

INVESTIGATION OF THE RELATIONSHIP BETWEEN
HUMAN THERMAL COMFORT AND ACTIVITY PATTERNS
WITHIN THE OUTDOOR SPACES OF BILKENT
UNIVERSITY'S MAIN CAMPUS

A Master's Thesis

by

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June 2023

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Bilkent University 2023



To all those who bravely chanted

"Woman, Life, Freedom"

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I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

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ABSTRACT

INVESTIGATION OF THE RELATIONSHIP BETWEEN HUMAN THERMAL COMFORT AND ACTIVITY PATTERNS WITHIN THE OUTDOOR SPACES OF BILKENT UNIVERSITY’S MAIN CAMPUS

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The impact of climate change, resulting in rising temperatures, is believed to significantly influence the success or failure of outdoor spaces, with climatic factors playing a crucial role. Research has indicated that the maintenance of a comfortable thermal environment can have a notable impact on individuals' welfare. To date, global climate studies have not provided sufficient local specificity for urban planning and design. Consequently, there has been an increasing interest in incorporating complementary bottom-up perspectives. In line with this interest and focused on a particular case study, this thesis presents the findings of an empirical investigation conducted between May and September of 2022 at the main campus of Bilkent University located in Ankara, Turkey.

In order to address physiological and psychological aspects of human thermal comfort and investigate the possible effect of human thermal comfort on lecturers' and students' activity patterns within outdoor spaces of the aforementioned campus, a two-phase study was designed. 12 days of observational studies during the first phase of this research produced a behavioral map, which when combined with a Shadow Behavior Simulation (SBS) map established the Points Of Interest (POI) of this research. Subsequently, in the second phase, 64 questionnaires were filled out by the pedestrian while microclimatic factors were measured in the POIs over the course of 13 days.

In order to address the stated research questions, test the hypotheses, and propose design recommendations, through the application of the biometeorological RayMan model, the Physiologically Equivalent Temperature (PET) index, and modified PET were applied, along with statistical analyses using the Statistical Package for the Social Sciences (SPSS) and the cognitive maps considering microclimate. The findings of this study demonstrated good agreement between quantitative and qualitative results, presenting solar radiation as the most significant microclimatic factor. Human thermal comfort also had an impact on activity patterns within the study area, but not as significantly as seating availability for stationary activities and planning and function for moving activities.

Keywords: Outdoor thermal comfort; PET; mPET; Academic campus; Activity patterns; Ankara

ÖZET

Bilkent Üniversitesi Merkez Kampüsünün Dış Mekanlarındaki İnsan Termal Konforu ve Aktivite Paternleri Arasındaki İlişkinin İncelenmesi

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İklim değişikliğinin, yükselen sıcaklıklar sonucunda, dış mekanların başarısı veya başarısızlığı üzerinde önemli bir etkisi olduğuna inanılmaktadır ve iklimsel faktörlerin bu konuda kritik bir rol oynadığı kabul edilmiştir. Araştırmalar, konforlu bir termal çevrenin korunmasının bireylerin refahı üzerinde belirgin bir etkisi olabileceğini göstermiştir. Bugüne kadar, küresel iklim çalışmaları, kentsel planlama ve tasarım için yeterli yerel özgünlük sağlamamıştır. Sonuç olarak, tamamlayıcı alttan-üste perspektifleri içermeye konusunda artan bir ilgi olmuştur. Bu ilgi doğrultusunda ve belirli bir vaka çalışmasına odaklanarak, bu tez, Ankara, Türkiye'deki Bilkent Üniversitesi'nin ana kampüsünde 2022'nin Mayıs ve Eylül ayları arasında yürütülen ampirik bir araştırmanın bulgularını sunmaktadır.

İnsan termal konforunun fizyolojik ve psikolojik yönlerini ele almak ve insan termal konforunun söz konusu kampüsteki öğretim görevlilerinin ve öğrencilerin dış mekanlardaki aktivite paternleri üzerindeki olası etkisini araştırmak için iki aşamalı bir çalışma tasarlandı. Bu araştırmanın ilk aşamasındaki 12 günlük gözlem çalışmaları, bir davranış haritası üretti ve bu, bir Gölge Davranış Simülasyonu (SBS) haritasıyla birleştirildiğinde bu araştırmanın İlgi Noktalarını (POI) belirledi. Daha sonra, ikinci aşamada, 13 gün boyunca POI'lerde mikroiklim faktörleri ölçülürken, rastgele seçilmiş kişiler tarafından 64 anket dolduruldu.

Belirtilen araştırma sorularını ele almak, hipotezleri test etmek ve tasarım önerileri sunmak amacıyla, biyometeorolojik RayMan modeli, Fizyolojik Eşdeğer Sıcaklık (PET) endeksi ve modifiye PET kullanıldı, ayrıca Sosyal Bilimler İçin İstatistiksel Paket (SPSS) kullanılarak ve mikroiklimi dikkate alan bilişsel haritalar ile istatistiksel analizler yapıldı. Bu çalışmanın bulguları, nicel ve nitel sonuçlar arasında iyi bir uyum göstermiş, güneş ışıınımını en önemli mikroiklim faktörü olarak sunmuştur. İnsan termal konforu da çalışma alanındaki aktivite paternleri üzerinde bir etkisi olmuştur, ancak sabit aktiviteler için oturma mevcudiyeti ve hareketli aktiviteler için planlama ve işlev kadar önemli olmamıştır.

Anahtar Kelimeler: Açık hava termal konforu; PET; mPET; Akademik kampüs; Aktivite paternleri; Ankara

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CS	Cold Stress
CTIS	Climate-Tourism/Transfer-Information-Scheme
EBM	Energy Balance Model
ENVI-met	Environmental Virtual Intelligent Model
HS	Heat Stress
HVAC	Heating, Ventilation, and Air Conditioning
KG	Köppen-Geiger
KHS	Kestrel Heat Stress Station
m	Meter
MAP	Mean Annual Precipitation
MAT	Mean Annual Temperature
MEMI	Munich Energy Balance Model for Individuals
mPET	Modified Physiological Equivalent Temperature
NS	No Thermal Stress
PET	Physiologically Equivalent Temperature

PMV	Predicted Mean Vote
POE	Post-Occupancy Evaluation
POI	Point Of Interest
PPD	Predicted Percentage of Dissatisfied
PR	Perspiration Rate
RH	Relative Humidity
RQ	Research Question
SBS	Shadow Behavior Simulation
SSV	Cold Sensation Vote
Sub-RQ	Sub Research Question
T_a	Air Temperature
T_{cold}	Temperature of the Coldest Month
T_{Cr}	Core Temperature
TCV	Thermal Comfort Vote
T_g	Globe Temperature
T_{hot}	Temperature of the Hottest Month
T_{mrt}	Mean Radiant Temperature
T_{sk}	Skin Temperature
TSV	Thermal Sensation Vote

UTCI	Universal Thermal Climate Index
V	Air/wind Velocity
WMO	World Meteorological Organization
WSV	Warm Sensation Vote



CHAPTER 1

INTRODUCTION

1.1. Problem Statement

As a consequence of climate change with increase in the temperature, climatic and specifically microclimatic factors are supposed to play important role in success or failure of outdoor spaces. Studies have shown that maintaining a comfortable thermal environment can significantly affect people's health, productivity, and general well-being (de Dear & Brager, 2002; Fanger, 1970). There exists a positive correlation between elevated air temperature and heightened mortality rates resulting from heat exposure during periods of extreme summer temperatures (Harlan et al., 2006). Furthermore, as per certain research, elevated temperatures have an impact not only on an individual's physical well-being but also on their mental well-being (Kuo, 2015). According to Anderson (2001), there exists a correlation between elevated temperatures and certain forms of aggressive behaviors. Furthermore, Hansen et al. (2008) have established a correlation between heat waves and the occurrence of psychological and behavioral

disorders. Even more intriguingly, climate and weather have an impact on people's perceptions of beauty (Thorsson et al., 2007).

Additionally, thermal comfort is intricately linked to the activity patterns and behavior of humans, with people often attending places with better weather parameters and adapting their activities and clothing choices in response to fluctuations in temperature (Ingegård Eliasson et al., 2007; Nicol et al., 2012). Comprehending the correlation between human thermal comfort and activity patterns in open-air areas is of importance in the creation of more livable, sustainable, and comfortable environments (Chen & Ng, 2012; Nikolopoulou & Steemers, 2003).

According to Nikolopoulou et al. (2001), a purely physiological approach falls short of describing comfort conditions outdoors, and creating public places requires an awareness of the dynamic human parameter. Regarding the same research, although the thermal environment has a significant impact on how people use these spaces, psychological adaptation also plays an important role in such spaces with few constraints. In a nutshell, the concept of thermal comfort has both physiological (quantitative approach) and psychological (qualitative approach) components, and we must comprehend how these components interact, in order to create the optimal comfort conditions (Aram et al., 2020; Lenzholzer & van der Wulp, 2010; Nikolopoulou & Steemers, 2003).

So far, in order to address local thermal comfort risk factors, a developing bottom-up perspective with a focus on the implementation of measures enables local decision makers and designers to investigate how the field of urban design can enhance the bioclimatic conditions within local scales (Nouri & Costa, 2017a). Nouri (2013) proposes a bottom-up approach to address climate change, which provides an opportunity to enhance the effectiveness of dominant top-down strategies in local contexts.

Additionally, there is a need for greater incorporation of microclimatic assessments to bridge the gap between urban climatology and urban planning/design, with the aim of mitigating the effects of climatic uncertainty. In this research, bottom-up perspective was taken to make sure that not just severe climatic conditions, but also constant changes in air temperature, wind speed, and sun radiation, are assessed.

There are a lot of research addressing physiological and / or psychological aspects of thermal comfort in outdoor and / or indoor built environments, such as public places, residential buildings, urban squares, and so on. Academic campuses are one of the built environment types in which a wide range of people (lecturers, staff, students, and visitors) spend majority of their time; hence, environmental factors may affect them significantly. In general, studies with a behavioral approach to environmental design seem of benefit for evaluation and development of these environments. However, according to Abu-Ghazze (1999), the inquiry into published literature pertaining to the utilization of open spaces on campuses has indicated that the available literature primarily focuses on technical advancements and design-related concerns, or alternatively, delves into the elucidation of financial considerations, educational policies, and extensive

planning. Insufficient scholarly inquiry exists regarding the manner in which individuals utilize outdoor spaces within campus environments (Abu-Ghazze, 1999; Göçer et al., 2018; Salama, 2009). In particular, there exists a pressing need for further investigation into the thermal comfort levels experienced within outdoor campus environments (Huang et al., 2019) considering the increasing need for solutions against global warming and importance of academic campuses outdoor spaces. In addition, relating these environmental factors, e.g. thermal comfort condition, with activity patterns in outdoor spaces of academic campuses seems of noteworthy importance that taken into account in the present research.

1.2.Aim of the Study

Main objective of the present research is to address the possible effect of human thermal comfort conditions on lecturers' and students' activities within the outdoor spaces of an academic campus. In this regard, Bilkent University's main campus in the city of Ankara was chosen to carry out the mentioned investigation, and a three-layered approach was taken which consisted of: i) behavioral studies, to determine activity patterns of the people in terms of places chosen for stationary and / or moving activities; ii) psychological aspects of human thermal comfort; and, iii) physiological aspects of human thermal comfort. Subsequently, the following sub-objectives were set for this research:

- i. To investigate possible relations among three layers of the research, which are: a) moving and stationary activities zones, b) physiological thermal comfort, and c) psychological thermal comfort;
- ii. To examine the possible effects of the built environment, natural elements, and amenities on physiological and psychological aspects of thermal stress levels of the people;
- iii. To identify the thermal risk factors that exert a greater influence on the physiological and psychological dimensions of thermal comfort experienced by individuals.

1.3. Structure of the Thesis

The current thesis is organized into six chapters with the aim of achieving the aforementioned objective and sub-objectives. These consecutive chapters are designated as follows:

Chapter 1 provides an introductory overview that includes a concise background of research topics. These topics encompass the significance of human thermal comfort studies, the psychological and physiological aspects of such studies, the bottom-up approach utilized in biometeorological research, and the environmental studies conducted

in academic campuses. Subsequently, the deficiencies in the current body of literature were identified, and the aim of the investigation as well as the organization of the thesis were delineated.

Chapter 2 provides a comprehensive review of the existing literature pertaining to studies that are similar in nature. This chapter encompasses a range of research endeavors, including behavioral studies conducted through observational methods, environmental studies conducted in outdoor spaces on academic campuses, and investigations into human thermal comfort from both psychological and physiological perspectives.

The third chapter elaborates on the biphasic methodology employed in the inquiry undertaken in this study. Following the disclosure of research questions and hypotheses, case study of this study was introduced. Then, this chapter expounded on the process of establishing points of interest through the utilization of behavioral map and shadow behavior map. Subsequently, the second phase of the investigation, comprising of the main experiments, involved conducting '*in-situ*' microclimatic measurements and questionnaires. Subsequently, the details of the data analyses were discussed.

Chapter 4 presents the results derived from both quantitative and qualitative evaluations, incorporating statistical and subjective analyses. The results are shown in 2 major parts: (1) determining points of interest (phase I), (2) main study (phase II). Results of this study are presented using various maps, tables, graphs, and Climate-Tourism/Transfer-Information-Scheme (CTIS) heat maps.

Chapter five of this study presents a discussion on the findings by means of a comparison with the extant literature and a connection to the hypotheses posited in this study.

Subsequently, the final chapter of the thesis provides a concise overview of the research objectives and highlights the key areas of focus. This chapter includes design recommendations, a discussion of the study's limitations, and an exploration of potential methods for improving the research through further applications.



CHAPTER 2

LITERATURE REVIEW

This chapter provides a comprehensive review of the literature with regard to the investigation of the relationship between human thermal comfort and activity patterns in outdoor environments on the main campus of Bilkent University. The primary objective of the literature review is to furnish a comprehensive comprehension of the present state of knowledge in this particular field, pinpoint research gaps, and establish the groundwork for our investigation.

Before delving into specific studies, it is necessary to develop a conceptual framework for comprehending human thermal comfort and its relationship to activity patterns in outdoor spaces. Thermal comfort, as defined by Fanger (1970), is the subjective gratification of an individual with their thermal environment. In environmental and urban design studies, the concept of activity patterns often refers to how individuals or groups use space over time. The activity patterns encompass variables such as the temporal and spatial characteristics of activities, their duration, and the transitions between them (Gehl & Svarre, 2013; Hillier & Hanson, 1989).

2.1. Observational Studies

Observational studies have been widely used to gather data on human behavior in different settings. They provide an opportunity to study human activity patterns as they occur naturally, without any form of experimental manipulation (Lofland et al., 2022). In the context of outdoor spaces, observational studies allow us to understand how individuals use and interact with these areas, including their choice of location based on environmental and personal factors. Direct observations facilitate comprehension of the factors that contribute to the utilization of certain spaces while others remain unused (Gehl & Svarre, 2013). Empirical observation of human behavior is proposed as a viable approach to comprehending human needs and preferences, as well as studying human behavior effectively (Studer, 1969). The same study claimed that the concept of need cannot be directly observed, but rather its presence can only be deduced through the examination of its observable manifestation, which is behavior; the analysis of human behavior is a suitable subject of study due to its pertinent characteristics that can be empirically verified and operationally defined.

A number of studies have utilized this approach to study outdoor spaces. For instance, the utilization of systematic observation was employed by William H. Whyte (1988) in his seminal work to gain insight into the patterns of human behavior in urban public spaces. The aforementioned methodology has yielded numerous insights regarding the optimal conditions and attributes of these environments as perceived by their users. These include

the significance of seating arrangements and the desirability of spaces that receive ample sunlight.

Another research that employed observation in environmental studies was conducted by Mehta (2009). Mehta utilized a combination of behavioral mapping and user interviews in his study to examine the impact of urban design on promoting social interactions in commercial streets within neighborhoods. Behavioral mapping is a methodical approach to observing and documenting the ways in which individuals utilize the physical space and time of the street environment. This facilitated the investigation to objectively capture the interaction between individuals and their urban environment.

Salama et al. (2013) claimed that unplanned observation have the potential to yield insufficient outcomes, which may merely uncover what appears to be self-evident. He also believed that the process of systematically observing behavior encompasses four distinct elements, namely people, activities, setting or space, and timing. Using this framework, Ashraf Salama has conducted observational studies in various environments (Salama, 2009; Salama et al., 2013). The utilization of observation as a research methodology in the aforementioned studies, as well as in other studies, e.g. (Abu-Ghazze, 1999; I. Eliasson et al., 2007; Katzschner et al., 2006; Manahasa & Özsoy, 2016; Mattsson, 2019; Sulaiman, Abdullah, & Othman, 2019; John Zacharias et al., 2001), highlights the significance and effectiveness of this approach in the realm of environmental and urban studies.

2.2. Study of Academic Outdoor Spaces

The investigation of the role of outdoor areas within educational environments has garnered attention from scholars, professionals in architecture, and urban planners alike (Dober, 2000). The significance of these areas for academic achievement, interpersonal communication, and the welfare of students is supported by an increasing amount of scholarly literature (Göçer et al., 2018; Manahasa & Özsoy, 2016). As claimed by Göçer et al. (2018), the outdoor spaces on university campuses can serve as hubs for social and cultural activities, catering not only to the student and staff populations, but also to the wider community. Furthermore, it is important to consider that inadequate environmental conditions can have a negative impact on the educational process and learning activities, leading to demotivation and interruptions; therefore, it is imperative to contemplate environmental factors in a more effective manner (Khalil et al., 2011; Manahasa & Özsoy, 2016).

Manahasa and Özsoy (2016) presented an argument regarding the significance of socialization for young individuals in a university setting. They emphasized that adopting a different viewpoint, in particular shared social-academic spaces, can render Post-Occupancy Evaluation (POE) a valuable tool for contemplation. Their research aimed to assess the impact of spatial characteristics and aesthetic quality on student satisfaction and work performance. Factors such as building layout, thermal comfort, lighting, sound

comfort, and maintenance are evaluated to determine if they align with designer expectations.

A study by Abu-Ghazze (1999) investigated the outdoor spaces at the University of Jordan in Amman, focusing on how these spaces were perceived and utilized by users, including students, faculty, and administrative staff. Using a qualitative approach, the study examined human-environment interactions and how these inform decision-making concerning outdoor spaces. The mentioned study findings suggested that the outdoor areas between university buildings served as key activity centers for students.

Huang et al. (2019) conducted a study that examined the thermal comfort experienced outdoors on a university campus. The objective was to enhance student engagement in outdoor activities and social interactions by comprehensively comprehending their thermal comfort preferences. The investigation involved the collection of field measurements and the administration of a questionnaire survey during both winter and summer seasons. The research investigated adaptive behavior and found that as the Physiologically Equivalent Temperature (PET) increased, the probability of individuals engaging in behaviors such as "using an umbrella", "removing clothing", and "moving to a shaded area" increased, while the likelihood of "staying under the sun" decreased. The investigation also encompassed an examination of the ambient temperatures during various seasons, which were subsequently juxtaposed with analogous results from prior

research endeavors. The findings provided significant perspectives for the strategic development and configuration of open-air areas to optimize the thermic milieu.

A research by Salama (2009) endeavored to investigate the outdoor spaces of Qatar University by juxtaposing the initial design objectives with the feedback provided by users after a period of two decades of use. The study employed various techniques such as walk-through evaluations, direct observations, behavioral mapping, and survey questionnaires to identify potential issues that could adversely affect diverse campus users. The study's findings suggested that a thorough comprehension of the extent to which these open-air areas cater to the requirements of their users could facilitate the formulation of suggestions aimed at alleviating the environment and augmenting work and educational encounters.

The study by Rinchumphu et al. (2021) aimed to explore potential strategies for enhancing outdoor thermal comfort in the Faculty of Engineering at Chiang Mai University, Thailand, where elevated temperatures were a prevalent issue. The decision-making process of this investigation involved the evaluation of three distinct design alternatives, namely the inclusion of a pond, large trees, or shrubs. The PET was computed for each alternative through the utilization of ENVI-met simulation software (Rinchumphu et al., 2021). The findings of the mentioned research indicated that the optimal strategy was to place sizable trees in the south-west region, as this led to a reduction of 3.17% in PET when compared to the reference scenario. The research

findings also suggested that this particular methodology can effectively facilitate the sustainable advancement of open-air communal areas situated in tropical university campuses.

2.3. Human Thermal Comfort

The matter of human thermal comfort and related fields have garnered significant attention from scholars, particularly in light of the current era of climate change and the rise in urban heat islands. Human thermal comfort refers to the condition of mind that expresses satisfaction with the surrounding thermal environment (ASHRAE, 2017). It is a complex perception shaped by a variety of physical, personal, and environmental factors (Fanger, 1970). More particularly, human thermal comfort is influenced by two categories of factors: environmental and individual. The main categories of meteorological (environmental) parameters that affect the thermal environment include air temperature, wind/air-speed, solar radiation, and relative humidity (Katzschner et al., 2006). The main personal characteristics are the level of clothing and metabolic rate.

The term ‘outdoor thermal comfort’ refers to the temperature at which a person feels comfortable and describes the state in which they do not feel hot or cold (ASHRAE, 2017; Staiger et al., 2012). Thermal comfort, according to this definition, is a personal experience that one has when in a location or environment and that differs from person to person (Nikolopoulou & Lykoudis, 2006). Because there are more interactions between

the physical environment, physiological and psychological mechanisms, and extra-temporal and spatial variables that may affect thermal comfort outdoors than indoors, it is more difficult to analyze thermal comfort outdoors (Aram et al., 2020; Nikolopoulou, 2011). Therefore, the concept of thermal comfort has two components: physiological and psychological, and in order to achieve the best conditions for comfort, we must comprehend how these two components interact (Aram et al., 2020; Lenzholzer & van der Wulp, 2010; Nikolopoulou & Steemers, 2003). Furthermore, according to Chen and Ng (2012), an assessment framework should operate on at least four levels: physical, physiological, psychological, and social/behavioral, in order to evaluate the perception of outdoor thermal comfort from a behavioral perspective. As per the same study, static and objective factors (such as physical and physiological traits) should be accurately measured and modeled to provide "climatic knowledge," while dynamic and subjective factors (such as psychological and social / behavioral traits) call for in-depth field observations and interviews to provide "human knowledge".

Based on the existing literature in the field reviewed, a review of examples of outdoor thermal comfort studies is provided in **Table 1**, which is designed in terms of: city and climate of the research, urban area in which the study was conducted, survey period, survey method, thermal comfort assessment index / indices employed in the study, levels of consideration which may range from Physical and Physiological to psychological and social / behavioral, and source.

Table 1. A review of examples of outdoor thermal comfort studies.

City & climate	Urban area	Survey period	Survey method	Thermal comfort index	Levels of consideration	Source
Chiang Mai, Thailand; Tropical	A campus public space	April 2020	Alternatives simulation, Meteorological measurements	PET	Physiological	(Rinchumphu et al., 2021)
Madrid, Spain; Mediterranean	Three places nearby an urban park	June – September 2018	Microclimatic measurements, Questionnaires	PET	Physiological, Psychological	(Aram et al., 2020)
Lisbon, Portugal; Mediterranean	Historical public space	July 2015	Simulation analyses, Microclimatic measurements, Interview	PET	Physical, Physiological, Psychological	(Nouri & Costa, 2017a)
Taichung, Taiwan; Subtropical	Public square	Four seasons 2007-2008	Physical measurements Observation, questionnaires	PET	Physiological, Psychological, Social/behavioral	(T.-P. Lin, 2009)
Athens, Greece; Temperate	Neighborhood square, seashore place	Four seasons 2001-2002	detailed microclimatic monitoring, Interview, questionnaires, observation	-	Physiological, Psychological, Social/behavioral	(Nikolopoulou & Lykoudis, 2007)
Tokyo, Japan; Temperate	Square and park	March, May 2004-2005	Interview, Observation, Micrometeorological measurements	PET	Physiological, Psychological, Social/behavioral	(Thorsson et al., 2007)
Kassel, Germany; Temperate	Open space near a bistro	April - June 2005	Observation, presence counting, Meteorological measurements	PET	Physiological, Psychological, Social/behavioral	(Katzschner et al., 2006)
Gothenburg, Sweden; Temperate	Urban park	Summer, Autumn 2002	Interview, questionnaires, vote	PMV	Psychological, Social/behavioral	(Sofia Thorsson et al., 2004)
Cambridge, UK; Temperate	Open spaces	Spring, Summer, Winter 1997	Interview, Attendance counting	PMV / PPD	Physical, physiological, psychological	(Nikolopoulou et al., 2001)
Montreal, Canada; Temperate	Plazas, Public squares	Spring, Summer, Autumn	Observation, presence counting	-	Psychological, Social/behavioral	(John Zacharias et al., 2001)

2.3.1. Microclimatic Factors

Research has shown that one of the most critical elements impacting thermal comfort is Air Temperature (T_a) with the unit of Celsius ($^{\circ}\text{C}$), and even tiny changes in it can significantly affect how individuals perceive their surroundings. For instance, a research by Fanger (1970) discovered that a 7% difference in the number of people reporting thermal discomfort might arise from a change in T_a of just 1°C . In addition, after Mean Radiant Temperature (T_{mrt}), Air Velocity (V), and Relative Humidity (RH), de Dear and Brager (2002) concluded that T_a was the most crucial element affecting thermal comfort. However, different T_a ranges may be viewed as either comfortable or uncomfortable since they are challenging to control, especially in outdoor settings. Due to this, it has been determined that T_a only is insufficient to measure '*in-situ*' human thermal comfort, particularly in outdoor settings (Charalampopoulos & Santos Nouri, 2019; dos Santos Nouri, 2018).

Relative Humidity (RH), which is measured in per cent (%), affects thermal sensation through its impact on evaporative cooling, which is the body's primary method of heat loss under warm and hot conditions (Höppe, 1999). Hence, the effect of RH is closely linked to T_a . When compared to other climatic variables, RH has a relatively small effect on human thermal comfort (both physiological and psychological) within a particular range (Jing et al., 2013; Li et al., 2011), yet its influence on thermal comfort at high and low temperatures should not be disregarded.

Wind velocity (V), typically measured in meters per second (m/s), affects thermal comfort by influencing convective heat exchange and evaporative cooling. Wind can provide relief in hot conditions, but it may exacerbate cold stress under cooler conditions (Nikolopoulou et al., 2001). The mechanical force of V may have a direct impact on how outdoor settings are used, or it may have an indirect impact through its capacity to control thermal conditions (Katzschner et al., 2006; Walton et al., 2007). Structures in the built/natural environment, such as buildings and landscape features, may have an impact on V and its impact on human thermal comfort. These structures can either increase or decrease the mechanical effect of V (Mironova, 2020; Ricci et al., 2022; van Druenen et al., 2019).

The Mean Radiant Temperature (T_{mrt}) in Celsius ($^{\circ}\text{C}$) is the other crucial meteorological factor affecting human thermal comfort and energy balance. T_{mrt} measures the impact of radiation heat exchange between the body and its surroundings (Guo et al., 2020). The temperature of the surfaces around it, as well as elements like sunlight and shadow, have an impact (Thorsson et al., 2007). T_{mrt} typically reveals a wide range in outdoors conditions, particularly when comparing sites that are shaded and those that are exposed to the sun. In addition to its significance in outdoor thermal comfort, according to (d'Ambrosio Alfano et al., 2023), the only interior thermal comfort factor that a Heating, Ventilation, and Air Conditioning (HVAC) system cannot directly alter is T_{mrt} . As stated by Guo et al. (2020), more work has to be put into T_{mrt} research to address the geometric difficulties of radiant heat transfer.

2.3.2. Human Factors in thermal comfort

Human factors, including metabolism, clothing, and personal preferences, significantly influence thermal comfort. Studies suggest that individuals can adapt to a wide range of conditions, indicating that thermal comfort is not purely a physical phenomenon but also has a strong subjective component (de Dear & Brager, 1998). Therefore, the degree of activity affects energy generation in the human body, resulting in influencing human thermal comfort. Another individual aspect influencing human thermal comfort is clothing insulation, which is defined as the thermal insulation given by clothes and is expressed in clo units (Schiavon & Lee, 2013). In this regard, a research by Lin and Chen (2019), examined the thermal impact on individuals wearing half-mask respirators such as N95 masks in indoor environments with high heat and humidity. The mentioned study found that wearing respirators created a thermal microclimate within the mask, with the heat index in N95 masks rising to a risk level of "Extreme Danger" (61.2–67.9 °C). The use of respirators led to increased metabolic heat, promoting localized thermoregulation (Lin & Chen, 2019). Furthermore, skin moisture increased by 77%-588% and transepidermal water loss increased by 18%-72% when wearing N95 masks. Additionally, stating that body surface area is important for heat exchange, Havenith (2001) claimed that physical fitness and acclimatization, anthropometric characteristics, and gender are also of importance in the human response to heat stress.

2.3.3. Thermal Comfort Indices

Thermal comfort indices are tools used to estimate human thermal comfort based on various environmental and personal parameters. Widely used indices include the Predicted Mean Vote (PMV) and the Physiological Equivalent Temperature (PET) (Blazejczyk et al., 2012). These indices aim to predict the thermal sensation and comfort of people in different environments.

The Predicted Mean Vote (PMV) index, developed by Fanger (1970), estimates the average thermal sensation of a group of individuals based on their clothing, activity levels, and environmental parameters. The Physiological Equivalent Temperature (PET) index, introduced by Höppe (1999), combines air temperature, humidity, wind speed, and radiation into a single value representing the perceived thermal environment. The PET index is defined as the temperature at which Skin Temperature (T_{sk}), Core Temperature (T_{cr}), and Perspiration Rate (PR) are identical to those under measured conditions (Höppe, 1999; Höppe, 1993; Mayer & Hoppe, 1987). Thus, the human body's heat equilibrium is maintained within a metabolic rate of 80 W and a heat resistance of 0.9 clo (clothing insulation). The PET index with the Celsius ($^{\circ}\text{C}$) unit is particularly well-suited for assessing outdoor thermal comfort because it transfers the assessment of a complex outdoor climatic environment to a simple interior situation on a physiologically similar basis, and it is easily interpreted and communicated to non-climatic professionals (Matzarakis & Amelung, 2008). So far, the modified Physiological Equivalent

Temperature (mPET) has been improved against the weaknesses of the original PET by enhancing evaluation of the humidity and clothing variability (Chen & Matzarakis, 2018). In the same study, the researchers claimed that comparisons of PET, mPET, and Universal Thermal Climate Index (UTCI) have shown that mPET gave a more realistic estimation of human thermal sensation than the other two thermal indices (PET, UTCI) for the thermal conditions in Freiburg. Another thermal comfort index popular among researchers of this field is Universal Thermal Climate Index (UTCI), proposed by Jendritzky et al. (2012). This thermal comfort index integrates multiple climatic parameters to assess thermal comfort.

CHAPTER 3

METHODOLOGY

The following chapter introduces the methodology of the present research discussing research questions and hypotheses, study area, and procedure of the study. The present study was conducted in two phases covering computational simulations and analyses, observational studies, '*in-situ*' microclimatic measurements, and '*in-situ*' questionnaires. The interdisciplinary nature of the present research addresses wide range of fields dealing with urban spaces, human beings, and climatic issues.

The general framework of the present study aims to include comprehensive levels of consideration ranging from qualitative to quantitative aspects associated with human wellbeing and preference. The aforementioned comprehensiveness employing the software (for physical aspects), field studies (for physical, physiological, and psychological aspects), and technical measurements (for physical and physiological aspects) is inspired by previous studies (Aram et al., 2020; Lenzholzer, 2012; Nouri & Costa, 2017a).

Also, study area chosen for this research is a part of an educational campus. Literature review shows that investigation on environmental conditions in educational campuses has been suffering (Salama, 2009). Even the existing literature investigating thermal comfort conditions in educational campuses mostly lack various approaches which are common in this field (e.g. psychological, physiological, and physical). Hence, more research is needed on thermal comfort in campus outdoor environments (Huang et al., 2019) .

3.1. Research Questions and Hypotheses

The undertaken research focuses upon the relationship between human thermal comfort conditions in one of the most crowded zones of Bilkent university's main campus with the activity of the users at the outdoor spaces. Accordingly, importance of thermal comfort conditions in attendance level at the outdoor spaces in a university campus was measured. In addition, importance level of various microclimatic measures were compared for conditions of this study. Within this context, the following major research question and also sub research questions were inquired, to interrogate the objectives of this study:

RQ: How much does thermal comfort condition affect activity patterns within the outdoor spaces of an academic campus?

Sub-RQ1: How much do natural elements (water and greenery) affect thermal perception of the occupants?

Sub-RQ2: How much do natural elements (water and greenery), amenities (benches), and entrances of the adjacent buildings affect stationary and moving activities patterns of the occupants?

Sub-RQ3: What are the microclimatic factors that put in a greater influence on thermal comfort and consequently activity patterns of the occupants?

Subsequently, the corresponding hypotheses were formulated to meet the objectives of this study which was conducted within the outdoor spaces of an academic campus:

H1: There is a positive relation between thermal comfort conditions and repetitions of activities of the people.

H2: Natural elements (water and greenery) affect thermal perception of the individuals significantly.

H3: Natural elements (water and greenery), amenities (benches), and entrances of the adjacent buildings affect stationary and moving activities patterns of the occupants significantly.

H4: Solar radiation and shading have the greatest influence on physiological and psychological aspects of thermal comfort and, by extension, the activities of the occupants.

3.2. Study Area

This study is carried out in two phases from May to September of 2022 in the capital city of Turkey, Ankara, where according to Nouri et al. (2021) little thermo-physiological investigations have been conducted thus far. Ankara is located at the latitude of 39° 55' 32" N and the longitude of 32° 51' 59" E. The principal Köppen-Geiger (KG) climate classification of Ankara is defined as '*Dsb*' which relates to a cold climate, with warm and dry summers (**Table 2**) (Peel et al., 2007). However, further studies showed that it is feasible to confirm that the KG classification of Ankara and its near surroundings has created some incongruity in terms of its KG classification (Nouri et al., 2021). Santos Nouri et al. (2021) revealed that the actual KG class of Ankara is '*Dsa*', which states a cold climate and dry and hot summers; also, it is adjacent to further classifications, namely that of '*Csa*' and '*BSk*', which equate to dry-hot summers and cold-semiarid climate, respectively. Being supposed to have critical climatic conditions, dry hot summers and also snowy cold winters, makes Ankara worth to host more climate studies in winter and summer.

According to the Turkish State Meteorological Service website (2022), average temperatures (recorded from 1981 to 2010) of Ankara for the months May, June, July, August, and September, are 16.3 °C, 20.3 °C, 23.7°C, 23.7°C, and 19.0 °C, respectively. This period of the year is selected for this research because all of the other months demonstrate lower average temperatures.

The field study of this research is carried out on the main campus of Bilkent University. Bilkent university is a private university in Turkey having its campus located about 12 kilometers west of the center of Ankara and covers an area of more than 300 hectares. Bilkent university has three campuses – Main, Middle and East.



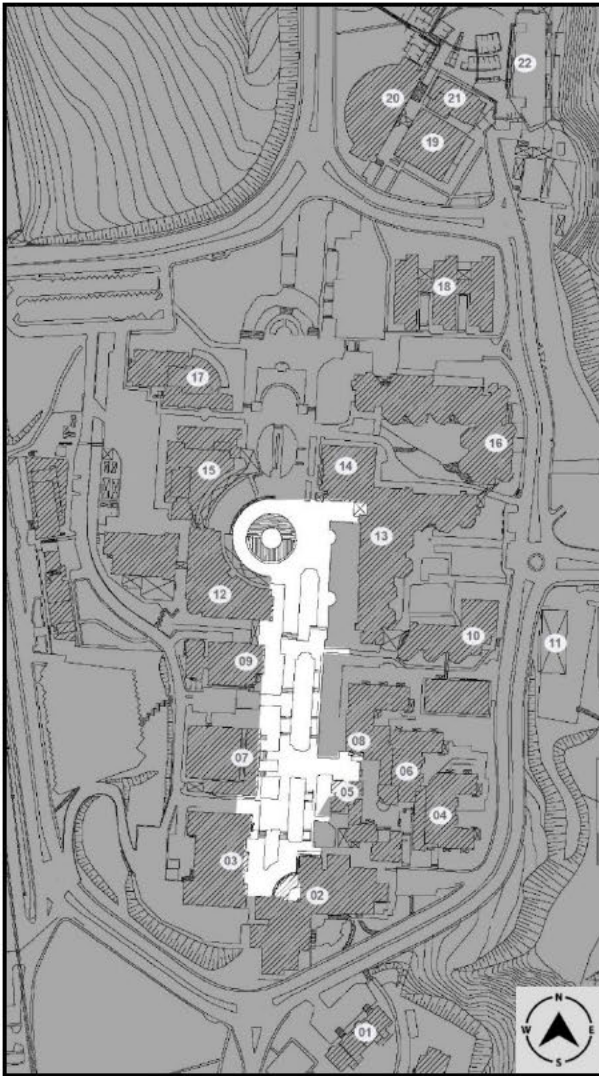
Table 2. Descriptive environmental summary of the Köppen-Geiger classification classes within Ankara (Peel et al., 2007) (Santos Nouri et al., 2021).

KG class	Colloquial name of sub-classification	General classification descriptors	Specific environmental thresholds			
			Precipitation descriptors		Temperature descriptors	
			General description	Climate specification	General description	Climate specification
'Dsb'	Snow/cold climate with dry/warm summer	$T_{hot} \leq 21\text{ }^{\circ}\text{C}$ and $T_{cold} \leq 0$	Dry summer	$P_{sdry} < 40$ and $P_{sdry} < P_{wwet}/3$	Warm summer	$T_{hot} \leq 21\text{ }^{\circ}\text{C}$ and $T_{mon10} \geq 4$
'Dsa'	Snow/cold climate with dry hot summer	$T_{hot} \leq 21\text{ }^{\circ}\text{C}$ and $T_{cold} \leq 0$	Dry summer	$P_{sdry} < 40$ and $P_{sdry} < P_{wwet}/3$	Hot summer	$T_{hot} \geq 22\text{ }^{\circ}\text{C}$
'Csa'	Warm temperate with dry hot summer	$T_{hot} > 10\text{ }^{\circ}\text{C}$ and $T_{cold} < 18$	Dry summer	$P_{sdry} < 40$ and $P_{sdry} < P_{wwet}/3$	Hot summer	$T_{hot} \geq 22\text{ }^{\circ}\text{C}$
'BSk'	Cold semi-arid climate	$MAP < 10 \times P_{threshold}$	Steppe	$MAP \geq 5 \times P_{threshold}$	Cold	$MAT < 18\text{ }^{\circ}\text{C}$

MAT, mean annual temperature; T_{hot} , temperature of the hottest month; T_{cold} , temperature of the coldest month; T_{mon10} , number of months where the temperature is above 10; MAP, mean annual precipitation; P_{sdry} , precipitation of the driest month in summer; P_{wdry} , precipitation of the driest month in summer; P_{wwet} , precipitation of the wettest month in winter; $P_{threshold, 2 \times MAT}$ (Nouri et al., 2021) (Peel et al., 2007).

More specifically, study area of this research is an academic campus outdoor space inside the main campus surrounded by educational buildings, health center, sports center, cafes, and restaurants (see **Figure 1**). There is a considerable diversity of functions in the buildings surrounding the mentioned space. This diversity, along with nearly all of the graduate and undergraduate classes (except for faculty of music and performing arts and English language preparatory programs) being held in this part of the campus, gives considerable importance to the above-mentioned part of the campus. In addition to having all of these important facilities, the selected zone, connects the student dorms to the library, rector's building, and Table d'Hote restaurant (see **Figure 2**). Regarding the surrounding facilities and connecting potential of the place, the selected zone is one of the main central footfall axes throughout Bilkent university campus.

Figure 1. Study area and its surrounding map
(Illustration by the author, 2023).



01, student dormitory (50. Yurt); 02, faculty of art, design, and architecture (FF); 03, food court (Speed-Kirac); 04, faculty of art, design, and architecture (FA); 05, faculty of art, design, and architecture (FD); 06, faculty of art, design, and architecture (FB); 07, sports center; 08, faculty of art, design, and architecture (FC); 09, advanced research laboratory; 10, faculty of business administration; 11, mosque; 12, Faculty of science (SA); 13, faculty of economics, administrative, and social sciences; 14, health center; 15, Faculty of science (SB); 16, faculty of education; 17, faculty of law; 18, school of applied languages; 19, 20, 21, library; 22, Table d'Hote restaurant.

Figure 2. The selected zone, connects the student dorms to the library, rector's building, and Table d'Hote restaurant
(Illustration by the author, 2023).

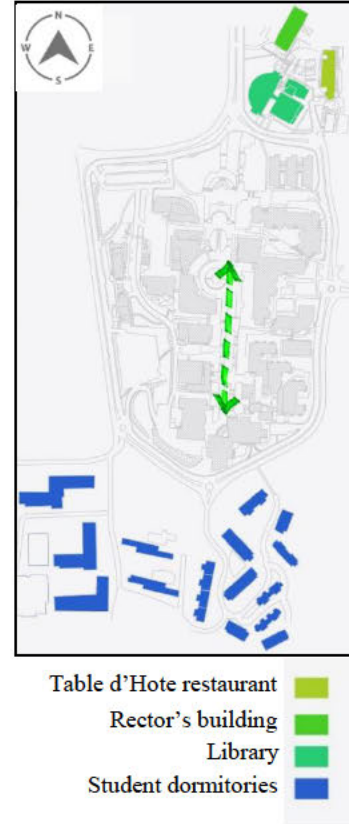


Table d'Hote restaurant
Rector's building
Library
Student dormitories

In order to have more accurate places for conducting the ‘*in-situ*’ microclimatic measurements, 6 Points Of Interest (POI) were determined inside the above-mentioned zone. All of the ‘*in-situ*’ microclimatic measurements and ‘*in-situ*’ questionnaires were conducted inside the shown circular areas with diameter of 5m (points of interest). POIs 1, 2, and 5 are located close to entrance of important buildings, which increases the possibility of having bigger footfall. In addition, POIs 1, 3, and 4 are located on a way which connects important facilities in north and south of the study area. POIs 3, 4, and 6 are supposed to have more stationary activities due to amenities. POIs 2, 3, and 4 have more adjacency with greenery, and POI 6 is adjacent to a pool with active water fountains. Attributes of any of these POIs in terms of users’ behavior and shadow/sun condition are discussed in more details in the 4th chapter.

Figure 3. Points Of Interest (POI) of the study area
(Illustration by the author, 2023).



-  Building entrance
-  Point Of Interest (POI)
-  Bench



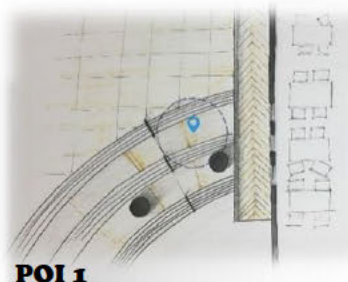
POI 5

- ✓ Adjacent to entrances of health center and faculty of economics, administrative, and social sciences
- ✓ Adjacent to Break café
- ✓ 0 hours of shading
- ✓ Moving activities zone



POI 3

- ✓ Adjacent to greenery
- ✓ Afternoon shaded
- ✓ Stationary activities zone



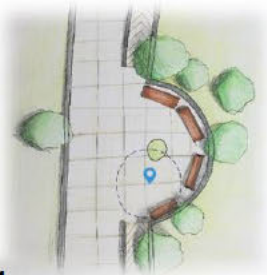
POI 1

- ✓ Entrance of FF building
- ✓ Mostly shaded
- ✓ Moving activities zone



POI 6

- ✓ Adjacent to entrance of SB building
- ✓ Adjacent to the pond
- ✓ 0 hours of shading
- ✓ Stationary activities zone



POI 4

- ✓ Adjacent to greenery
- ✓ Sometimes shaded
- ✓ Stationary activities zone



POI 2

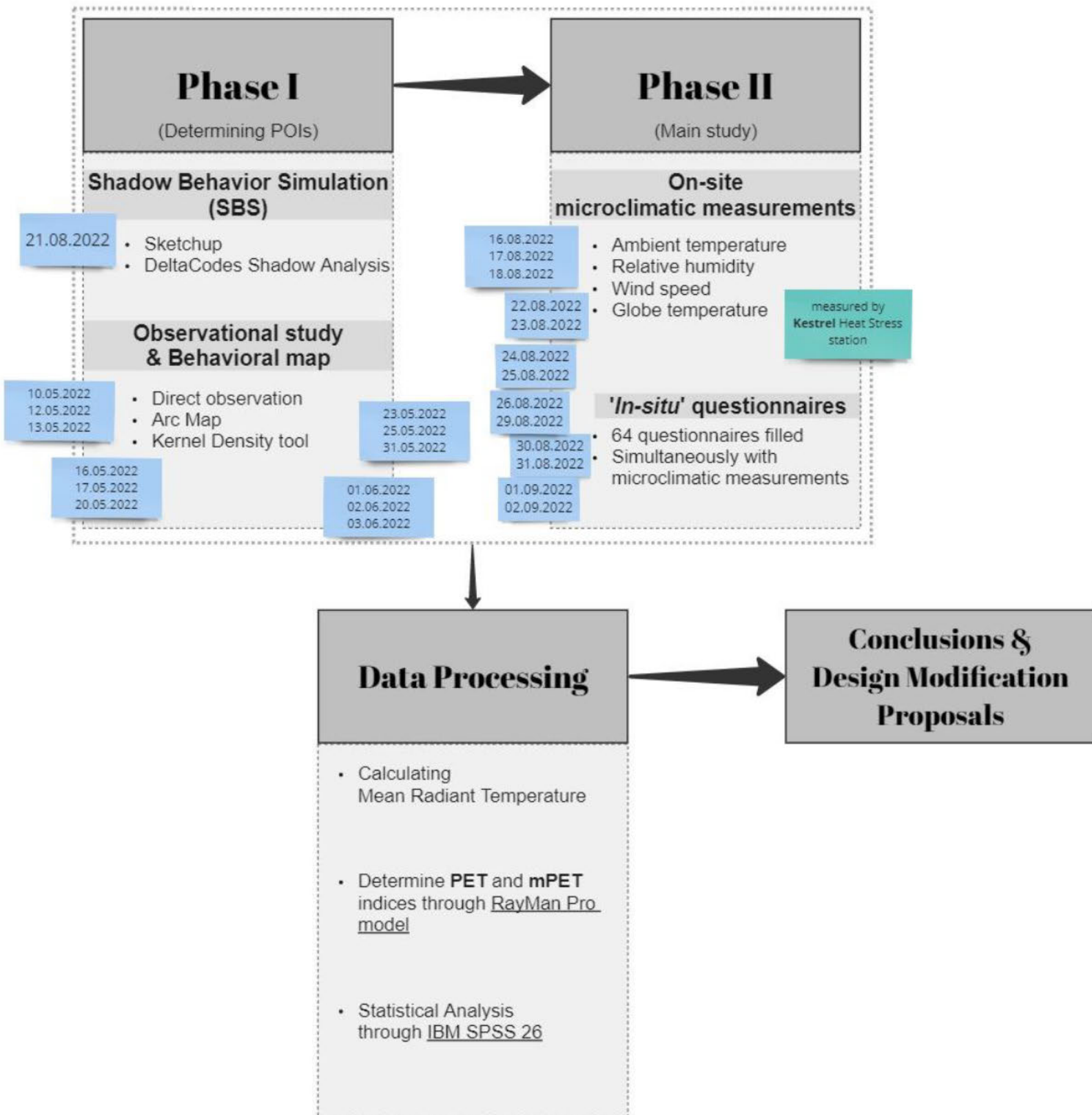
- ✓ Adjacent to entrances of FB, FC, and FD buildings
- ✓ Adjacent to Starbucks Café
- ✓ Adjacent to greenery
- ✓ 0 hours of shading
- ✓ Moving activities zone

3.3. Procedure of the Study

In order to figure out responses to the research questions and check the hypotheses mentioned in part 3.1., a two-phase experiment was designated as shown in figure 3. Similar to the methodology of Lenzholzer (2012), in this research, inquiring microclimate perceptions of the people using a place (research for design) was accompanied by objective testing of a design (in the case of this research, an existing place) and then having more general applicable results (research by design). Overall, general approach in methodology of this study was inspired by methodology of Nouri and Costa (2017a). In this methodological approach, firstly, Points Of Interest (POI) were established based on congregation of shadow behavior map and behavioral map (first phase); then, ‘*in-situ*’ microclimatic measurements and questionnaires were conducted in the established POIs (second phase), and design proposals were given accordingly.

As addressed in 1.1., in order to achieve optimal thermal comfort conditions (Aram et al., 2020; Lenzholzer & van der Wulp, 2010; Nikolopoulou & Steemers, 2003), interactions between two aspects (physiological and psychological) were assessed in the main study section (second phase) of this research. In addition to assessing spatial and qualitative features in the first phase of this research, more qualitative and also quantitative assessments were conducted in the second phase.

Figure 4. Procedure of the study (Illustration by the author, 2023).



3.3.1. First Phase

The first phase of this experiment was undertaken in order to determine Points Of Interest (POI) which are: (i) areas more prone to microclimatic risk factors; and, (ii) areas more preferred by the users for different kinds of activities. In this regard, two studies were undertaken which resulted in a behavioral map and a Shadow Behavior Simulation (SBS) map. Procedure of these two studies are described in more details in parts 3.3.1.1 and 3.3.1.2. Using this procedure, locations having crucial conditions on both of the aforementioned maps are combined and chosen as POIs.

3.3.1.1. Observational Study

With the purpose of investigating attendance at the outdoor spaces in Bilkent university main campus, an observational study with a human centered approach was undertaken as starting point of this research. Observation, with its simple and inexpensive means, and tweaking the observations into a system is the key to provide information about relationship between public life and public space (Gehl & Svarre, 2013). Whyte (1988), in his book '*The social life of small urban spaces*' emphasized the importance of observational studies in understanding how people use and interact with public spaces. He argued that these studies provide valuable insights into the patterns of behavior that shape the character of public spaces and can inform the design and management of those spaces (Whyte, 1988). Also, Carmona (2010) , in his book '*Public places, urban spaces*'

similarly emphasized the value of behavioral mapping as a tool for understanding how people use public spaces. He argued that behavioral mapping, which involves systematically observing and recording the activities and movements of people in a given space, can reveal patterns of behavior that are not immediately apparent and can help designers and planners make more informed decisions about how to design and manage public spaces (Carmona, 2010). In addition, according to Mehta (2009), in order to figure out human needs, we could empirically study interrelationships between the features of the place and the behaviors and perceptions of the users by behavior mapping and user interviews. Also, Lynch and Hack (1984) believed that more importance should be given to people's activities than physical elements; hence, behavior observation is essential for a designer to know who will use the site and how they will use it.

A walk-by observation in a structured manner was conducted in above-mentioned study area during 12 days during May and June of 2022 which covered three days of spring semester classes time, 5 days of spring semester final exams time, and 4 days of between semesters time (see **Table 3**) according to Bilkent university academic calendar. Due to being in an academic environment, special attention is paid to conduct the observations in weekdays and to cover two or three repetitions of any of the week days. To decide on the time intervals needed for any tour, researcher of this study walked along the place starting in front of FF building and ending in front of Break cafe and recorded nearly 4 minutes. However, observing the people around and taking notes while walking would take more time so a 15-minute period was considered for a walk along the mentioned place. Also, as we have two parallel ways with trees in between we needed to double this

time (so that we needed 30 minutes for any tour) because some parts in the other way were hard to observe while walking through a way (see **Figure 5**). Hence, 30-minute observations were conducted six times during a day (morning (9:00-9:30 & 9:30-10:00), lunchtime (13:00-13:30 & 13:30-14:00), and late-afternoon (17:00-17:30 & 17:30-18:00)) to make sure that different periods in a day are covered. 72 observation sheets were filled at the end of this process.

Table 3. Time table of observational studies in terms of academic period, date, and weekday.

Academic period	Date	Weekday
Spring semester classes	10.05.2022	Tuesday
	12.05.2022	Thursday
	13.05.2022	Friday
Spring semester final exams	16.05.2022	Monday
	17.05.2022	Tuesday
	20.05.2022	Friday
	23.05.2022	Monday
	25.05.2022	Wednesday
Between semesters	31.05.2022	Tuesday
	01.06.2022	Wednesday
	02.06.2022	Thursday
	03.06.2022	Friday

Figure 5. Observation route
(Illustration by the author, 2023).



As claimed by Gehl and Svarre (2013), questions referring to ‘how many’, ‘who’, ‘where’, ‘what’, and ‘how long’ could be answered in observational studies; In addition, they believed that number of walking people and number of stationary people could show how successful a public space is, and also, categorize status of places into transit / destination places. In this part of our study, similar to Mehta (2009), Sulaiman, Abdullah and Raja Othman (2019) Salama et al. (2013), Salama (2009), J. Zacharias et al. (2001), and I. Eliasson et al. (2007), gathered information are designed to demonstrate: (i) count of people; (ii) stationary/ moving activities (and details for types of activities); (iii) posture; and, (iv) location.

As a result of this process, a behavioral map was produced which tried to find the places with bigger footfall and categorize them into moving activities zones and stationary activities zones. For this purpose, similar to Dehkharghani (2021), and Mattsson (2019), the gathered data from the study area are converted to Arc map. The points on the observation marking sheets were transformed into dots in blue or red which showed stationary or moving activities. Then, the combination of all of the colorful dots is used to create a density map by Kernel density tools. Kernel density is a tool in ArcMap that is used to create a density map from point or polyline data. It calculates the density of points or lines in a specific area by spreading each point or line's value across the surface using a kernel function (ESRI., 2021). Consequently, this map put on the SBS map can show us the places with more critical conditions considering user’s attendance and sun / shade status.

3.3.1.2. Shadow Behavior Study

As shown by Matzarakis et al. (2016), radiation fluxes and wind patterns are the microclimatic factors with most effect from morphological and physical properties of the environment, and also have big influence on urban thermal comfort. Solar radiation is proven to be one of the strongest parameters on urban thermal comfort (Andreou, 2013; Matzarakis et al., 2016; Charalampopoulos et al., 2017; Lin et al., 2010; Venhari et al., 2019). Hence, solar radiation was selected to be checked as an important microclimatic factor to determine spaces with more potential to have critical microclimatic condition in the study area. In this regard, Shadow Behavior Simulation (SBS) was directed to explain an initial assessment of solar radiation within the study area.

For directing SBS, a massing model was created with Sketchup which represents the study area showing buildings, floors, stairs, slopes, and trees. Elevations of the floors, forms and heights of the buildings and the trees, and geo-location and orientation of the site were of importance in creating the massing model. Subsequently, the model was imported into DeltaCodes Shadow Analysis software and SBS map of the place was produced for 21.08.2022. The produced map shows diurnal analysis of shading hours of the place from 08:00 to 18:00 (these hours are supposed as starting and finishing hours in which more people use the place due to its academic environment). Subsequently, two more SBS analyses were undertaken for before noon (8:00-13:00) and afternoon (13:00-18:00) to observe maximum shadow extents in different times of a day. The diurnal SBS

map was used with the behavioral map to make sure that POIs have sufficient variety concerning solar radiation status.

3.3.2. Second Phase

After determining the POIs , main part of this study was undertaken. Second phase was mentioned as main part of our study because this phase directly dealt with the research questions and hypotheses checking process. This phase consisted of two parts which covered physiological and psychological approaches to investigate the relationship between thermal comfort and activity patterns at the outdoor spaces in Bilkent university main campus. '*In-situ*' microclimatic measurements, which refers to physiological approach, and '*In-situ*' questionnaire, which related to psychological approach, were undertaken during 13 weekdays during August and September of 2022.

3.3.2.1. '*In-situ*' Microclimatic Measurements

In order to be able to evaluate thermal condition of the study area with a physiological approach, microclimatic parameters data were collected according to table 4 in 13 weekdays during August and September of 2022 (August 16, August 17, August 18, August 22, August 23, August 24, August 25, August 26, August 29, August 30, August 31, September 1, and September 2) which covered a part of the time between summer

semester and fall semester according to Bilkent University academic calendar. In this regard, four meteorological parameters, including Ambient Temperature (T_a) ($^{\circ}\text{C}$), Relative Humidity (RH) (%), Wind Speed (V) (m/s), and Globe Temperature (T_g) ($^{\circ}\text{C}$), were recorded at a timeframe of 10 minutes (where measurements were recorded every minute). Any of the cycles (10 minutes of measurement) succeeded 8 minutes of waiting for the heat stress station to get adapted with the environment, and preceded 2 minutes of gap to relocate and be set in the next POI. These parameters were chosen for this research because of their importance in determining the thermophysiological influence on the human biometeorological system. In addition, these singular microclimatic parameters provide an entire understanding of the association to human thermoregulation dynamics and the approach to the human body (A. S. Nouri et al., 2018).

To record these '*in-situ*' measurements, Kestrel Heat Stress Station (KHS) (**Figure 6**) was held at 1.5 m above the ground (Aram et al., 2020; Nouri & Costa, 2017a). The process of collecting microclimatic parameters data repeated four times in a day for any of the POIs to record diurnal microclimatic oscillations in the study area (**Table 4**). As a result of this process, 12480 measurements were recorded in 52 sheets during hottest days of the year.

Table 4. Daily measurements schedule showings time of measurements at each POI.

	09:00-11:00	12:00-14:00	15:00-17:00	18:00-20:00
POI 1	09:08-09:18	12:08-12:18	15:08-15:18	18:08-18:18
POI 2	09:28-09:38	12:28-12:38	15:28-15:38	18:28-18:38
POI 3	09:48-09:58	12:48-12:58	15:48-15:58	18:48-18:58
POI 4	10:08-10:18	13:08-13:18	16:08-16:18	19:08-19:18
POI 5	10:28-10:38	13:28-13:38	16:28-16:38	19:28-19:38
POI 6	10:48-10:58	13:48-13:58	16:48-16:58	19:48-19:58



Figure 6. Kestrel Heat Stress (KHS) 5400 station

(<https://kestrelinstruments.com/kestrel-5400-heat-stress-tracker-pro>)

3.3.2.2. Identification of Local Human Thermophysiological Thresholds

To identify local human thermophysiological thresholds for a better understanding of effects of environmental features on POIs, a dataset retrieved from World Meteorological Organization (WMO) station 17130 (representing Ankara, central (Turkey)), at the latitude of 39°57' N, longitude of 32°53' E, and altitude of 891 m. This dataset contained Ambient Temperature (T_{amb}), Relative Humidity (RH), Wind Velocity (V), and Cloud Cover (Total Oktas) corresponding the days in which '*In-situ*' Microclimatic measurements were undertaken. Wind speed was reduced to pedestrian height, 1.1 m, which is the center of gravity for standing subjects in the human body (Kuttler, 2004).

The temporal frame of the analysis was undertaken during the diurnal period, between the hours of 09:00 and 20:00, with a measurement resolution of 1 hour. Afterwards, PET, mPET, and Mean Radiant Temperature (T_{mrt}) were calculated using RayMan model. As climatic data can be difficult for non-climatologists to grasp, developing methods to more effectively show such data based on color thresholds connected with PS levels allows for a more interdisciplinary portrayal of results. In this regard, the results were taken into the Climate-Tourism/Transfer-Information-Scheme (CTIS) software (Matzarakis, 2014) for visual interpretations.

3.3.2.3. *'In-situ'* Questionnaire

In addition to physiology, psychological factors play a significant role in the subjective assessment of outdoor thermal comfort (Aram et al., 2020; Nikolopoulou et al., 2001). Based on similar studies (Aram et al., 2020; Lenzholzer, 2012; Nouri & Costa, 2017a; Spagnolo & de Dear, 2003), this part sought to identify psychological elements that could support the thermophysiological analysis, subsequent design recommendations, and general bioclimatic advice at the conclusion of the study. Hence, during the 13 days of measurement, at the same time as collecting the microclimatic data (10 min), random people in the POIs were asked to fill *'In-situ'* questionnaires. During this process, 64 questionnaires were filled by students and lecturers of Bilkent university (14, 6, 16, 7, 15, and 6 questionnaires were filled in POIs 1, 2, 3, 4, 5, and 6, respectively).

For this purpose a questionnaire was prepared in 6 parts. In the first part of this questionnaire, demographic information are asked, similar to (T. P. Lin, 2009; Thorsson et al., 2007; S. Thorsson et al., 2004); in the second part, the participants' activities and also place (indoor / outdoor) for the last half hour are asked, similar to (T. P. Lin, 2009; Spagnolo & de Dear, 2003; Thorsson et al., 2007); in the third part, two questions are asked about color and thickness of clothes of the participants, similar to (I. Eliasson et al., 2007; T. P. Lin, 2009; Spagnolo & de Dear, 2003; Thorsson et al., 2007); in the fourth part, microclimate perception of the participants are asked, including Thermal Sensation Vote (TSV), Wind Sensation Vote (WSV), Solar Sensation Vote (SSV), and Thermal

Comfort Vote (TCV), similar to (Aram et al., 2020; I. Eliasson et al., 2007; Lenzholzer, 2012; T. P. Lin, 2009; Nouri & Costa, 2017a; Spagnolo & de Dear, 2003; Thorsson et al., 2007; S. Thorsson et al., 2004); in the fifth part, participants are provided with a map showing the study area and asked to draw their basic cognitive map concerning microclimate using blue and red pens, similar to (Aram et al., 2020; Lenzholzer, 2012; Nouri & Costa, 2017a); and in the sixth part, the participants are asked to concisely compose modification proposals to make the place better in terms of thermal comfort. The above-mentioned questionnaire consists of open-ended, close-ended, 7-point scale Likert-type questions, and also cognitive map drawing, any of which treated differently. The questionnaire sheets are shown in appendix A.

3.3.3. Data Processing

Succeeding data collection in first and second phases of this study, research questions and hypotheses were interrogated through quantitative and qualitative analyses; and subsequently, conclusions and design recommendations were provided.

In addition to four preliminary microclimatic variables (T_a , V , RH , and T_g), Mean Radiant Temperature (T_{mrt}) was calculated for the microclimatic measurements based on the following equation from the ISO 7726 standard (ISO, 1998):

$$T_{mrt} = \left[(T_g + 273)^4 + \frac{(0.25 \times 10^8)}{\varepsilon} \left(\frac{|T_g - T_a|}{D} \right)^{1/4} (T_g - T_a) \right]^{1/4} - 273$$

Where T_a is Air Temperature, T_g is Globe temperature, D is the globe diameter (0.025 in this study), and ε is its emissivity (0.95 for a black globe).

Afterwards, the retrieved data was processed through the RayMan Pro model (Matzarakis & Rutz, 2006; Matzarakis et al., 2010) to determine Physiologically Equivalent Temperature (PET) index (Mayer & Hoppe, 1987) and also modified PET (mPET) index (Chen & Matzarakis, 2018). PET is an Energy Balance Model (EBM) thermal index based on the Munich Energy Balance Model for Individuals (MEMI) (Höppe, 1984; Höppe, 1993), to determine the effects of the thermal environment upon human body. The decision for utilizing PET for this study was because of: (i) calibration on easily obtainable microclimatic parameters; (ii) its extensive usage in the field; (iii) the use of °C as the unit of measurement to evaluate thermal comfort, which in turn enables other specialists to more effectively comprehend and address urban climatological aspects (A. S. Nouri et al., 2018). Furthermore, the outputs in PET index could subsequently be compared to different grades of human thermal perception and Physiological Stress (PS), as shown in Table 3 (A. S. Nouri et al., 2018). In addition, Nouri et al. (2021) adapted two new grades beyond the original 'extreme heat stress' classification (> 41 °C) based on the exploratory 'What if?' approach for extreme environmental scenarios, based on an increment of roughly 5 °C per physiological threshold within the existing grade system.

As the fourth and fifth levels of Heat Stress (HS) after the 'no thermal stress' categorization, these new grades were classified as HS4 and HS5 according to the stress level abbreviation system shown in **Table 5**. According to Chen and Matzarakis (2018), by enhancing evaluation of the humidity and clothing variability, the mPET has been strengthened against the shortcomings of the original PET. The same research claimed that mPET model can be considered to provide a more accurate representation of core temperature and mean skin temperature compared to the PET model.

The data retrieved from physiological and psychological approaches are subsequently analyzed through IBM SPSS statistics 26 software to find possible relations. Through SPSS, in addition to statistical descriptive and graph production, One-Way ANOVA was used for mean comparisons. Afterwards, the conclusions are made and design modification proposals are given.

Table 5. Ranges of the thermal index Physiologically Equivalent Temperature (PET) for different grades of Thermal Perception and Physiological Stress on human beings; internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (according to (Matzarakis & Mayer, 1997) | Source: Retrieved from Matzarakis et al. (1999) and Santos Nouri et al. (2021).

<i>PET</i> (°C)	<i>Thermal Perception</i>	<i>Physiological Stress</i>	<i>Stress Level Abbreviation</i>	
< 4	Very Cold	Extreme Cold Stress	Cold Stress	CS4
4~8	Cold	Strong Cold Stress		CS3
8~13	Cool	Moderate Cold Stress		CS2
13~18	Slightly Cool	Slight Cold Stress		CS1
18~23	Comfortable	No Thermal Stress	(-)	NS
23~29	Slightly Warm	Slight Heat Stress	Heat Stress	HS1
29~35	Warm	Moderate Heat Stress		HS2
35~41	Hot	Strong Heat Stress		HS3
41~46	Very Hot	Extreme Heat Stress		HS4
> 46	Extremely Hot	Beyond Extreme Heat Stress		HS5

Chapter 4

Results

4.1. Determining POIs (phase I)

4.1.1. Shadow Behavior Simulation (SBS)

Shadow Behavior Simulation (SBS) study was conducted for 21.08.2022 to show diurnal hours of shading of the study area from 08:00 to 18:00. Due to SBS study, hours of shading for the study area ranged from 0 hours to 10 hours during the aforementioned period, which means some places didn't receive direct sunlight at all, while there were spots receiving direct sunlight for the whole period. As shown in **Figure 7**, under and near tree canopies and also near the buildings more hours of shading is identified. On the other hand, the least hours of shading is observed in the spots neither adjacent to trees nor adjacent to buildings in eastern, western, or southern sides of them. As trees are spread in most parts of the area, despite the variety in hours of shading throughout the area, just less than 15% of the studied area was shaded less than 2 hours during the mentioned period of time. However, a big spot in the northern part of the study area, the parking lot

between sports center and advanced research laboratory in the western part, another parking lot between sports center and food court in the western part, the spot leading to a pedestrian way between faculty of economics and FC building in the eastern part, and also a spot between FC and FD buildings in eastern part of the study area, are more prone to direct sun radiation.

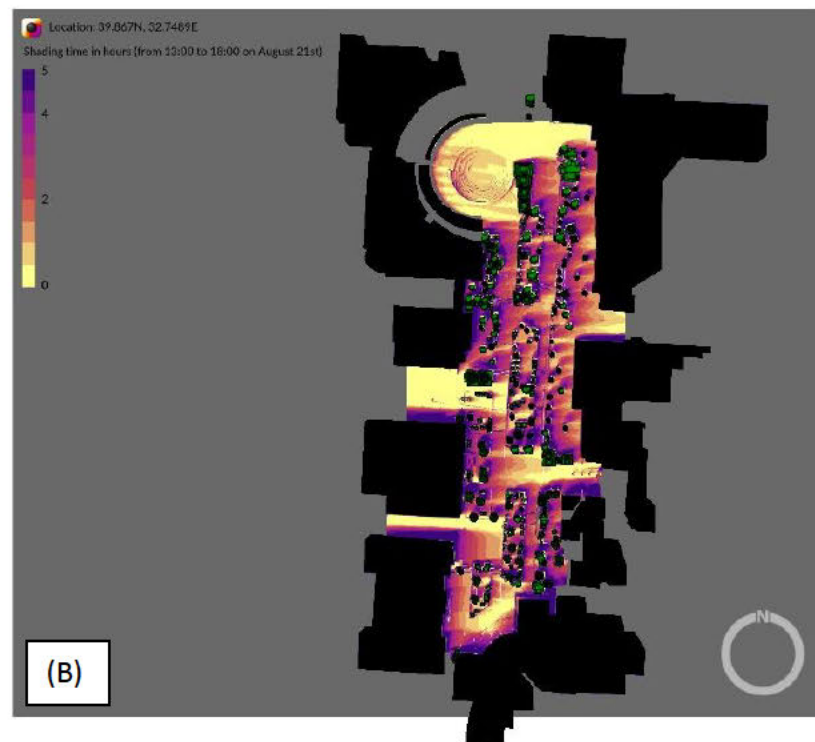
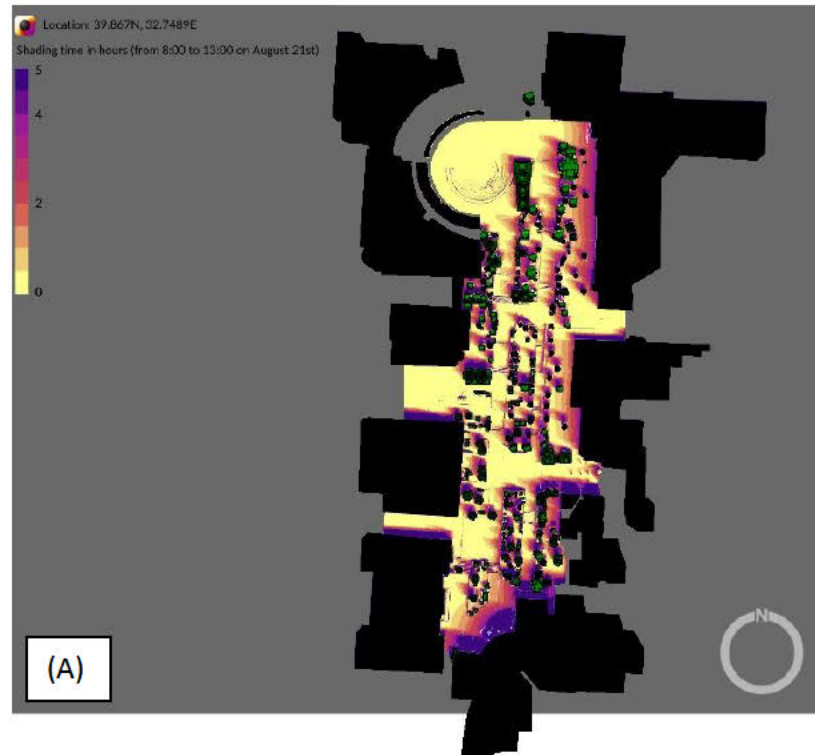


Figure 7. Diurnal (08:00-18:00) shading time simulation through Shadow Behavior Simulation (SBS)
(Simulation and illustration by the author, 2023).



In addition, two more SBS analyses are conducted for before lunch-time (08:00-13:00) and after lunch-time (13:00-18:00) to observe maximum shadow extents in different times of a day. As shown in **Figure 8**, bigger area is shadowed during afternoon and evening period (13:00-18:00) than morning period (08:00-13:00). Comparing figures 8(A) and 8(B) shows that nearly all of the zones have more hours of shading during second 5-hour period (13:00-18:00) than the first 5-hour period (08:00-13:00) except for the space in front of the entrance of FF building which has more hours of shading during the first 5-hour period.

Figure 8. (A) Before lunch-time (08:00-13:00) shading time simulation through SBS; (B) After lunch-time (13:00-18:00) shading time simulation through SBS (Simulation and illustration by the author, 2023).



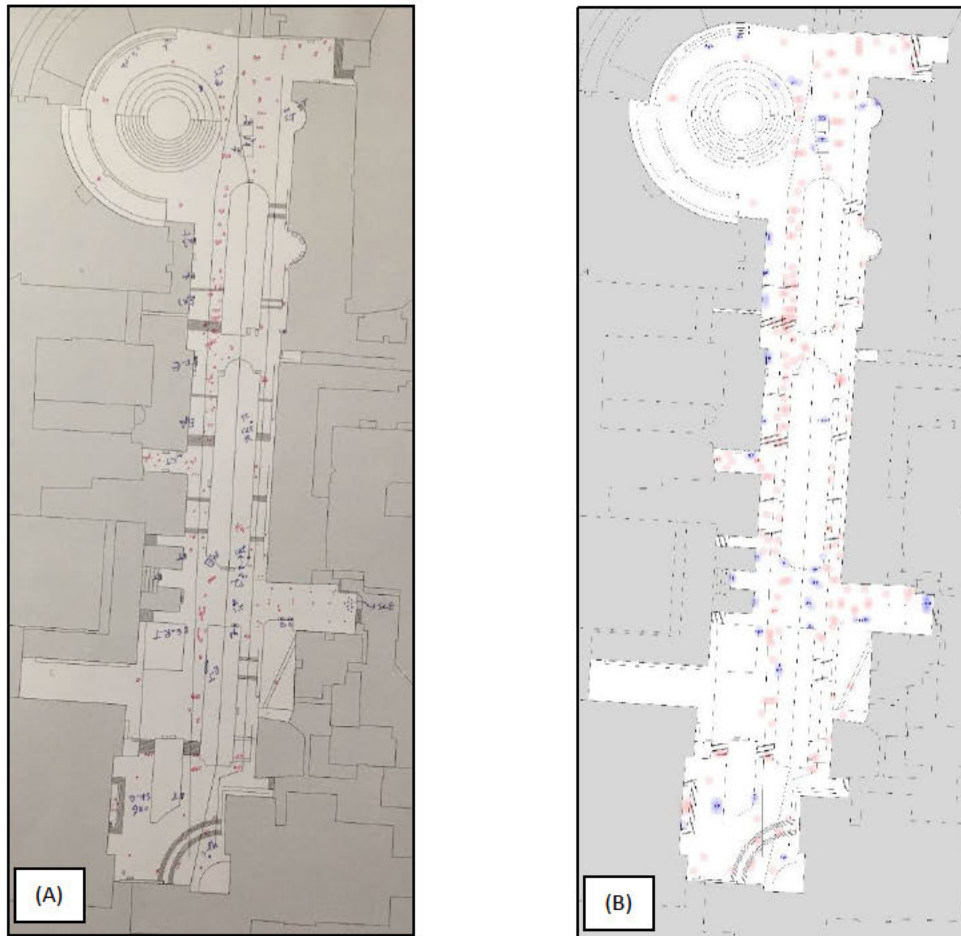
4.1.2. Behavioral Map

As a result of the observational study conducted in May and June of 2022, 72 observation marking sheets were filled which showed presence of people in specific places in specific times and their activities. **Figure 9**, shows the marking sheet corresponding 12.05.2022 between 13:00 and 13:30 as an example of the 72 sheets. For more clarity and to be able to compare, all of these sheets (showing exact places, activities, and sub-activities of the observed people) are transmitted into Adobe Photoshop documents. In all of these documents, red color represents moving activities while blue color refers to stationary activities. Also, words showing activities and their descriptions are shown in **Table 6**.

Table 6. Symbols (words) showing activities and their descriptions (retrieved from Mehta (2009) and edited by the author, 2023).

Symbol (word)	Description
b	Riding bike / scooter
E	Eating / drinking
L	Lying/ sleeping
P	Walking pets
pe	Petting animals
ph	Using phone
R	Reading or using a laptop computer
S	Standing
St	Sitting
T	Talking

Figure 9. (A) Marking sheet of 12.05.2022 (13:00-13:30); (B) the same observation marking sheet transmitted into Adobe Photoshop document.



Subsequently, as explained in 3.3.1.1, all of the corresponding dots were transmitted into ArcMap in blue or red dots. In this phase, accurate place of the observed people and their activities in terms of moving/ stationary are considered. As a result, an overall behavioral map has been produced which shows the areas with biggest footfalls and also categorizes these areas into two types of zones (stationary activities zones, and moving activities zones) (see **Figure 10**). Differentiating the zones, in cases of two or more same color zones, sub-activities (sitting, standing, using phone, etc.) were also considered. Afterwards, this map was used accompanying the shadow behavior map to establish the POIs.

Figure 10. Overall behavioral map using kernel density tool with radius of 5 & output cell size 0.01
(Analysis and illustration by the author, 2023).



4.1.3. Points of Interest (POI)

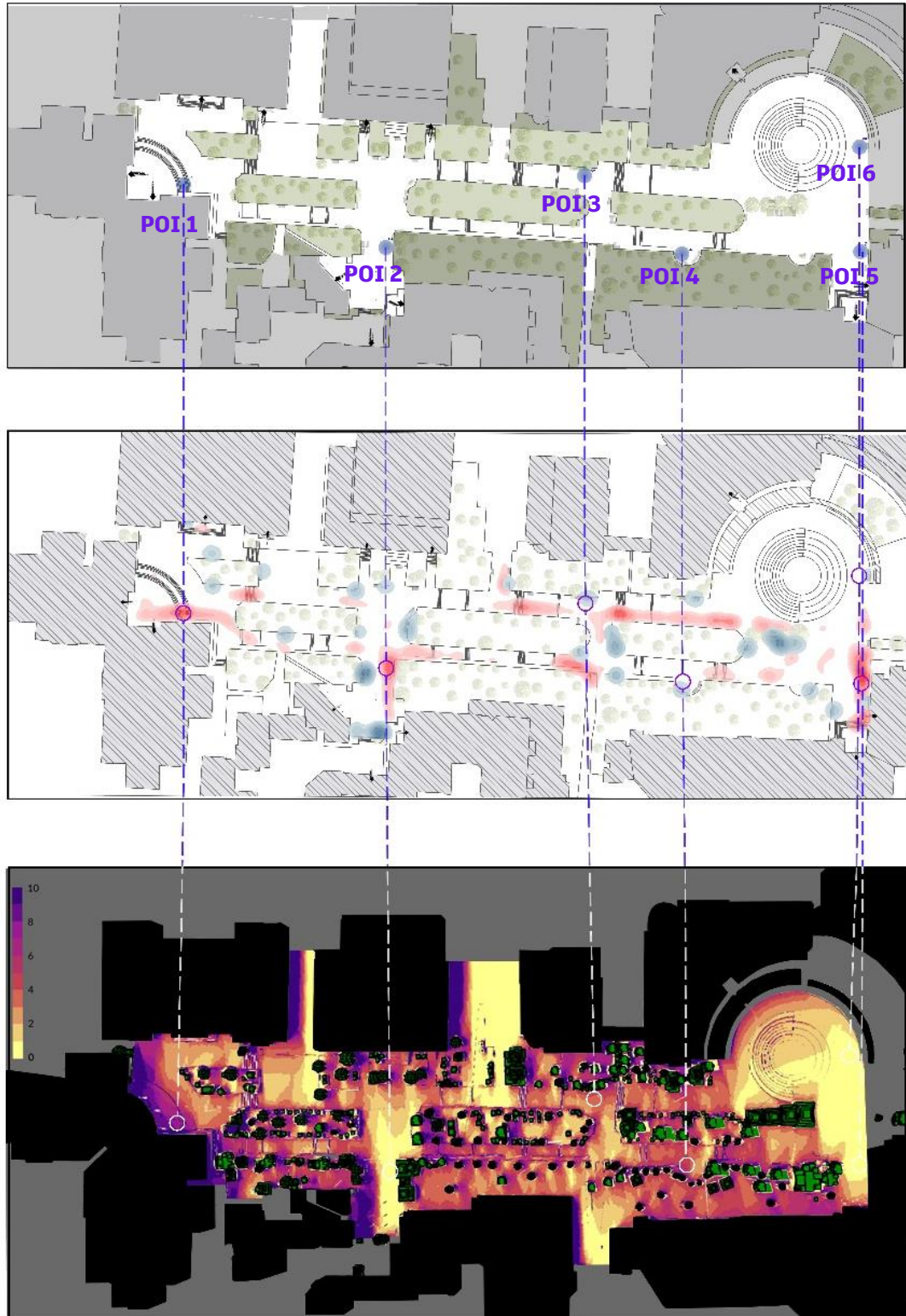
As a result of the first phase of this research (described in detail in section 3.3.1), a behavioral map and a Shadow Behavior Simulation (SBS) map were produced which showed areas more preferred by the users for various activities, and areas more prone to microclimatic risk factors, respectively. Subsequently, as shown in **Figure 11**, these two maps put on together showed us spaces with more critical conditions considering the users' attendance and the sun / shade status of the environment. Also, it was preferred to have variety of conditions regarding users' activities and the sun / shade status of the environment among the established Points Of Interest (POI).

Regarding the behavioral map, POIs 1, 2, and 5 represent moving activities zones with bigger footfalls in the studied area. However, considering sub-activities, these zones are not identical. For instance, the users were mostly using their phones while walking through POI 1, while in POI 2, they were mostly conversing, and in some cases eating/drinking while walking. Also, in POI 5, people were mostly using their phones, while in some cases, conversations were also observed. In addition, POI 1 was in some cases selected for sitting or standing as well (stationary activities) and in POI 5 standing stationary activities were observed, while any kind of stationary activities were not observed in POI 2.

POIs 3, 4, and 6 represent moving activities zones with bigger footfalls in the studied area. According to the observational studies, people mostly used POIs 3 and 4 for sitting and talking / eating / drinking / using phone. POI 4 was also used for reading or using a laptop computer. However, POI 6 was mostly used only for using phones by individuals.

Regarding diurnal Shadow Behavior Simulation (SBS) map, (on 21.08.2022 between 08:00 and 18:00) 7, 4, and 5 hours of shading were estimated for POIs 1, 3, and 4, respectively. POIs 2, 5, and 6 showed about 0 hours of shading during the above-mentioned 10-hour period. Also, for POI 1, more hours of shading were estimated for before lunch-time period (08:00-13:00); while for POI 3, similar to majority of the areas in simulated zone, more hours of shading were estimated for after lunch-time period (13:00-18:00). The other POIs didn't show critical differences between before lunch-time and after lunch-time periods.

Figure 11. Top to bottom: Points Of Interest (POI); Behavioral map; Shadow Behavioral Simulation (SBS)
(Illustration by the author, 2023).



4.2. Main Study (phase II)

The qualitative and quantitative results of the main phase of the present research which was conducted during August and September of 2023 are provided in this section. This experiment was carried out in the 6 POIs which were established according to the results of the first phase of this research.

4.2.1. Physiological Evaluations

4.2.1.1. Human Thermophysiological Thresholds of Ankara

The local heat stress thresholds were identified using daily PET, mPET, and Tmrt values of Ankara at 1-hour resolution from 09:00 to 20:00 for the days of '*in-situ*' studies, in order to validate the thermophysiological heat stress risks of outdoor heat events for a better understanding of effects of environmental features on POIs.

According to **Figure 13**, the CTIS heatmap illustrating PET values, shows mostly higher values between hours 10:00 and 15:00; with maximum value of 45.4 °C which refers to 'Extreme Heat Stress' (HS4) and occurred at 12:00 on 22.08.2022. Hence, relatively high

values of PETs are expected to be calculated as a result of microclimatic measurements for the afternoon periods (12:00-14:00). In addition, higher mPET values are showed between hours 10:00 and 14:00; with maximum value of 40.2 °C which refers to ‘Strong Heat Stress’ (HS3) and occurred at the same time with that of PET values. Also, T_{mrt} values are found to be more between hours 9:00 and 16:00; with maximum value of 57.4 °C which took place at 12:00 on 30.08.2022. On the other hand, between 18:00 and 20:00, the lowest values were found for PET, mPET, and T_{mrt}. Values of PET and mPET for the mentioned hours referred to the ranges of ‘Slight Cold Stress’ (CS1), ‘No Thermal Stress’ (NS), and ‘Slight Heat Stress’ (HS1).

Comparing the days of the measurements, more heatwave events were occurred during 22, 23, 24, 29, 30, 31 August and 02 September. In general, PET values ranged from 17.4 °C to 45.4 °C which encompass CS1, NS, HS1, HS2, HS3, and HS4. Also, mPET values varied from 18.5 °C to 40.2 °C which refer to NS, HS1, HS2, and HS3. Considering the T_{mrt} heatmap, values encompassed a wide range from 14.1 °C to 57.4 °C. First to third highest T_{mrt} values (57.4 °C, 57.2 °C, and 57.1 °C) are reported for 12:00 o’clock on 30, 22, and 23 August, respectively.

Figure 12. T_{mrt} values of Ankara at 1-hour resolution from 09:00 to 20:00 for the days of ‘*in-situ*’ studies (Produced in CTIS program by author, 2023).

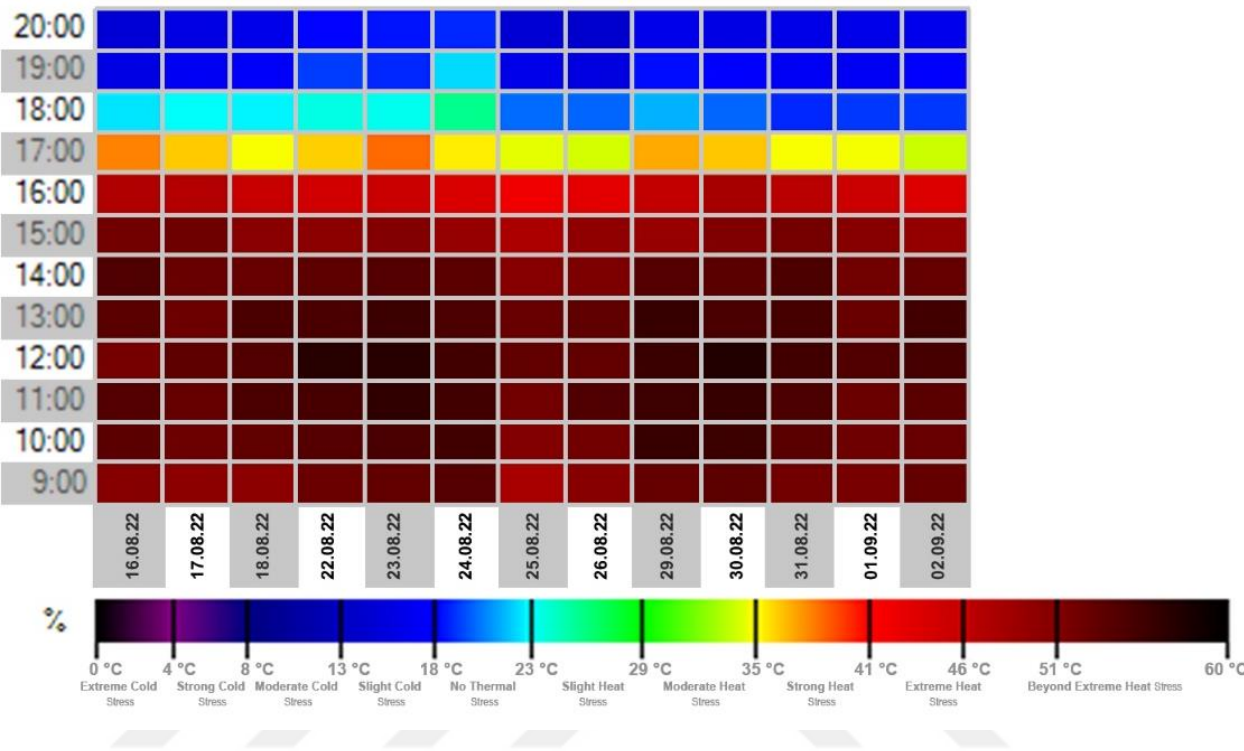
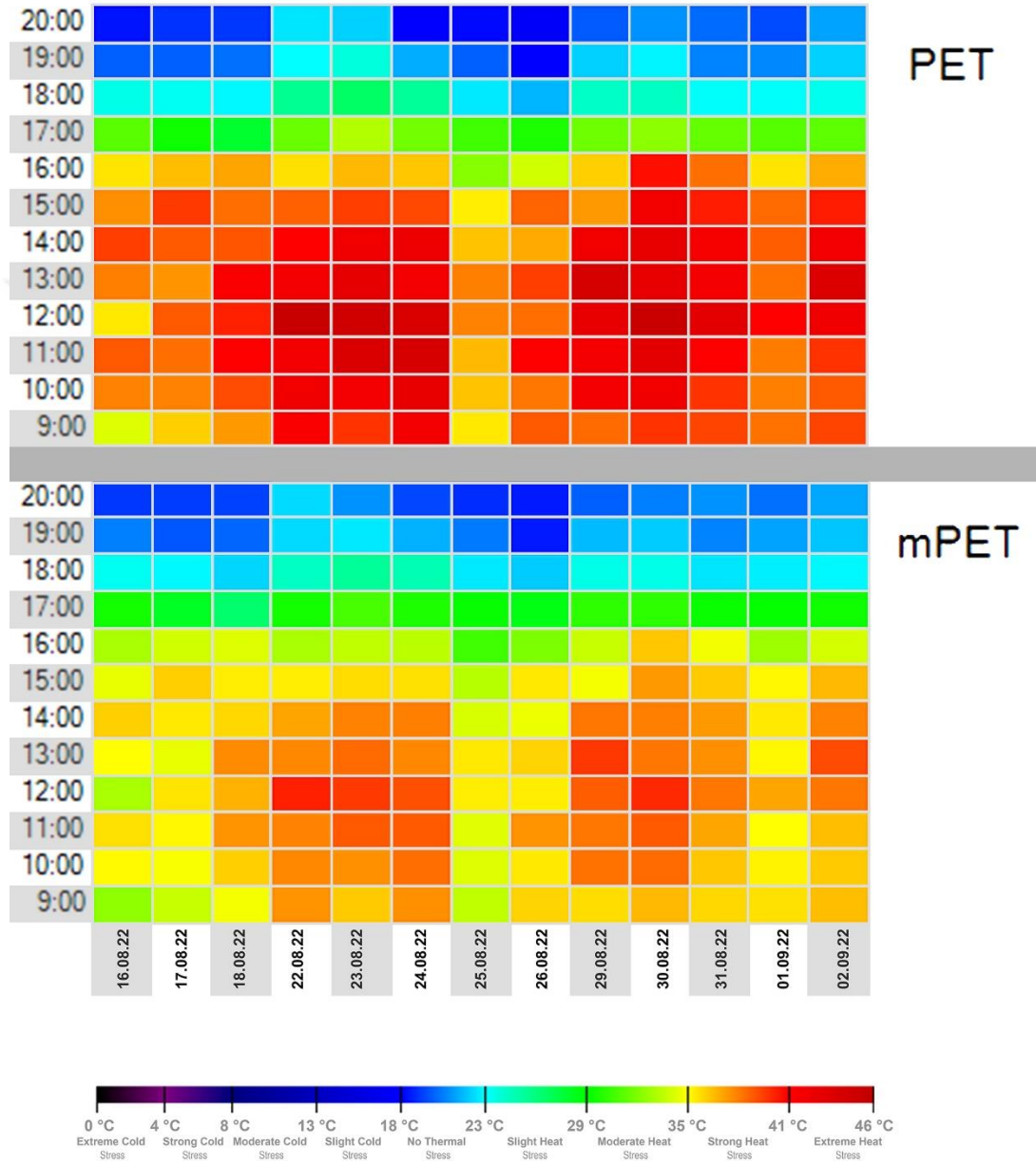


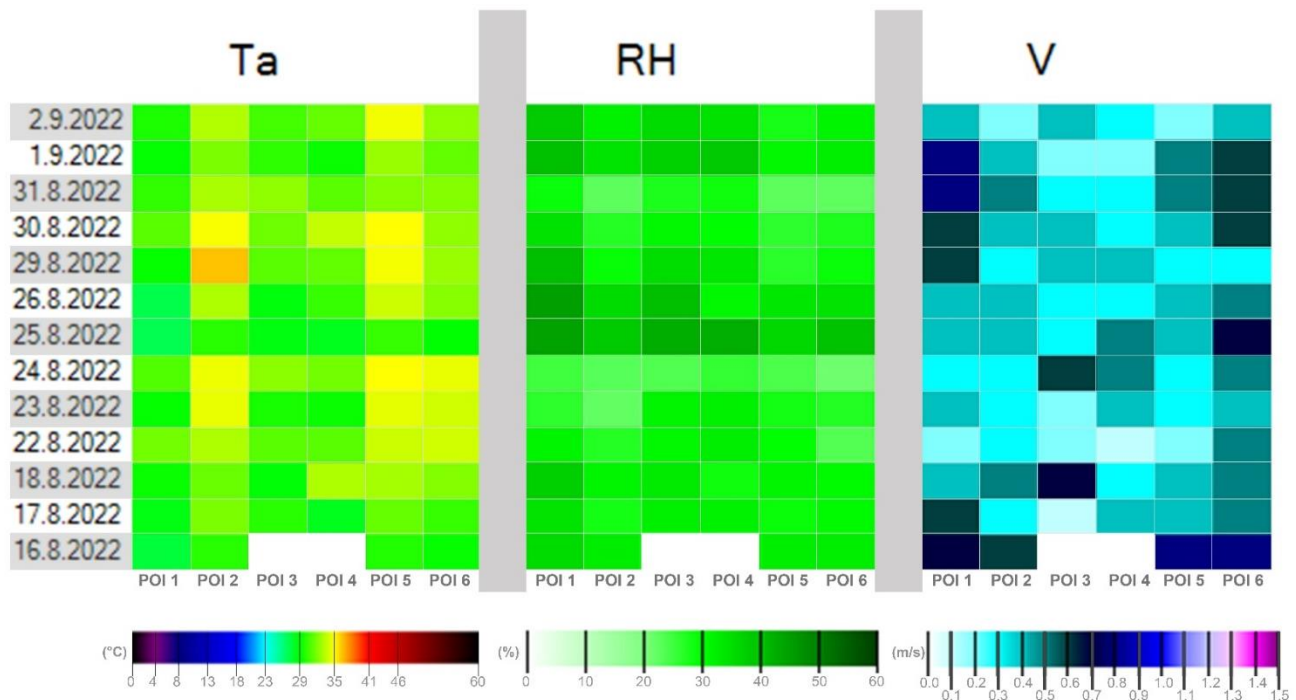
Figure 13. PET and mPET values of Ankara at 1-hour resolution from 09:00 to 20:00 for the days of 'in-situ' studies (Produced in CTIS program by author, 2023).



4.2.1.2. ‘In-situ’ Microclimatic Parameters

Microclimatic parameters were recorded in the POIs to evaluate the physiological aspects of thermal comfort in the study area. According to **Figure 14**, Air Temperature (T_a) daily averages in the POIs varied from 27.1 °C (POI 1 on 25 August) to 36.4 °C (POI 2 on 29 August). Differences are clearly visible in T_a daily averages between POIs. For instance, higher values of T_a are shown for POIs 2&5, while POIs 1 and 3 show relatively lower T_a values. Regarding Relative Humidity (RH) daily averages in the POIs, although values were close to each other in terms of POIs, considerable fluctuations were found comparing the days. For example, RH values in POIs on 24 August were obviously different from those of 25 August. According to Wind Velocity (V) daily averages in the POIs, these values ranged from 0.1 m/s (POI 3 on 17 Aug. and POI 4 on 22 Aug.) to 0.8 m/s (POIs 5&6 on 16 Aug. and POI 1 on 31 Aug. & 01 Sept.). The oscillations in these values don't seem critical and don't seem to follow regular and meaningful patterns.

Figure 14. Daily averages of T_a ($^{\circ}\text{C}$), RH (%), and V (m/s) in POIs (Produced in CTIS program by author, 2023).



After measuring T_a , RH, V, and Globe Temperature (T_g), through a process described in 3.3.2.1, correspondent Mean Radiant Temperature (T_{mrt}) values were calculated using the formula given in 3.3.3. These values are subsequently translated into heat map graphs using CTIS software (**Figures 15 and 16**). Regarding daily average differences, POIs 2, 5, and 6 represented noticeably dissimilar values from those of POIs 1, 3, and 4. The highest T_{mrt} daily average (53.6 °C) was calculated for POI 2 on 16 August while the lowest T_{mrt} daily average (27.7 °C) was calculated for POI 1 on 26 August.

As seen in **Figure 16**, values corresponding evening (18:00- 20:00) measurements are mostly lower than those of morning (09:00- 11:00), afternoon (12:00-14:00), and late afternoon (15:00- 17:00). However, the oscillations in T_{mrt} values of POI 1 showed a different pattern. Unlike the other POIs, evening averages of T_{mrt} values calculated for POI 1 were mostly higher than those of morning and afternoon.

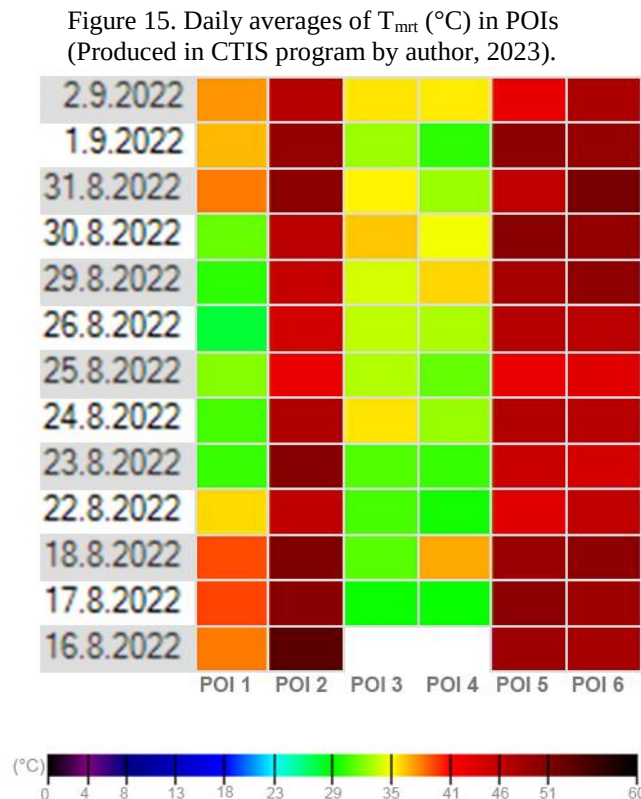
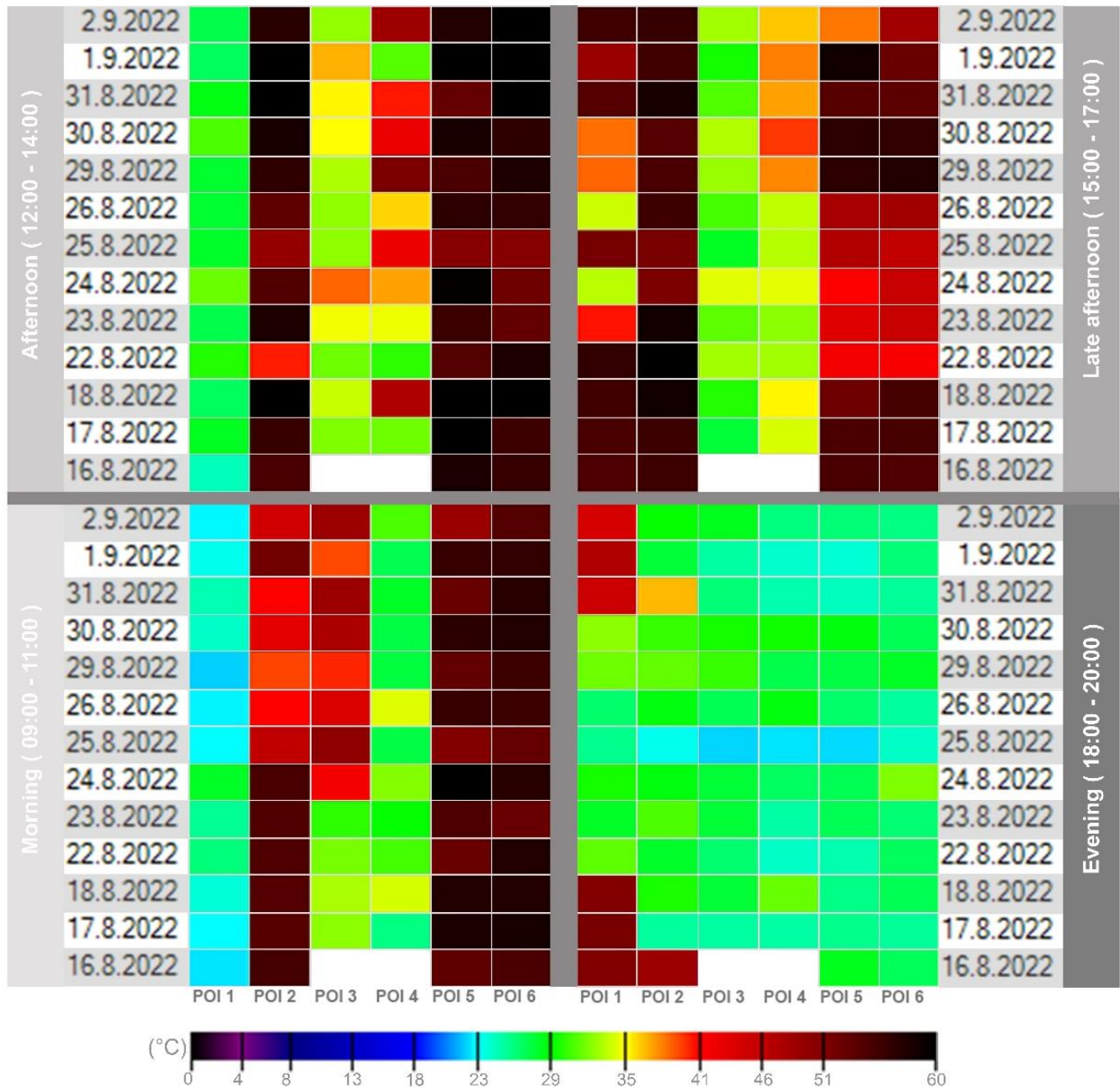


Figure 16. T_{mrt} (°C) in POIs during four daily cycles of measurements- morning (09:00-11:00), afternoon (12:00-14:00), late afternoon (15:00-17:00), and evening (18:00-20:00) (Produced in CTIS program by author, 2023).



All in all, total means of all T_a values in POIs were close to each other while compared by POIs. However, RH mean for POI 1 (35.5%) was higher than the others (by 6.3% more

than that of POI 5). RH values showed noticeable oscillations in all of the POIs; for instance, range of the RH values in POI 1 was 43.1 %. V values didn't vary critically among the POIs; however, an oscillation of about 1 (m/s) was observed in all of the POIs. T_{mrt} values had critical fluctuations among POIs and also daylong cycles. POI 2 had the highest T_{mrt} mean (48 °C) followed by POIs 6 and 5 (respectively 47.8 °C and 46.9 °C) while the others (POIs 1, 3, and 4) had 34.4 °C, 33.2 °C, and 32.7 °C. Also big ranges are seen for all of the POIs regarding T_{mrt} values.

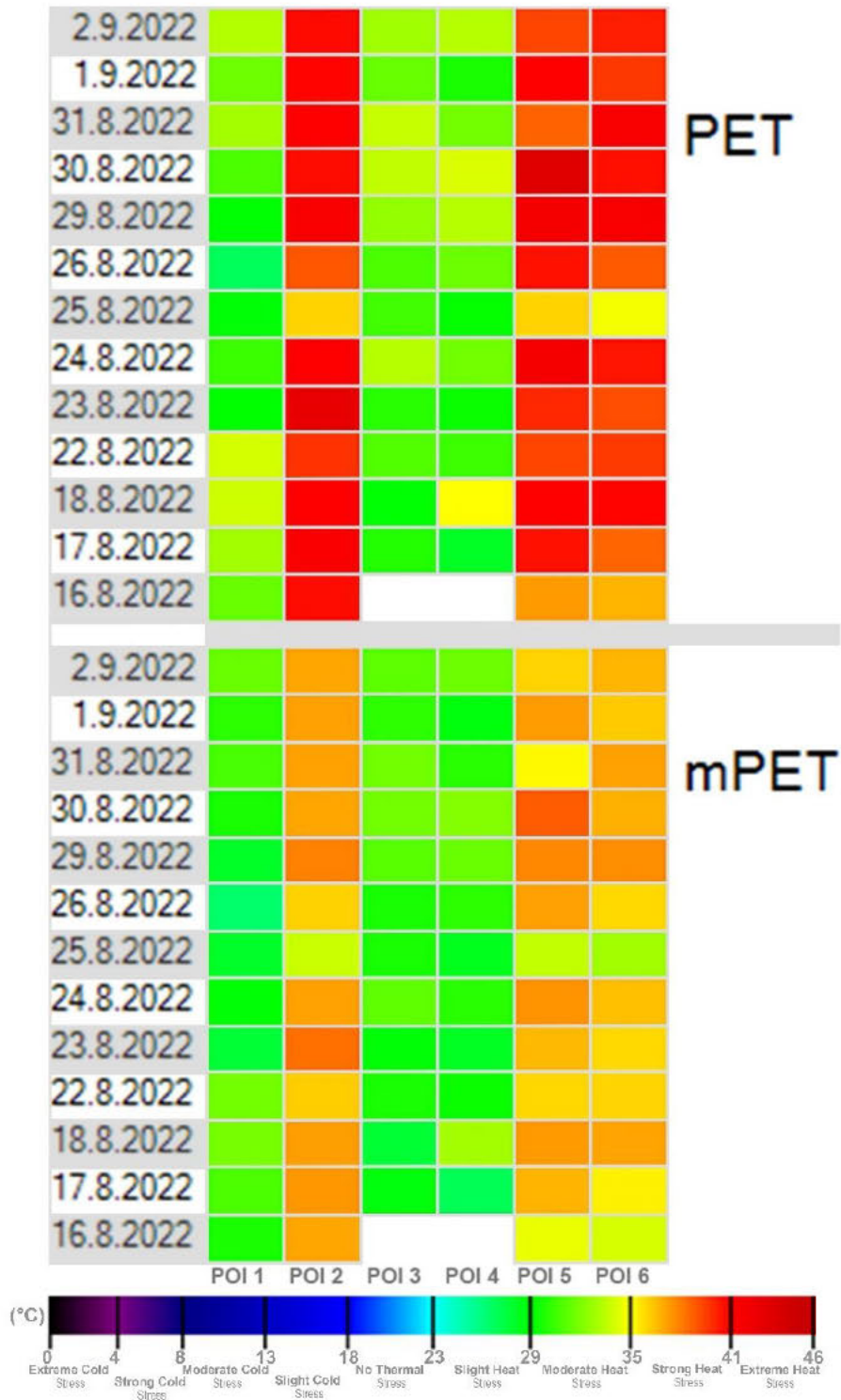
4.2.1.3. Thermal Comfort Indices (PET & mPET)

The RayMan model used the participants' metabolic rates of 0.9 clo and 80 W to analyze the human biometeorological system's response to the identified microclimatic variables (Matzarakis et al., 2007) to determine the effects of the identified microclimatic variables on the human biometeorological system. As seen in **Figure 17**, both PET and mPET values declined noticeably on 25th August which aligned with local heat stress thresholds shown in **Figure 13**. Also, similar to T_{mrt} values, POIs 2, 5, and 6 showed higher values in PET and mPET indices. Total means of all PETs and mPETs showed similar difference between POIs 2, 5, and 6 and POIs 1, 3, and 4. Total means of all PETs for POIs 2, 5, 6, 3, 4, and 1 were respectively 40.5 °C, 40.1 °C, 39.4 °C, 31.5 °C, 31.4 °C, and 31.1 °C. Similarly, total means of all mPETs for POIs 2, 5, 6, 3, 4, and 1 were respectively 36.9 °C, 36.5 °C, 36 °C, 30.1 °C, 30 °C, and 29.6 °C.

PET and mPET values measured in the six POIs at four daylong cycles are shown in **Figure 18**. According to mPET values, during late afternoon on 22 August, Extreme Heat Stress (HS4) was experienced in POI 1. During late afternoons of other days, Strong Heat Stress (HS3) or mPET values close to this range were observed. In POI 2, mPET values corresponded with HS4 during afternoons on 18, 23, 29, 30, and 31 August and 1 and 2 September. Also, according to mPET values, HS4 was experienced in POI 2 during late afternoons on 18, 22, 23, 26, 29, and 31 August and 1 and 2 September. In POI 3, mPET values related to HS3 during mornings on 31 August and 2 September; Slight Heat Stress

(HS1) and Moderate Heat Stress (HS2) were experienced in all of the other cycles in this POI. In POI 4, regarding mPET values, during afternoons on 18, 29, and 30 August and 2

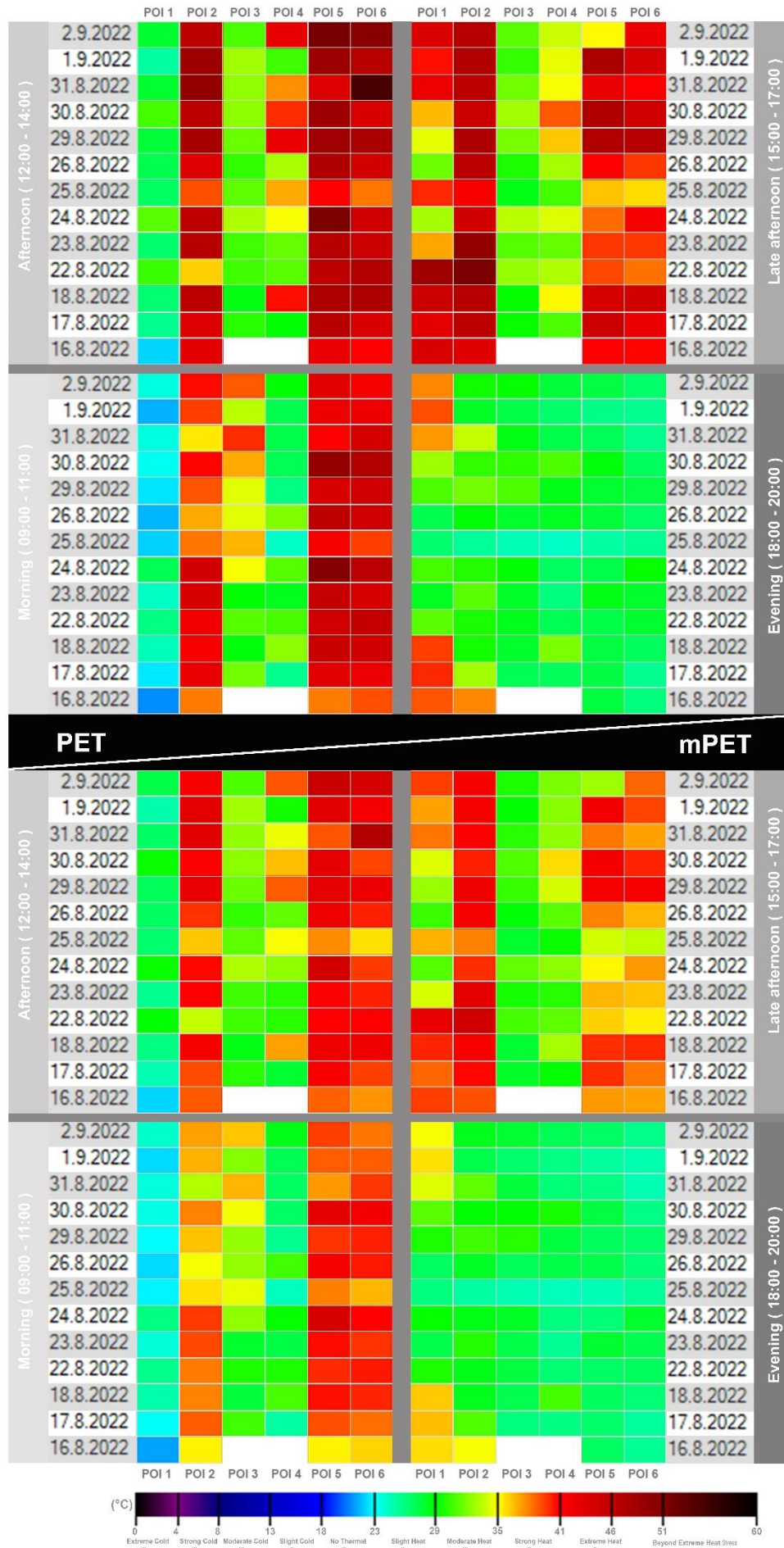
Figure 17. Daily averages of PET and mPET in POIs (Produced in CTIS program by author, 2023).



September, and also late afternoon on 30 August, HS3 was experienced. Considering mPET values measured in POI 5, during mornings on 24, 26, and 30 August, afternoons on 17, 18, 22, 23, 24, 26, 29, and 30 August and 1 and 2 September, as well as late afternoons on 29 and 30 August and 1 September, HS4 was experienced. In POI 6, during afternoon of 31 August, Beyond Extreme Heat Stress (HS5) was experienced, regarding mPET. In addition, during mornings on 24 and 30 August, afternoons on 18, 22, 29 August and 1 and 2 September, and late afternoon on 29 August, HS4 was experienced in this POI.

Additionally, regarding the PET and mPET values in all of the results given, describing a comparison between these two indices is also possible. For instance, mean PET for POI 2 was 40.5 while that of mPET was 36.9. Hence, 3.6 °C difference was found between mean PET and mean mPET for same measurements from one POI. It is also noteworthy that the mPET values predominantly tend to keep closer to neutral condition.

Figure 18. PET and mPET in POIs during four daily cycles of measurements- morning (09:00-11:00), afternoon (12:00-14:00), late afternoon (15:00-17:00), and evening (18:00-20:00) (Produced in CTIS program by author, 2023).



4.2.2. Psychological Evaluations

A three-part analysis based on the qualitative characteristics of the five-part questionnaires conducted during microclimatic measurements was used to draw conclusions about the findings of psychological evaluations. Within this context, the findings of parts 1, 2, and 3 will be summed under Respondents' General Conditions (4.2.2.1), while the results of parts 4 and 5 will be launched at Microclimate Perception (4.2.2.2) and Cognitive Map Considering Microclimate (4.2.2.3), respectively.

4.2.2.1. Respondents' General Conditions

Regarding responses given to the 1st part of the conducted questionnaires, 42.2% of the subjects aged between 18 and 24, and 39.1% belonged to the age group 25-29. Rest of the respondents (18.7%) were more than 30 years old. Nearly half (46.9%) of the questionnaires were filled by the females while the rest (53.1%) were filled by the males. According to the questionnaires, 43.8% of the subjects heighted between 171cm and 180cm, which was followed by the range of 161-170cm (31.3%). Also, 31.3% of the respondents weighed between 61 kg and 70 kg, which was followed by the ranges 51-60kg, and 71-80kg, 21.9% and 17.2%, respectively. Majority of the questionnaires (56.3%) were filled by the Turkish, followed by the Iranian (17.2%), and the Pakistani (14.1%). The rest of the subjects were Turkman, Nigerian, Albanian, Bangladeshi, and Syrian. Regarding the answers given to the last question of part 1 of the questionnaire,

54.7% of the questionnaires were filled by the graduate students (35 people), while 34.4% of the subjects were undergraduate students (22 people), and 9.4% of them were lecturers in different departments at Bilkent university (6 people).

Questions 8-13 in the questionnaire, asked the people about their activities at the moment and half an hour before filling the questionnaire. Accordingly, 51.6% of the subjects (33 people) had been out for at least half an hour before filling the questionnaire, while 28 people (43.8%) were coming from indoor places. And, 3 people had experienced both indoor and outdoor spaces during that period. According to the question 9, 34.4% had been walking at least half an hour before filling the questionnaire, 31.3% had been sitting, and 12.5% of the people had been studying. Question 10 asked people “*What are you doing at the moment?*” 40.6% of the people responded ‘*sitting*’ while 32.8% selected ‘*standing*’ and 21.9% selected walking. Also, 2 people were studying and 1 person was eating / drinking while we asked them to fill the questionnaire. In question 11, being asked about the reason of choosing that place for their activities, given responses were ‘*walking to/ from department*’, ‘*just passing by*’, ‘*the available amenities*’, ‘*to get fresh air*’, ‘*to visit a friend*’, ‘*good weather*’, and ‘*walking to / from library*’, and ‘*walking to / from living place*’ by 15, 15, 10, 5, 4, 2, 2, and 1 people, respectively. In addition, 10 people had misunderstood the question and answered irrelevantly. The 12th question revealed that 73.4% of the people had been in the place for less than half an hour, 14.1% of them half an hour to one hour, 1.6% (1 person) one hour to two hours, and 3.1% (2 people) two hours and more. Also, 5 people had misunderstood the question and answered irrelevantly. As the last question of the 2nd part, question 13 asked people “*Are*

you going to stay in this place for more time?” According to the responses, majority of them (68.8%) replied ‘No’, 18.8% replied ‘*half an hour or less*’, and just 12.5% chose ‘*more than half an hour*’.

Questions 14 & 15 concerned clothing information of the people while filling the questionnaires. According to the question 14 which asked “*How do you describe your clothes in terms of thickness?*”, the responses were ‘*thin*’, ‘*moderate*’, ‘*very thin*’, and ‘*thick*’ by 32, 28, 2, and 1 people, respectively. The next question asked the people “*How do you describe your clothes in terms of color?*”, which was answered ‘*moderate*’, ‘*light*’, ‘*dark*’, ‘*very dark*’, and ‘*very light*’ by 22, 19, 16, 4, and 2 people, respectively.

4.2.2.2. Microclimate Perception:

The responses given to the 4th part of the questionnaire revealed the respondents’ perception of microclimatic factors (temperature, wind speed, and sun radiation) in POIs. Question 16 which asked people about their perception of the temperature at the moment showed that, in total, POI 1 (with mean Thermal Sensation Vote (TSV) 4.6) scored the best among the POIs. Regarding these votes, POI 1 was followed by POIs 3, 4, 5, 2, and 6 with mean TSV scores 4.4, 4.3, 3.5, 3.2, and 1.5, respectively. Although most of the responses ranged widely from ‘*unsupportable*’ (given score 1) to ‘*perfect*’ (given score 7), only ‘*unsupportable*’ and ‘*very unpleasant*’ (scores 1 and 2, respectively) were found for POI 6. Furthermore, in POIs 1, 3, and 5, majority of the respondents preferred to have

'cooler' weather while 28.6%, 31.3%, and 13.3%, respectively, preferred to have 'no change' in the temperature. In POI 4, despite majority of the respondents who selected 'cooler', only one person preferred to have 'warmer' weather. In POIs 2 and 6, all of the people preferred to have 'cooler' temperature.

Regarding the Wind Sensation Votes (WSV) of the respondents, question 18, POIs 1, 3, 2, 4, 5, and 6, showed mean WSVs 4.6, 4.4, 3.2, 3.1, 3.1, and 2.3, respectively. In POIs 1, 5, and 6, majority of the people preferred to have 'more air movement' while just one or two people wanted 'no change' in the wind speed. In POI 2, all of the respondents chose 'more air movement'. In POI 3, almost 40% preferred to have 'no change' while the rest preferred 'more air movement'. Also, in POI 4, respondents chose 'more air movement', 'no change', 'less air movement', respectively from the most to the least.

According to the answers given to question 20, people seemed to be more satisfied with sun radiation in POI 3 (mean Solar Sensation Vote (SSV) 4.4) among all six POIs. POIs 2, 1, 4, 5, and 6 had lower mean SSV scores (4.3, 4.0, 3.9, 2.8, and 1.8, respectively).

While in most of the POIs, a big range of answers were selected by the correspondents, in POI 6, answers ranged from 'unsupportable' to 'unpleasant'. In POIs 2 and 6, all of the respondents preferred to have 'more shade'. Also, in POI 5, except for only one person who preferred to have 'no change', all others chose 'more shade'. However, in POIs 1, 3, and 4, around 30% of the people had preferred to have 'no change' while the rest wanted 'more shade'.

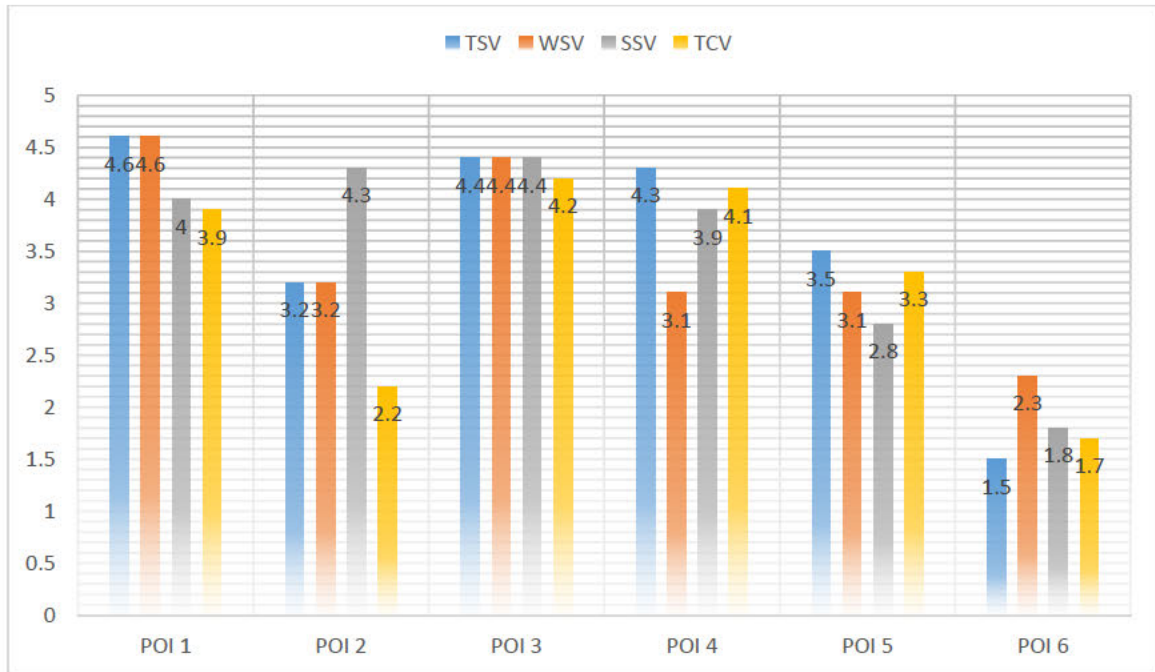
Last but not least, the 4th part of the questionnaire concluded with a question about overall thermal comfort of the respondents. POIs 3, 4, and 1 (with mean Thermal Comfort Votes (TCV) 4.2, 4.1, and 3.9, respectively) seemed to be the most comfortable spaces for the people, in terms of thermal perception; while, POIs 5, 2, and 6 (with mean TCVs 3.3, 2.2, and 1.7, respectively) seemed to be the least comfortable spaces for the people, in terms of thermal perception.

Table 7. Mean, minimum, and maximum values of thermal perception votes given for questions 16, 18, 20, and 22 of the questionnaire.

		POI1	POI2	POI3	POI4	POI5	POI6
TSV	Mean	4.6	3.2	4.4	4.3	3.5	1.5
	Min.	2	1	2	1	1	1
	Max.	7	7	7	6	7	2
WSV	Mean	4.6	3.2	4.4	3.1	3.1	2.3
	Min.	1	1	3	1	1	1
	Max.	7	5	7	5	5	4
SSV	Mean	4.0	4.3	4.4	3.9	2.8	1.8
	Min.	1	1	3	2	1	1
	Max.	7	7	7	7	7	3
TCV	Mean	3.9	2.2	4.2	4.1	3.3	1.7
	Min.	1	1	2	2	3	1
	Max.	7	3	6	6	4	2

TSV, Thermal Sensation Votes; WSV, Wind Sensation Votes; SSV, Solar Sensation Votes; TCV, Thermal Comfort Votes.

Figure 19. Mean results of thermal perception votes.



To be able to compare the respondents' microclimate perception votes (questions 16, 18, 20, and 22) among POIs, One-Way ANOVA means comparison analyses were conducted using SPSS software. In this regard, firstly, Levene's test was conducted to check homogeneity of variances (as a condition for one-way ANOVA analysis). The results of Leven's tests revealed that the answers of questions 16, 20, and 22 didn't have homogeneity of variances (sig. values were less than 0.05) while responses given to question 18 met the homogeneity of variances (sig. value was more than 0.05). Hence, for question 18, ANOVA table was used while for the others, Welch test of equality of means conducted. In these analyses the null hypothesis was that 'there is no mean difference among the levels'.

According to Tables 8 and 9, the sig. values of 0.005, 0.000, 0.001, and 0.000 indicate that null hypotheses for all four dependent variables were rejected. So, it can be said that at least one of the POIs (levels) are different in any of the dependent variables. Then, to find out the sources of differences, results of the post-hoc tests should be checked. For question 18, since homogeneity of variance assumption was met, Bonferroni can be used; while for questions 16, 20, and 22, as homogeneity of variance assumption was not met, Games-Howell can be used.

Table 8. ANOVA table for the Wind Sensation Votes (WSV).

		Sum of Squares	df	Mean Square	F	Sig.
Question18	Between Groups	37.865	5	7.573	3.728	.005
	Within Groups	115.786	57	2.031		
	Total	153.651	62			

Table 9. Robust Tests of Equality of Means for Thermal Sensation Votes (TSV), Solar Sensation Votes (SSV), and Thermal Comfort Votes (TCV).

		Statistic ^a	df1	df2	Sig.
Question16	Welch	11.943	5	21.229	.000
Question20	Welch	6.523	5	20.651	.001
Question22	Welch	12.354	5	19.311	.000

a. Asymptotically F distributed.

Based on Games-Howell post-hoc test on the answers given to question 16 (TSV), there are significant mean differences between (i) POIs 1 and 6, (ii) POIs 3 and 6, and (iii) POIs 5 and 6. Furthermore, the significance value for the mean difference observed between POIs 4 and 6 (0.064) is in close proximity to the critical threshold value (0.05), and the mean difference itself is 2.786. Therefore, despite the lack of statistical significance in the mean difference between POIs 4 and 6, the magnitude of the difference is noteworthy.

Regarding Bonferroni post-hoc test on WSVs, there is a significant mean difference between POIs 1 and 6. Also, the sig. value for mean difference between POIs 3 and 6 (0.060) is so close to the extreme (0.05) and the mean difference is 2.067; hence, although there isn't statistically significant mean difference between POIs 3 and 6, the difference is considerable.

Regarding Games-Howell post-hoc test on SSVs, there are significant mean differences between (i) POIs 1 and 6, and (ii) POIs 3 and 6. Also, the statistical sig. value for the mean difference between POIs 3 and 5 is 0.129, which is in close proximity to the extreme value of 0.05. Additionally, the mean difference between the two POIs is 1.6. Therefore, despite the lack of statistical significance in the mean difference between POIs 3 and 5, the difference between them is noteworthy.

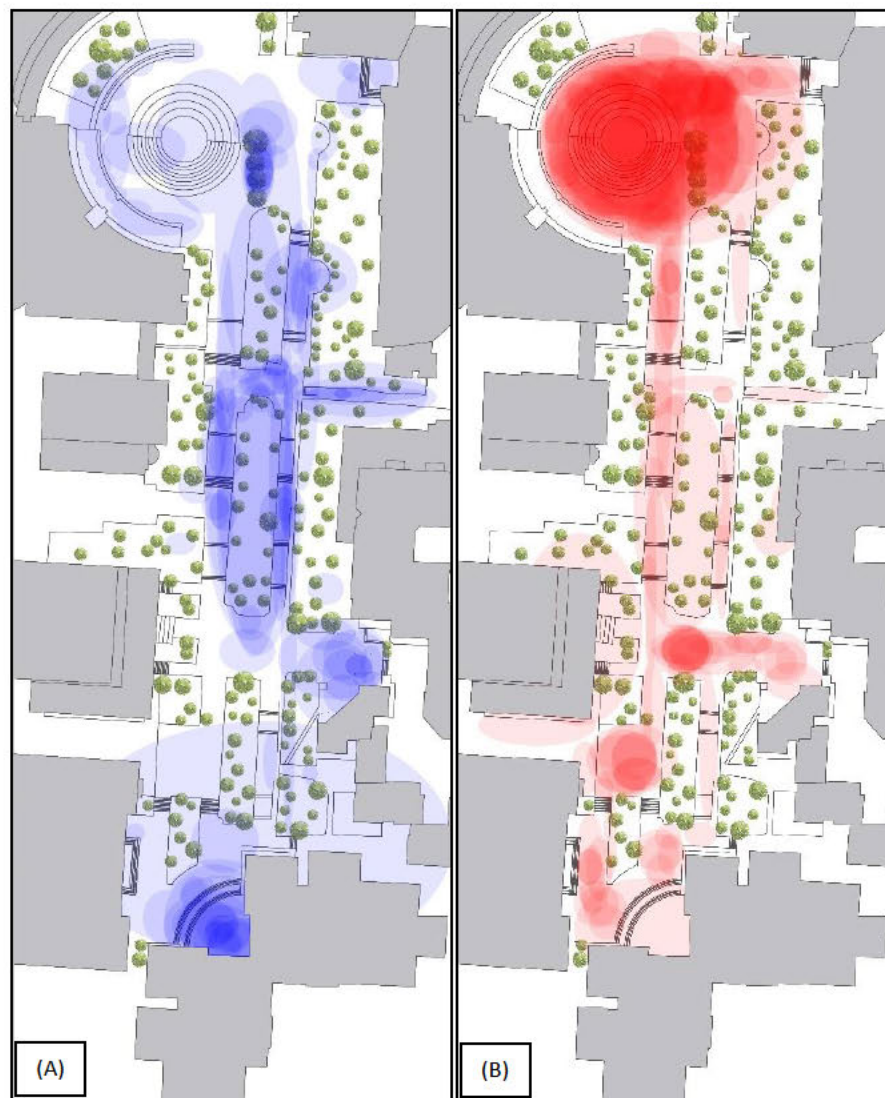
According to Games-Howell post-hoc test on the answers given to question 22 (TCV), there are significant mean differences between (i) POIs 1 and 6, (ii) POIs 2 and 3, (iii) POIs 3 and 6, (iv) POIs 4 and 6, and (v) POIs 5 and 6. In addition, the sig. value for the mean difference observed between POIs 1 and 2 was determined to be 0.144, with a corresponding mean difference of 1.762. Thus, while the mean difference between POIs 1 and 2 did not reach statistical significance, it was noteworthy. Also, the same could be said about the mean difference between POIs 2 and 4, where sig. value was 0.146 and mean difference was 1.976.

4.2.2.3. Cognitive Map Considering Microclimate:

In the fifth part of the conducted ‘in-situ’ questionnaires, in order to inquire about how the respondents perceived general microclimate within the study area, they were given a map showing the study area and asked to encircle coolest and hottest parts using blue and red pens. As a result, **Figure 20A/B** was made by overlapping those circles. According to **Figure 20A**, the space in front of the entrance of FF building (near POI 1), the space near FD building (southeast of POI 2), the central parts in the pedestrian which connects north to south (including POIs 3 and 4), and the place under the big crowns of the trees beside pool, were shown as the coolest areas with more blue circles by the respondents. Also, as shown in **Figure 20B**, the space between food court (Speed-Kirac) and sports center, the central space between sports center and POI 2, and the space surrounding the pool, were encircled in red more repeatedly as the hottest areas by the pedestrians. Additionally,

upon supplementing the aforementioned findings with the geographical location of the respondents, it was ascertained that 16.7% of the participants were situated in their assigned cool region, whereas 26.7% were situated in their designated hot region. Interestingly, majority of the pedestrians (56.7%) were located in none of the coolest nor hottest areas designated by themselves.

Figure 20. Cognitive maps considering microclimate; (A) coolest parts designated by the respondents; (B) hottest parts designated by the respondents (Illustration by the author, 2023).



Chapter 5

DISCUSSION

5.1. Activity Patterns within the Academic Campus Outdoor Spaces

According to the behavioral map (**Figure 10**) given in 4.1.2, POI 1 was one of the most crowded zones in terms of moving activities. Adjacency of this place to entrance of FF building seems to have a critical effect. The responses given to question 11 in '*in-situ*' questionnaires showed that 85.7% of the respondents used this place with the purposes of '*walking to / from department*' or '*passing by*'. Also, the pedestrian route which connects the student dorms (in the south) to the library, rector's building, and Table d'Hote restaurant (in the north) (see **Figure 2**), continues through POI 1, which caused an increase in moving activities in this place. The mentioned route caused many other moving activities zones as well. Furthermore, two branches were made from the mentioned pedestrian route to the FC building and faculty of economics, administrative, and social sciences, which caused moving activities zones in POIs 2 and 5, respectively. Adjacency to Starbucks café may have strengthened POI 2 in terms of number of pedestrians; and, the pharmacy may have influenced POI 5 similarly. The answers given

to the 11th question in the questionnaires conducted in POI 2, showed that 60% of the respondents used that places for '*walking to / from department*' or '*passing by*'. Overall, circulation routes and adjacency to entrances of the buildings played an important role in designation of moving activities zones. However, dissimilar to the research by Salama (2009), the places in this study area were not all used just as circulation spaces in movements between different educational buildings or colleges.

The blue spots in **Figure 10**, which means stationary activities zones, clearly show the importance of amenities (benches) in terms of stationary activities. In line with this, Whyte (1988) claimed that well-placed and well-designed seating can encourage socialization, relaxation, and longer stays, contributing to vibrant public spaces. Although the mentioned finding by William H. Whyte referred to urban plazas, the present study shows that can be true for outdoor spaces in academic campuses as well. Mostly, location of the benches designated repeated stationary activities which resulted in stationary activities zones. For instance, according to the answers given to question 11 in the questionnaires filled in POI 4, 50% of the people chose this place because of the amenities. However, despite the weight of the benches, users moved them frequently. This action may have been in response to variations in shadow patterns or in search for more / less interactions with others. Hence, movable seats seem to be better amenities than heavy benches for the study area of this research. Whyte (1988) supports the use of movable seating in public spaces due to their adaptability and flexibility. According to the mentioned book, individuals or groups can adjust the seating arrangement according to their requirements, preferences, and social dynamics using movable seating, that can

help create public spaces that are more inclusive and user-friendly. Furthermore, the research by Nouri and Costa (2017a) observed that even individuals who wished to sit in the sunlight were faced with a shortage of seating alternatives, and were reprimanded by security personnel for sitting on the edges of the water fountains located in close proximity to the points of interest. From this observation, the mentioned researchers inferred the significance of taking into account psychological factors, specifically the element of "choice," alongside thermophysiological factors.

On the whole, the repetitions of stationary activities showed that, in addition to availability of seats, trees with wide crowns and adjacency to cafés, may be important factors in establishment of stationary activities zones. Also, regarding the observational studies, the small pool near POI 6 attracted people for stationary activities at around sunset time, which shows direct sunlight (lack of shade) may be the reason that has objected this place from being one of the stationary activities zones. These being said, along with importance of entrances of adjacent buildings on designation of moving activities zones as mentioned before in this chapter, the 3rd hypothesis, **H₃**, “*Natural elements (water and greenery), amenities (benches), and entrances of the adjacent buildings affect stationary and moving activities patterns of the occupants significantly.*” is confirmed.

5.2. Human Thermal Comfort

5.2.1. Psychological Aspects of Thermal Comfort

Regarding the cognitive map considering microclimate (**Figure 20**), the selected '*coolest parts*' overlapped a lot in POIs 3, 4, and 1, respectively; while the drawn '*hottest parts*' repeated a lot in POIs 6, 5, and 2, respectively. Additionally, no respondent in POI 4 had encircled that place as '*hottest part*'; on the other hand, no one in POIs 5 or 6 encircled the corresponding POI as '*coolest part*'.

Also, regarding the results of the One-Way ANOVA analyses on microclimate perception votes of the respondents, there were statistically significant mean differences between POIs 1 and 6 in all TSV, WSV, SSV, and TCV. Also, there were statistically significant mean differences between POIs 3 and 6 in TSV, SSV, and TCV. In addition, POI 6 showed statistically significant mean differences with POIs 4 and 5 in TSV and TCV. Another significant statistical mean difference was also found between POIs 2 and 3 in TCV. Summing up, the differences in TCV were found to be most similar to those of TSV, followed by SSV, and at least similarity with WSV. Also, among POIs, regarding the means given in **Table 7**, POI 6 received weakest votes in all four categories, mostly followed by POIs 2 and 5. On the other hand, POIs 1 and 3, were given the highest votes in most of the perception categories.

Comparing the cognitive map considering microclimate and the microclimate perception votes, it was possible to verify that these two tools of psychological analyses were mostly

in line with each other. In all of the psychological assessments, POI 6 was found to be the most vulnerable POI in terms of heat exposure. However, regarding POI 2, the output from the cognitive map was not as extreme as the result from TCV. Checking the responses in POI 2 showed that except for only one person, all others chose that POI as hottest part or none of the hottest or coolest parts in the study area; in other words, nearly all of the drawings that designated POI 2 as coolest part, were made by people who were located in one of the other POI s.

To address the 2nd hypothesis, **H₂**, “*Natural elements (water and greenery) affect thermal perception of the individuals significantly.*” it must be repeated that there is only one blue space all along the main campus. This small circular pond with its active but modest fountains, located close to POI 6. The findings suggest that the POI 6 exhibited poor performance with respect to the psychological thermal comfort of the participants. It can be inferred that the presence of water did not significantly enhance the perception of thermal comfort in the surrounding environment. However, it should be noted that other factors, e.g. lack of shade, and also size of the pond and height of the active fountains may have affected the place. Furthermore, in terms of vegetation, it appears that trees with broad canopies had a notable influence on thermal comfort due to their shading capabilities (e.g. POIs 3 and 4, as well as the area beneath the trees adjacent to the pool), similar to Shashua-Bar et al. (2011). Conversely, vegetation lacking shading capabilities did not have a significant impact on people's perception of thermal comfort (POI 1 outperformed POIs 2 and 5, despite being further from the vegetation than the latter two). Hence, in spite of relative impact of greenery, **H₂** was rejected.

5.2.2. Physiological Aspects of Thermal Comfort

Comparing the data given in detail in sections 4.2.1.2 and 4.2.1.3, a similarity in oscillations of T_a , T_{mrt} , PET, and mPET, in the POIs was observed. More specifically, POIs 1, 3, and 4 displayed distinct T_a , T_{mrt} , PET, and mPET oscillations than POIs 2, 5, and 6. These differences were even more considerable in T_{mrt} and PET values, which consisted of several extreme values in POIs 2, 5, and 6. Regarding the POIs' hours of shading on SBS maps, too, this division into two categories (POIs 1, 3, and 4, and POIs 2, 5, and 6) seems appropriate. POI 1 experienced shade for a significant portion of the day due to the presence of the FF building, which is situated to the east and south of the POI. POIs 3 and 4 were predominantly shaded by the adjacent trees. Conversely, POIs 2, 5, and 6 were exposed to direct sunlight throughout the entire day.

Regarding RH and V, as shown in 4.2.1.2, RH values did not follow meaningful oscillation patterns comparing the POIs, and the changes were more meaningful comparing the days. Similarly, V values didn't show critical oscillations to make critical effects; however, POIs 1 and 6 showed subtle differences in comparison with the other POIs (by just 0.1 (m/s) more than those of POIs 2 and 5). Hence, RH and V may not have had critical impact on physiological or psychological thermal comfort conditions of the people in this study.

In conclusion, comparing the oscillations of T_{mrt} (which depends on T_a and T_g) with those of PET and mPET and also congruence of SBS map with these oscillations among POIs, reveals that solar radiation and shading had the most critical impact on physiological aspect of thermal comfort conditions of the people in the present experiment (in line with Chatzidimitriou and Yannas (2016); Hodder and Parsons (2007); Jamei et al. (2016)). T_a and TSV, as well, had positive relations with PET, mPET, and TCV; however, T_a showed less fluctuations than PET, mPET, and TCV.

The utilization of the mPET index in this research provided an opportunity to contrast and employ a revised PET iteration that is founded on an enhanced thermoregulation framework established by Chen and Matzarakis (2018). The present study's observations regarding PET and mPET align with the conclusions drawn by other scholars, such as Chen and Matzarakis (2018), and Andre Santos Nouri et al. (2018). The mPET material exhibits a tendency to maintain closer to thermal neutrality and comfort conditions, particularly when exposed to extreme temperatures, whether hot or cold. Furthermore, the aforementioned system exhibits an increased number of nodes that facilitate the computation of the thermal index, and possesses an enhanced ability to comprehend the various layers of clothing. Hence, mPET values exhibit fewer distinct and more real outcomes when contrasted with PET values. Despite the fact that the computation of mPET values is more time-consuming due to its complex equations, it is better suited for the indication of PS grades and a more reliable thermal index.

5.2.3. Comparing Psychological and Physiological Aspects of Thermal Comfort

As mentioned in 4.2.1.3, the highest mean PET and mPET referred to POI 2, followed by POIs 5, 6, 3, 4, and 1, respectively. Also, regarding mean T_a and T_{mrt} , POIs 2, 5, and 6 represented higher values than POIs 1, 3, and 4. On the other hand, mean TCV value was the best for POI 3, followed by POIs 4, 1, 5, 2, and 6, respectively. Furthermore, mean TSV was the highest for POI 1, followed by 3, 4, 5, 2, and 6, respectively. In other words, POIs with lower T_{as} , T_{mrt} s, PETs, and mPETs (POIs 1, 3, and 4) received better TCVs and also TSVs than POIs with higher PETs and mPETs (POIs 2, 5, and 6). The analysis revealed a surprising alteration in the classification of the Points of Interest (POIs) based on the mean SSV scores, with POI 2 exhibiting the second-highest mean SSV value. This surprising alteration recurred in mean WSVs, too. The reason of this disagreement may be misunderstanding by some of the respondents. Last but not least, the cognitive map considering microclimate also confirmed classification of the POIs into two groups.

Psychological and physiological results showing thermal comfort conditions, mostly comply. Although in some details there were some disagreements, both aspects nominated POIs 2, 5, and 6 as more critical spaces in terms of thermal stress. SSVs of only POI 2 didn't comply sufficiently with TCVs, and also T_{mrt} , PET, and mPET values; however, TCVs, TSVs, SSVs of all other POIs, and also, the cognitive map all exhibited considerable congruence with SBS map. Saying all these in line with the explanations in

the previous section, the 4th hypothesis, **H4**, “*Solar radiation and shading have the greatest influence on physiological and psychological aspects of thermal comfort and, by extension, the activities of the occupants.*” is affirmed.

5.3. Relationship between Thermal Comfort and Activity Patterns within the Academic Campus Outdoor Spaces

Based on multiple studies, e.g. (Lai et al., 2020; Martinelli et al., 2015; Nikolopoulou & Steemers, 2003), outdoor thermal comfort has a considerable impact on type and intensity of the people’s activities within outdoor spaces. Nouri and Costa (2017b) revealed that incorporating user-based approaches to microclimates and potential climate change can contribute to the elements of a "successful" location, ensuring its future viability and socio-economic well-being. In this regard, outcomes of the present study in both domains of activity patterns and human thermal comfort are compared for possible any relationships.

According to psychological and physiological findings of the present research, POIs 1, 3, and 4 are found to be more comfortable than POIs 2, 5, and 6 for the people in terms of thermal conditions. According to some studies (Eliasson, 2000; T.-P. Lin, 2009; Nikolopoulou & Lykoudis, 2006; Yahia & Johansson, 2013) the use of outdoor spaces often depends on whether they offer a thermally comfortable environment. Therefore, POIs 1, 3, and 4 are supposed to be used more than POIs 2, 5, and 6. However, the

behavioral map (**Figure 10**), shows that POIs 2 and 5 are of most crowded moving activities zones. Apart from the thermal environment, several other parameters have been shown to be of significance to the subjective assessment and satisfaction of the outdoor environment, e.g. context (design, function) (Thorsson et al., 2007). In addition, Katzschner et al. (2006) demonstrated that people's behavior is highly dependent on outside climatic conditions, but also influenced by weather expectations and the activities for which open spaces are utilized.

The notes made throughout the experiments revealed that several people declined to fill up the questionnaires in extreme microclimates because they wanted to leave those regions quickly; consequently, although people used thermally uncomfortable spaces for moving activities, they couldn't tolerate pauses there even for a few minutes.

Additionally, it was found that pedestrians moved more slowly in favorable microclimates (sometimes even talked, ate, or drank) while they mostly moved quickly toward their destination in adverse microclimates. Thus, even if not significantly, thermal comfort had an impact on moving activities. As stated by Brown (2010), landscape architects and urban designers typically prioritize elements such as visual appeal, functionality, and arrangement in their design schemes; however, thermal comfort, a crucial aspect that often goes unnoticed, also warrants significant attention. He believed that in the absence of it, individuals may not be motivated to utilize the area, irrespective of its other attributes.

Addressing stationary activities, thermal comfort level seems to have more significant impact. Although availability of seating seems critical as mentioned in the section 5.1, thermal comfort, especially in terms of shading, plays important role. For instance, the area surrounding pool showed that despite existence of blue space, availability of seating, and adjacency to café and other building entrances with big footfall, was not used frequently for stationary activities. It should be noted that this place is so close to POI 6 which was the poorest in all of the psychological thermal comfort investigations and one of the most extreme POIs in terms of physiological thermal comfort condition.

In conclusion, although not as strongly as functionality, *“There is a positive relation between thermal comfort conditions and repetitions of activities of the people.”* Which means 1st hypothesis, **H₁**, is verified.

Chapter 6

CONCLUSION

The present research investigated physiological and psychological aspects of human thermal comfort in outdoor spaces of an academic campus in Ankara during summer of 2022. For a better understanding of human thermal comfort, stationary and moving activity patterns, and their possible relationships, the study undertook a three-layered approach which consisted of behavioral studies simultaneous with physiological and psychological aspects of human thermal comfort. Within behavioral investigations, a walk-by observational study in a structured manner was conducted during 12 days that resulted in a behavioral map which designated stationary / moving activities zones with bigger footfalls. To study physiological aspect of thermal conditions, a shadow behavior simulation was conducted on the 21st of August 2022 which resulted in a shadow behavior map; then, collecting meteorological variables and the incorporation of PET and mPET thermal indices, facilitated the understanding of the thermophysiological stress imposed upon the human biometeorological system during the allocated experiment days. In addition, a study was conducted to investigate the psychological impact of thermal conditions. During a period of 13 days, 64 '*in-situ*' questionnaires were conducted alongside the quantitative assessments to also assess the qualitative aspect of both '*in-*

situ’ and spatial thermal comfort perception within one of the main circulation areas of the campus. Subsequently, following a comparative analysis of the findings from studies on psychological and physiological thermal comfort, they were compared with the activity patterns observed in the outdoor spaces of Bilkent University’s main campus. The findings of this research were moreover aimed at assisting the interdisciplinary understanding and decision making for design orientated professionals, including architects, landscape architects, and urban designers within educational contexts. Such an approach presented a developed approach in aiding non-climatic experts in improving the bioclimatic planning, management of further thermally comfortable and, by extension, the assurance of active outdoor spaces within an academic campus. The three-layered approach is one which was moreover aimed at being later explored within other case studies as well.

At this point, the concluding remarks are reviewed briefly as follows, and then presented concisely with design recommendations in Table 8:

- POIs 2, 5, and 6 performed weaker than POIs 1, 3, and 4 in terms of air temperature, mean radiant temperature, PET, mPET, and also psychological thermal comfort evaluations. Additionally, SBS map disclosed that POIs 2, 5, and 6 were sun-exposed all daylong while the other three POIs were shaded at least during half of the day. Furthermore, the oscillations of mean radiant temperature were considerably similar to the oscillations of PET and mPET. Hence, solar radiation showed strong relation with thermal comfort indicators. It is moreover

believed that while wind speed did not carry the same weight upon thermal comfort evaluations, this was resultant due to the relatively low speeds, including within the shaded areas of the study.

- This research assessed the potential impact of mPET index, a recently revised thermo-physiological metric that was adapted from the Munich Energy-Balance Model for Individuals, a subsequent energy based model index after PET. The outcomes revealed that the oscillations of mPET values were somewhat similar to PET, however remained closer to neutral condition in conditions of higher thermophysiological stress. In accordance with the existing literature, the updated version of the PET index provides a more comprehensive understanding and precise evaluation of the encircling microclimate upon the human biometereological system. Nevertheless, and also in alignment with the existing literature, the PET index still proved to be an effective thermal index, which although less accurate, due to its reduced algorithmic and computational nodes, provided an effective means to identify heat stress vulnerabilities, with considerably reduced processing time/power.
- Among the measured microclimatic factors, relative humidity and wind velocity were not as influential as air temperature and solar radiation on the people's thermal comfort. As stated, relative humidity and wind velocity did not have considerable fluctuations during the experiment days and also did not meet critical values. However, the study still revealed the imperative requirement to

account for a combination of variables in order to understand the true effects upon humans, and avoid the reliance on singular variables when assessing and designing with thermal sensitivity. The impact of air temperature, relative humidity and wind velocity, and mean radiant temperature on individuals' thermal comfort may vary significantly across different locations and seasons.

- POI 6 had the lowest performance in psychological evaluations of thermal comfort. Despite adjacency to blue space, POI 6 had the worst thermal sensation vote, wind sensation vote, solar sensation vote, and thermal comfort vote means. Also, this POI was labeled as hottest part by several participants in the cognitive map considering microclimate while no one chose this space as the coolest part. POI 6 exhibited a poor performance in physiological evaluations as well.
- Findings of physiological and psychological evaluations on human thermal comfort mostly complied with one another, except for a dissimilarity which was based on half of solar sensation votes given in POI 2. However, existence of the above-mentioned dissimilarity and also some trivial differences in the results remind that considering both (physiological and psychological) aspects in human thermal comfort studies is beneficial.
- The observational study revealed that the blue space beside POI 6 attracted people for stationary activities in cloudy hours and also evenings with weaker solar radiation. However, although the mentioned zone contained pool with active

fountains, different types of seating availabilities, and adjacency to entrances of café and other buildings with big footfalls, it failed in terms of repetitions of activities during strong solar radiation hours.

- Comparing the POIs with different features in terms of greenery, showed that greenery had critical impact on physiological and psychological thermal comfort of the individuals only in case of performing shading capabilities. The greenery without shading possibility mostly failed to mitigate thermal stress.
- The presence of amenities, specifically benches, was identified as the primary determinant in the creation of stationary activity zones. However, subtle changes in locations of the benches were realized during the observational studies. Hence, using movable seating instead of the existing heavy benches could be of benefit in the studied academic campus outdoor spaces.

Table 10. Relationship between study conclusion remarks and bioclimatic design recommendations to enhance thermal comfort condition and activity patterns in an academic campus outdoor spaces.

Conclusion remarks	Design recommendations
Solar radiation was found to be the most critical meteorological factor in terms of human thermal comfort in outdoor spaces of Bilkent University's main campus.	Shading possibilities should be considered specifically to reach supportable thermal comfort levels. In this regard, SBS analyses may help designers evaluate effects of buildings, shades, trees, and other environmental elements, on sun/shade status of a space.
The results indicated that the oscillations of mPET values were somewhat similar to PET, however remained closer to neutral condition in conditions of higher thermophysiological stress.	Designers are recommended to use mPET index in their thermal sensitive design assessments to gain a more comprehensive understanding and precise evaluation of open-air environments, with an acceptable temporal resolution.
Among the measured microclimatic factors, RH and V were not as influential as T_a and solar radiation on the people's thermal comfort.	It is recommended to consider as many microclimatic factors as possible in thermal sensitive designs. The mentioned contribution of T_a , V, RH, and T_{mrt} in people's thermal comfort could be totally different in other places or even in other seasons.
POI 6 performed the poorest, in terms of psychological aspect of human thermal comfort.	Adjacency to the blue space couldn't neutralize negative effect of lack of shade. However, size and elevation of the pool and height of the fountains could be critical in this case.
The congruence between physiological and psychological assessments regarding human thermal comfort was predominantly observed.	Regarding some subtle dissimilarities in the results, considering both (physiological and psychological) aspects in thermal sensitive design evaluations proved beneficial in the wholesome assessment of local microclimatic conditions on campus.
Blue space attracted people but not in strong solar radiation times.	It is recommended to pay special attention to shading in thermal sensitive designs. Lack of shade may ruin performance of a place with considerable environmental potentials like blue space, accessibility, and availability of seats.

Greenery with shading capability enhanced thermal comfort condition.	Trees with broad canopies can be used to improve shading hours and consequently physiological and psychological thermal comfort of the people.
Amenities (benches) were found to be the most important factor in establishment of stationary activities zones.	It is recommended to place seating availabilities to enhance stationary activities. Also, movable seating may result in more inclusive and user-friendly spaces that enhance the availability of choice.

6.1. Study Limitations and Suggestions for Future Studies

Albeit all endeavors to make the present study as comprehensive and accurate as possible, like any other experimental research, it had some methodological limitations. Firstly, it should be considered that this study was conducted in Ankara, Turkey, and the findings correspond to climatic conditions of this region. Complementation of similar studies in other places with different Köppen Geiger classifications could help the research come up with more comprehensive outcomes and also it could provide possibility of comparison between similar studies in different climatic conditions. Furthermore, as this research was conducted for thermal stress, a similar investigation for cold stress in winter could complement this study fruitfully. Another limitation in the process of the experiment was small sample size in some of the POIs as not many people were available there in the periods of experiment. Also, in some cases, the pedestrians refused to fill up the questionnaire due to extreme thermal condition. In addition, due to

variety in nationalities of the lecturers and students in the campus, English language was chosen as the only mutually known language. However, English was not native language of any of the respondents. Thus, different levels of literacy in English could result in misunderstandings and consequently unintended responses. Last but not least, due to educational nature of the environment, there were temporary changes in it, which could affect accuracy of the findings. For instance, the Starbucks café in FC building, which put a significant impact on the results of observational studies, was closed during the '*in-situ*' measurements and questionnaires. This issue caused changes in places of the POIs after the first day of measurements.

Future similar studies can concentrate on various tree species as shapes and sizes of trees were found to be of importance in this research in terms of shading capabilities. Also, evergreen trees can be compared to deciduous trees in terms of their contribution in outdoor thermal comfort conditions in winter and summer. Similar studies are suggested to be conducted in Bilkent university campuses in other seasons, specifically winter, as well; because according to academic calendar, the campus is used more during other seasons than summer. Additionally, extreme cold thresholds are probably experienced in winters due to climate of Ankara. Computational Fluid Dynamic studies could not be run due to the time limitation of the study; however, this methodology could be complemented with the Shadow Behaviour Studies for POI stipulation. This would be particularly pertinent during the winter where wind speeds are higher and may be accelerated due to local morphology and topography.

Within this study, two widely used energy-based model indices were employed due to their prevalence in such research, but they could have been supplemented with the Universal Thermal Comfort Index. This would allow for a deeper examination of the physiological responses of site users to the microclimate conditions. As a consequence of the algorithmic nature of the Fiala model, there is a known problem with the processing of low wind speeds (below 0.5 m/s) in this particular thermal index.

The study calls for further studies of indoor-outdoor relationships, including the identification of indoor stationary areas (such as classrooms, studios, lecture halls), and movement areas. These could shed further light upon the described entrances of the buildings, and immediately adjacent activity areas in terms of identified footfall and behaviour patterns outside. Furthermore, due to a paucity in human thermal comfort studies in outdoor spaces of academic campuses, the researchers are recommended to study the impact of human thermal comfort in such environments on: i) educational performance of the students, ii) social interactions of the students, iii) mental health of the students, iv) lecturer-student relationships.

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APPENDIX A

QUESTIONNAIRE SHEET



Date:

Time:

POI:

**“Investigation of the relationship between thermal comfort and attendance
at the social areas in Bilkent university main campus.”**

This questionnaire is for a part of master's thesis research which aims to figure out how thermal comfort conditions affect attendance of the users at the social areas in an important part of Bilkent university main campus, and how this zone could be better in terms of thermal comfort conditions.

This questionnaire includes 27 questions in 5 pages. There are no correct or incorrect answers and you may skip any of them if you want to.

Part 1: Personal information:

1. Age:	18-24 ☐	25-29 ☐	30-34 ☐
	35-39 ☐	40-44 ☐	45-49 ☐
	50 or more ☐		
2. Gender:	Male ☐ Female ☐		
3. Height (cm):	150 or less ☐	151-160 ☐	
	161-170 ☐	171-180 ☐	
	181-190 ☐	191-200 ☐	
	201 or more ☐		
4. Weight (kg):	50 or less ☐	51-60 ☐	
	61-70 ☐	71-80 ☐	
	81-90 ☐	91-100 ☐	
	101 or more ☐		
5. Nationality:			
6. Department:			
7. Role in the department:	Undergraduate student ☐ Graduate student ☐ Lecturer ☐ Staff ☐		

Date:

Time:

POI:

Part 2: Activity information:

Answer 8th and 9th questions of this part according to the last half hour and 10th and 11th questions according to the moment.

8. For the last half hour, where have you been?	Indoor ☐ Outdoor ☐
9. For the last half hour, what have you been doing?	Sitting ☐ Standing ☐ Walking ☐ Studying ☐ Eating ☐ Doing exercise ☐ Sleeping ☐ Other activity:
10. What are you doing at the moment?	Sitting ☐ Standing ☐ Walking ☐ Studying ☐ Eating ☐ Doing exercise ☐ Other activity:
11. Why have you chosen this place for your activity?	
12. How long have you been in this place?	
13. Are you going to stay in this place for more time?	Yes ☐ No ☐ If 'Yes', how long are you going to stay in this place: Half an hour or less ☐ About 1 hour ☐ About 2 hours ☐ About 3 hours or more ☐

Date:

Time:

POI:

Part 3: Clothing information:Answer 14th and 15th questions concerning what you are wearing at the moment.

14. How do you describe your clothes in terms of <u>thickness</u> ?				
Very thick	Thick	Moderate	Thin	Very thin
☐	☐	☐	☐	☐
15. How do you describe your clothes in terms of <u>color</u> ?				
Very dark	Dark	Moderate	Light	Very light
☐	☐	☐	☐	☐

Part 4: Microclimate perception:Answer 16th to 19th questions concerning how you feel at the moment.(for 16th to 19th questions, the numbers (-3) to (+3) respectively refer to 'unsupportable', 'very unpleasant', 'unpleasant', 'satisfactory', 'pleasant', 'very pleasant', and 'perfect'.)

16. How do you find the <u>temperature</u> at the moment?	-3	-2	-1	0	+1	+2	+3
17. Regarding the <u>temperature</u> at the moment, I'd prefer:	Cooler		No change		Warmer		
18. How do you find the <u>wind</u> at the moment?	-3	-2	-1	0	+1	+2	+3
19. Regarding the <u>wind</u> at the moment, I'd prefer:	More air movement		No change		Less air movement		
20. How do you find the strength of the <u>sun</u> at the moment?	-3	-2	-1	0	+1	+2	+3
21. Regarding the strength of the <u>sun</u> at the moment, I'd prefer:	More shade		No change		More sun		
22. How comfortable are you <u>overall</u> at the moment?	-3	-2	-1	0	+1	+2	+3

Date:

Time:

POI:

Part 5: Cognitive map concerning microclimate:

(The map in this page shows a part of the bilkent university main campus which is chosen to be studied for this research.)

Answer 23rd, and 24th questions according to this map.

23. Are you familiar with all of the white places shown in the map given?
24. In the map provided, using your spatial perception of the space, encircle the **coolest** part using blue pen, and the **hottest** part using red pen.

25. Which conditions are most probable for the chosen **coolest** part?

Warm ☐ Hot ☐
Cool ☐ Cold ☐
Too windy ☐
Insufficient air movement ☐
Too shady ☐
Too sunny ☐
Other reasons for comfort or discomfort:

26. Which conditions are most probable for the chosen **hottest** part?

Warm ☐ Hot ☐
Cool ☐ Cold ☐
Too windy ☐
Insufficient air movement ☐
Too shady ☐
Too sunny ☐
Other reasons for comfort or discomfort:



Date:

Time:

POI:

Part 6: Modification proposals:

27. What modification(s) do you think could make the study area, which is shown in the map on previous page, better? (with an emphasis on thermal comfort issues.)

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APPENDIX B

BILKENT UNIVERSITY ETHICS COMMITTEE APPROVAL FORM





Bilkent Üniversitesi

Akademik İşler Rektör Yardımcılığı

Tarih : 11 Ağustos 2022
Gönderilen : Hadi Seydnouri
Tez Danışmanı : Andre Naghi Lopes Dos Santos Nouri
Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı
Konu : "Investigation of ..." çalışması etik kurul onayı



Üniversitemiz İnsan Araştırmaları Etik Kurulu, 11 Ağustos 2022 tarihli görüşme sonucu, "Investigation of the relationship between thermal comfort and attendance at the social areas in Bilkent university main campus" isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlüsünüz.

Kovid-19 salgını nedeniyle konulmuş olan kısıtlamaların yürürlükte olduğu süre içinde, tüm komite toplantıları elektronik ortamda yapılmaktadır; aşağıda isimleri bulunan Bilkent Üniversitesi Etik Kurulu Üyeleri adına bu yazıyı imzalama yetkisi kurul başkanındadır.

Etik Kurul Üyeleri:

Ünvan / İsim	Bölüm / Uzmanlık	
Prof.Dr. H. Altay Güvenir	Bilgisayar Mühendisliği	Başkan
Prof.Dr. Erdal Onar	Hukuk	Üye
Prof.Dr. Haldun Özaktas	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Dr. Öğr. Üyesi Didem Özkul McGeoch	İletişim ve Tasarımı	Yedek Üye
Dr. Öğr. Üyesi A.Başı Özben	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2022_08_11_01

APPENDIX C

CONSENT FORM





Dr. Andre Santos Nouri



Bilkent University

Investigation of the relationship between thermal comfort and attendance at the social areas in Bilkent university main campus

PARTICIPANT INFORMATION AND CONSENT FORM

Who is carrying out the study?

You are invited to participate in a study conducted by Hadi Seyednouri as part of a research project at Bilkent University.

What is the study about?

The ongoing research titled aims to investigate the relation between thermal conditions in the specified zone and attendance of the users at the social areas. The ultimate goal in this research is to figure out how thermal comfort conditions affect attendance of the users at the social areas in the most crowded part of Bilkent university main campus, and how could this zone be better in terms of thermal comfort conditions.

What does the study involve?

As a part of the above-mentioned master's thesis research. A questionnaire of 27 questions is designed in 6 parts. The first part asks about the participant's personal information which consists of age, gender, length, weight, nationality, department, and role in the department. The second part asks where have the participants been and what have they been doing during the last half an hour and also at the moment of filling the questionnaire. Then, this part asks about reasons of the participants to be in the place and tries to figure out their attitude towards the place. The 3rd part asks about thickness and colour of the participant's clothes which may be easily answered by checking the proper adjectives proposed. 4th part tries to find out the participant's microclimate perception of the place regarding temperature, wind, and sun/ shade conditions, and whether he/ she wants any change in the microclimatic conditions or not. The 5th part provides a map of the study place and asks the participant to draw perceived coolest and hottest place using blue and red pens; then, he/ she is to be asked about the reasons behind these drawings. Finally, the 6th part asks the participant about any modifications in the place to make the place better.

All in all, the above-mentioned questionnaire includes open-ended and close-ended questions, accompanied by a simple drawing. The questions are not using the participants' identities.

How much time will the study take?

It will take approximately 15 minutes in total.

Will the study benefit me?

The study will not benefit you directly, but will tell us more about how thermal comfort conditions is linked with attendance of the users at the social areas. Also, the results of this study may tell us how we may have better campus public places in terms of thermal comfort conditions.

Will the study involve any discomfort for me?

The questionnaire does not include any content that may cause any discomfort for you. However, if you feel discomfort in any way, you can stop filling the questionnaire.

How will the confidentiality of my responses be ensured? How will the results be disseminated?

All aspects of the study, including results, will be anonymized, and only the researchers will have access to information on participants. The group results will be written up as part of the thesis study (Bilkent University, Instructor: Assist. Prof. Dr. Andre Santos Nouri). Also, the questions are not using the participants' identities. Hence, all the responses are recorded for unidentified participants.

Can I withdraw from the study?

Participation is entirely voluntary. You are not obliged to be involved and if you do participate you can withdraw at any time without giving any reason and without facing any consequences.

Can I tell other people about the study?

Approach of this study is to consider random participants being in the study place during the survey hours.

What if I require further information?

When you have read this information, your researcher will discuss it with you further and answer any questions you may have. Also, you are always welcome to contact the researcher [REDACTED]

What if I have a complaint?

This study has been approved by the Bilkent University Department of Interior Architecture and Environmental Design Ethics Committee. If you have any complaints or reservations about the ethical conduct of this research, you may contact the research supervisor Assist. Prof. Dr. Andre Santos Nouri by email at [REDACTED] Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

If you agree to participate in this study, please sign the informed consent form below.

I have been asked to participate in the research project **“Investigation of the relationship between thermal comfort and attendance at the social areas in Bilkent university main campus”** and give my free consent by signing this form. I acknowledge that:

1. The research project will be carried out as described above. I have read and understood the information provided and have had the opportunity to discuss the information and my involvement in the project with the researcher(s) to my satisfaction.
2. My involvement is confidential and the information gained during the study may be published, but no personal information will be used in any way that reveals my identity.
3. My consent to participate is voluntary. I may withdraw from the study at any time, without affecting my relationship with Bilkent University. I do not have to give a reason for the withdrawal of my consent.
4. I am above 18 years old and I am not currently taking any classes from Assist. Prof. Dr. Andre Santos Nouri.

Signed:

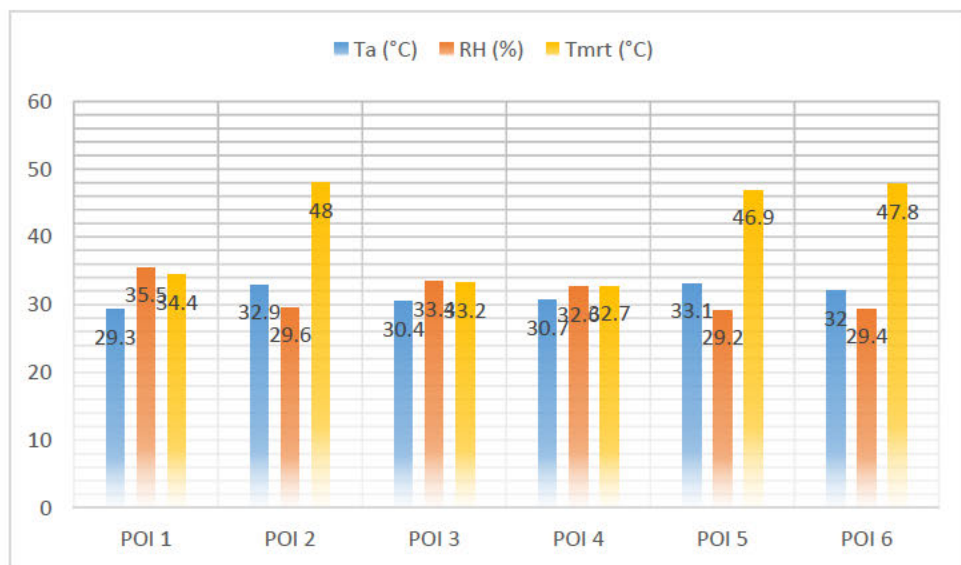
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Date:

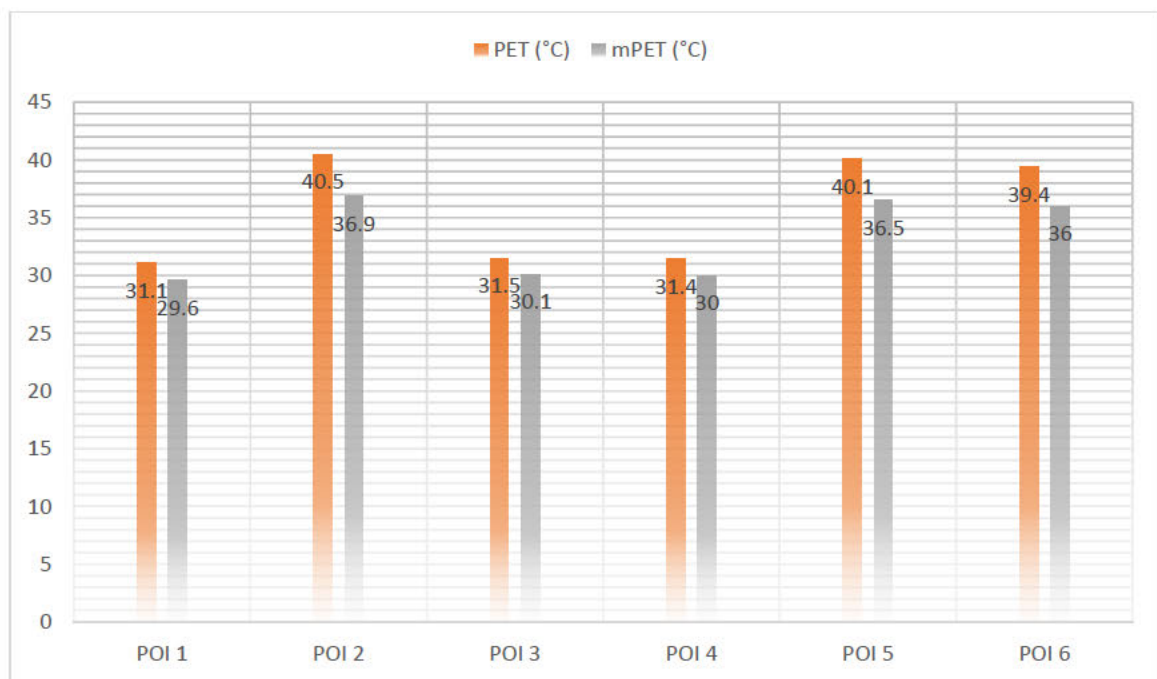
APPENDIX D

Overall mean, minimum, and maximum values of measured microclimatic factors and thermal indices.

		POI1	POI2	POI3	POI4	POI5	POI6
T _a (°C)	Mean	29.3	32.9	30.4	30.7	33.1	32
	Min.	22.4	27.3	26.8	24.5	27	26.5
	Max.	39.1	38.7	34.2	37.6	42.6	37.4
RH (%)	Mean	35.5	29.6	33.4	32.6	29.2	29.4
	Min.	18.6	18.5	19.5	20.3	16.5	16.9
	Max.	61.7	47.3	49.5	53.1	45.3	44.3
V (m/s)	Mean	0.5	0.4	0.3	0.3	0.4	0.5
	Min.	0.0	0.0	0.0	0.0	0.0	0.1
	Max.	1.1	1.0	1.1	0.8	1.0	1.2
T _{mrt} (°C)	Mean	34.4	48.0	33.2	32.7	46.9	47.8
	Min.	22.1	23.4	22.2	22.5	22.3	24.3
	Max.	56.4	63.6	49.9	51.3	62	69.9

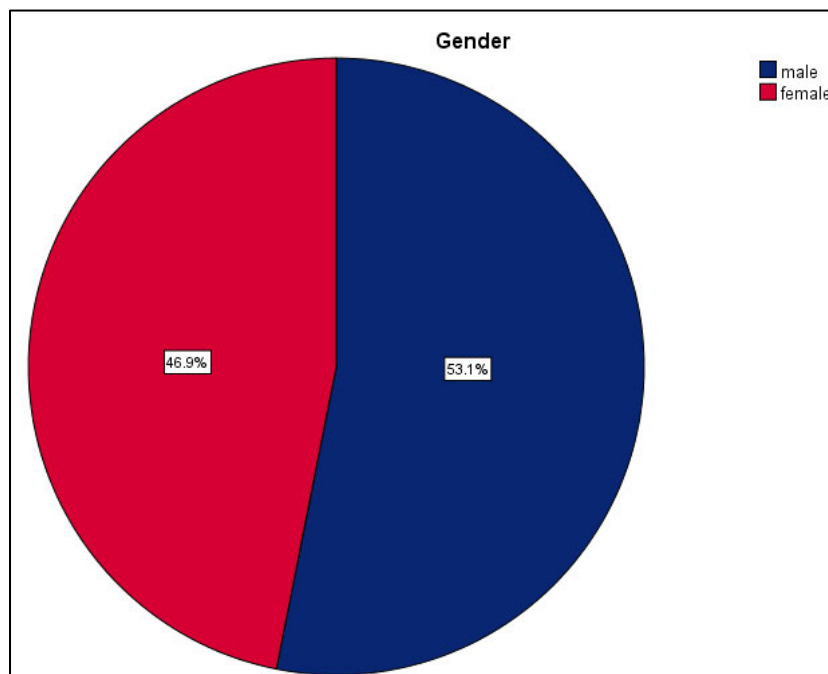
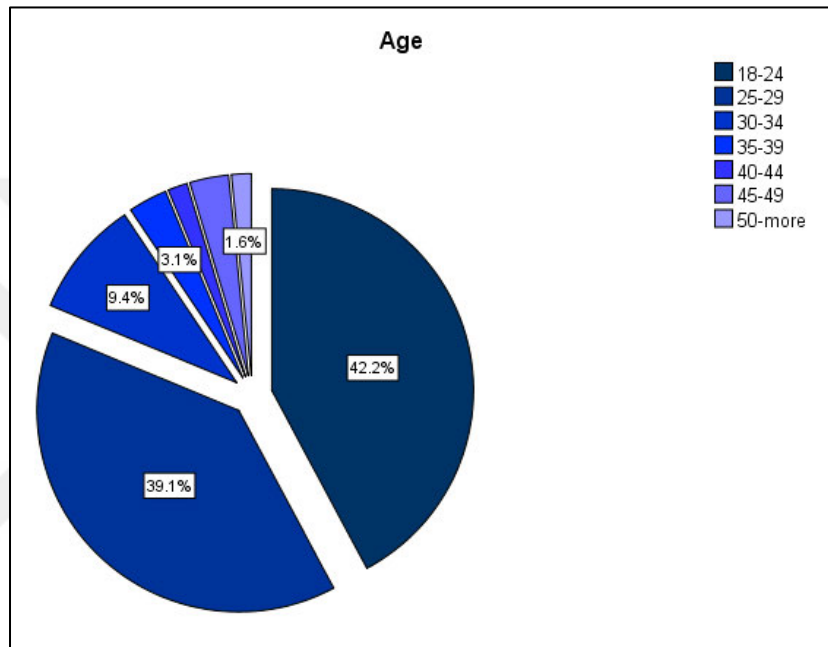


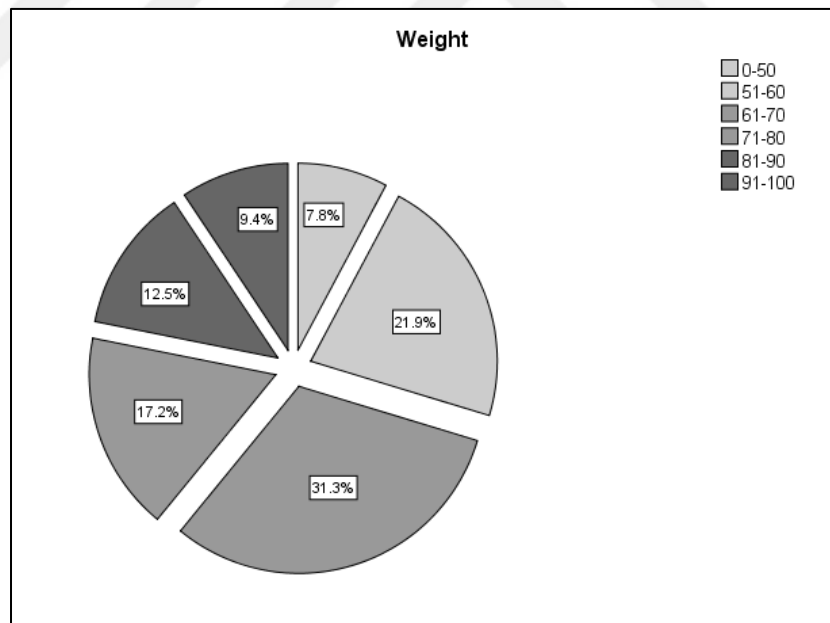
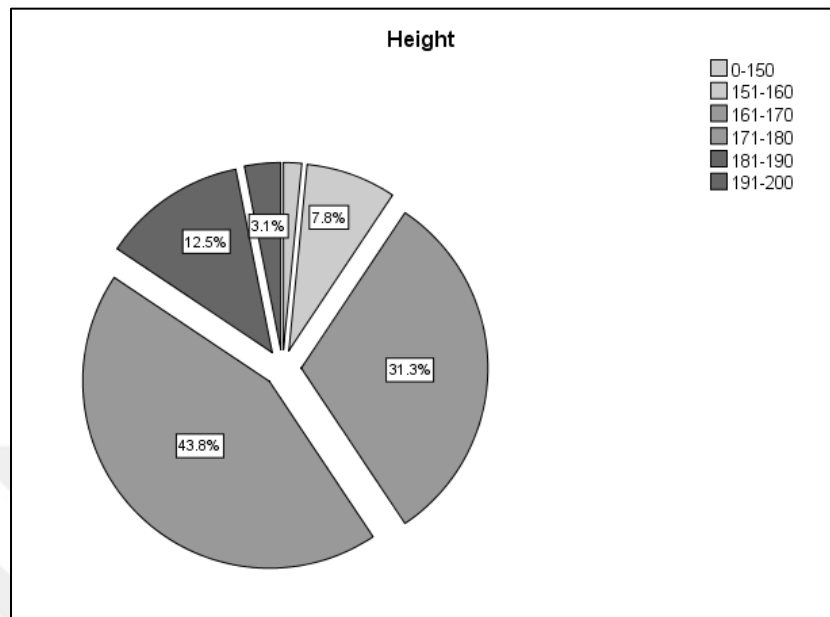
		POI1	POI2	POI3	POI4	POI5	POI6
PET (°C)	Mean	31.1	40.5	31.5	31.4	40.1	39.4
	Min.	20.8	25.4	24.7	24.3	25.2	25.5
	Max.	48.5	51.2	39.9	42.9	51.5	54.7
mPET (°C)	Mean	29.6	36.9	30.1	30.0	36.5	36.0
	Min.	21.2	25.2	24.8	24.5	24.7	24.8
	Max.	42.7	44.6	36.7	39.0	45.2	47.0

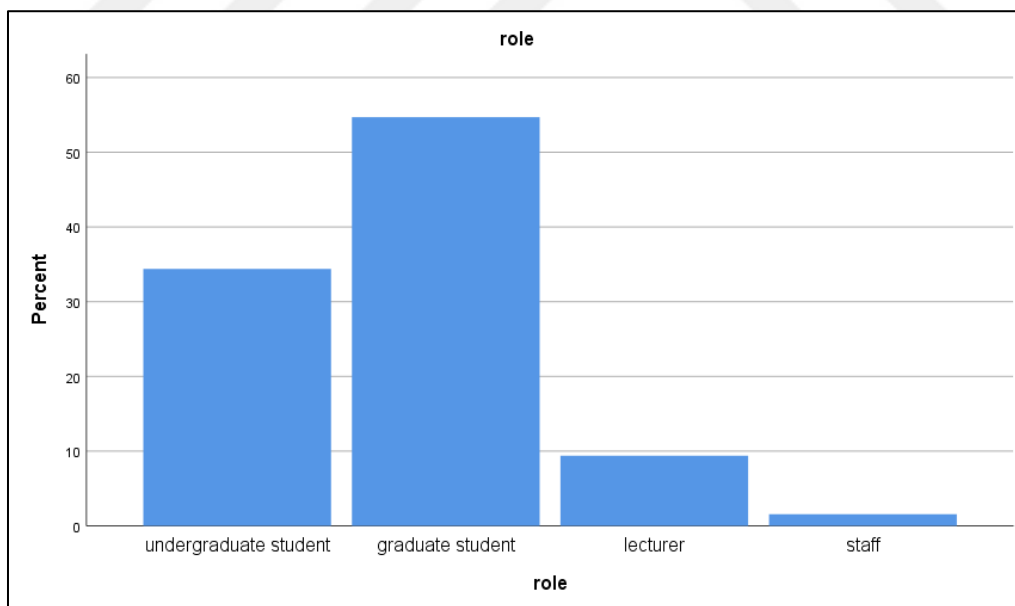
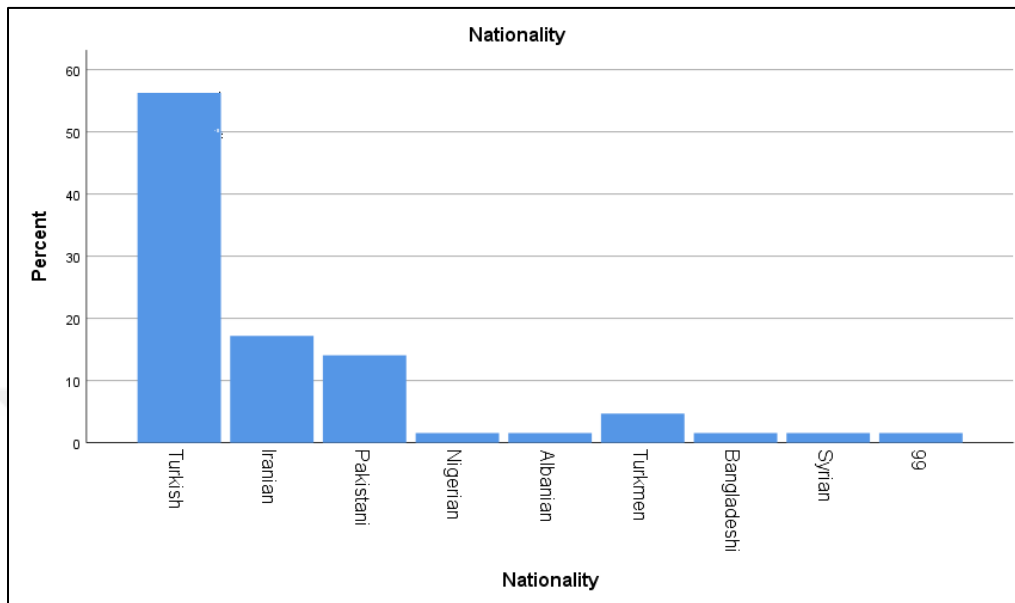


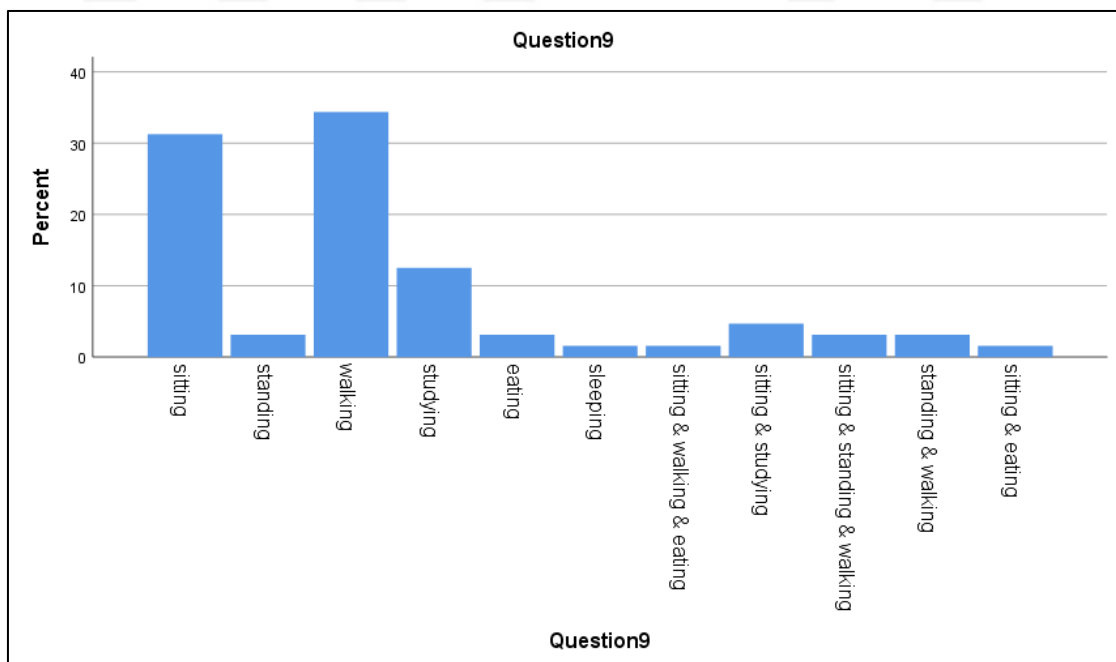
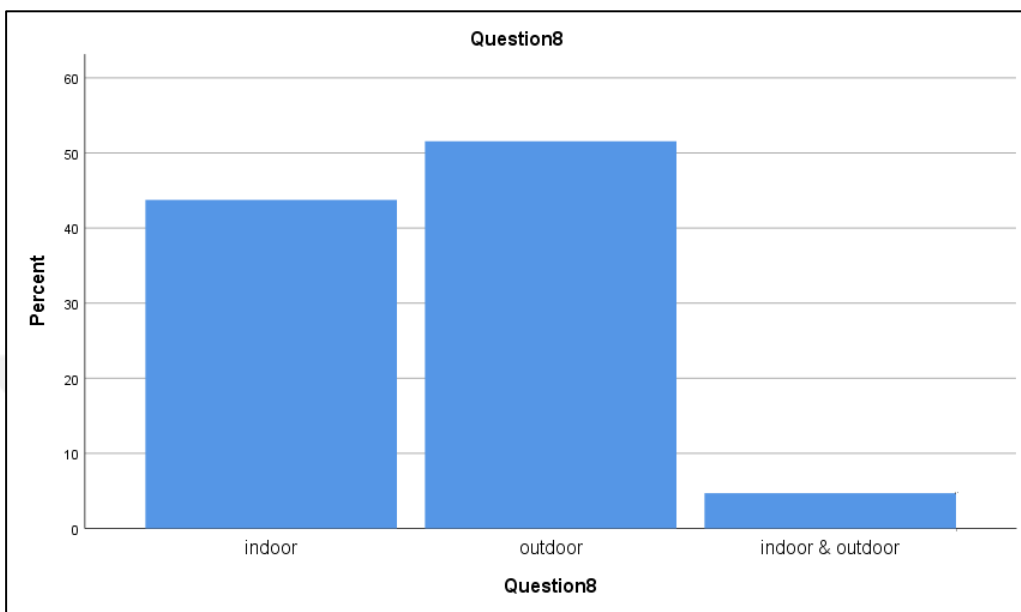
APPENDIX E

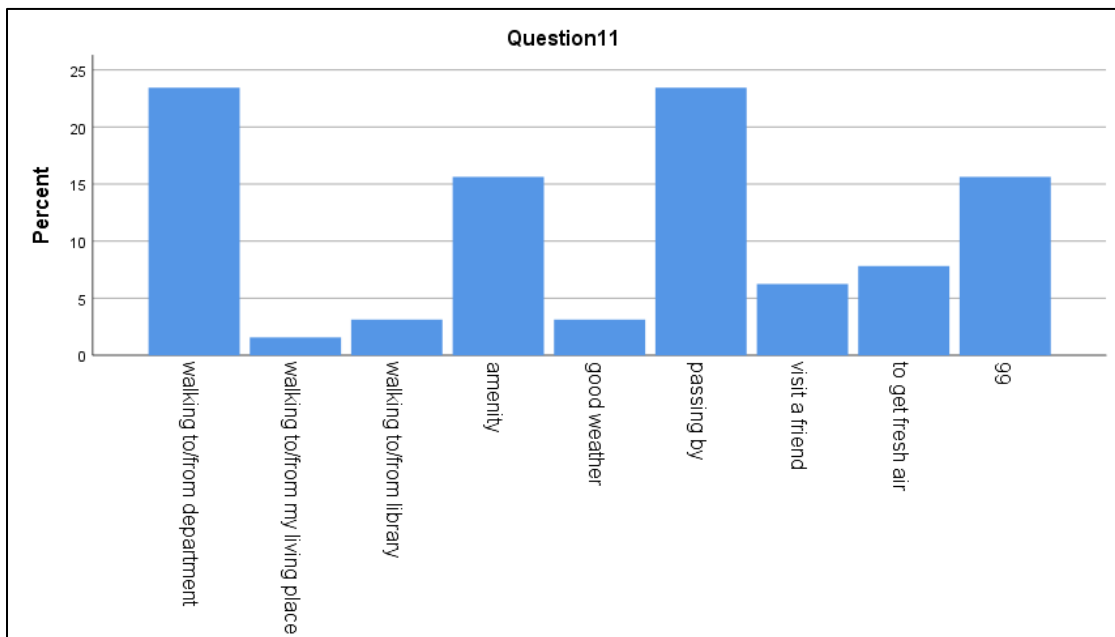
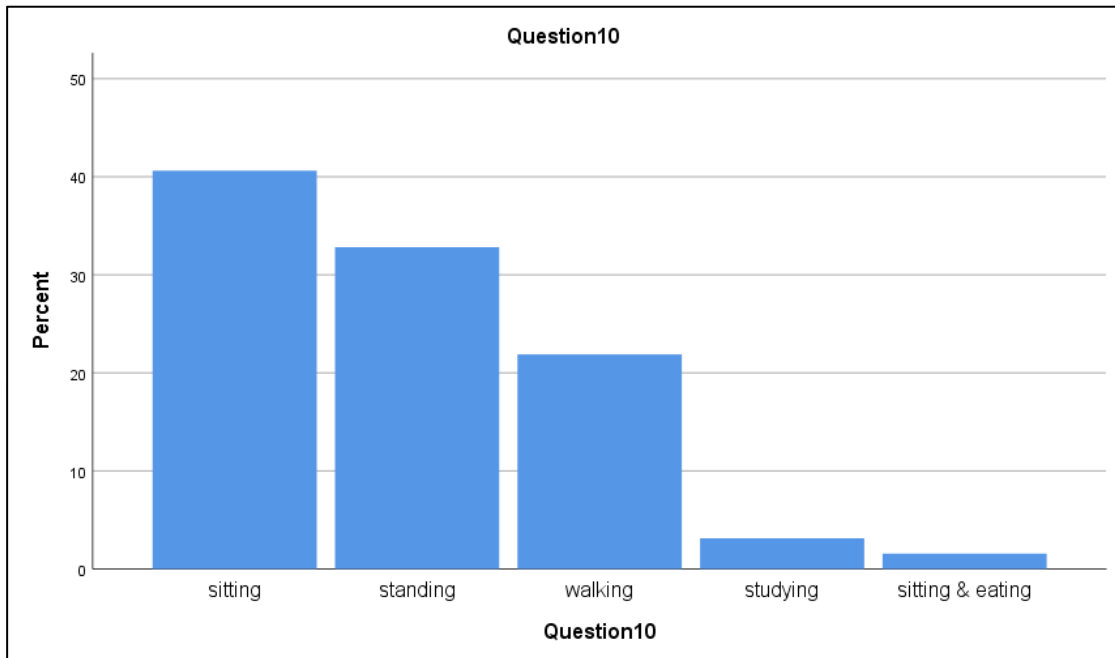
GRAPHS SHOWING RESPONDENTS' GENERAL CONDITIONS

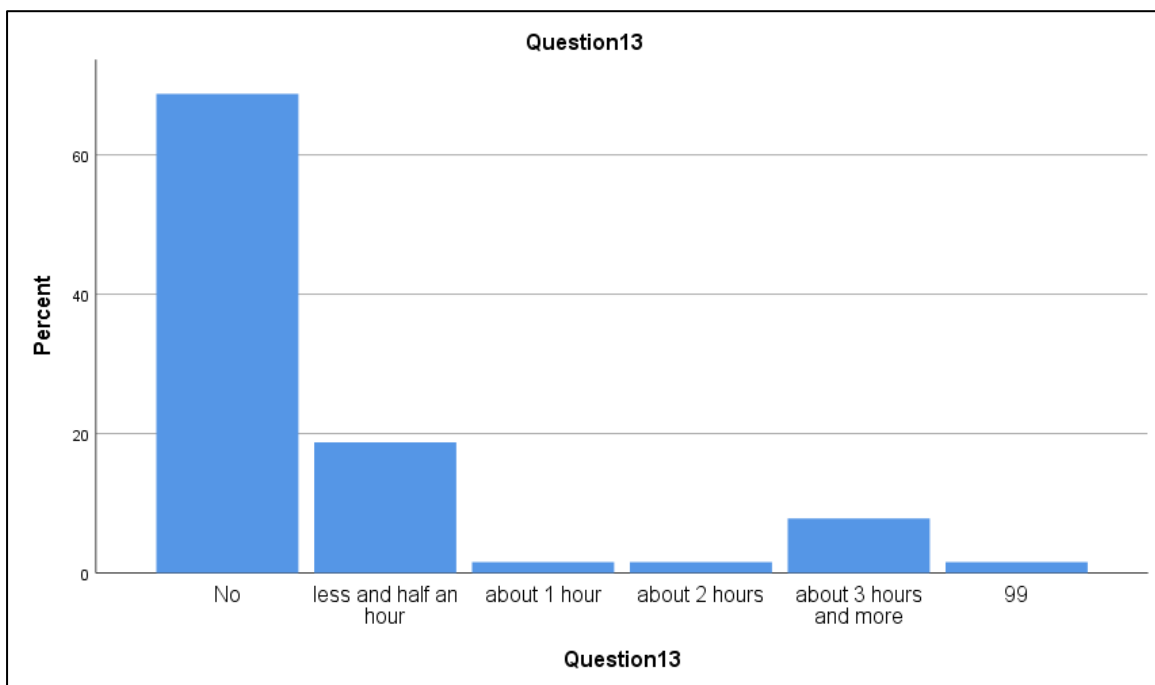
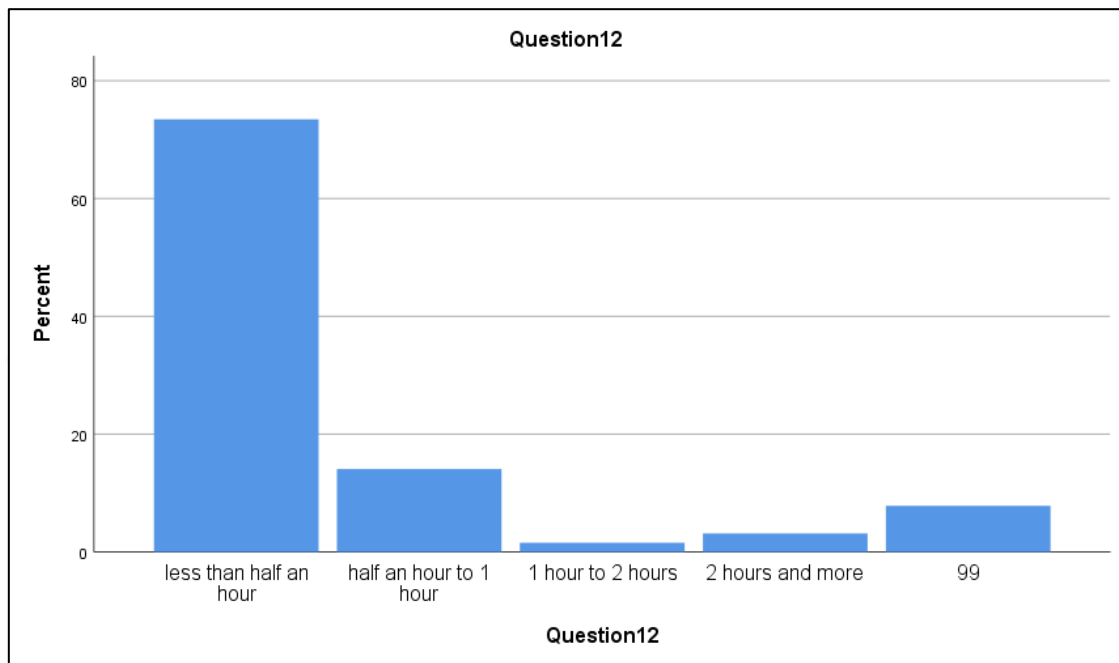


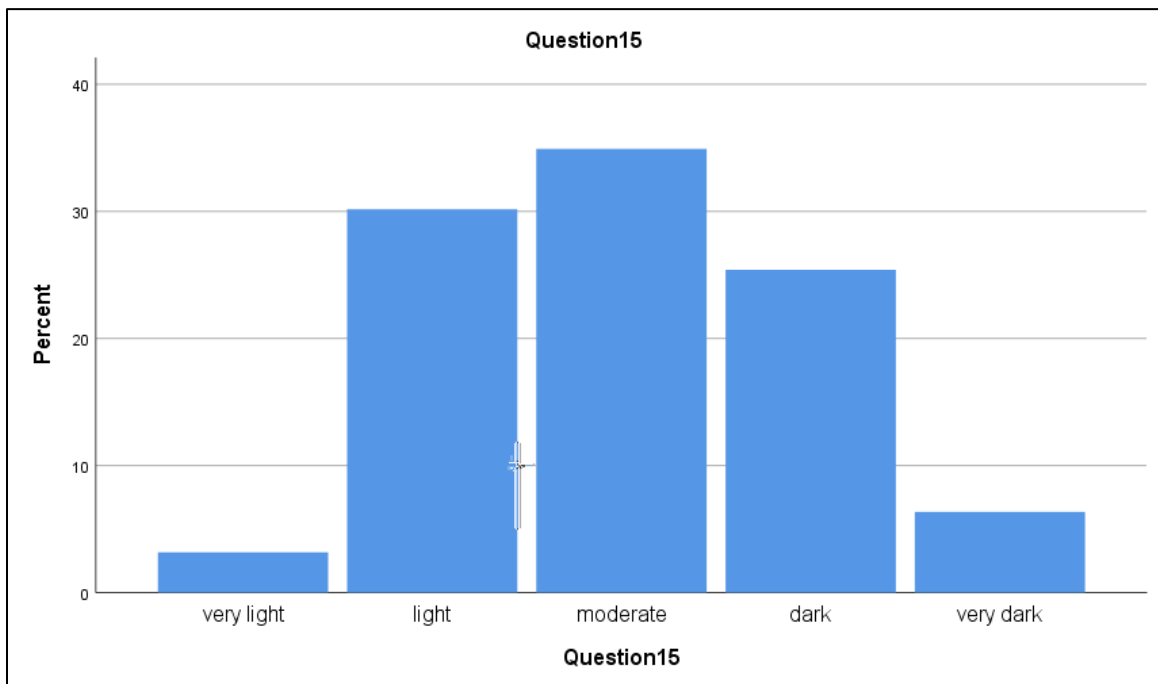
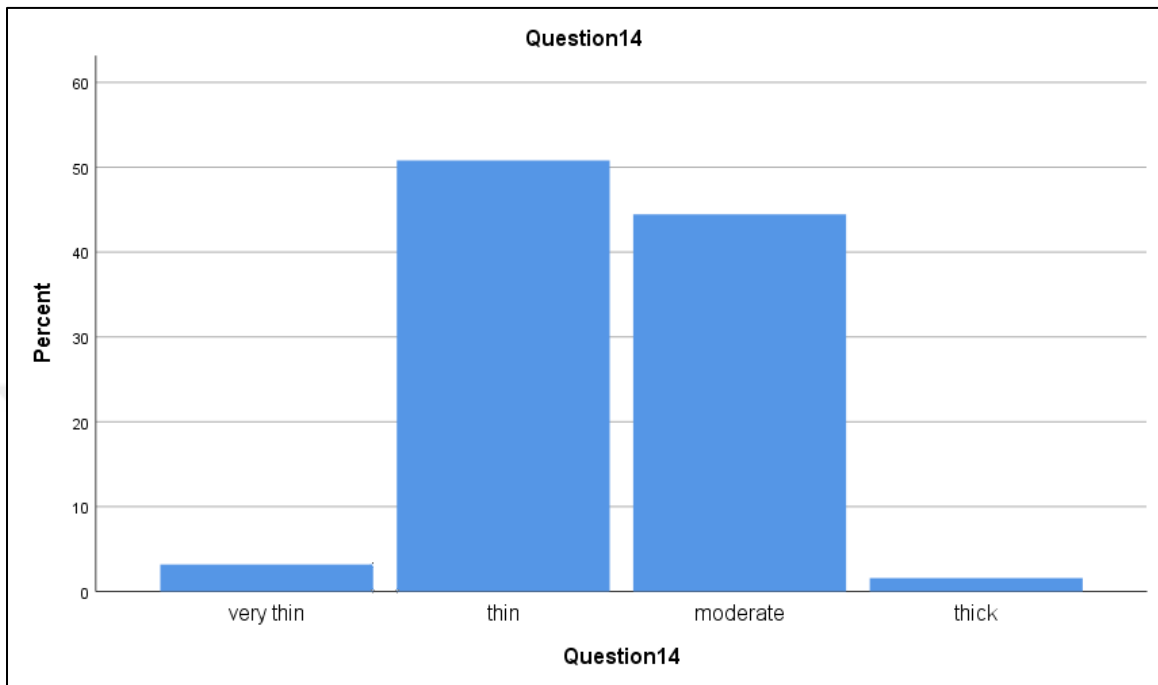












APPENDIX F

RESULTS OF ONE-WAY ANOVA MEANS COMPARISON OF MICROCLIMATIC PERCEPTION VOTES AMONG POIS

Descriptives

			N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
							Lower Bound	Upper Bound		
Question16	1	14	4.64	2.023	.541	3.47	5.81	2	7	
	2	6	3.17	2.041	.833	1.02	5.31	1	7	
	3	15	4.40	1.595	.412	3.52	5.28	2	7	
	4	7	4.29	1.976	.747	2.46	6.11	1	6	
	5	15	3.47	1.552	.401	2.61	4.33	1	7	
	6	6	1.50	.548	.224	.93	2.07	1	2	
	Total	63	3.83	1.888	.238	3.35	4.30	1	7	
Question18	1	14	4.57	1.651	.441	3.62	5.52	1	7	
	2	6	3.17	1.722	.703	1.36	4.97	1	5	
	3	15	4.40	1.298	.335	3.68	5.12	3	7	
	4	7	3.14	1.574	.595	1.69	4.60	1	5	
	5	15	3.13	1.187	.307	2.48	3.79	1	5	
	6	6	2.33	1.211	.494	1.06	3.60	1	4	
	Total	63	3.68	1.574	.198	3.29	4.08	1	7	
Question20	1	14	4.00	2.253	.602	2.70	5.30	1	7	
	2	6	4.33	2.658	1.085	1.54	7.12	1	7	
	3	15	4.40	1.298	.335	3.68	5.12	3	7	
	4	7	3.86	1.952	.738	2.05	5.66	2	7	
	5	15	2.80	1.971	.509	1.71	3.89	1	7	
	6	6	1.83	.753	.307	1.04	2.62	1	3	
	Total	63	3.62	2.003	.252	3.11	4.12	1	7	
Question22	1	14	3.93	2.018	.539	2.76	5.09	1	7	
	2	6	2.17	.983	.401	1.13	3.20	1	3	
	3	15	4.20	1.320	.341	3.47	4.93	2	6	
	4	7	4.14	1.574	.595	2.69	5.60	2	6	

5	15	3.33	.488	.126	3.06	3.60	3	4
6	6	1.67	.516	.211	1.12	2.21	1	2
Total	63	3.49	1.533	.193	3.11	3.88	1	7

Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
Question16	Based on Mean	2.524	5	57	.039
	Based on Median	.751	5	57	.589
	Based on Median and with adjusted df	.751	5	43.587	.590
	Based on trimmed mean	2.432	5	57	.046
Question18	Based on Mean	.731	5	57	.603
	Based on Median	.519	5	57	.761
	Based on Median and with adjusted df	.519	5	43.976	.761
	Based on trimmed mean	.702	5	57	.625
Question20	Based on Mean	2.907	5	57	.021
	Based on Median	2.049	5	57	.085
	Based on Median and with adjusted df	2.049	5	41.332	.092
	Based on trimmed mean	2.801	5	57	.025
Question22	Based on Mean	10.794	5	57	.000
	Based on Median	8.316	5	57	.000
	Based on Median and with adjusted df	8.316	5	45.499	.000
	Based on trimmed mean	10.880	5	57	.000

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Question16	Between Groups	52.770	5	10.554	3.574	.007
	Within Groups	168.310	57	2.953		
	Total	221.079	62			
Question18	Between Groups	37.865	5	7.573	3.728	.005
	Within Groups	115.786	57	2.031		
	Total	153.651	62			

Question20	Between Groups	43.833	5	8.767	2.437	.045
	Within Groups	205.024	57	3.597		
	Total	248.857	62			
Question22	Between Groups	44.060	5	8.812	4.940	.001
	Within Groups	101.686	57	1.784		
	Total	145.746	62			

Robust Tests of Equality of Means

		Statistic ^a	df1	df2	Sig.
Question16	Welch	11.943	5	21.229	.000
	Brown-Forsythe	3.647	5	34.022	.009
Question18	Welch	3.588	5	19.511	.018
	Brown-Forsythe	3.542	5	36.321	.010
Question20	Welch	6.523	5	20.651	.001
	Brown-Forsythe	2.371	5	28.283	.065
Question22	Welch	12.354	5	19.311	.000
	Brown-Forsythe	5.512	5	34.132	.001

a. Asymptotically F distributed.

Post Hoc Tests

Multiple Comparisons

Dependent Variable	(I) POI	(J) POI	Mean Difference	Std. Error	Sig.	95% Confidence Interval		
			(I-J)			Lower Bound	Upper Bound	
Question16	Games-Howell	1	2	1.476	.993	.680	-2.01	4.97
			3	.243	.680	.999	-1.85	2.34
			4	.357	.922	.999	-2.72	3.44
			5	1.176	.673	.516	-.90	3.25
			6	3.143*	.585	.001	1.27	5.02
		2	1	-1.476	.993	.680	-4.97	2.01
	3		-1.233	.929	.765	-4.68	2.21	
	4		-1.119	1.119	.908	-4.96	2.73	
	5		-.300	.925	.999	-3.74	3.14	
	6		1.667	.863	.467	-1.83	5.16	
	3	1	2	-.243	.680	.999	-2.34	1.85
			3	1.233	.929	.765	-2.21	4.68
			4	.114	.853	1.000	-2.86	3.09
			5	.933	.575	.590	-.82	2.69
			6	2.900*	.469	.000	1.42	4.38
	4	1	2	-.357	.922	.999	-3.44	2.72
			3	1.119	1.119	.908	-2.73	4.96
			5	-.114	.853	1.000	-3.09	2.86
			6	.819	.848	.918	-2.15	3.79
			3	2.786	.780	.064	-.16	5.73
	5	1	2	-1.176	.673	.516	-3.25	.90
			3	.300	.925	.999	-3.14	3.74
			5	-.933	.575	.590	-2.69	.82

Question 18			4		- .819	.848	.918	-3.79	2.15
			6		1.967*	.459	.005	.52	3.42
		6	1		-3.143*	.585	.001	-5.02	-1.27
			2		-1.667	.863	.467	-5.16	1.83
			3		-2.900*	.469	.000	-4.38	-1.42
			4		-2.786	.780	.064	-5.73	.16
			5		-1.967*	.459	.005	-3.42	-.52
		Bonferroni	1	2	1.405	.695	.721	-.73	3.54
				3	.171	.530	1.000	-1.45	1.79
				4	1.429	.660	.518	-.59	3.45
				5	1.438	.530	.131	-.18	3.06
				6	2.238*	.695	.032	.11	4.37
		2	1		-1.405	.695	.721	-3.54	.73
				3	-1.233	.688	1.000	-3.34	.88
				4	.024	.793	1.000	-2.41	2.45
				5	.033	.688	1.000	-2.08	2.14
				6	.833	.823	1.000	-1.69	3.35
	3		1		-.171	.530	1.000	-1.79	1.45
			2		1.233	.688	1.000	-.88	3.34
			4		1.257	.652	.885	-.74	3.26
			5		1.267	.520	.271	-.33	2.86
			6		2.067	.688	.060	-.04	4.18
	4		1		-1.429	.660	.518	-3.45	.59
			2		-.024	.793	1.000	-2.45	2.41
			3		-1.257	.652	.885	-3.26	.74

Question 20		5	5	.010	.652	1.000	-1.99	2.01
			6	.810	.793	1.000	-1.62	3.24
			1	-1.438	.530	.131	-3.06	.18
			2	-.033	.688	1.000	-2.14	2.08
			3	-1.267	.520	.271	-2.86	.33
			4	-.010	.652	1.000	-2.01	1.99
			6	.800	.688	1.000	-1.31	2.91
		6	1	-2.238*	.695	.032	-4.37	-.11
			2	-.833	.823	1.000	-3.35	1.69
			3	-2.067	.688	.060	-4.18	.04
			4	-.810	.793	1.000	-3.24	1.62
			5	-.800	.688	1.000	-2.91	1.31
			6					
	Games-Howell	1	2	-.333	1.241	1.000	-4.83	4.17
			3	-.400	.689	.991	-2.56	1.76
			4	.143	.952	1.000	-2.99	3.27
			5	1.200	.788	.654	-1.22	3.62
			6	2.167*	.676	.048	.01	4.32
		2	1	.333	1.241	1.000	-4.17	4.83
			3	-.067	1.136	1.000	-4.59	4.46
			4	.476	1.312	.999	-4.18	5.13
			5	1.533	1.199	.788	-2.95	6.02
			6	2.500	1.128	.351	-2.04	7.04
		3	1	.400	.689	.991	-1.76	2.56
			2	.067	1.136	1.000	-4.46	4.59
			4	.543	.810	.981	-2.37	3.45

			5	1.600	.609	.129	-.28	3.48	
			6	2.567 [*]	.455	.000	1.10	4.03	
			4	1	-.143	.952	1.000	-3.27	2.99
			2	-.476	1.312	.999	-5.13	4.18	
			3	-.543	.810	.981	-3.45	2.37	
			5	1.057	.896	.838	-1.96	4.07	
			6	2.024	.799	.220	-.90	4.95	
			5	1	-1.200	.788	.654	-3.62	1.22
			2	-1.533	1.199	.788	-6.02	2.95	
			3	-1.600	.609	.129	-3.48	28	
			4	-1.057	.896	.838	-4.07	1.96	
			6	.967	.595	.593	-.91	2.85	
			6	1	-2.167 [*]	.676	.048	-4.32	-.01
			2	-2.500	1.128	.351	-7.04	2.04	
			3	-2.567 [*]	.455	.000	-4.03	-1.10	
			4	-2.024	.799	.220	-4.95	90	
			5	-.967	.595	.593	-2.85	91	
			Question22	LSD	1	2	1.762 [*]	.652	.009
3	-.271	.496				.587	-1.27	.72	
4	-.214	.618				.730	-1.45	1.02	
4	-.810	.611				.191	-2.03	.41	
6	1.667 [*]	.645				.012	.37	2.96	
6	1	-2.262 [*]				.652	.001	-3.57	-.96
2	-.500	.771			.519	-2.04	1.04		
3	-2.533 [*]	.645			.000	-3.83	-1.24		

Question 22	Games-Howell	1	4	-2.476*	.743	.002	-3.96	-.99
			5	-1.667*	.645	.012	-2.96	-.37
		2	2	1.762	.672	.144	-.38	3.91
			3	-.271	.638	.998	-2.26	1.71
			4	-.214	.803	1.000	-2.82	2.39
			5	.595	.554	.884	-1.21	2.40
			6	2.262*	.579	.013	.40	4.12
		3	1	-1.762	.672	.144	-3.91	.38
			3	-2.033*	.527	.020	-3.79	-.28
			4	-1.976	.718	.146	-4.46	.51
			5	-1.167	.421	.189	-2.84	.51
			6	.500	.453	.867	-1.18	2.18
		4	1	.271	.638	.998	-1.71	2.26
			2	2.033*	.527	.020	.28	3.79
			4	.057	.686	1.000	-2.32	2.43
			5	.867	.363	.214	-.29	2.02
			6	2.533*	.401	.000	1.27	3.80
		5	1	.214	.803	1.000	-2.39	2.82
			2	1.976	.718	.146	-.51	4.46
			3	-.057	.686	1.000	-2.43	2.32
			5	.810	.608	.762	-1.54	3.16
			6	2.476*	.631	.039	.13	4.82
		5	1	-.595	.554	.884	-2.40	1.21
			2	1.167	.421	.189	-.51	2.84
			3	-.867	.363	.214	-2.02	.29

		4	-.810	.608	.762	-3.16	1.54
		6	1.667*	.246	.001	.79	2.54
	6	1	-2.262*	.579	.013	-4.12	-.40
		2	-.500	.453	.867	-2.18	1.18
		3	-2.533*	.401	.000	-3.80	-1.27
		4	-2.476*	.631	.039	-4.82	-.13
		5	-1.667*	.246	.001	-2.54	-.79

*. The mean difference is significant at the 0.05 level.

APPENDIX G

MICROCLIMATIC MEASUREMENT SITE PHOTOS OF THE STUDY

POI 1



POI 2



POI 3



POI 4



POI 5



POI 6

