vice versa; 2) men are easier to gain thermal comfort than women; and 3) the greater the distance from the proportional body, the higher the standard of comfort. This research was conducted for one year by quantitative methods using a printed questionnaire media. The relationship between the three variables would be analyzed by the multivariate analysis method. Based on the analysis results, there is no significant correlation of age, gender, and body proportion to outdoor thermal comfort. The well-protected privacy's character of Japanese people may affects the number of question's response of age, height, and weight by visitor. From the total respondent, 64.5% has full personal data (age, height, and weight). The 35.5% (147 data) has missing.

Chapter 7, relationship between micro-meteorological and personal variables of outdoor thermal comfort in urban park, this study aims to determine: 1) the people's perceptions of outdoor thermal sensation (TSV), wind flow sensation (WFSV), and humidity sensation (HSV); 2) the acceptability and satisfaction level of outdoor thermal comfort; 3) the satisfaction preference for shading, sunlight, and wind performance; 4) the most significant micro-meteorological variables for PET; 5) relationship between micro-meteorological and personal variables (TSV, WFSV, and HSV); and 6) relationship between PET and personal variables (TSV, WFSV, and HSV). The data collection of outdoor thermal comfort is carried out using two methods in combination: micro-meteorological measurement and questionnaire survey. The result shows six important points. First, most of respondent were feeling comfort with the thermal, wind, and humidity performance. The sensation of thermal and the wind flow were mostly neutral, and the sensation of humidity were also in the mid-range (just right, nor humid and dry). Second, the acceptability and satisfaction level of thermal comfort were positive. Third, the satisfaction preferences for shading, most of the respondents in three seasons (summer, autumn, and spring) were dissatisfied with the actual shading performance and agreed to gain more shading, to get more chance for shelter from the hot sun. Only respondents of winter season were mostly feeling satisfied. For the sunlight and wind satisfaction preferences, most of respondents in all seasons were feeling satisfied with the actual performance, no compliment. Fourth, the most significant micro-meteorological variable for the PET value is mean radiant temperature (Tmrt), this finding shows that the shadow was very important to the thermal comfort performances. Fifth, the most influential micro-meteorological variable for the three different personal variables (TSV, WFSV, and HSV) is air temperature. The last important point is the strongest relationship between PET and personal variables is between the variable of TSV and PET.

Chapter 8, simulation of thermal and physical environment in urban park. The study aims to determine factors that influencing outdoor thermal environmental performance and the relationship between the thermal environment and urban structure in an urban park through an ENVI-met simulation model. The case of the study is Green Park Kitakyushu, Japan. There are three main results: First, the median SVF value is high (between 0.86 and 0.94) which means barely shaded for all time. The overall the Park's surface has a low albedo (between 0.10 and 0.25). Second, the outdoor thermal comfort of Green Park Kitakyushu is statistically not comfortable in summer and autumn, but very comfort in winter and spring. It also found that the higher surface temperature is the higher PET value. Third, it was found that the correlation between PET and urban structure factors is significant, with negative relationship. The shading is important to increase the outdoor thermal comfort performance. The correlation between Tmrt and urban structure factors is also significant, with positive relationship.

Chapter 9, conclusion and recommendation. Finally, this section concludes all the key findings and provides recommendations for future researches. There are five key findings, they are: 1) The visitor perception and expectation of urban park is related to their emotional experience and satisfaction of its facilities; 2) There is no significant correlation between personal variables (age, gender, and body proportion) and outdoor thermal comfort in urban park; 3) The most influential micro-meteorological variable for the outdoor thermal comfort (PET) is mean radiant temperature; 4) The thermal environmental performance and urban structure in urban park found that the outdoor thermal comfort is statistically not comfortable in summer and autumn, but very comfortable in winter and spring; and 5) The factors of urban structure (physical environment) which significantly affect the outdoor thermal comfort in urban park are sky view factor (SVF). For further research, it is useful to use this approach as one of evaluation instruments.

The finding of this dissertation could be an important contribution for the city authorities as a basic guideline for urban and regional development planning, especially those related to the urban parks, urban environment, and tourist attractions.

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NOMENCLATURE

Abbreviation	Definition
3D	Three dimension
A_Du	Surface area of the human body
ASHRAE	American Society of Heating, Refrigerating and Air Performance Engineers
BIO-met	A tool used to calculate PMV in ENVI-met software
BMI	Body Mass Index
BPR	Building Plot Ratio
Cfa	humid subtropical climate
DISC	Discomfort
ENVI-met	Environment and climate based simulation software
ET	Effective temperature
ET*	New effective temperature
GnPR	Green Plot Ratio
GOS	Green Open Space
H	Internal heat production
HSV	Humidity Sensation Vote
Icl	Clothing Insulation; also known as Clo
MET	Metabolism rate; also known activity level
OEHI	Outdoor Environmental Heat Index
Out_SET*	Outdoor Standard effective temperature
PET	Physiologically Equivalent Temperature
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity
RDTR	Detailed Spatial Planning
SA	Surface Albedo
SET	Standard effective temperature
SVF	Sky View Factor
Ta	Air Temperature
Tmrt	Mean Radiant Temperature
Ts	Surface Temperature
TSV	Thermal Sensation Vote
UGOS	Urban Green Open Space
UHI	Urban Heat Island
UN	United Nations
UTCI	Universal Thermal Climate Index
v	Wind speed or air velocity
VP	Vapor pressure
w	Skin wetted-ness
WFSV	Wind Flow Sensation Vote

CHAPTER 1

INTRODUCTION

1.1. Background

Urban population has rapidly increased along with the growth of economy and industrialization all over the world. Many cities prepare city development plans by incorporating elements of open space in order to regulate space density and maintain stability for the comfort of its citizens, both in terms of physical (spatial comfort) and non-physical (psychological comfort). For this reason, the city regulates urban park development planning as one of the vital environmental components, namely helping to supply leisure and recreational activities and social interaction spots for the community. In order to create a comfortable urban park for the community, there are many ways to evaluate its performance. Urban park comfort can be measured by the level of visits (frequency), the level of satisfaction, the level of activity, the level of crowds, the level of environmental comfort, the level of citizen participation, and so on. A level of environmental comfort can be measured by outdoor thermal comfort.

The outdoor thermal comfort (OTC) has a complexity which would be influenced by the climate's performance, human factors, and urban structures, such as vegetation ratio or Green Plot Ratio (GnPR), Building Plot Ratio, sky view factors, and so on. Meanwhile, urban parks provide facilities for visitors to gain environmental benefit such as relaxation or urban healing, family entertainment, child's play, and many other similar things but sometimes it has problems with its thermal comfortability. Therefore, computational simulations could be used to evaluate outdoor thermal comfort and determine significant factors to increase the quality of urban environment.

1.1.1. The Trends and Importance of Urban Park

The trend of urban park's development seems positive in many cities. In Japan, it is positive based on the increasing of its surface area (MLIT, 2006). In 1960 the total area of urban parks is about 14,323 ha or 2.1 m2/person. This number then continued to increase (about 2% per 5 years) until 2004 the total area was 106,370 ha or 8.9 m2/person. The Japanese government develop urban parks as population and industry is accelerated through rapid economic growth (MLIT, 2005). The rapid growth made the loss of green spaces along with urban development increased.

Urban parks as green open spaces are important factors in shaping urban sustainability. Developing more sustainable cities is not just about improving the abiotic and biotic aspects of urban life, it is also about the social aspects of city life, that is about people's satisfaction, experiences and perceptions of the quality of their everyday environments (Chiesura, 2004).

People visit the park primarily because they want to relax. The essential reasons for people's visits to the park are also because of the need to experience nature and to escape from the stressful rhythm of the city.

There are many benefits of urban park, including social and environmental services (Rouhi, Monfared, & Forsat, 2017). For example, it can mitigate the heat island effect and improve the outdoor thermal environment quality (Yan, Wu, & Dong, 2018), and also increase residents' satisfaction and enjoyment as well as avoid stresses produced by activities (Razak, Othman, & Nazir, 2016). It also has social, economic, and ecological roles in improving the quality of life and community development (Chiesura, 2004; Othman, Mohamed, Ariffin, & Razak, 2015; Riki, Rezazade, & Miri, 2016; Ward, Parker, & Shackleton, 2010).

Urban parks are urban structures where people living in the city, who have different cultures and socio-economic status, come together in their leisure time and commune with nature; which are organized for physical, ecological, psychological, and recreational purposes; which bear active and passive outdoor activities such as meeting, entertainment, and recreation, which help reduce the stresses of urban life (Ter, 2011). The quality of urban parks is directly related to the level of realization of optional activities among the outdoor activities, which can be assessed under three headings as: necessary activities, optional, and social activities (Gehl & Koch, 2011).

1.1.2. Urban Park, Outdoor Thermal Comfort, and Climate Issues

Half of the world's population lives in cities (United Nations, Department of Economic and Social Affairs, 2018), this demands a quality and livable environment inside the city. Cities occupy 2% of the earth's surface but their inhabitants consume 75% of the world's energy resources (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013). Some cities experience problems with the thermal quality of their environment. Kolokotroni stated, in the city of London there was an increase in temperature due to the Urban Heat Island (UHI) phenomenon, the cooling load in the city was 25% higher than in rural environments, whereas the heating load diminished by 22% (Kolokotroni, Zhang, & Watkins, 2007). The same phenomenon is also found in other cities. In the U.S., on a yearly average, urban areas are found to be substantially warmer than the non-urban fringe by 2.9 °C, except for urban areas in biomes with arid and semiarid climates (Imhoff, Zhang, Wolfe, & Bounoua, 2010). Moreover, the average UHI amplitude is remarkably asymmetric with a 4.3 °C temperature difference in summer and only 1.3 °C in winter (Imhoff et al., 2010). The UHI phenomenon is generally seen as being caused by an increase in sensible heat in urban areas as vegetated and evaporating soil surfaces are replaced by relatively impervious low albedo paving and building materials and a reduction in latent heat flux (Imhoff et al., 2010).

Many cities experience the Urban Heat Islands (UHI). Various mitigation strategies were carried out to reduce the impact of this phenomenon, including vegetation, material of pavement, building orientation, and city infrastructure planning (Farhadi, Faizi, & Sanaieian, 2019). However, the effectiveness of vegetation to cool the temperature of urban green open spaces is still a hot topic of discussion (Armson, Stringer, & Ennos, 2012). How big is the role of vegetation in reducing urban micro-temperature and what efforts have been made to improve thermal comfort (Gago et al., 2013; Gunawardena, Wells, & Kershaw, 2017). Because it was purported that some policy makers and engineers in such countries do not have adequate information and understanding about the UHI phenomenon (Ramakreshnan et al., 2019). According these studies, it is important to mitigate the climate change and UHI phenomenon by an outdoor thermal comfort evaluation of an urban area.

Study of thermal comfort in subtropics has been developed well in many cities. In 2003, a field study of thermal comfort in outdoor and semi-outdoor environments is conducted in Sydney, Australia which found that the thermal neutrality in terms of the thermal comfort index OUT SET* of 26.2°C was significantly higher than the indoor SET* counterpart of 24°C (Spagnolo & de Dear, 2003). In 2009, a field measurement and simulation study investigating the effects of windbreak forests on the summer thermal environment in a residence found that surface temperatures in the tree-shaded spaces were near ambient air temperature on a sunny summer day (He & Hoyano, 2009a). The surface temperatures of the shaded ground covered with wet soil or lawn were about 2°C lower than ambient air temperature. Study of the shading effect on long-term outdoor thermal comfort in Taiwan found that the barely shaded (high SVFs) locations were uncomfortable in summer and highly shaded locations (low SVFs) were uncomfortable in winter (T. P. Lin, Matzarakis, & Hwang, 2010). The median shading levels (SVF = 0.129) contributed to the longest thermal comfort period in an entire year. Spaces with little or excessive shading have short thermal comfort periods. Another study in Taiwan found that people's thermal perceptions were strongly related to the air temperature (Ta) and mean radiant temperature (Tmrt), but not significant to air speed and air humidity (T. P. Lin, de Dear, & Hwang, 2011). In Hong Kong, an outdoor thermal comfort study found that the *neutral* physiological equivalent temperature (PET) in summer in Hong Kong is around 28 °C and under shaded performance, a wind speed of 0.9-1.3 m/s is needed for a person in light clothing to achieve neutral thermal sensation in an urban environment (Ng & Cheng, 2012). In Campinas, Brazil, a study to determine the effect of tree planting design and tree species on human thermal comfort is conducted. It is found that shading of trees can influence significantly human thermal comfort expressed by PET. The species C. pluviosa F. presents the best possibility in terms of PET because it can reduce between 12 and 16 ◦C for individual trees cluster can reduce between 12.5 and 14.5 ◦C (de Abreu-Harbich, Labaki, & Matzarakis, 2015). While in Wuhan, China, an experiment study found that the outdoor thermal environment is a strong predictor of mean attendance over a period of time, but not spontaneous occupancy at a specific time or space (Huang, Zhou, Zhuo, Xu, & Jiang, 2016). Another study in Taizhou, China found that the effect of pavement material in reducing PET in the daytime is not obvious, sometimes may lead to a negative impact (Ma, Fukuda, Zhou, & Wang, 2019). While in Fuzhou, China the study found that larger-sized green spaces produce a higher cooling effect (Yu, Guo, Jørgensen, & Vejre, 2017). Many relevant studies have contributed a lot to the development of thermal comfort studies in the subtropics, especially for outdoor cases. However, studies for specific areas of urban parks have not been widely carried out. For this reason, an outdoor thermal comfort study in an urban park needs to be developed.

1.1.3. Urban Problems in Indonesia and Japan

The study of outdoor thermal comfort in urban parks can be conducted in many cities. This study chosen Indonesia and Japan, especially the city of Bandung (Indonesia) and Kitakyushu (Japan) as the cases. There are two main reason: 1) both cities experienced the environmental problem; and 2) both cities can represent each climate zone for tropics and subtropics.

Bandung and its metropolitan region experience relatively low population growth rates. As a result of continuous rural-urban migration, trends show that approximately 60% of the population of Indonesia will live in urban areas by 2025 (Maroso & Rinne, 2017). Respectively, the growth rates of Bandung is around 1.16% and 1.98% compared to other cities in West Java located near the capital city of Jakarta which its rates reaching from 7% to 8%. Nevertheless, the city of Bandung is still subject to the rapid growth expansion of its urban area.

The urban areas expansion and rapid economic growth significantly increase the mobility and transportation demand (Maroso & Rinne, 2017). It had caused a traffic congestion, high growth rate of the private vehicle fleet and high level of air pollution and greenhouse gases. In fact, Indonesia as a country has committed to reducing greenhouse gas (GHG) emissions by 29 percent by 2030. These problems indicate that the city has experienced environmental problem.

The Kitakyushu city had experienced severe pollution problems in the past (around 1950s and 1960s) as the economic was rapidly developed. Then the residents, companies and government tried to improve the environment quality by enormous efforts and later on its problem was dramatically solved. Learn from this problem, the city became the pioneer to promote comprehensive environmental initiatives, including the Eco-town Project which aims to promote international cooperation with developed countries and to realize a low-carbon society. The Japanese government recognized this efforts and selected the Kitakyushu City as an Environmental Model City (2008), Environmental Future City (2011), and SDGs Future City (2018). This city also won the UNEP Global 500 Award (1990) and the UN Local Government Honors Award (1992). In 2018, the city was selected by OECD as the only SDGs Model City in Asia.

Kitakyushu City's SDGs strategy (vision) is a "green growth city" that is full of "true affluence", contributes to the world, and is trusted. There are five mission to be accomplished in 2030 which can be applied by the citizens (Planning and Coordination Bureau Regional Creation SDGs Promotion, 2021), they are: 1) "a city where sustainable businesses are born and grow" that leads to the solution of social issues; 2) "a city where everyone can play an active role" by promoting diversity; 3) "a city where future human resources grow" by practicing education based on the SDGs; 4) "a city aiming for a zero-carbon city" through a virtuous cycle of the environment and economy; and 5) "a city that drives the world's green cities" centered on Asian cities.

The city of Kitakyushu is also suspected to experience the UHI phenomenon. Most of the northern part of the Kyushu region became warmer because of urbanization, with an average increase over the land surface of 0.236°C (Kawamoto, 2016). The temperature increases in the areas surrounding Fukuoka city and Kitakyushu city were significant because of the urban sprawl. The urbanization process in the Fukuoka-Kitakyushu metropolitan area also had an effect on the sea breeze penetration from Hakata Bay to Fukuoka city. In 2005, Japanese government designated 10 cities and 13 areas as model areas in which intensive environmental and energy-saving measures will be implemented to mitigate the urban heat island effect, Kitakyushu city is one of them (Yamamoto, 2005). The government promoted model area of Kokura (city center area of Kitakyushu), Kurosaki and Dokaiwan oceanfront area. The major approaches are the promotion of environmentally friendly housing, wind paths and district heating and cooling systems, and effective use of energy produced by adjacent factories in parallel with the redevelopment of idle land owned by companies in partnership with operating factories. In order to promote global warming measures, the city took advantage of existing industrial infrastructure and integrated them into a community planning package.

1.2. Problem Statement

According to The Ministry of Land, Infrastructure, and Transportation of Japan (2006), there was a positive trend of urban park's development based on the increasing of its surface area. The urban parks were developed because of the population and industry is rapidly growth as the increase in Japan's economy sector. Meanwhile, one goal of urban development is creating a comfortable environment of open spaces. The outdoor thermal is one of the comfort parameters which can be develop by the urban planners, architects, government, and citizens. Further developments have and will be continued to focus on the spatial analysis of human thermal comfort in urban outdoor environments and on the impacts and adaptations of climate change (Ren, Ng, & Katzschner, 2011). As the quality of life will increase with the increasing of environmental quality of open space (Nikolopoulou, 2011).

Relevant studies have contributed a lot in urban park, but the study for its outdoor thermal comfort have not been widely carried out. So that, this study is important. As a guidance on the study, the five research questions are developed as follow:

1. How is the visitor perception and expectation of urban park?
2. How is the relationship between personal variables (age, gender, and body proportion) and outdoor thermal comfort in urban park?
3. How is the relationship between micro-meteorological and personal variables of outdoor thermal comfort in urban park?
4. How is the performance of thermal and structure (physical) environment in urban park?
5. What is the factor of urban structure (physical environment) variables which is significantly affect the outdoor thermal comfort in urban park?

1.3. Research Objectives

The relevant study of outdoor thermal comfort in subtropics has been carried out by many scholars. This research aim to understand and evaluate the outdoor thermal performance of urban parks.

1. To understand the visitor perception and expectation of urban park.

2. To understand the relationship between personal variables (age, gender, and body proportion) and outdoor thermal comfort in urban park.
3. To understand the relationship between micro-meteorological and personal variables of outdoor thermal comfort in urban park.
4. To investigate the performance of thermal and physical environment in urban park.
5. To define the factor of urban structure (physical environment) variables which is significantly affect the outdoor thermal comfort in urban park.

1.4. Scopes and Limitations

To improve the quality of an urban environment, it is necessary to discuss the existence of thermal comfort.

1. The study is limited to the evaluation of outdoor thermal comfort for the category of large scale urban park.
2. The assessment is focused on the microclimate, urban structure, and personal factors.
3. Thermal comfort values are determined by the type of scale; thermal environment (PET and PMV) and thermal sensation (TSV).
4. The study in Bandung (Indonesia) is only used as a preliminary study for basic methods in preparing and conducting the study in Kitakyushu (Japan).
5. The mean radiant temperature (Tmrt) data in this study are estimated by a computer software and has not been measured in the field investigation.
6. The number of data units is relatively small according to the result of the regression analysis which is shown by the small value of reliability (R^2). The lack of these information may affect the results of the study.

1.5. Structure of Research

This dissertation comprise nine chapters. Each chapter represents each stage of the research. The structure of this dissertation is following this sequence:

Chapter 1, introduction, presents the current issue of urban park trends and development in a global, then puts forward to the outdoor thermal comfort and climate issue. In this chapter, urban problems in Indonesia and Japan are shown as the background of this study. Furthermore, the topic gradually leads to the outdoor thermal comfort studies in urban parks as an important strategy and effective way to solve the environmental problems. The sub-chapters also provides the purpose of the study, scope and limitations, and structure of research and research framework.

Chapter 2, literature review for identifying the classification of urban parks, influencing factors, motives, and barriers to outdoor thermal comfort, and the relationship between outdoor thermal comfort and vegetation in urban green open spaces based on literature.

Chapter 3, research methods, shows the way of data collection, data analysis, and the target of results. There are two types of data, the primary and the secondary data. The field measurement data such as air temperature (Ta), relative humidity (RH), and wind speed (v) are categorized by the primer along with questionnaire data. Meanwhile, the secondary data are including weather station, urban policies, published journal papers, and conference papers.

Chapter 4, outdoor thermal comfort in three urban parks in Indonesia This section focused on the preliminary study which is used as a sample for research methodology, such as preparing data collection and analysis for the study. The finding in this study contribute to the outdoor thermal comfort of tropical climate zones.

Chapter 5, visitor perceptions and expectations of urban park. This section focused on the questionnaire survey data. This study aims to understand tourists' reasons, preferences, and expectations in Green Park, Kitakyushu, Japan. The distribution analysis is used to identify the reason for visiting this park, significance, favorite season and area, and the expectations of park facilities. Then, the correspondence analysis is used to describe the relationship between the frequency and the source of the visits and the relationship between the significance of visiting and their origins.

Chapter 6, relationship of age, gender, and body proportion to outdoor thermal comfort. This section was focused on relationship between human factor (age, gender, and body proportion) and thermal sensation vote (TSV). The study was conducted by quantitative methods using a printed questionnaire media. The sampling method used a simple random sampling approach and the questionnaire was directly distributed in Green Park, one of the urban parks in Kitakyushu, Japan. The relationship between the three variables is analyzed by the multivariate analysis method.

Chapter 7, relationship between micro-meteorological and personal variables of outdoor thermal comfort in urban park, the study examines a relationship between micro-meteorological and personal variables of outdoor thermal comfort performances in an urban park. The data collection of outdoor thermal comfort is carried out using two methods in combination: micro-meteorological measurement and questionnaire survey.

Chapter 8, simulation of thermal and physical environment in urban park, the study aims to determine factors that influencing outdoor thermal environmental performance and the relationship between the thermal environment and urban structure in an urban park through an ENVI-met simulation model. The case of the study is Green Park Kitakyushu, Japan.

Chapter 9, conclusion and recommendation. The last section concludes all the key findings and provides recommendations for future researches.

1.6. Research Framework

Some part of this chapter have been published in scientific journals and proceedings. Chapter one includes the research background for the study. Chapter two is literature reviews to summary motivations, directions, and possible contributions of this study for the global knowledge. Chapter three describing the method of research. Chapter four is preliminary study of outdoor thermal comfort in urban parks in Indonesia. Chapter five, six, and seven describes the main findings of the research. Principally, the findings have two roles, they are: validation and reflection. The chapter five found the reasons and preferences of visitor in urban park, especially at The Green Park Kitakyushu. It is also found that water body was the most wanted facility. It is not only confirms the effect of seasonality difference but also outdoor thermal quality for visiting the park. The chapter six found that there are no significant correlation between outdoor thermal comfort and three personal variables: gender, age, and body proportion. But this finding found other important thing that the character of a person to answer the question from stranger (interviewer) influences the result of studies. For this research, Japanese people's character which are relatively have a closed personality (introvert) influences the number of data gain that are related to private reason (age, height, and weight).

The study in chapter seven found the user's perception of outdoor thermal comfort and the relationship between micro-meteorological and personal variables of outdoor thermal comfort. It is found that the most significant micro-meteorological variable for the PET value is mean radiant temperature (Tmrt). The study in chapter eight simulate the thermal environmental performance and urban structure in urban park. The last, chapter nine is the section for conclusions and recommendations.

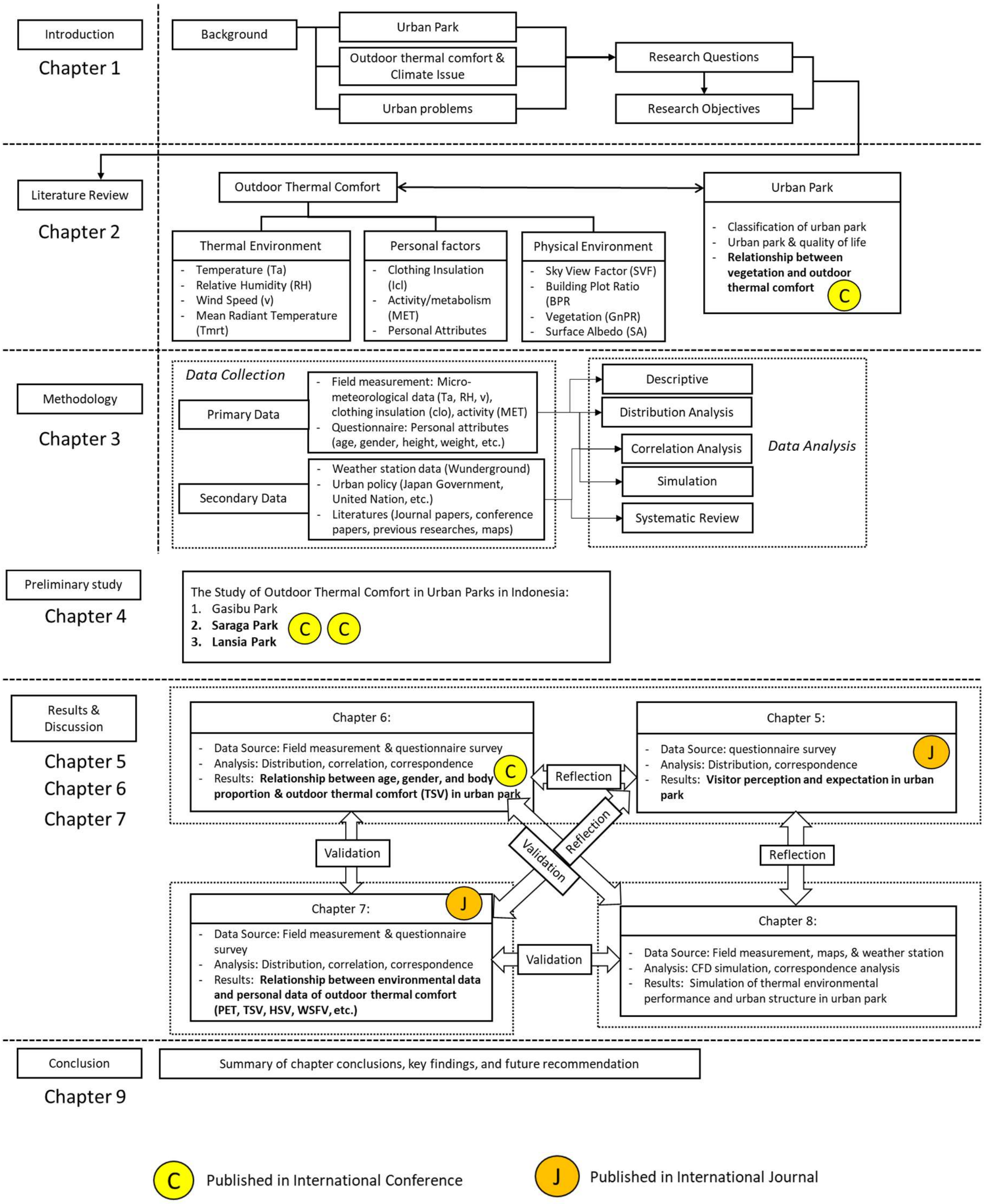


Figure 1. Research framework

CHAPTER 2

LITERATURE REVIEW

2.1. Overview of Urban Park

2.1.1. Classification of Urban Park

According to Hayward in Brill et al. (1989), urban park are community assets. It provide a convenient setting for a broad variety of leisure and recreational activities, as well as enhancing the image and perceived value of the community (Brill et al., 1989). Urban parks can serve a variety of needs and interests: rich and poor, groups and individuals, men and women, young and old, and all cultural and ethnic groups. This breadth of coverage makes city parks an extraordinary asset, both for social, behavioral, and physical interests, for a better quality of life. The reason for the community to visit the park is not only because of proximity distance, but also park's attractiveness and the suitability of community characteristics with the theme of the park (Widyahantari & Rudiarto, 2019). The classification of activities leads to the type of park's activities, such as sports, cultural, arts, and social (Adiati, Lestari, & Wiastuti, 2018).

According to The Ministry of Land, Infrastructure, Transport, and Tourism of Japan (MLIT, 2006), the urban park is divided into five types: Basic Parks for Community Use, Basic Parks for City Wide Use, Large Scaled Parks, National Government Park, and Buffer Green Belts. The residential neighborhood unit is equal to residence unit of about 1km square (surface area of 100 ha) surrounded by arterial streets. The classification is differed into several types which been shown on the table 1.

The definition of Green Open Space (GOS) is stated in Law Number 26 of 2007 concerning Spatial Planning and Minister of Public Works Regulation No. 05/PRT/M/2008 concerning Guidelines for Provision and Utilization of Green Open Space in Urban Areas. GOS is defined as an area/lane that extends and/or clusters, whose use is more open, where plants grow, both those that grow plants naturally or those that are intentionally planted. In particular, Law no. 26 of 2007 mandates the need for the provision and utilization of green open space, the proportion of which is set at least 30% of the city's area. Meanwhile, the definition of Urban Green Open Space (UGOS) based on the Minister of Home Affairs Regulation Number 1 of 2007 concerning UGOS is part of the open space of an urban area filled with plants and plants to support ecological, social, cultural, economic, and social benefits and aesthetics.

Table 1. Classification of city parks by MLIT (Japan)

Types	Classification	Description
Basic Parks for Community Use	City Block parks	Those which are to be placed for the use of most nearby residents; their standard area is 0.25 ha per park, and each will be intended to be used by residents who live within a certain area with radius of 250 m.
	Neighborhood parks	Those which are to be placed for use by residents who live in the neighborhood; one neighborhood park will be provided in each neighborhood unit. Their standard area is 2 ha par park, and each will be intended for use by residents who live within a certain catchments area with radius of 500 m.
	Community parks	Those which are to be placed for use by those who live within walking distance; their standard is 4ha or more for specific district parks (Specified community parks) in certain municipalities that are not covered in urban planning areas.
Basic Parks for City Wide Use	Comprehensive parks	Those which are to be placed for use by all residents in a city for various purposes, including rest, walking, playing and sport; their standard area range from 10 to 50 ha according to the size of the city.
	Sport parks	Those which are to be placed for use by all residents in a city mainly for athletic activities; their standard area range from 15 to 75 ha according to the size of the city.
Large Scaled Parks	Regional Parks	Those which are placed for the purpose of satisfying area-wide weekend recreation needs of residents of more than one municipality. Their standard area is at least 50 ha and their recreational facilities are placed organically.
	Recreation Cities	Areas where a variety of recreation facilities are provided mainly in a large-scale urban park; these cities aim at meeting area-wide recreation needs of residents of large cities or other cities, which are constructed in accordance with a comprehensive city plan. Total area will be 1,000 ha.
National Government Parks		Large-scaled parks established by the government for use by residents of more than one prefecture; their standard area is at least 300 ha per park; in case these parks are constructed as the government's commemorative project, they should have facilities suitable for their objectives.
Buffer Green Belts	Specific Parks	Special parks, such as scenic parks, zoos and botanical parks, historical parks, cemeteries, etc. are set up in accordance with their objectives.
	Buffer Green Belts	Green belts intended to help prevent or reduce pollutions like air contamination, noises, vibrations and bad odors, or to prevent disasters in industrial complexes, etc. They are provided at locations where areas with sources of pollution or disasters and residential or commercial areas must be separated.
	Ornamental Green Spaces	Green Space provided to maintain and improve natural environment of a city and to better urban landscape, and their standard area is at least 0.1 ha per lot; when in an established city area there are existing woods, etc., or when green belts are provided to expand green belts by planting trees for a better urban environment, the standard area is 0.05 ha or more.
	Greenways	Green belts which are mainly composed of passages with tree plantings, pedestrian ways or cycling courses. They aim to secure escape roads in an emergency case. They naturally connect parks to houses, schools, shopping centers, etc.

Source: The Ministry of Land, Infrastructure, Transport, and Tourism of Japan (MLIT, 2006)

The Minister of Public Works of Indonesia regulates the provision of green open space based on the population of an area and park category in the regulation No.05/ PRT/M/2008 (Guidelines of Provision and Utilization of Green Open Space in Urban Areas, 2008). The type of GOS is categorized by nature, function, structure, and ownership as shown on the table 2.

Table 2. Green open space categories by Minister of Public Works (Indonesia).

Nature	**Function**	**Structure**	**Ownership**
Natural	Ecology	Ecological pattern	Public
	Social-cultural		
Artificial	Aesthetic	Planological pattern	Private
	Economy		

The provision of park in Indonesia is classified based on the population of an area. There are five park category which included, they are Taman RT (neighborhood park), Taman RW (hamlet park), urban village park, district park, and city parks (Sahalessy, Krisantia, & Budiyanti, 2019; Widyahantari & Rudiarto, 2019).

Table 3. Park category and service coverage by Minister of Public Works (Indonesia).

Unit (population)	**Park Category**	**Wide area (m^2)**	**Standard (m^2/person)**	**Location**	**Service coverage (m)**
250	Neighborhood parks	250	1.0	Neighborhood area	100
2,500	Hamlet park	1,250	0.5	Hamlet area	1,000
30,000	Urban Village park	9,000	0.3	Urban village area	1,500
120,000	District parks	24,000	0.2	District area	2,000
480,000	City's parks	144,000	0.3	In the city center	5,000

Adapted from Sahalessy et.al. (2019) and Widyahantari et al. (2019)

2.1.2. Urban Park and the Quality of Life

The topic of urban parks has been discoursed in various studies. Urban parks offer tremendous benefits towards improving people's quality of life (Shuib, Hashim, & Nasir, 2015). Some studies discuss it from an environmental perspective as one of the contributors to green open space for a city. Another study sees it from a social perspective, namely as a public open space and its relation to its nature, function, and use for society. Others see it as a space to increase the economic value of the urban community, a space that directly functions as a place for buying and selling activities. These three aspects are parameters often used to assess the quality of life in urban society.

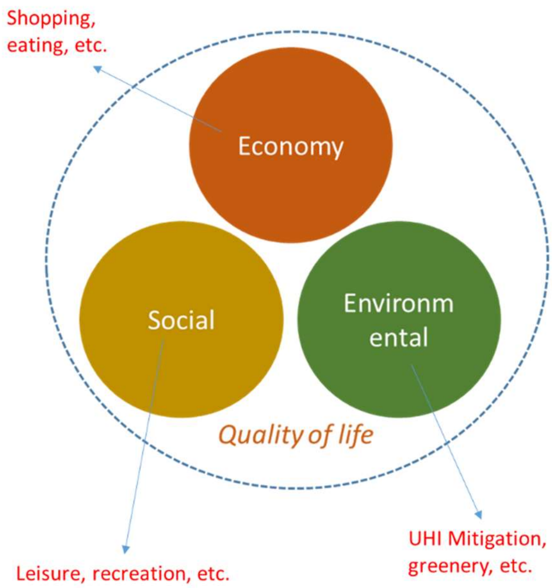


Figure 2. Urban park and the quality of life

The environment aspect of urban park comprises the elements of vegetation, water, material, and physical attributes. The elements of urban park such as green spaces, water elements, and physical attributes is also needed for the interaction between human and nature (Ibrahim, Omar, & Nik Mohamad, 2017). The contribution of vegetation in urban parks is important for habitat of bird community (Sulaiman, Mohamad, & Idilfitri, 2013). To enrich vegetation it is recommended to use large trees and lawns for the construction of open spaces, which not only to provide visual permeability, but also to allow more shade for the recreational space, avoiding direct sunlight in the hot summer (Cheng, Cheng, & Tang, 2020). It is reported that a large park has a cooling effect on the urban environments adjacent to the park, and this cooling effect extended approximately 1.4 km from the park boundary. Increasing the percent vegetation cover could significantly decrease air temperature (Yan et al., 2018). The planting design of an urban park has a significant influence on thermal comfort, especially on winter (Afshar, Karimian, Doostan, & Nokhandan, 2018). Other study found that the material factor has a significant effect on both auditory and haptic perception which confirming that the soundscape appreciation for people walking in urban parks is likely to be affected (Aletta, Kang, Fuda, & Astolfi, 2016). It also means that the footpaths and the walking sounds are other important factors to be considered in designing an urban park.

In social perspective, a study in Shah Alam, Malaysia confirmed that urban park provided the potential for psychological well-being, comprises people's level of satisfaction and emotion as one of attributes to value the quality of life (Hamdan, Khalid, & Baba, 2017). Other study found that there was a difference of seasonal variation in visitor satisfaction of an urban park. The natural characteristics was important in the high-season, while the park activities was important in off-season (D. C. Geng, Innes, Wu, Wang, & Wang, 2021). This finding was confirmed by another study in Malaysia, while the aspects of park quality are significantly correlated to the level of physical activity (Rosli, Leh, Adzmi, & Marzukhi, 2020). A study in five urban park in Netherlands revealed that urban park can stimulate people to do a social interaction, whether with the people with whom they visit the park or with other, neither known or unknown people (Peters, Elands, & Buijs, 2010). Other found that diversity of subspaces including vegetation density, animal populations, undulating landforms and water bodies afford social interaction behavior (Rasidi, Jamirsah, & Said, 2012).

Other perspective is from the administrational view. A study of public green open spaces in Palembang, Indonesia, found that the development of the open spaces is also involving cooperation between the government sector and the private sector (Alfatih, D. Sartika, & H. Enh, 2018). The government acts as a land provider and the private sector as the organizer or financial supporter in managing the city park.

2.2. Overview of Outdoor Thermal Comfort

2.2.1. Thermal Comfort

The study of thermal comfort began in the mid-1930s when Winslow, Herrington and Gagge laid the foundations for human thermoregulation and partition calorimetry (A P Gagge, Herrington, & Winslow, 1937). The American Society of Heating, Refrigerating and Air Performance Engineers (ASHRAE) defines thermal comfort as a state of mind that expresses satisfaction with the thermal environment (ASHRAE, 2013). This definition provides a physiological and sensory basis for the concept of "thermal comfort" (A. P. Gagge, Stolwijk, & Hardy, 1967). In indoor environment, the range of thermal comfort for neutral temperature sensation is between 28 °C and 30 °C, where there is an absence of temperature regulatory effort by sweating, vasoconstriction, and vasodilation (A. P. Gagge et al., 1967).

The topic of outdoor thermal comfort study has been carried out by many experts (Binarti, Koerniawan, Triyadi, & Matzarakis, 2022; Huang et al., 2016; Kruger & Drach, 2017; Lai, Liu, Gan, Liu, & Chen, 2019; Watanabe, Nagano, Ishii, & Horikoshi, 2014). Studies on the impact of shading, the presence of trees, and vegetation on decreasing city temperatures show a positive effect during the day (Duarte, Shinzato, Gusson, & Alves, 2015; Morakinyo, Kong, Lau, Yuan, & Ng, 2017). Many evaluations and simulations of the city's temperature cooling performance through vegetation have also been carried out (Gao, Li, & Ojima, 2002; Salata, Golasi, de Lieto Vollaro, & de Lieto Vollaro, 2016; Tan, Liao, Bedra, & Li, 2021; J. Wang et al., 2002). Tan, Liao, Bedra, and Li evaluated the 3D cooling performances of the three vegetation combination scenarios in the urban area using the ENVI-met model. Based on this study, shadow can directly affect the 3D cooling effect of the vegetation combination (Tan et al., 2021). The larger the shaded area, the better the cooling effect for the same vegetation cover.

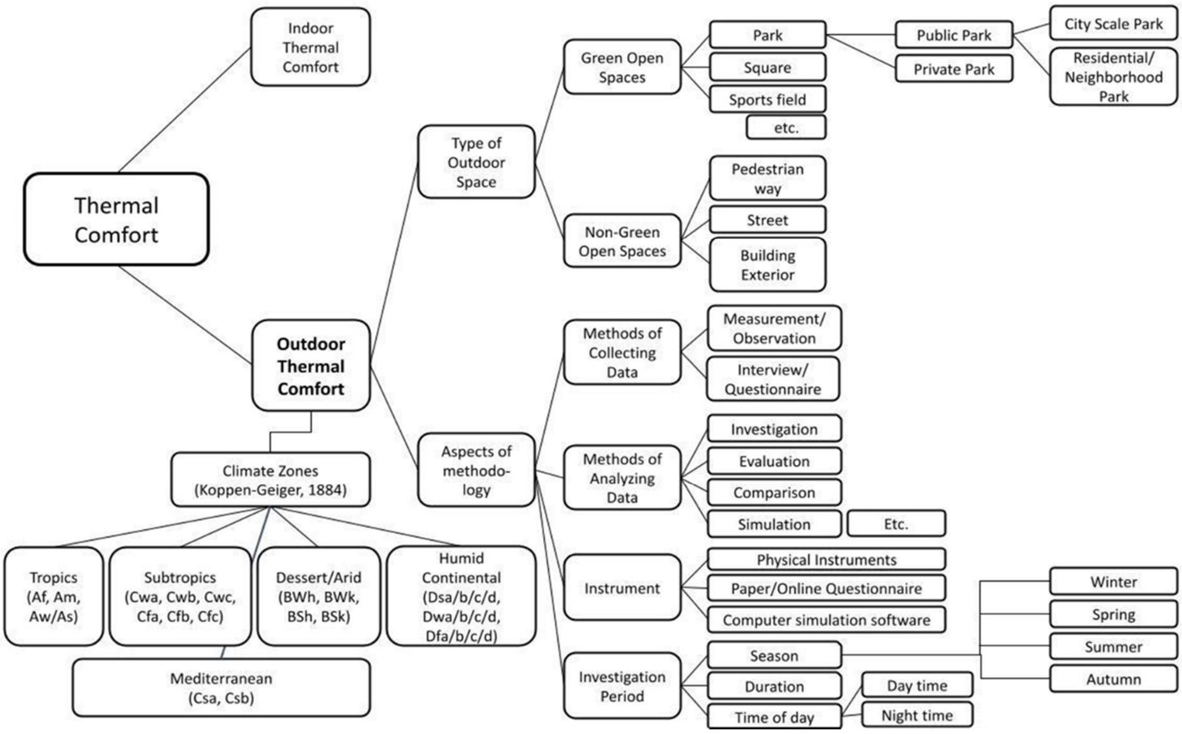


Figure 3. Framework of thermal comfort study

A study in Sao Paulo found that during autumn, April 2013, the average maximum air temperature difference reached 0.5 °C and in February 2014, during the extreme warm summer, air temperature differences became more significant, and the effect of vegetation was slightly more pronounced showing maximum air temperature differences up to 0.6 °C (Duarte et al., 2015). An outdoor thermal comfort study in Taiwan found that there are three categories of thermal comfort values based on the PET (physiologically equivalent temperature) value, namely: thermal suitable (PET between 22–34 °C), thermal stress (PET >38 °C), and cold stress (PET <18 °C) (T. P. Lin & Matzarakis, 2011). Other study found the thermal acceptable range for an entire year was 21.3–28.5 °C PET (L. Chen & Ng, 2012). While in Qinghai-Tibet Plateau (a cold highland area) using three categories of thermal performances that are still acceptable to the community, namely PET 13–18 °C (slightly cool), PET 18–23 °C (neutral), and PET 23–29 °C (slightly warm) (R. Li & Chi, 2014).

2.2.2. Thermal Comfort Factors

2.2.2.1. Thermal Environment Factors

A. Air Temperature (Ta)

Air temperature is the temperature of the air surrounding the human body in degree Celsius (°C). It can be measured by a *dry bulb thermometer* and *thermal recorder*.

B. Relative Humidity (RH)

Relative humidity is the ratio between the actual amount of water vapor in the air and the maximum amount of water vapor that the air can hold at that air temperature. This variable can be measure by *thermal recorder*.

C. Mean Radiant Temperature (Tmrt)

Thermal radiation is the heat that radiates from warm objects which may be present if there is a heat source in an environment. Radiant temperature has a greater influence than air temperature on how we lose or gain heat to the environment. Mean radiant temperature is a uniform temperature of a black radiating surrounding surface, which has the same radiation gain for the human body as the actual outdoor radiation fluxes, which are frequently very non-uniform. The measurement of Tmrt for the indoor space uses a *globe thermometer*, while the outdoor uses a *solarimeter*.

D. Wind Speed or Air Velocity (v)

The air velocity describes the speed of air moving across the human body. Outdoor wind speed is measured by an *anemometer*, while indoor wind speed is measured by a *kata-thermometer*. In 1805, the wind speed scale was first discovered. For wind gusts that can cause destruction, the scale starts from 1 for the calmest gust of wind to 12. The Beaufort scale is an empirical measure that relates wind speed to observed conditions at sea or on land. The scale was devised in 1805 by the Irish hydrographer Francis Beaufort. The scale that carries Beaufort's name had a long and complex evolution from the previous work of others. Wind speed on the 1946 Beaufort scale is based on the empirical relationship (Beer, 1996):

$$v = 0.836\ B^{3/2}\ \text{m/s}$$

Where v is the equivalent wind speed at 10 meters above the sea surface and B is Beaufort scale number. For example, B = 9.5 is related to 24.5 m/s which is equal to the lower limit of "10

Beaufort". Using this formula the highest winds in hurricanes would be 23 in the scale. The following table shows the Beaufort scale of wind speed.

Table 4. Beaufort scale of wind speed

Beaufort scale	**Wind power**	**Wind speed (km/h)**	**Wind speed (m/s)**
0	Calm	<1	<0,27
1	A little calm	1-5	0,28 – 1,38
2	A little gust of wind	6-11	1,67 – 3,05
3	Gentle wind	12-19	3,33 – 5,27
4	Medium gust of wind	20-29	5,55 – 8,05
5	Cool breeze	30-39	8,33 – 10,83
6	Strong wind	40-50	11,11 – 13,88
7	Close to tight	51-61	14,67 – 16,94
8	Tight	62-74	17,22 – 20,55
9	So tight	75-87	20,83 – 24,16
10	Storm	88-101	24,44 – 28,05
11	Great storm	102-117	28,33 – 32,5
12	Typhoon	>118	>32,77

2.2.2.2. Personal Factors

A. Clothing Insulation (I_{cl})

The existence of clothing reduces the power of heat release from the human body. Therefore, clothing grades are classified according to their insulation value. The unit commonly used for measuring clothing insulation is the Clo unit. The more technical unit m^2 °C/W is also often used (1 Clo = 0.155 m^2 °C/W). The Clo value can be calculated by adding the Clo value to each outfit. Currently, there are many ways to measure clothing levels, one of which is using the CBE Thermal Comfort Tool web application (Tartarini, Schiavon, Cheung, & Hoyt, 2020). The calculation standard used refers to the ASHRAE 55-2020 standard.

B. Activity level

The level of human activity is measured based on the value of its metabolism. Metabolism is the energy released in the oxidation process in the human body which depends on muscle activity. Metabolism is measured in MET (1 MET = 58 W/m^2 body surface). A normal adult human has a surface area of 1.7 m^2, and a person in thermal comfort with an activity level of 1

MET will have a heat loss of approximately 100 W. In assessing metabolic rate, it is important to use the average human activity shown in the last 1 hour.

Table 5. Human activity metabolism rate

No.	Activity	W/m^2	Metabolism Rate (MET)
1	Sitting, relaxed	58	1
2	Standing, relaxed	70	1,2
3	Fixing clock	65	1,1
4	Sedentary activities (office, school, home)	70	1,2
5	Driving a car	80	1,4
6	Standing, light activity (shopping, laboratory, light industry)	93	1,6
7	Teaching	95	1,6
8	Household work, including washing	100	1,7
9	Walking at a speed of 2 km/h	110	1,9
10	Standing, moderate activity (homework)	116	2
11	Running at a speed of 5 km/h	200	3,4

Adapted from Sugini (2014) and Olesen et al. (2001)

B. Age, Gender, and Body Posture

Age, gender, and body posture are used in calculating the value of human thermal comfort. Studies on this have been carried out and concluded that there is no significant difference between men and women (S. Karjalainen, 2012). It is clear that women express dissatisfaction more easily than men in the same thermal environment with a ratio of 1.74 (95% confidence interval: 1.61 – 1.89). In addition, women are also more sensitive to deviations from an optimal temperature, especially in colder room performances. Similarly, the results with differences in gender and body posture (Sugini, 2014).

2.2.2.3. Urban structure Factors

A. Sky View Factor (SVF)

Sky View Factor (SVF) is the ability to view the sky. This visibility can be blocked by buildings and other objects on the city surface (Wicahyani, Sasongko, & Izzati, 2014). An analytical study in Beijing found that the extent of shading contributes to variations in thermal perception distribution. Highly shaded areas (SVF <0.3) typically exhibit less frequent hot conditions during summer, while enduring longer periods of cold discomfort in winter than moderately shaded areas (0.3< SVF <0.5) and slightly shaded areas (SVF >0.5), and vice versa (Dirksen, Ronda, Theeuwes, & Pagani, 2019). SVF is related to human thermal comfort because it can affect Tmrt which is the average of direct radiation and reflected long and short wave radiation that hits the body (Middel, Lukasczyk, Maciejewski, Demuzere, & Roth, 2018). The closer the location of the building or tree canopy, the less SVF and increased heat release at night because the area becomes a heat trap for solar radiation so that heat is difficult to release into the atmosphere during the day (Wicahyani et al., 2014).

SVF has a value of 0-1 where an SVF value of 1 means that the view of the sky is open or unobstructed on all sides. A higher SVF value indicates a decrease in shade density so that high radiation reception increases the PET value which reduces thermal comfort. A lower SVF value means that the sky is getting bigger. Areas that are open and have a wider view of the sky give the effect of higher heat.

B. Green Plot Ratio (GnPR)

The existence of vegetation in the urban open space can be known by calculating the value of the vegetation ratio. The Regional Vegetation Ratio or also known as Green Plot Ratio (GnPR) is the percentage of the green zone seen in regional images. The green zone is vegetation, which can be on the form of trees, shrubs, or grass. The term GnPR was first put forward by Ong in 2003 in a journal that discussed landscape and urban design issues. It is based on a common biological parameter called Leaf Area Index (LAI), which is defined as the area (one side) of a leaf per unit area of land (Ong, 2003). Simply put, it is the average LAI of the green area in an area and is presented as a ratio similar to the Building Plot Ratio (BPR). GnPR allows for more precise regulation without eliminating the presence of buildings in an area. This can make it easier to design while protecting the green area in a design. It was developed intending to optimize the amount of green space, or plant coverage, in an urban environment (Scott Henson, 2019). To calculate the percentage of GnPR, the area observed is the total area or 100%. Meanwhile, the value of the GnPR percentage is calculated from the comparison of the green area with the total area. For example, if the area is 2000 m^2 and the green area is 1000 m^2, then the GnPR percentage value for the area is 50%.

C. Building plot ratio (BPR)

The term of Building Plot Ratio (BPR) is used to determine the ratio of built surface area to the total area of an environment. Plot ratio is the ratio of the total floor area of a building to the area of the site (Shape Urban, 2019). For example a plot ratio of 1.0 means that the floor area is equal to the site area. The land cover associated with low temperature is vegetation, while the location associated with high temperature is built-up land (Wicahyani et al., 2014).

D. Surface Albedo (SA)

Albedo is originally comes from Latin which means whiteness. It also means the ratio of reflected to incident light. Albedo refers to how reflective and bright something is. For example, snow has a high albedo. It compares the amount of light hitting the surface of the object to the amount of reflected light (IXL Learning, 2022). Surface albedo is a key ingredient in remote sensing of surface and atmospheric properties from space (Coakley, 2003). The fraction absorbed by the surface is thus given by the fraction not reflected. It is energy which raises the surface temperature, evaporates water, spawns turbulent exchange with the overlaying atmosphere, etc. (Coakley, 2003). A related study in California found that the measured albedo of pavement materials is high in the early morning and in the late afternoon; it is low and constant over time in the mid-day (Hui Li, 2012). It suggests that the albedo should be measured in the mid-day of a clear day to get a stable and conservative value.

Different albedo concept are defined into two (VITO NV, 2022):

1) The black-sky albedo (directional albedo or directional-hemispherical reflectance) is the integration of bi-directional reflectance over the viewing hemisphere. All energy is assumed coming from a direct radiation of the sun. It is computed for specific time.
2) The white-sky albedo (hemispherical albedo or bi-hemispherical reflectance) is the integration of directional albedo over the illumination hemisphere. It assumes a complete diffuse illumination.

The urban air temperature performances reduce as tree quantity, ground surface albedo values, and green roof area increase (Y. Chen, Zheng, & Hu, 2020). Increasing the albedo of the courtyard walls and roof led to higher mean radiant temperatures within the courtyard which also means to higher PET (Taleghani, 2018). By increasing the albedo by 0.1, PET increased 0.8 °C. Therefore, increasing the surface albedo made the open space of the courtyard uncomfortable. Other research (Hui Li, 2012) mentioned that lower surface albedo not automatically leads to lower stress on humans, since the reflected shortwave radiation has a strong influence on mean radiant temperature and human body energy balance. In a recent study (Lopez-Cabeza, Alzate-Gaviria, Diz-Mellado, Rivera-Gomez, & Galan-Marin, 2022), it is found that albedo has a low influence on the maximum air temperature of the courtyard (up to 0.2 °C higher with low albedo around 0.1). In contrast, the influence of albedo on the temperature of the surfaces is high (up to 25 °C higher with low albedo surfaces), as is the mean radiant temperature of the courtyard (up to 5 °C higher with high albedo), affected by reflected solar radiation and surface temperature radiation.

2.2.3. Thermal Comfort Indices

Several indices are being used to calculate thermal comfort, such as new effective temperature (ET*) (A. Pharo Gagge & Gonzalez, 1974), operative temperature (ASHRAE, 2013), and standard effective temperature (SET) (A P Gagge, Fobelets, & Berglund, 1986), Out_SET* (ASHRAE, 2013; Janelle Pickup & de Dear, 2000), Universal Thermal Climate Index (UTCI) (Höppe, 2002; Lai, Guo, Hou, Lin, & Chen, 2014; Lai et al., 2019), PET (Höppe, 1999; Mayer & Matzarakis, 1998), and Outdoor Environmental Heat Index (OEHI) (Golbabaei, Heidari, Shamsipour, Forushani, & Gaeini, 2019). For the indoor environment, the most popular index is Predicted Mean Vote (PMV) (Broday, Moreto, Xavier, & de Oliveira, 2019).

1) ET, ET*, and SET

ET (Effective Temperature) was discovered by Houghten, Yaglou and colleagues in 1923, while the New Effective Temperature (ET*) was discovered by Winslow, Herrington, and Gagge in 1980. A new finding in ET* is to (operative temperature). The next finding is the SET (Standard Effective Temperature) which adds two other indicators, namely Discomfort (DISC) and w.

To calculate the SET value, a formula is used based on the findings of Winslow, Herrington, and Gagge (1980) as follows (Sugini, 2014).

1. Collecting data that can be known, namely:
    a) Metabolic rate based on activity in met units
    b) The value of the insulation of clothing worn in units of clo
    c) Air temperature (Ta) with units of °C
    d) Average radiation temperature (Tmrt) in units of °C
    e) Wind speed (v) with units (m/s = m/s)
    f) Air humidity (RH)
2. Finding the operative temperature (to) based on the standard chart
    a) Choose a graph to match the performances of RH, v, and activity (met)
    b) Based on the graph, it can be found to by converging the lines Ta and Tmrt.
3. Search for SET, DISC, and w with the standard graphs available
    a) Choose a graph that matches the characteristics of v, clo, and activity (met)

b) Based on the selected graph, SET will be found by: 1) Finding the point where the to line meets the humidity (RH) line; 2) SET is obtained by looking at the position of the point on the scale point formed by the meeting of the humidity line with 7 lines of known SET value in the graph. SET is calculated by interpolation. 3) The same way is done to search for DISC and w.

2) PMV *(Predicted Mean Vote)* and PPD *(Predicted Percentage of Discomfort)*

PMV is an index of thermal comfort introduced by Fanger from the University of Denmark in 1982 and has been standardized to ISO 7730 (ISO, 2005). This index indicates the sensation of cold (cold) and warm (warmth) felt by humans on a scale of -3 to +3. With indications of -3 very cold (cold), -2 cold (cool), -1 slightly cold (slightly cool), 0 normal (neutral), +1 slightly warm (slightly warm), +2 warm (warm), and +3 hot (hot). Thermal comfort parameters are in the range of PMV values -0.5 to +0.5. PMV-PPD accuracy varied strongly between ventilation strategies, building types and climate groups (Cheung, Schiavon, Parkinson, Li, & Brager, 2019).

The equation uses steady-state heat balance for the human body and postulates a relationship between the deviation from the minimum load on the heat balance reception mechanism and thermal comfort vote. The bigger the load, the more the comfort vote deviates from 0. To calculate the PMV value, it can be calculated manually using the following equation (Mayer & Matzarakis, 1998):

$$PMV = f\ (H/A_{Du}\,, I_{cl}, T_a, VP, v, T_{mrt}) \qquad (1)$$

H/A_{Du} : Internal heat production per m^2 surface area of the human body (depends on the kind of human activity)

I_{cl} : Heat transfer resistance of the clothing

T_a : Air temperature

VP : Vapor pressure

v : Relative wind velocity (relative to human body)

T_{mrt} : Mean radiation temperature of the environment

Where the values for H/A_{Du} and I_{cl} are available within handbooks of physiology written by Hoppe (1984 and 1993).

As for the PPD index, the thermal comfort performance is at a value of less than or equal to 5%. The table for comparison of PMV and PPD index values is shown in table below.

Table 6. Thermal sensation scale, PMV, and PPD

PMV	PPD	Thermal Sensation
+3	100	Hot
+2	75	Warm
+1	25	Slightly warm
0	5	Neutral
-1	25	Slightly cool
-2	75	Cool
-3	100	Cold

Adapted from ISO 7730:2005 (ISO, 2005)

3) PET *(Physiological Equivalent Temperature)*

Thermal comfort can also be determined by using the PET (Physiological Equivalent Temperature) index. The advantage of using this index when compared to other thermal indices is that PET uses a unit of degrees Celsius (ºC) which is widely known by the public, so the results are easier to understand (Matzarakis et al., 1999). To determine the value of thermal comfort in outdoor spaces, the PET index is more widely used compared to other indices (Koerniawan, 2013, Chen, 2015; and Targhi, 2015).

PET is defined as the air temperature required to reproduce in a room with a certain standard of body heat production and human skin surface heat (Mayer & Matzarakis, 1998). The internal heat production standard is 80 W and the clothing resistance value to heat transfer is 0.9 clo. The following table is a comparison between PMV and PET scale. It also shows a range of PET values for various human-perceived thermal perceptions and human psychological burdens.

Table 7. Comparison of PMV and PET scale

PMV	PET[a] Moderate Region (ºC)	PET[b] (Sub) Tropical Region (ºC)	Thermal Perception	Grade of Physiological Stress
			Very cold	Extreme cold stress
-3.5	4	14	Cold	Strong cold stress
-2.5	8	18	Cool	Moderate cold stress
-1.5	13	22	Slightly cool	Slight cold stress
-0.5	18	26	*Comfortable*	*No thermal stress*
+0.5	23	30	Slightly warm	Slight heat stress
+1.5	29	34	Warm	Moderate heat stress
+2.5	35	38	Hot	Strong heat stress
+3.5	41	42	Very hot	Extreme heat stress

Adapted from Mayer and Matzakaris (1998) and Lin and Matzarakis (2011).

4) TSV *(Thermal Sensation Vote)*

TSV adopts the thermal sensation scale with the same standard as PMV (7 points), i.e. cold, cool, slightly cool, average (neutral), slightly warm, warm, and hot. Until now, the TSV index is an index that is often used in research to determine user perceptions of thermal comfort in outdoor spaces (Lin, 2009; Koerniawan, 2013; Chen, 2015).

2.2.4. Thermal Comfort Calculations

To determine the value of thermal comfort in an environment can be done in two ways, namely manually and digitally or with the help of a computer. To calculate manually, you can use the formulas according to the thermal comfort index used. For example, to calculate SET manually, it is used the formula by Winslow, Herrington, and Gagge (1980). While digitally, currently there are several software that can calculate thermal comfort with the help of a computer. Among them are parameter software from ASHRAE, Excel worksheets from Håkan Nilsson, RayMan calculation software, and ENVI-met simulation software.

1) Parameter Software from ASHRAE

ASHRAE is a global community founded in 1894 to advance human well-being through environmental technologies. This software can generate several types of data, including ET*, SET*, DISC, PMV, and PPD. Calculations in this software use ASHRAE-55 2004 guidelines.

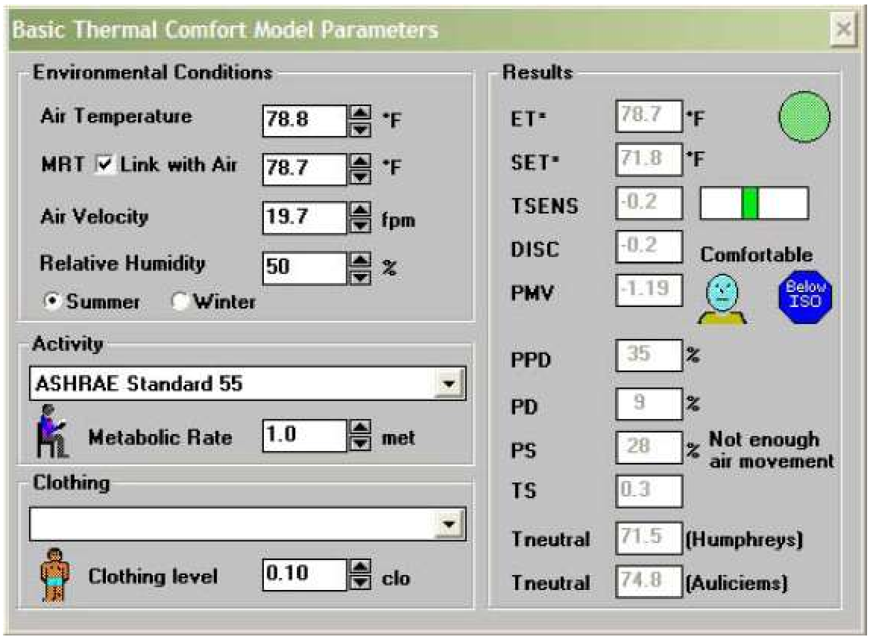


Figure 4. ASHRAE Software Interface

2) Worksheets Ms. Excel from Håkan Nilsson

In addition, there is a special modification table to calculate the thermal comfort figure for the PMV model which was carried out by Håkan Nilsson from the Department of Technology and Built Environment, Laboratory of Ventilation and Air Quality, University of Gävle. This table is made in worksheet format for Microsoft Excel (.xls) software and works by entering data to be calculated, including: clothing (clo), air temperature (°C), mean radiant temperature (°C), activity (met), water speed (m/s), and relative humidity (%). This software produces data as operative temperature (°C), PMV and PPD. The following figure is an interface of the PMV/PPD calculation table that created by Håkan Nilsson.

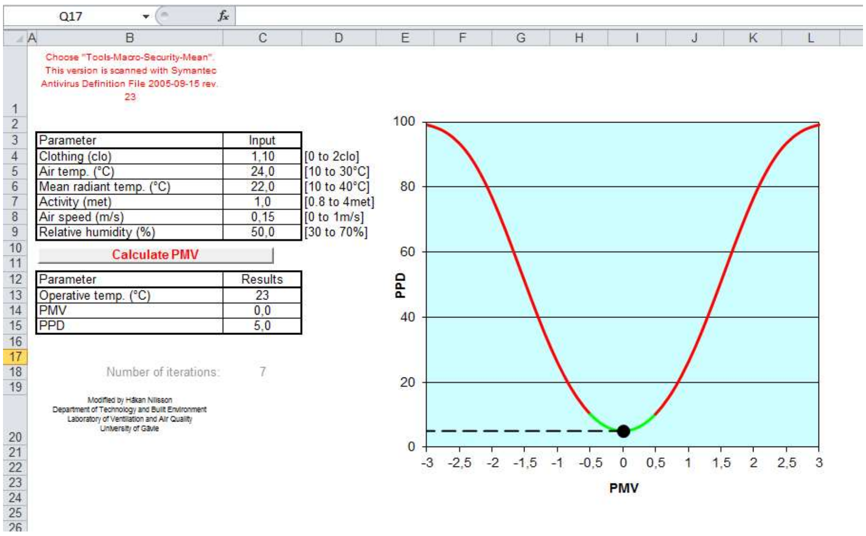


Figure 5. Home Worksheet from Håkan Nilsson

3) RayMan Calculation Software

In addition there is a software called RayMan which was developed by Dr. Andreas Matzarakis and team from the Meteorological Institute, University of Freiburg, Germany since the early 2000s. This device can calculate radiation changes and showing thermal properties such as PET, in both simple and complex environments (Matzarakis et al, 2000). From this software, it can be seen the value of thermal comfort as PMV, PET, and SET*. This software can be downloaded for free by accessing the internet site http://www.mif.uni-freiburg.de/RayMan/intro.htm. The following figure is an interface of the RayMan software version 3.1 Beta.

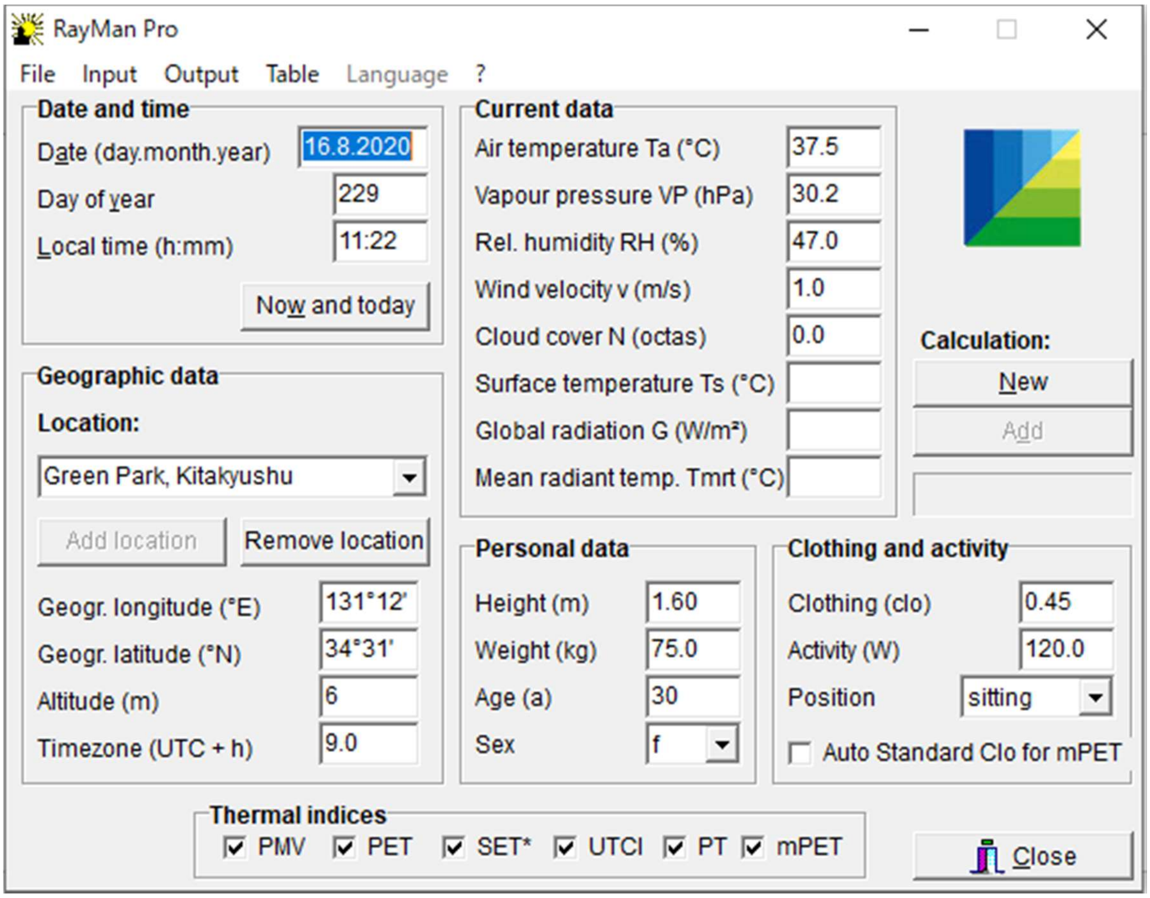


Figure 6. RayMan Software Interface

4) ENVI-met Simulation Software

ENVI-met is one simulation software that can calculate and display the thermal comfort performance of an environment in a square-form so that researchers can find out what variables need to be increased or decreased to reach a comfortable level. This software is very suitable for evaluating thermal comfort in spaces outside buildings. The following figure is the interface of the ENVI-met version 5.0.2 software.

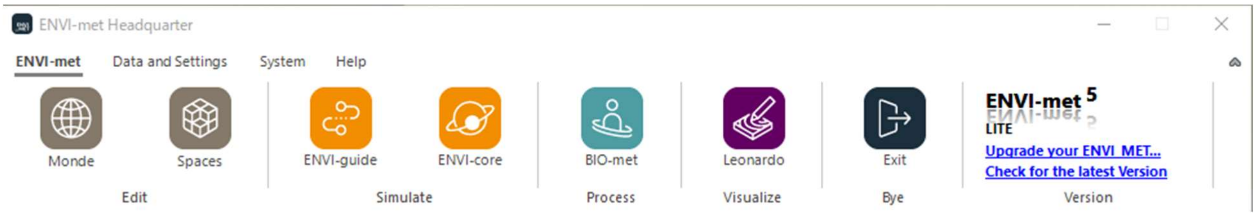


Figure 7. ENVI-met Software Interface

This simulation software has four main tools, they are:

1) *Editing tools: Monde and Spaces* to animate the existing performance of urban structure, such as buildings, vegetation, road, and paving; these tools plays as the base part of simulation.

2) *Simulation tools: ENVI-guide and ENVI-core* to calculate the thermal performance of a built environment, such as potential air temperature, relative humidity, specific humidity, wind speed, wind direction, mean radiant and temperature; where ENVI-guide is a tool for setting the general information and meteorology of simulation data and the ENVI-core is a tool to check and run the simulation. These two tools plays a key role as the machine of the software.

3) *Processing tool: BIO-met* to evaluate thermal comfort based on several most popular indices used in the topic, such as PMV/PPD, PET, UTCI, and SET. This tool provides a standard personal human parameter like age, gender, weight, height, clothing, and activity (metabolism rate) which also can be edited manually based on researchers' data sources.

4) *Visualizing tool: Leonardo* to visualize the results of calculation, such as atmosphere data (potential air temperature, and relative humidity), surface data (surface albedo, and sky view factor), and Biomet data (PMV and PPD).

2.3. Relationship between Vegetation Planning and Thermal Comfort of Urban Open Spaces

2.3.1. Introduction

This study summarizes the relationship between the planning of vegetation and the human thermal comfort of urban green open spaces through a literature review. It used a qualitative method and structured literature study. The process begins by collecting references to many articles related to the topic using keywords such as outdoor thermal comfort, urban green spaces, cooling effect, urban cooling island, park cooling island, urban heat island mitigation, and vegetation planning. This study is built on a systematic mindset. Research frameworks are structured to sharpen the flow of thought, so that researchers can focus on certain aspects that are under the research objectives. The focus of this literature study is exploring the outdoor thermal comfort papers, they are the type of outdoor space whether green or non-green open spaces. Whether it is park, square, sports field, or others, the type of green open spaces is being identified. The non-green open space's type is also being specified, whether it is a pedestrian way, street, building exterior space, or others. Public or private parks and the scale of parks are also being identified.

The aims of this study are:

1. To find out the most popular methods for collecting outdoor thermal data in thermal comfort and urban open space studies.
2. To find out the most popular methods for analyzing outdoor thermal data in thermal comfort and urban open space studies.
3. To find out the most popular outdoor thermal instruments in thermal comfort and urban open space studies.
4. To find out the popular time for investigation periods in thermal comfort and urban open space studies.
5. To understand the role of Urban Cooling Island (UCI) and Park Cooling Island (PCI) in thermal comfort and urban open space.
6. To understand the vegetation effects on thermal comfort in urban open space.

2.3.2. Materials and Methods

In the aspects of method, the research papers is classified based on four aspects; a) method of collecting data, b) method of analyzing data, c) instrument, and d) investigation period. How to obtain data determines the results of research findings, for that there are at least two ways that are commonly used in research on thermal comfort, namely direct measurement or observation, and interview or distributing questionnaires. There are many ways to analyze data, including evaluation, comparison, simulation, and investigation. While research instruments that are often used comprise at least three types, namely physical instruments (such as data loggers, thermal recorders, and wind speed meters), paper / online questionnaires, and computer simulation software (which functions to predict the thermal performances of an outdoor). The investigation period is divided into three types, namely season, duration (getting data), and time of day (data collection time, day or night).

The climate zone where the research is conducted is also one of the distinguishing factors of the research results related to outdoor thermal comfort. The zoning division uses the theory from Wladimir Koppen [6] which divides climates into five main climate groups, with each group being divided based on seasonal precipitation and temperature patterns. The five main groups are A (tropical), B (dry/desert/arid), C (temperate/ subtropical/ mediterranean), D (continental), and E (polar).

Thermal comfort refers to a mental performance which expresses satisfaction with the thermal environment (Atmaca, Kaynakli, & Yigit, 2007). Research on outdoor thermal comfort has been carried out in various aspects, both related to human behavior (L. Chen & Ng, 2012), anthropometric variables (Kruger & Drach, 2017), and with a sense of place (Zabetian & Kheyroddin, 2019). Likewise with the planning aspect, an open space that is thermally comfortable is the hope of many people, so that research related to urban form is important (Taleghani, Kleerekoper, Tenpierik, & Van Den Dobbelsteen, 2015).

Research on the effect of landscape design on thermal comfort in urban green spaces through computer simulations has also been conducted (Karimi, Sanaieian, Farhadi, & Norouzian-Maleki, 2020; Taleghani et al., 2015). Some papers have reviewed the UHI and outdoor thermal comfort studies which related to urban pavement (Nwakaire, Onn, Yap, Yuen, & Onodagu, 2020), urban geometry and pedestrian level greening (Jamei, Rajagopalan, Seyedmahmoudian, & Jamei, 2016), green infrastructure (Bartesaghi Koc, Osmond, & Peters, 2018), and built environment (Rupp, Vásquez, & Lamberts, 2015). The sky view factor (SVF) has been used to determine the amount of shade (Donny Koerniawan & Gao, 2015; A. H. A. Mahmoud, 2011). Furthermore, energy savings can be obtained when the entire façades of buildings are shaded (Palme, Privitera, & La Rosa, 2020).

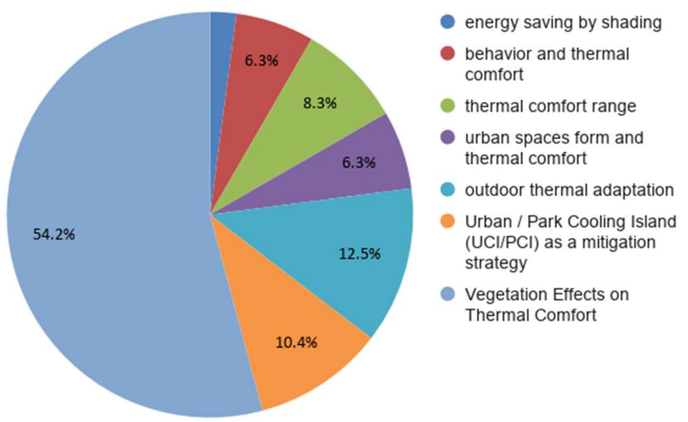


Figure 8. Topics of reviewed papers

The total numbers of reviewed papers in this study are 48 papers. The majority (54.2 %) talks about vegetation effects on outdoor thermal comfort. Research on Urban Cooling Island (UCI) or Park Cooling Island (PCI) is in third place (10.4%) following outdoor thermal adaptation

(12.5%). Research were mostly (52.1%) conducted in Group C: Temperate / Subtropical climates. For the example Cfa (Humid Subtropical Climate) and Csa (Hot Summer Mediterranean Climate) are the most common. Then followed by Group A: Tropical Climates at 14.6 percent. Included in this group are Af (Tropical Rainforest Climate), Am (Tropical monsoon climate), and Aw / As (Tropical Wet and Dry or Savanna Climate). Thus, little is known about outdoor thermal comfort in other climates.

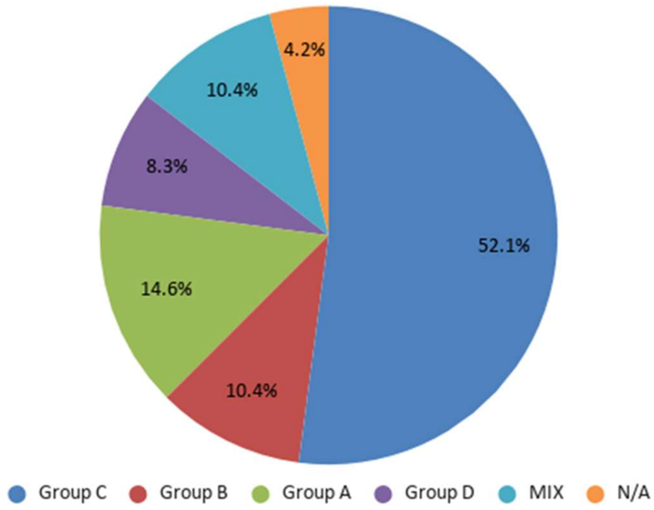


Figure 9. Climate zones group of reviewed papers

Most of the studies were conducted in mixed open spaces (Green and Non-Green open spaces), namely 45.8 percent. Meanwhile, research only conducted in Green open spaces is in the second place (25 percent), followed by Non-Green open spaces (18.8 percent). For the type of open space, most of the research (25 percent) was conducted in mixed open spaces (comprising several types of open spaces, such as Garden, Plaza, Park, Marketplace / modern outdoor shopping mall, sports and recreational park). Then followed by Street canyon, crossroad, and square (16.7 percent), Urban Park and Residential Area with 14.6 percent each. The rest are as a theme park, university square, university area, and coastal area.

2.3.3. Results and Discussions

2.3.3.1. The most popular methods for collecting outdoor thermal data

There are many ways to collect data on research on outdoor thermal comfort, including field measurement, questionnaires, and interview. While data source are mostly retrieved from meteorological stations in the local area, and data from satellites. For research that is reviewing, data is got from literature that comes from journals or proceedings. From the total number of research papers that have been reviewed, 66.7 percent used the field measurement method, while 62.5 percent used the questionnaire / interview method. For research using meteorological data / satellite images as much as 87.5 percent.

2.3.3.2. The most popular methods for analyzing outdoor thermal data

The most popular way of analyzing data for research related to outdoor thermal comfort is Physiological Equivalent Temperature (PET) with a percentage of 59.5%. This value is greater than other similar techniques such as Effective Temperature SET*/ET* (9.5%), Predicted Mean Vote/PMV (9.5%), and Universal Thermal Climate Index/UTCI (7.1%). Meanwhile, to analyze the value of perception, adaptation, and human sensation on thermal comfort, the most popular method is to use the Thermal Sensation Vote (TSV) measurement method (26.2%). This percentage is greater than other similar methods, namely Thermal Sensation/TS (2.4%) and Optimum Thermal Environment/OTE (2.4%). Some studies also use the Sky View Factor (SVF) method (21.4%) to find out the value of the aperture at a measuring point. Some other analysis techniques are statistical data analysis (31%) and LST analysis (14.3%).

The method of analyzing the thermal comfort environment which is quite popular besides PET is the Simulations (50%) method. This method is considered easier and more efficient because it can be done using only a computer. In addition, the simulation method can predict the thermal environment performances of a point based on the available climatic data.

2.3.3.3. The most popular outdoor thermal instruments

Instruments which commonly used to get thermal environment data were Data logger. Data logger is an instrument that usually used to record air temperature and air humidity. Apart from that, another tool is a globe temperature sensor which functions to measure the temperature of radiation at a point. Furthermore, there is a Wind-meter or Anemometer which functions to measure wind speed and direction. These tools are usually assembled into a set of what is called a meteorological data sensor or a local meteorological station.

In addition to climate measurement tools, an instrument that is often used is the Fish Eye Lens which functions to measure SVF at a measuring point. This is done by capturing an image facing the sky and forming 360 degrees. The captured lens is then processed using certain software to generate SVF values for that location. To obtain perceptual, sensational, or adaptation data, the instrument used is a questionnaire in both paper and online forms. In addition, several studies combined a questionnaire and an interview simultaneously to get more accurate answers from respondents.

The most frequently used software in research on outdoor thermal comfort is ENVI-met, followed by RayMan software. ENVI-met software is usually used to simulate thermal performances in an environment, either using data from field measurements or data from meteorological stations. Meanwhile, RayMan software is usually used to calculate the PET value of a point, using field measurement data and / or weather data from secondary sources. To determine the correlation or regression relationship between parameters, there are several commonly used software, such as Microsoft Excel, SPSS, and JMP statistics.

2.3.3.4. The most popular time for investigation periods

The most popular data collection season in this study was summer (72.1%). Then it was followed by winter (44.2%), spring (11.6%), and autumn (7%). The longest data collection duration by field measurement is 20 hours and the shortest is 31 minutes. Meanwhile, the most popular duration for research on outdoor thermal comfort is 12 hours and 8 hours. The most popular data collection time is day time, which is 54.2 %. The rest is a mix of day time and night time.

2.3.3.5. The Urban/Park Cooling Island as mitigation strategy

Urban Cooling Island (UCI) or Park Cooling Island (PCI) is a terminology to define the significant impact of urban open spaces or park to reduce the heat stress which is occurred in a city. A study found that larger-sized green spaces produce a higher cooling effect (Yu et al., 2017). The circles and squares green spaces have a significant correlation with Land Surface Temperature (LST) and also show the highest UCI intensity and efficiency. 92% of the maximum extend of green spaces are within the 30–180 m limit, and the mean UCI extent and intensity are 104 m and 1.78 °C. The green spaces connected with water bodies intensified the UCI effects, whereas the grassland-based green space shows the weakest UCI effects.

Al-Gretawee, et.al (2016) found that the park has a significant cooling effect for a distance of up to 860 m from its boundaries and that this is most significant in the early morning (Al-Gretawee, 2016). The study also shows that land surface temperatures are more sensitive to park cooling effects than are air temperatures. Aram, et.al (2019) said that the highest cooling effect distance and cooling effect intensity are for large urban parks with an area of more than 10 ha (Aram, Higueras García, Solgi, & Mansournia, 2019); however, in addition to the area, the natural elements and qualities of the urban green spaces, as well as climate characteristics, highly inform the urban green space cooling effect.

A research in Zhengzhou, China, showed that parks have a cooling effect in the city, the mean LST of the park is 0.79 ◦C lower than in the city (Huawei Li, Wang, Tian, & Jombach, 2020). Among the five studied park types, the theme park category has the largest cooling effect while the linear park category has the lowest cooling effect. It is supposed that the increase of vegetation cover rate within water areas as well as the decrease of impervious surface in landscape planning and design will make future parks colder. Based on a recent review study, it is found that the information about thermal benefits of urban greening in tropical and desert climates, developing countries, and southern-hemisphere regions are very limited (Bartesaghi Koc et al., 2018). The analysis reveals a lack of standardized protocols and classification systems for green infrastructure enabling the reporting and comparison of thermal data. Most studies overlooked the spatial heterogeneity, connectivity and multi-functionality of green infrastructure which are necessary to understand the interplay and cumulative effects of natural and artificial features.

2.3.3.6. Vegetation effects on thermal comfort

The impact of tree in mitigating air temperature has been well documented. Balany, et.al. (2020) found that trees were able to reduce air temperature by a value ranging from 0.2 to 2.27 ◦C (Balany, Ng, Muttil, Muthukumaran, & Wong, 2020). Meanwhile, the PET can be reduced by up to 14 ◦C in the spots where trees are added. Grass and green roofs showed a lower capability to reduce temperature, with a limited thermal comfort improvement. While Armson, et.al (2012) found that grass reduced maximum surface temperatures by up to 24°C, and tree shade reduced them by up to 19°C (Armson et al., 2012). In contrast, surface composition had little effect upon globe temperatures, whereas shading reduced them by up to 5-7°C. A. Dimoudi and M. Nikolopolou (2003) reported that an average temperature reduction of around 1°K can be expected for every 100 m2 of vegetation added to the park (Dimoudi & Nikolopoulou, 2003). The surface temperatures in the tree-shaded spaces were near ambient air temperature on a sunny summer day. Surface temperatures of the shaded ground covered with wet soil or lawn were about 2°C lower than ambient air temperature (He & Hoyano, 2009b). A recent study in 2020 revealed that in open spaces with vegetation, mean air temperature was lower by 1 °C, mean radiant temperature was lower by 6 °C and PET index was lower by 7 °C in comparison to open spaces without any vegetation (Davtalab, Deyhimi, Dessi, Hafezi, & Adib, 2020).

Beneficial effect of the localized shadowing provided by the palm trees positively reduce the thermal stress of the users were found in Middle East (Mijorski, Cammelli, & Green, 2019). In other study, the species C. pluviosa F. presents the best possibility in terms of PET because it can reduce between 12 and 16. °C for individual trees cluster can reduce between 12.5 and 14.5. °C (de Abreu-Harbich et al., 2015). Appropriate vegetation used for shading public and private areas is essential to mitigate heat stress and can create better human thermal comfort especially in cities. Based on SVF analysis, the barely shaded (high SVFs) locations were uncomfortable in summer and highly shaded locations (low SVFs) were uncomfortable in winter (T. P. Lin et al., 2010).

A regression analyses showed that the most significant influential factor on the moderation of thermal comfort is the higher trees, while the hardened ground exhibits a negative effect (Sun et al., 2017). Mahmoud, et.al (2011) suggested that the park may include shade trees in the seating areas, outdoor shelters for the Peak areas, minimizing the area of hardscape pavement and careful design of shading plants along walkways. The presence of vegetation along the canyons was also found to affect the air temperature considerably (Andreou, 2013). Air temperature in planted canyons is up to 1.5°K lower in comparison with unplanted streets with the same aspect ratio, i.e. 37.3°C against 38.8°C. The use of trees leads to a decrease of PET up to 22°K directly under the tree crowns because of less solar irradiation.

However, the park and building configuration factors that could enhance the thermal comfort in parks were quite different between summer and winter (Chan & Chau, 2021). For example, park area was a significant factor in summer, while building spacing and length-to-width ratio of the park only were significant factors in winter. Another report from Lin, B., et.al (2018) that the greening pattern with a tree is not always effective in improving the pedestrian thermal comfort in summer in all directions around buildings or compared with the average value on the site. When the arrangements and orientation of buildings and incoming wind are changed, the same planting pattern for the improvement of the outdoor comfort should be re-evaluated.

Andreou, E., et.al (2013) investigate the parameters that influence thermal comfort performances in urban canyon environment: street geometry, orientation, wind speed, surface albedo, and trees. It was found that the most important parameter in the streets is tree shading and the second parameter is wind speed. While in Hong Kong, trees and their canopies, shrubs, flower beds, and grass area are effective to reduce the localized thermal load (Ng & Cheng, 2012). In Southern China, the vegetation and landscape can be recommended as an influential factor (Ma et al., 2019). For open spaces and West-East oriented street, increasing buildings height cannot reduce PET obviously, because the only method is to improve the coverage of the vegetation. While in Tehran, Iran, it was stated that proper design of urban forms would largely mitigate UHI especially for new sustainable developments while thermal comfort improvements can be effectively achieved by increasing the urban vegetation coverage (Farhadi et al., 2019). In Cairo, Egypt, the highest thermal discomfort risk was found in urban areas of the old Cairo, but the risk is marginally smaller at new cities where there are vegetation covers (S. H. Mahmoud & Gan, 2018). A research in Malaysia also illustrate that the use of trees and vegetation lead to a reduction in the PET values of area by protection from direct solar radiation (Makaremi, Salleh, Jaafar, & GhaffarianHoseini, 2012). The results show that although the climatic performances strongly influence thermal sensation of users but, psychological adaptation plays an important role in outdoor human thermal comfort. In a larger scale, the distribution and arrangement of the buildings in a city affect the formation of heat island and thermal comfort (Jamei et al., 2016), they are; the site layout, spacing between the buildings, positioning of the building in relation to the sun, wind and to the adjacent buildings, landscaping, arrangement and type of the plants that can be used as windbreakers or wind channeling and the choice of surface and pavement materials.

CFD simulations also play role to improve the thermal comfort performances in an outdoor space in design process. A model for thermal comfort using ''TS-Givoni'' and ''Comfa'' methods was been evaluated by two scenario (Gaitani, Mihalakakou, & Santamouris, 2007). It was found that the thermal comfort performances were significantly improved with the use of the second scenario, mainly because of the use of green and water spaces as well as because of the use of construction materials with high emissivity and reflectivity values.

2.3.4. Conclusion

1. The most popular methods for collecting outdoor thermal data is field measurement, questionnaires, and interview. While data source are mostly retrieved from meteorological stations in the local area, and data from satellites.
2. The most popular index used in data analysis is Physiological Equivalent Temperature (PET). Meanwhile, to analyze the thermal perception or human sensation on thermal comfort, the most popular method is to use the Thermal Sensation Vote (TSV) scale.
3. Instruments which commonly used to get thermal environment data were data logger, to record air temperature and relative humidity. While wind-meter or anemometer is popular in measuring wind speed and direction. The most frequently used software in research on outdoor thermal comfort is ENVI-met, followed by RayMan software.

4. The most popular data collection season in this study is summer. The most popular data collection time is day time. The longest data collection duration by field measurement is 20 hours. Meanwhile, the most popular duration is 12 hours.
5. The Urban Cooling Island (UCI) and Park Cooling Island (PCI) are the alternative strategies in outdoor thermal comfort mitigation. The circles and squares green spaces show the highest UCI intensity and efficiency, whereas the grassland-based green space shows the weakest.
6. Vegetation planning has great impact for the air cooling in mitigating Urban Heat Island phenomenon, especially to reduce the urban thermal stress. Trees, grass, lawn, and green roofs empirically proved that vegetation has a power to create a thermally comfort open spaces. In general, trees showed promising capability to reduce temperature and improve human thermal comfort as compared to other types of green infrastructures. For outdoor space design, multiple shading types and different shading levels are recommended to allow users to choose their preferred thermal comfort performance. Studies also shown that tree shading is the most important parameter in the streets and the second is wind speed. However, the impacts is different in summer and winter. The arrangement of vegetation around building is also have an effects in air cooling. There is a corresponding optimized pattern for the tree arrangements around buildings, especially when the outdoor space comfort on the south and west sides are more important.

CHAPTER 3

RESEARCH METHODS

3.1. Data collection

The data collection of this research includes both primary and secondary data. Quantitative method are consisted of primary data. The primary data were collected from site survey or field measurement, questionnaire survey, and observation. For secondary data, the related information to thermal comfort, urban park, green open space, and case study were collected.

3.1.1. Site Survey

The site survey of field measurement is conducted to get the actual data of thermal and urban structure. The thermal environment data includes Air Temperature (Ta), Relative Humidity (RH), and Wind Speed or Air Velocity (v). While the urban structure data is related to Sky View Factor (SVF), building, and vegetation.

Figure 10. Field survey

3.1.2. Questionnaire Survey

The questionnaire survey is aim to gain information from the visitor of an urban park that related to thermal comfort, thermal sensation, thermal preferences, thermal satisfactions, and expectation about facilities. It was composed of three parts: basic personal information, question about the park, and question about thermal comfort. In the first part, there were questions of gender, age, height, weight, nationality, and the current city of living. The second part consisted of question about reason to visit the park, frequency, seasonality, importance of park, most favorite area, and expectation of facilities. The third part includes the thermal sensation, wind flow sensation, humidity sensation, thermal acceptability, thermal preference, thermal satisfaction, visitor activities 30 minutes before doing the survey, and expectation about shading, sunlight, and winds.

3.1.3. Sampling Size

The population size is the maximum monthly visitor (26 days) at Green Park Kitakyushu which is counted by the limit of permanent parking times to 4 person (number of seat of normal city car). The number of permanent parking is 847 unit. Therefore the population size is 88,088. Sampling size of questionnaire survey was calculated based on Taro Yamane formula with 95% confidence level. The Taro Yamane formula is shown on this equation:

$$\mathrm{n} = \frac{N}{1 + Ne^2}$$

Where, n = the sample size

N = the population size (26 days x 847 unit x 4 person = 88,088)

e = the acceptable sampling error (95% or 0.05)

So, the sample size or total respondents is:

$$\mathrm{n} = \frac{88{,}088}{1 + 88{,}088 \times (0.05)^2} = 398.19 \approx 400$$

Therefore, making a simple number of respondents, this study conducts with the target of 100 respondents per season (summer, autumn, winter, and spring) and the total should be 400 respondents. In fact, the respondents were limited to visitor who participated by a random and voluntary approach. The research also excluding children under 10 years to avoid bias/misunderstanding. After collecting data, the number of respondents gained is 425 people.

3.2. Data analysis

3.2.1. Analysis Methods

Several analysis methods were used to analyze the findings obtained, both from primary and secondary data. There are six type of analysis used in this study, they are: correlation, significance, correspondence, distribution, prediction, and descriptive analysis. There are many ways to find out correlation analysis, this study uses the method of one-way analysis, Fit X by Y, bivariate fit analysis, and linear fit analysis. The type of analysis and its functions is shown on the table 8.

Table 8. Type of analysis and its functions

Type of Analysis	Analysis Methods	Function(s)
Correlation Analysis	One way Analysis	It is used for the analysis of two different data types (numeric versus character). To understand the correlation among them, it is analyzed by Compare Densities, Composition of Densities, and Proportion of Densities.
	Fit Y by X analysis	It is used for two different variables, ex: numeric & character.
	Bivariate Fit Analysis	For the data which are both numeric types.
	Linear Fit Analysis	It is used to understand the correlation between dependent and independent variables.
Significance Analysis	Reliability test	The significant value (Prob>F) is used to test the data reliability to be used in a study. It is commonly tested by Analysis of Variance (ANOVA).
Correspondence analysis	Correspondence	It is used to determine the closeness between factors, importance, and frequency of visiting urban park.
Distribution analysis	Distribution	It is used to determine the reasons, frequency, and importance of tourists to the existence of urban park. It also used to obtain the most favorite season, area, and tourists' expectations of urban park facilities.
Prediction Analysis	Software Simulation	It is used to predict the actual performance of an environment, ex: thermal environment, thermal comfort, etc.
Descriptive	Explanatory	It is used to describe or explain a certain situation/condition.

3.2.2. Analysis Instrument

The analysis data were processed in several computer soft wares. The ENVI-met simulation software is utilized to evaluate environmental thermal performances of the urban park. The input data in this software are air temperature, relative humidity, and an aerial view picture of urban park, while output are in the form of thermal maps and statistical data. While the RayMan Model simulation is used to calculate outdoor thermal comfort value such as PET and PMV. The input data are Ta, RH, V, age, height, weight, clothing insulation (Icl), and activity level (MET). To draw a sectional view of urban park's structure, Corel Draw software is used. Statistical analysis of data which are retrieved from questionnaire, field measurement, calculation, and simulation are done by Microsoft Excel and JMP software. The output data are in the form of pictures and tables that show the correlation, distribution, and others. The table no.9 shows the research instruments and its roles.

Table 9. Research instruments

Software	Type	Objectives	Input	Output
ENVI-met	Simulation	Evaluating environmental thermal performances	Ta, RH, maps	Thermal maps, statistic data
RayMan	Simulation	Calculating Outdoor Thermal Comfort	Ta, RH, V, Age, Height, Weight, Icl, MET	PET, PMV, etc.
CorelDraw	Drawing	Drawing physical condition of environment	Google maps, survey pictures	Drawings
JMP	Statistics	Calculating and analyzing statistical data	Various statistic data	Correlations, Distributions, etc.
Microsoft Excel	Statistics	Calculating and analyzing statistical data	Various statistic data	Correlations, Distributions, etc.

3.3. Case study

3.3.1. Overview of Kitakyushu City, Japan

Kitakyushu City is located in Fukuoka Prefecture, Kyushu Island, Japan. Geographically, it is located at 33° 53′ N and 130° 53′ E of the northernmost point of Kyushu on the Kanmon Straits, separating the island from Honshu, across from the city of Shimonoseki. The altitude or elevation above sea level is 6 m. The climate of Kitakyushu city is mild, and generally warm and temperate (Alexandre Merkel, 2021).

Kitakyushu City is an ordinance-designated city with a population of 946,338. It is located at the gateway to Kyushu Island, across the Kanmon Strait (the importance strait for trade and tourism activities which has a great connection with Korea and China). This city is one of the four largest industrial zones in Japan. It supports the development of Japan's modern industries since it had built the foundation of the Yawata Steel Works in 1901 which is run by the government. The key industries are steel, chemical, ceramic, electric, and cement. In recent years, the city also develop automobile-related and environment/energy-related industries.

According to the Köppen-Geiger climate classification (1980-2016), this climate is Cfa or a humid subtropical climate. The average temperature in Kitakyushu is 15.9 °C. The average temperature of August, the hottest month of the year, is 26.9 °C. January is the coldest month of the year at 5.5 °C on average. The variation in annual temperature is around 21.4 °C.

Kitakyushu has four types of seasons, namely summer, autumn, winter, and spring. Summer starts at the end of June and ends in September, while autumn starts from October to November. Winter usually comes in December and disappears in February, while spring is from March to May.

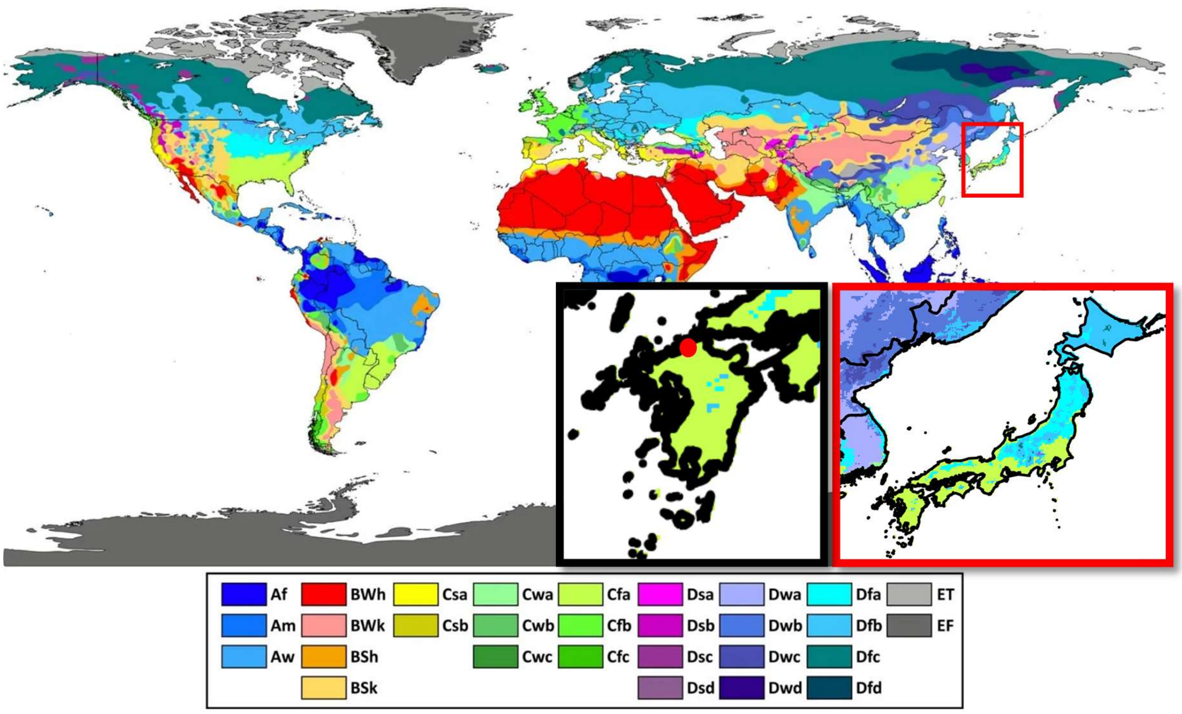


Figure 11. Kitakyushu climate zone based on Köppen-Geiger climate classification.

The rainfall in Kitakyushu is around 1818 mm per year, with precipitation even during the driest month (Alexandre Merkel, 2021). The lowest precipitation is in December, with an average of 97 mm. In June, the precipitation reaches its peak, with an average of 281 mm. There is a difference in precipitation between the driest and wettest months. January has the highest number of rainy days. The month with the lowest number of rainy days is October (8.90 days). July has the highest relative humidity. The month with the lowest of relative humidity is January (69.80%). In August, the highest number of daily hours of Sunlight is measured in Kitakyushu on average. In August, there is an average of 10.47 h of Sunlight a day and 324.58 h of Sunlight throughout August. In January, the lowest number of daily hours of sun-shine is measured in Kitakyushu on average. In January, there is an average of 5.21 h of Sunlight per day and 161.64 h of Sunlight. Around 2998.26 h of Sunlight is counted in Kitakyushu throughout the year. On average, there are 98.43 h of Sunlight per month.

3.3.2. Site Selection

According to the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) of Japan, the city park is divided into five categories, they are basic parks for community use, basic parks for city wide use, large-scaled parks, national government parks, and buffer green belts (MLIT, 2006). Where the urban park is associated to the basic parks for city-wide use or the large-scaled parks. There are two types of basic parks for city wide use, a comprehensive park (for use by all residents in a city for various purposes, the standard area ranges from 10 to 50 ha according to the size of the city) and a sport park (mainly for athletic activities, from 15 to 75 ha). For the large-scaled parks, it is divided into two types: regional park and recreation cities. The regional park has the standard area at least 50 ha and its recreational facilities are placed organically, while the recreation cities are areas where a variety of recreation facilities are provided mainly for the entire population area of a large city or other city and has a total area of about 1000 ha. In 2005, there are 1973 basic parks for city-wide use and 190 large-scaled parks in all over Japan.

Based on the legal classification of Japanese parks, there are two types of park, they are natural and urban park (MLIT, 2006). Urban parks are created by central government or local bodies who acquire a certain area of land and open it for public use. While natural parks remain the property of various private individuals, and its natural landscape is maintained by legislation restricting land use. In Kitakyushu city, there are 23 parks which are mentioned on the official tourism information website of Kitakyushu City (KCTIC, 2021). The Hibikinada Green Park is one of urban park which is created by the city government of Kitakyushu. The list of parks in Kitakyushu City is shown on the table 10.

The selection of the study case is based on two criteria, they are it should be classified as a large-scale park (a regional park) and has the legal classification as an urban park. This criteria is important for mitigating the UHI as many researchers suggest that the selection of urban park should consider a large area size for the study case (Aram, Solgi, García, Mosavi, & Várkonyi-Kóczy, 2019; Blachowski & Hajnrych, 2021). An investigation of large urban park cooling effects in Madrid also showed that large-scale urban parks generally play a significant part in creating a cognitive state of high-perceived thermal comfort spaces for residents (Aram, Solgi, et al., 2019). While in Wroclaw it was also found that the cooling distance varied from 110 m to 925 m depending on park size, forest area, and land use type in the park's vicinity (Blachowski & Hajnrych, 2021).

Table 10. List of parks in Kitakyushu City

Name of Park	Area Size* (ha)	Park Type **	Legal Classification **	Location (Ward)
Itozu-no-mori Zoological Park	10.82 ha	Buffer Green Belts (Specific parks for zoos)	Urban Park	Kokurakita
Hibikinada Green Park	66.91 ha	Large-scaled parks (Regional parks)	Urban Park	Wakamatsu
Agriculture and Livestock Information and Research Center (Hananooka Park)	9.88 ha	Buffer Green Belts (Specific parks for agriculture)	Urban Park	Kokura-minami
Kawachi Wisteria Garden	2.17 ha	Buffer Green Belts (Specific parks for botany)	Urban and Natural Park	Yahatahigashi
Shiranoe Botanical Gardens	8.91 ha	Buffer Green Belts (Specific parks for botany)	Urban and Natural Park	Moji
Mekari Park	48.78 ha	Basic Parks for City Wide Use (Comprehensive parks)	Urban and Natural Park	Moji
Hiraodai Countryside Park	25.32 ha	Basic Parks for City Wide Use (Comprehensive parks)	Urban Park	Kokura-minami
Adachi Park	7.27 ha	Buffer Green Belts	Natural Park	Kokurakita
Takatoyama Park	4.86 ha	Basic Parks for City Wide Use (Comprehensive parks)	Urban and Natural Park	Wakamatsu
Kisshoji Park	5.21 ha	Buffer Green Belts (Specific parks for botany and history)	Urban and Natural Park	Yahatanishi
Yamada Green Zone/Yamada Park	10.06 ha	Buffer Green Belts (Specific parks as a scenic park)	Natural Park	Kokurakita
Tamukeyama Park	11.03 ha	Buffer Green Belts (Specific parks as a scenic park)	Natural Park	Kokurakita
Asano Ocean Breeze Park	1.61 ha	Basic Parks for Community Use (Neighborhood parks)	Urban Park	Kokurakita
Katsuyama Park	9 ha	Basic Parks for City Wide Use (Comprehensive parks)	Urban Park	Kokurakita
Rozanso Park	1.2 ha	Basic Parks for City Wide Use (city block parks)	Urban and Natural Park	Kokurakita
Oma Bamboo Grove Park	2.83 ha	Buffer Green Belts (Specific parks as a forest park)	Urban and Natural Park	Kokura-minami
Mitsutake Plum Field	1.59 ha	Buffer Green Belts (Specific parks for agriculture)	Natural Park	Kokura-minami
Bijutsunomori Park	6.06 ha	Buffer Green Belts (Greenways)	Urban Park	Tobata
Yomiya Park	8.63 ha	Basic Parks for Community Use (Community parks)	Urban and Natural Park	Tobata
Fukuoka Kenei Central Park & Konpirayama	28.24 ha	Basic Parks for City Wide Use (Comprehensive Park)	Urban and Natural Park	Tobata & Yahatahigashi
Korodai Park	7.67 ha	Basic Parks for City Wide Use (Comprehensive Park)	Urban Park	Yahatahigashi
Senbonsou Park	16.31 ha	Buffer Green Belts (Specific parks for botany)	Natural Park	Wakamatsu
Seita-no-mori Park	33.82 ha	Basic Parks for City Wide Use (Comprehensive Park)	Urban and Natural Park	Yahatanishi

* Size area is calculated by Calcmaps.com (Calcmaps, 2021)

** Park type and legal classification are categorized according to MLIT, Japan (MLIT, 2006)

Based on this two criteria, it is found that the Hibikinada Green Park (hereinafter referred to as Green Park) is the most eligible for study case. According to CalcMaps (2021), the area size of this park is 66.91 ha or more than 50 ha. This park also popular and to be one of favorite places for weekend recreation needs of residents of more than one municipality, such as residents from Kitakyushu, Nakama, Fukuoka, and others. It means that this park can be classified as the regional park of the large scale parks type. The following figure is the calculation method used in this study.

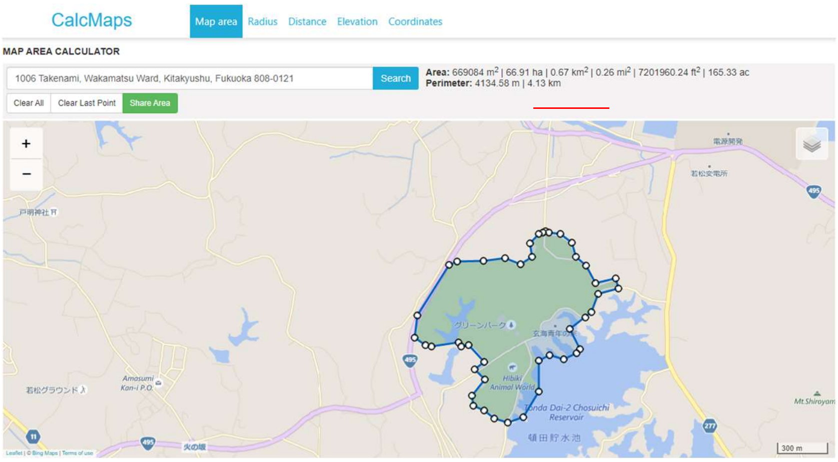


Figure 12. Area size calculation of the Green Park Kitakyushu by CalcMaps

3.3.3. Selected Site: Green Park

The Green Park is located at 1006 Takenami, Wakamatsu-ku, Kitakyushu City, Fukuoka Prefecture, Japan. This is the biggest park in the city where visitors can interact with nature and animals. It has been operated from 1 April 2014, under the management of the Green Park Revitalization Consortium (Hibikinada Green Park, 2020). This park has a variety of natural landscapes and tourism attractions. It has forests, wilderness, beaches, and reservoir. There are plenty of attractions such as Pony Square, Kangaroo Square, rose garden, and tropical ecological garden (which is divided by three greenhouses).

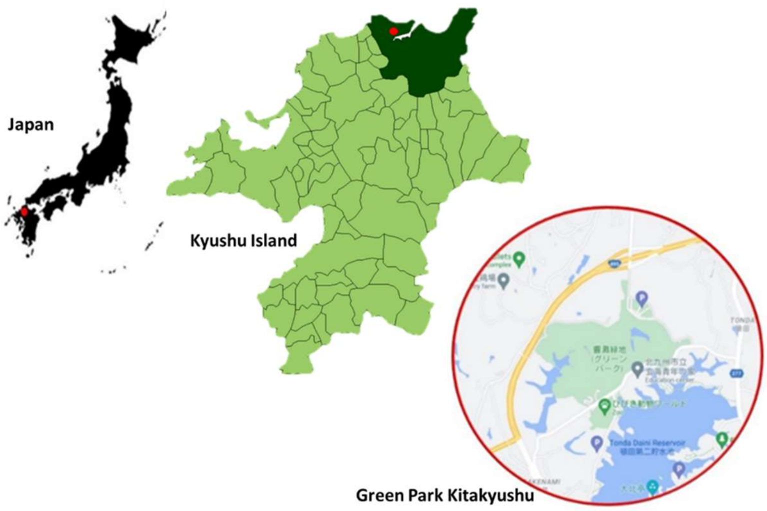


Figure 13. Green Park Kitakyushu (the red circle shows the location on the map)

It also has outdoor stage, large lawn open space, adventure forest, Jabjabu pond, cycling terminal, ground golf, the world-longest swing, and some newest attractions, such as Bumpy open space, Dino Park, Nyoki-nyoki forest, and Fossil valley. The following figure is the location of Green Park Kitakyushu on the map.

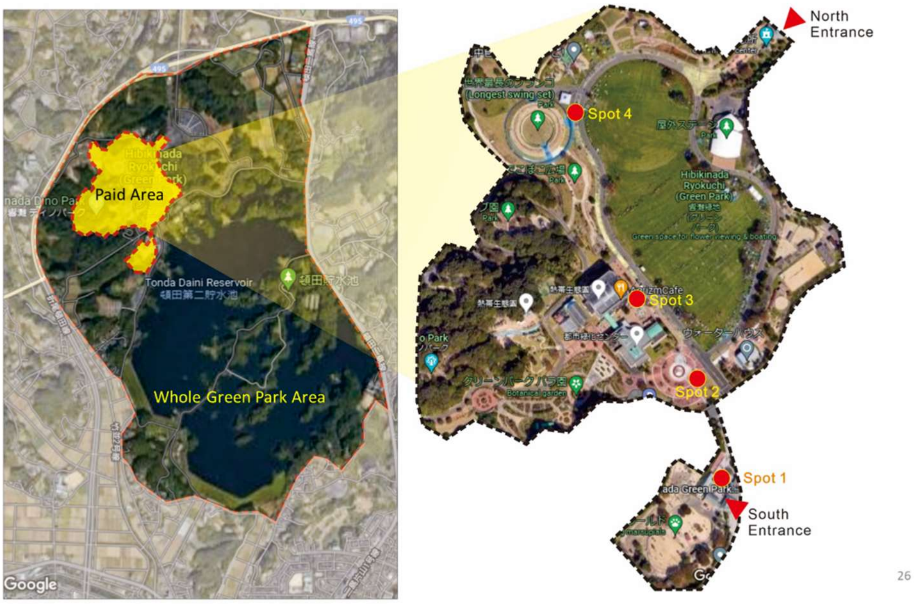


Figure 14. Green Park location and boundary

The study was conducted in paid area of Green Park. There are 4 spots for data measurements. In each spots a data logger and a wind meter were installed to record air temperature, relative humidity, and wind speed.

Figure 15. Green Park Kitakyushu facilities; left-right-top-down: Lawn square, Bumpy open space, and the World-Longest Swing

As a supporting facility, this park also provides the Waterhouse which is a relax room with curtain-fountain, baby nursing room, and toilet. There is an urban greening center for transmitting the information on greenery and flowers, it plays a role as a consultation reception, and an exhibition and seminar holder. There is also a cafe for the visitors to taste dishes that use a variety of local vegetables. The following table is the facilities of Green Park Kitakyushu as shown on its official website.

Table 11. Urban Park Facilities at the Green Park Kitakyushu

No.	**Name of facility**	**Type of facility**	**Function**
1.	Urban Greening Center/ Flower and Green Counseling Center	Exchange	Information center
2.	Outdoor Stage	Exchange	Performance
3.	Lawn square / Large open space	Exchange	Outdoor playground, Day camp
4.	Agrizm Café	Food	Eat, drink, rest
5.	Terrace & BBQ	Food	Eat, drink, rest
6.	Kitchen Car Paradise	Food	Eat, drink, take-out menu
7.	Waterhouse	Rest room	Toilet, Baby nursing room
8.	Tropical Ecological Garden	Attraction	Flowers/Green experience
9.	Second Greenhouse	Attraction	Flowers/Green experience
10.	Third Greenhouse	Attraction	Flowers/Green experience
11.	Rose Garden	Attraction	Flowers/Green experience
12.	View Terrace	Attraction	Flowers/Green experience
13.	Maze Flowerbed	Attraction	Flowers/Green experience
14.	Pony Square	Attraction	Seeing & feeding animals
15.	Kangaroo Square	Attraction	Seeing & feeding animals
16.	Dino Park (new)	Attraction	Education and entertainment
17.	Fossil Valley (new)	Attraction	Education and entertainment
18.	The World-Longest Swing	Attraction	Physical activity
19.	Ami-go!	Attraction	Physical activity
20.	Adventure Forest	Attraction	Physical activity
21.	Bumpy Open Space (new)	Attraction	Physical activity
22.	Nyoki Nyoki no Mori	Attraction	Physical activity
23.	Spring Forest (new)	Attraction	Physical activity
24.	Jabjabu Pond (only in summer)	Attraction	Physical activity, water play experience
25.	Cycling Terminal	Attraction	Physical activity
26.	Ground Golf	Attraction	Physical activity
27.	Interesting Bicycle	Attraction	Physical activity
28.	Cycle Boat	Attraction	Physical activity, water play experience

Source: The official website of Green Park Kitakyushu, 2022

3.4. Psycho-Ecological Condition

This study was conducted during the COVID-19 pandemic. The virus outbreak began to spread since it was first reported in the city of Wuhan, China in December 2019. It has caused more than 543 million confirmed cases and more than 6.33 million deaths worldwide as of 17 June 2022 (Worldometer, 2022). A study in Korea identified that easy access from home was more important than the park size during the pandemic (Sung, Kim, Oh, Lee, & Lee, 2022). It showed that the pandemic affected the people behavior in urban park.

During the COVID-19 pandemic, outdoor spaces were unsafe places for the public. However, some people prefer outdoor or open spaces, such as parks or urban forests, where they can maintain health by exercising by maintaining physical distancing compared with indoors. A research found that most countries show that park visitation has increased since February 16th, 2020 compared to visitor numbers prior to the COVID-19 pandemic (D. (Christina) Geng, Innes, Wu, & Wang, 2021). Restrictions on social gathering, movement, and the closure of workplace and indoor recreational places, are correlated with more visits to parks. Stay-at-home restrictions and government stringency index are negatively associated with park visits at a global scale. Demand from residents for parks and outdoor green spaces has increased since the outbreak began, and highlights the important role and benefits provided by parks, especially urban and community parks, under the COVID-19 pandemic. Another research reported that park visitation decreased after issuing the shelter-in-place order and increased after this order was lifted (Ding, Li, & Sang, 2022). Results indicated that the higher the greenness density of the park, the smaller the decrease in park visitation during the shelter-in-place period compared to before the shelter-in-place order. Therefore, the COVID-19 pandemic may has an effect to the results in this study.

CHAPTER 4

OUTDOOR THERMAL COMFORT IN THREE URBAN PARKS IN INDONESIA

Summary

This study aims to determine the quality of thermal comfort which can be adopted by the city of Bandung. This study uses a quantitative approach method that is a method that uses measurable analysis and can be calculated using certain formulas. Sampling type used for this study is a non-random sampling with purposive sampling technique (Kumar, 2005). The case study was selected based on the criteria of urban park and the percentage of the value of Green Plot Ratio (GnPR). The study cases are Gasibu Park, Lansia Park, and Saraga Park. According to the results it was found that: 1) the best quality of the thermal performance among the three samples was Lansia Park, this finding indicates that the hypothesis that the greater the ratio of vegetation an urban park, the greater the thermal comfort value is correct; 2) the community adaptation to the thermal quality of the urban park's environment as a whole is quite good. Most respondents were able to accept thermal performances and want to get cooler than the actual performances. Satisfaction of the performance of shading, sunlight, and wind within the area is quite good; 3) the average value of PET on urban parks in Bandung is in the range of 22.9 °C to 25.1 °C with slightly cooler thermal sensation, with a slight cold stress. PET values that can be adapted by the people of Bandung is lower than the cities in other tropical countries; and 4) the environmental thermal factor that most influences the TSV value in the three urban parks in Bandung is RH (relative humidity) with a probability value or P-value <0.0001 with a correlation value of -0.03. This means that the higher the humidity in an urban park, the lower the thermal comfort value. Based on this finding, the quality of thermal comfort of urban parks should be increased in order to get more convenience by some works. One of them is by making more shadowing area to get lower temperature. It is important to get people satisfied about thermal performance, because it also can increase their satisfaction of urban parks.

4.1. Introduction

4.1.1. Background

Indonesia is categorized as wet tropical climate or hot humid tropical climate areas which are characterized by: 1) relatively high air humidity (generally above 90%); 2) high rainfall; 3) annual temperatures above 18 °C (and can reach 38 °C in the dry season); 4) differences between seasons are not very visible, except for periods of little rain and lots of rain accompanied by strong winds. According to the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) of West Java (2014), the average temperature of Bandung city has increased which is equal to 0.05 per year from 2010 to 2013. These statistics show the possibility of the occurrence of the phenomenon of UHI in the town, causing city climate hotter than ever. To face that, since 2014 the city government of Bandung has made various efforts to improve the quality and quantity of Urban Green Open Space (UGOS), one of them by preparing the Spatial Detail Plan.

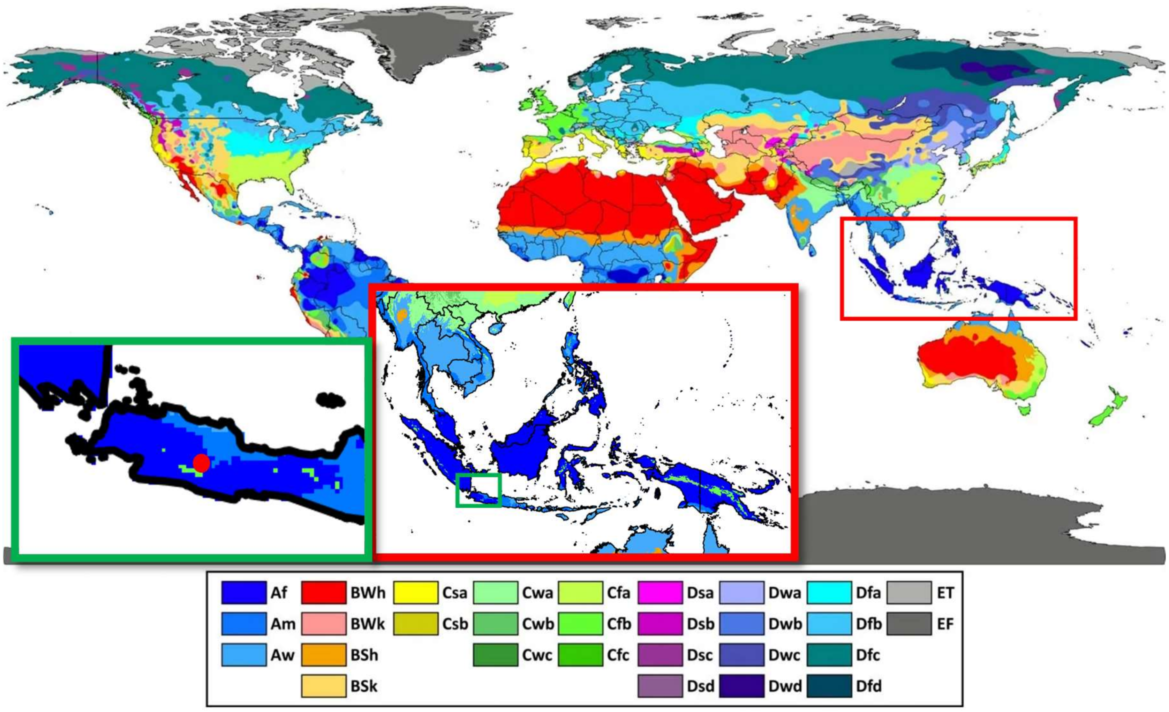


Figure 16. Bandung climate zone based on Köppen-Geiger climate classification

According to Köppen climate classification, Bandung is tropical monsoon climate (Am). Basically, a tropical climate can be divided into dry tropical and humid tropical regions. The dry tropics include steppes, dry savanna and desert. Whereas the humid tropics include tropical rain forests, areas with wet seasons, and humid savanna. The wettest month is February, while the driest month is September. The average temperature throughout the year only has little variations due to its location near the equator and tends to be cooler than most cities in Indonesia due to the altitude influence.

Bandung city is located in West Java, Indonesia. It has a population of 2,444,160 as of 2020 census. The population density is 14,609/km^2 with the total area of 167.31 km^2. It is a capital city of West Java province. The City Government of Bandung has built 30 thematic parks within three years from 2014 to 2017 (Widyahantari & Rudiarto, 2019). Bandung City form a cluster pattern of thematic parks on certain sub-city region (SWK) namely SWK Cibeunying. The park development is a revitalization of old urban parks and mostly located in the city center area. It were remain of city planning in the Dutch colonial era.

To determine the influence of the presence of UGOS for the city, it is necessary to know how the user's perception of the thermal performance. UGOS can provide benefits for cities, both in terms of environmental aspects, ecological, social, and economic. In addition, urban open space is also very necessary for health for the lives of urban communities (Gehl, 2006; Whyte, 1980). To improve the quality of the outdoor environment and attract the attention of the public to use outdoor space is an extraordinary goal of urban space design (Zacharias et al, 2001). Local micro-meteorological performances in city spaces, such as temperature, wind speed, and solar radiation significantly affect visitor comfort and behavior. An understanding of the importance of micro-meteorological factors such as this is essential for urban spatial planning and rejuvenation (Chen et al, 2015). Thus, the existence of green open space in the city of Bandung is very important for city development because it is included in the long-term vision, mission, and goals written in the RDTR. Therefore, research on green open space is needed as a consideration for future urban and landscape designers.

4.1.2. Purpose of the study

This study aims to determine the quality of thermal comfort can be adopted in the urban parks that have been selected by the criteria of a city park (Budiyanti, 2014) and the percentage of the value of Green Plot Ratio (GnPR). There are three the research questions, they are:

(1) How is the thermal quality of urban parks based on Thermal Sensation Vote (TSV) and weather data?
(2) How are people adapted to its thermal quality (thermal preferences, thermal reception, and satisfaction with wind performances, shading performances and sunlight within the area)?

(3) How is the range of PET value (Physiological Equivalent Temperature) that comfortable to be adapted by user in Bandung. Is it equal, higher, or lower than the standard PET values in (sub) tropical cities based on the study by Matzarakis (1997)?

(4) How is the influence of environmental thermal factors (air temperature, relative humidity, wind speed, and mean radiant temperature) on respondents' perception (TSV value)? Which environmental thermal factors have the most influence?

4.2. Literature Review

4.2.1. Green Open Space in Bandung

Based on data from the 2014 Bandung City RDTR, the number of Green Open Spaces (GOS) in Bandung is 606 units. There are 8 SWKs (Sub-District Areas), but only 6 SWKs have data on the existence of green open space in their respective areas. Among the six SWKs, Cibeunying SWK is the sub-district area that has the greenest open space in its area.

Table 12. Distribution of Green Open Spaces in Bandung

Sub-District Area	District Area	Number of GOS	Total
SWK Bojonagara	Sukasari	23	95
	Sukajadi	27	
	Cicendo	30	
	Andir	15	
SWK Cibeunying	Cidadap	8	151
	Sumur Bandung	26	
	Coblong	39	
	Bandung Wetan	54	
	Cibeunying Kidul	12	
	Cibeunying Kaler	12	
SWK Tegallega	Astanaanyar	5	30
	Babakan Ciparay	2	
	Bandung Kulon	3	
	Bojongloa Kidul	4	
	Bojongloa Kaler	16	
SWK Karees	Kiaracondong	17	78
	Batununggal	8	
	Lengkong	41	
	Regol	12	
SWK Gedebage	Buah Batu	41	105
	Rancasari	49	
	Bandung Kidul	10	
	Cinambo	5	
SWK Ujungberung	Antapani	24	147
	Arcamanik	45	
	Mandalajati	20	
	Ujungberung	7	
	Panyileukan	45	
	Cibiru	6	
Total			606

Source: RDTR of Bandung City, 2014

The green open space development plan of Bandung consists of: 1) The Environmental Unit Park is developed in stages with the direction of a total area of approximately 2,717 hectares located in the Gedebage KDP park, the ex-TPA Pasir Impun and ex-TPA Cicabe parks as well as sub-district parks and urban village parks; 2) The Road and River Network Border Park is developed in stages with a total area of approximately 392 hectares; 3) Cemetery areas are developed in stages through revitalization of cemeteries and expansion of public cemeteries in Nagrog, Ujung Berung and in Rancacili, Rancasari as well as the existing burial area with a total area of approximately 291 hectares; 4) City Forest is developed in Babakan Siliwangi covering an area of 3.1 (three point one) hectares; 5) Maintain function and organize green open space; and 6) Restore the RTH function which has gradually switched functions.

4.2.2. Selection of study case

The urban green open spaces that will become a case study or research sample must be able to meet the following 8 aspects of criteria (Budiyanti, 2014): 1) Have an area of at least 1 acre (0.4 ha or 4,000 m2); 2) Has a city service scale; able to accommodate 100,000 people/day; 3) Strategic location; can be reached in 5-10 minutes from office, commercial or residential areas; 4) Easily accessible by public transportation; 5) Have facilities for children, teenagers, adults, and the elderly, or pets; 6) Able to bring up active activities, such as sports, playing, social interaction, and so on; 7) Have attractiveness, uniqueness, certain characteristics, and elements of novelty; and 8) Public in nature; accessible to all levels/classes of society.

Based on these criteria, it is possible to select all UGOS in the city of Bandung so that it can be seen which UGOS are relevant to be used as research samples. Based on records from the RDTR of the city of Bandung, there are 44 UGOS that meet the initial criteria, which have an area of over 4,000 m2. After that, further selection is carried out, namely the fulfillment of 7 other aspects that are needed contained in 8 aspects of UGOS criteria. Based on the continued selection, it was found that there were 13 UGOS that matched the criteria, namely: Dewi Sartika Park, Maluku Park, Zoo, Saraga Park, West Java People's Struggle Monument Park, Kodya Park (located on the south side of City Hall), Traffic Park, Lansia Park, Flower Library Park, Pet Park, Gasibu Park, Alun-alun Bandung, and Tegallega Park.

To find out the role of buildings in thermal comfort in urban green open spaces, it is necessary to first know the value of the Green Plot Ratio (GnPR) of each of the city's green open spaces. This is to determine the percentage of land surface area covered by buildings, pavement materials, and vegetation. The greater the GnPR value, the greater the land surface area covered by vegetation. The table below shows the GnPR value of each UGOS.

Table 13. GnPR value of urban green open spaces in Bandung

No.	**Urban Green Open Space (UGOS)**	**Wide Area* (m^2)**	**Vegetation Area* (m^2)**	**GnPR (%)**
1.	Dewi Sartika Park	14,729.00	11,914.00	80.88
2.	Maluku Park	24,023.24	16,237.24	67.58
3.	Zoo	35,874.67	34,102.67	95.06
4.	Saraga Park	71,568.13	33,123.13	46.28
5.	West Java People's Struggle Monument Park	53,462.00	36,267.00	32,16
6.	Kodya Park	13,965.89	10,581.89	75.76
7.	Traffic Park	45,600.87	40,241.00	88.16
8.	Lansia Park	16,620.00	16,275.00	97.92
9.	Flower Library Park	6,487.00	6,487.00	100.00
10.	Pet Park	9,753.00	9,081.00	93.10
11.	Gasibu Park	25,845.34	6,873.00	26.59
12.	Alun-alun Bandung	9,904.05	3,989.00	40.27
13.	Tegallega Park	190,011.02	125,990.02	66.30

*The size of areas were calculated by Auto Cad software based on images which retrieved from Google maps (2016)

Based on the table, it can be seen the values of GnPR in each UGOS. The GnPR shows the percentage of vegetation elements, while the opposite number (100% - n%) indicates the percentage of non-vegetative elements (buildings and pavements). To see the influence of building configuration or non-vegetative elements on the thermal quality, three locations which representing the GnPR percentage for each category of large, medium, and small urban parks were selected. After conducting a field survey of the prospective locations, three urban parks were selected that could represent each category of the percentage of GnPR, namely Gasibu Park for a small percentage of GnPR (26.59%), Saraga Park for a medium percentage of GnPR (46, 28%), and Elderly Park for the large percentage of GnPR (97.92%).

4.3. Methods

4.3.1. Data collection

Based on the type of data, there are two types, namely primary data and secondary data. Primary data were obtained directly from the source, such as observational photo data, interview notes, and weather recordings when collecting data in the field. While secondary data were obtained from literature sourced from books, scientific articles/journals, proceedings, and internet websites. The respondent's interview data collection in Gasibu Park, Lansia Park, and Saraga Park were carried out in certain days between November 16, 2016 and 3 April 2017.

Table 14. Day and Time of Data Collection

Urban Parks	**Time range**		
	09:00-11:59	**12:00-14:59**	**15:00-17:00**
Gasibu Park	16/11/2016	16/11/2016	16/11/2016
	17/11/2016	17/11/2016	17/11/2016
	18/11/2016	18/11/2016	18/11/2016
	22/11/2016	22/11/2016	22/11/2016
	23/11/2016	23/11/2016	23/11/2016
	24/11/2016	24/11/2016	24/11/2016
	27/03/2017	27/03/2017	27/03/2017
	28/03/2017	28/03/2017	28/03/2017
Lansia Park	29/12/2016	29/12/2016	29/12/2016
	30/12/2016	30/12/2016	30/12/2016
	31/12/2016	31/12/2016	31/12/2016
	29/03/2017	29/03/2017	29/03/2017
	30/03/2017	30/03/2017	30/03/2017
	31/03/2017		
Saraga Park	09/01/2017	09/01/2017	09/01/2017
	10/01/2017	10/01/2017	10/01/2017
	11/01/2017	11/01/2017	11/01/2017
		31/03/2017	31/03/2017
	01/04/2017		
	02/04/2017	02/04/2017	
	03/04/2017	03/04/2017	03/04/2017

Data collection techniques using three methods, namely observation (direct observation), interview, and documentation. The data obtained in the form of image data and text data. Image data in the form of photographs at the study site, while text data in the form of written data, both from literature and interview notes. In addition to interview, direct observations were also made (observation) of the performance of clothing and activities of respondents as open space users. Questionnaires are used to assist researchers in getting answers from respondents about their perceptions of thermal comfort at the observed location. Field data from observations were obtained using research instruments, including Anemometer, Thermal Recorder, and cameras. Anemometer is a weather tool that can be used to capture the amount of wind speed in the observed environment. While the thermal recorder is a device that can record changes in temperature and humidity that occur at the observed location.

Figure 17. Thermal recorder (left) and weather meter (right)

4.3.2. Data analysis

Data analysis uses computer assistance, which is to analyze respondents' responses to the quality of thermal comfort. The analysis approach uses a structured method or commonly referred to as quantitative (Kumar, 2011), which is everything that forms the research process (research objectives, sample determination, list of respondents' questions) has been predetermined.

4.2.2.1. Observation Data Analysis

Initially the data from observation (field measurement) is entered into a digital file with the help of computers in Microsoft Excel software. Although the process is still done manually with data tabulation techniques. Data analysis of the results of this observation uses PET's thermal comfort index with the help of RayMan software. In addition to the PET value, the mean radian temperature (Tmrt) value will also be known to determine which environmental factors affect thermal comfort based on respondents' answers.

4.2.2.2. Interview Data Analysis

Analysis of interview data (respondent responses) using data tabulation techniques with the help of computers in Microsoft Excel software. Data analyzed included responses to perceived thermal sensations (TSV values), acceptance of thermal performances, and satisfaction of shading, Sunlight, and wind performances in the area.

4.3.3. Study cases

Green open space in the city area of Bandung can be seen from the book RDTR (Detailed Spatial Planning). Based on data from the Bandung City RDTR in 2014, the number of Green Open Space (RTH) in Bandung was 606 units. There are 8 SWK (City Sub-Areas), but there were only 6 areas that have data on the presence of green space in their respective regions. Among the six areas, Cibeunying area has the most. There are three urban parks in this area which are chosen as the study cases, they are Gasibu Park, Lansia Park, and Saraga Park. It have been selected based on the criteria of a city park by Budiyanti (2014) and the percentage of the value of Green Plot Ratio (GnPR).

4.3.3.1. Gasibu Park

According to the RDTR, the Gasibu Park is included in the sub-district park type green open space with an area of 25,845.34 m2. This field is located in the Bandung Wetan sub-district, SWK Cibeunying. Gasibu Park is included in the green open space which has active activities, because it is used as a sports facility for the general public. Although in the division of green open space classification, this Park is included in the sub-district park, but in reality the people who visit here do not only come from the local sub-district area, but can also come from other areas, even from outside the city and abroad.

Figure 18. Aerial view (left) and side view (right) of Gasibu Park

4.3.3.2. Lansia Park

The Lansia Park has an area of 16,620.00 m2, located within the Bandung Wetan sub-district, SWK Cibeunying. This park is also included in green space that has active activities, because it is commonly used as a recreational and sports facility for the general public. Its location is close to the center of the tourist destination, making it always crowded with tourists, both local and international. Physically, it has a lot of big and tall trees, so that it can attract the attention of the public to stop by even for just resting, chatting casually, and exercising lightly, such as jogging.

Figure 19. Aerial view (left) and side view (right) of Lansia Park

4.3.3.3. Saraga Park

The Park has an area of 71.568,13 m2, located within the Coblong sub-district, SWK Cibeunying district. This park is also included in active green open space, because it is commonly used as a public sports facility. Its location is close to universities, so that it has a big role as a living laboratory for universities surrounding area.

Figure 20. Aerial view (left) and side view (right) of Saraga Park

4.4. Results and Discussion

4.4.1. Outdoor Thermal Perception based on TSV Value

The TSV value indicates 7 scale of thermal sensations, they are: very cold (1), cool (2), slightly cool (3), neutral (4), slightly warm (5), warm (6), and hot (7). Based on the results of the interview, most respondents feel neutral (scale number 4) with a percentage of 53%. Most of the respondents at Gasibu Park felt a slightly warm thermal sensation (5) with a percentage of 33%. Meanwhile, in Lansia Park and Saraga Park, most of the respondents felt a normal thermal sensation (4) with a percentage of 53% and 37%, respectively. However, the percentage of respondents who feel a slightly cold thermal sensation (3) at Saraga Park is not much different from a normal sensation (4), which are 36% and 37%, respectively. Thus, among the three research samples, the most thermally comfortable RTHK was Lansia park with a neutral TSV value (53%), followed by Saraga Park (37%), and Gasibu Park (25%).

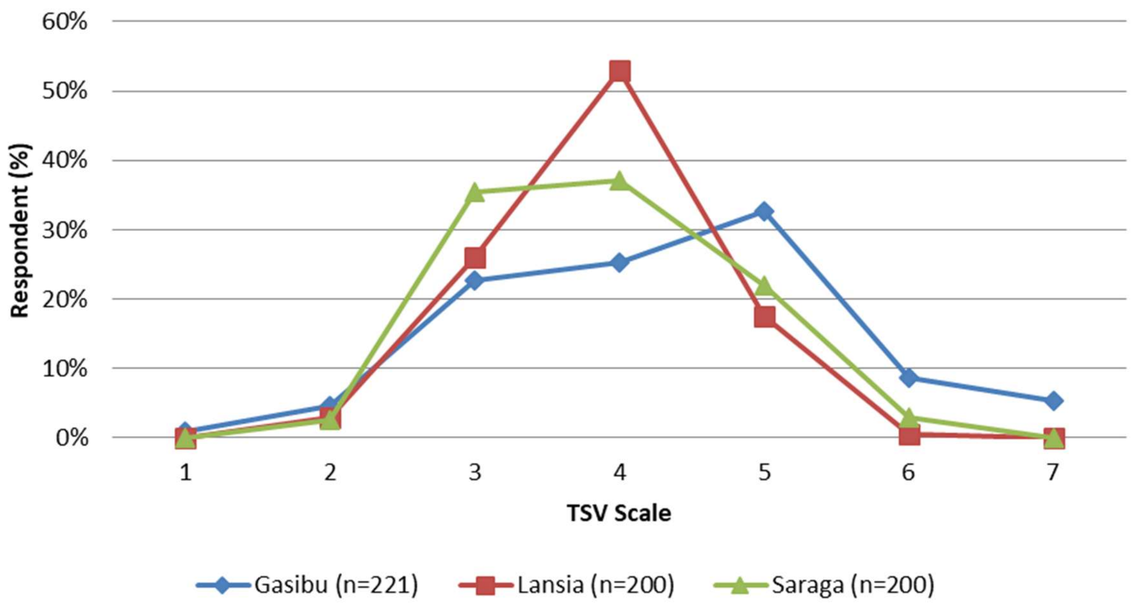


Figure 21. TSV value of the three urban parks

4.4.2. Preference and Acceptance of Thermal Performances

Visitors' responses to their preferences for thermal comfort are known by asking selective questions. Respondents were confronted with the answer choices "want to be cooler", "enough (want to remain as current performances)", or "want to be warmer". Based on the results of the interview, most of the respondents' thermal preferences answered "wanting to be cooler". With details, 52.1% at Gasibu Park, 55% at Lansia Park, and 47% at Saraga Park. This was followed by “enough” in second, and “want to be warmer” in third for each park.

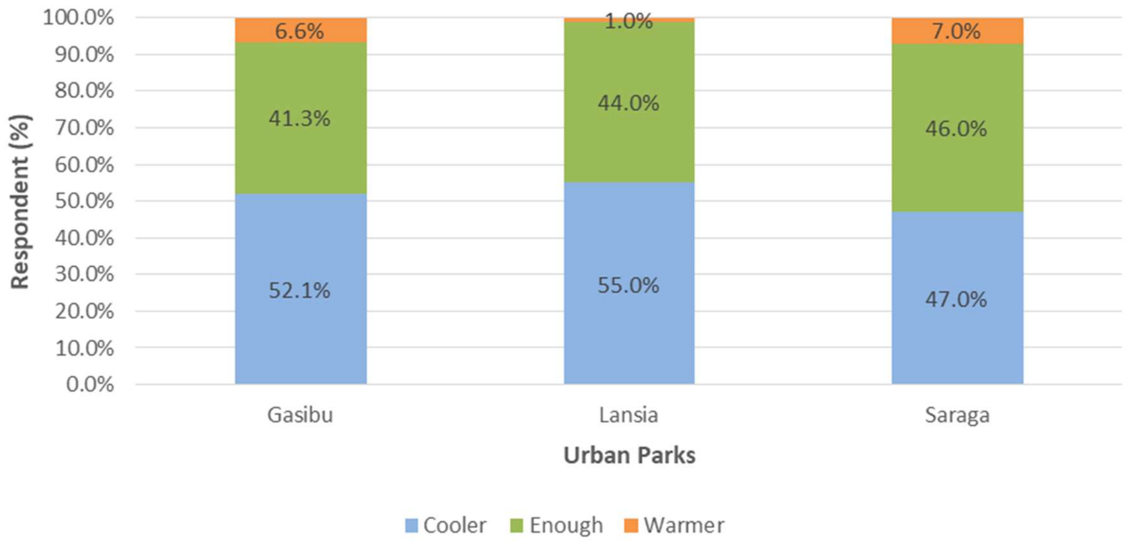


Figure 22. Percentage of User's Thermal Preferences

While the respondent's response regarding acceptance of the thermal performances (thermal acceptability) felt by the respondent at the time of the interview was very positive. Most of the respondents in the three research samples can accept the thermal conditions well, namely 94.1% at Gasibu Park, 100% at Lansia Park, and 98.5% at Saraga Park. Thus, it can be seen that most of the respondents (more than 90%) are able to accept the thermal conditions of urban parks, although in the answers to the other questions there is still dissatisfaction (regarding thermal preferences).

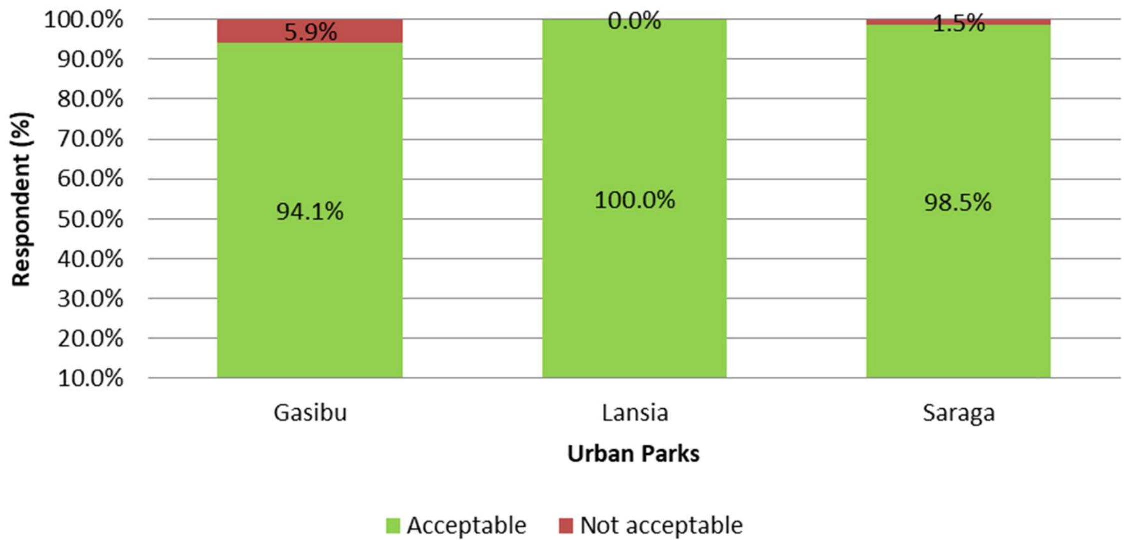


Figure 23. Percentage of User's Thermal Acceptances

4.4.3. Satisfaction of Shading, Sunlight, and Wind Performances

The questions of satisfaction of shading, sunlight, and wind performances for respondents were confronted with the answer choices "needed more", "enough (want to remain as current performances)", or "needed less".

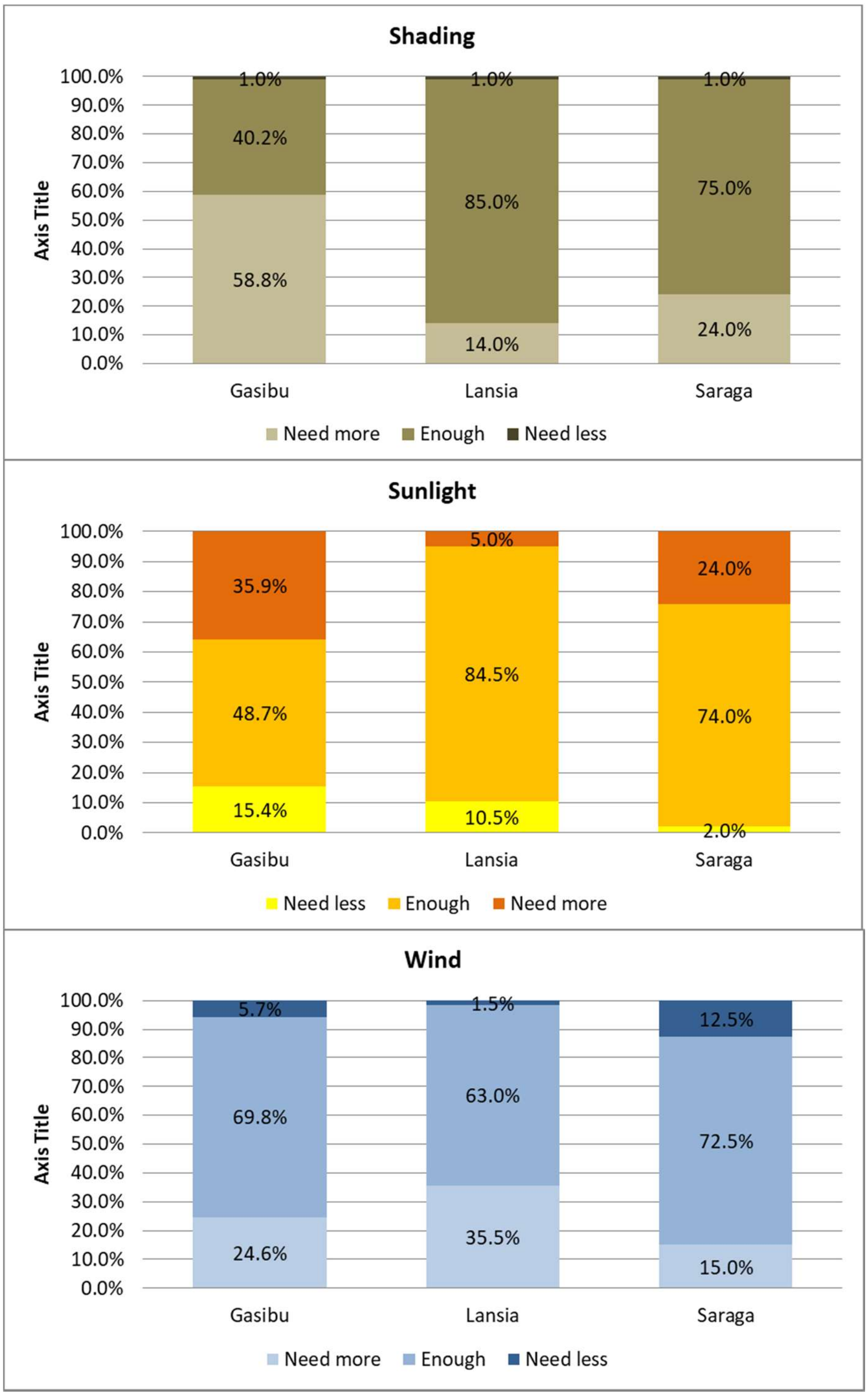


Figure 24. User Preferences of Shading, Sunlight, and wind performance

Most of the respondents at Gasibu Park were dissatisfied with the shadow conditions in the area. The percentage of respondents who felt they needed more shadows at Gasibu Park was 58.8%, 40.2% felt they had enough and only 1% felt they needed less shadows. Meanwhile, at Lansia Park and Saraga Park, most of the respondents were satisfied with the percentages of 85% and 75%, respectively. Thus, it can be seen that according to respondents, Gasibu Park still needs a lot of shaded areas, both by buildings and trees.

The level of respondent satisfaction with the condition of sunlight entering the area at each urban park location. The results of the interview showed that most of the respondents in the three research samples were satisfied with the conditions of sunlight entering the area, with details of 48.7% at Gasibu Park, 84.5% at Lansia Park, and 74% at Saraga Park. While the respondents' satisfaction level with the wind conditions in the area, most of the respondents in the three research samples were satisfied with the wind conditions in their respective areas. The percentages of satisfaction are 69.8% at Gasibu Park, 63% at Lansia Park, and 72.5% at Saraga Park.

4.4.4. Thermal Quality based on Field Measurement Data

Thermal quality based on field observations is calculated using the PET index. PET values are calculated on average per 1 hour based on the time of measurement in the field. While the daily average PET (mean PET) value is calculated based on the average value of hourly PET. PET values are obtained based on the results of calculations using RayMan software, by entering data on temperature (Ta), relative humidity (RH), and wind speed (v), activity level (W), clothing level (clo), height (m), weight body (kg), and average age of users (years) based on field observations.

4.4.4.1. Average PET of Gasibu Park

In Gasibu Park, the daily average PET value is 25.1 °C. Observations on sample 1 were carried out for 8 days in the wet season. Thus, based on the Matzakaris and Mayer (1997) thermal scale in the (sub) tropical region, the average thermal sensation felt by users at Gasibu Park is slightly cold (slightly cool), with a light psychological burden (slight cold stress).

Table 15. Average PET value of Gasibu Park

Time/ Date	**16/11/ 2016**	**17/11/ 2016**	**18/11/ 2016**	**22/11/ 2016**	**23/11/ 2016**	**24/11/ 2016**	**27/03/ 2017**	**28/03/ 2017**	**Average PET**
09:00-11:59	26,8	25,8	26,0	25,1	27,5	27,3	35,9	22,8	27,2
12:00-14:59	25,9	25,6	23,1	22,7	25,9	24,9	26,0	26,4	25,1
15:00-17:00	25,8	24,5	23,8	22,9	21,0	24,8	17,7	24,4	23,1
Daily average PET	26,2	25,3	24,3	23,6	24,8	25,7	26,5	24,5	**25,1**

4.4.4.2. Average PET of Lansia Park

In Lansia Park, the daily average PET value is 22.9 ° C (see Table 3). Thus based on the thermal scale of Matzakaris and Mayer (1997) in the (sub) tropical region, the average thermal sensation felt by users in the Lansia Park is slightly cool, with a slight psychological burden (slight cold stress). Observation in this park is carried out for 6 days in the wet season.

Table 16. Average PET value of Lansia Park

Time/ Date	**29/12/ 2016**	**30/12/ 2016**	**31/12/ 2016**	**29/03/ 2017**	**30/03/ 2017**	**31/03/ 2017**	**Average PET**
09:00-11:59	22,8	21,7	25,2	22,9	22,4	21,3	22,7
12:00-14:59	23,9	23,1	25,2	24,1	23,3	-	23,9
15:00-17:00	22,8	22,6	23,8	19,7	21,9	-	22,2
Daily average PET	23,2	22,4	24,8	22,2	22,6	21,3	**22,9**

4.4.4.3. Average PET of Saraga Park

The daily average PET value of Saraga Park is 23.7 °C. Observations on sample 3 were carried out for 7 days in the wet season. Thus, based on the Matzakaris and Mayer (1997) thermal scale in the (sub) tropical region, the average thermal sensation felt by users at the Saraga Park is slightly cold (slightly cool), with a light psychological burden (slight cold stress).

Table 17. Average PET value of Saraga Park

Time/ Date	**09/01/ 2017**	**10/01/ 2017**	**11/01/ 2017**	**31/03/ 2017**	**01/04/ 2017**	**02/04/ 2017**	**03/04/ 2017**	**Average PET**
09:00-11:59	23,1	22,6	25,5	-	25,8	26,3	22,2	24,2
12:00-14:59	23,4	23,7	25,4	22,5	-	21,6	23,1	23,3
15:00-17:00	20,9	24,3	25,9	23,8	-	-	22,5	23,5
Daily average PET	22,5	23,5	25,6	23,1	25,8	23,9	22,6	**23,7**

This finding show that the average PET value in an urban parks with a tropical climate is different. When compared, among the three research samples, the lowest PET value is sample 2 (Lansia Park), which is 22.9°C. While in second place is sample 3 (Saraga Park) which is 23.7°C and sample 1 (Gasibu Park) is 25.1°C. Thus, the average PET values in the three research samples are in the range of 22 - 26°C with a slightly cold thermal sensation (slightly cool), with a light psychological burden (slight cold stress).

This PET value is a new finding which shows that the average PET value is in the range of 22.9°C to 25.1°C. If it is connected with the interview results, most of the respondents feel they are able to accept thermal conditions (in each research sample), then the range of PET values shows the amount of PET value that can be adapted by the people of Bandung (which in this study is represented by visitors of urban parks which amounted to 621 people). According to research results in the country of Taiwan, as stated on the PET thermal scale for the (sub) tropical regions recorded by Matzakaris and Mayer (1997), it was found that the thermal comfort figures of PET are in the range of 26 ° C to 30 ° C. So when compared with this finding, the value of thermal comfort (PET) that can be adapted by the people of Bandung is lower than in other tropical climate cities.

4.4.5. Influence of Environmental Thermal Factors on Respondents' Perception

To find out which environmental thermal factors have the most influence on the respondent's perception of thermal comfort, a correlation between environmental thermal factors and the TSV value was carried out using JMP software. The environmental thermal factors are air temperature (Ta), relative humidity (RH), wind speed (v), and mean radiant temperature (Tmrt).

The total number of simulated data units is 57 data units. All data units have tested factor values, namely the value of thermal comfort according to TSV, Ta, RH, v, and Tmrt. Based on the results, it was found that the R^2 value of the influence of environmental thermal factors on the TSV value was 0.62 (close to 1). This means that the results of the data analysis are reliable for a scientific finding. The data analyzed amounted to 45 data units which are the best data units capable of representing all data units collected (a total of 57 data units, excluded 12 data units). The significance value of the regression analysis between environmental thermal factors and TSV is <0.001.

Table 18. Regression value among four variables

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0,127315	0,067121	-1,90	0,0651
Ta	-0,478878	0,497944	-0,96	0,3420
RH	-0,031087	0,006949	-4,47	<,0001
Air velocity	-0,155584	0,065997	-2,36	0,0234
Tmrt	0,1980651	0,132109	1,50	0,1417

Based on this table, an equation is formed as follow:

$$TSV = -0.13\ Ta - 0.03\ RH - 0.15\ v + 0.19\ Tmrt$$

By finding this equation, it can be predicted what the value of TSV in an observed environment is based on the value of the environmental thermal factors (Ta, Tmrt, RH, v). In addition, this equation can determine which factors can be increased in order to achieve a neutral TSV value.

Based on the results, it was found that the most influential factor was RH (relative humidity) with a probability value or P-value <0.0001 with a correlation value of -0.03. This means that the higher the humidity in an urban park, the lower the thermal comfort value. Referring to the recommended value in the ANOVA (analysis of variance) which is <0.05 or the probability of predicting the findings being wrong is 5%, this RH significance value is significant. Then the second most significant factor is wind speed with a P-value of 0.0234. Thus, it can be concluded that the environmental thermal factor that has the most influence on the user's thermal comfort is relative humidity (RH). This finding indicates that in order to establish a thermally comfortable urban park's environment in the city of Bandung, the urban park planning team, urban designers, and related government agencies really need to pay attention to various aspects that are able to regulate the humidity of the environment.

4.5. Conclusion

According to the results it was found that:

1) Based on interview and field measurement, the best quality of the thermal performance among the three samples was sample 2 (Lansia Park), followed by sample 3 (Saraga Park) and sample 1 (Gasibu Park). These findings indicate that the hypothesis that the greater the ratio of vegetation an urban park, the greater the thermal comfort value is correct.
2) The community adaptation to the thermal quality of the urban park's environment as a whole is quite good. Most of the respondents were able to accept thermal performances in all three locations or research samples. Although on the other hand, most of the respondents want to be cooler than the performances that occurred during the interview. Satisfaction of the performance of shading, sunlight, and wind within the area is quite good.
3) The average value of PET on urban parks in Bandung is in the range of 22.9 °C to 25.1 °C with slightly cooler thermal sensation, with a slight cold stress. PET values that can be adapted by the people of Bandung is lower than the cities in other (sub) tropical countries.
4) The environmental thermal factor that most influences the TSV value in the three urban parks in Bandung is RH (relative humidity) with a probability value or P-value <0.0001 with a correlation value of -0.03. This means that the higher the humidity in an urban park, the lower the thermal comfort value.

CHAPTER 5

VISITOR PERCEPTION AND EXPECTATION IN URBAN PARK

Summary

The quality of an urban park can be evaluated by understanding the visitor's reasons, preferences, and expectations. The study analyzes several variables based on answers to field survey questionnaires using 425 respondents. Furthermore, Green Park, located in Kitakyushu, Japan, serves as the case study. The result found six essential variables: 1) "Playing with children" is the most popular reason for visiting this park; 2) Tourists living closer to the area frequently visit; 3) The existence is necessary; 4) The relationship between the importance and the origins of the tourists is related to a sense of place; 5) Tourist preferences are affected by seasonality; 6) The most favorite expectation is the availability of water facilities. This further can contribute to tourism development in urban parks with similar climatic and environmental characteristics.

5.1. Introduction

5.1.1. Background

Understanding visitors' motivation to visit public open spaces is important as the number of people visiting open spaces increases each year (Mohamed, Othman, & Ariffin, 2012). Many reasons have been shown in previous studies and it is including appreciation of aesthetics, design, visual quality, and recreational value of open spaces (Connell, 2004). A study in Oslo, Norway, found that attributes that affect visitor motivation when seeking psychological restoration were water elements, trees, ground cover (Nordh, Alalouch, & Hartig, 2011). Other studies found that spending social time with friends and family, physical and mental relaxation, or other hobbies are the common reasons for the visitors (Ballantyne, Packer, & Hughes, 2008; Ward et al., 2010).

The criteria considered for the eligibility of the case study are a large-scale park (Aram, Higueras García, et al., 2019) with a legal classification. According to the Ministry of Land, Infrastructure, and Transport of Japan (MLIT, 2006), there are two legal classifications of Japanese parks: natural and urban parks. Urban parks are specific areas of land opened for public use and created by central government or local bodies. In the Kitakyushu City area, 23 parks fall within the territorial area, according to their official tourism information website (KCTIC, 2021). Based on these criteria, Green Park Kitakyushu was the most eligible to serve as a case study.

5.1.2. Purpose of the study

This study aims to understand tourists' reasons, preferences, and expectations in Green Park, Kitakyushu, Japan. The six crucial questions to be considered are:

1) What is the reason for visiting this park?
2) What is the relationship between the frequency and the distance of the visits?
3) How importance is this park to visitors?
4) What is the relationship between the importance of visiting and the distance?
5) Are tourists more inclined to visit during specific seasons and area?
6) What are the expectations of this park facilities?

5.2. Literature Review

5.2.1. Reason to visit urban park

Visiting urban parks is a fun activity for many people, and the experience can reduce mental stress (Ulrich, 1981), increase meditation, and provide peace of mind (Kaplan, 1985). There is a significant relationship between park use and perceived health performances. Frequent users of local parks are more likely to have good health (Godbey & Mowen, 2010) since they visit for functional needs such as exercise, relaxation, and outings with children (H. Liu, Li, Xu, & Han, 2017). Parks and urban green spaces can provide opportunities for recreation, sport, leisure, and residents' physical and mental health (Riki et al., 2016). Urban nature fulfills many citizens' social functions and psychological needs, making it a valuable municipal resource and an essential ingredient for city sustainability (Chiesura, 2004). According to a study conducted in Malaysia (Othman et al., 2015; Razak et al., 2016), the primary reason for visiting an urban park is for recreational purposes. It shows that the feelings and the emotions evoked in this park are perceived by people as significant contributions to their well-being, such as regeneration of psychophysical equilibrium, relaxation, break from the daily routine, and the stimulation of a spiritual connection with the natural world (Chiesura, 2004).

Furthermore, Riki et al., (2016) and Jones (2006) stated that the reasons for visiting a park are: exercise or fitness, picnics with family, playing with children, educational/study purposes, taking part in certain activities or events, and relaxing or having pleasant diversion (Jones, 2006; Riki et al., 2016). Chiesura (2004) stated that visitors conduct several activities with different motives. Children are always eager to explore water because it is fascinating and intriguing (McMillan, 2014). Water play can also help them acquire problem-solving and thinking skills (Hoisington, Chalufour, Winokur, & Clark-Chiarelli, 2014; Olowe, Ojoko, & Onuegbu, 2020). These findings show that tourists' behavior and activities are related to age, reason/purpose to visit, and the urban park's environment. The design and management also play an essential role in increasing tourists' feelings and emotions.

5.2.2. Satisfaction and expectation

The tourist's satisfaction and expectation of environmental performances can affect their perception of comfort in outdoor space, and the park quality is significantly correlated to physical activity (Rosli et al., 2020). Nature and human interactions need elements of open spaces such as green environments, water elements, and physical attributes to enhance the interactions between human-human and human-nature (Ibrahim et al., 2017). According to Klanicka (2006), expectations for developing urban park facilities can indicate a sense of belonging to the local community. This is strongly associated with memories of childhood and youth (Klanicka, Buchecker, Hunziker, & Böker, 2006).

5.2.3. Visitor preferences in urban park

One of the most significant challenges an urban park faces as a tourist destination is seasonality. It affects the optimal use of investment and infrastructure and can create a negative experience of crowding at destinations (Sætórsdóttir, Hall, & Stefánsson, 2019). Visits are also affected by seasonality variation (Corluka, 2019; Corluka, Mikinac, & Milenkovska, 2017; D. C. Geng et al., 2021; Sætórsdóttir et al., 2019; Zainol & Au-Yong, 2016) and tourist preferences.

5.3. Materials and Methods

5.3.1. Study subject

The study subject is the tourist of Green Park Kitakyushu, which are participated by a random and voluntary approach. Except for children under 10 years, there are no special provisions to avoid bias/misunderstanding. The number of respondents is 425 people, consisting of 187 males, 236 females, and 2 did not fill out the gender question. The study location is focused on the large grass open space, as the most frequently visited, based on the observation results of the pre-study.

5.3.2. Data collection method

The data collection method was conducted by distributing field survey questionnaires to tourists. Respondents were limited to volunteers who had been screened by entering this park on purpose (Statistic-Canada, 2017). This study was conducted in 4 different seasons within one year. Each season consists of 3-4 days of data collection, and each day consists of 2-3 location spots.

Table 19. Seasons, number of days, and period of data collection

Seasons	Number of days	Period
Summer	4	19 July - 16 August 2020
Autumn	3	14 - 18 October 2020
Winter	4	17 January - 14 February 2021
Spring	4	10 April - 8 May 2021
Total	11	

5.3.3. Data analysis method

Data analysis was carried out using quantitative approaches and statistical techniques using computer software. The distribution analysis technique determined the reasons, frequency, and importance of tourists to the existence of Green Park Kitakyushu. In addition, it obtained the most favorite season, area, and tourists' expectations of urban park facilities. The correspondence analysis technique was used to determine the closeness between factors, importance, and frequency of visiting the Green. Meanwhile, the analysis data were processed in Microsoft Excel and illustrated by graphs. The JMP statistical software is utilized to gain a correspondence analysis.

5.4. Results and Discussion

5.4.1. Reason to visit urban parks

This study determined tourists’ reasons, preferences, and expectations at Green Park, Kitakyushu. The trends on the bar graph indicate an urban park that is friendly to families with children. The most popular reason is playing with children, which is popular for spring’s respondents. “Having a picnic or gathering with friends” accounts for the second reason.

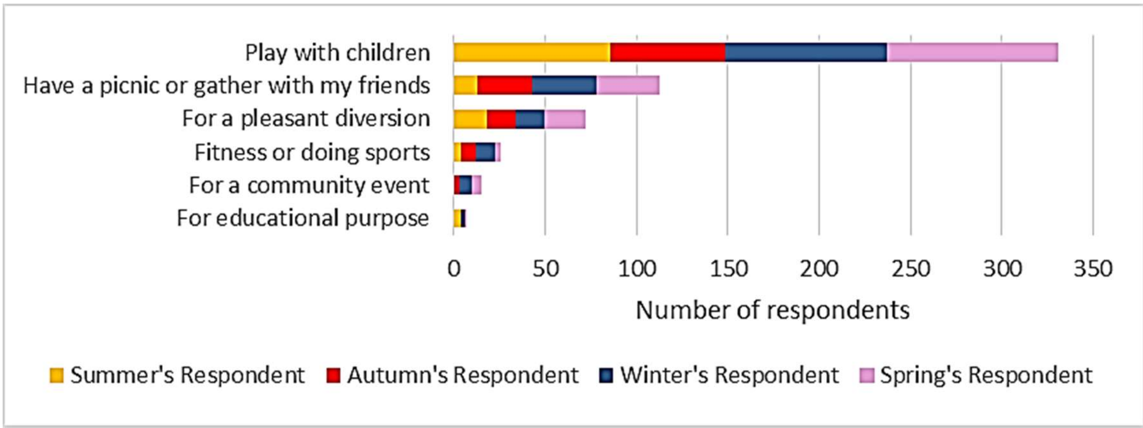


Figure 25. Reason for visiting Green Park Kitakyushu

The heat-map graph presents the correlation between reason and age groups. The result shows that adults between 30 and 40 years mostly have a motive to play with children. Meanwhile, most teenagers are motivated to have a picnic or gather with friends. The elderly above 70 years visit this park for pleasure or pleasant diversion.

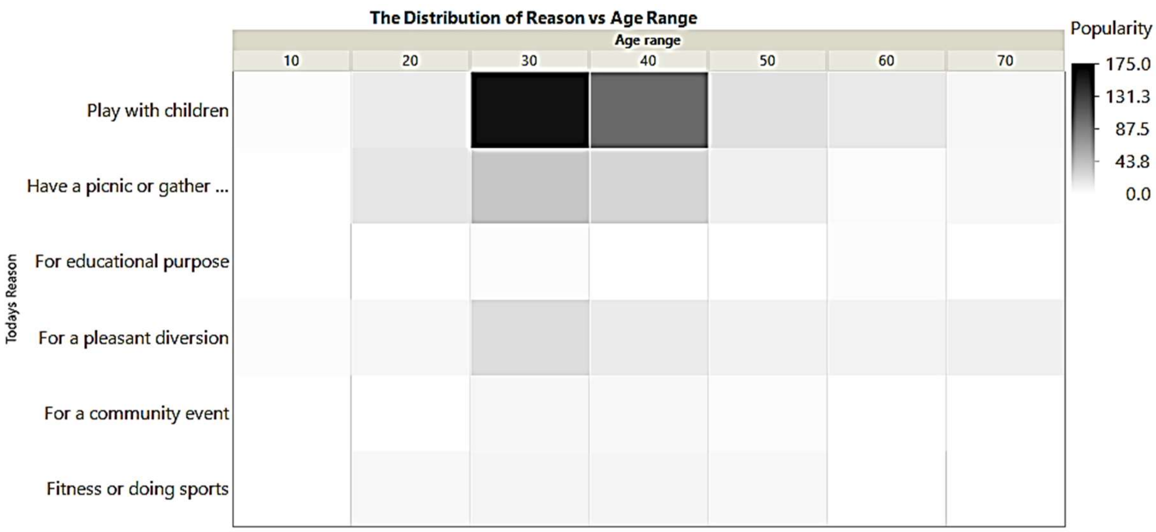


Figure 26. Correlation between current reason and the age-group

5.4.2. Frequency of visiting

Tourists were asked how often they visit Green Park Kitakyushu. Based on the survey results, 61%, 26%, and 11% answered (4) "once or twice a year", (3) "monthly or more often", and (5) "this is my first time", respectively. Compared to the results obtained, this pattern occurs in all seasons. This finding shows that most respondents "rarely" visit this park. It also shows that the tourist living outside the city, i.e., Fukuoka or other cities in Japan, are primarily associated with the first-timer tourist to this park.

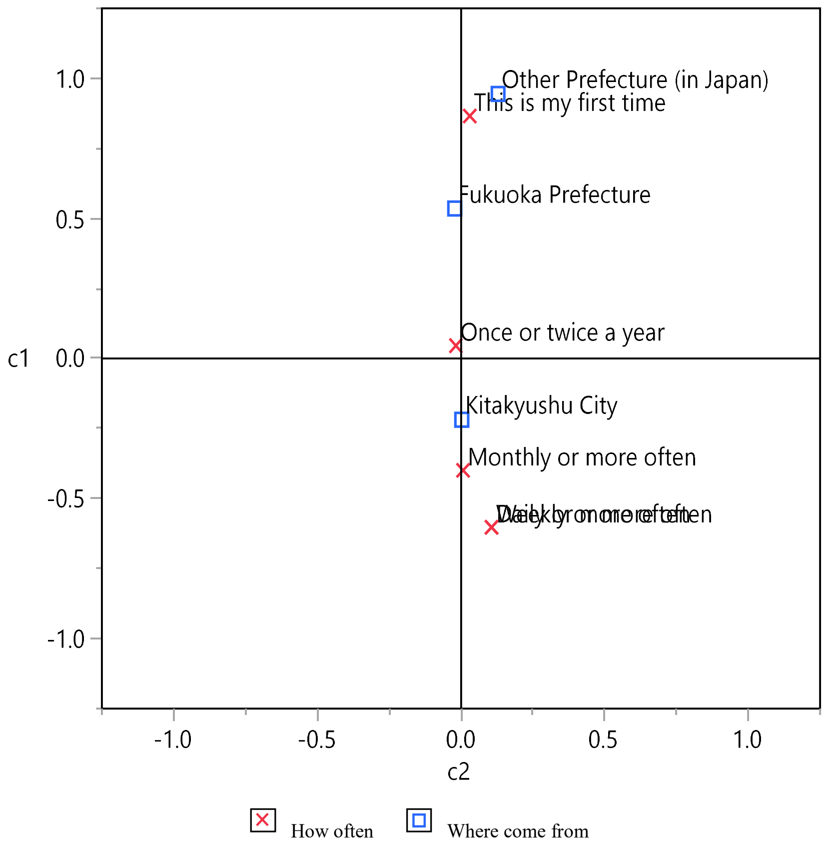


Figure 27. Correspondence analysis between "Where come from" and "How often"

Tourists are classified according to their frequency of visits. Based on this correspondence analysis, it is founded that tourists living closer to this park frequently visit.

5.4.3. Importance of visiting urban parks

The frequency analysis (Figure 22) shows that 33%, 29%, 21%, and 16% answered (+1) slightly important, (+2) important, (+3) very important, and (0) neutral, respectively. Almost no respondents answered negatively, and each season has a different pattern. From these findings, tourists feel that the existence of Green Park Kitakyushu is important to their lives.

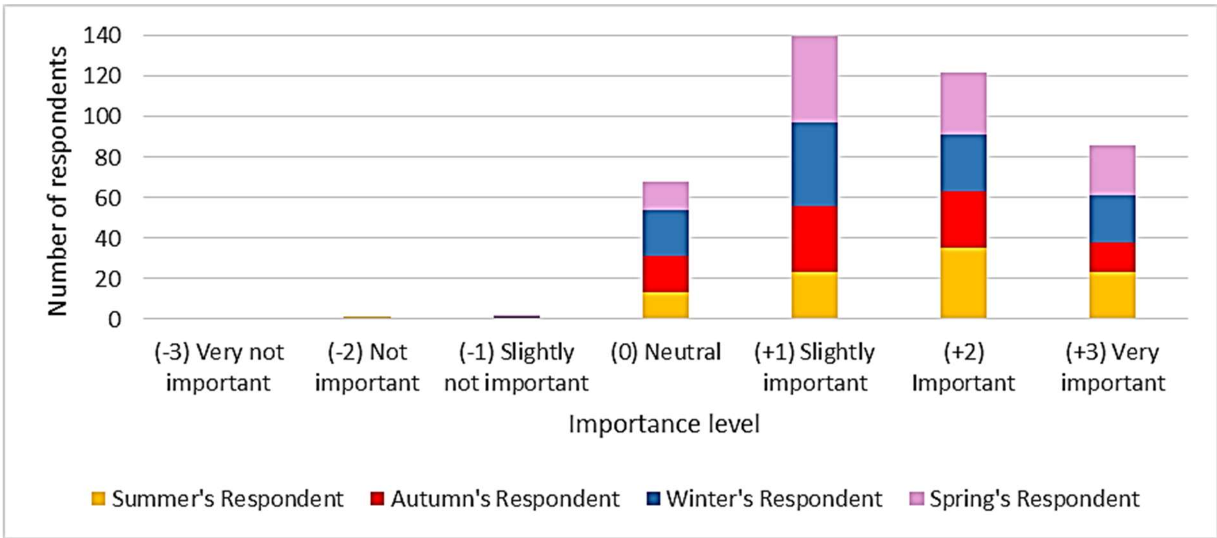


Figure 28. Importance of visiting Green Park Kitakyushu

5.4.4. Relationship between the importance and the distance of location

Based on the correspondence analysis, the correlation between the importance and the distance of location tends to be positive. Respondents who answered that visiting this park is important (+1, +2, and +3) are from inside the Kitakyushu City (local tourists). While the majority from outside Kitakyushu (such as other cities but still in the same prefecture (Fukuoka Prefecture) and other prefectures in Japan) answered neutrally (0). This finding indicates that the sense of belonging felt by visitors is related to the distance of urban parks to their living.

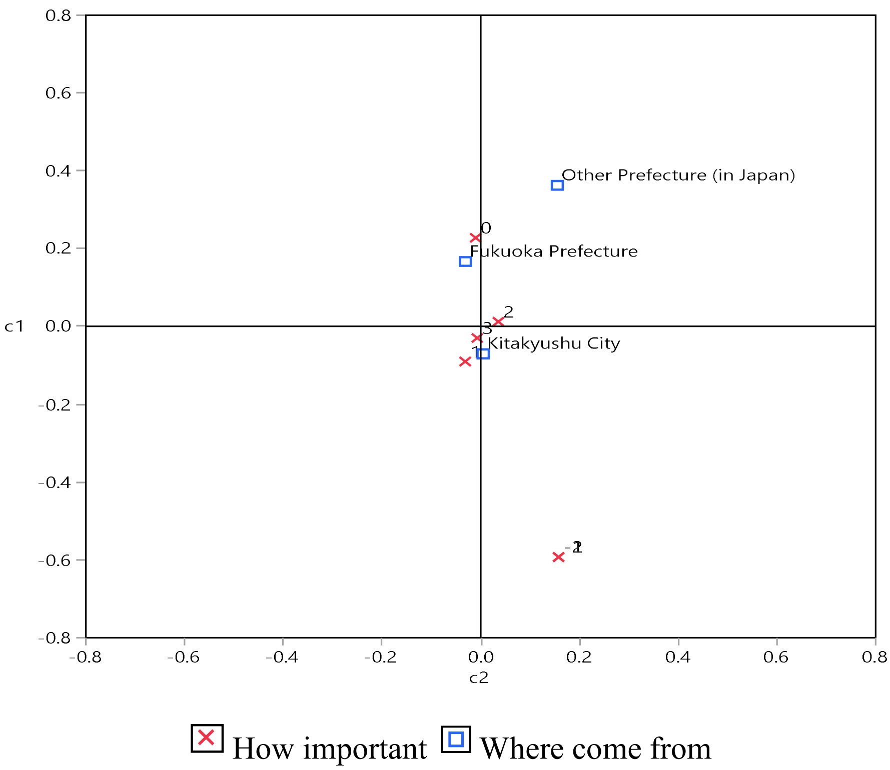


Figure 29. Correspondence analysis between importance and distance of visiting urban park

5.4.5. Most favorite season and area of urban park

The result confirms that seasonality affects tourist preferences to visit an urban park. Most tourists select the spring season as their favorite, followed by autumn and summer. Almost all respondents selected "spring" as their favorite season, except autumn. Meanwhile, the summer respondent has two favorite seasons, spring and autumn.

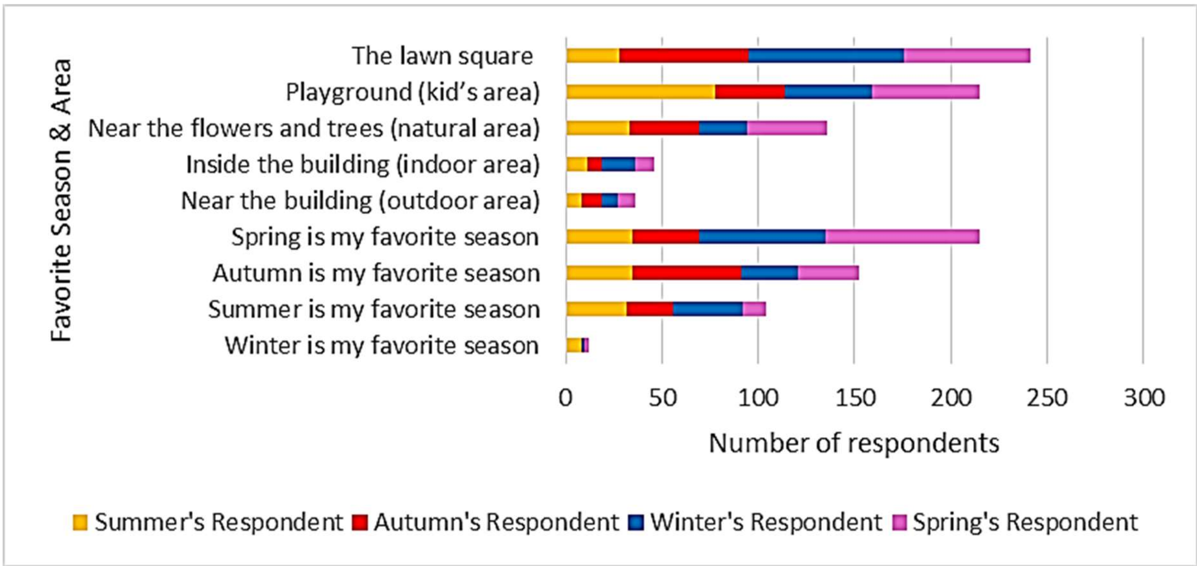


Figure 30. Most favorite season and area of Green Park Kitakyushu

Based on the survey results, the favorite area in Green Park Kitakyushu is the lawn square, followed by the playground for kids, then the natural, indoor, and outdoor areas. The lawn square is used as a picnic area, setting up a tent or storing personal belongings based on field observations. This result is correlated to the tourists' answers regarding the reason for visiting this park.

5.4.6. Visitor expectations for urban parks

The survey result shows that most respondents selected the expectation of the availability of permanent water play facilities as the most popular one. This is followed by camping space facilities, the answer of "I am satisfied with the current performance," pets play facilities, can stay all night, more animal varieties, athletic ground or sports space, and skate park. This result shows that even though the temporary water play facilities are provided only in summer, it is still the best for all seasons. This may be due to children's great interest in water-related play facilities.

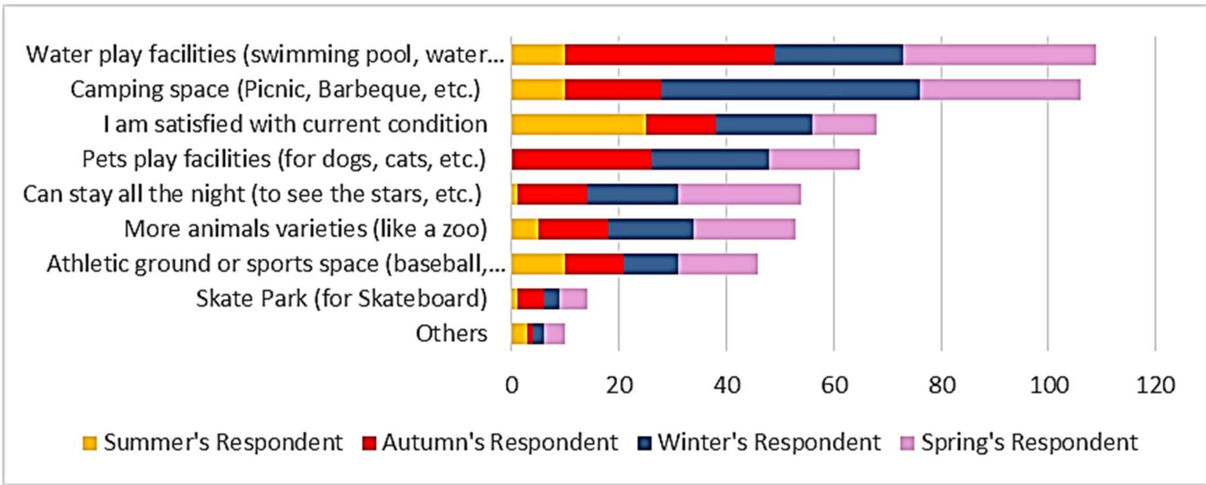


Figure 31. Visitor expectation of park facilities in Green Park Kitakyushu

5.5. Conclusion

This study found six points:

1) Most of respondents visited to play with children. These findings indicate that Green Park Kitakyushu is friendly to families and children. The adult and older age groups mostly visited because of children, while teenagers visited for picnics. The motive of the elderly groups above 70 years is to seek pleasure.
2) Most respondents rarely visit this park, and the tourists living closer to the area visit frequently. This result strengthens the finding that distance tends to affect the frequency of visits.
3) The existence of this park is critical for tourists, and there is a positive correlation between its importance and origin.
4) Respondents who stated that visiting this park is important were from Kitakyushu, while the majority from outside gave a neural answer. This finding indicates that the sense of belonging felt by visitors is related to the distance of urban parks to their living.
5) Visitors mostly select spring season as their favorite, followed by autumn and summer. This finding confirms that seasonality affects tourist preferences to visit. The most favorite area in this park is the lawn square, followed by the playground for kids, as well as natural, indoor, and outdoor areas. These results may be correlated to the tourists' answers regarding the reason for visiting this park.
6) Even though the temporary water play facilities are provided in winter, most respondents expect that permanent facilities will be provided in different seasons. This may be due to children's great interest in water-related play facilities.

CHAPTER 6

RELATIONSHIP OF AGE, GENDER, AND BODY PROPORTION TO OUTDOOR THERMAL COMFORT

Summary

The study analyzes relationship between the age, gender, and body proportion and the outdoor thermal comfort based on Thermal Sensation Vote (TSV) value. The hypothesis are: 1) the older a person is, the lower the standard of comfort will be, and vice versa; 2) men are easier to gain thermal comfort than women; and 3) the greater the distance from the proportional body, the higher the standard of comfort. These hypotheses will be scientifically proven through this research. This research was conducted for one year by quantitative methods using a printed questionnaire media. The relationship between the three variables would be analyzed by the multivariate analysis method. Based on the analysis results, there is no significant correlation of age, gender, and body proportion to outdoor thermal comfort.

6.1. Introduction

6.1.1. Background

Outdoor thermal comfort is influenced by many factors, including environmental factors and human factors. Behavioral responses to the thermal environment differ by gender, age, and type of activity (Huang et al., 2016). The individual thermos-neutral zone (TNZ) is influenced by many factors, namely: body composition, clothing, energy expenditure, age, and gender (Kingma, Frijns, & Lichtenbelt, 2012). A person's age are thought to affect thermal comfort. Older people have lower standards of thermal comfort than younger people, and vice versa (Novieto & Zhang, 2010). Age-related changes in physiological function can affect the ability of the elderly to maintain body temperature when exposed to hot or cold environments (Blatteis, 2012). Children tend to be affected by heat exposure in outdoor playgrounds (Vanos, 2015). Older subjects exhibit slightly lower neutral temperatures than younger subjects (Karyono, 2000). Another finding found that the thermal comfort expression for the younger (age ≤ 25 years) is slightly comfortable, but its temperature is significantly higher than older age > 25 years) (Indraganti, Ooka, & Rijal, 2015).

The differences in thermal comfort based on gender, men are easier to get thermal comfort than women. According to Karyono (2000), men feel warmer than women, but the difference is negligible and statistically insignificant at the 5% level. Karjalainen (2007) conducted a controlled experiment assessing thermal responses regarding gender differences (Sami Karjalainen, 2007). The results showed that women tend to feel hot discomfort more often than men. K.C. Parsons (2002) studied the thermal comfort effect based on gender with the thermal performances and standard clothing insulation are under controlled and the number of samples are 16 young women and 16 men. It is reported that women feeling hotter than men (Parsons, 2002). Another investigation of the effect of gender on thermal comfort with 10 young women and 10 young men, found that women felt less comfortable and more dissatisfied than their men (Schellen, Loomans, de Wit, Olesen, & Lichtenbelt, 2012). The females' thermal acceptability, comfort temperature, and use of windov are significantly higher than males (Bryman, 2012).

The proportion of a person's weight and height is also thought to affect the level of thermal comfort. The further its distance from the proportional body which is measured by Body Mass Index (BMI), the higher the standard of comfort. As for Body Mass Index (BMI), Karyono (2000) found that the subjects with normal body mass (20 – 25 kg/m2) tend to have higher neutral temperatures than those with higher body mass. Indraganti et al. (2015) showed that subjects with low BMI (< 18.5Kg/m2) had higher comfort temperatures than the subjects with high BMI (> 25 kg/m2).

6.1.2. Hypothesis

Based on literature, there are three hypothesis can be concluded, they are:

1) The older person harder to feel comfortable than the younger
2) Men easier to feel comfortable than women
3) The more ideal a person's body proportions are the easier to feel comfort

6.1.3. Purpose of the study

Based on those previous findings, this research aims to determine the relationship between thermal comfort and 3 variables, namely: age, gender, and body proportion. As assistance, there are 3 research questions formulated:

1) How is the correlation between Outdoor Thermal Comfort and Age, using Thermal Sensation Vote (TSV), does the older person harder to feel comfortable than the younger?
2) How is the relationship between Outdoor Thermal Comfort and Gender, using Thermal Sensation Vote (TSV), are men easier to feel comfortable than women?
3) How is the correlation between Outdoor Thermal Comfort and Body Proportion, using Thermal Sensation Vote (TSV) and Body Mass Index (BMI), is it true that the more ideal a person's body proportions are the easier to feel comfort?

6.2. Literature Review

6.2.1. Personal factors in Thermal Comfort Study

6.2.1.1. Age and gender

Numerous epidemiological studies have indicated that the internal body ('core') temperature of both healthy men and women over 60–65 years of age is generally lower than that of their younger adult counterparts (Blatteis, 2012). The average difference between clinically healthy adult (ages 20–64) and elderly with special care (ages 65–95) male and female groups reported in the literature is approximately 0.4°C, a statistically significant difference but physiologically safe. A study in California with cross-sectional data from 18,630 white adults aged 20–98 years found that women had higher mean temperatures (97.5 ± 1.2°F) than men (97.2 ± 1.1°F). Mean temperature decreased with age, with a difference of 0.3°F between oldest and youngest groups after controlling for sex, body mass index, and white blood cell count (Waalen & Buxbaum, 2011). An indoor thermal comfort study found that adults (above 20 years old) had a higher values in the neutral temperature (25.45 °C), a higher upper limit of comfortable temperature (28.61 °C), and acceptable temperature (32.7 °C) than the youth (20 years old and younger), while the youth had a narrower comfortable temperature range (22.83–27.24 °C) (P. Li, Liu, & Dong, 2020). Furthermore, the elder adults also showed a stronger adaptability and resistance to the warm environment.

A study of thermal comfort of eight young adults (age 22–25 year) and eight older subjects (age 67–73 year) was investigated in Eindhoven, Netherlands. The results indicate that thermal sensation of the elderly was 0.5 scale units lower in comparison with the younger (Schellen, van Marken Lichtenbelt, Loomans, Toftum, & de Wit, 2010). Thermal sensation of the elderly was related to air temperature only, while the younger adults was related to air temperature and skin temperature. The elderly preferred a higher temperature in comparison with the young adults during the constant temperature session. An indoor thermal comfort study in Xi'an, China, found that the neutral temperature for elderly is 20.4 °C, the temperature ranges of 80 and 90% acceptability were 13.8–30.5 and 17.2–27.0 °C (Zheng, Che, Zhou, Liu, & Seigen, 2020). In comparison with the standard temperature of thermal comfort, this study confirmed that elderly has a lower neutral temperature than human thermal standard (age 35) which is in a range of 26 – 30°C (T. P. Lin & Matzarakis, 2008). An evaluation study of human thermal sensation in Finland also found that increase in age seems to decrease thermal sensation values (Tuomaala, Holopainen, Piira, & Airaksen, 2013).

In the other hand, a thermal comfort environmental chamber study found that there were no significant difference between the thermal sensation, comfort and acceptability of older (over 65; average 69.7 years old) and younger (average 29.6 years old) subjects (Soebarto, Zhang, & Schiavon, 2019). It also found that there were no correlation between subjects' frailty level and their thermal sensation, comfort, acceptability and preference. The hand's skin temperature had a significant correlation with the local and overall thermal sensation in both older and younger subjects. Another study found that no consistent conclusions could be drawn on the size and significance of inter-group differences in the preferred/neutral temperature between females and males, nor the young and the elderly (Z. Wang et al., 2018).

6.2.1.2. Body weight and height

A study of the impact of individual characteristics on human thermal sensation, such as age, gender, body mass index (BMI), and fitness has been conducted in Finland. It is found that, in general, BMI seems to have minor impact on thermal sensation (Tuomaala et al., 2013). Another study conducted an experimental evaluation of the effect of body mass on thermal comfort perception. Despite the result that there was no significant impact of BMI on the thermal sensation, the overweight and obese participants preferred lower temperatures compared to normal-weight and underweight participants (Lipczynska, Mishra, & Schiavon, 2020).

In Shanghai, China, a study of the correlation between human body fat percentage, human body muscle percentage, and thermal comfort in conditioned environments found that there was a significant relationship between the body fat and individual thermal comfort. The lean people were less sensitive to the cold condition (M. Liu, 2019). Another study observed that there was a tendency of decreasing clothing insulation as BMI increased. Thermal sensation, preference and comfort showed a significant relationship with the two modes of operation, when considering BMI values (Menegatti, Rupp, & Ghisi, 2018). It also found that individuals with higher BMIs feel warmer, tended to prefer cooler environments and feel more thermally comfortable than users with lower BMI values.

6.2.2. Unique Character and Personality in Japan

In general, every culture has a role in shaping one's character in public. Likewise with Japanese society where some people think they tend to be introverted or less daring to express opinions in public speaking. A study on the influence of personality and anonymity on electronic brainstorming was found that the anonymous condition in electronic brainstorming is suited to introverts ' idea generation (Mukahi & Tetsuo, 1998). Japanese are introverts and sensitive to conformance pressure. This well-protected privacy’s character of Japanese have been a common in their daily lifestyle.

Another study investigated the relationship between personality and anxiety characteristics of Japanese students and their oral performance in English. The findings suggest that participants who were more extraverted produced better global impressions during their oral performance, and those who were experiencing higher levels of state anxiety made more errors in their spoken use of clauses (Oya, Manalo, & Greenwood, 2004). Japanese people tend to keep to themselves not because they are necessarily shy or “introverted”, but it is a sign of humility

(Yurchenko, 2018). They believe that not pushing one's opinions on others and keeping it by their self is a good and respectful manner.

6.3. Methods

This research was conducted at Green Park, Kitakyushu city, Fukuoka prefecture, Japan, one of the most popular recreational park in Kitakyushu City. The total number of samples is 415 people obtained in 4 periods of data collection based on the type of season in 1 year. In summer, there were 97 respondents (23.37% of data), in the fall of 86 respondents (20.72% of data). Meanwhile, in winter and spring, there were 117 respondents (28.19% of data) and 115 respondents (27.71% of data), respectively.

6.3.1. Data collection

Methods of data collection using a questionnaire. The activity index is measured by the question of the person's activity about 30 minutes before the measurement is being held. Respondents also filled in the weight and height columns, this data will later be useful for calculating their respective BMI values, their body proportion category is determined based on the BMI value. The survey was conducted in 4 periods based on different types of seasons in 1 year: summer (19 July 2020 – 16 August 2020), autumn (14 – 18 October 2020), winter (17 January 2021 – 14 February 2021) and spring (10 April 2021 – 8 May 2021).

6.3.2. Data analysis

The method of analyzing data is using Fit Y by X analysis between two different variables. For the data which are both numeric types, it is analyzed by Bivariate Fit Analysis. To understand the correlation among them (R^2), it is analyzed by Linear Fit and the significant value (Prob>F) by Analysis of Variance. For the analysis of two different data types (numeric versus character), it is analyzed by One way Analysis. To understand the correlation among them, it is analyzed by Compare Densities, Composition of Densities, and Proportion of Densities. All these types of analysis is assisted by JMP statistic software.

6.4. Results and Discussion

The age category is divided based on certain age ranges. Since this study was conducted in Japan, where the majority of the population is more sensitive to privacy issues and to avoid missing answers about age, the age category uses a ten-year number range, namely: 10s (10 – 19 years old), 20s (20 – 29 years old), 30s (30 – 39 years old), 40s (40 – 49 years old), 50s (50 – 59 years old), 60s (60 – 69 years old), and 70+ (70 years old and more). Meanwhile, gender is divided into 2 groups, male and female. Based on the survey, most of respondents (43%) are in the range of 30s age and it followed by 40s (27%). The rest range of ages are less than 10% of total respondents. It means that the majority of respondents are adult person.

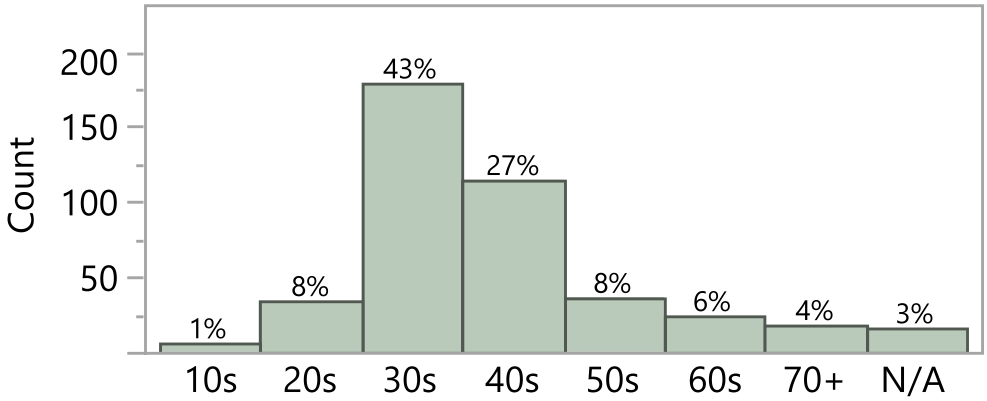


Figure 32. Age range

The Body Mass Index (BMI) is a person's weight in kilograms divided by the square of height in meters (Centers for Disease Control and Prevention, 2020). With the metric system, the formula for BMI is weight in kilograms divided by height in meters squared. Because height is commonly measured in centimeters, divide height in centimeters by 100 to obtain height in meters. BMI is an inexpensive and easy screening method for weight category: underweight, normal or healthy weight, overweight, and obesity. For adults 20 years old and older, BMI is interpreted using the category of standard weight status. This category applies for all body types and ages of men and women. The category is shown in the following table.

Table 20. Weight Status Interpretation of BMI

BMI	**Weight Status**
Below 18.5	Underweight
18.5 – 24.9	Normal or Healthy Weight
25.0 – 29.9	Overweight
30.0 and Above	Obese

Source: Centers for Disease Control and Prevention, 2020

Based on the survey, it was found that from the total respondent (415 people), only 64.5% (268 people) which has full BMI data. The 147 data has missing data, either data of height or weight. From that situation of data, most of the respondents (68.6%) have a healthy weight (normal). The second most one is overweight (16.7%). The smallest percentage is the obesity (2.9%).

Table 21. BMI Index of Respondents

BMI Index	Count	Percentage (%)
Healthy Weight (Normal)	184	68.6
Obese	8	2.9
Overweight	45	16.7
Underweight	31	11.5
Total	268	100
N Missing	147	

Thermal comfort is analyzed based on the character of the location, namely indoor, semi-outdoor, and outdoor. The outdoor thermal comfort value was determined by using the Thermal Sensation Vote (TSV). The TSV value is a perceptual measurement which is obtained from the respondent's answer to the actual thermal environmental performances. This value is usually on an ordinal Likert scale of 7, from feeling very cold to very hot (cold, cool, slightly cool, neutral, slightly warm, warm, and hot).

6.4.1. The Correlation between Thermal Sensation Vote (TSV) and Age

Based on the results of the Bivariate Fit analysis of Thermal Sensation Vote (TSV) by Age Range, it was found that there was almost no correlation between the two variables. The correlation coefficient value (R2) is 0.054654 (far from 1 and less than the recommended minimum 0.6), so the data used is not reliable or not accurate to be used as material for analysis in a study. Likewise, the significance value (Prob>F) is 0.2773, which means the effect is not significant (> 0.05). So based on the results, it can be concluded that the hypothesis that the older a person is the more difficult it is to obtain thermal comfort is not proven true. This may occur because the amount of data available is still not sufficient to see the relationship between the two variables.

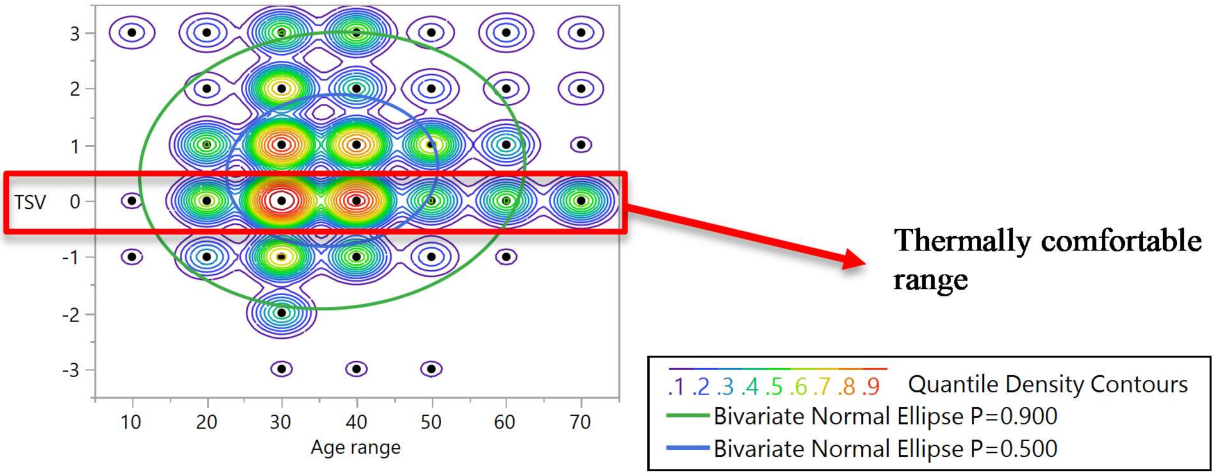


Figure 33. Correlation between TSV and age range

By the number of data, from a total of 415 data, only 397 data (95.67%) which has age data, or the data that can be used for this analysis. This shows that some respondents (4.33%) are not open to questions about age. This result seems to confirm that Japanese people tend to be introverts. In this case, they were closed to age matters due to privacy issue. This issue certainly affects the significance value of the correlation of the two variables.

6.4.2. The Correlation between Thermal Sensation Vote (TSV) and Body Proportion

The Bivariate Fit analysis of Thermal Sensation Vote (TSV) by BMI shows that there was almost no correlation between the two variables. The correlation coefficient value (R2) is 0.029686 (far from 1.00) and the significance value (Prob>F) is 0.6305, meaning that the effect is not significant (>0.05). So based on the results of this survey, it can be concluded that the hypothesis that the more ideal a person's body proportions are, the easier it is to obtain thermal comfort is not proven true. This may occur because the amount of data available is still not sufficient to see the relationship between the two variables.

Based on analysis result, from a total of 415 data, only 265 data have a BMI value, in other words, only 63.85% of the data can be used for analysis. This shows that some respondents (36.15%) are not open to questions about height and weight. This reinforces the notion that Japanese people tend to be closed to privacy matters. This issue certainly affects the significance value of the correlation of the two variables.

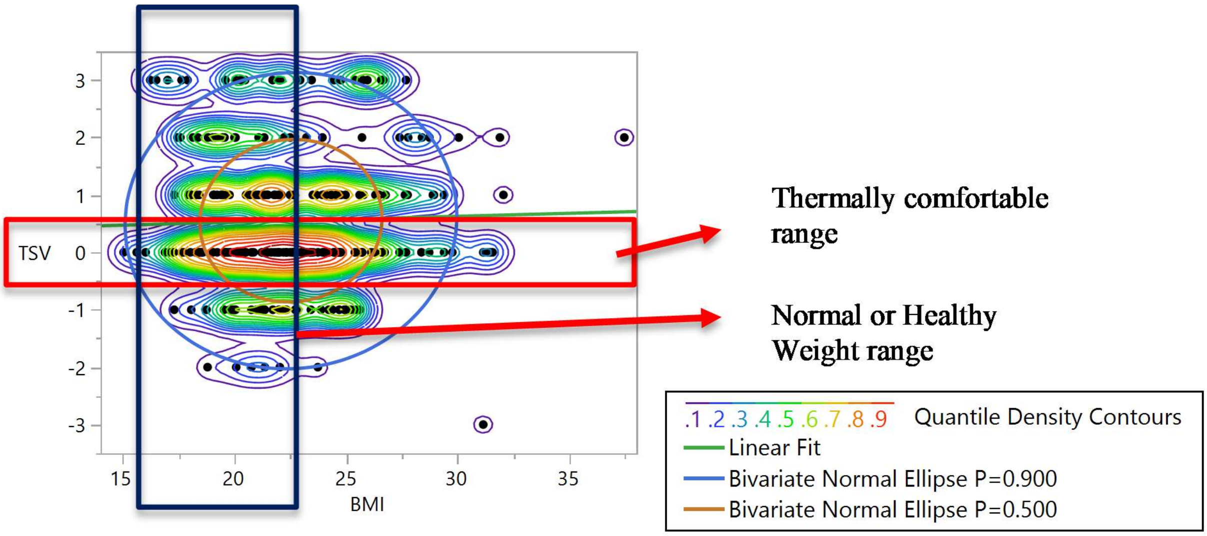


Figure 34. Correlation between TSV and BMI

6.4.3. The Correlation between Thermal Sensation Vote (TSV) and Gender

The results of the oneway analysis of TSV by gender shows that there was almost no significant difference in TSV between the two sexes. The majority of male and female respondents were in the range of 0 (comfortable) to 1 (quite comfortable). The contribution of males to TSV density at level 0 (comfortable) is in the range 110 – 200, while women are in the range 0 – 110.

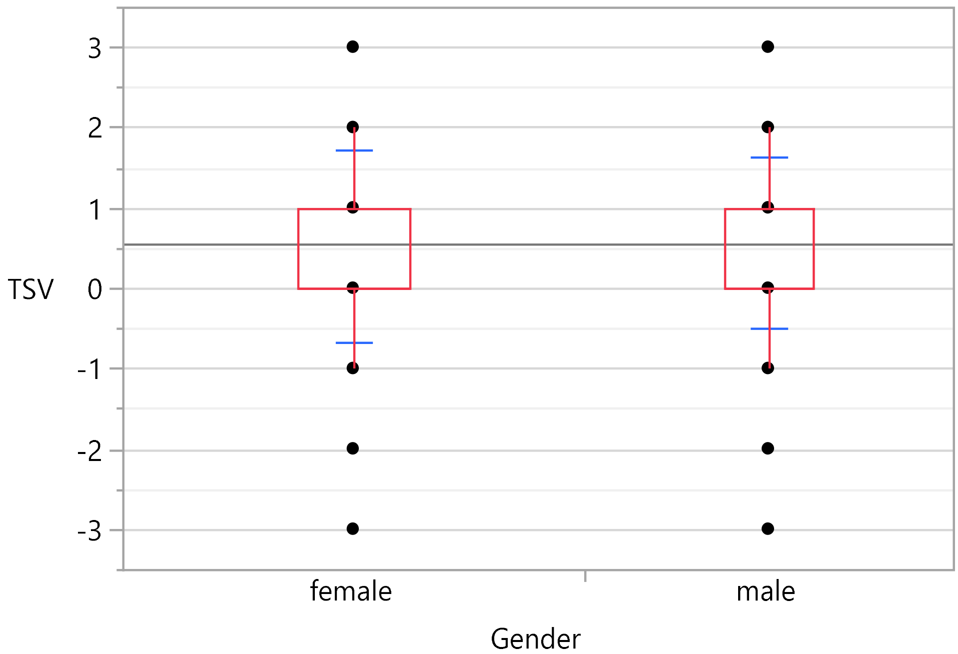


Figure 35. Correlation between TSV and Gender

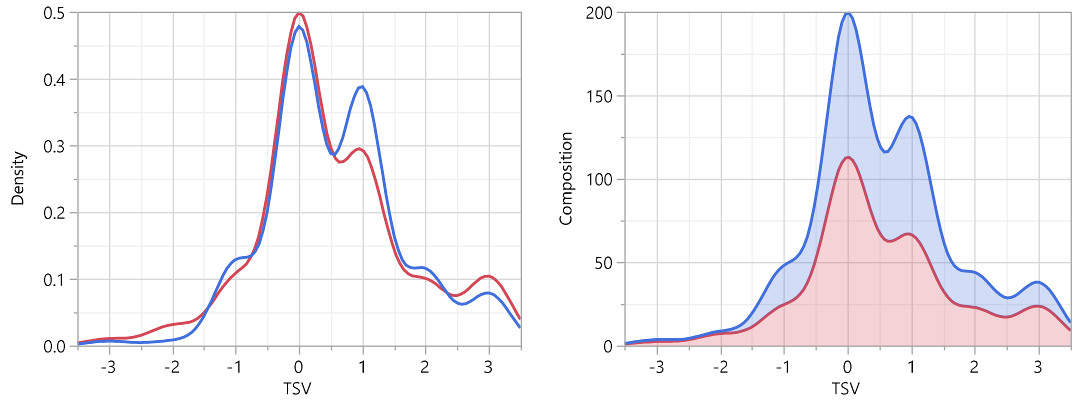


Figure 36. Comparison and composition of male and female densities

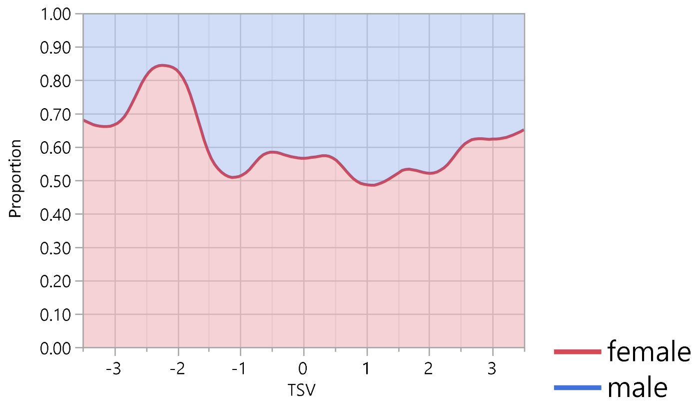


Figure 37. Proportion of male and female densities

Females contributed about 56% to TSV density at level 0 (comfortable). It shows that the hypothesis of "men are easier to obtain thermal comfort than women" is not proven true. This finding can occur because the amount of data required is not sufficient. Based on experience when the survey was conducted, there were refusals by visitors to become respondents. This may be due to a culture that is somewhat closed to foreigners and/or privacy concerns.

6.5. Conclusion

This study was conducted at Green Park Kitakyushu, Japan. There is no a significant correlation between Outdoor Thermal Comfort and Age, Gender. Body Proportion.

(1) There is no a significant correlation between Outdoor Thermal Comfort and Age. It can be concluded that the hypothesis that the older a person is the more difficult it is to obtain thermal comfort is not proven true.

(2) There is no a significant correlation between Outdoor Thermal Comfort and Gender. It can be concluded that the hypothesis that men are easier to obtain thermal comfort than women is not proven true.

(3) There is no a significant correlation between Outdoor Thermal Comfort and Body Proportion. It can be concluded that the hypothesis that the more ideal a person's body proportions are, the easier it is to obtain thermal comfort is not proven true.

The study found that there is a privacy matter may affecting the result. The well-protected privacy’s character of Japanese people was indicated to affects the number of question’s response of age, height, and weight by visitor. It seems that Japanese people tend to be introverts, especially speaking about age and body proportion due to privacy issue. The results also shows that it is needed to take more data to get more significant value of the correlation of the two or more variables. Further study should consider about the methods to get data which are involving privacy due to the unique characteristic of people.

CHAPTER 7

RELATIONSHIP BETWEEN MICRO-METEOROLOGICAL AND PERSONAL VARIABLES OF OUTDOOR THERMAL COMFORT IN URBAN PARK

Summary

Outdoor thermal comfort is an important indicator to create a quality and livable environment. This study examines a relationship between micro-meteorological and personal variables of outdoor thermal comfort performances in an urban park. The data collection of outdoor thermal comfort is carried out using two methods in combination: micro-meteorological measurement and questionnaire survey. This finding shows that most of the respondents were comfortable with the thermal, wind, and humidity performance. The acceptability and satisfaction level of thermal comfort were positive. The most significant micro-meteorological variable for the physiologically equivalent temperature (PET) value is mean radiant temperature (Tmrt). As the Tmrt value is influenced by how much shading is produced from the presence of vegetation or buildings around the measurement location, this finding shows that the shadow was very important to the thermal comfort performances in the Green Park Kitakyushu. The most influential micro-meteorological variable for the three different personal variables (TSV, WFSV, and HSV) is air temperature. The strongest relationship among the four variables is between TSV and PET. The findings will be the basis for the city authorities in preparing regional development plans, especially those related to the planning of city parks or visitor attractions.

7.1. Introduction

7.1.1. Background

Study on outdoor thermal comfort commonly uses PET as the index (Binarti et al., 2022; Hartabela, Dewancker, & Vidyana, 2021; T. P. Lin et al., 2010). The PET enables person to compare the effects of the outdoor thermal performances based on his/her own indoor experiences (Höppe, 1999). Another advantage is PET uses a commonly known degree (°C) to calculate the thermal comfort index which is suitable in various climates (Donny Koerniawan & Gao, 2015). The PET variables conclude four environmental parameters (air temperature, humidity, wind, and mean radiant temperature) and two personal variables (clothing insulation level and metabolic rate or activity level). Earlier (Nikolopoulou, 2011), PET did not consider clothing and activity levels as variables, but later in an outdoor thermal comfort software RayMan Model (Matzarakis, Rutz, & Mayer, 2007, 2010), these variables are added. Based on these reasons, this study uses PET as an outdoor thermal comfort index.

The outdoor thermal comfort variables are divided into two types: 1) micro-meteorological variables; and 2) personal variables. As for the micro-meteorological variables has four variables: air temperature (Ta), relative humidity (RH), wind velocity or wind speed (v), and mean radiant temperature (Tmrt or Tmrt). The personal variables are metabolic heat (M), clothing insulation (Icl), and a questionnaire survey which consists of respondents' thermal comfort performance during the survey (e.g., thermal sensation and acceptability) and demographic backgrounds (e.g., gender and age).

There are several uses of the perception index of thermal comfort, including thermal sensation TS-Givoni (Givoni et al., 2003), thermal sensation vote (TSV) (ASHRAE, 2013), optimum thermal environment (OTE) (Huang et al., 2016), thermal perception classification (TPC) (T. P. Lin & Matzarakis, 2011), and human thermal sensation (HTS) (H. Zhang, 2003). The most popular index to calculate thermal comfort perception in sub-tropics is TSV (Hartabela et al., 2021). According to this reason, this study uses TSV as a thermal perception index.

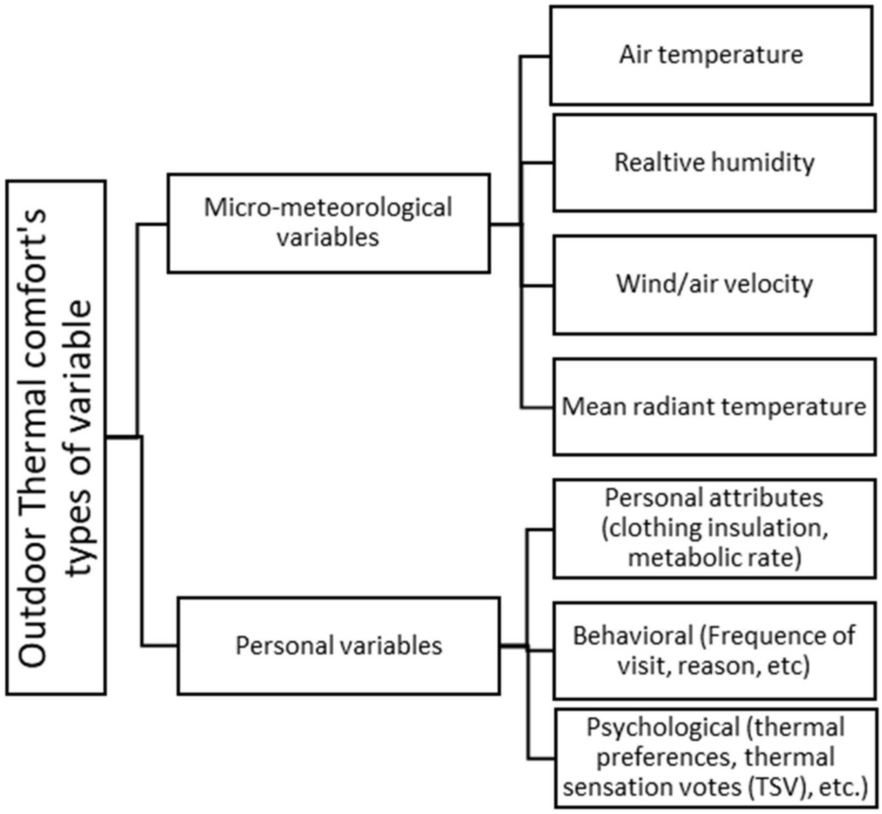


Figure 38. Type of the variable of outdoor thermal comfort

The TSV are rated on the ASHRAE 7-point scale (ASHRAE, 2017) and ISO 7730 (ISO, 2005). The 7-point sensation scale ranges from "cold" (−3), "cool" (−2), "slightly cool" (−1), "neutral" (0), "slightly warm" (+1), "warm" (+2) and "hot" (+3) performances. Other researchers (Velt & Daanen, 2017; Y. Zhang, Wang, Chen, Zhang, & Meng, 2010) use 9-point scale by adding "very cold" and "very hot". The main point of these scales is to give an optional range of answer of the actual thermal sensation that was felt by the respondents during the research. The actual thermal discomfort limit can be determined based on the user's perception. Thus, the results of this TSV survey will be compared with survey results based on measurements using thermal measuring instruments in the field. This study uses a 7-point scale of thermal sensation.

Table 22. Thermal sensation scale

7-Point Scale		**9-Point Scale**	
		Very hot	9
Hot	3	Hot	8
Warm	2	Warm	7
Slightly warm	1	Slightly warm	6
Neutral	0	Neutral	5
Slightly cool	−1	Slightly cool	4
Cool	−2	Cool	3
Cold	−3	Cold	2
		Very cold	1

7.1.2. Purpose of the study

This study determines a relationship between micro-meteorological and personal variables of outdoor thermal comfort in an urban park. The micro-meteorological variables are air temperature, (Ta), relative humidity (RH), wind speed or air velocity (v), and mean radiant temperature (Tmrt). The personal variables are activity level/metabolic rate (M), and clothing insulation level (Icl). In this study, PET and thermal sensation vote (TSV) are used as the thermal comfort indices. This study also introduces new two indices, they are wind flow sensation vote (WFSV) and humidity sensation vote (HSV). To facilitate understanding of the material, the following questions were used.

1) How are the people's perceptions of outdoor thermal sensation (TSV), wind flow sensation (WFSV), and humidity sensation (HSV)?
2) How are the acceptability and satisfaction level of outdoor thermal comfort?
3) How are the satisfaction preferences for shading, sunlight, and wind performance?
4) What is the most significant micro-meteorological variables for PET?
5) How is the relationship between micro-meteorological and personal variables (TSV, WFSV, and HSV)?
6) How is the relationship between PET and personal variables (TSV, WFSV, and HSV)?

7.2. Literature Review

7.2.1. Determinant Factors of Outdoor Thermal Comfort

There are four micro-meteorological factors which are essential in determining outdoor thermal comfort (Fanger, 1986), they are: air temperature (Ta), relative humidity (RH), wind speed or air velocity (v), and mean radiant temperature (Tmrt). These variables are used in calculating PET value, one of thermal comfort indices which is commonly used in outdoor studies (Binarti et al., 2020; Honjo, 2009; Klemm, Heusinkveld, Lenzholzer, Jacobs, & Van Hove, 2015; Lai et al., 2014; L. Zhang et al., 2020).

Personal factors of outdoor thermal comfort are level of clothing insulation, level of activity or metabolism rate (Cena & de Dear, 1999; De Carli, Olesen, Zarrella, & Zecchin, 2007; McIntyre, 1973; J Pickup & Dear, 2000; Tartarini et al., 2020; Zhao, Chow, & Sharples, 2019). Some studies shown age, gender, and body mass index are another personal attributes which affect the human thermal comfort (Blatteis, 2012; P. Li et al., 2020; M. Liu, 2019; Novieto & Zhang, 2010; Tuomaala et al., 2013).

7.2.2. Human Perception of Outdoor Thermal Comfort

Human perception is a subjective parameter to determine the thermal comfort. Therefore, there are several indices used into this subject. The thermal sensation vote (TSV) is one of the most commonly used thermal perception parameter in outdoor thermal environment studies (Cheng et al., 2020; Elnabawi, Hamza, & Dudek, 2016; Hanan, Hartabela, Novianto, Munawaroh, & Fukuda, 2020; Lau & Choi, 2021; J. Li, Niu, Mak, Huang, & Xie, n.d.; Zhou, Chen, Deng, & Mochida, 2013). Another parameter which also familiar is thermal comfort vote (TCV) (Dahlan & Gital, 2016; Lau & Choi, 2021; Xi, Li, Mochida, & Meng, 2012). Assessing thermal perception became complicated since it involves one's feelings which are also inseparable from psychological experience, cultural and social habits (Lam, Gallant, & Tapper, 2018). Some experts reported that elderly is more sensitive about air temperature which is related to their ability to adapt thermal environment condition (Schellen et al., 2010).

7.3. Materials and Methods

7.3.1. Population and Samples

The number of samples was obtained from the number of visitors who were willing to become respondents (answer the questionnaire) at the time the survey was conducted. The survey was conducted for approximately 2 h, between 9 and 12.30 (depending on the season and when the park gates opened). According to the Statistics Government of Canada, this kind of sampling method is included in volunteer sampling, where the respondents are only volunteers who must be screened (by ticket to get into this park) to get a set of characteristics suitable for the purposes of the survey (Statistic-Canada, 2017). As only visitors who already have tickets are allowed to enter the Kitakyushu Green Park area, so all visitors who are already in this area and have passed the screening stage are eligible to become volunteers of this survey. Based on this sampling method, the number of samples collected is 425 people of which 187 were male, 236 were female, and 2 left the answer blank (see the following table).

Table 23. Number of respondents

Seasons	**Number of Respondents**			
	Male	**Female**	**(Blank)**	**Total**
Summer	48	48	1	97
Autumn	45	50	1	96
Winter	47	70	0	117
Spring	47	68	0	115

7.3.2. Time and durations

All four seasons were included; summer, autumn, winter, and spring. The surveys were conducted in four periods, summer (from 19 July to 16 August 2020), autumn (from 14 to 18 October 2020), winter (from 17 January to 14 February 2021), and spring (from 10 April to 8 May 2021).

Table 24. Time and Durations

Seasons	Date Period	Days durations	Date of survey (dd/m)	Time durations per day	Time of survey (Japan Standard Time)
Summer	19 July–16 August 2020	4 days	19/7, 25/7, 9/8, and 16/8	2 hours	10.00 – 12.00
Autumn	14–18 October 2020	3 days	14/10, 11/10, and 18/10		
Winter	17 January–14 February 2021	4 days	17/1, 31/1, 7/2, and 14/2		
Spring	10 April–8 May 2021	4 days	10/4, 11/4, 1/5, and 8/5		

7.3.3. Measurement Tools

Micro-meteorological data were collected using thermal recorder and anemometer which are placed at a height of 1.2 m above ground level. In this study, an illuminance UV recorder TR-74Ui was used to record the temperature and humidity with temperature ranging from 0 to 55 °C and humidity from 10 to 95% RH (Technology Park, 2014). For measuring wind speed, a Pro Anemometer from the Hold-Peak manufacture series HP-866B-APP was used, which has a range from 0.67 to 67.1 mph (+/−5% of readings), wind temperature from −10 to 45 °C (+/−2 °C), and resolution 0.1 m/s (Davis et al., 2021). For the Tmrt, estimated data from RayMan Model software (Matzarakis et al., 2007, 2010) are used because of lack of data measurement in the investigation. The detailed information of the measurement tools is provided in the following table.

Table 25. Micro-meteorological measurement tools

Name	Resolution	Accuracy	Output Data
UV recorder TR-74Ui	0 to 55 °C	+/−0.5 °C	Air Temperature (Ta)
UV recorder TR-74Ui	10 to 95%RH	+/−5%RH	Relative Humidity (RH)
Pro Anemometer HP-866B-APP series	0.67 to 67.1 mph	+/−5% of readings	Wind/air velocity (v)

7.3.4. Data Collection Method

The data collection were used two methods, a micro-meteorological measurement and questionnaire survey. These two methods were conducted in Green Park, Kitakyushu, Japan.

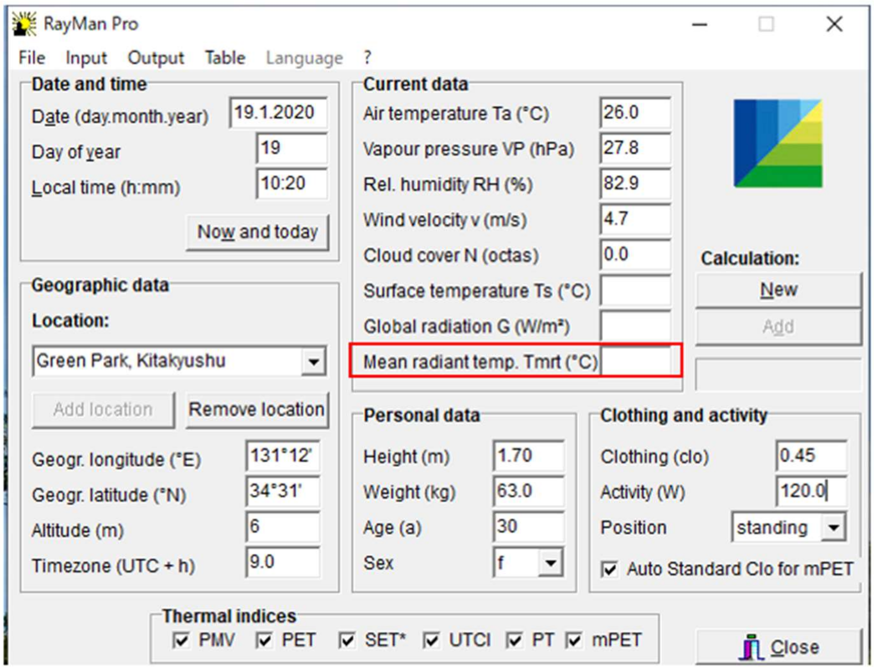
All four seasons were included; summer, autumn, winter, and spring. The surveys were conducted in four periods, summer (from 19 July to 16 August 2020), autumn (from 14 to 18 October 2020), winter (from 17 January to 14 February 2021), and spring (from 10 April to 8 May 2021). The respondent data were collected by questionnaire papers. To fill out the questionnaire, collectors passively standing near the weather station asked the visitors to fill the form who were walking or by actively approaching the visitors.

7.3.5. Data Analysis Method

The data obtained both from micro-meteorological measurement and questionnaire survey are processed using a computer software. The PET value of each data unit is found by RayMan Model (Matzarakis et al., 2010). To calculate the PET, a unit data consisting of air temperature, (Ta), relative humidity (RH), wind velocity (v), mean radiant temperature (Tmrt), activity level/metabolic rate (M), and clothing insulation level (Icl) are needed. For the estimation of long-term studies without directly measured radiation fluxes, Tmrt can be calculated through models like RayMan (Matzarakis et al., 2007, 2010). To calculate Tmrt, the relevant properties and dimensions of the radiating surfaces and of the visible section of the sky must be known. The posture of the human body (e.g., seated or standing) is also required.

In this study, the Tmrt values are estimated by the RayMan Model software. The estimation was produced at the same time as calculating the PET value. The calculation was processed by inputting unit data from each respondent. The unit data consisted of air temperature, (Ta), relative humidity (RH), wind velocity (v), activity level/metabolic rate (M), and clothing insulation level (Icl), height, weight, age, and sex/gender. The date and time information were also included in the calculation. The geographical data of Green Park Kitakyushu location was also inputted (e.g., longitude, latitude, altitude, and time zone).

For example, a unit data of respondent no. 01 from day one of the summer season is provided in the following figure. This figure shows the inputted data which consisted of many variables but with no Tmrt value. The geographical data inputted are 131°12’ (longitude), 34°31’ (latitude), 6 m (altitude), and UTC + 9 (time zone). The date, time, micro-meteorological data measured, height, weight, age, sex, clothing, activity, and position da-ta varied for each respondent. The values of the sky view factor (SVF) and horizon limitation are auto filled after the calculation is run by the software (SVF =1 and horizon limitation =0%, which means the complete sky is visible). Following figure also shows the output data which produced the Tmrt estimation and PET value.



(a)

RayMan Pro 2.3 beta © 1999 – 2014
Meteorological Institute, University of Freiburg, Germany
place: Green Park, Kitakyushu
geogr. long 131° 12′ latitude: 34° 31′ timezo +9.0 h
horizon lim 0.00% sky view fa 1

date	time	Latit.	Long.	Altit.	UTC	Gmax	Gact	A	E	Ts	Ta	VP	RH	v	C	Tmrt	height	weight	age	sex	cloth.	activ.	PMV	PET
d.m.yyyy	h:mm	° N	° E	m	h	W/m²	W/m²	W/m²	W/m²	° C	° C	hPa	%	m/s	octas	° C	m	kg	a		clo	W		° C
19.7.2020	10:20	34.52	131.2	6	9	841.4	841.4	372.1	500.6	34.4	26	27.8	82.9	4.7	0	50.1	1.7	63	30	f	0.45	120	1.1	26.7

(b)

Figure 39. RayMan Model software: (a) Input data; (b) output data

The TSV value and other questionnaire-based data are processed by Microsoft Excel and then processed into graphs for the analysis step. To analyze the relationships among variables, JMP statistical software is being used. A regression fit model analysis with standard least squares approaches is used to understand the relationship between micro-meteorological variables and personal variables. While a correlation analysis with multivariate analysis approaches is developed to find out the correlation among personal variables. To understand the respondent tendency on some psychological questions (i.e., TSV, shading satisfaction preference, etc.), some various graphical distribution analyses are developed.

7.3.6. Indices Used in This Study

This study used well-known indices, PET and TSV. It also introduces new indices, wind flow sensation vote (WFSV) and humidity sensation vote (HSV) to measure humidity and wind flow sensation based on respondents' vote. At the time the survey was conducted, respondents gave their opinions regarding the perceived thermal sensation, wind flow, and humidity through a questionnaire. The form of the question is in the form of a Bipolar Likert scale, where respondents are asked to circle the answer choices on a dotted line (answer choices) that contradict each other at each end. The closer the selected point is to one end of the line (sensation), the greater the value of the sensation is felt by the respondent.

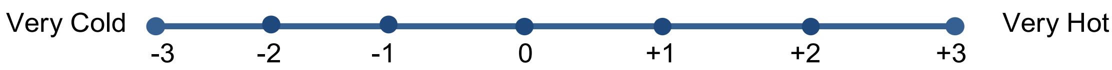


Figure 40. Scale of TSV

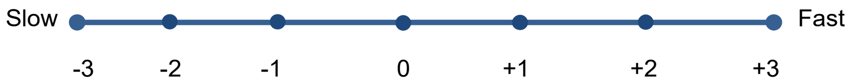


Figure 41. Scale of WFSV

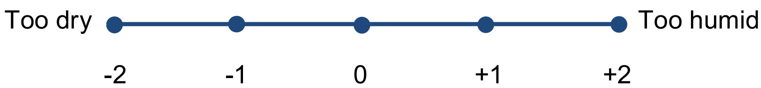


Figure 42. Scale of HSV

This study uses 7-point scale of TSV. The scale ranges are "cold" (−3), "cool" (−2), "slightly cool" (−1), "neutral" (0), "slightly warm" (+1), "warm" (+2), and "hot" (+3) performances. It was written on the questionnaire paper that the type of TSV and WFSV data are continuous, but HSV data type is discrete. These different types of data were a limitation of the questionnaire writing during the survey stage. So, at the time of analysis, all data types are equated to be continuous. This change in HSV data type does not affect the interpretation of respondents' answer because they have the same meaning, counter-preference between dry (−2) and humid (+2) performances, and the answer "just right" is a "neutral (0)" answer. For the WFSV, it also uses 7-point scale, they are "very slow" (−3), "slow" (−2), "slightly slow" (−1), "normal" (0), "slightly fast" (+1), "fast" (+2), and "very fast" (+3). While, the HSV only uses 5-pont scale, they are "too dry" (−2), "slightly dry" (−1), "just right" (0), "slightly humid" (+1), and "too humid" (+2).

7.4. Result and Discussion

7.4.1. Outdoor Thermal Environment Performance based on Field Measurement and Rayman Calculations

Performance of outdoor thermal comfort in Green Park Kitakyushu is calculated by Rayman software based on data from the field measurement. According to the calculation, the average PET value in all season is 26.64 °C with the neutral thermal sensation (comfortable) and no thermal stress. With details, the average PET in summer is 36.18 °C (warm and moderate heat stress), in autumn is 29.67 °C (comfortable and no thermal stress), in winter is 15.97 °C (cold and strong cold stress), and in spring is 24.72 °C (slightly cool and slight cold stress).

This PET value result shows that in summer the average PET value is in the range of 34°C and 38°C. When it is connected with the questionnaire results, almost half of the respondents in summer were able to accept its thermal conditions (56%), then this range of PET values were quite adaptable by the people in Kitakyushu. But not enough to confirm the acceptable PET value for the city (less than 80%). While, in other three season (autumn, winter, and spring), the thermal acceptability are more than 80%, so most of respondent were able to accept its thermal condition. For these three season, the PET value range could be finding for the PET range in subtropics. In autumn, the comfortable PET range in Kitakyushu is similar to the PET range in Taiwan, between 26°C and 30°C. For the winter, the range is quite far from the PET range for (sub) tropical region in Taiwan, it was between 14°C and 18°C, with cold thermal sensation and strong cold grade of physiological stress. It means that in winter, the PET range is lower than the standard. Spring also has a lower value of PET range which is between 22°C and 26°C with slightly cool thermal sensation and slight cold stress. Despite the seasonality, the average PET range in Kitakyushu is between 26 and 30 which means that this range is similar to the comfortable PET range standard (T. P. Lin & Matzarakis, 2011).

Table 26. Average PET, thermal sensation, and grade of physiological stress

Season	**Average PET**	**Thermal sensation**	**Grade of Physiological Stress**
Summer	36.18	Warm	Moderate heat stress
Autumn	29.67	Comfortable	No thermal stress
Winter	15.97	Cold	Strong cold stress
Spring	24.72	Slightly cool	slight cold stress
Average	26.64	Comfortable	No thermal stress

Thermal environmental variables were varies in each season. Overall, the average Air Temperature (Ta) is 21.92 °C, with summer at 30.09 °C, autumn at 23.94 °C, winter at 14.24 °C, and spring at 19.39 °C. The highest average air temperature is summer, along with the relative humidity (RH), and mean radiant temperature (Tmrt). While the highest average wind speed is winter (3.47 m/s). The detailed information of these data are shown on the following table.

Table 27. Average Air Temperature, Relative Humidity, and Wind speed

Season	Ta	RH	v	Tmrt
Summer	30.09	65.18	3.39	53.99
Autumn	23.94	62.11	1.82	47.62
Winter	14.24	48.26	3.47	31.48
Spring	19.39	50.81	1.70	43.06
Average	21.92	56.59	2.60	44.04

7.4.2. Respondents' Votes for Thermal, Wind Flow, and Humidity Sensation

7.4.2.1. Thermal Sensation Vote (TSV)

A distribution analysis has been used to understand the visitors' perception of out-door thermal comfort in Green Park Kitakyushu. Overall, most respondents feel comfortable with the thermal performances at Green Park Kitakyushu (with a neutral sensation of 41%, slightly warm 9%, and slightly cool 9%). Especially in the spring season, the number of respondents who chose neutral was 66 (57%).

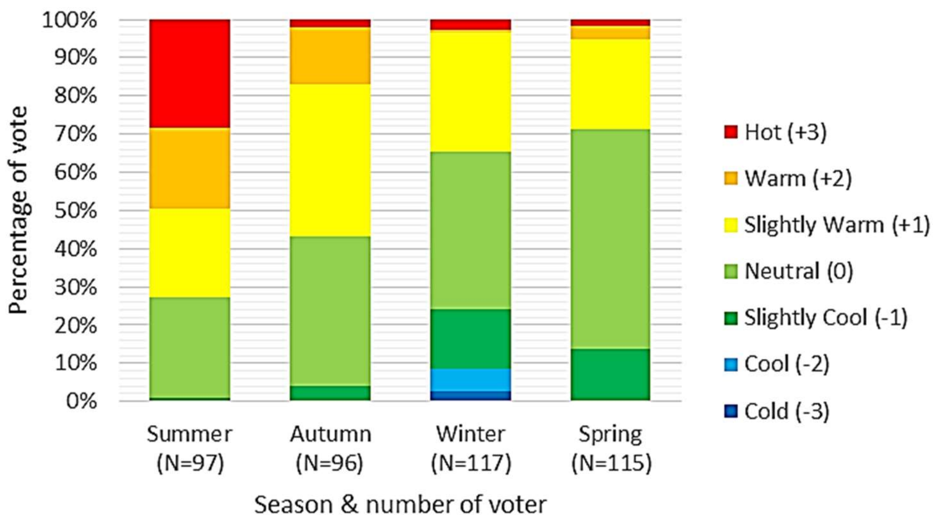


Figure 43. Thermal Sensation Vote (TSV)

During summer, although the number of respondents who chose the hot sensation (28%) was more than neutral (26%), but when viewed from the thermal comfort category where the slightly warm sensation (21%) was still comfortable. Overall, summer is still categorized as comfortable. In autumn, the most experienced thermal sensation by respondents was slightly warm (40%), followed by neutral (39%). While in winter, most feel neutral (41%). It is interesting to observe that in winter, only a small number of respondents chose cool and cold answers. This means that most people do not feel cold. When it is compared with the results of field measurement, the average air PET in winter is 15.9 which means cold thermal sensation with strong cold stress. So, there may be another influencing factor. This may invite the next question, what variables have the most influence on the answer, whether the variables are personal variables (e.g., clothing insulation or activity level) or environmental performances (air temperature, humidity, wind, and radiant temperature). The quality of shading (both from buildings and vegetation) may also affect the response to thermal sensation (TSV).

If we return to the results of the regression analysis between TSV and micro-meteorological variables, it was found that the most influencing factor for thermal comfort is air temperature. Therefore, logically in winter people will choose a cool or cold sensation. But in this result, it is the opposite. According to Velt and Daanen, people feel more uncomfortable because their mean body temperature is lower than ideal (Velt & Daanen, 2017). Then most likely there are other factors that cause it.

The first possibility is because in winter people wear the appropriate clothes (winter clothes) for outdoor activities. According to De Carli, people tend to dress appropriately when they know they will be in cold outdoor performances, to a large extent, the temperature outside at 6 am affects people's clothing choices (De Carli et al., 2007). The second possible reason is the role of activity level (metabolism rate) in a person's decision to choose which environmental thermal performances are more suitable with the thermal performances felt by the body. Typically, core body temperature is elevated when we face continuous whole-body work and exercise (Racinais, Cocking, & Périard, 2017). The many choices of attractions and play facilities offered at Green Park could increase one's activity level. Then, this high activity level affects choosing a suitable thermal sensation for the body temperature.

7.4.2.2. Wind Flow Sensation Vote (WFSV)

In the WFSV question, respondents are asked to determine their tendency of sensation to air movement that is felt around their place. Overall, most respondents feel that the wind around them is neutral (44%) or the wind speed is moderate (not fast and not slow). Meanwhile, when comparing the four seasons, according to respondents, the season with the most neutral wind speed is autumn (50%), followed by winter (45%), and spring (44%).

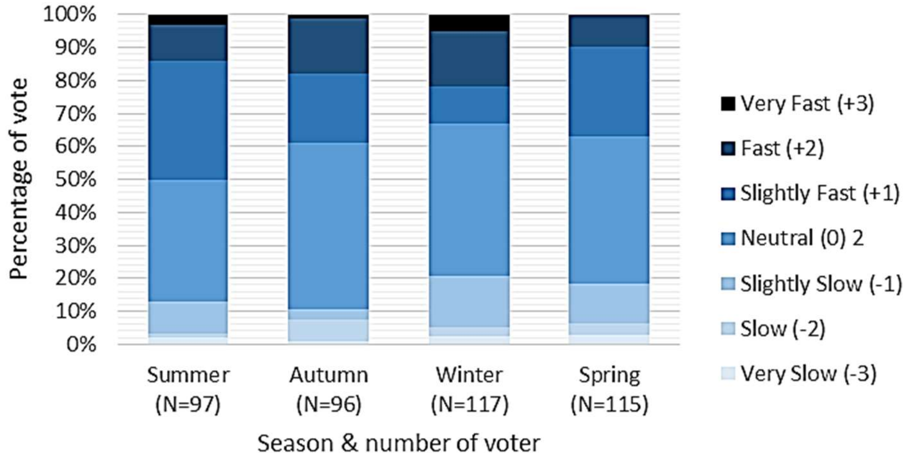


Figure 44. Wind Flow Sensation Vote (WFSV)

The season that feels the most uncomfortable with high wind speeds is winter, with the percentage of Fast and Very fast voters being 16% and 5%, respectively. Then followed by autumn, namely Fast (17%) and Very fast (1%).

7.4.2.3. Humidity Sensation Vote (HSV)

Regarding the air humidity felt by visitors when the survey was carried out, broadly most of the respondents (56%) answered Just Right (do not feel the sensation of moist or dry). Of the five answer choices, there are two categories based on comfort, namely the comfortable category (consisting of Slightly Dry, Just Right, and Slightly Hu-mid) and the uncomfortable category (Too Dry and Too Humid). Based on this category, most visitors (83%) feels comfortable with the humidity performances in the Green Park Kitakyushu. Viewed from the season period, the highest number of respondents who feel Slightly Humid and Humid sensation is summer, with a percentage of 39% and 16%, respectively. While the highest percentage for the sensation of neutral humidity (Just Right) is winter, which is 68%.

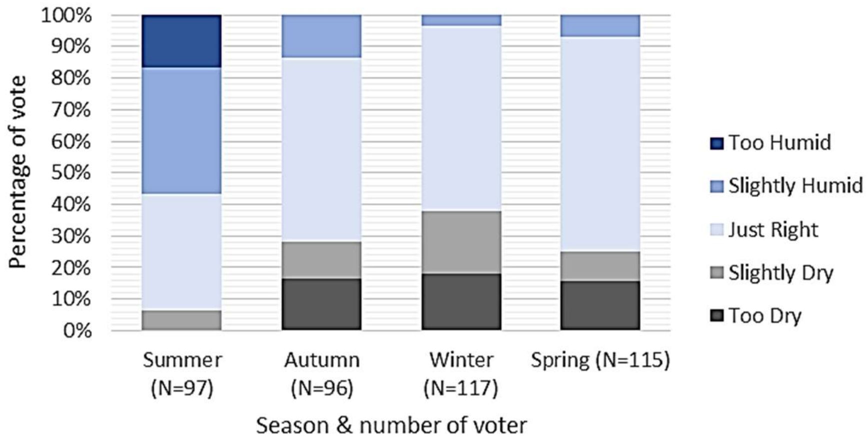


Figure 45. Humidity Sensation Vote (HSV)

7.4.3. Acceptability and Satisfaction Level of Thermal Comfort

7.4.3.1. Thermal Acceptability

Most respondents (84%) can accept the thermal performances in the Green Park environment. If observed further, only summer has a slight difference between the number of respondents who can accept (56%) and who cannot accept (42%) the thermal performances of their environment. Meanwhile, the other three seasons (autumn, winter, and spring) have significant differences in the number of voters (thermally acceptable >90% and not acceptable <10%).

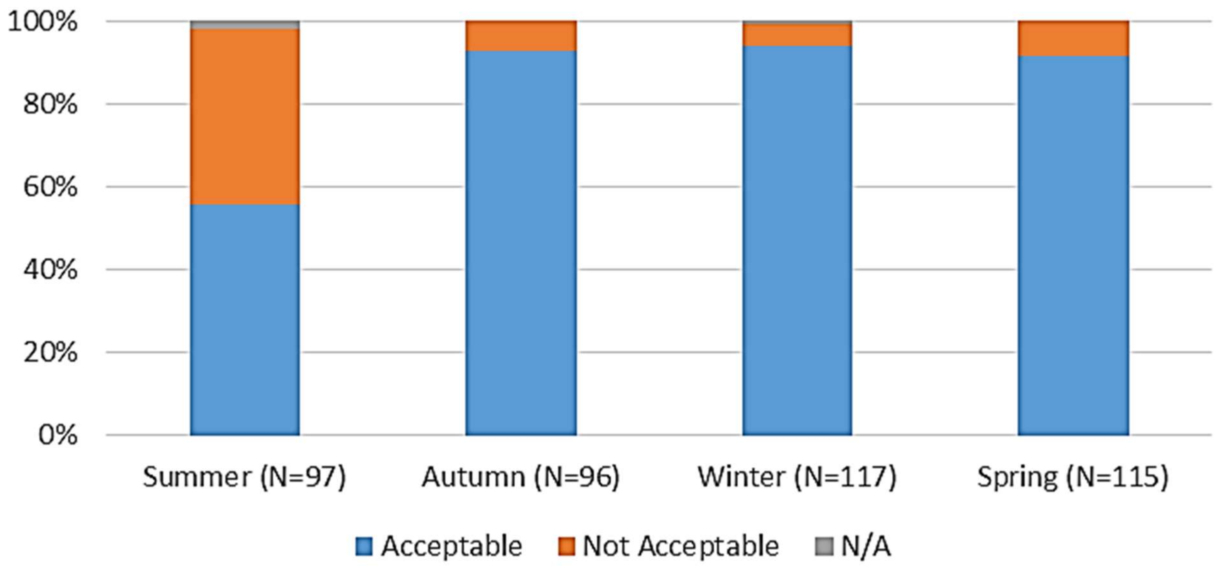


Figure 46. Thermal acceptability

7.4.3.2. Thermal Satisfaction Level

Overall, there were two most answers regarding the level of satisfaction with the thermal environment at the time this survey was conducted, namely Just like this (49%) and Cooler is better (41%). The interesting thing about the results of this survey is that in winter, the number of voters who answered Cooler is better (28%) and was higher than that of Warmer is better (19%). This begs the question whether there are other factors that cause respondents to have such a level of satisfaction. Although when compared to other seasons, the highest number of voters for Warmer is better is in winter (summer 2%, autumn 4%, and spring 9%). The distribution results is shown in the following figure.

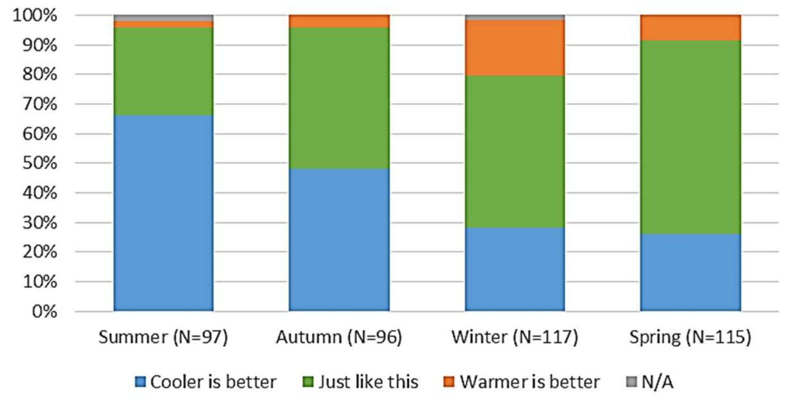


Figure 47. Thermal satisfaction level

The highest voter for Cooler is better was in summer (66%), then followed by autumn (48%). This certainly shows that in summer and autumn, the thermal performances of the Green Park environment are relatively hotter than in winter and spring.

7.4.4. Satisfaction Preferences for Shading, Sunlight, and Wind Performances

7.4.4.1. Shading Satisfaction Preferences

In summer, respondents were dissatisfied with the existing shading performances, most of them felt Need more shading (75%). In the autumn season, most of the respondents also answered Need more shading (54%), while those who answered "Fit right" were 46%, and no one answered Need less shading (0%). In winter, most chose Fit right (66%), followed by "Need more shading" (32) and "Need a less shading" (2%). For the spring season, the results are relatively the same as in summer and autumn, where most of them answered "Need more shading".

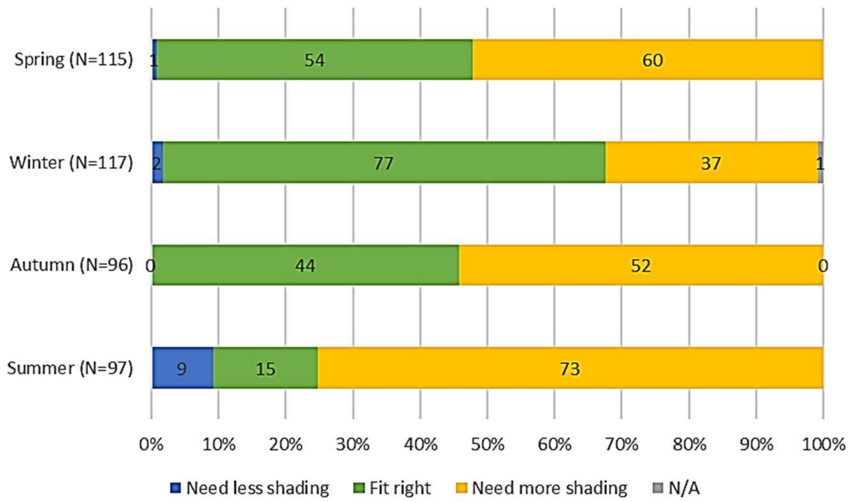


Figure 48. Shading satisfaction preferences

Thus, it is only in winter that voters are most satisfied with the shading performances in the Kitakyushu Green Park environment. Overall most of the respondents were dissatisfied and needed more shading than was available at the time the survey was conducted. However, if observed in Figure 6, the difference in the percentage of respondents who are not satisfied (Need more shading) and satisfied (Fit right) is not so significant, which is only 7%.

7.4.4.2. Sunlight Satisfaction Preferences

The results of the survey on the question of respondents' satisfaction preferences for the presence of sunlight in the Green Park environment showed that visitors were satisfied (Fit right), with an overall percentage of 83%. Among the four seasons, in summer the most respondents chose Need less sunlight (16%). While other seasons are the opposite, more people choose to need more sunlight than need less sunlight.

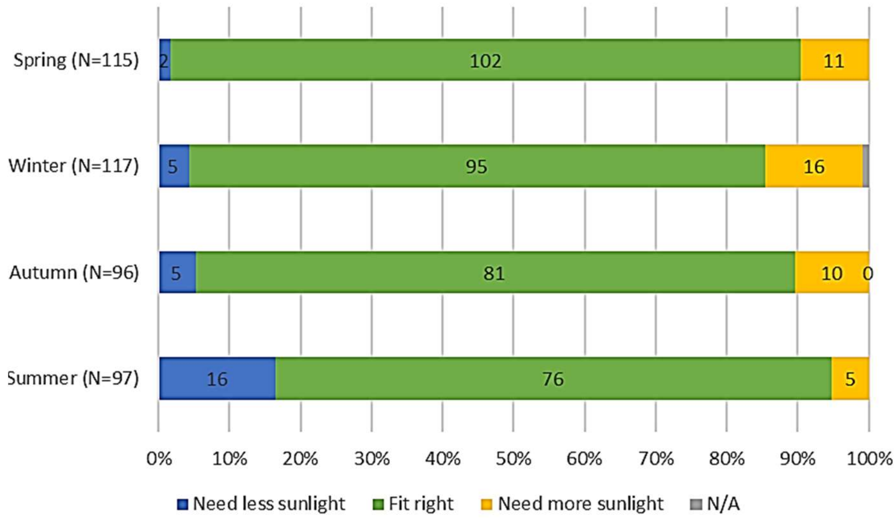


Figure 49. Sunlight satisfaction preferences

7.4.4.3. Wind Satisfaction Preferences

Like the results of the previous survey on sunlight, the satisfaction preference for wind performances in the Green Park environment is dominated by Fit right answers (with an overall percentage of 72%). The number of respondents who chose need more wind over need less wind was summer and autumn, with a percentage ratio of 28% versus 9% and 9% versus 8%, respectively). Whereas in the opposite situation, winter and spring have a higher percentage of voters who need less wind than need more shading, with a percentage ratio of 16% versus 7% and 22% vs. 11%, respectively. Overall, the respondents were satisfied with the wind performances in the Green Park environment, especially in the location where this survey was conducted.

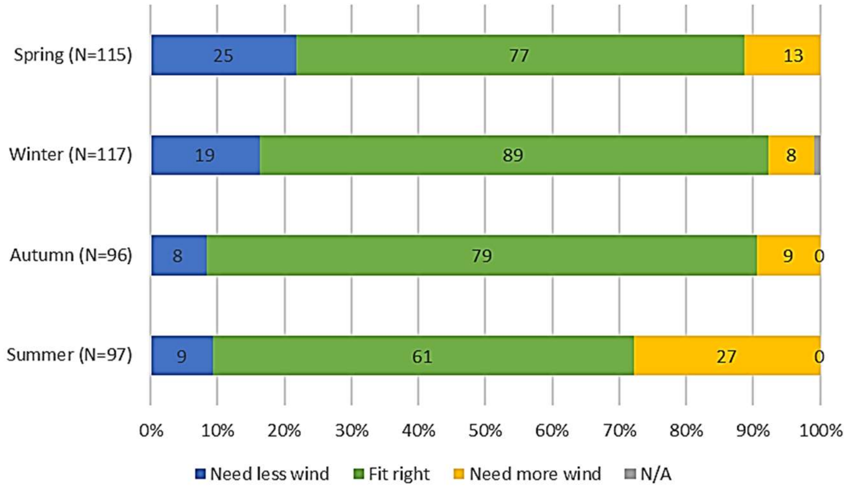


Figure 50. Wind satisfaction preferences

7.4.5. Relationship between Micro-Meteorological and Personal Variables

7.4.5.1. Most Significant Micro-Meteorological Variable of PET

To understand the relationship between PET and the micro-meteorological variables, a regression analysis is used by applying the Fit Model method with the Standard Least Squares approach. There were five variables analyzed, namely PET, air temperature (Ta), relative humidity (RH), air velocity (v), and mean radiant temperature (Tmrt). All the variables' data have been standardized before analysis by JMP statistical software. This is done to maintain the equality of the values of the five variables analyzed.

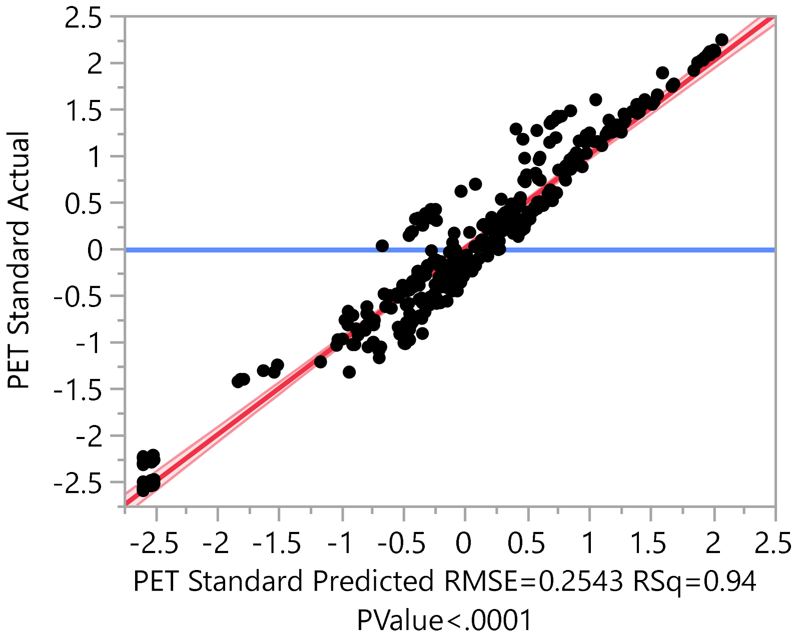


Figure 51. Correlation between PET and micro-meteorological variables

Based on the results, the value of reliability (R^2) of the correlation of the five variables is 0.94 (close to 1), so the data used are reliable or accurate to be used as material for analysis in a study. The significance value (p value) is < 0.0001 (close to 0), meaning that it is significant, or in other words, the chances of this finding being missed are almost non-existent.

Table 28. Parameter estimates between PET and micro-meteorological variables

Term	Estimate	Std Error	t Ratio	Prob >|t|
Intercept	0.0008044	0.012397	0.06	0.9483
Ta Standard	0.263544	0.053904	4.89	<0.0001 *
RH Standard	−0.10604	0.015478	−6.85	<0.0001 *
v Standard	−0.168424	0.017673	−9.53	<0.0001 *
Tmrt Standard	0.6577773	0.060381	10.89	<0.0001 *

*p value is significant.

Based on the parameter estimates above, an equation can be drawn up as follow:

$$PET = 0.26\ Ta - 0.1\ RH - 0.16\ v + 0.65\ Tmrt \tag{1}$$

The most influencing environmental factor to the PET value is mean radiant temperature (Tmrt) (Equation 1). Its positive relationship (0.65) means the higher the Tmrt value, the higher the PET value.

Based on the result, it can be seen the type of relationship between PET and micro-meteorological variables. Factors that are positively related are the temperature variable (Ta), and the mean radiant temperature (Tmrt) variable, which means the higher the value of Ta and Tmrt, the higher the PET value. On the other hand, the relation value of air velocity (v) and RH variables are negative, meaning that the smaller the value, the higher the PET value.

The most influencing micro-meteorological variables to the PET value is mean radiant temperature (Tmrt) with a positive relationship. It means the higher the Tmrt value, the higher the PET value. According to Tan, the Tmrt value is influenced by how much shading is produced from the presence of vegetation or buildings around the measurement location (Tan et al., 2021). This shows that the presence of shadow greatly affects the thermal comfort value in the Green Park Kitakyushu. This finding strengthens the previous studies that show the important role of shading in cooling urban temperatures.

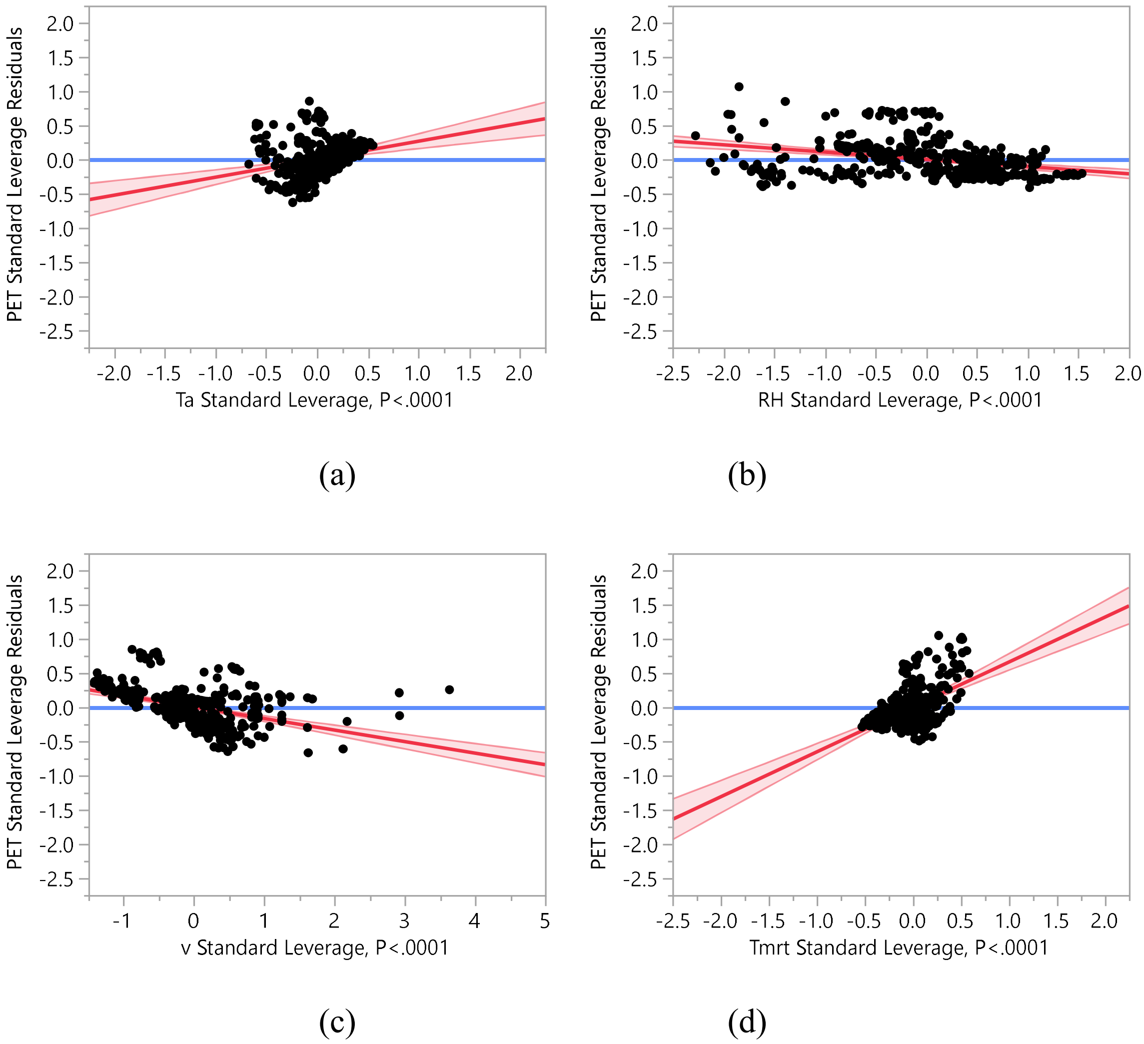


Figure 52. Correlations between PET standard and micro-meteorological variables: (a) PET and Ta; (b) PET and RH; (c) PET and v; (d) PET and Tmrt

7.4.5.2. Relationship between Micro-Meteorological Variables and TSV

The relationship between micro-meteorological variables (Ta, RH, v, and Tmrt) and TSV is analyzed by regression analysis method, with Fit Model approach and Standard Least Squares personality. Based on the results of the analysis, the reliability value (R^2) of the relationship between TSV and the four micro-meteorological variables is 0.30 (far from 1 and less than the recommended minimum 0.6), so the data used is not reliable or not accurate to be used as material for analysis in a study.

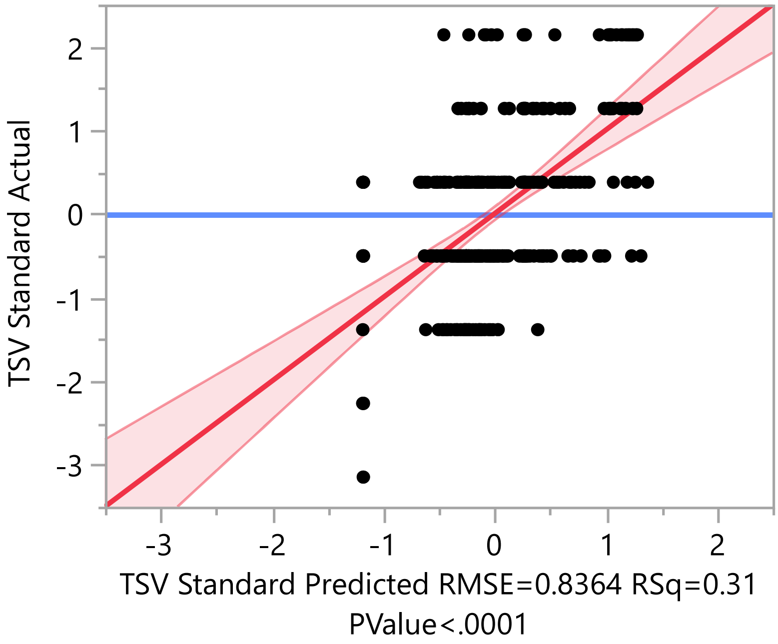


Figure 53. Correlation between TSV standard actual and predicted

However, the significance value (p value) is <0.0001 (close to 0), meaning that it is significant, or in other words, the chances of this finding being missed are almost non-existent. The relationship between micro-meteorological variables (Ta, RH, v, and Tmrt) and TSV, is shown in following table.

Table 29. Parameter estimates between TSV and micro-meteorological variables

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0018202	0.040768	0.04	0.9644
Ta Standard	0.6432868	0.17727	3.63	0.0003 *
RH Standard	−0.050148	0.050901	−0.99	0.3251
v Standard	0.0218456	0.058119	0.38	0.7072
Tmrt Standard	−0.079883	0.198571	−0.40	0.6877

*p value is significant.

Based on the parameter estimates table, an equation can be drawn up as follow:

$$TSV = 0.64\ Ta - 0.05\ RH + 0.02\ v - 0.07\ Tmrt \qquad (2)$$

It can be seen from Equation (2), the environmental factor that most influences the TSV value is Ta (air temperature), with a positive relationship (0.64). In other words, the greater the Ta value, the greater the TSV value. This shows that according to the respondents' perception, the most influential factor on the value of thermal comfort in the Kitakyushu Green Park environment is temperature performances. The relationship between the TSV variable and the Ta and v variables is positive, while the RH and Tmrt variables are negative.

7.4.5.3. Relationship between Micro-Meteorological Variables and WFSV

Based on the results of the analysis (Figure 48), the reliability value (R^2) of the relationship between WFSV and the four micro-meteorological variables is 0.02 (very far from 1 and less than the recommended minimum 0.6), so the data used is very unreliable or in-accurate for analysis. Likewise, the significance value is 0.12 (>0.1), meaning that it is not significant, or in other words there is a 12% chance that these findings are wrong.

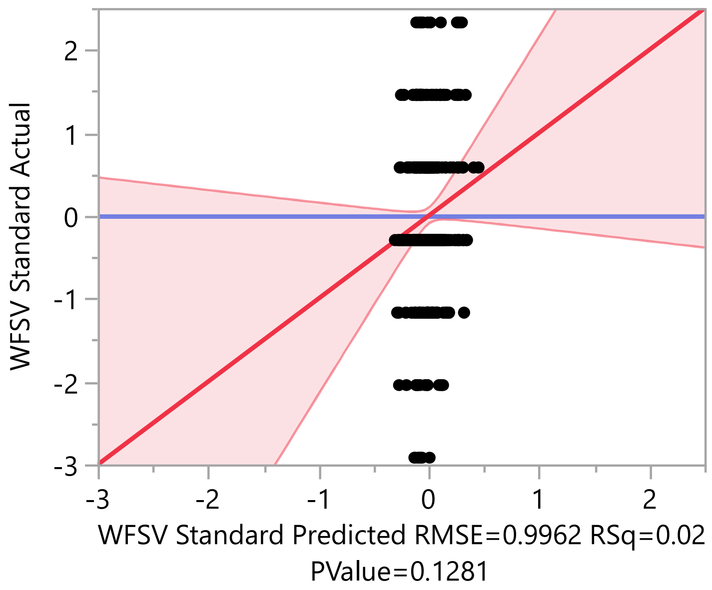


Figure 54. Correlation between WFSV standard actual and predicted

However, the correlation between micro-meteorological variables (Ta, RH, v, and Tmrt) and WFSV is shown in following table.

Table 30. Parameter estimates between WFSV and micro-meteorological variables

Term	Estimate	Std Error	t Ratio	Prob >|t|
Intercept	0.001687	0.048732	0.03	0.9724
Ta Standard	0.3932379	0.213465	1.84	0.0662
RH Standard	−0.023098	0.061511	−0.38	0.7075
v Standard	0.0054662	0.071915	0.08	0.9394
Tmrt Standard	−0.323141	0.239887	−1.35	0.1787

Based on the parameter estimates table above (Table 8), an equation can be drawn up as follow:

$$WFSV = 0.39\ Ta - 0.02\ RH + 0.005\ v - 0.32\ Tmrt \quad (3)$$

The most influential environmental factor on the WFSV value (Equation 3) is air temperature (Ta), with a positive relationship (0.39). In other words, the greater the Ta value, the greater the WFSV value. This shows that according to the respondent's perception, the most influential factor on the sensation of wind flow in the Kitakyushu Green Park environment is temperature.

The relationship between variables that has a positive value is between WFSV with Ta and v, while the negative value is between WFSV with variables RH and Tmrt.

7.4.5.4. Relationship between Micro-Meteorological Variables and HSV

The regression analysis result between HSV and the four micro-meteorological variables shows that the value of reliability (R^2) is 0.22, so the data used are very un-reliable or very inaccurate for analysis. However, the significance value is <0.0001 (close to 0), meaning that it is significant, or in other words, the chances of this finding being missed are almost non-existent.

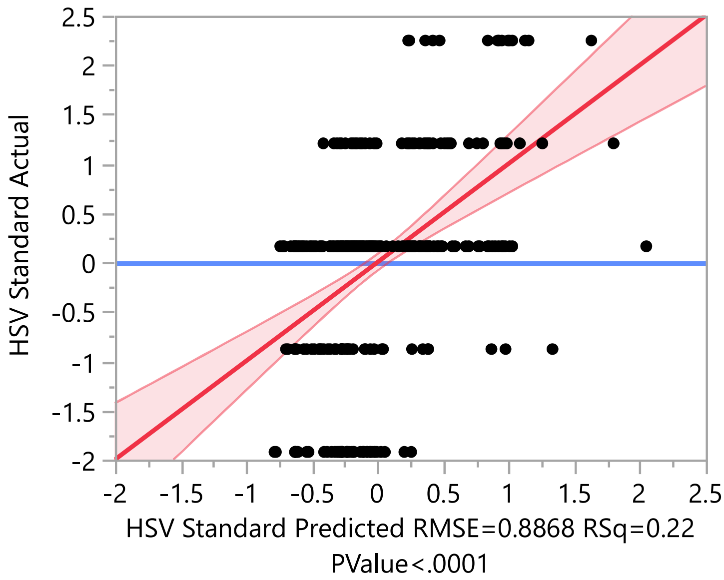


Figure 55. Correlation between HSV standard actual and predicted

However, the results of the estimated correlation between micro-meteorological variables (Ta, RH, v, and Tmrt) and HSV are shown in following table.

Table 31. Parameter estimates between HSV and micro-meteorological variables

Term	Estimate	Std Error	t Ratio	Prob >|t|
Intercept	0.0011969	0.043221	0.03	0.9779
Ta Standard	0.3628165	0.187936	1.93	0.0542
RH Standard	−0.066378	0.053964	−1.23	0.2194
v Standard	0.2413083	0.061616	3.92	0.0001 *
Tmrt Standard	0.1568445	0.210519	0.75	0.4567

*p value is significant.

According to the parameter estimation results between HSV and micro-meteorological variables, an equation can be drawn up as follow:

$$HSV = 0.36\ Ta - 0.06\ RH + 0.24\ v + 0.15\ Tmrt \quad (4)$$

Based on the HSV Equation (4), the HSV value is also strongly influenced by the value of Ta (air temperature), with a positive correlation (0.36). In other words, the HSV value will increase as the Ta value increases. This shows that according to the respondent's assessment, the most influential variable on the sensation of humidity in the Kitakyushu Green Park environment is air temperature performances. In addition to air temperature, a positive relationship is between Tmrt and v, while a negative relationship is RH.

7.4.5.5. Relationship between PET and Personal Variables (TSV, WFSV, and HSV)

The multivariate analysis result shows the correlations between the four variables (PET, TSV, WFSV, and HSV). Based on the table, the strongest relationship in the four variables is between TSV and PET. The correlation coefficient between TSV and PET is 0.5 (positive correlation). It means that both variables move in the same direction or when the PET value is high, the TSV value is also high. The correlation coefficient between PET and HSV also indicates a positive relationship (0.34). In the contrary, this table indicates that there is no relationship between PET and WFSV. The correlations are estimated by pairwise method as shown in the following table.

Table 32. Pairwise correlations between PET and personal variables

Variable	by Variable	Correlation	Signif Prob	Pairwise correlations
TSV	PET	0.5095	<0.0001 *	
HSV	PET	0.3407	<0.0001 *	
HSV	TSV	0.2580	<0.0001 *	
WFSV	TSV	0.1020	0.0372 *	
WFSV	PET	0.0409	0.4041	
HSV	WFSV	−0.0690	0.1589	

* p value is significant.

The regression analysis result between micro-meteorological variables and personal variables shows there are some lacks of reliability values. These might be because of the adequacy of the number of data units, the timeliness between recording micro-meteorological measurement data and the questionnaire, or accuracy in preparing research methods and plans. Future research can be developed by increasing the number of visitor participation (respondents), so that research results can be more accurate and develop a more detailed and measurable research plan.

7.5. Conclusion

Based on the results, it is found that:

1) Most of respondent were feeling comfort with the thermal, wind, and humidity performance. The sensation of thermal and the wind flow were mostly neutral, and the sensation of humidity were also in the mid-range (just right, nor humid and dry).
2) The acceptability and satisfaction level of thermal comfort were positive. Most of respondents accepted and were satisfied with the thermal performance.
3) For the satisfaction preferences for shading, most of the respondents in three seasons (summer, autumn, and spring) were dissatisfied with the actual shading performance and agreed to gain more shading, to get more chance for shelter from the hot sun. Only respondents of winter season were mostly feeling satisfied. For the sunlight and wind satisfaction preferences, most of respondents in all seasons were feeling satisfied with the actual performance, no compliment.
4) The most significant micro-meteorological variable for the PET value is mean radiant temperature (Tmrt). As the Tmrt value is influenced by how much shading is produced from the presence of vegetation or buildings around the measurement location, this finding shows that the shadow was very important to the thermal comfort performances of the Green Park Kitakyushu.
5) The most influential micro-meteorological variable for the three different personal variables (TSV, WFSV, and HSV) is air temperature.
6) The strongest relationship between PET and personal variables (TSV, WFSV, and HSV) is between TSV and PET. The correlation coefficient between TSV and PET is 0.5 (positive correlation).

CHAPTER 8

SIMULATION OF THERMAL AND PHYSICAL ENVIRONMENT IN URBAN PARK

Summary

Study of outdoor thermal comfort had been widely developed in all over the world as a mitigation strategy for understanding Urban Heat Island (UHI) phenomenon. The study aims to determine factors that influencing outdoor thermal environmental performance and the relationship between the thermal environment and urban structure in an urban park through an ENVI-met simulation model. The case of the study is Green Park Kitakyushu, Japan. The results shows that: (1) Number of vegetation area of the Park is higher than building area. The median SVF value is high (between 0.86 and 0.94) which means barely shaded for all time. The overall the Park's surface has a low albedo (between 0.10 and 0.25). The area which has high albedo (above 0.7) is area which covered by pavements. (2) The potential air temperature of Green Park in four different seasons is between 16.78°C and 30.75°C, and the average is 22.84°C. the wind speed is between 0 and 2.26 m/s, and the average is 1.76 m/s. While the relative humidity is between 49.57% and 107.75%, and the average is 61.13%. The correlation between PET and surface temperature is positively significant, which means that the higher surface temperature is the higher PET value. (3) The correlation between PET and urban structure factors is also significant, with negative relationship. The higher SVF value (barely shaded), the lower PET value means that shading is important to increase the outdoor thermal comfort performance. While the most influential factor for Tmrt is SVF which means the higher SVF value (barely shaded), the higher Tmrt value. However, the findings can contribute as basic knowledge to build an urban planning and development strategy for urban planner or city authorities, especially for designing an urban park in subtropics climate cities.

8.1. Introduction

8.1.1. Background

The impact of built environment on wellbeing and human health should be considered due to urban heat island phenomenon. Urban Heat Island (UHI) phenomenon can result in temperature differences up to 8 °C between cities and their surrounding suburban and rural areas (Huawei Li et al., 2020; B. S. Lin & Lin, 2016; Nwakaire et al., 2020). The UHI phenomenon, which refers to the higher air temperature in urban areas than in suburban areas, is currently one of the serious problems of urban areas. It has been pointed out that UHI increases energy consumption in summer and is harmful to human health through effects such as hyperthermia (Kyakuno, Sotoma, Miyazaki, & Moriyama, 2005). Increasing awareness of the urban heat island (UHI) effect has raised attention about the outdoor thermal comfort.

8.1.2. Purpose of the study

Outdoor thermal comfort is trusted as an important factor to attract urban residents to urban parks. Thermal comfort is defined as the "condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation" (ASHRAE, 2017). The study aims to determine factors that influencing outdoor thermal environmental performance and the relationship between the thermal environment and urban structure in an urban park through micro-meteorological model simulation, ENVI-met. Employing physiological equivalent temperature (PET), the outdoor thermal comfort was characterized along with predicted mean vote (PMV) and surface temperature (Ts). The urban structure variables, such as sky view factor (SVF) and surface albedo (SA) were also investigated to understand the environment performance. The research objectives are shown as follows:

1) Determine the urban structure performance of urban park which is represented by:
    a. The performance of building plot ratio (BPR) and green plot ratio (GnPR)
    b. The performance of sky view factor (SVF)
    c. The performance of surface albedo (SA)
2) Determine the outdoor thermal environment performance of urban park which is evaluated by:
    a. The mitigation of thermal environment variables (PMV, Ta, RH, and v)
    b. The impact of thermal environment variables (PMV, Ta, RH, and v) to urban structures variables (building, and surface area).
    c. The relationship between PET and surface temperature.

3) Determine the relationship between urban structure variables and outdoor thermal environment variables which is are represent by:
    a. The correlation between PET and urban structure variables.
    b. The correlation between Tmrt and urban structure variables.

8.2. Literature Review

8.2.1. Thermal Environmental Performance Simulation

Simulation analysis of outdoor thermal environmental performance had been widely used in many studies (Chan & Chau, 2021; Hui Li, 2012; B. Lin, Li, Zhu, & Qin, 2008; Morakinyo & Lam, 2016; Morakinyo, Lau, Ren, & Ng, 2018; Palme et al., 2020; Perini, Chokhachian, Dong, & Auer, 2017; Salata et al., 2016; Taleghani, 2018). The study commonly used to evaluate the effects and performance of vegetation, shading, or building to an outdoor thermal environment. Many studies utilize ENVI-met model as simulation tool to estimate the outdoor thermal performance (Ali-Toudert & Mayer, 2007; Barakat, Ayad, & El-Sayed, 2017; Binarti et al., 2022; Chan & Chau, 2021; Faragallah & Ragheb, 2021; B. S. Lin & Lin, 2016; Perini et al., 2017; Salata et al., 2016; Soelaiman et al., 2018; Tan et al., 2021; R. Wang, Gao, Zhou, Kammen, & Peng, 2021). Another simulation tool is TRNSYS (Transient Systems Simulation) by means of Grasshopper which calculate the mean radiant temperature to ensure the correct consideration of the thermal mass effect of the building surfaces exposed to solar radiation (Perini et al., 2017). It was found that the combination of these two software can be effectively used to estimate the effect of design choices on outdoor thermal comfort, especially during night.

8.2.2. Data Usability in Performance Simulation

8.2.2.1. Thermal environmental variables

Having obtained the surface temperature (Ts), outdoor air temperature (Ta), mean radiant temperature (Tmrt), and physiologically equivalent temperature (PET), a study in Toronto compares the possible mitigation of net surface radiation and thermal radiative power (Y. Wang, Berardi, & Akbari, 2016). The results demonstrate that the duration of direct sun and the mean radiant temperature, which are strongly influenced by the urban form, play a significant role in urban thermal comfort. A simulation study using ENVI-met in winter found that by planting different types and ratios of vegetation, relative humidity (RH) and wind velocity (v) are influence the outdoor thermal comfort performance (Afshar et al., 2018). The scenario of grasses and the scenarios with high ratio of deciduous trees in comparison with other scenarios indicated lower wind speeds.

8.2.2.2. Urban Structure variables

A study in warm and humid climate of India investigated the correlation between thermal and physical environmental factors. It is found that sky view factor (SVF) and mean radiant temperature (Tmrt) are major influencing factors determining the street's thermal conditions. SVF showed a strong correlation with PET. The results indicated that by modifying physical parameters, significant improvement in overall outdoor comfort can be attained. Another study introduced green plot ratio (GnPR) and aspect ratio H/W (building height per width) as important variables for outdoor thermal investigation (Hartabela & Koerniawan, 2018; Ong, 2003; Scott Henson, 2019; Syafrina, Koerniawan, Novianto, & Fukuda, 2020). Building plot ratio (BPR) plays as a counterpart of GnPR. While surface albedo (SA) is also considered as one of the important factors of the urban heat island phenomenon (Kyakuno et al., 2005).

8.3. Materials and Methods

8.3.1. Data Collection

Data were collected by field measurement, observation, and computer simulation through ENVI-met software model. There are two types of data, they are image and statistics. The simulation time is absolutely similar to the field measurement time. Overall there are 15 simulation data which are divided by four different seasons, they are summer, autumn, winter, and spring. The simulation of summer has 4 data, autumn has 3 data, winter has 4 data, and spring has 4 data. The following table shows the data collection methods used in this study.

To calculate Building Plot Ratio and GnPR, data type used is image from an aerial view of the Park taken by Google maps in 2021. The purpose is to calculate the percentage of area which is covered by buildings or vegetation manually by measurement. While to extract the simulation result data from the surface that is produced by the Leonardo tool, statistics data from ENVI-met simulation data are utilized resulting data of SVF (Sky View Factor), Ts (Surface Temperature), and SA (Surface Albedo). To illustrate and calculate the thermal environmental data impacts on its urban structures, data of image is extracted from sectional drawing by Corel Draw and data of statistics are extracted from ENVI-met simulation data. It aims to draw the section of built environment, extract the simulation result data from the atmosphere that is produced by the Leonardo tool, and then the results are displayed parallel to the image.

Table 33. Data collection methods

Objectives	Data type	Data source	Collecting Data Methods
To calculate *Building Plot Ratio* and GnPR.	Image	An aerial view of the Park taken by Google maps in 2021.	Calculate the percentage of area which is covered by buildings or vegetation manually by measurement.
To calculate the SVF, *Surface temperature* and *surface albedo*	Statistics	ENVI-met simulation data.	Extract the simulation result data from *the surface* that is produced by the Leonardo tool.
To illustrate and calculate the thermal environmental data impacts on its urban structures	Image and Statistics	Section drawing and ENVI-met simulation data.	Draw the section of built environment. Extract the simulation result data from *the atmosphere* that is produced by the Leonardo tool. Then the results are displayed parallel to the image.
To validate the simulation data for the accuracy	Statistics	ENVI-met simulation data.	Extract the simulation result data from *the atmosphere* that is produced by the Leonardo tool.
To map the performance of thermal environment	Images	ENVI-met simulation data.	Extract the simulation result data from *the atmosphere* that is produced by the Leonardo tool.
To calculate the relationship between urban structure variables and thermal variables	Statistics	ENVI-met simulation data and JMP Statistical software.	Extract the simulation result data from *the atmosphere, the surface, and the Biomet* that is produced by the Leonardo tool. Then the relationship is ready to be analyzed by JMP.

8.3.2. Data Analysis

There are three type of analysis, they are correlation, model simulation, and description. The correlation analysis is used to determine the relationships between outdoor thermal environment and urban structure. Model simulation is used to evaluate the performance of urban structure and thermal environment. While description analysis is used to interpret the results from model simulation, in relation to performances of thermal environment and urban structure.

8.3.2.1. Analyzing the relationships between outdoor thermal environment and urban structure

The relationship between variables of outdoor thermal environment and urban structure is analyzed by correlation methods from data statistics. There are three main issue to be determined, they are: (1) A relationship between PET (dependent) and urban structure variables (SVF, GnPR, BPR, and SA); (2) A relationship between Tmrt (independent) and urban structure variables (SVF, GnPR, BPR, and SA); and (3) A relationship between PET (dependent) and surface temperature (Ts). The framework of relationship analysis is shown on the following picture.

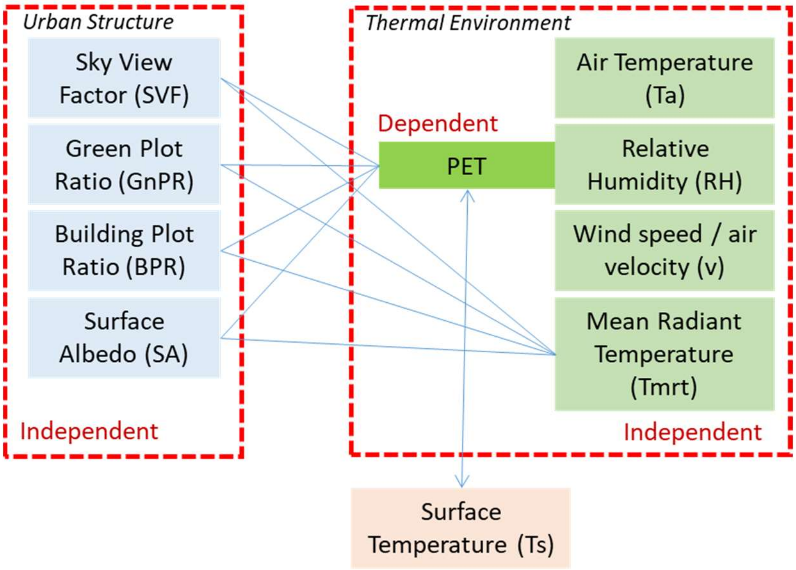


Figure 56. Framework of Relationship Analysis

8.3.2.2. Simulating the performance of urban structure and thermal environment

The urban structure and environment drawn in the simulation are interpretations of the images on *Google Maps* and observations in the field, including the height of buildings and other physical elements of the environment, such as vegetation and water. While the thermal environment simulation utilize ENVI-met software. The following table is the condition which is used for simulation process in ENVI-met software.

Table 34. Simulation conditions used in ENVI-met software

Setting	**Data input**														
Coordinate and location	Latitude 33.85°N; Longitude 130.85°E; Kitakyushu city, Japan														
Domain cells (x*y*z)	50 * 50 * 40														
Time and duration	5 hours (09.00 – 14.00)														
Year	2020							2021							
Day (dd/m)	19/7	25/7	09/8	16/8	04/10	11/10	18/10	17/1	31/1	07/2	14/ 2	10/4	11/4	01/5	08/5
Max. Ta (°C)	24	29	30	34	30	25	21	9	16	20	20	18	23	21	22
Min. Ta (°C)	20	23	27	26	22	20	16	3	7	9	11	10	10	14	16
Max. RH (%)	94	94	89	84	88	78	88	70	76	82	100	62	82	67	100
Min. RH (%)	69	74	74	59	51	65	46	45	32	45	54	21	30	51	70
Constant wind speed	2 m/s														
Constant wind direction	90°														
Cloud cover	Low clouds 0; med clouds 0; high clouds 0.														

The *simple force* method used in ENVI-met simulation. There were two variables force in the calculation, they are: temperature (Ta) and RH. The position of view plane used in the thermal mapping analysis is at a height of 2 meters. While, the personal human parameters used in this study is according to ISO 7730 standard. The table below shows the simulation performance which is used to calculate the PMV value by *Biomet tool* in ENVI-met simulation software.

Table 35. Simulation conditions used in ENVI-met (Biomet) for the calculation of PMV

Attributes	**Data Input**
Clothing insulation	0.90 Clo
Activity	1.48 met (164.49 W = 86.21 W/m^2)
Age	35 years old
Height	1.75 m
Weight	75 kg
Gender	Male

8.3.2.3. Dividing the Simulation Area into 16 Grids

The study area of Green Park Kitakyushu is divided into 16. The division is a simplification in understanding the actual performance of thermal environment and urban structure. The area size is ± 500m x 500m and the grid size is 50x50 in the two axis (x and y). So there are 16 different zone which is shown on the picture below.

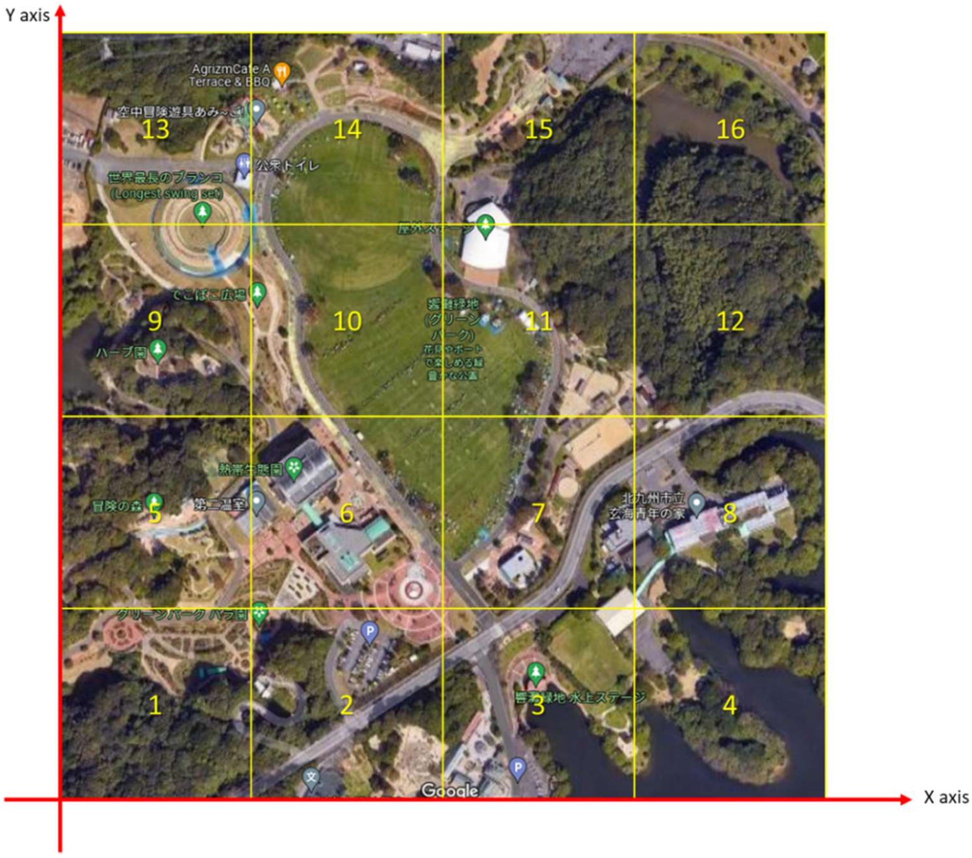


Figure 57. Spots in ENVI-met simulation

Based on the grid shown in figure 56, the spots' axis (x and y) is decided as shown on the picture below. The spots' axis is used to gain the each value of all variables that extracted from the ENVI-met simulation, they are variables of atmosphere (Ta, RH, v, Tmrt), surface (SVF, T surface, Surface Albedo), and Biomet (PMV and PPD).

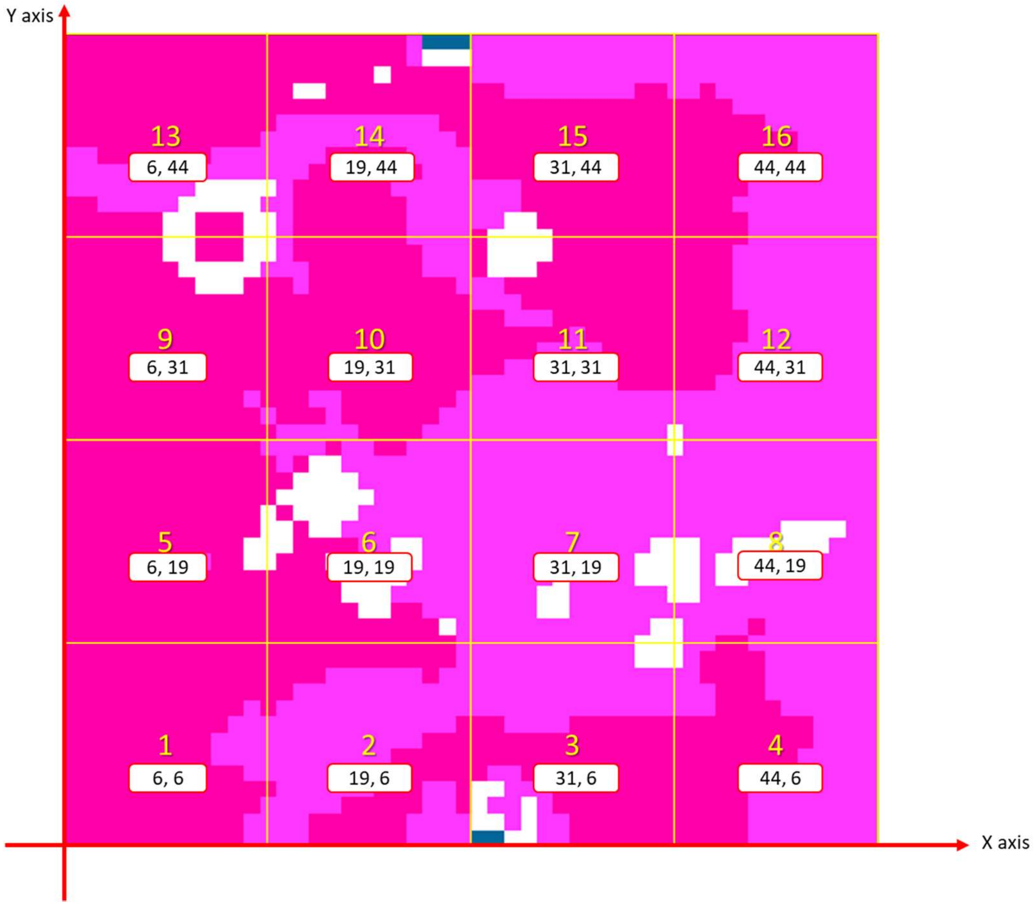


Figure 58. Axis of each spots in ENVI-met simulation

Only the selected spots of these grid are used for the outdoor thermal simulation in ENVI-met software. The selection is based on the position that should be in the center of the grids. Principally, the spots are the combination of four numbers, they are 6, 19, 31, and 44. The X and Y axis of spots which are used in simulation are shown on this following table.

Table 36. The X and Y axis of spots used in simulation

Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
X	6	19	31	44	6	19	31	44	6	19	31	44	6	19	31	44
Y	6	6	6	6	19	19	19	19	31	31	31	31	44	44	44	44

8.4. Results and Discussion

8.4.1. Performance of Urban Structure

8.4.1.1. Performance of Building Plot Ratio (BPR) and Green Plot Ratio (GnPR)

The Building Plot Ratio (BPR) and Green Plot Ratio (GnPR) are calculated by measuring building and vegetation area in comparison with total area of The Green Park Kitakyushu. The calculation is assisted by Auto Cad software. Based on calculation, the value of BPR and GnPR are shown in this following table.

Table 37. Value of BPR and GnPR in each location

Grid number	BPR	GnPR
1	0.000	0.664
2	0.002	0.419
3	0.069	0.380
4	0.002	0.494
5	0.023	0.703
6	0.236	0.241
7	0.099	0.343
8	0.161	0.517
9	0.091	0.728
10	0.000	0.711
11	0.084	0.707
12	0.006	0.947
13	0.130	0.529
14	0.025	0.796
15	0.018	0.667
16	0.005	0.862

The minimum value of BPR is 0 and the maximum is 0.236. While the average BPR is 0.06 (6%). It means that the number of building area is relatively low in comparison with its total area. In the other hand, the average GnPR value is 0.607 (60.7%) means that the number of vegetation area is higher than building area. The minimum value of GnPR is 0.24 and maximum is 0.94.

8.4.1.2. Performance of Sky View Factor and Surface Albedo

1) Sky View Factor

A data collection of Sky View Factor is conducted in the field survey. The SVF is captured by smartphone camera with a plugin of Fish eye lens. The SVF performance of four different spots of field measurement is shown on the following pictures.

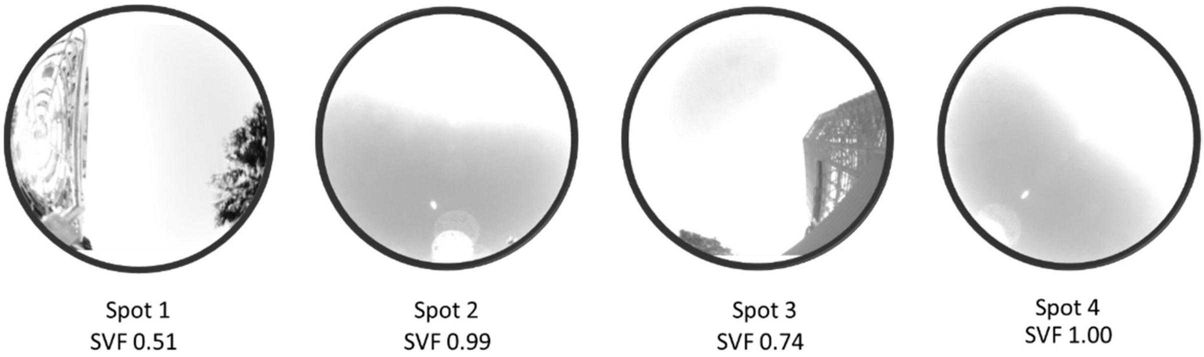


Figure 59. Sky View Factor of Green Park in four survey spots

The calculation of SVF is conducted manually by measuring the white area of sky view. As the SVF has a value of 0-1, an SVF value of 1 means that the view of the sky is open on all sides. A higher SVF value indicates a decrease in shade density. A lower SVF value means that the sky view is getting wider. Areas that are open and have a wider view of the sky give the effect of higher heat. Based on the calculation, it is found that the SVF value of spot 1 is 0.51 (half shaded area), spot 2 is 0.99 (barely shaded area), spot 3 is 0.74 (shaded area), and spot 4 is 1.00 (not shaded at all).

The performance of SVF is generated from ENVI-met simulation. The accuracy data of SVF value between simulation and field measurement can be evaluated by comparing the SVF value of a spot in the same position. As the result, the SVF value in spot number 3 (SVF 0.74) is similar with the value of the simulation in axis of x and y = 19 and 19 (SVF between 0.70 and 0.80). Therefore, it can be concluded that the SVF simulation results in this study is reliable for further analysis.

A. Summer case

In summer, the median SVF value is 0.86 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

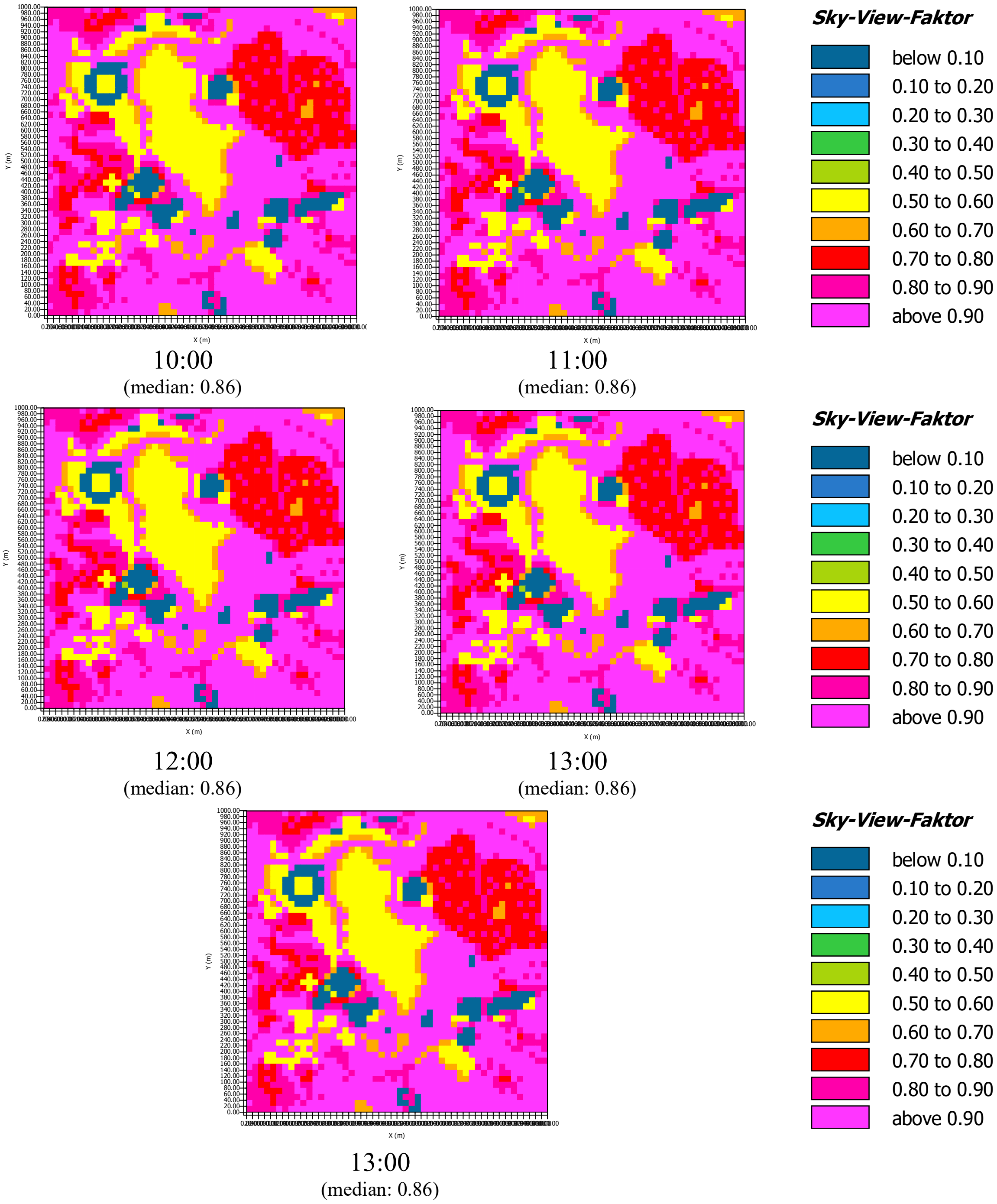


Figure 60. Performance of SVF in summer

B. Autumn case

In autumn, the median SVF value is 0.9 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

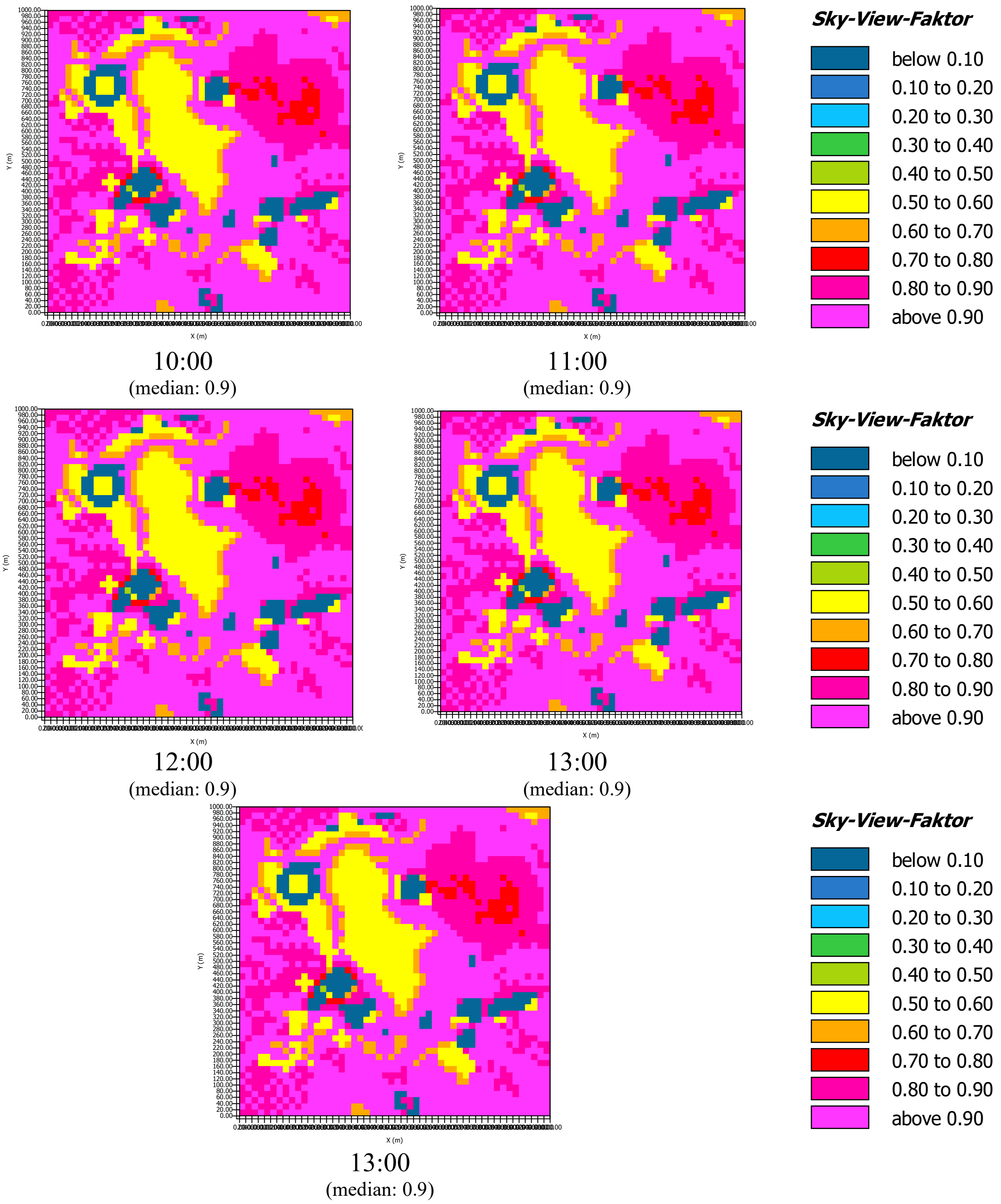


Figure 61. Performance of SVF in autumn

C. Winter case

In summer, the median SVF value is 0.94 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

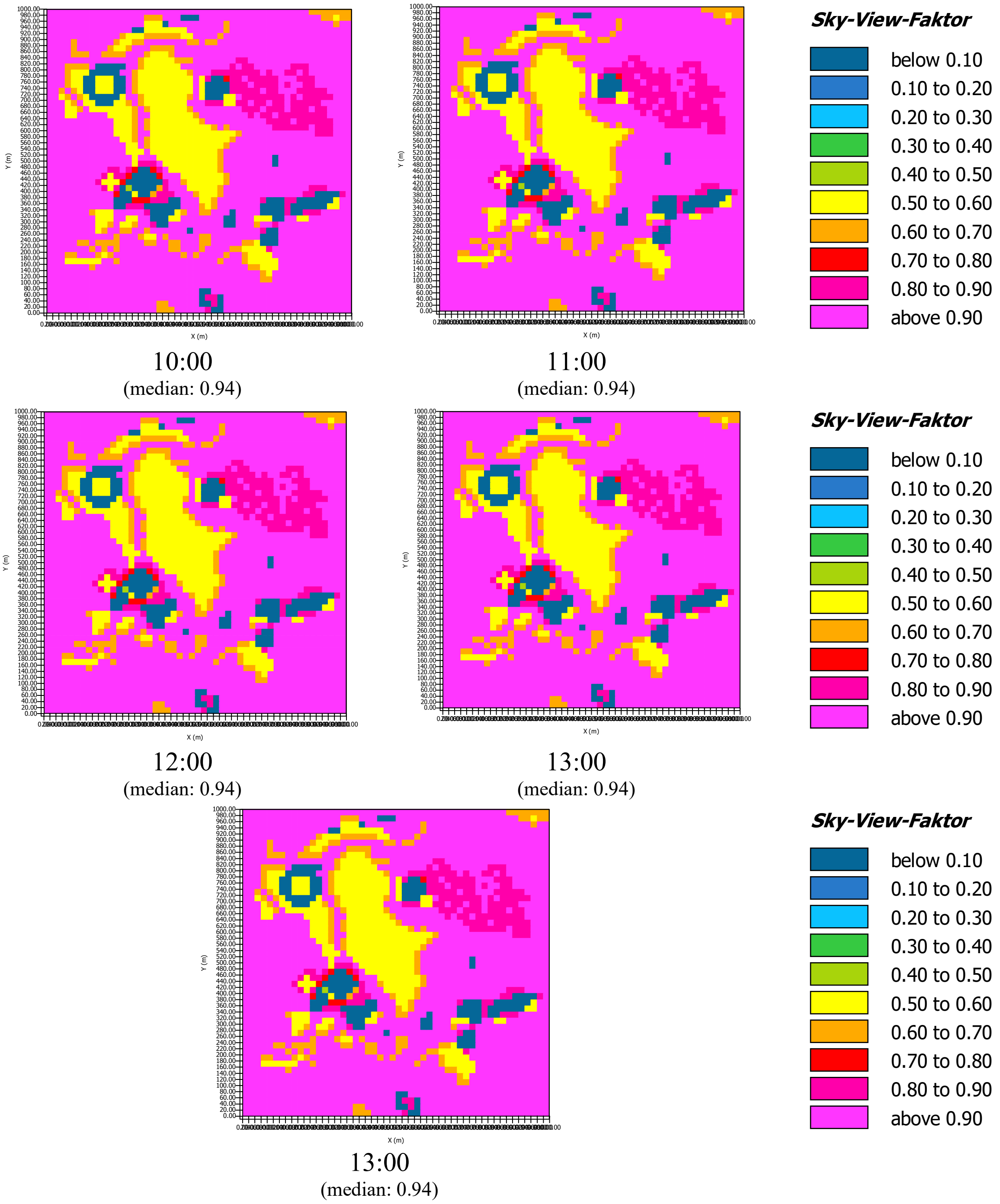
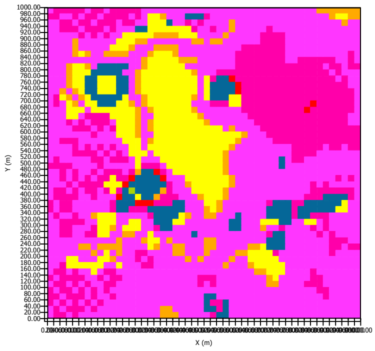


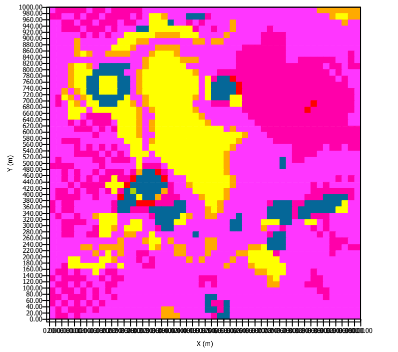
Figure 62. Performance of SVF in winter

D. Spring case

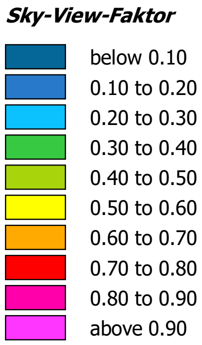
In summer, the median SVF value is between and (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

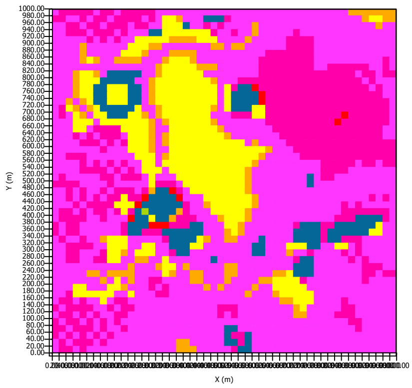


10:00
(median: 0.9)

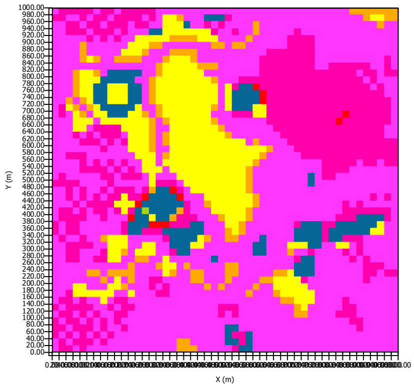


11:00
(median: 0.9)

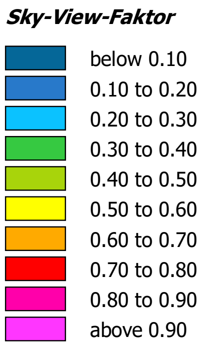


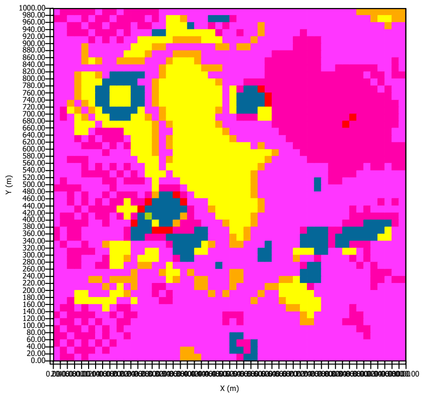


12:00
(median: 0.9)



13:00
(median: 0.9)





13:00
(median: 0.9)

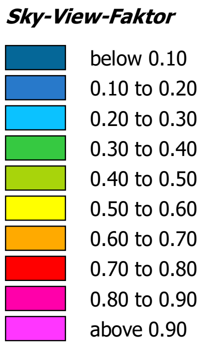


Figure 63. Performance of SVF in spring

E. Summary of season's SVF

The actual performance of Sky View Factor (SVF) is being analyzed based on simulation by ENVI-met software. The SVF value is relatively similar in different times, and days. Overall, the median SVF value is between 0.86 and 0.94 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees. The following thermal maps shows SVF for each season's representative days.

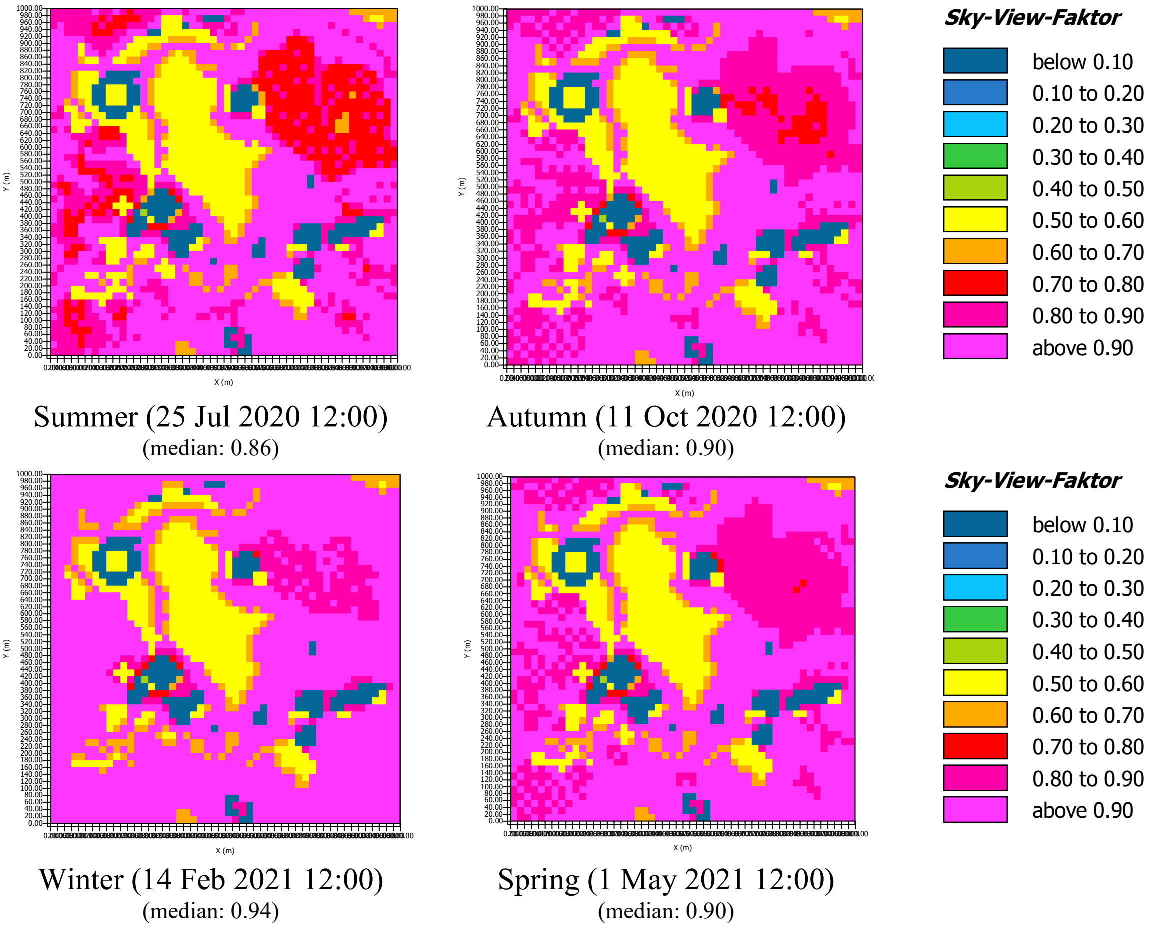


Figure 64. Overall performance of SVF

The performances of Sky View Factor (SVF) in each season are summarized as follows:

a) In summer, the median SVF value is 0.86 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.
b) In autumn, the median SVF value is 0.9 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

c) In winter, the median SVF value is 0.94 (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.
d) In spring, the median SVF value is between and (high SVF) means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

2) Surface Albedo

The performance of surface albedo (SA) is also analyzed by ENVI-met simulation. The value of SA is between 0 and 1 which represents the percentage of whiteness of an environment surface. The detailed performances of Surface Albedo (SA) in each season are summarized as follows:

a) In summer, the median surface albedo value is between 0.17 and 0.23. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.
b) In autumn, the median surface albedo value is between 0.17 and 0.20. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.
c) In winter, the median surface albedo value is between 0.17 and 0.20. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.
d) In spring, the median surface albedo value is between 0.18 and 0.23. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.

A. Summer case

In summer, the median surface albedo value is between 0.17 and 0.23. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.

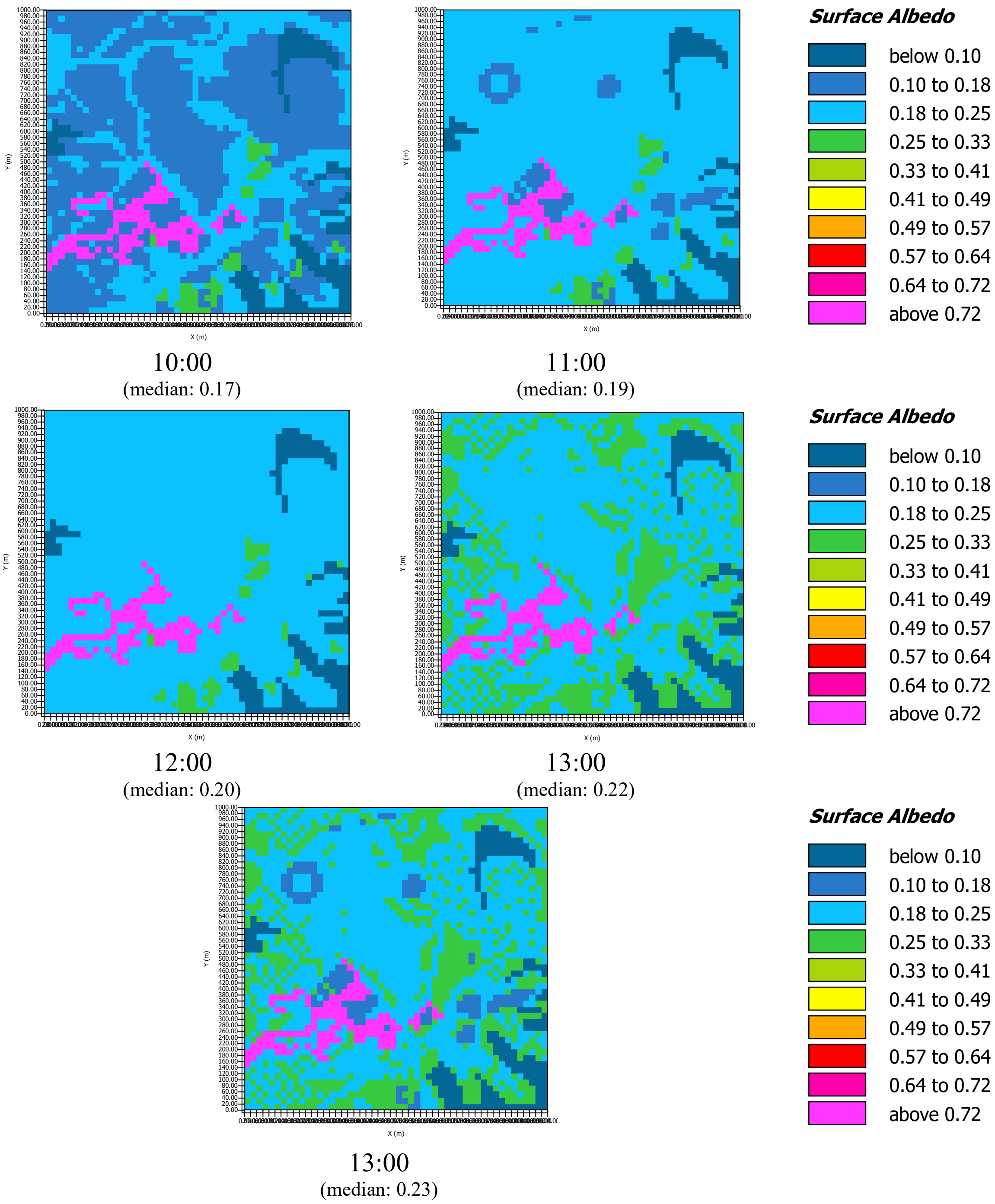


Figure 65. Performance of SA in summer

B. Autumn case

In autumn, the median surface albedo value is between 0.17 and 0.20. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.

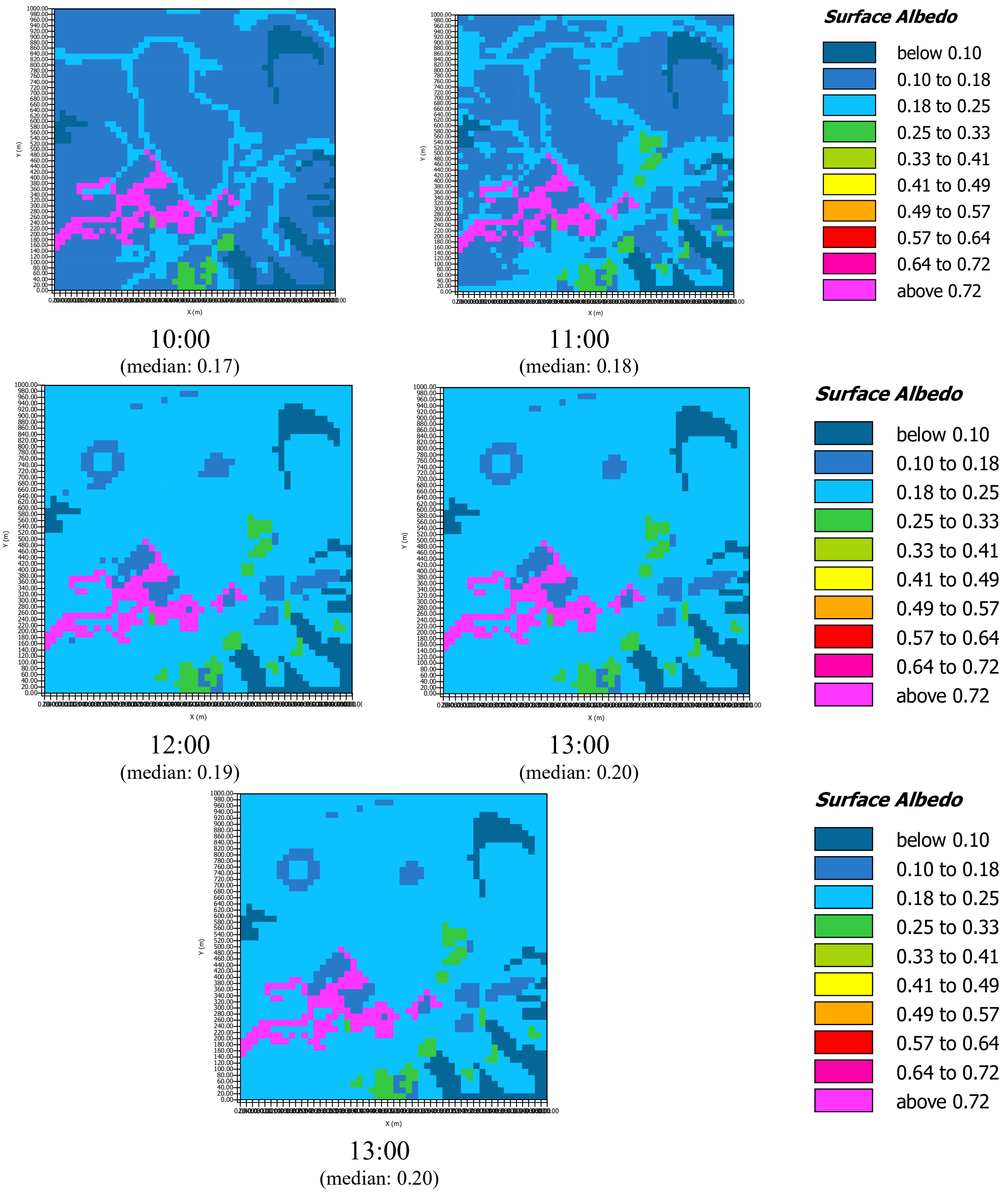


Figure 66. Performance of SA in autumn

C. Winter case

In winter, the median surface albedo value is between 0.17 and 0.20. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.

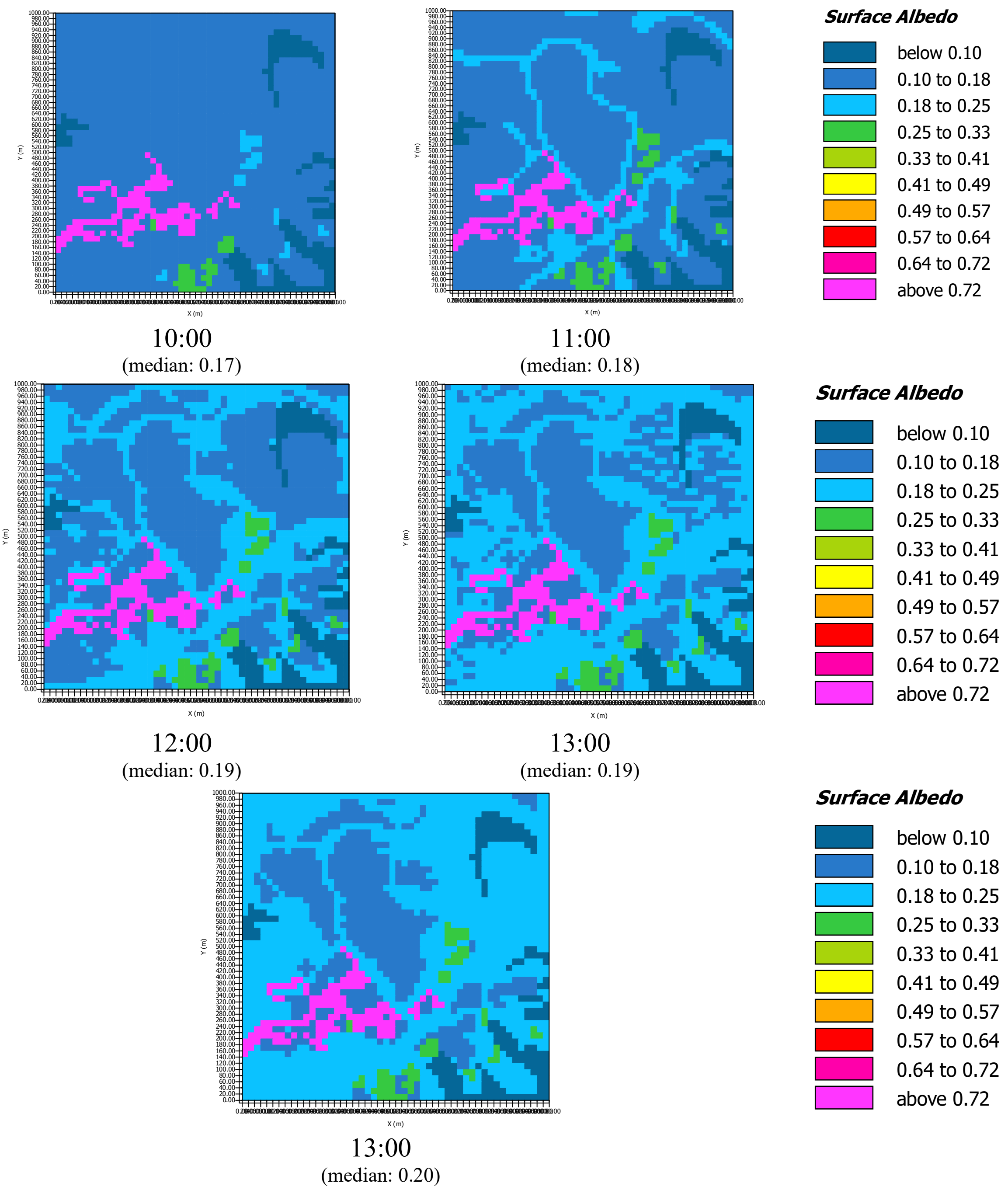


Figure 67. Performance of SA in winter

D. Spring case

In spring, the median surface albedo value is between 0.18 and 0.23. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.

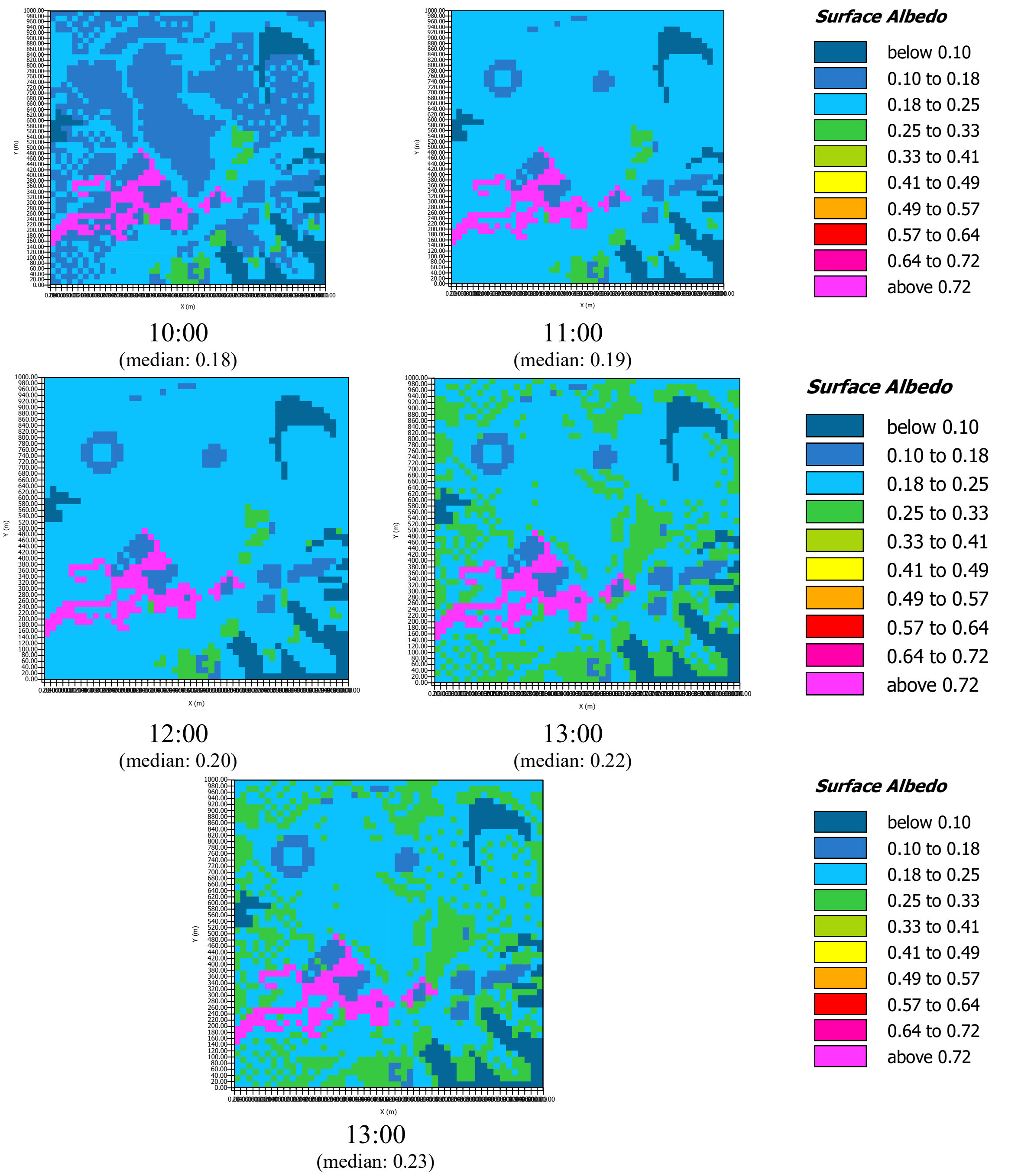


Figure 68. Performance of SA in spring

E. Summary of Season's Surface Albedo

Overall the Park's surface has a low albedo (between 0.10 and 0.25). In the mid-day (12:00) the median value of surface albedo is between 0.19 and 0.20 means a low albedo. The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material. The simulation results on the Surface Albedo (SA) value can be seen in the following figures.

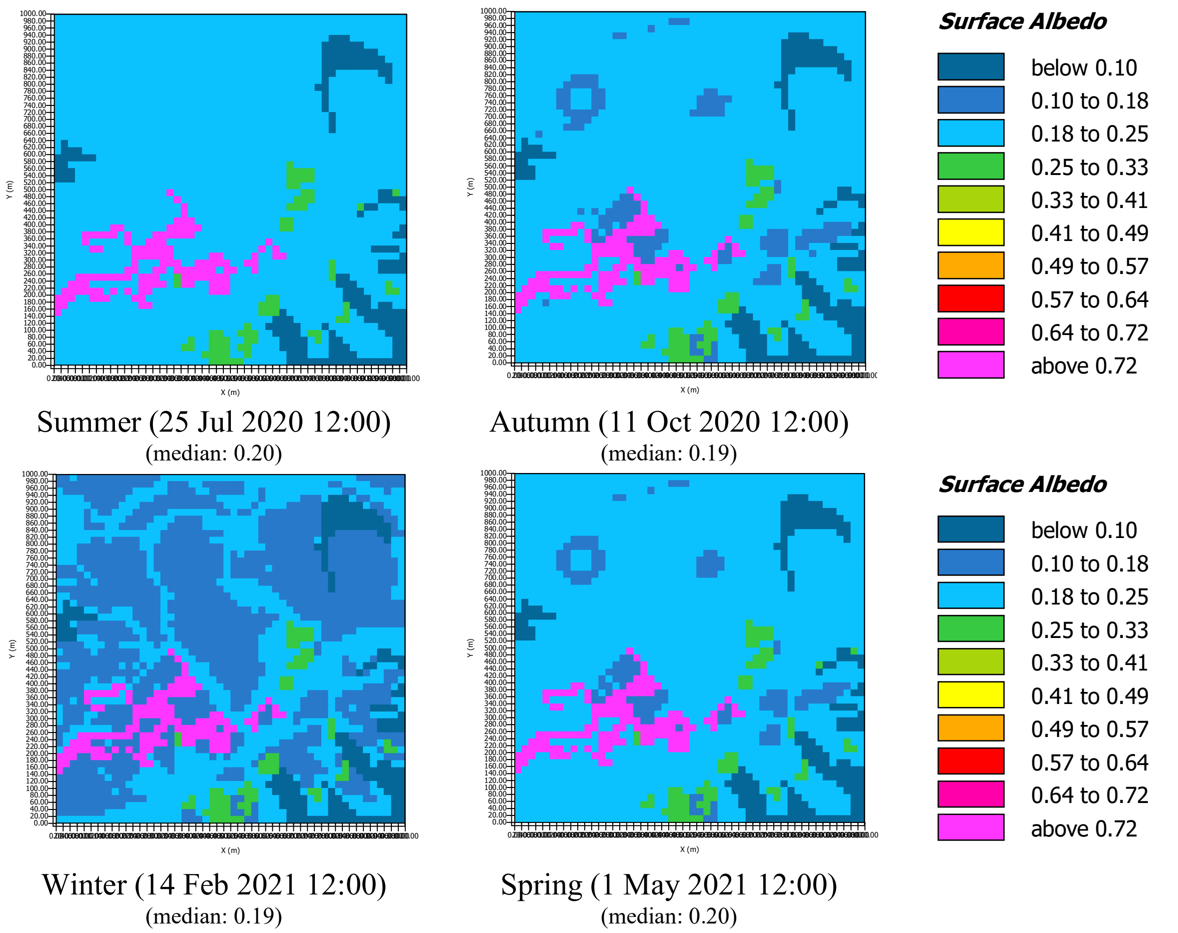


Figure 69. Overall performance of SA

8.4.2. Performance of Outdoor Thermal Environment

8.4.2.1. Validating the Simulation Data Accuracy by Field Measurement Data

Simulation using ENVI-met produces an image in the form of a map containing various information about the thermal environment, such as Potential Air Temperature (Ta), Relative Humidity (RH), Wind Speed (v), Mean Radiant Temperature (Tmrt), and so on. To obtain accurate simulation results, a validation process was carried out by comparing the values of Ta, RH, and V from field measurements and simulation results at each data collection date. Based on the regression analysis, it was found that the respective R^2 values were found. The R^2 value which is more than 0.6 (strong correlation) and closer to 1 indicates that the simulation data is more accurate, in accordance with the field measurement data.

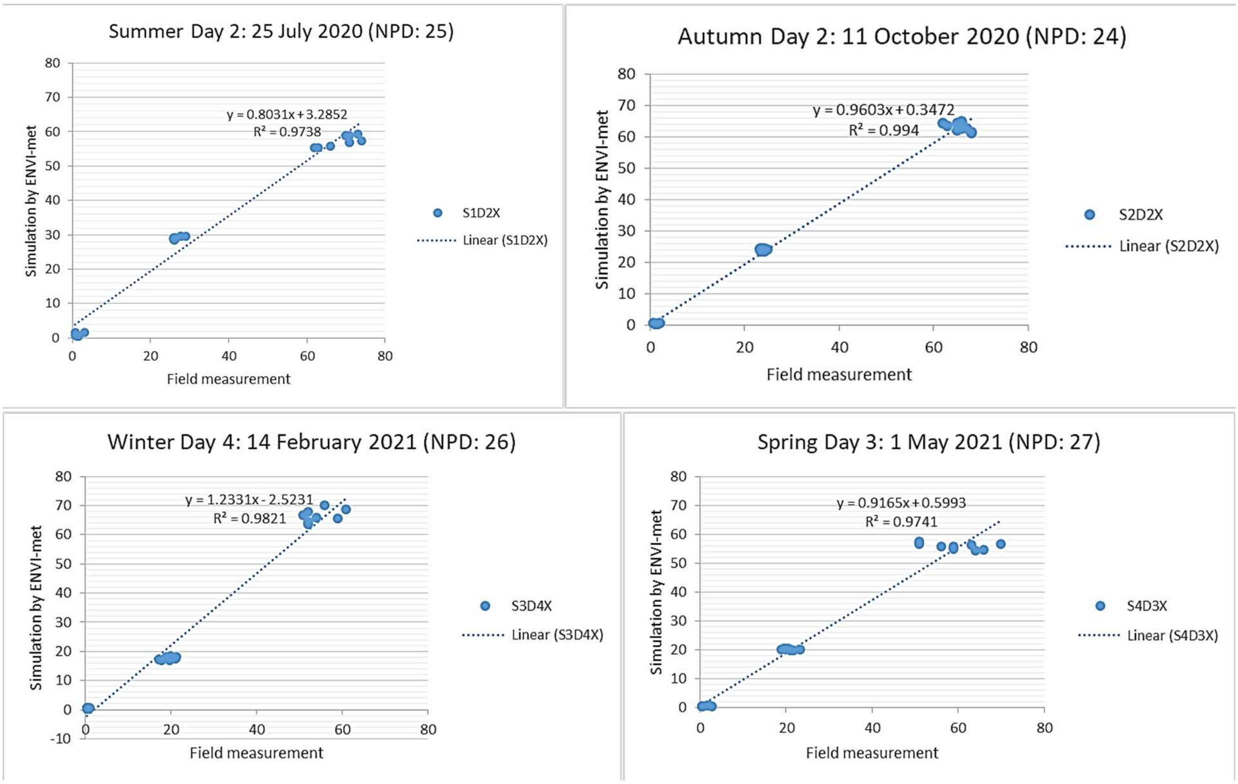


Figure 70. Data validation between simulation and field measurement

Based on the pictures above, it was found that almost all of the data had an R^2 value above 0.6 (the full validation data is provided in the appendix C of this dissertation book). Thus all data pairs can be used in principle. However, it should be noted that not all data pairs have the same amount (especially the amount of field measurement data). So in each season, one best day is chosen which has the largest R^2 value and the largest Number of Pair Data (NPD). Based on these considerations, the best days in each season are as follows.

Table 38. Representative days in each season

Season	**Day Number**	**Date**	**NPD**	**R^2**
Summer	Day 2	25 July 2020	25	0.9738
Autumn	Day 2	11 October 2020	24	0.994
Winter	Day 4	14 February 2021	26	0.9821
Spring	Day 3	1 May 2021	27	0.9741

8.4.2.2. Mapping the Performance of Outdoor Thermal Environment Simulation

The map of the thermal environmental performances in each season is extracted after the simulation data is completed. The thermal maps of the performance of outdoor thermal environment is extracted from ENVI-met simulation software. There are four simulation days which representing its season, they are summer day (25 July 2020), autumn day (11 October 2020), winter day (14 February 2021), and spring day (1 May 2021). There are three thermal environment variables of performance to be determined, they are air temperature (Ta), wind speed (v), and relative humidity (RH). The maps show the performances of Green Park from 10.00 AM to 14.00 AM. The overall performance of Potential Air Temperature (°C), Wind Speed (m/s), Relative Humidity (%) are shown in the table 39.

Table 39. Overall performance of outdoor thermal environment

Season	**Time**	**Air Temperature (°C)**			**Wind Speed (m/s)**			**Relative Humidity (%)**		
		Min	**Max**	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**Median**
Summer (25 July 2020)	10:00	19.85	29.34	28.38	0	2.26	2.04	57.47	107.75	60.61
	11:00	19.87	30.04	28.92	0	2.21	1.95	55.41	107.65	58.71
	12:00	19.92	30.69	29.35	0	2.17	1.88	54.06	107.31	56.99
	13:00	20.02	30.75	29.50	0	2.13	1.82	53.24	106.63	56.21
	14:00	20.18	30.57	29.54	0	2.10	1.77	52.72	105.59	55.69
	Average	19.97	30.28	29.14	0	2.17	1.89	54.58	106.99	57.64
Autumn (11 October 2020)	10:00	19.85	24.38	23.62	0	2.05	1.87	63.17	86.46	65.86
	11:00	19.86	24.96	24.05	0	2.03	1.83	61.32	86.41	64.40
	12:00	19.89	25.43	24.37	0	2.01	1.79	60.65	86.22	63.09
	13:00	19.96	25.37	24.43	0	2.00	1.77	59.75	85.85	62.56
	14:00	20.07	25.22	24.33	0	1.98	1.75	59.68	85.28	62.62
	Average	19.93	25.07	24.16	0	2.01	1.80	60.91	86.04	63.71
Winter (14 February 2021)	10:00	16.78	19.85	17.16	0	1.80	1.64	57.24	71.78	69.54
	11:00	17.25	19.85	17.68	0	1.81	1.64	57.22	69.65	67.13
	12:00	17.65	20.06	18.15	0	1.82	1.64	54.3	67.45	64.67
	13:00	17.83	19.91	18.28	0	1.82	1.64	57.03	66.44	64.31
	14:00	17.81	19.97	18.18	0	1.82	1.64	56.81	66.82	65.31
	Average	17.46	19.93	17.89	0	1.81	1.64	56.52	68.43	66.19
Spring (1 May 2021)	10:00	19.44	21.23	19.90	0	1.93	1.75	50.43	59.60	57.32
	11:00	19.69	21.22	20.13	0	1.91	1.73	50.27	58.98	57.01
	12:00	19.53	21.23	20.20	0	1.90	1.71	50.03	58.97	57.00
	13:00	18.95	21.29	20.29	0	1.89	1.69	49.57	60.30	56.91
	14:00	18.27	21.19	20.30	0	1.89	1.68	49.83	61.74	56.79
	Average	19.18	21.23	20.16	0	1.90	1.71	50.03	59.92	57.01
Overall		16.78	30.75	22.84	0	2.26	1.76	49.57	107.75	61.13

The purpose of the mapping is to determine the threat of problems that can occur due to the thermal performances of the environment. For example, if at a certain point the wind is too strong, it is necessary to provide a special strategy to deal with it, such as planting wind speed breaking trees or guiding trees. Another strategy can also be given if there is a problem with the temperature being too high, then it is necessary to provide shade trees or shelter buildings as shading.

The potential air temperature of Green Park in four different seasons is between 16.78°C and 30.75°C, and the average is 22.84°C. In summer, the minimum air temperature is 19.97°C, the maximum is 30.28°C, and the average is 29.14°C. The autumn has a value of 19.93°C, 25.07°C, and 24.16°C on its minimum, maximum, and average. While in winter, the air temperature is in the range of 17.46°C and 19.93°C, with an average of 17.89°C. The minimum, maximum, and average value for the spring are 19.18°C, 21.23°C, and 20.16°C.

The wind speed performance of Green Park in four different seasons is between 0 and 2.26 m/s, and the average is 1.76 m/s. The summer has a value of 0 m/s, 2.17 m/s, and 1.89 m/s on its minimum, maximum, and average. In autumn, the minimum wind speed is 0 m/s, the maximum is 2.01 m/s, and the average is 1.80 m/s. The minimum, maximum, and average value for the winter are 0 m/s, 1.81 m/s, and 1.64 m/s. While in spring, the wind speed is in the range of 0 m/s and 1.90 m/s, with an average of 1.71 m/s.

The relative humidity performance of Green Park in four different seasons is between 49.57% and 107.75%, and the average is 61.13%. The minimum, maximum, and average value for the summer are 54.58%, 106.99%, and 57.64%. In this case, the maximum RH is above 100% which is known as supersaturation. At any given temperature and air pressure, a specific maximum amount of water vapor in the air will produce a relative humidity (RH) of 100 percent. Supersaturated air contains more water vapor than is needed to cause saturation with respect to a plane surface of pure water or pure ice. Supersaturation results when the temperature of air containing no condensation nuclei falls below its dew point (Allaby & Allaby, 2018). While in autumn, the relative humidity is in the range of 60.91% and 86.04%, with an average of 63.71%. The winter has a value of 56.52%, 68.43%, and 66.19% on its minimum, maximum, and average. In spring, the minimum relative humidity is 50.03%, the maximum is 59.92%, and the average is 57.01%.

A. Summer case

It can be seen that almost for all the survey time the average temperature is above 28.5°C. According to the range of PET in (sub) tropical region, this thermal perception is slightly warm with slight heat stress. If it is aligned with the respondent's answer that half of them feel they cannot accept the thermal performances in the summer, it can be concluded that the thermal performances of Green Park in the summer are quite uncomfortable.

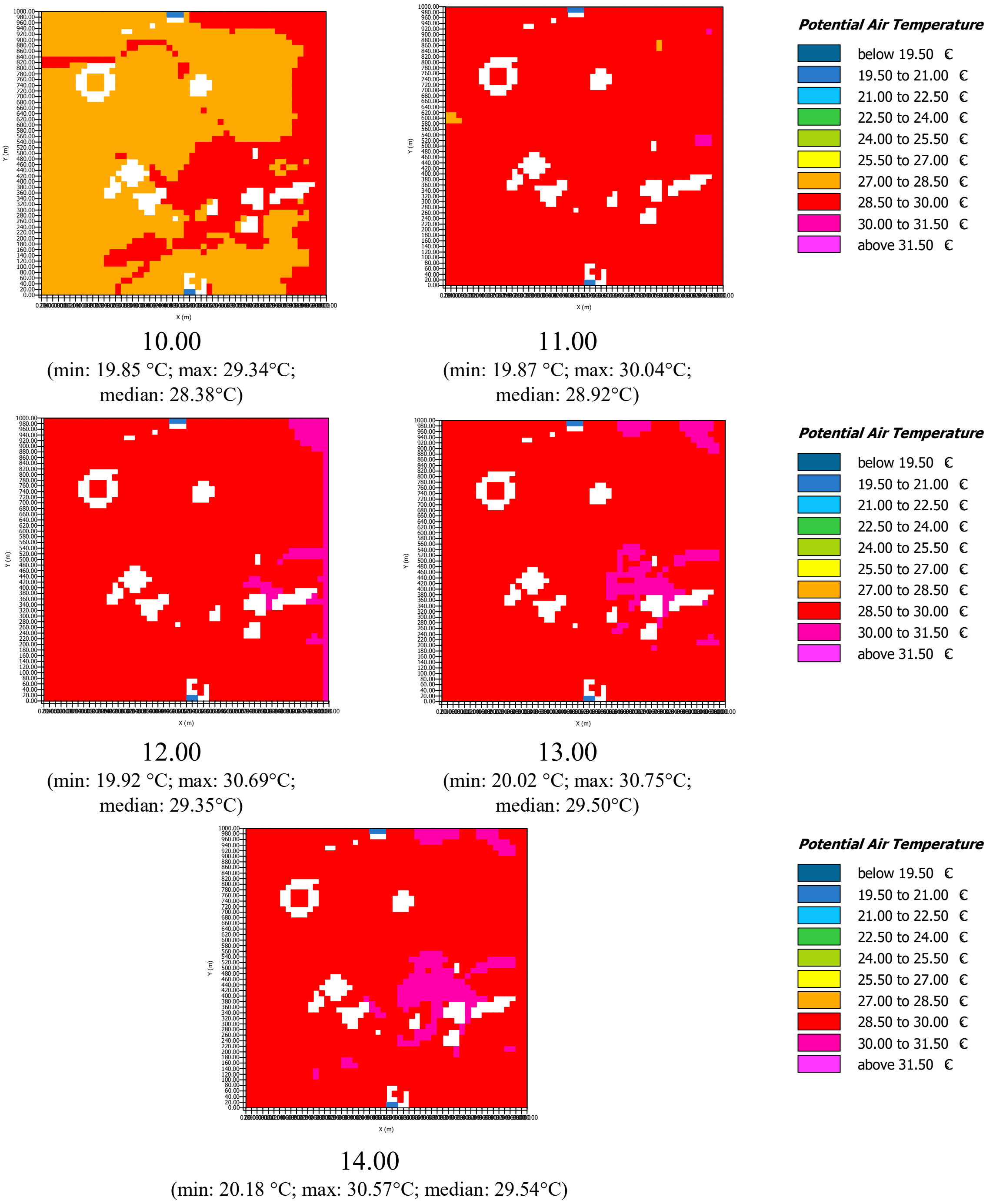


Figure 71. Performance of Air Temperature in summer

Wind speed performances can be seen from the following figure. Most of the pink and red areas (1.75 m/s – 2.25 m/s) are open spaces which only consist of trees (forest) and water elements. While areas with public facilities such as pavements and grass fields have lower wind speeds (between 1.25 m/s and 1.50 m/s) which are symbolized in yellow.

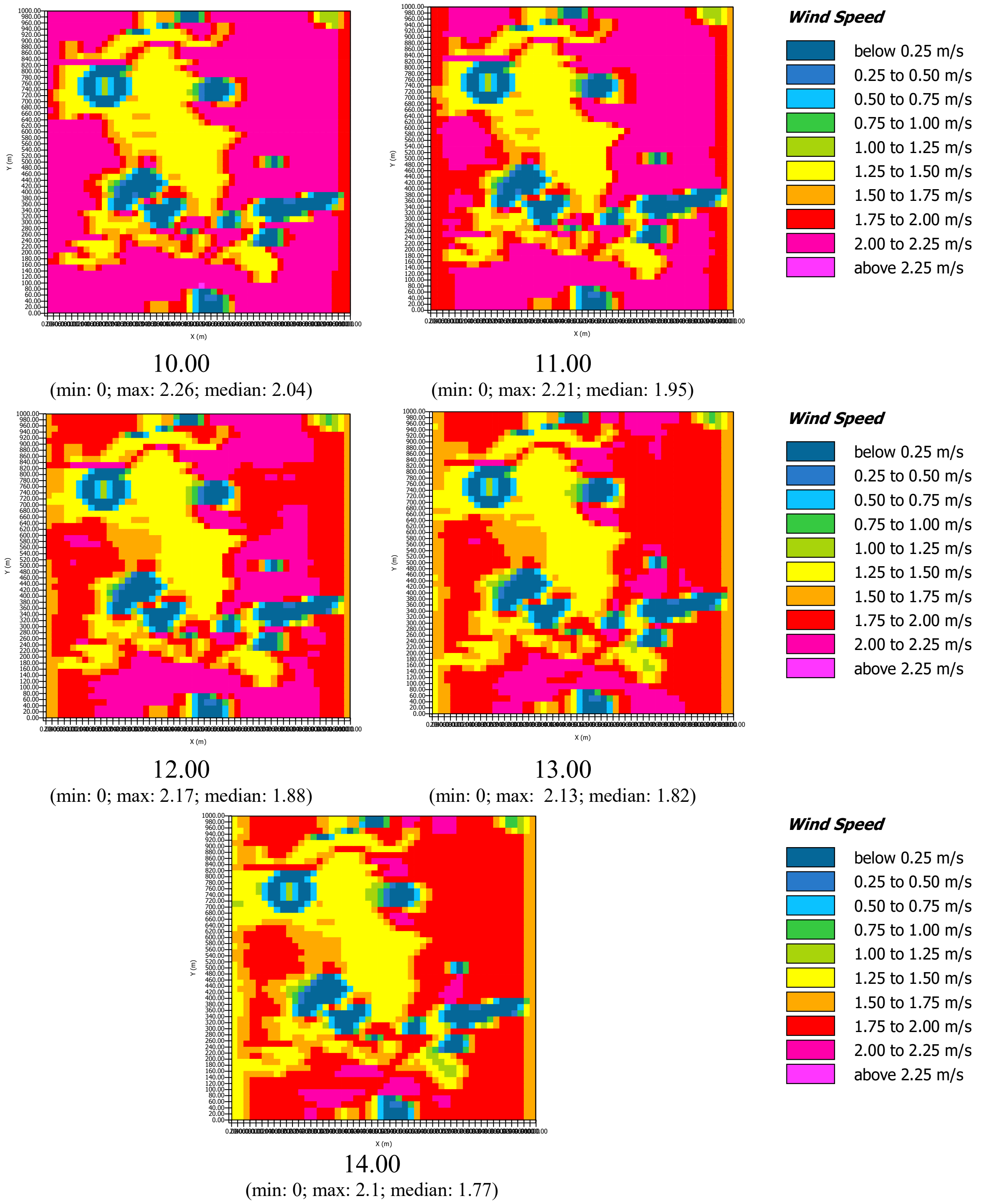


Figure 72. Performance of Wind Speed in summer

While the performance of air humidity can be seen from the following image. Most of the area is light green which has an RH value between 50% and 60%. This shows that the local climate of Green Park is neither dry nor humid.

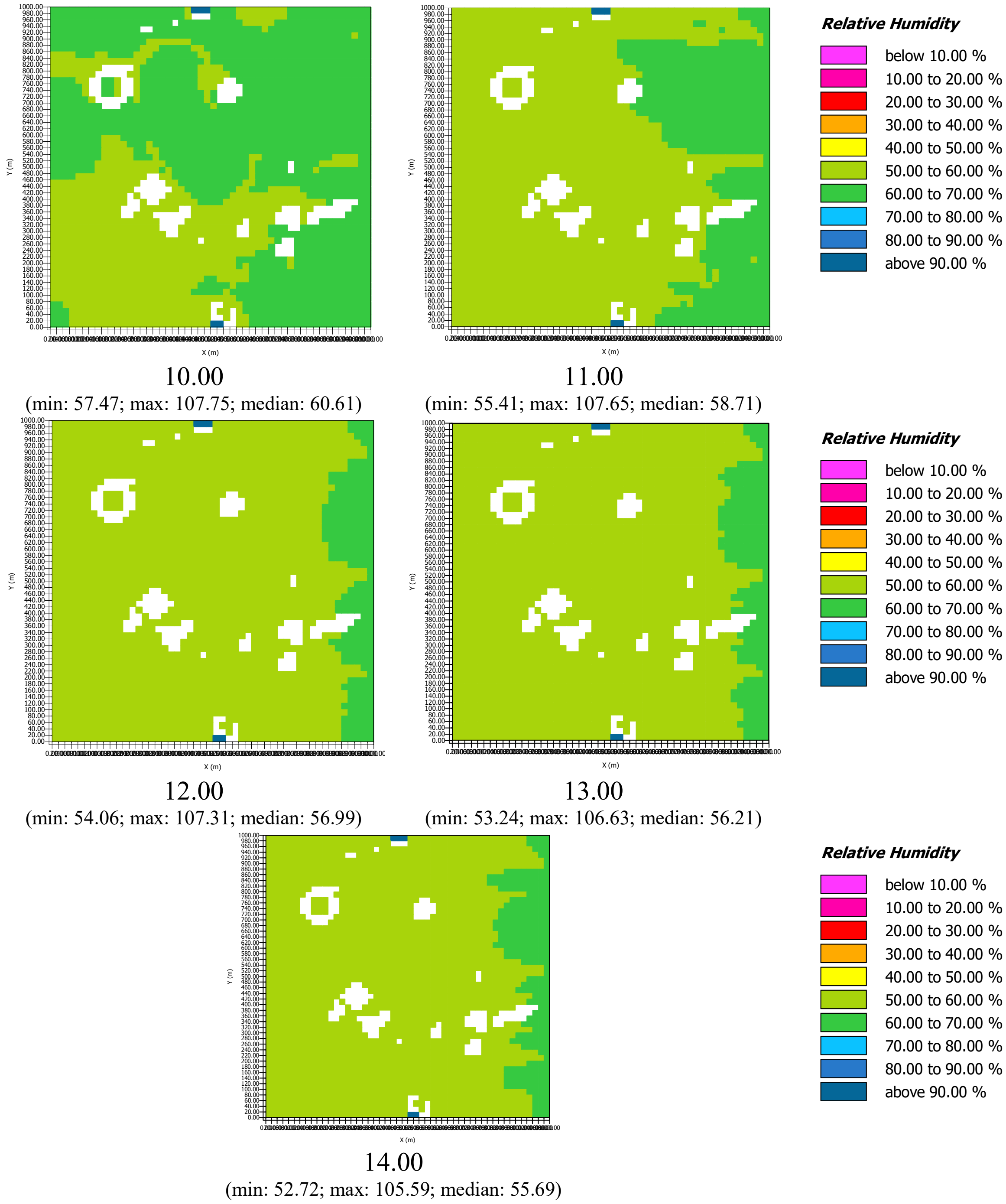
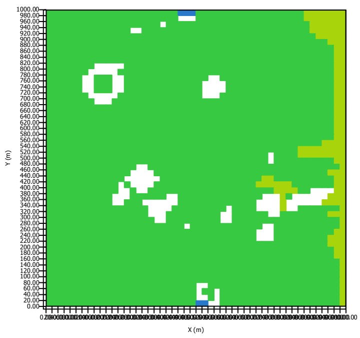


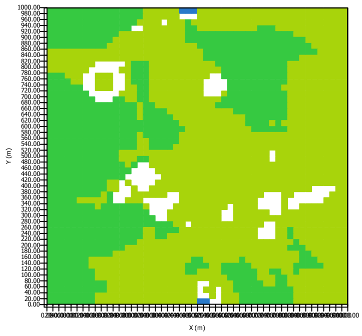
Figure 73. Performance of Relative Humidity in summer

B. Autumn case

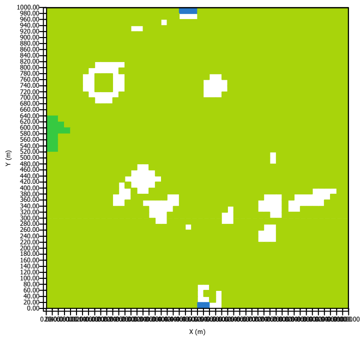
In the autumn season, most areas have air temperatures that are in the range of 22.5°C to 25.5°C. This shows that in the autumn season, Green Park is thermally quite comfortable with a neutral to slightly warm thermal sensation. Meanwhile, the highest level of physical stress is in the category of slight heat stress.



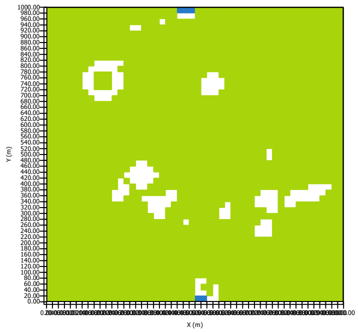
10.00
(min: 19.85 °C; max: 24.38°C; median: 23.62°C)



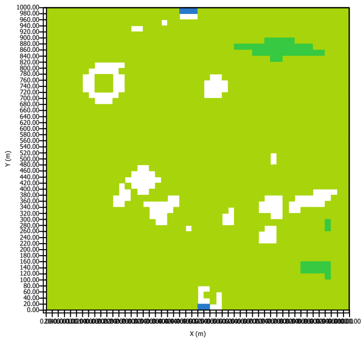
11.00
(min: 19.86 °C; max: 24.96°C; median: 24.05°C)



12.00
(min: 19.89 °C; max: 25.43°C; median: 24.37°C)



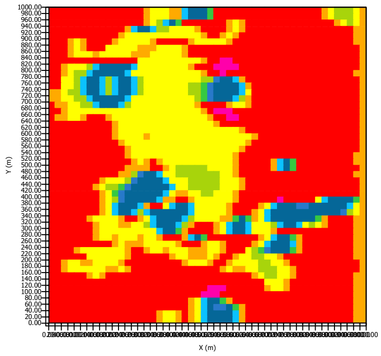
13.00
(min: 19.96 °C; max: 25.37°C; median: 24.43°C)



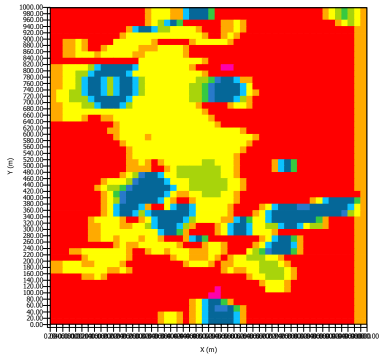
14.00
(min: 20.07 °C; max: 25.22°C; median: 24.33°C)

Figure 74. Performance of Air Temperature in autumn

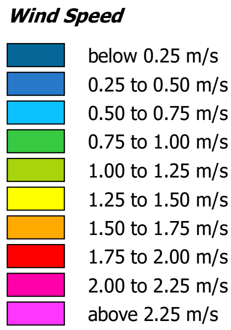
Wind speed performances in the autumn season can be seen from the following figure. Open spaces which only consist of trees (forest) and water elements have higher wind speeds of 1.75 m/s – 2.00 m/s. While areas such as pavements and grass fields have lower wind speeds (between 1.00 m/s and 1.50 m/s) which are symbolized by light green and yellow colors.

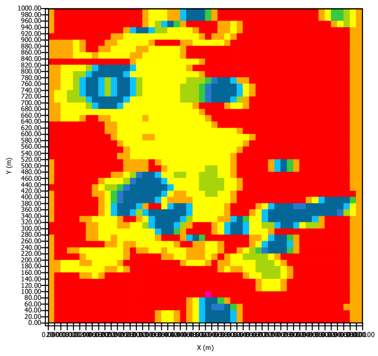


10.00
(min: 0; max: 2.05; median: 1.87)

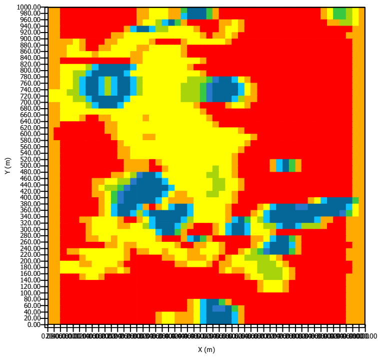


11.00
(min: 0; max: 2.03; median: 1.83)

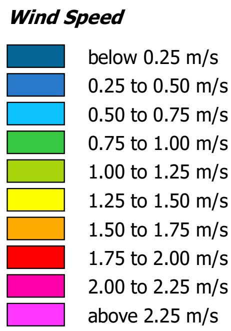


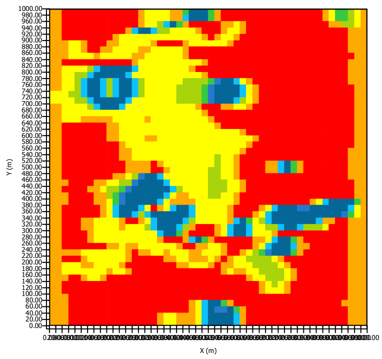


12.00
(min: 0; max: 2.01; median: 1.79)



13.00
(min: 0; max: 2; median: 1.77)





14.00
(min: 0; max: 1.98; median: 1.75)

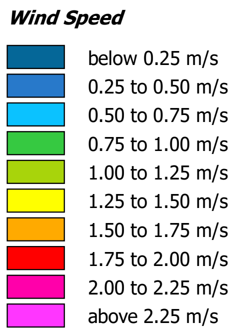
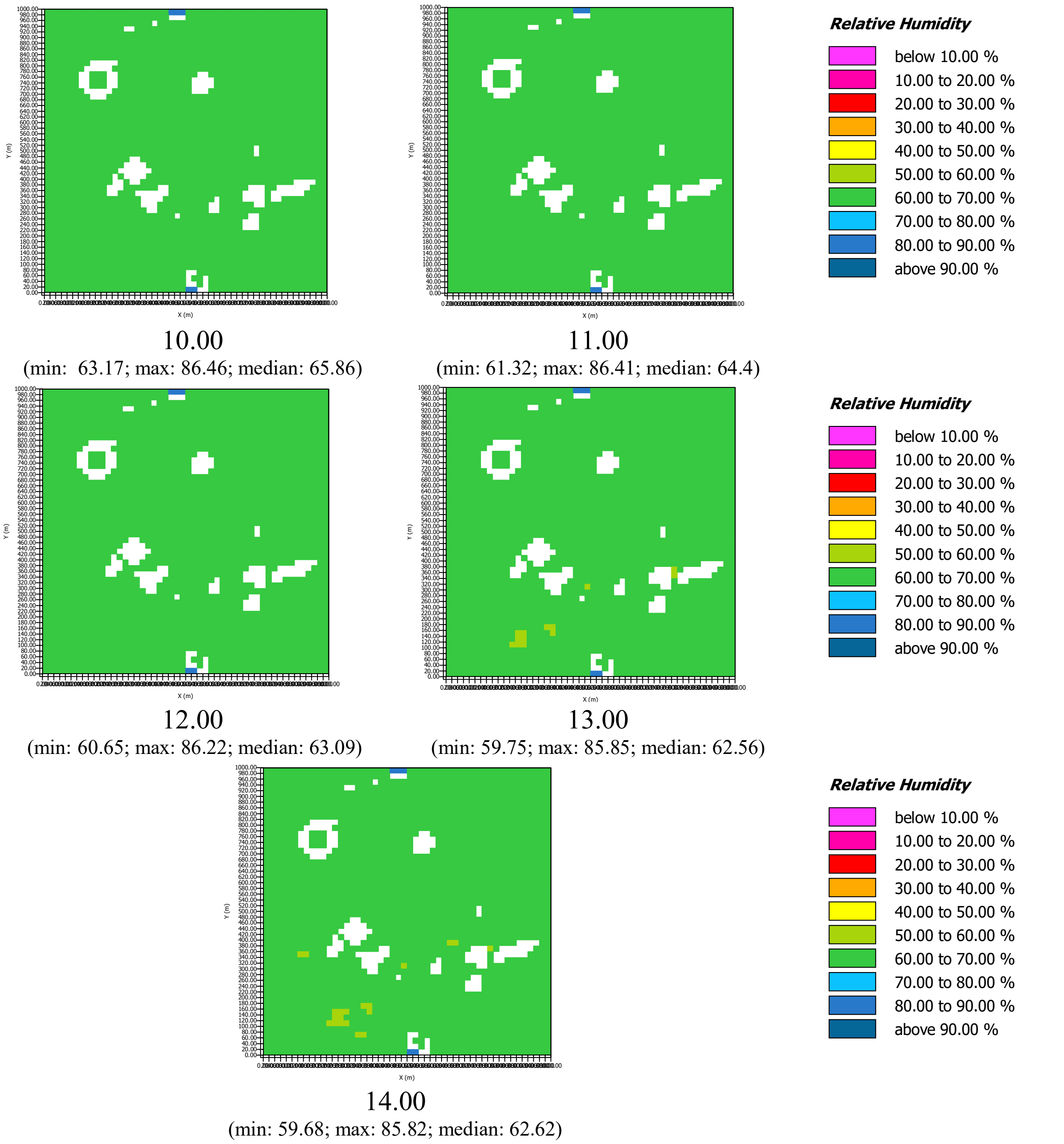


Figure 75. Performance of Wind Speed in autumn

The following image describes the humidity performances in the autumn season. Most of the area is green which has an RH value between 60% and 70%. This shows that the local climate of Green Park is relatively humid.



10.00
(min: 63.17; max: 86.46; median: 65.86)

11.00
(min: 61.32; max: 86.41; median: 64.4)

12.00
(min: 60.65; max: 86.22; median: 63.09)

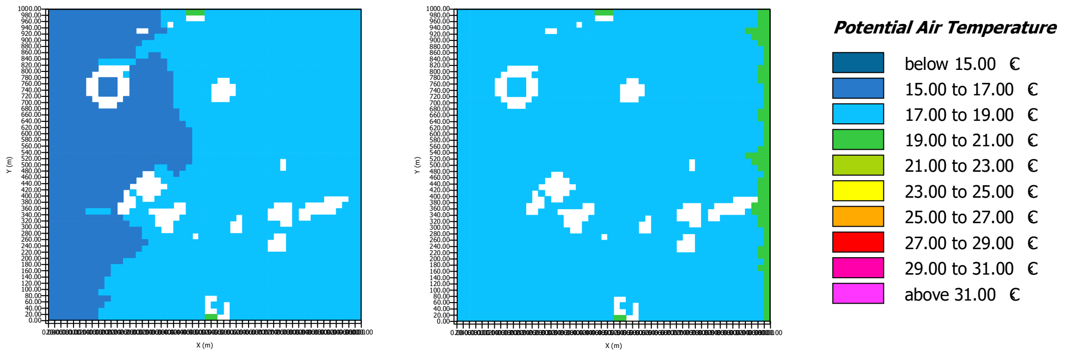
13.00
(min: 59.75; max: 85.85; median: 62.56)

14.00
(min: 59.68; max: 85.82; median: 62.62)

Figure 76. Performance of Relative Humidity in autumn

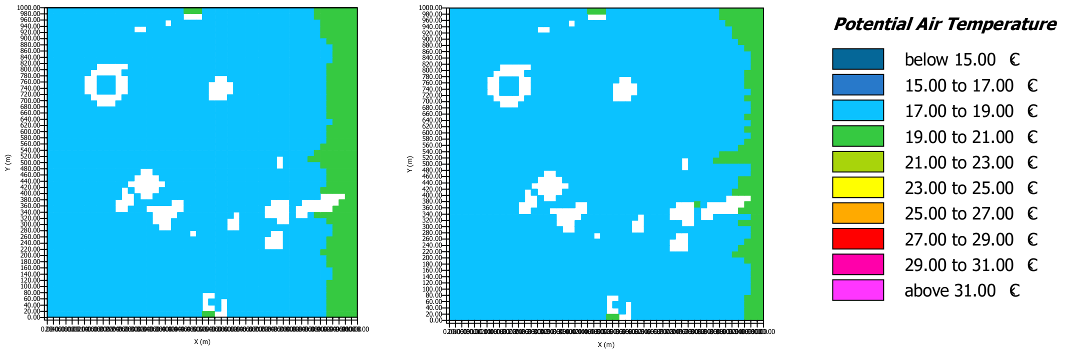
C. Winter case

In winter, most areas have air temperatures that are in the range of 16°C to 20°C. This shows that in the autumn season, thermally Green Park is somewhat uncomfortable with a cool thermal sensation. While the level of physical stress is in the category of moderate cool stress.



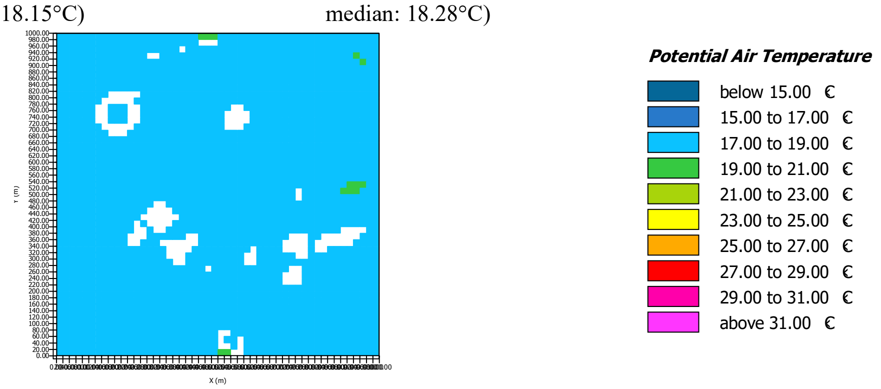
10.00
(min: 16.78°C; max: 19.85°C;
median: 17.16°C)

11.00
(min: 17.25 °C; max: 19.85°C;
median: 17.68°C)



12.00
(min: 17.65 °C; max: 20.06°C;
median: 18.15°C)

13.00
(min: 17.83°C; max: 19.91°C;
median: 18.28°C)



14.00
(min: 17.81°C; max: 19.97°C; median: 18.18°C)

Figure 77. Performance of Air Temperature in winter

Wind speed performances in winter can be seen from the following figure. Open spaces which only consist of trees (forest) and water elements have higher wind speeds of 1.5 m/s – 1.75 m/s (orange color). While areas such as pavements and grass fields have lower wind speeds (between 1.25 m/s and 1.50 m/s) which are symbolized in yellow.

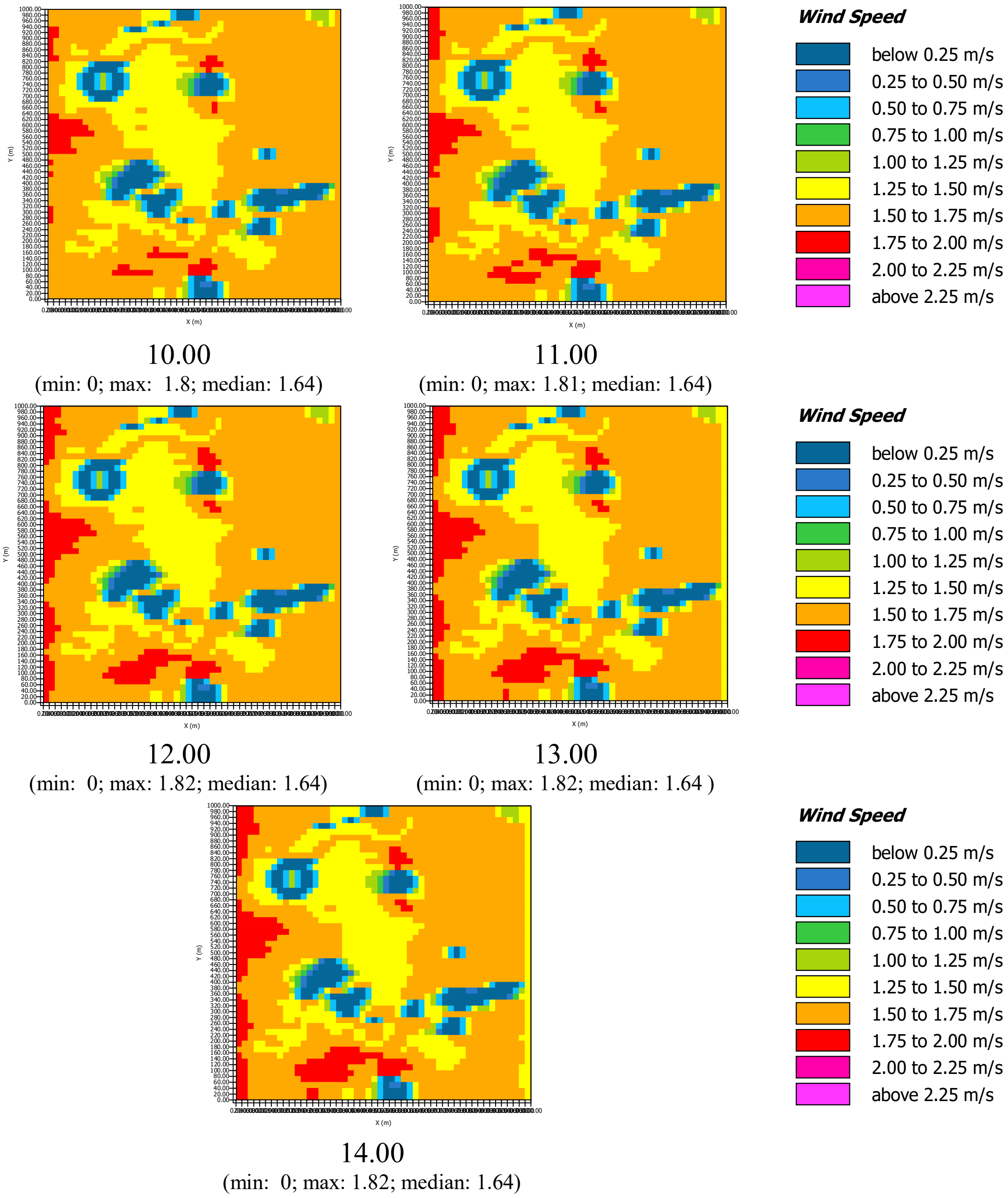


Figure 78. Performance of Wind Speed in winter

The following figure describes the humidity performances in winter. Most of the green areas have RH values between 60% and 70%. A small amount of blue is a more humid area which is between 70% and 80%. This shows that the local climate of Green Park is relatively humid.

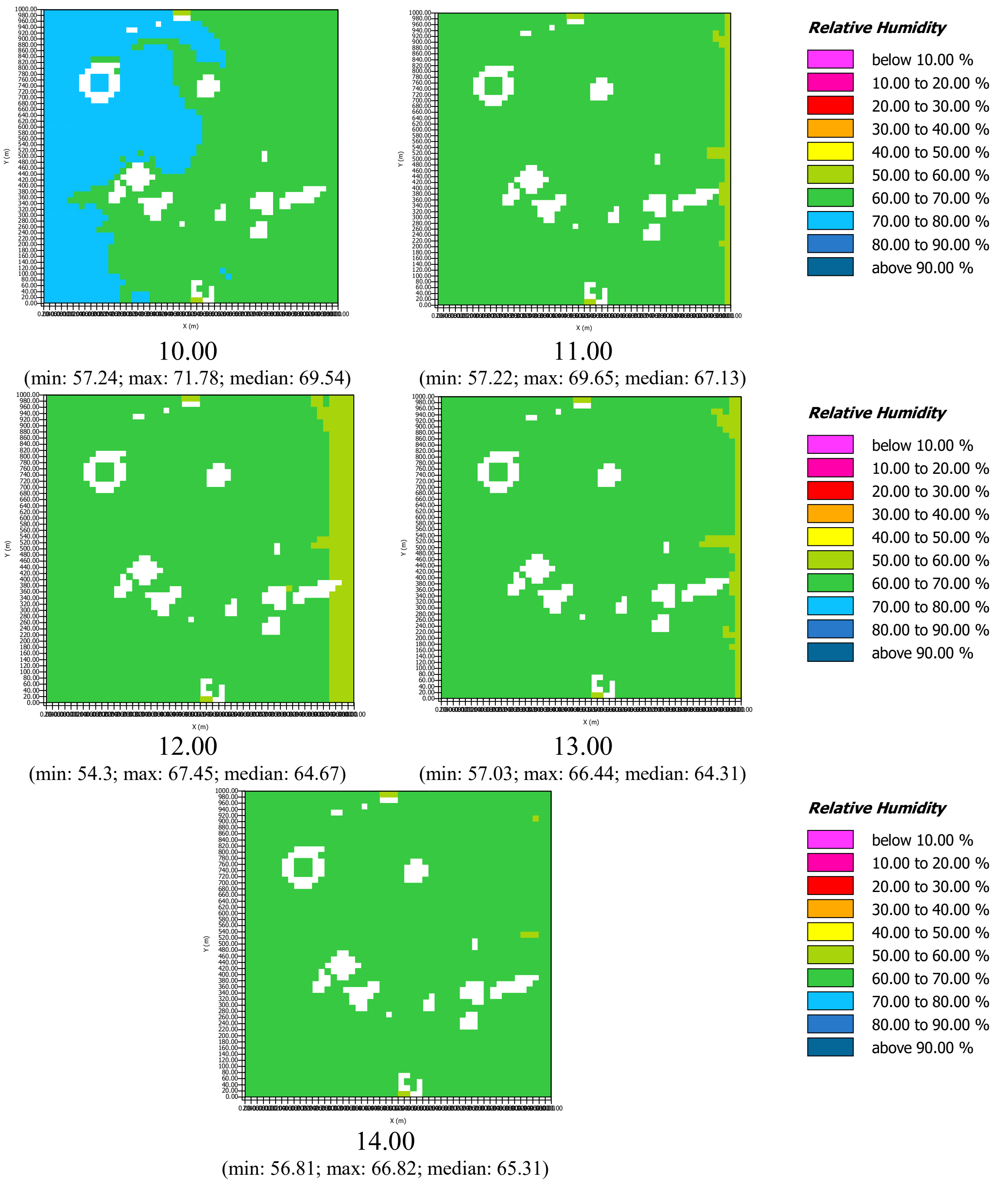
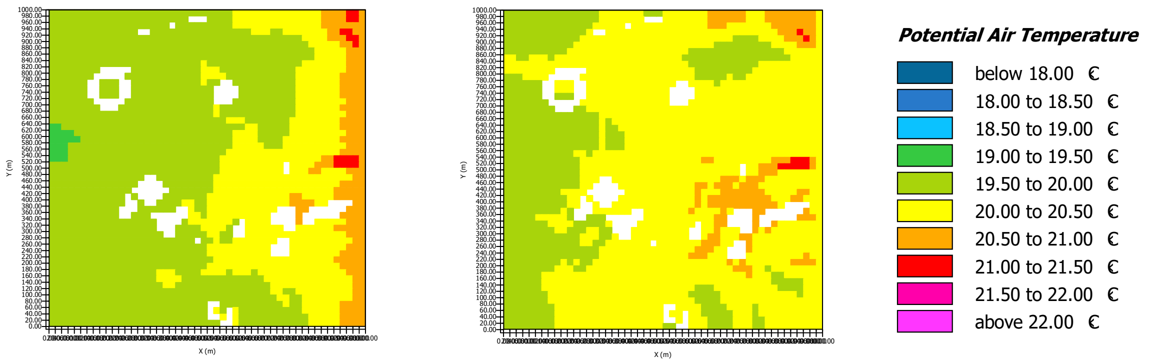


Figure 79. Performance of Relative Humidity in winter

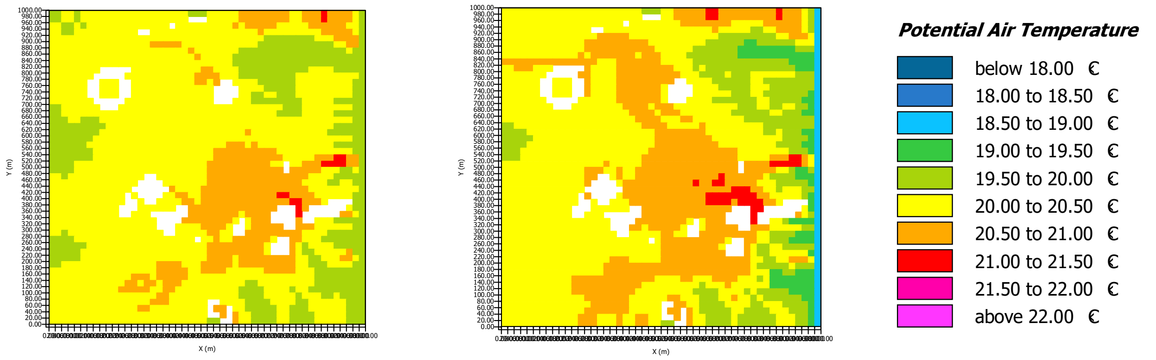
D. Spring case

In spring, most areas have air temperatures that are in the range of 18°C to 22°C. This shows that in the spring season, Green Park is a bit uncomfortable thermally with a cool thermal sensation. While the level of physical stress is in the category of moderate cool stress.



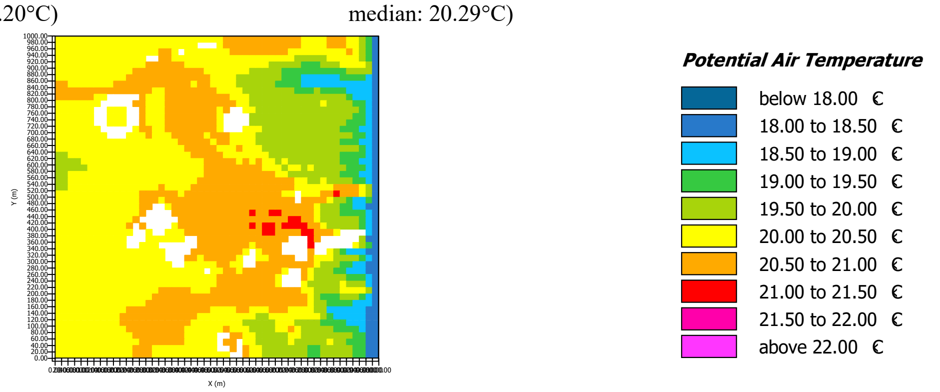
10.00
(min: 19.44°C; max: 21.23°C; median: 19.90°C)

11.00
(min: 19.69 °C; max: 21.22°C; median: 20.13°C)



12.00
(min: 19.53 °C; max: 21.23°C; median: 20.20°C)

13.00
(min: 18.95°C; max: 21.29°C; median: 20.29°C)



14.00
(min: 18.27°C; max: 21.19°C; median: 20.30°C)

Figure 80. Performance of Air Temperature in winter

Wind speed performances in the spring can be seen from the following figure. Most areas have high wind speeds of 1.75 m/s – 2.00 m/s (red). The tree area has a medium speed of 1.5 m/s – 1.75 m/s (orange). While areas such as pavements and grass fields have lower wind speeds (between 1.25 m/s and 1.50 m/s) which are symbolized in yellow.

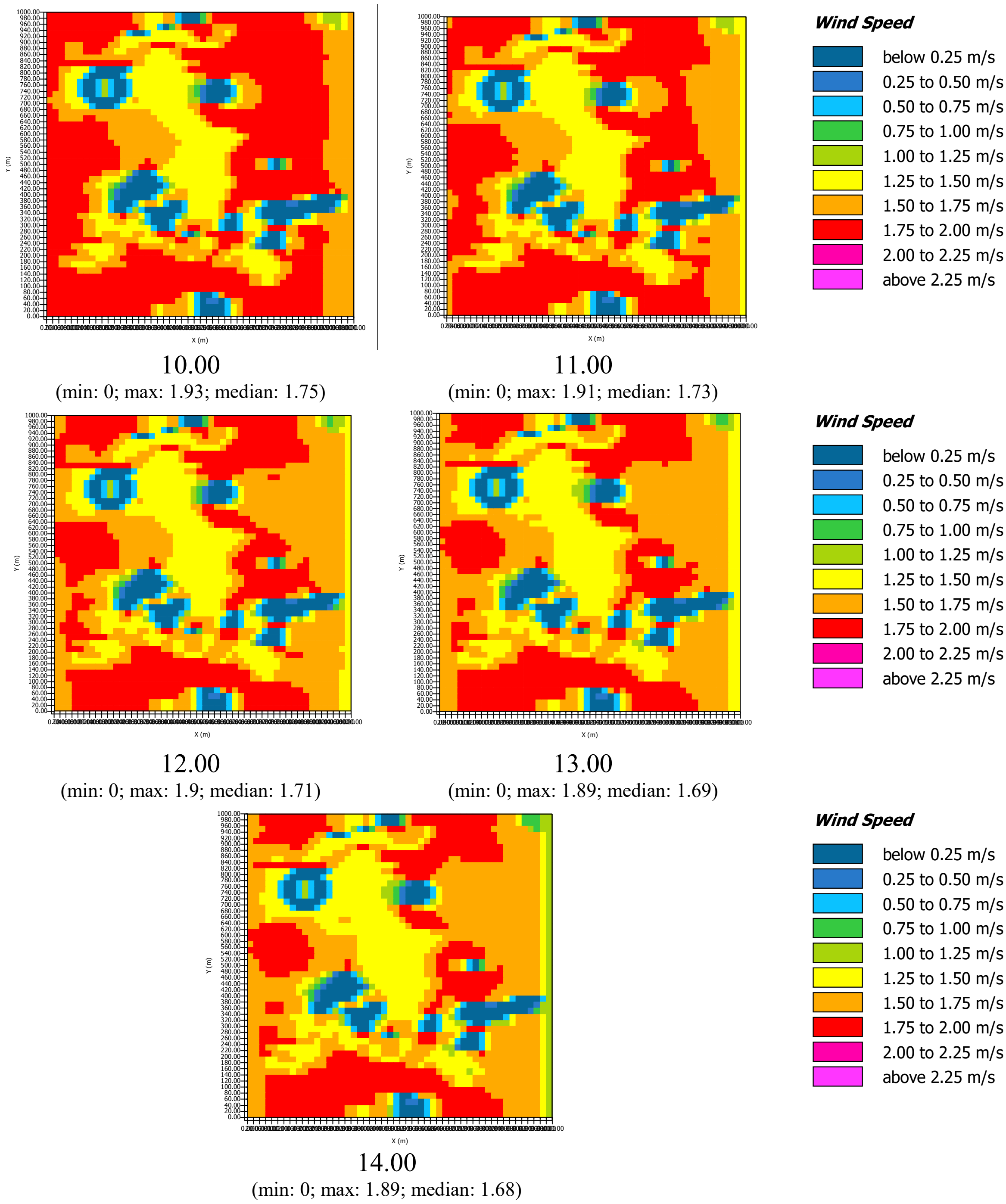


Figure 81. Performance of Wind Speed in winter

The following figure describes the air humidity performances in the spring season. Most of the area is light green which has an RH value between 50% and 60%. This shows that the local climate of Green Park is neutral, neither dry nor humid.

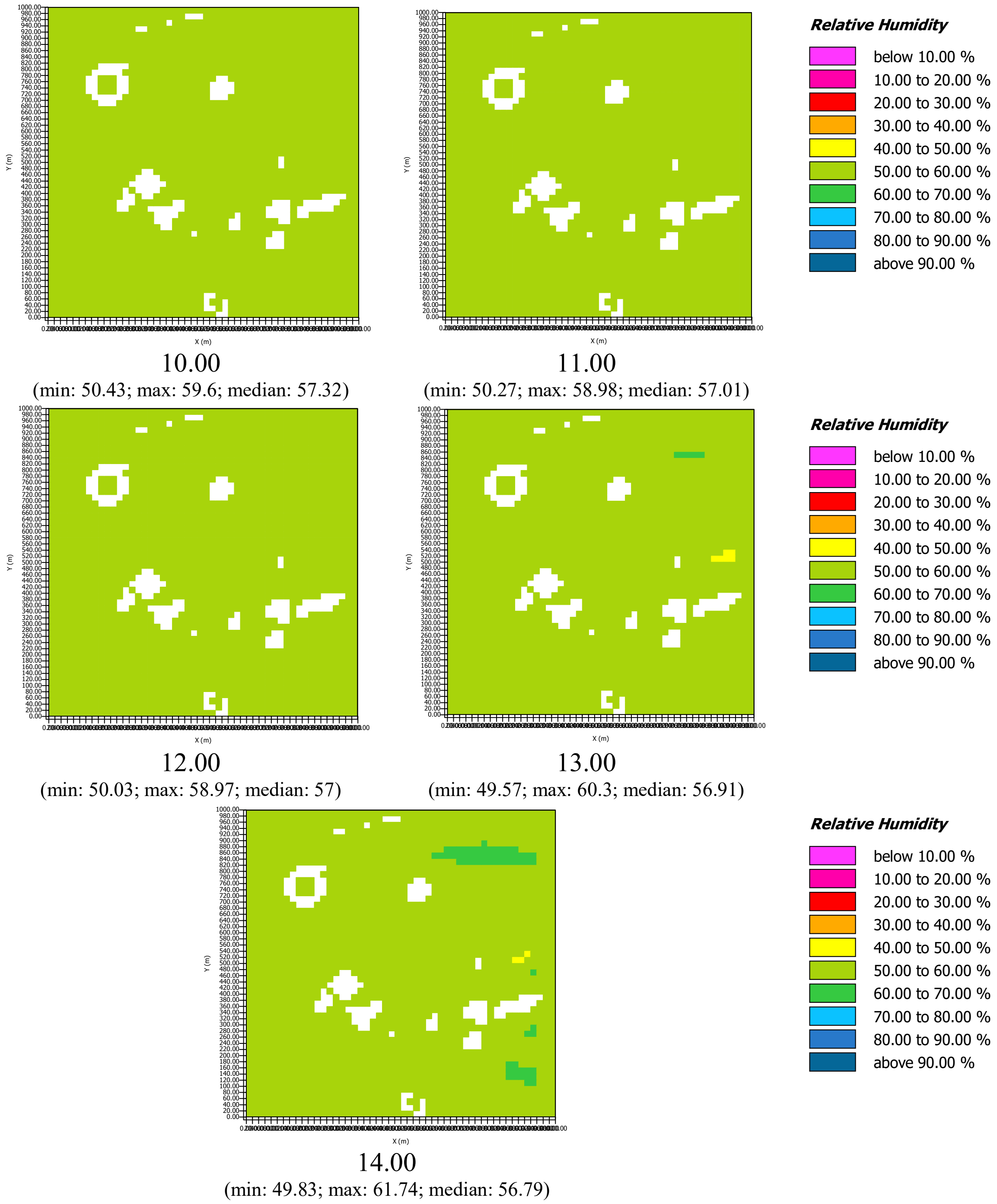


Figure 82. Performance of Relative Humidity in winter

8.4.2.3. Defining the Thermal Environment Impacts to Urban Structures

To define the impact of thermal environment to urban structure and urban structure a computer-based simulation software is used. For the illustration of environment condition, a graphic design software took the position. A statistical software is also put to good use. The thermal environment performance of Green Park Kitakyushu is simulated by ENVI-met software. This following picture shows the performance in the axis of x = 19 and y = from 0 to 49.

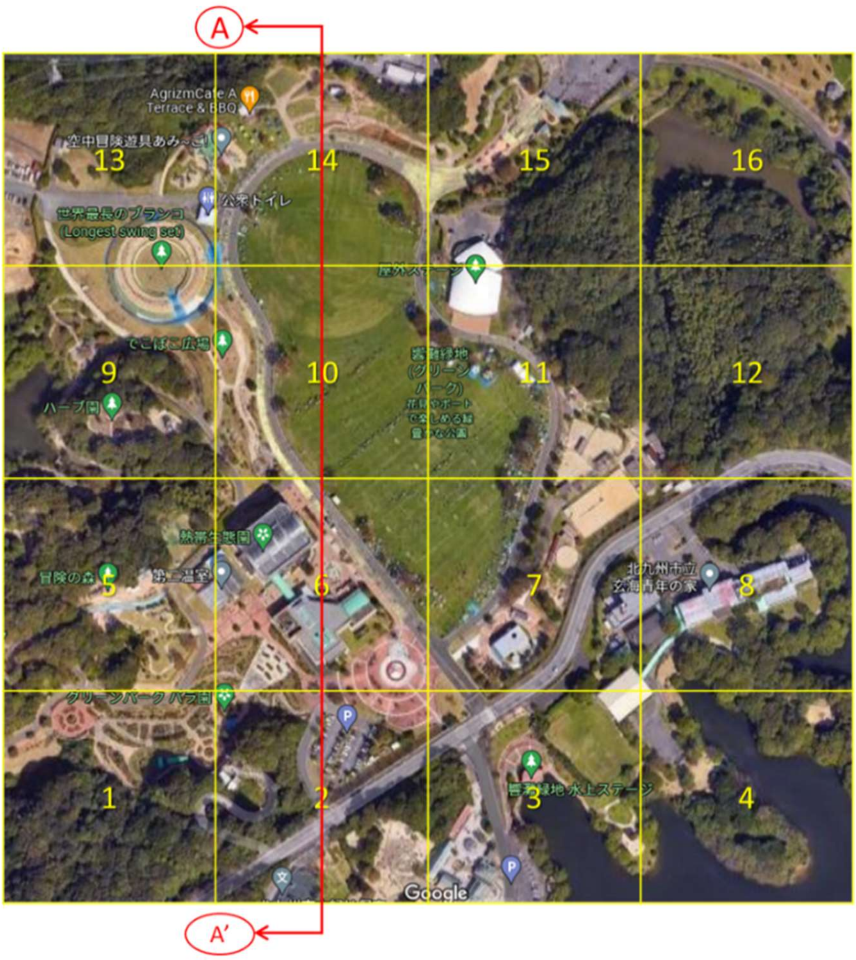


Figure 83. Sectioned Area of Green Park; x = 19, y = 0 to 49.

The section illustration is shown in the picture below. The land contour shown on this picture may not accurate due to lack of data and limitation of survey instrument in the field measurement.

Figure 84. Section of Green Park; x = 19, y = 0 to 49.

A. Summer case

In summer, PMV value is in the range of +2.05 to +3.38 with average +2.6 means thermally not comfortable, with thermal perception is *hot* and *strong heat stress* sensation. Based on the picture below, the area near to building and covered by asphalt or hard materials is relatively has a higher PMV than other area.

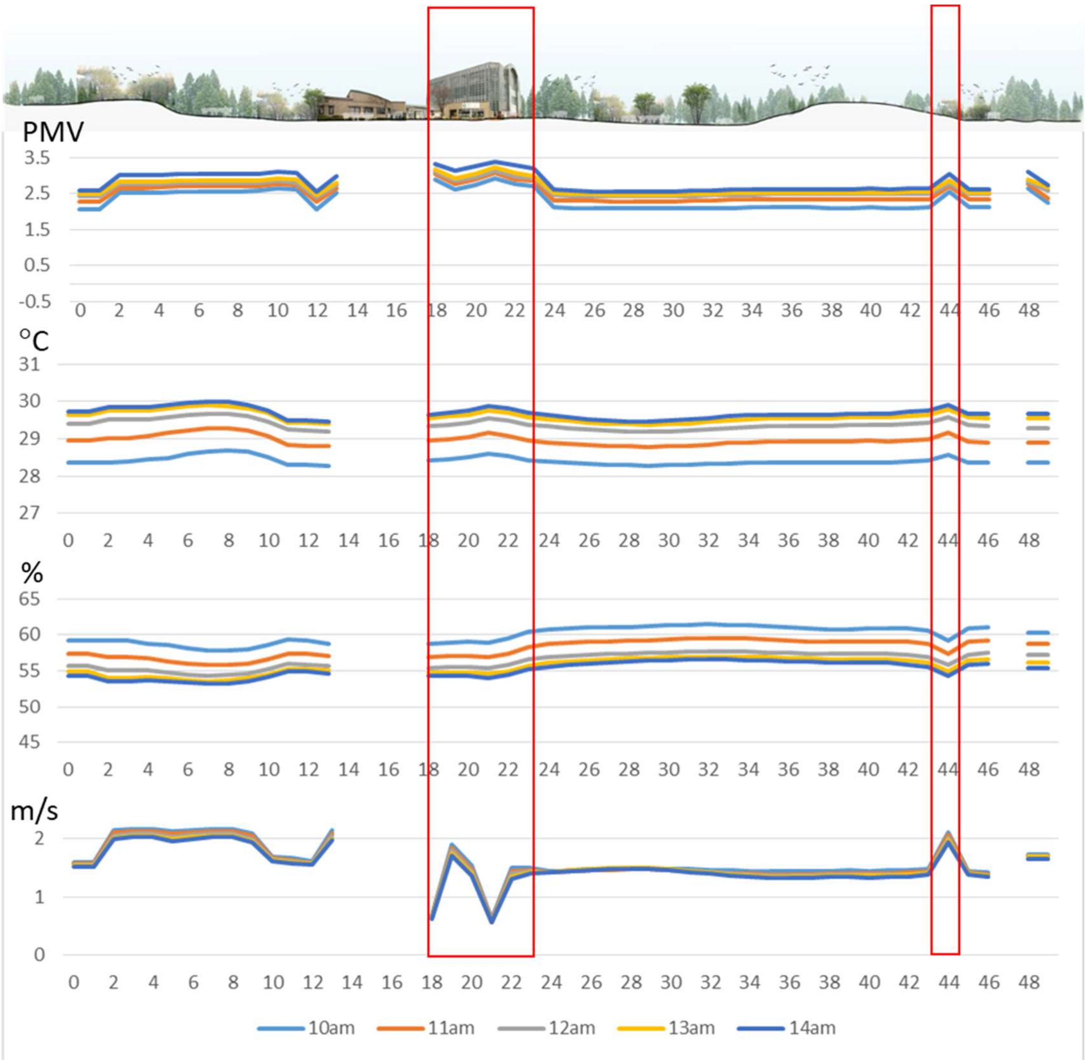


Figure 85. PMV, Ta, RH, and v value of sectioned area in summer

The air temperature performance is between 28°C and 30°C, and the average temperature is 29.21°C. The area near to building and covered by asphalt or hard materials is also relatively hotter than other area. The RH performance is between 53.18% and 61.46%, and the average is 57.07%. The area near to building and covered by asphalt or hard materials is relatively dryer than other area. The wind speed performance is between 0.55 m/s and 2.17 m/s, and the average is 1.56 m/s. The area near to vegetation (trees zone) is relatively has a faster wind than area near to building and open spaces.

B. Autumn case

In autumn, PMV value is in the range of 0.72 to 1.95 with average 1.34 means thermally *slightly warm* and *slight heat stress* sensation. Based on the picture below, the area near to building and covered by asphalt or hard materials is relatively has a higher PMV than other area.

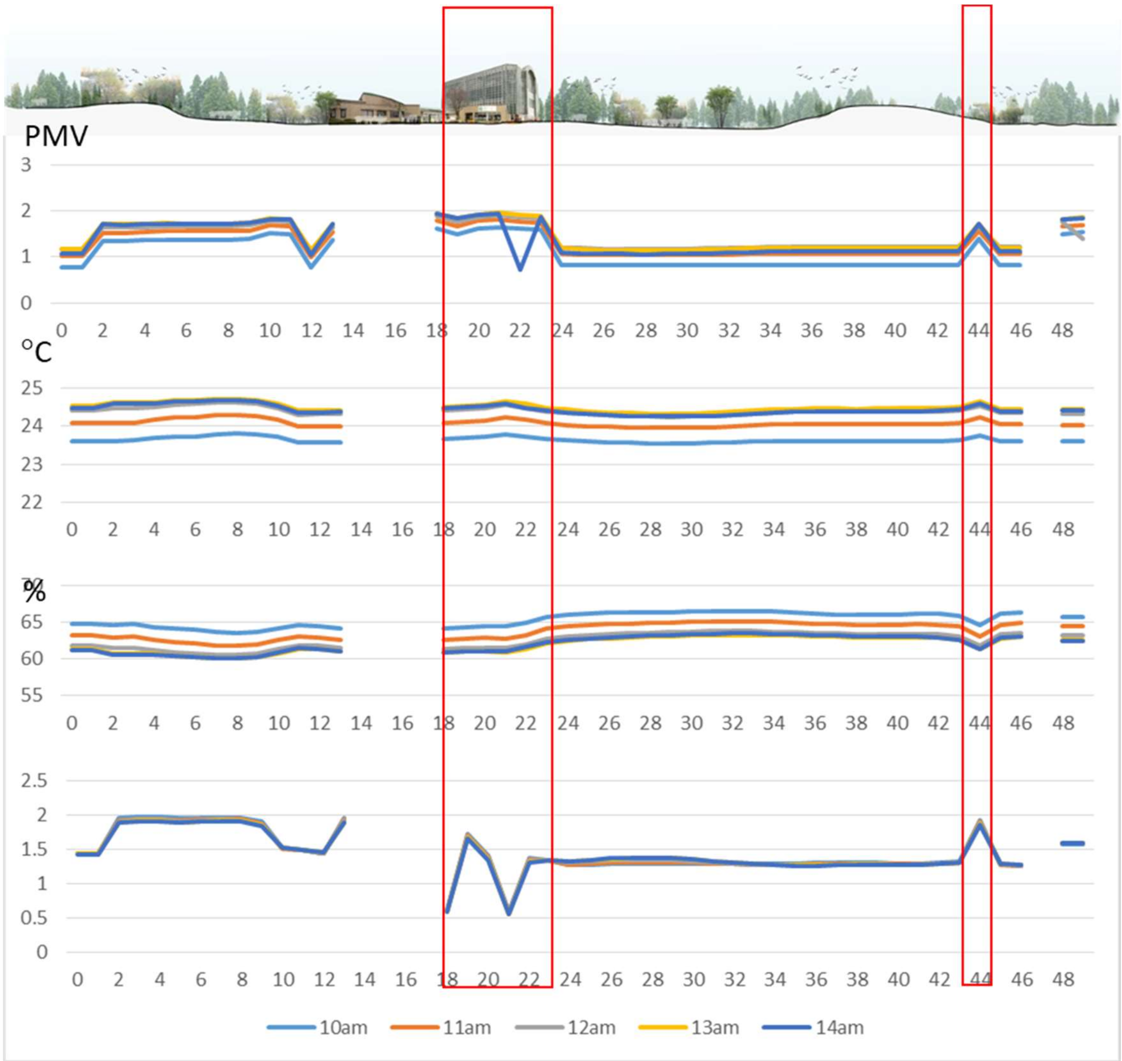


Figure 86. PMV, Ta, RH, and v value of sectioned area in autumn

The air temperature performance is between 23.55°C and 24.72°C, and the average temperature is 24.21°C. The area near to building and covered by asphalt or hard materials is also relatively hotter than other area. The RH performance is between 60.11% and 66.54%, and the average is 63.14%. The area near to building and covered by asphalt or hard materials is relatively dryer than other area. The wind speed performance is between 0.55 m/s and 1.96 m/s, and the average is 1.45 m/s. The area near to vegetation (trees zone) is relatively has a faster wind than area near to building and open spaces.

C. Winter case

In winter, PMV value is in the range of -1.17 to +0.26 with average -0.29 means *neutral* (thermally comfortable) with *no thermal stress* sensation. Based on the picture below, the area near to building and covered by asphalt or hard materials is relatively has a higher PMV than other area.

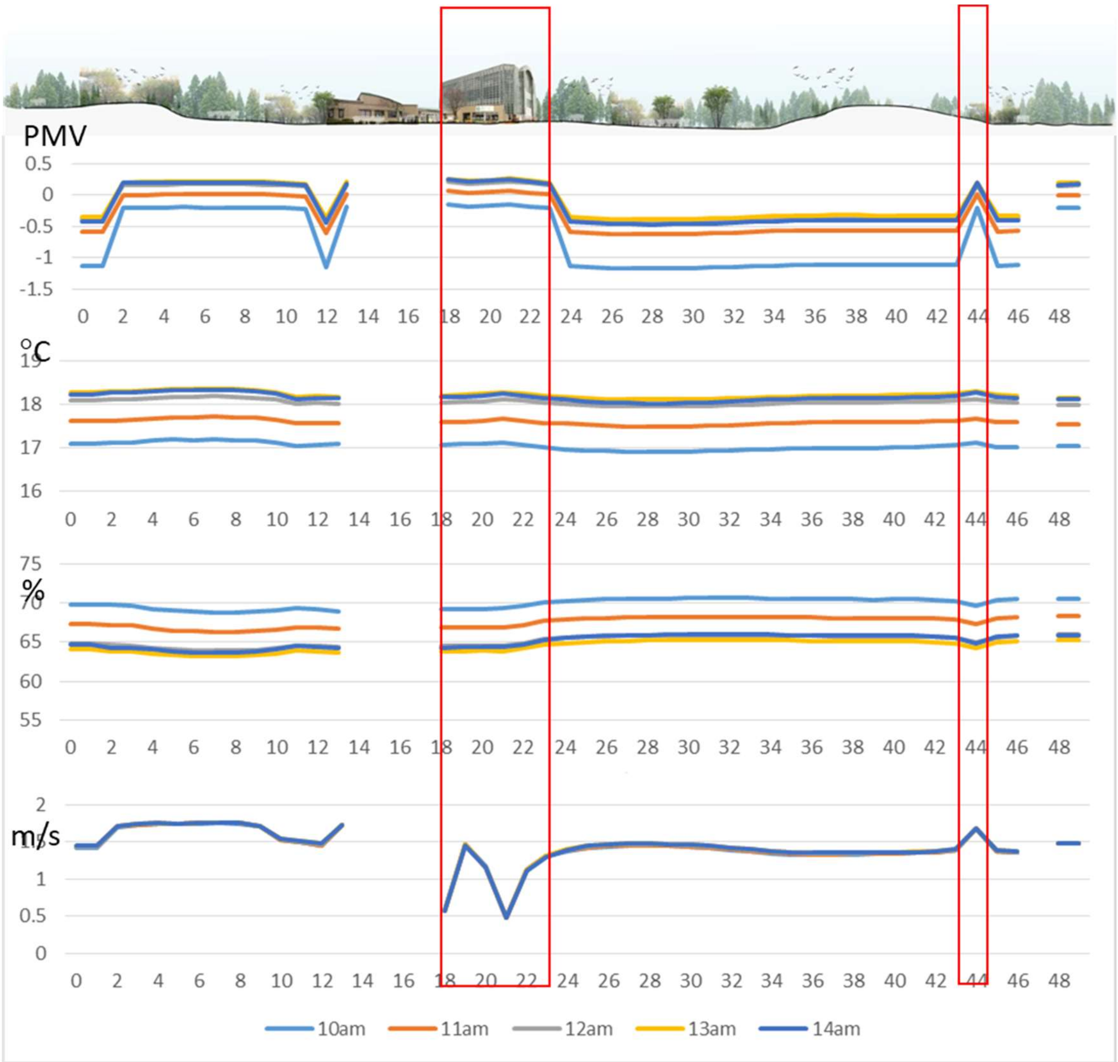


Figure 87. PMV, Ta, RH, and v value of sectioned area in winter

The air temperature performance is between 16.92°C and 18.36°C, and the average temperature is 17.81°C. The area near to building and covered by asphalt or hard materials is also relatively hotter than other area. The RH performance is between 63.19% and 70.61%, and the average is 66.46%. The area near to building and covered by asphalt or hard materials is relatively dryer than other area. The wind speed performance is between 0.47 m/s and 1.77 m/s, and the average is 1.43 m/s. The area near to vegetation (trees zone) is relatively has a faster wind than area near to building and open spaces.

D. Spring case

In winter, PMV value is in the range of +0.02 to +0.95 with average +0.45 means *neutral* (thermally comfortable) with *no thermal stress* sensation. Based on the picture below, the area near to building and covered by asphalt or hard materials is relatively has a higher PMV than other area.

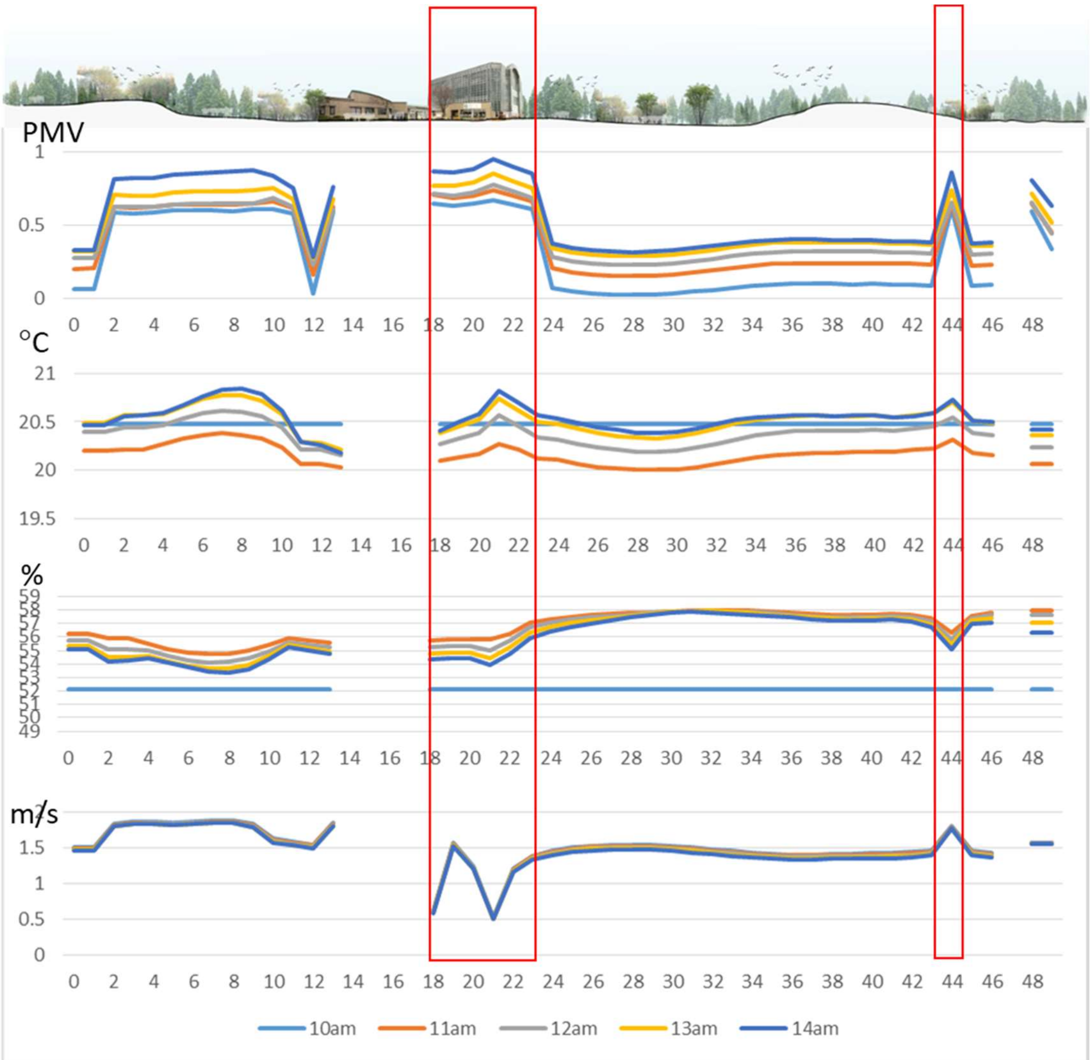


Figure 88. PMV, Ta, RH, and v value of sectioned area in spring

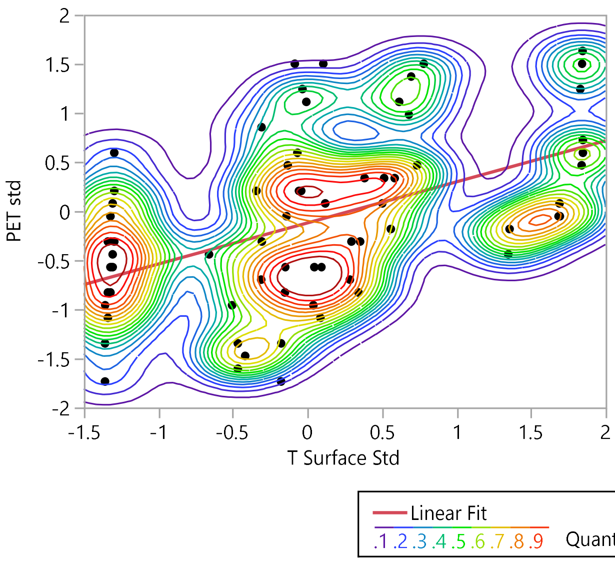
The air temperature performance is between 20°C and 20.85°C, and the average temperature is 20.41°C. The area near to building and covered by asphalt or hard materials is also relatively hotter than other area. The RH performance is between 52.14% and 57.96%, and the average is 55.49%. The area near to building and covered by asphalt or hard materials is relatively dryer than other area. The wind speed performance is between 0.50 m/s and 1.88 m/s, and the average is 1.49 m/s. The area near to vegetation (trees zone) is relatively has a faster wind than area near to building and open spaces.

8.4.2.4. Relationship between PET and Surface Temperature

The surface temperature is one variable which can affects the outdoor thermal comfort. The relationship is determined based on the bivariate analysis by Fit Line between PET and Surface temperature (Ts).

A. Summer case

In summer, it is found that there are significant correlation with positive relationship (+0.418). The result shows that value of reliability (R^2) is 0.27 with the significance value (Prob > F) is <0.001. It means that although the model has not a high reliability value, but has a significant correlation between the two variable.



Summary of Fit

RSquare	0.270087
RSquare Adj	0.258501
Root Mean Square Error	0.707839
Mean of Response	-0.10125
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11.680001	11.6800	23.3117
Error	63	31.565287	0.5010	**Prob > F**
C. Total	64	43.245288		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.122708	0.087909	-1.40	0.1677
T Surface Std	0.4186449	0.086708	4.83	<.0001*

Figure 89. Correlation between PET and Ts in summer

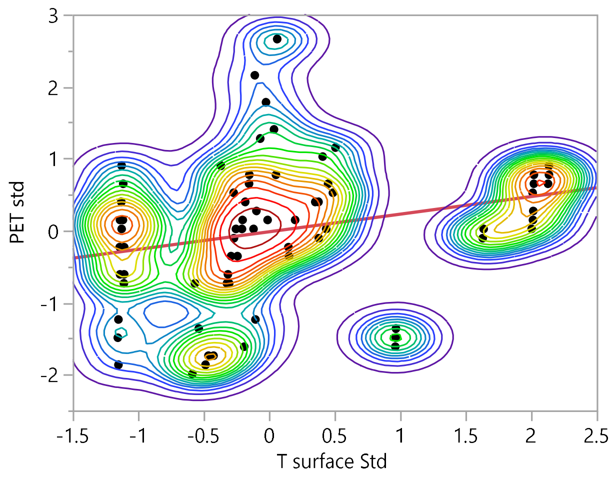
The linear fit model formula is shown by this following equation:

$$PET = -0.122 + 0.418Ts$$

This means that the higher surface temperature is the higher PET value, or in other words, the surface temperature affects the outdoor thermal comfort.

B. Autumn case

In autumn, it is found that there are significant correlation with positive relationship (+0.244). The result shows that value of reliability (R^2) is 0.05 with the significance value (Prob > F) is <0.0371. It means that although the model has not a high reliability value, but has a significant correlation between the two variable.



Summary of Fit

RSquare	0.058179
RSquare Adj	0.045277
Root Mean Square Error	0.977099
Mean of Response	1.2e-14
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4.305211	4.30521	4.5094
Error	73	69.694789	0.95472	Prob > F
C. Total	74	74.000000		0.0371*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.019005	0.11318	-0.17	0.8671
T surface Std	0.2449143	0.115334	2.12	0.0371*

Linear Fit
.1 .2 .3 .4 .5 .6 .7 .8 .9 Quantile Density Contours

Figure 90. Correlation between PET and Ts in autumn

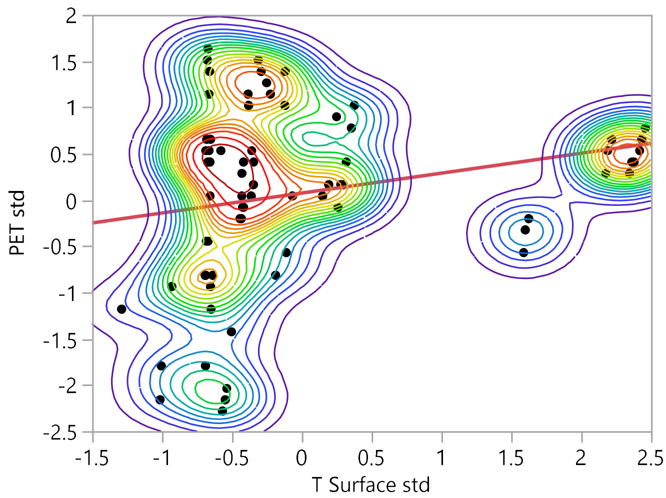
The linear fit model formula is shown by this following equation:

$$PET = -0.019 + 0.244Ts$$

This means that the higher surface temperature is the higher PET value, or in other words, the surface temperature affects the outdoor thermal comfort.

C. Winter case

In winter, it is found that there are significant correlation with positive relationship (+0.215). The result shows that value of reliability (R^2) is 0.05 with the significance value (Prob > F) is <0.0491. It means that although the model has not a high reliability value, but has a significant correlation between the two variable.



Summary of Fit

RSquare	0.05417
RSquare Adj	0.040658
Root Mean Square Error	0.929358
Mean of Response	0.074714
Observations (or Sum Wgts)	72

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.462677	3.46268	4.0091
Error	70	60.459398	0.86371	Prob > F
C. Total	71	63.922076		0.0491*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0712876	0.109539	0.65	0.5173
T Surface std	0.2150178	0.107387	2.00	0.0491*

Linear Fit
.1 .2 .3 .4 .5 .6 .7 .8 .9 Quantile Density Contours

Figure 91. Correlation between PET and Ts in winter

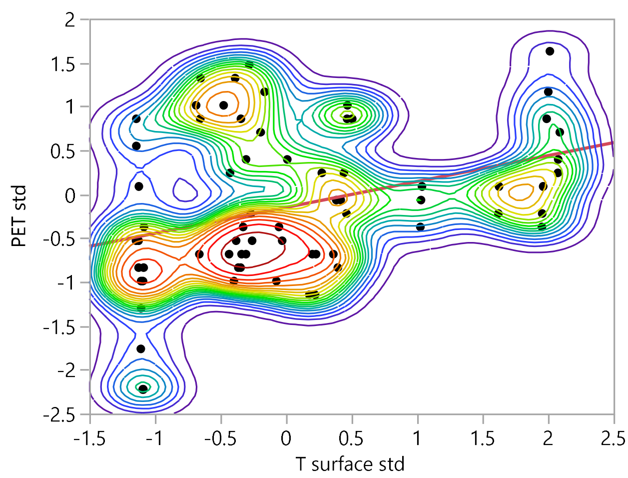
The linear fit model formula is shown by this following equation:

$$PET = 0.071 + 0.215Ts$$

This means that the higher surface temperature is the higher PET value, or in other words, the surface temperature affects the outdoor thermal comfort.

D. Spring case

In spring, it is found that there are significant correlation with positive relationship (+0.295). The result shows that value of reliability (R^2) is 0.12 with the significance value (Prob > F) is <0.0028. It means that although the model has not a high reliability value, but has a significant correlation between the two variable.



Summary of Fit

RSquare	0.122133
RSquare Adj	0.109411
Root Mean Square Error	0.805868
Mean of Response	-0.12865
Observations (or Sum Wgts)	71

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6.234233	6.23423	9.5996
Error	69	44.810231	0.64942	**Prob > F**
C. Total	70	51.044464		0.0028*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.152224	0.095941	-1.59	0.1172
T surface std	0.2953934	0.09534	3.10	0.0028*

Figure 92. Correlation between PET and Ts in spring

The linear fit model formula is shown by this following equation:

$$PET = -0.152 + 0.295Ts$$

This means that the higher surface temperature is the higher PET value, or in other words, the surface temperature affects the outdoor thermal comfort.

E. Overall Relationship

In summary, the correlation between PET and surface temperature is significant, with positive relationship. The higher surface temperature is the higher PET value. The overall relationship is shown by the following table.

Table 40. Overall relationship between PET and Surface Temperature

Season	Reliability (R^2)	Significance value (Prob > F)	Relationship
Summer	0.27 (not reliable)	<0.001 (significant)	Positive (+0.418)
Autumn	0.05 (not reliable)	<0.0371 (significant)	Positive (+0.244)
Winter	0.05 (not reliable)	<0.0491 (significant)	Positive (+0.215)
Spring	0.12 (not reliable)	<0.0028 (significant)	Positive (+0.295)

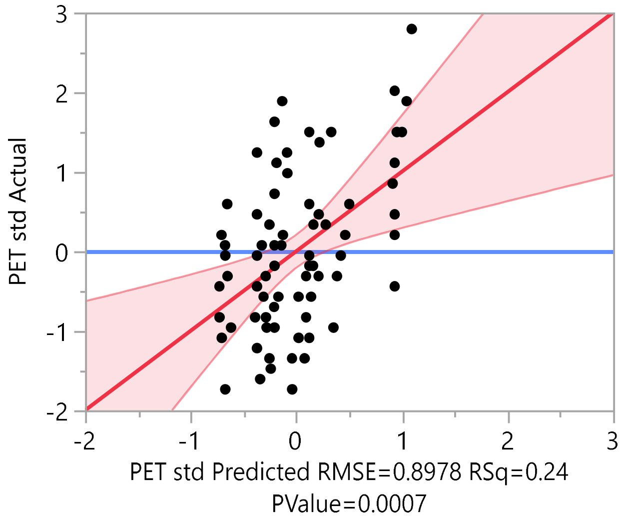
8.4.3. Relationship between Urban Structure Variables and Thermal Variables

The relationship between Urban Structure Variables and Thermal Variables can be analyzed by the correlation between four variables of urban structure (Sky View Factor, Green Plot Ratio, Building Plot Ratio, and Surface Albedo) and the variables of outdoor thermal comfort (PET and Tmrt).

8.4.3.1. Correlation between PET and Urban Structure Variables

A. Summer case

The correlation between PET and four variables of urban structure (SVF, GnPR, BPR, and SA) is analyzed by Fit Model analysis. The value of reliability (R^2) is 0.24 (less than 0.4) means the data is not reliable or not accurate, it may because of the number of data is not fit enough. However, the significance value (Prob > F) is <0.0007, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.237503
RSquare Adj	0.193932
Root Mean Square Error	0.897813
Mean of Response	-4.6e-15
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	17.575246	4.39381	5.4509
Error	70	56.424754	0.80607	Prob > F
C. Total	74	74.000000		0.0007*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1231554	0.126668	0.97	0.3343
SVF Std	-0.683152	0.282188	-2.42	0.0181*
Surface Albedo Std	0.4488776	0.154959	2.90	0.0050*
BPR STD	-0.327316	0.182429	-1.79	0.0771
GnPR std	-0.156306	0.140112	-1.12	0.2684

Figure 93. Correlation between PET and urban structure variables in summer

The result shows that the most significant factor among the four variables in summer is SVF with the following equation:

$$PET = 0.45SA - 0.68SVF - 0.32BPR - 0.15GnPR$$

It is also found that the relationship is negative (-0.68) with significance value (Prob > F) 0.0181 (significant). It means if the value of SVF factor is high (barely shaded), so the value of PET is low. Therefore to get a certain comfortable thermal value of PET, it has to set the SVF value as the SVF value is between 0 (fully covered sky view) and 1 (fully barely shaded). It means that the outdoor thermal comfort is depends on the surrounding materials covering the area spot. For the example, the number of building, roof, or vegetation. The goal is to get a certain SVF value. The correlation between PET and SVF is shown by the picture below.

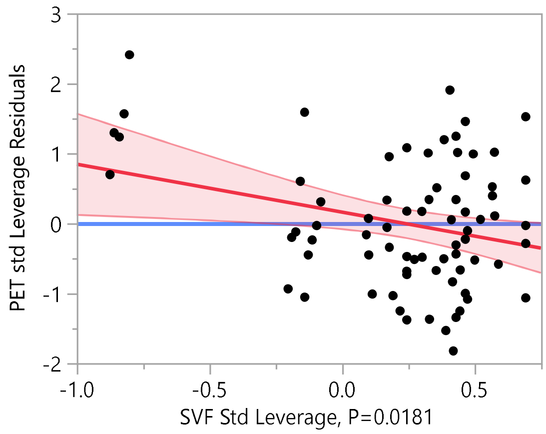


Figure 94. Correlation between PET and SVF in summer

There is also a positive correlation from the surface albedo (0.45) which means the higher surface albedo value, the higher PET value. It also means that the material of the outdoor surface has an impact for the outdoor thermal comfort.

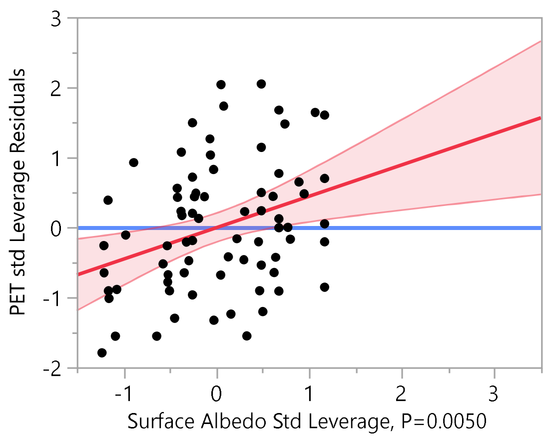


Figure 95. Correlation between PET and Surface Albedo in summer

Surprisingly, there is no significant correlation from the variable of vegetation (GnPR) and building (BPR). The picture below shows the results.

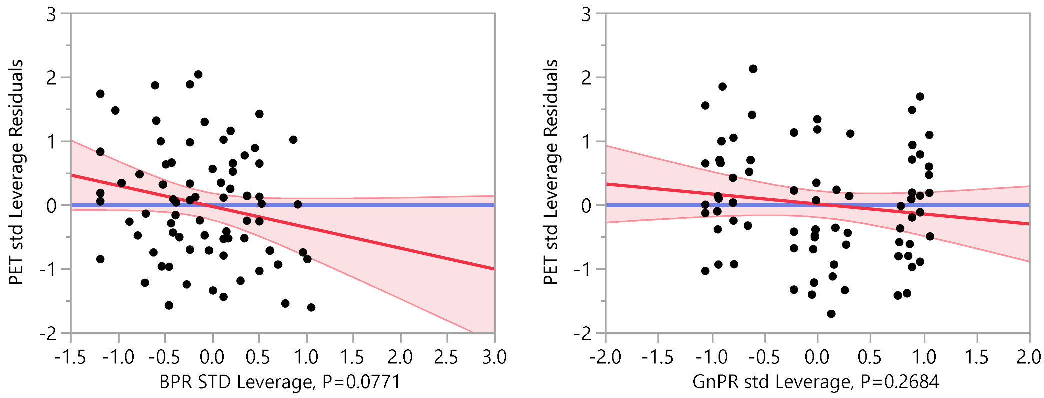
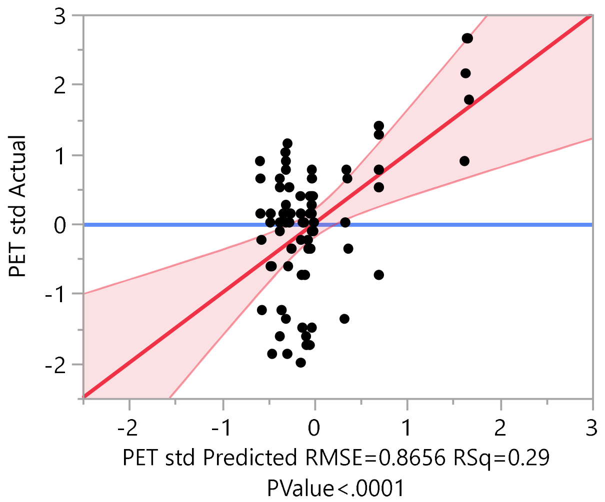


Figure 96. Correlation between PET, BPR, and GnPR in summer

B. Autumn case

In the autumn case, the value of reliability (R^2) is 0.29 (less than 0.4) means the data is not reliable or not accurate, it may because of the number of data is not fit enough. However, the significance value (Prob > F) is <0.001, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.291163
RSquare Adj	0.250658
Root Mean Square Error	0.865645
Mean of Response	1.21e-14
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	21.546053	5.38651	7.1883
Error	70	52.453947	0.74934	Prob > F
C. Total	74	74.000000		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.272929	0.124805	2.19	0.0321*
SVF Std	-1.231314	0.283623	-4.34	<.0001*
Surface Albedo Std	0.2190385	0.158326	1.38	0.1709
BPR STD	-0.206629	0.183208	-1.13	0.2632
GnPR std	-0.193694	0.129363	-1.50	0.1388

Figure 97. Correlation between PET and urban structure variables in autumn

The result shows that the most significant factor among the four variables in autumn is SVF with the following equation:

$$PET = 0.22SA - 1.23SVF - 0.2BPR - 0.19GnPR$$

It is also found that the relationship is negative (-1.23) with significance value (Prob > F) < 0.001 (significant). It means if the value of SVF factor is high (barely shaded), so the value of

PET is low. Therefore to get a certain comfortable thermal value of PET, it has to set the SVF value as the SVF value is between 0 (fully covered sky view) and 1 (fully barely shaded). It means that the outdoor thermal comfort is depends on the surrounding materials covering the area spot. For the example, the number of building, roof, or vegetation. The goal is to get a certain SVF value. The correlation between PET and SVF is shown by the picture below.

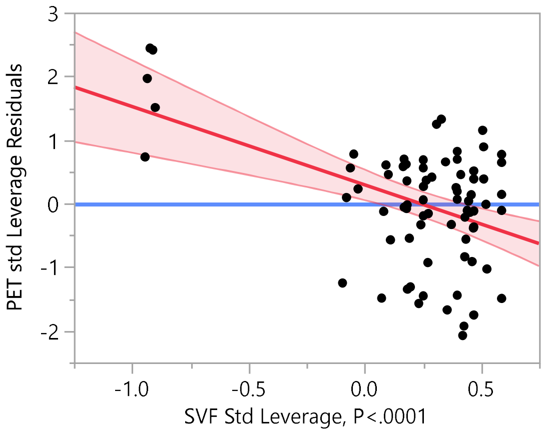


Figure 98. Correlation between PET and SVF in autumn

The other physical variables, there is no significant correlation from the variable of surface ratio, vegetation (GnPR) and building (Building Plot Ratio). The picture below shows the results.

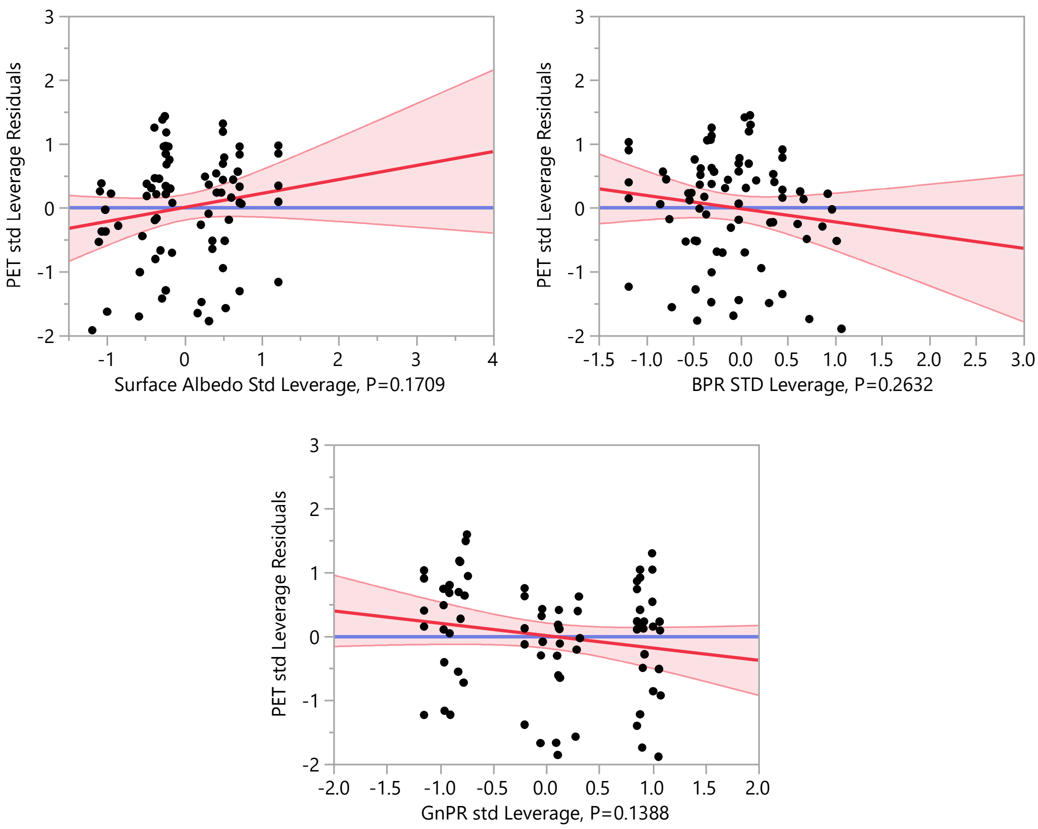
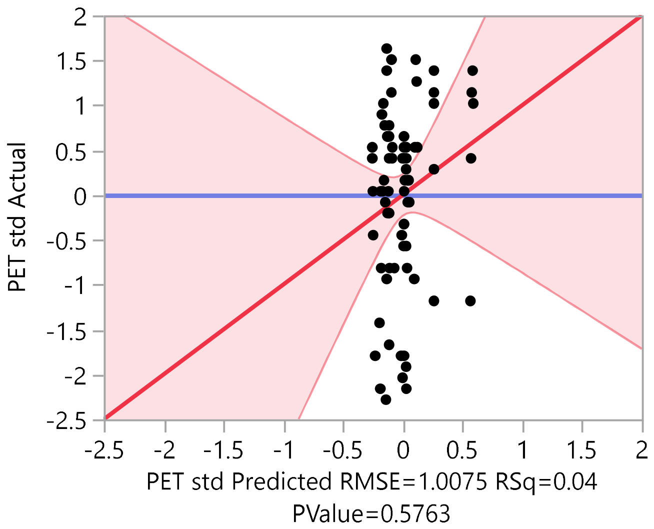


Figure 99. Correlation between PET, SA, BPR, and GnPR in autumn

C. Winter case

In the winter, the value of reliability (R^2) is 0.04 (less than 0.4) means the data is not reliable or not accurate, it may because of the number of data is not fit enough. The significance value (Prob > F) is 0.57, meaning that it is not significant or the chances of this finding being missed are existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.039903
RSquare Adj	-0.01496
Root Mean Square Error	1.007452
Mean of Response	-1.5e-15
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	2.952804	0.73820	0.7273
Error	70	71.047196	1.01496	Prob > F
C. Total	74	74.000000		0.5763

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0717605	0.145507	0.49	0.6234
SVF std	-0.365173	0.328546	-1.11	0.2702
Surface Albedo std	0.1467611	0.185541	0.79	0.4316
BPR STD	-0.132936	0.215729	-0.62	0.5398
GnPR std	-0.013983	0.144564	-0.10	0.9232

Figure 100. Correlation between PET and urban structure variables in winter

However, the result shows that the most significant factor among the four variables in winter is SVF with the following equation:

$$PET = 0.14SA - 0.36SVF - 0.13BPR - 0.01GnPR$$

It is also found that the relationship is negative (-0.36) with significance value (Prob > F) 0.27 (not significant). It means if the value of SVF factor is high (barely shaded), so the value of PET is low. Therefore to get a certain comfortable thermal value of PET, it has to set the SVF value as the SVF value is between 0 (fully covered sky view) and 1 (fully barely shaded). It means that the outdoor thermal comfort is depends on the surrounding materials covering the area spot. For the example, the number of building, roof, or vegetation. The goal is to get a certain SVF value. The correlation between PET and SVF is shown by the picture below.

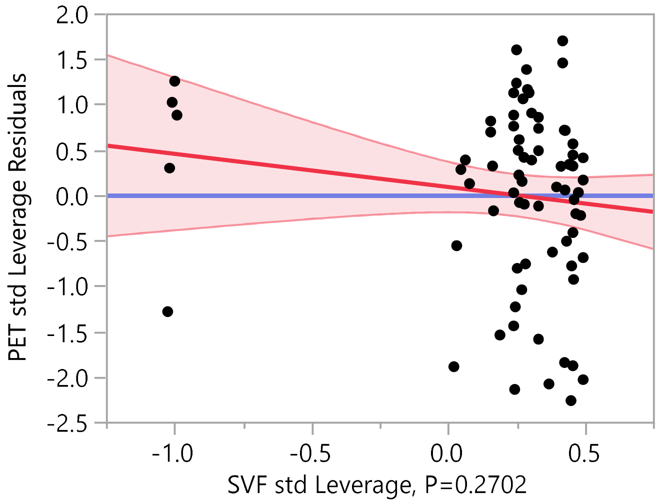


Figure 101. Correlation between PET and SVF in winter

The other physical variables, there is no significant correlation from the variable of surface ratio, vegetation (GnPR) and building (Building Plot Ratio). The picture below shows the results.

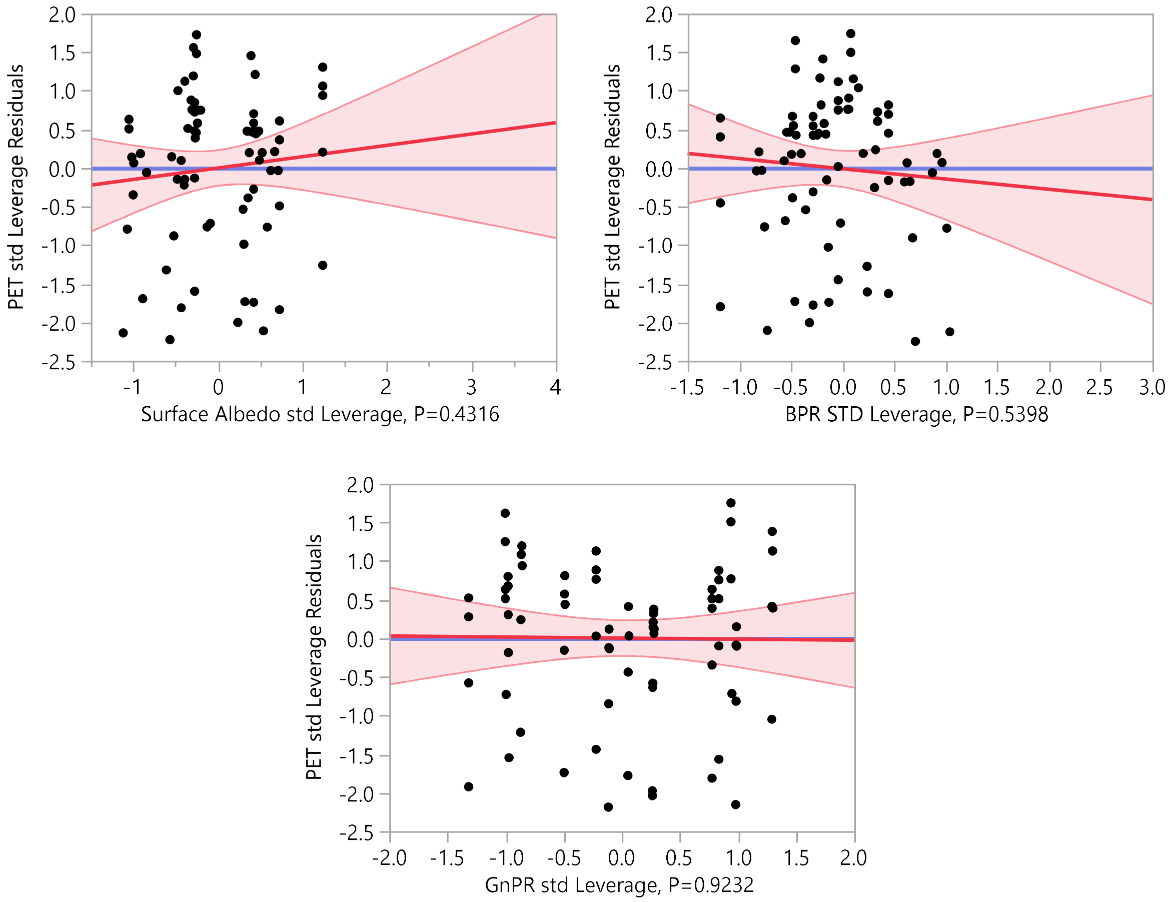
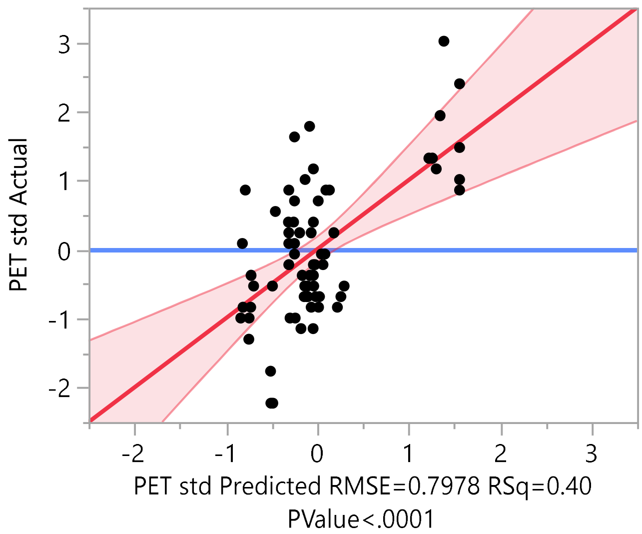


Figure 102. Correlation between PET, SA, BPR, and GnPR in winter

D. Spring case

The correlation between PET and four variables of urban structure (SVF, GnPR, Building Plot Ratio, and Surface Albedo) is analyzed by Fit Model analysis. The value of reliability (R^2) is 0.4 means the data is reliable or acceptable. The significance value (Prob > F) is <0.001, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.39795
RSquare Adj	0.363548
Root Mean Square Error	0.79778
Mean of Response	-1.3e-14
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	29.448329	7.36208	11.5674
Error	70	44.551671	0.63645	Prob > F
C. Total	74	74.000000		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2094779	0.115295	1.82	0.0735
SVF std	-0.967435	0.263119	-3.68	0.0005*
Surface Albedo std	0.4724101	0.14066	3.36	0.0013*
BPR std	-0.157809	0.165344	-0.95	0.3432
GnPR std	-0.147324	0.117892	-1.25	0.2156

Figure 103. Correlation between PET and urban structure variables in spring.

The result shows that the most significant factor among the four variables in summer is SVF with the following equation:

$$PET = 0.47SA - 0.96SVF - 0.15BPR - 0.14GnPR$$

It is also found that the relationship is negative (-0.96) with significance value (Prob > F) 0.0005 (significant). It means if the value of SVF factor is high (barely shaded), so the value of PET is low. Therefore to get a certain comfortable thermal value of PET, it has to set the SVF value as the SVF value is between 0 (fully covered sky view) and 1 (fully barely shaded). It means that the outdoor thermal comfort is depends on the surrounding materials covering the area spot. For the example, the number of building, roof, or vegetation. The goal is to get a certain SVF value. The correlation between PET and SVF is shown by the picture below.

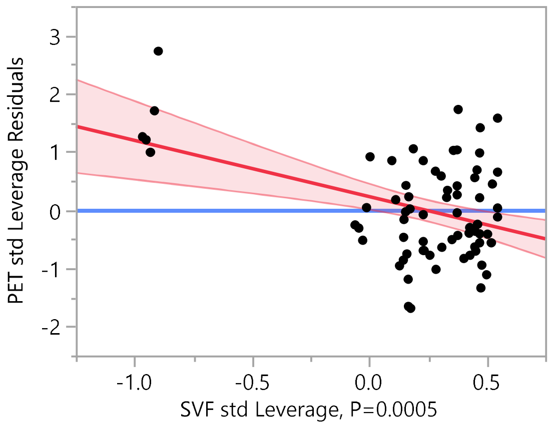


Figure 104. Correlation between PET and SVF in spring

There is also a positive significant correlation from the surface albedo (0.47) with significance value (Prob > F) 0.0013 which means the higher surface albedo value, the higher PET value. It also means that the material of the outdoor surface has an impact for the outdoor thermal comfort.

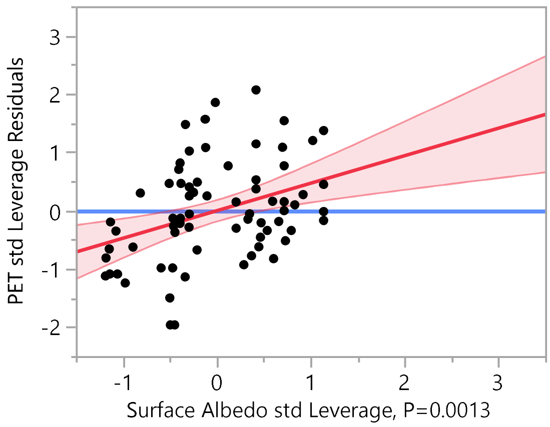


Figure 105. Correlation between PET and Surface Albedo in spring

Surprisingly, there is no significant correlation from the variable of vegetation (GnPR) and building (BPR). The picture below shows the results.

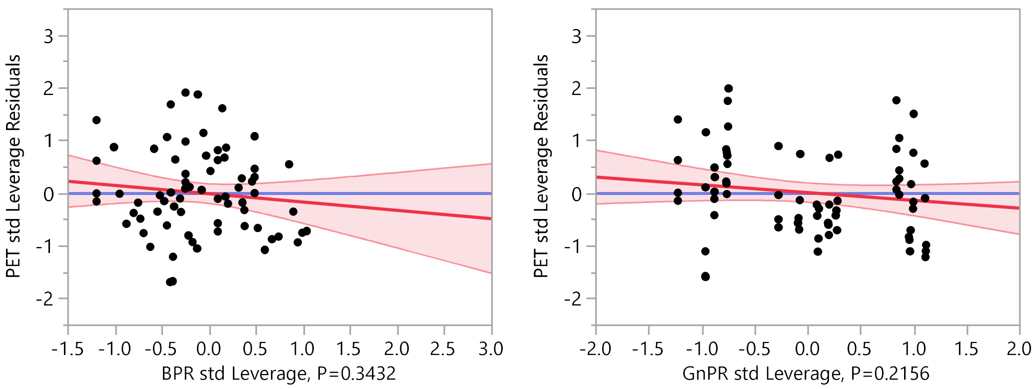


Figure 106. Correlation between PET, BPR, and GnPR in spring

E. Overall Relationship

In conclusion, the correlation between PET and urban structure factors is significant, with negative relationship. It means the higher SVF value (barely shaded), the lower PET value. It also means that the shading is important to increase the outdoor thermal comfort performance. The overall relationship is shown by the following table.

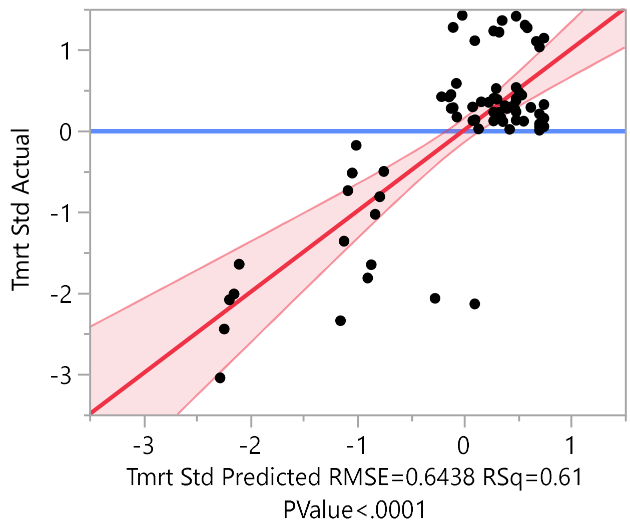
Table 41. Overall relationship between PET and urban structure factors

Season	**Reliability (R^2)**	**Significance value (Prob > F)**	**The most influential factor**	**Relationship**
Summer	0.24 (not reliable)	<0.0007 (significant)	SVF	Negative (-0.68)
Autumn	0.29 (not reliable)	<0.001 (significant)	SVF	Negative (-1.23)
Winter	0.04 (not reliable)	<0.5763 (not significant)	SVF	Negative (-0.36)
Spring	0.40 (not reliable)	<0.001 (significant)	SVF	Negative (-0.96)

8.4.3.2. Correlation between Tmrt and Four Variables of Urban structure

A. Summer case

The correlation between Tmrt and four variables of urban structure (SVF, GnPR, BPR, and SA) is analyzed by Fit Model analysis. The value of reliability (R^2) is 0.64 (more than 0.4) means the data is reliable. The significance value (Prob > F) is <0.001, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.607961
RSquare Adj	0.585559
Root Mean Square Error	0.643771
Mean of Response	-2.8e-15
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	44.989128	11.2473	27.1384
Error	70	29.010872	0.4144	Prob > F
C. Total	74	74.000000		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.502704	0.090827	-5.53	<.0001*
SVF Std	1.9965474	0.202341	9.87	<.0001*
Surface Albedo Std	0.4400289	0.111112	3.96	0.0002*
BPR STD	-0.261972	0.130809	-2.00	0.0491*
GnPR std	0.1508457	0.100467	1.50	0.1377

Figure 107. Correlation between Tmrt and urban structure variables in summer

The result shows that the most significant factor among the four variables in summer is SVF with the following equation:

$$Tmrt = 1.99SVF + 0.44SA - 0.26BPR + 0.15GnPR$$

It is also found that the relationship is positive (+1.99) with significance value (Prob > F) <0.001 (significant). Based on this results, it can be concluded that the higher value of SVF factor, the higher value of Tmrt. In other words, to decrease the Tmrt value (which also consequently decrease the PET value), the area should has a low SVF. It means the area should be well shaded.

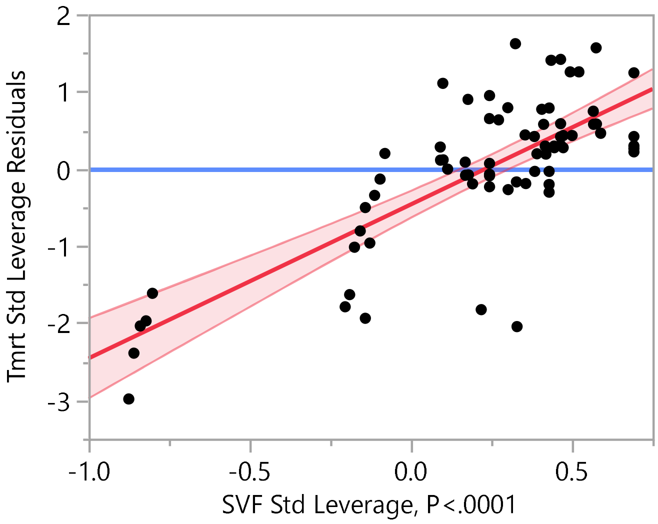


Figure 108. Correlation between Tmrt and SVF in summer

There is also a positive correlation from the surface albedo (+0.44) which means the higher surface albedo value, the higher Tmrt value. It also means that the material of the outdoor surface has an impact for the outdoor thermal comfort. The picture below shows the results.

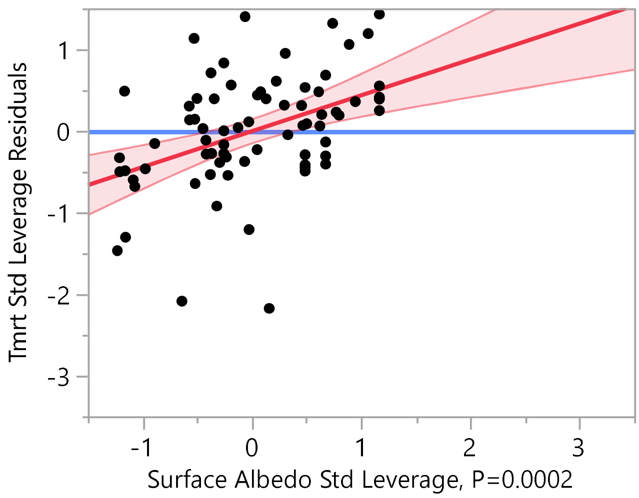


Figure 109. Correlation between Tmrt and Surface Albedo in summer

There is also a negative correlation between Tmrt and Building Plot Ratio (-0.26) with the significance value (Prob > F) 0.049 (significant). It means the lower of area covered by buildings, the higher Tmrt value. It means that to decrease the Tmrt, the covered area of building should be increased. The picture below shows the results.

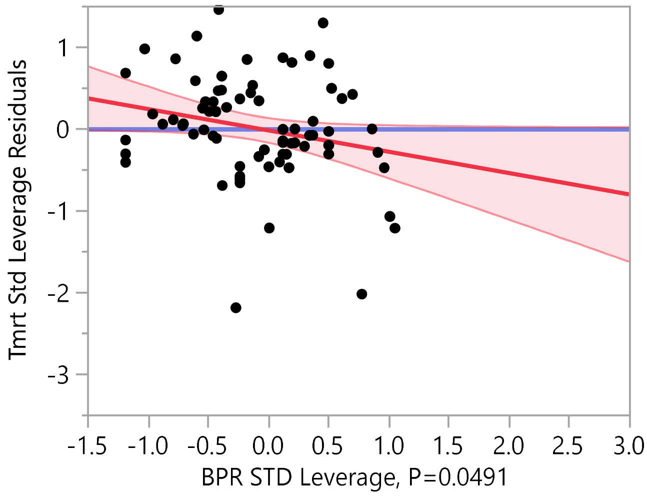


Figure 110. Correlation between Tmrt and BPR in summer

Surprisingly, there is no significant correlation between Tmrt and the variable of vegetation (GnPR). The picture below shows the results.

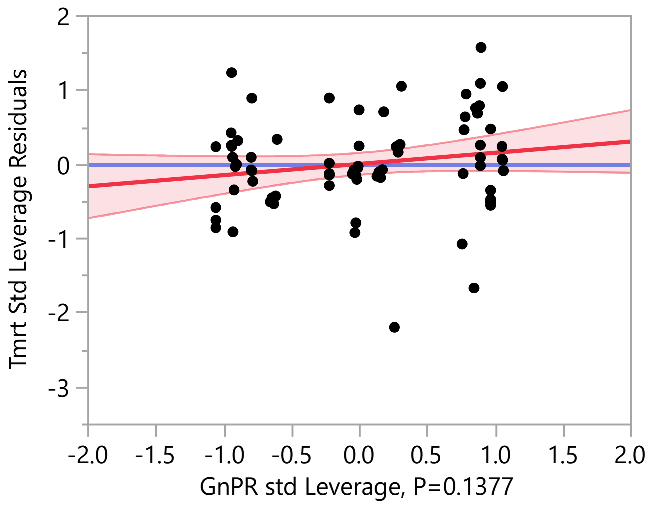
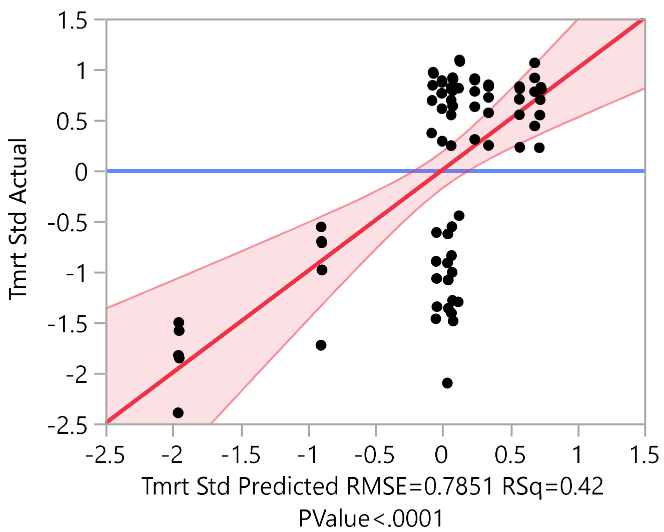


Figure 111. Correlation between Tmrt and GnPR in summer

B. Autumn case

The correlation between Tmrt and four variables of urban structure (SVF, GnPR, BPR, and SA) is analyzed by Fit Model analysis. The value of reliability (R^2) is 0.42 (more than 0.4) means the data is reliable. The significance value (Prob > F) is <0.001, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.416976
RSquare Adj	0.383661
Root Mean Square Error	0.785073
Mean of Response	1.87e-15
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	30.856254	7.71406	12.5159
Error	70	43.143746	0.61634	Prob > F
C. Total	74	74.000000		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.29799	0.113188	-2.63	0.0104*
SVF Std	1.3496889	0.257224	5.25	<.0001*
Surface Albedo Std	0.0382899	0.143589	0.27	0.7905
BPR STD	0.1898003	0.166155	1.14	0.2572
GnPR std	-0.079503	0.117322	-0.68	0.5002

Figure 112. Correlation between Tmrt and urban structure variables in autumn

The result shows that the most significant factor among the four variables in summer is SVF with the following equation:

$$Tmrt = 1.35SVF + 0.04SA + 0.19BPR - 0.07GnPR$$

It is also found that the relationship is positive (+1.35) with significance value (Prob > F) <0.001 (significant). Based on this results, it can be concluded that the higher value of SVF factor, the higher value of Tmrt. In other words, to decrease the Tmrt value (which also consequently decrease the PET value), the area should has a low SVF. It means the area should be well shaded.

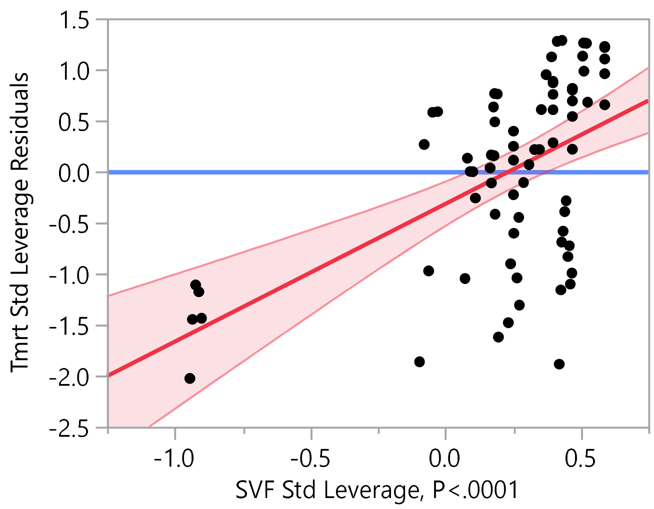


Figure 113. Correlation between Tmrt and SVF in autumn

Surprisingly, there is no significant correlation between Tmrt and the three variables: surface albedo (SA), building plot ratio (BPR), and green plot ratio (GnPR). The picture below shows the results.

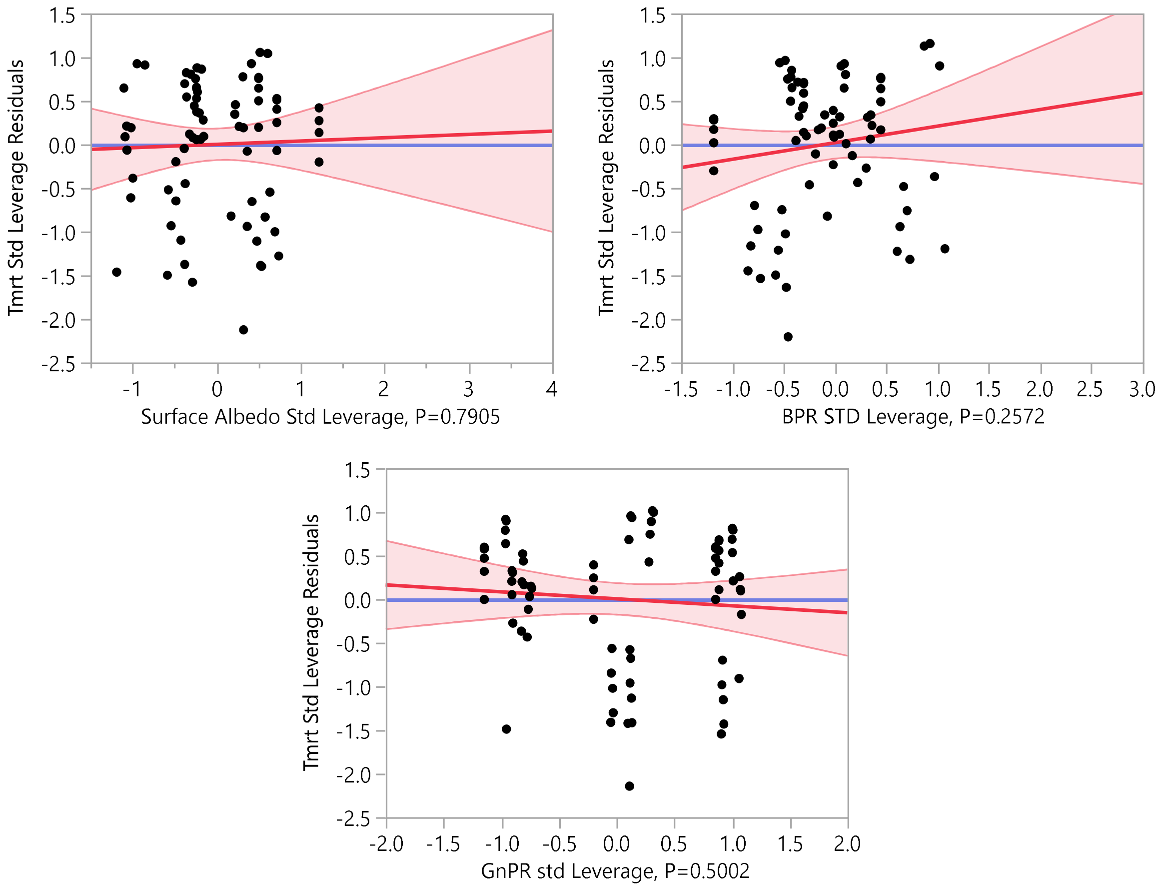
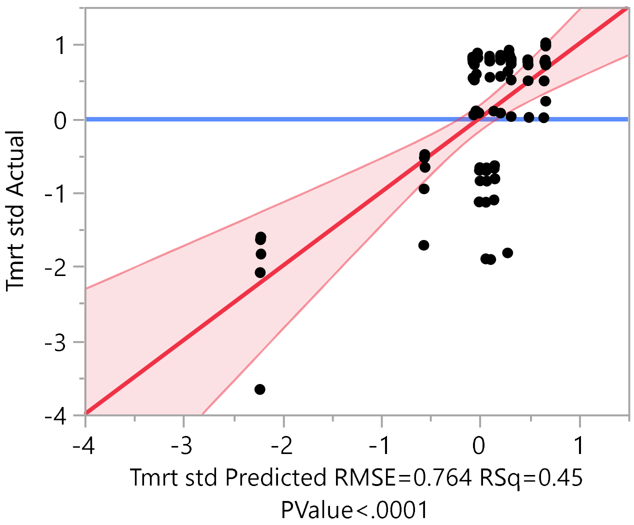


Figure 114. Correlation between Tmrt, SA, BPR, and GnPR in autumn

C. Winter case

The correlation between Tmrt and four variables of urban structure (SVF, GnPR, BPR, and SA) is analyzed by Fit Model analysis. The value of reliability (R^2) is 0.45 (more than 0.4) means the data is reliable. The significance value (Prob > F) is <0.001, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.44788
RSquare Adj	0.416331
Root Mean Square Error	0.763983
Mean of Response	-3.8e-15
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	33.143142	8.28579	14.1960
Error	70	40.856858	0.58367	**Prob > F**
C. Total	74	74.000000		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.329397	0.110343	-2.99	0.0039*
SVF std	1.4697406	0.249147	5.90	<.0001*
Surface Albedo std	0.0664501	0.140702	0.47	0.6382
BPR STD	0.1752801	0.163594	1.07	0.2877
GnPR std	-0.109164	0.109627	-1.00	0.3228

Figure 115. Correlation between Tmrt and urban structure variables in winter

The result shows that the most significant factor among the four variables in summer is SVF with the following equation:

$$Tmrt = 1.47SVF + 0.06SA + 0.17BPR - 0.10GnPR$$

It is also found that the relationship is positive (+1.47) with significance value (Prob > F) <0.001 (significant). Based on this results, it can be concluded that the higher value of SVF factor, the higher value of Tmrt. In other words, to decrease the Tmrt value (which also consequently decrease the PET value), the area should has a low SVF. It means the area should be well shaded.

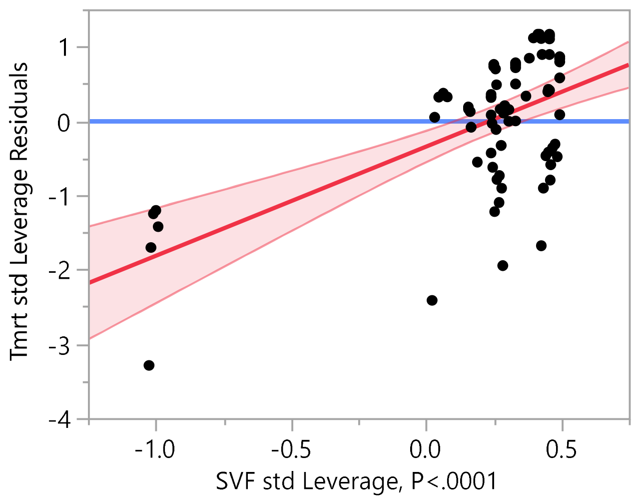


Figure 116. Correlation between Tmrt and SVF in winter

Surprisingly, there is no significant correlation between Tmrt and the three variables: surface albedo (SA), building plot ratio (BPR), and green plot ratio (GnPR). The picture below shows the results.

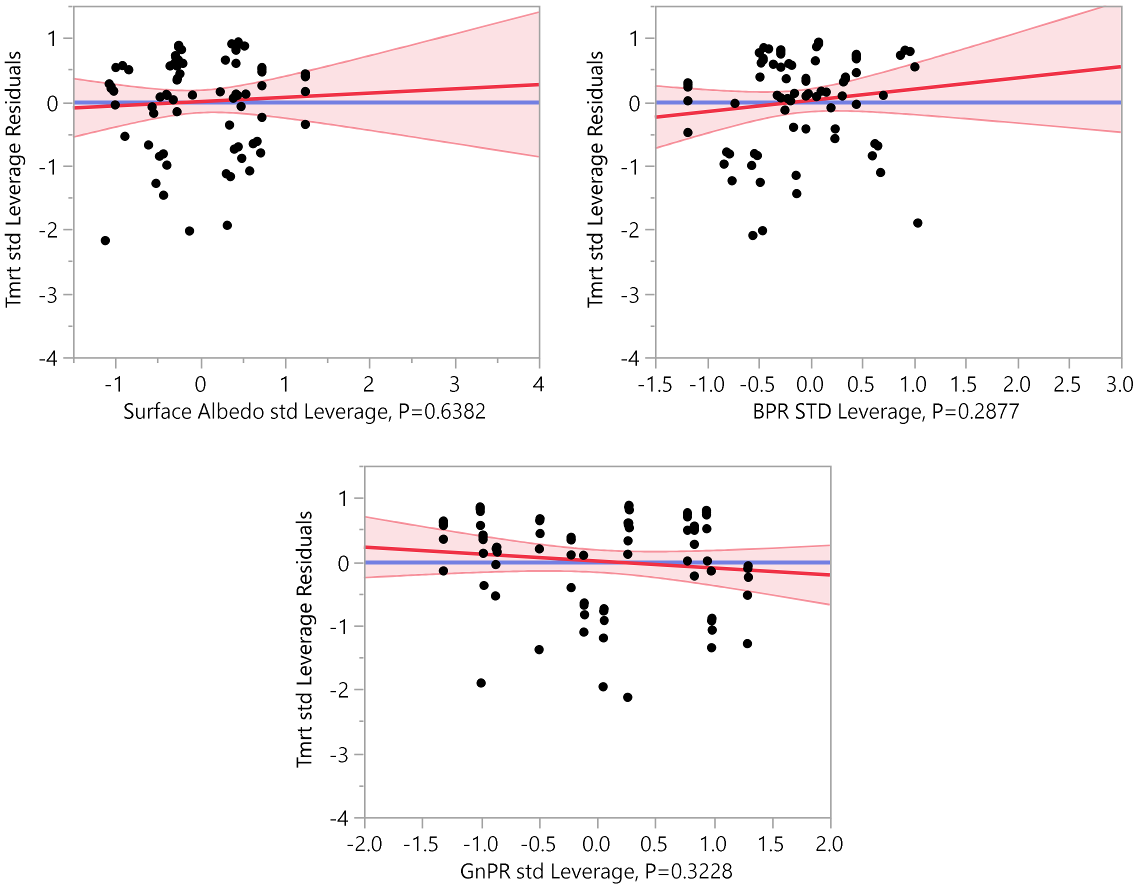
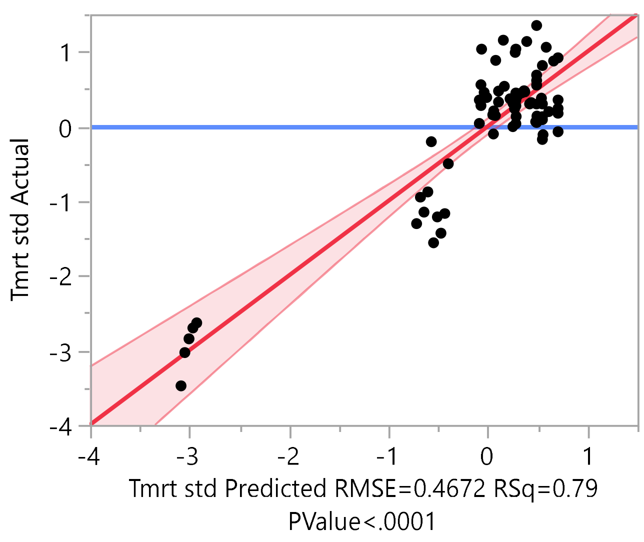


Figure 117. Correlation between Tmrt, SA, BPR, and GnPR in winter

D. Spring case

The correlation between Tmrt and four variables of urban structure (SVF, GnPR, BPR, and SA) is analyzed by Fit Model analysis. The value of reliability (R^2) is 0.79 (more than 0.4) means the data is reliable. The significance value (Prob > F) is <0.001, meaning that it is significant, or in other words, the chances of this finding being missed are almost not existed. The visualization of the correlation is on this following diagram.



Summary of Fit

RSquare	0.7935
RSquare Adj	0.7817
Root Mean Square Error	0.467226
Mean of Response	-2.6e-16
Observations (or Sum Wgts)	75

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	58.719002	14.6798	67.2458
Error	70	15.280998	0.2183	Prob > F
C. Total	74	74.000000		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.610049	0.067524	-9.03	<.0001*
SVF std	2.4378922	0.154098	15.82	<.0001*
Surface Albedo std	0.4570817	0.082379	5.55	<.0001*
BPR std	-0.21297	0.096835	-2.20	0.0312*
GnPR std	0.1279925	0.069044	1.85	0.0680

Figure 118. Correlation between Tmrt and urban structure variables in spring

The result shows that the most significant factor among the four variables in summer is SVF with the following equation:

$$Tmrt = 2.43SVF + 0.45SA - 0.21BPR + 0.12GnPR$$

It is also found that the relationship is positive (+2.43) with significance value (Prob > F) <0.001 (significant). Based on this results, it can be concluded that the higher value of SVF factor, the higher value of Tmrt. In other words, to decrease the Tmrt value (which also consequently decrease the PET value), the area should has a low SVF. It means the area should be well shaded.

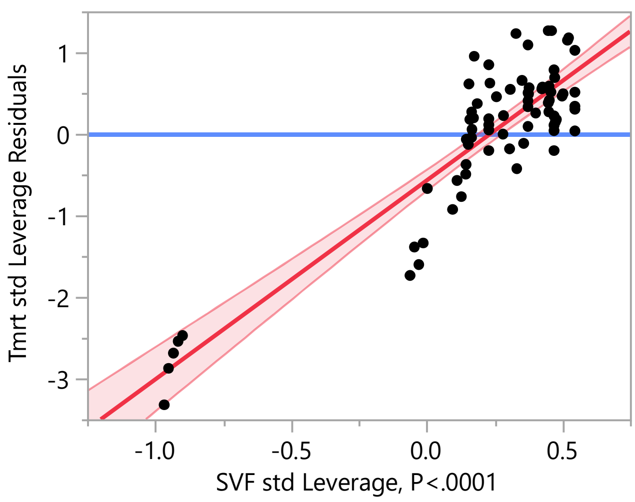


Figure 119. Correlation between Tmrt and SVF in spring

There is also a positive correlation from the surface albedo (+0.45) with significance value (Prob > F) <0.001 (significant) which means the higher surface albedo value, the higher Tmrt value. It also means that the material of the outdoor surface has an impact for the outdoor thermal comfort. The picture below shows the results.

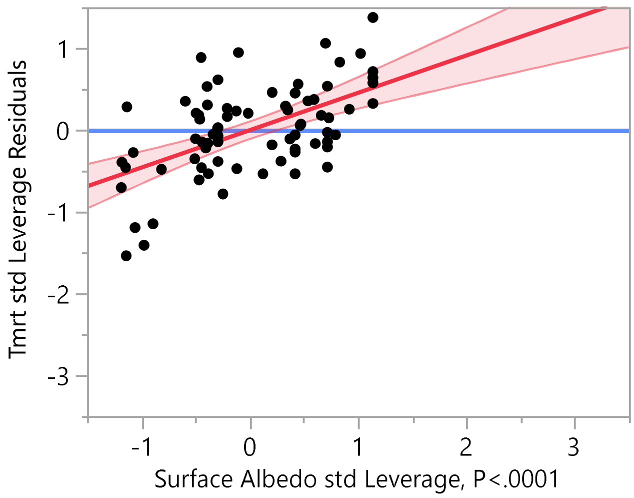


Figure 120. Correlation between Tmrt and Surface Albedo in spring

There is also a negative correlation between Tmrt and Building Plot Ratio (-0.21) with significance value (Prob > F) <0.001 (significant). It means the lower of area covered by buildings, the higher Tmrt value. It means that to decrease the Tmrt, the covered area of building should be increased. The picture below shows the results.

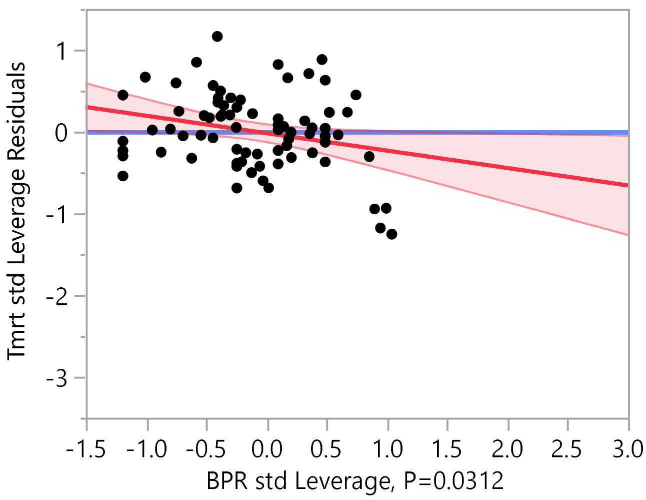


Figure 121. Correlation between Tmrt and BPR in spring

Surprisingly, there is no significant correlation between Tmrt and the variable of vegetation (GnPR). The picture below shows the results.

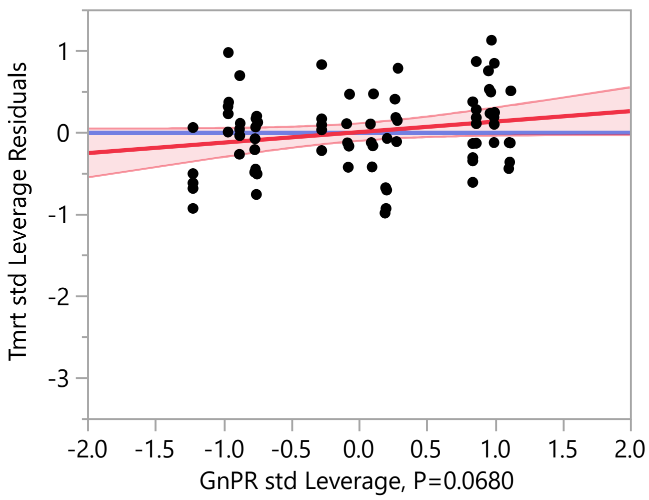


Figure 122. Correlation between Tmrt and GnPR in summer

E. Overall Relationship

In conclusion, the correlation between Tmrt and urban structure factors is significant, with positive relationship. The most influential factor is SVF. It means the higher SVF value (barely shaded), the higher Tmrt value. The overall relationship is shown by the following table.

Table 42. Overall relationship between Tmrt and urban structure factors

Season	**Reliability (R^2)**	**Significance value (Prob > F)**	**The most influential factor**	**Relationship**
Summer	0.6 (reliable)	<0.001 (significant)	SVF	Positive (+1.99)
Autumn	0.4 (reliable)	<0.001 (significant)	SVF	Positive (+1.34)
Winter	0.45 (reliable)	<0.001 (significant)	SVF	Positive (+1.46)
Spring	0.79 (reliable)	<0.001 (significant)	SVF	Positive (+2.43)

8.5. Conclusion

Based on the findings, it can be concluded that:

1. The performance of urban structure is represented by building plot ratio (BPR), green plot ratio (GnPR), sky view factor (SVF), and surface albedo (SA). The results shows that:

    a. The number of vegetation area is higher than building area.

    b. The median SVF value is high (between 0.86 and 0.94) which means barely shaded for all time. The most shaded area is near the building, while the medium shaded (SVF 0.5 to 0.6) are the lawn square and areas which near to trees.

    c. The overall of the Park's surface has a low albedo (between 0.10 and 0.25). The area which has high albedo (above 0.7) is area which covered by pavements. While medium albedo area (between 0.3 and 0.7) is spread in several locations, especially in surface areas covered by light material.

2. The performance of outdoor thermal environment is evaluated by determining the thermal environment impacts (PMV, Ta, RH, and v) to urban structures (vegetation and building) and the relationship between PET and surface temperature.

    a. In summer, PMV value is in the range of 2.05 to 3.38 with average 2.6 means thermally not comfortable, with thermal perception is *hot* and *strong heat stress* sensation. In autumn, PMV value is in the range of 0.72 to 1.95 with average 1.34 means thermally *slightly warm* and *slight heat stress* sensation. In winter, PMV value is in the range of -1.17 to +0.26 with average -0.29 means *neutral* (thermally comfortable) with *no thermal stress* sensation. In spring, PMV value is in the range of +0.02 to +0.95 with average +0.45 means *neutral* (thermally comfortable) with *no thermal stress* sensation. Overall, the outdoor thermal comfort of Green Park Kitakyushu based on simulation model for PMV value is statistically not comfortable in summer and autumn, but very comfort in winter and spring.

       The potential air temperature of Green Park in four different seasons is between 16.78°C and 30.75°C, and the average is 22.84°C. The wind speed is between 0 and 2.26 m/s, and the average is 1.76 m/s. While the relative humidity is between 49.57% and 107.75%, and the average is 61.13%.

b. Area near to building and surface area covered by asphalt or hard materials are relatively higher PMV, hotter Ta, dryer RH, unstable wind speed.

c. The correlation between PET and surface temperature is significant, with positive relationship. It means that the higher surface temperature is the higher PET value.

3. The relationship between urban structure variables and outdoor thermal environment variables are determined by the correlation between PET and urban structure variables and the correlation between Tmrt and four variables of urban structure. Based on the results, it was found that:
    a. The correlation between PET and urban structure factors is significant, with negative relationship. It means the higher SVF value (barely shaded), the lower PET value. The shading is important to increase the outdoor thermal comfort performance.
    b. While another results found that the correlation between Tmrt and urban structure factors is also significant, with positive relationship. The most influential factor for Tmrt is SVF. It means the higher SVF value (barely shaded), the higher Tmrt value.

CHAPTER 9

CONCLUSION AND RECOMMENDATION

9.1 Summary of Research

Outdoor thermal comfort is one essential topic in urban micro-climate change mitigation. This study has tried to carry out some important investigations of outdoor thermal issues in urban parks. These thermal comfort investigations are written in several chapters, from introduction to conclusion. The first chapter is introduction part which offer an overview of the research. It provides a research background, problem statement, objectives, scopes and limitations, structure of research and framework. The method to develop this idea is by seeing actual trends which related to urban parks development. Urban problems in Indonesia and Japan are shown as the background of this study. Outdoor thermal comfort studies in urban parks were seen as an important strategy and effective way to solve the environmental problems. Based on findings, this research justified the aim to investigate to what extend the outdoor thermal comfort can be used to evaluate the quality of urban parks in Indonesia and Japan.

After structuring the research background and objective, the next chapter is to build a brief understanding and widen the view of study. Chapter 2 aims at conducting a literature review for identifying the classification of urban parks, influencing factors, motives, and barriers to outdoor thermal comfort. This chapter also try to find the relationship between outdoor thermal comfort and vegetation in urban green open spaces based on literature study.

Chapter 3 provides way of data collection, data analysis, and the target of results. The types of data consist of a primary and secondary data. The primary data were conducted as a field measurement which found out some environmental data, such as air temperature (Ta), relative humidity (RH), and wind speed (v). The questionnaire data was also categorized as a primary data because it was also directly collected at the field. Meanwhile, the secondary data are including weather station, urban policies, published journal papers, conference papers, and so on. The data analysis methods used in this study are descriptive, distribution, correlation, numerical and computational simulation, and systematic review.

A preliminary study to determine the quality of outdoor thermal comfort in Bandung, Indonesia is systematically arranged in chapter 4. The study used a quantitative approach method that uses measurable analysis and can be calculated using certain formulas. The case study was selected based on the criteria of urban park and the percentage of the value of Green Plot Ratio (GnPR). Sampling type used for this study is a non-random sampling with purposive sampling technique. The study cases were Gasibu Park, Lansia Park, and Saraga Park. Based on the results, it was found that: 1) the best quality of the thermal performance among the three samples was Lansia Park, this finding indicates that the hypothesis that the greater the ratio of vegetation an urban park, the greater the thermal comfort value is correct; 2) the community adaptation to the thermal quality of the urban park's environment as a whole is quite good. Most respondents were able to accept thermal performances and want to get cooler than the actual performances. Satisfaction of the performance of shading, sunlight, and wind within the area is quite good; 3) the average value of PET on urban parks in Bandung is in the range of 22.9 °C to 25.1 °C with slightly cooler thermal sensation, with a slight cold stress. PET values that can be adapted by the people of Bandung is lower than the cities in other tropical countries; and 4) the environmental thermal factor that most influences the TSV value in the three urban parks in Bandung is RH (relative humidity) with a probability value or P-value <0.0001 with a correlation value of -0.03. This means that the higher the humidity in an urban park, the lower the thermal comfort value. Based on this finding, the quality of thermal comfort of these urban parks should be increased in order to get more convenience by some works. One alternative is by increasing the number of shadowing area in order to get a lower air temperature. The finding in this study contribute to the outdoor thermal comfort of tropical climate zones.

The discussion part for outdoor thermal comfort study in Kitakyushu, Japan is provided in four different chapter, from chapter 5 to chapter 8. The chapter 5 aims to understand the visitor perceptions and expectations of urban park. The study analyzes several variables based on answers to field survey questionnaires using 425 respondents. Furthermore, Green Park, located in Kitakyushu, Japan, serves as the case study. The result found six essential variables: 1) "Playing with children" is the most popular reason for visiting this park; 2) Tourists living closer to the area frequently visit; 3) The existence is necessary; 4) The relationship between the importance and the origins of the tourists is related to a sense of place; 5) Tourist preferences are affected by seasonality; 6) The most favorite expectation is the availability of water facilities. This further can contribute to tourism development in urban parks with similar climatic and environmental characteristics.

Chapter 6 aims to investigate relationship between the age, gender, and body proportion and the outdoor thermal comfort based on Thermal Sensation Vote (TSV) value. There are hypothesis, they are: *first*, the older a person is, the lower the standard of comfort will be, and vice versa; *second*, men are easier to gain thermal comfort than women; and *third*, the greater the distance from the proportional body, the higher the standard of comfort. These hypotheses was being observed to be scientifically proved. This research was conducted by quantitative methods using a printed questionnaire media. The relationship between the three variables would be analyzed by the multivariate analysis method. Based on the analysis results, there is no significant correlation to outdoor thermal comfort of age, gender, and body proportion. The character of Japanese people for a privacy matter may affects the number of response of age, height, and weight. The missing data is 35.5% (147 data) or only 64.5% from the total respondent has full personal data (age, height, and weight).

Chapter 7 aims to determine people's perceptions of outdoor thermal sensation (TSV), wind flow sensation (WFSV), and humidity sensation (HSV), outdoor thermal acceptability and satisfaction, shading, sunlight, and wind performance preferences, significant micro-meteorological variables for PET, relationship between micro-meteorological and personal variables (TSV, WFSV, and HSV), and relationship between PET and personal variables. Data collection was carried out using two methods in combination: micro-meteorological measurement and questionnaire survey. Data analysis using JMP statistics and RayMan model software. Result shows that most of respondent were feeling comfort with the thermal, wind, and humidity performance. Sensation of thermal and the wind flow were mostly neutral, and the sensation of humidity were also in the mid-range (just right, nor humid and dry). Acceptability and satisfaction level of thermal comfort were positive. Satisfaction preferences for shading, most of the respondents in summer, autumn, and spring were dissatisfied with the actual shading performance and agreed to gain more shading, to get more chance for shelter from the hot sun. Respondents of winter season were the only one who mostly feeling satisfied. For the sunlight and wind satisfaction preferences, most of respondents in all seasons were feeling satisfied with the actual performance, no compliment. Most significant micro-meteorological variable for the PET value is mean radiant temperature (Tmrt) which means that shadow was very important to the thermal comfort performances. Most influential micro-meteorological variable for the three different personal variables (TSV, WFSV, and HSV) is air temperature. Lastly, it also found that the strongest relationship between PET and personal variables is between TSV and PET. This chapter comprehensively studies the relationship between the thermal environment and the human factor, especially in urban parks.

The last part of discussion is Chapter 8 which aims to determine three points: urban structure performance of urban park, outdoor thermal environment performance, and relationship between urban structure variables and outdoor thermal environment variables. Data were collected by field measurement, observation, and computer simulation through ENVI-met software model. There are three type of analysis, they are correlation, model simulation, and description. There result shows that: the median SVF value is high (between 0.86 and 0.94) which means barely shaded for all time. The overall the Park's surface has a low albedo (between 0.10 and 0.25). The outdoor thermal comfort of Green Park Kitakyushu is statistically not comfortable in summer and autumn, but very comfort in winter and spring. It also found that the higher surface temperature is the higher PET value. It was also found that the correlation between PET and urban structure factors is significant, with negative relationship. The shading is important to increase the outdoor thermal comfort performance. The correlation between Tmrt and urban structure factors is also significant, with positive relationship. This chapter is an extension of field research that utilizes the development of digital technology in analyzing the performance of a microclimate in an outdoor environment. In the end, this study is expected to be able to provide an overview of what factors can be improved and avoided to achieve optimal outdoor thermal comfort.

The last chapter concludes all the results of the research and provides recommendation for the future. Based on the results there are five key findings, they are: 1) The visitor perception and expectation of urban park is related to their emotional experience and satisfaction of its facilities; 2) There is no significant correlation between personal variables (age, gender, and body proportion) and outdoor thermal comfort in urban park; 3) The most influential micro-meteorological variable for the outdoor thermal comfort (PET) is mean radiant temperature; 4) The thermal environmental performance and urban structure in urban park found that the outdoor thermal comfort is statistically not comfortable in summer and autumn, but very comfortable in winter and spring; and 5) The factors of urban structure (physical environment) which significantly affect the outdoor thermal comfort in urban park are sky view factor (SVF). For further research, it is useful to use this approach as one of evaluation instruments.

9.2 Key Findings of Research

The research has a contribution to the topic of outdoor thermal comfort and urban park studies. At least, there are five key findings that need to be highlighted, including the following.

1. *The visitor perception and expectation of urban park is related to their emotional experience and satisfaction of its facilities.* Children play ground and distance of tourists living to the urban park area is the most influential factor in designing an urban park. The sense of place is essential for developing and maintaining an urban park and attracting people. The preferences are affected by seasonality and types of area. Mostly visitor feels more enjoyable to visit urban park in spring and more likely to play in lawn

square (green open space). The availability of water facilities should is an important attribute based on visitor's expectation.

2. *There is no significant correlation between personal variables (age, gender, and body proportion) and outdoor thermal comfort in urban park.* Most of respondent were feeling comfort with the thermal (TSV), wind (WFSV), and humidity (HSV) performance. The acceptability and satisfaction level of thermal comfort were positive. For the satisfaction preferences for shading, most of the respondents in three seasons (summer, autumn, and spring) were dissatisfied with the actual shading performance and agreed to gain more shading. Only respondents of winter season were mostly feeling satisfied. For the sunlight and wind satisfaction preferences, most of respondents in all seasons were feeling satisfied with the actual performance, no compliment.

3. *The relationship between micro-meteorological and personal variables of outdoor thermal comfort in urban park found that the most influential micro-meteorological variable for the outdoor thermal comfort (PET) is mean radiant temperature (Tmrt).* It means that the shadow was very important to the thermal comfort performances in urban park. The most influential micro-meteorological variable for the personal variables (TSV, WFSV, and HSV) is air temperature. The strongest relationship between the four variables (PET, TSV, WFSV, and HSV) is between TSV and PET, with positive relationship. The two new indices (HSV and WFSV) are proposed to be considered for the future study in general.

4. *The performance of thermal and physical environmental in urban park found that the outdoor thermal comfort is statistically not comfortable in summer and autumn, but very comfortable in winter and spring.* The number of vegetation area (GnPR) is higher than building area (BPR). The Green Park has a high SVF value (between 0.86 and 0.94) which means barely shaded for all time. It also has a low surface albedo (between 0.10 and 0.25) which means surface area are mostly dark. The outdoor thermal comfort (PMV) is statistically not comfortable in summer and autumn, but very comfortable in winter and spring. The potential air temperature of Green Park in four different seasons is between 16.78ºC and 30.75ºC, and the average is 22.84ºC. The average wind speed is 1.76 m/s and the average relative humidity is 61.13%.

5. *The factor of urban structure (physical environment) which significantly affect the outdoor thermal comfort in urban park is sky view factor (SVF).* The most significant factor between PET and urban structure (physical environment) variables is SVF, with negative relationship. The higher SVF value (barely shaded), the lower PET value. The correlation between PET and surface temperature is significant, with positive relationship. The higher surface temperature is the higher PET value. The correlation between Tmrt and urban structure factors is significant, with positive relationship. The most influential factor for Tmrt is SVF. The higher SVF value (barely shaded), the higher Tmrt value.

9.3 Future Research

This research had found out some important points for the study development of outdoor thermal comfort, especially in urban park. However, research in this field can certainly be developed further. Given the limitations obtained during the research process, some recommendations that need to be considered for further research include the following.

1. The study proposed two new indices to be considered to use in outdoor thermal comfort studies, they are HSV (Humidity Sensation Vote) and WFSV (Wind Flow Sensation Vote).
2. The amount of data needs to be considered. Several correlation analyzes got a low reliability value (R^2) due to lack of data, so that the output data from the analysis in this study was allegedly not able to represent the research topic in general.
3. Due to privacy issue, some people are not comfortable to answer questions about age, height, and weight, especially for Japanese people. Therefore, more appropriate approaches are suggested to be consider for the future research development.
4. To get a broader view in mitigation efforts to deal with UHI and climate change issues, many similar studies are needed in several different climates, locations and cities. So that the results are expected to be more accurate and reliable as a material for consideration and studies.

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APPENDIX

A. QUESTIONNAIRE PAPER (ENGLISH VERSION)

University of Kitakyushu Graduate School of Environment Engineering
Bart Dewancker Laboratory
2020

Date:	Time:

Questionnaire

My name is Dadang Hartabela, I'm a doctoral student in The University of Kitakyushu. At this time, I'm doing a research about Study on Thermal Perception on Public Parks in Kitakyushu, Fukuoka. Please answer the following questionnaire. The survey results will only be used for my doctoral thesis purposes.

A. Basic Personal Information:

1) Gender :☐ Male ☐Female
2) Age :☐10's ☐20's ☐30's ☐40's ☐50's ☐60's ☐70's plus
3) Height : cm weight : kg
4) Nationality :
5) The current city (you live) :

☐ Inside Kitakyushu* ☐ Other prefecture (In Japan)
☐ In Fukuoka prefecture ☐ Abroad (Outside Japan)

*) If you live in Kitakyushu city, how long have you been living here?

☐Less than 1 year ☐ Between 3 and 10 years
☐Between 1 and 3 years ☐ More than 10 years

B. Questions about This Park

1) Please tell us what your reason to visit this park today? Please circle (O) one or more from the list below.

1A	Fitness or doing sports
1B	Play with children
1C	Have a picnic or gather with my friends
1D	For educational purpose
1E	For a pleasant diversion
1F	For a community event

2) Please tell us what your reason to visit this park on the previous days? Please circle (O) one or more from the list below. If this is your first time, please leave it blank.

1A	Fitness or doing sports
1B	Play with children
1C	Have a picnic or gather with my friends
1D	For educational purpose
1E	For a pleasant diversion
1F	For a community event

3) How often do you come here?

☐ Daily or more often
☐ Weekly or more often
☐ Monthly or more often
☐ Once or twice a year
☐ This is my first time

4) Please choose the season you like most in this park.

☐ Summer
☐ Autumn
☐ Winter
☐ Spring

5) How important is this park for you? Please circle (O) one of this nodes.

Very Not Important	-3	-2	-1	0	+1	+2	+3	Very Important

6) Which your favourite area(s) of this Park? Please check (v) one or more.

☐ The lawn square
☐ Inside the building (indoor area)
☐ Near the building (outdoor area)
☐ Near the flowers and trees (natural area)
☐ Playground (kid's area)

7) What do you want to be available in the future on this park? (Your expectations)

☐ Water play facilities (swimming pool, water fountain, etc.)
☐ Pets play facilities (for dogs, cats, etc.)
☐ More animals varieties (like a zoo)
☐ Camping space (Picnic, Barbeque, etc.)
☐ Can stay all the night (to see the stars, etc.)
☐ Athletic ground or sports space (baseball, dodgeball, softball, soccer, badminton, etc.)
☐ Skate Park (for Skateboard)
☐ Others ....
☐ I am satisfied with current condition.

C. Questions about Thermal Comfort

1) **How do you feel about the temperature at this moment? Please circle (O) one of this nodes.**

Temperature

Very Cold	-3	-2	-1	0	+1	+2	+3	Very Hot

2) **How do you feel about the air flow at this moment? Please circle (O) one of this nodes.**

Air Flow

Slow	-3	-2	-1	0	+1	+2	+3	Fast

2a) Do you feel being disturbed by the air flow?

☐ Yes ☐ No

3) **How do you feel about humidity at this moment?**

☐ Too dry ☐ Slightly dry ☐ Just right ☐ Slightly humid ☐ Too humid

4) **Are you satisfied with the current outdoor environment?**

☐ Yes ☐ No

6) **Which the outside temperature that suitable for you?**

☐ Cooler is better ☐ Just like this ☐ Warmer is better

7) **How satisfied are you with the temperature in here? Please circle (O) one of this nodes.**

Very Disappointed	-3	-2	-1	0	+1	+2	+3	Very Satisfied

8) **Your activity (30 minute before doing the survey)**

☐ Sitting ☐ Standing ☐ Walking ☐ Running ☐ Others

9) **Your expectation about Shading in this park:** how much the shade do you think is ideal for this park? **Please circle (O) one of this nodes.**

	The Shading	
Less is better	-1 —— 0 —— +1	More is better

10) **Your expectation about Sunlight in this park:** how much the shade do you think is ideal for this park? **Please circle (O) one of this nodes.**

	The Sunlight	
Less is better	-1 —— 0 —— +1	More is better

11) **Your expectation about Winds in this park:** how much the shade do you think is ideal for this park? **Please circle (O) one of this nodes.**

	The Wind	
Less is better	-1 —— 0 —— +1	More is better

Thank you for your cooperation.

B. QUESTIONNAIRE PAPER (JAPANESE VERSION)

University of Kitakyushu Graduate School of Environment Engineering
Bart Dewancker Laboratory
2020

Date:	Time:

アンケートご協力のお願い

私はダダンハルタベラです。北九州市立大学の博士課程の学生です。「北九州市における公園訪問者の熱的快適性に関する研究」を行っています。よろしければ下記のアンケートにご協力よろしくお願いいたします。なお調査結果は学術目的以外に使用することはありません。

A. 基本データ

1) 性別 ： □男性 □女性
2) 年齢 ： □10 代 □20 代 □30 代 □40 代 □50 代 □60 代 □70 歳以上
3) 身長 ： cm 体重: kg
4) 国：
5) お住まい :

□北九州市内* □他県

□北九州市外（福岡県内） □国外

*) 前質問で北九州市内にお住まいと答えた方のみお答えください。

北九州でのお住まいの期間:

□1 年未満 □3 年以上 10 年未満

□1 年以上 3 年未満 □10 年以上

B. この公園に関する質問

1) a. 今日の訪問の目的は何ですか。以下のリストに丸を付けてください (ふくすうか)。

1A	フィットネスまたはスポーツをする
1B	子供と遊ぶ
1C	ピクニックをするか、友人や家族と一緒に集まります
1D	教育目的で
1E	気分転換のために
1F	コミュニティイベントの場合

b.　以前に訪問したの目的は何でしたか。以下のリストに丸を付けてください(ふくすうか)。

1A	フィットネスまたはスポーツをする
1B	子供と遊ぶ
1C	ピクニックをするか、友人や家族と一緒に集まります
1D	教育目的で
1E	気分転換のために
1F	コミュニティイベントの場合

2)　どの頻度でこの公園に来ますか。

☐ 毎日またはより頻繁に
☐ 毎週またはより頻繁に
☐ 少なくとも月に 1 回
☐ 年に 1~2 回
☐ 初めてで

3)　この公園がもっとも好きな季節を選んで下さい。

☐ 夏
☐ 秋
☐ 冬
☐ 春

4)　この公園はあなたにとってどれほど重要ですか。

重要ではない -3 -2 -1 0 +1 +2 +3 重要

5)　この公園の好きなエリアはどれですか。 1 つ以上に丸を付けてください。

☐ 芝生広場
☐ 建物内（屋内エリア）
☐ 建物の近く（屋外エリア）
☐ 花や木々の近く（自然地域）
☐ 遊び場（キッズエリア）

6) この公園整備して欲しいものは下のリストから 1 つ以上を選んでください。

- ☐ 水遊び施設（プール、噴水など）
- ☐ ペットの遊び場（犬、猫など）
- ☐ より多くの動物の種類（動物園など）
- ☐ キャンプスペース（ピクニック、バーベキューなど）
- ☐ 一晩中滞在できる場所（星などを見るために）
- ☐ 運動場またはスポーツスペース（野球、ドッジボール、ソフトボール、サッカー、バドミントンなど）
- ☐ スケートパーク (スケートボード用)
- ☐ その他……………………………………………。
- ☐ 現状に満足しています

C. 熱に関する質問

1) 現在あなたがいるところの気温はどう感じていますか。(丸をつけてください)

温度

とても寒い -3 -2 -1 0 +1 +2 +3 とても暑い

2) あなたの周りの空気の流れについてどう感じていますか。(丸をつけてください)

気流

穏やか 3 2 1 0 +1 +2 +3 激しい

3) 不快な風ですか。　☐ はい　☐ いいえ

4) 現在あなたがいるところの湿度はどう感じていますか。

☐ とても乾燥　☐ 少し乾いた　☐ ちょうどいい　☐ 少し湿気がある　☐とてもしっとり

5) 現在の屋外環境に満足していますか。

☐ はい　☐ いいえ

6) 外気温は適していますか。

☐ 少し涼しいほうが良い　☐ そのままでよい　☐ 少し暖かいほうが良い

7) 現在あなたがいる空間の気温についてどの程度満足していますか。(丸をつけてください)

不満がある	-3	-2	-1	0	+1	+2	+3	非常に満足

8) この調査を記入前にどんな行動をしましたか。

- ☐ 座っていた
- ☐ 立っていた
- ☐ 歩いていた
- ☐ ランニングした
- ☐ その他

9) この公園にはどのくらいの日陰が理想的だと思いますか。(丸をつけてください)

日陰

少ないほうが良い	-1	0	+1	もっといります

10) この公園にはどのくらいの陽光が理想的だと思いますか。(丸をつけてください)

陽光

少ないほうが良い	-1	0	+1	もっといります

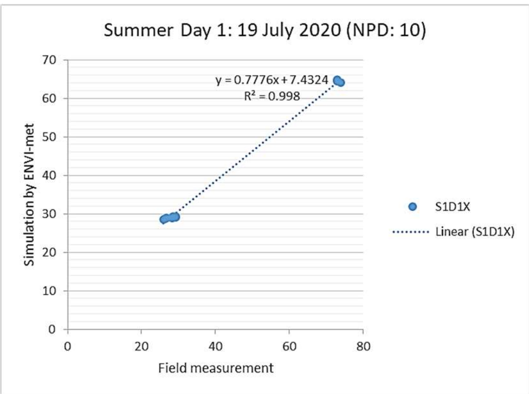
11) この公園にはどのくらいの風が理想的だと思いますか。(丸をつけてください)

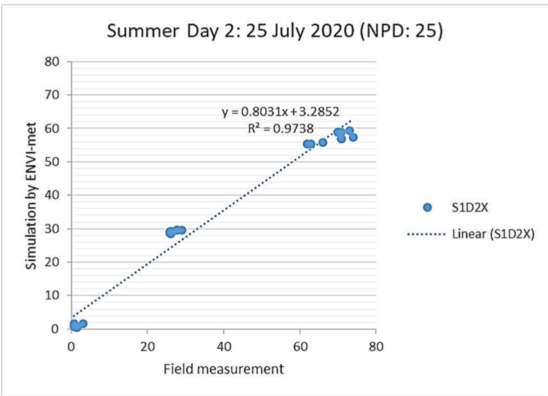
風

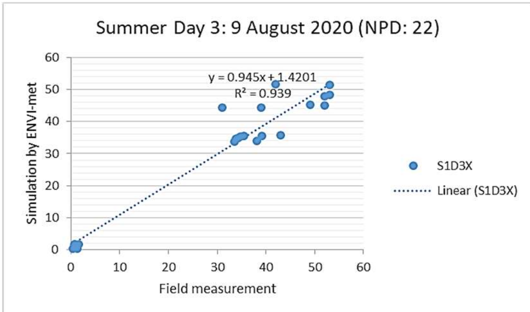
少ないほうが良い	-1	0	+1	もっといります

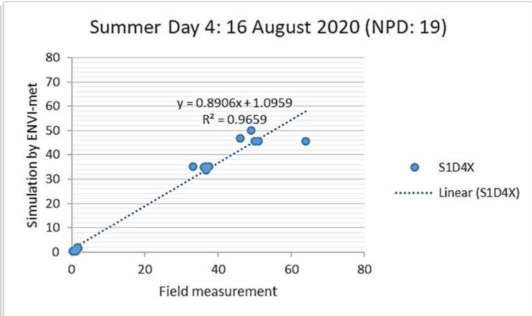
ご協力をいただき、ありがとうございました。

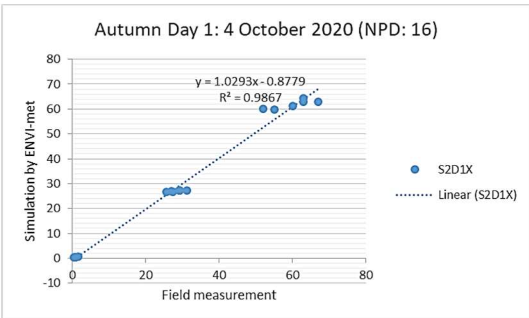
C. DATA VALIDATION BETWEEN SIMULATION AND FIELD MEASUREMENT

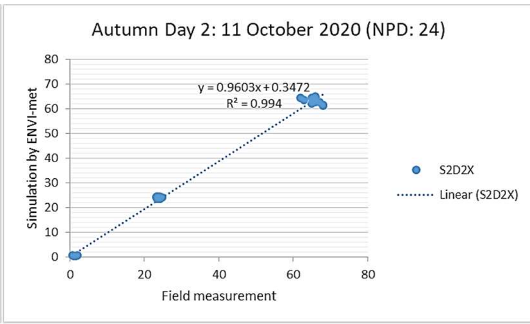


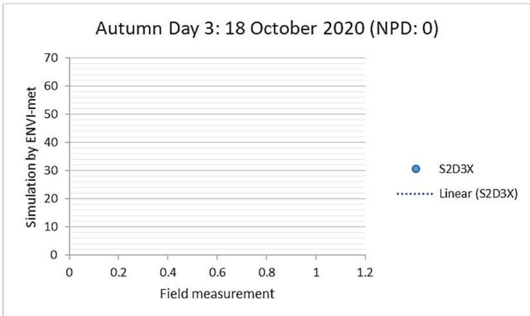


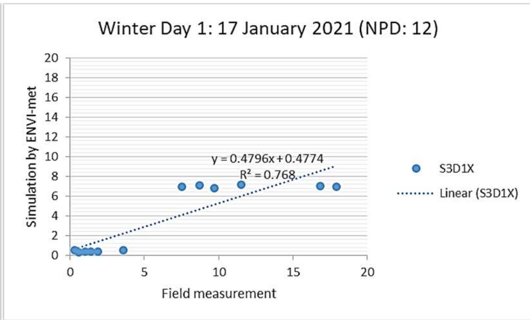


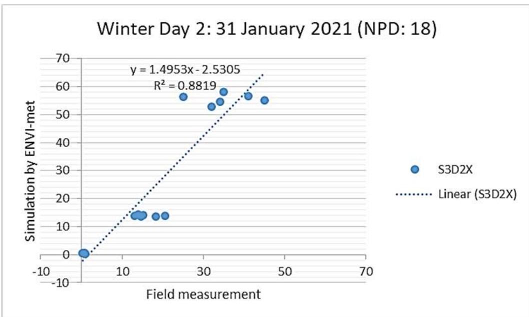


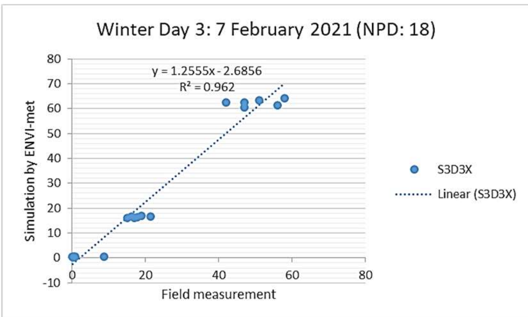


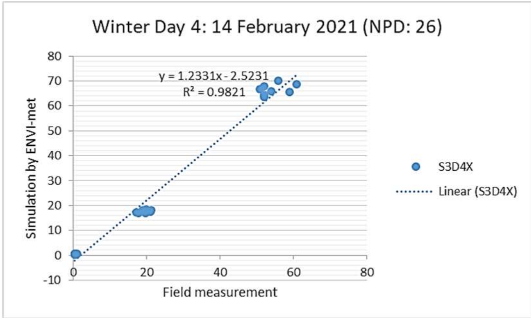








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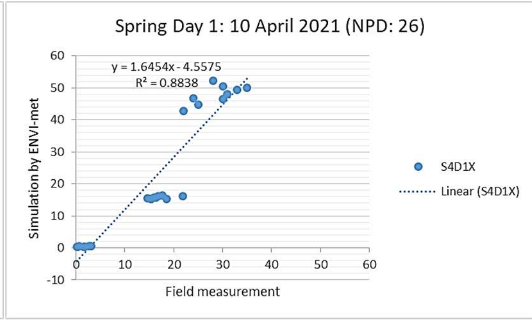
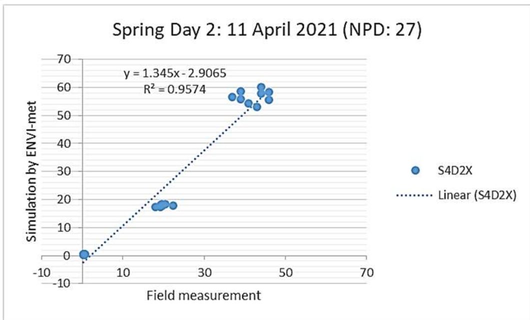
R² = 0.9821
Simulation by ENVI-met
Field measurement
S3D4X
Linear (S3D4X)


Spring Day 1: 10 April 2021 (NPD: 26)
y = 1.6454x - 4.5575
R² = 0.8838
Simulation by ENVI-met
Field measurement
S4D1X
Linear (S4D1X)


Spring Day 2: 11 April 2021 (NPD: 27)
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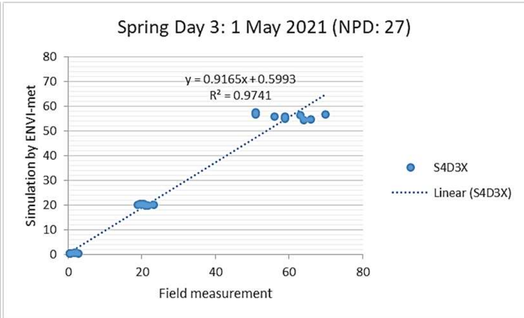
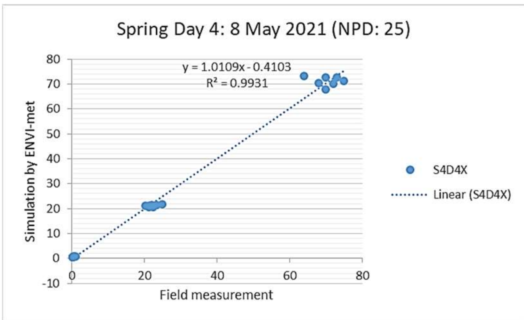
R² = 0.9574
Simulation by ENVI-met
Field measurement
S4D2X
Linear (S4D2X)


Spring Day 3: 1 May 2021 (NPD: 27)
y = 0.9165x + 0.5993
R² = 0.9741
Simulation by ENVI-met
Field measurement
S4D3X
Linear (S4D3X)


Spring Day 4: 8 May 2021 (NPD: 25)
y = 1.0109x - 0.4103
R² = 0.9931
Simulation by ENVI-met
Field measurement
S4D4X
Linear (S4D4X)