INVESTIGATING THE INFLUENCES OF SHADED OUTDOOR SPACES ON THERMAL ADAPTATION AND COGNITIVE PERFORMANCE OF UNIVERSITY STUDENTS IN CLASSROOM ENVIRONMENTS

A Master's Thesis

by

BETÜL GÜNDOĞDU

Department of
Interior Architecture and Environmental Design
İhsan Doğramacı Bilkent University
Ankara

June 2022

BETÜL GÜNDOĞDU

INVESTIGATING THE INFLUENCES OF SHADED OUTDOOR SPACES ON THERMAL ADAPTATION AND COGNITIVE PERFORMANCE

Bilkent University 2022

To my parents,

Gülsen & Hakan

INVESTIGATING THE INFLUENCES OF SHADED OUTDOOR SPACES ON THERMAL ADAPTATION AND COGNITIVE PERFORMANCE OF UNIVERSITY STUDENTS IN CLASSROOM ENVIRONMENTS

The Graduate School of Economics and Social Sciences
of
İhsan Doğramacı Bilkent University

by

BETÜL GÜNDOĞDU

In Partial Fulfillment of the Requirements for the Degree of
MASTER OF FINE ARTS

THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
İHSAN DOĞRAMACI BILKENT UNIVERSITY
ANKARA

June 2022

INVESTIGATING THE INFLUENCES OF SHADED OUTDOOR SPACES ON THERMAL ADAPTATION AND COGNITIVE PERFORMANCE OF UNIVERSITY STUDENTS IN CLASSROOM ENVIRONMENTS
By Betül Gündoğdu

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 lnterior Architecture and Environmental Design.

…………………………………
Andre Santos Nouri (Advisor)

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 lnterior Architecture and Environmental Design.

…………………………………
Yasemin Afacan (Co-advisor)

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 lnterior Architecture and Environmental Design.

…………………………………
Çağrı İmamoğlu

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 lnterior Architecture and Environmental Design.

…………………………………
Mert Ekşi

Approval of the Graduate School of Economics and Social Sciences

…………………………………
Refet Soykan Gürkaynak
Director

ABSTRACT

INVESTIGATING THE INFLUENCES OF SHADED OUTDOOR SPACES ON THERMAL ADAPTATION AND COGNITIVE PERFORMANCE OF UNIVERSITY STUDENTS IN CLASSROOM ENVIRONMENTS

Gündoğdu, Betül

MFA, Department of Interior Architecture and Environmental Design

Supervisor: Asst. Prof. Dr. Andre Santos Nouri

Co-Supervisor: Assoc. Prof. Dr. Yasemin Afacan

June 2022

The effects of shading strategies have been identified as an effective means to reduce urban risk factors such as the Urban Heat Island (UHI) effect. Although the importance of shaded outdoor spaces and thermal comfort has been well documented in the existing literature; there is still limited research on how these spaces can influence thermal adaptability and cognitive performance of university students.

As a result, the aim of the study is twofold: (1) to evaluate the effect of shaded outdoor spaces upon thermal comfort; and, (2) link such results upon the cognitive performance of university students in a classroom environment with natural ventilation. A case study was conducted with university students between the ages of 19-22 at the Bilkent University in Ankara, during the autumn season in the month of October.

The quantitative thermal microclimatic conditions of unshaded/shaded areas of the university campus and indoor classroom settings were obtained through the Physiologically Equivalent Temperature (PET) index. The qualitative evaluation of thermal comfort was undertaken by using both the adaptive model and a complementary thermal comfort survey. D2 test of attention was conducted to measure the cognitive performance of students with different outdoor shading level experiences.

This study revealed that the shade condition may improve thermal adaptation, and impact PET in outdoor and indoor contexts. Experiencing such space contributed to an improvement in cognitive performance of students within classroom settings in an era of climate change, where urban fabric continues to be susceptible to existing and future heat-related stress factors.

Keywords: Thermal adaptation; Cognitive performance; Shaded spaces; PET

ÖZET

GÖLGELENDİRİLMİŞ DIŞ MEKANLARIN ÜNİVERSİTE ÖĞRENCİLERİNİN ISIL ADAPTASYONUNA VE SINIF ORTAMLARINDAKİ BİLİŞSEL PERFORMANSLARINA ETKİLERİNİN İNCELENMESİ

Gündoğdu, Betül

İç Mimarlık ve Çevre Tasarımı Yüksek Lisans Programı

Tez Danışmanı: Dr. Öğr. Üyesi Andre Santos Nouri

2. Tez Danışmanı: Doç. Dr. Yasemin Afacan

Haziran 2022

Gölgeleme stratejileri, Kentsel Isı Adası (KIA) etkisi gibi kentsel risk faktörlerini azaltmak için etkili bir araç olarak tanımlanmıştır. Gölgeli dış mekanların ve ısıl konforun önemi mevcut literatürde iyi belgelenmiş olmasına rağmen; bu alanların üniversite öğrencilerinin ısıl adaptasyonunu ve bilişsel performansını nasıl etkileyeceği konusunda hala sınırlı araştırma bulunmaktadır.

Sonuç olarak, çalışmanın amacı iki yönlüdür: (1) dış mekan gölgeli alanların ısıl konfor üzerindeki etkisini değerlendirmek; ve (2) bu tür sonuçları, doğal havalandırmalı bir sınıf ortamında üniversite öğrencilerinin bilişsel performansları ile ilişkilendirmek. Ankara’da Bilkent Üniversitesi'nde 19-22 yaş arası üniversite öğrencileri ile, sonbahar mevsiminde, Ekim ayında, bir saha çalışması yapılmıştır. Üniversite kampüsünde bulunan gölgesiz/gölgeli alanların ve sınıf ortamlarının nicel mikro iklim koşulları, Fizyolojik Eşdeğer Sıcaklık (FES) indeksi ile elde edilmiştir. Isıl konforun nitel değerlendirmesi, hem uyarlanabilir model hem de tamamlayıcı ısıl konfor anketi kullanılarak gerçekleştirilmiştir. Farklı dış mekan gölgeleme düzeyi deneyimlerine sahip öğrencilerin bilişsel performanslarını ölçmek amacıyla D2 dikkat testi uygulanmıştır.

Bu çalışma, gölgeli koşulların ısıl adaptasyonu iyileştirebileceğini ve iç ve dış ortamlarda FES'ı etkilebileceğini ortaya koymuştur. Kentsel dokunun mevcut ve gelecekteki ısıyla ilgili stres faktörlerine duyarlı olmaya devam ettiği iklim değişikliği çağında, bu alanları deneyimlemek, sınıf ortamındaki öğrencilerin bilişsel performanslarının iyileşmesine katkıda bulunmuştur.

Anahtar Kelimeler: Isıl adaptasyon; Bilişsel performans; Gölgeli alanlar; PET

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratefulness to my thesis supervisor, Asst. Prof. Dr. Andre Santos Nouri, for his professional and valuable guidance, and also constructive support throughout my thesis. My intellectual development has been greatly aided by his forward-thinking ideas and insightful direction, both of which have been very beneficial to my academic career. His valuable guidance and incisive criticism kept me motivated throughout this process, which ultimately led to the successful completion of my thesis. Also, I would like to express my gratitude to my co-supervisor, Assoc. Prof. Dr. Yasemin Afacan, for her insightful help. It is a privilege for me to be able to collaborate with and learn from academicians who have achieved such a high level of achievement.

Secondly, I would like to express my appreciation to my committee members, Asst. Prof. Dr. Çağrı İmamoğlu and Assoc. Prof. Dr. Mert Ekşi, for their insightful feedback and helpful criticism. Their comments on my thesis provided me with new insight for further research.

Last but most importantly, my deepest gratitude goes out to my parents, Gülsen and Hakan Gündoğdu, as well as our precious Şapşik, for their endless love and support. I also would like to my dearest friend Beste Demiral, for her unconditional encouragement and friendship. Without their motivation and unwavering love during every stage of this process, I would not be the person I am today. I owe a great deal of gratitude to them for the inspiration and drive they have given me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASHRAE:	American Society of Heating, Refrigerating and Air- Conditioning Engineers
ATCV:	Air Temperature Comfort Vote
$ATCV_{IN}$:	Indoor Air Temperature Comfort Vote
$ATCV_{OUT}$:	Outdoor Air Temperature Comfort Vote
ATPV:	Air Temperature Preference Vote
$ATPV_{IN}$:	Indoor Air Temperature Preference Vote
$ATPV_{OUT}$:	Outdoor Air Temperature Preference Vote
ATSV:	Air Temperature Sensation Vote
$ATSV_{IN}$:	Indoor Air Temperature Sensation Vote
$ATSV_{OUT}$:	Outdoor Air Temperature Sensation Vote
CP:	Concentration Performance
CTIS:	Climate-Tourism/Transfer-Information-Scheme
E%:	Percent of Error
E:	Total Number of Errors
E1:	Errors of Omission
E2:	Errors of Commission

EBM:	Energy Balance Model
FR:	Fluctiation Rate
Grad:	Global Radiation
$Grad_{OUT}$:	Outdoor Global Radiation
$Grad_{IN}$:	Indoor Global Radiation
KG:	Köppen Geiger
KHS:	Kestrel Heat Stress
KHS_{IN}:	Indoor Kestrel Heat Stress
KHS_{OUT}:	Outdoor Kestrel Heat Stress
MEMI	Munich Energy balance Model for Individuals
OTCV:	Overall Thermal Comfort Vote
$OTCV_{IN}$:	Indoor Overall Thermal Comfort Vote
$OTCV_{OUT}$:	Outdoor Overall Thermal Comfort Vote
PET:	Physiologically Equivalent Temperature
POI:	Point of Interest
PR:	Perspiration Rate
PS:	Physiological Stress
RH:	Relative Humidity (%)
RH_{IN}:	Indoor Relative Humidity (%)
RH_{OUT}:	Outdoor Relative Humidity (%)
RH_{OUT}POI 1:	Outdoor Relative Humidity in POI 1 (%)
RH_{OUT}POI 2:	Outdoor Relative Humidity in POI 2 (%)
SR:	Solar Radiation
SRCV:	Solar Radiation Comfort Vote

SRCV: Solar Radiation Comfort Vote

$SRCV_{OUT}$: Outdoor Solar Radiation Comfort Vote

SRPV: Solar Radiation Preference Vote

$SRPV_{IN}$: Indoor Solar Radiation Preference Vote

$SRPV_{OUT}$: Outdoor Solar Radiation Preference Vote

SRSV: Solar Radiation Sensation Vote

$SRSV_{OUT}$: Outdoor Solar Radiation Sensation Vote

SVF: Sky-View-Factor

Ta: Air Temperature (°C)

Ta_{IN}: Indoor Air Temperature (°C)

Ta_{OUT}: Outdoor Air Temperature (°C)

Ta_{OUT}POI 1: Outdoor Air Temperature in POI 1 (°C)

Ta_{OUT}POI 2: Outdoor Air Temperature in POI 2 (°C)

T_{Cr}: Core Temperature (°C)

Tg: Globe Temperature (°C)

Tg_{IN}: Indoor Globe Temperature (°C)

Tg_{OUT} : Outdoor Globe Temperature (°C)

Tg_{OUT}POI 1: Outdoor Globe Temperature in POI 1 (°C)

Tg_{OUT}POI 2: Outdoor Globe Temperature in POI 2 (°C)

Tmrt : Mean Radiant Temperature

$Tmrt_{IN}$: Indoor Mean Radiant Temperature

$Tmrt_{OUT}$: Outdoor Mean Radiant Temperature

$Tmrt_{OUT}$POI 1: Outdoor Mean Radiant Temperature in POI 1 (°C)

$Tmrt_{OUT}$POI 2: Outdoor Mean Radiant Temperature in POI 2 (°C)

TN:	Total Number of Characters Processed
TN-E:	Total Correctly Processed
T_{Sk}:	Skin Temperature (°C)
UHI:	Urban Heat Island
V:	Wind Speed (m/s)
Va:	Air-speed (m/s)
V_{IN}:	Indoor Wind Speed (m/s)
V_{OUT}:	Outdoor Wind Speed (m/s)
V_{OUT}POI 1:	Outdoor Wind Speed in POI 1 (m/s)
V_{OUT}POI 2:	Outdoor Wind Speed in POI 2 (m/s)
WSCV:	Wind Speed Comfort Vote
$WSCV_{IN}$:	Indoor Wind Speed Comfort Vote
$WSCV_{OUT}$:	Outdoor Wind Speed Comfort Vote
WSPV:	Wind Speed Preference Vote
$WSPV_{IN}$:	Indoor Wind Speed Preference Vote
$WSPV_{OUT}$:	Outdoor Wind Speed Preference Vote
WSSV:	Wind Speed Sensation Vote
$WSSV_{IN}$:	Indoor Wind Speed Sensation Vote
$WSSV_{OUT}$:	Outdoor Wind Speed Sensation Vote

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Thermal comfort and adaptation are becoming a very important phenomenon in outdoor and indoor contexts as a consequence of climate change with the increase in the Earth’s temperature. For this reason, the Urban Heat Island (UHI) effect occurring due to ongoing urbanization patterns and insufficient use of vegetation has given great importance to human thermal comfort as a result of discomfort in thermal environments in particularly warming cities (Santamouris, 2019). Therefore, people have a tendency to adapt themselves to the thermal conditions to improve their comfort and continue their daily routines (Nouri & Matzarakis, 2019). Many studies have indicated that human perceptions and preferences for thermal environments can differentiate because of the differences in behavioural adjustments, physiological adaptation to the climatic conditions, and psychological adaptation such as expectations, environmental stimulation, and thermal history (Nikolopoulou & Steemers, 2003). Therefore, in order to increase human thermal comfort within the era of climate change, it is necessary to provide adaptive strategies in thermal environments.

For adaptation to the thermal environments in warming cities, increasing shaded outdoor spaces is becoming one of the most effective adaptive strategies to improve human thermal comfort (Abdallah, Hussein, & Nayel, 2020; Chen, Zhang, Han, & Li, 2021; Emmanuel, Rosenlund, & Johansson, 2007; Hwang, Lin, & Matzarakis, 2011). Shading effects especially with the architectural structures such as buildings can provide a possibility of a decrease in the intensity of solar radiation, the ground surface temperature, and long and short-wave radiation (Ali-Toudert & Mayer, 2007a; Shashua-Bar, Tsiros, & Hoffman, 2012; Vanos et al., 2012; Watanabe, Nagano, Ishii, & Horikoshi, 2014).

Subsequently, thermal environment can considerably impact cognitive performance of students within university campus settings (Bajc, Banjac, Todorovic, & Stevanovic, 2019; Barbic et al., 2019; Siqueira, da Silva, Coutinho, & Rodrigues, 2017). In this context, understanding the related factors affecting cognitive performance with regard to thermal comfort can help to provide an essential understanding of how thermal comfort affects cognitive performance of students within indoor settings (Jensen, Toftum, & Friis-Hansen, 2009; Jiang, Wang, Liu, Xu, & Liu, 2018; Lan & Lian, 2009; Woo, Rajagopalan, & Andamon, 2022).

Previous studies have well documented the importance of shaded outdoor spaces and thermal comfort; however, most of these studies mainly focus on outdoor and indoor thermal comfort separately. Therefore, inadequate information is available on how shaded outdoor spaces can affect the outdoor and indoor thermal adaptability of university students. In addition, previous studies that investigated the relationship between thermal environment and cognitive performance primarily focus on the effect of indoor thermal conditions on cognitive performance. Yet, there is very limited disseminated research on the effects of outdoor thermal conditions with different shading strategies on the cognitive performance of students in indoor environments.

1.2. Aim of the Study

Considering the Turkish growing capital city of Ankara, which is a vulnerable city to existing and future heat stress factors (Çalışkan & Türkoğlu, 2014; Nouri, Afacan, Çalışkan, Lin, & Matzarakis, 2021a; Nouri, Çalışkan, Charalampopoulos, Cheval, & Matzarakis, 2021b), in the autumn of 2021, the aim of the study is twofold to aid interdisciplinary guidelines on how architects and designers can better approach the learning environments with regards to urban morphological characteristics. More specifically, this is an approach to: (1) evaluate the effect of shaded outdoor spaces upon thermal comfort of university students by considering both quantitative aspects based upon the collection and processing of singular microclimatic parameters from *in-situ* stations through the use of a human bio-meteorological model, and qualitative aspects of thermal comfort with complementary subjective outdoor and indoor thermal comfort questionnaire surveys; and, (2) link such quantitative and qualitative results of thermal comfort upon the cognitive performance of university students with d2 test of attention in a classroom environment with natural ventilation.

1.3. Structure of the Thesis

This thesis mainly consists of six sequential chapters based upon the specifically stated aims. The first chapter presents the introduction including a brief background of research topics including the importance of the study and the research gaps in the existing literature, followed by the aim of the study and the structure of the thesis.

The second chapter provides a theoretical background behind this study by focusing on climatic aggravation upon consolidated urban fabrics, thermal comfort with affecting factors, and followed by explaining the heat balance model, adaptive comfort model, relationship between outdoor climate and indoor thermal environment, and relationship between outdoor climate and thermal comfort in outdoor thermal environment. In addition, the impact of the shading and wind strategies on thermal comfort, and cognitive performance regarding its relation to thermal comfort are examined within this chapter.

The third chapter introduces the methodology used in this study. The majority of the methodology is based upon the theoretical background that is provided in the previous chapter. The chapter begins by stating the research questions and hypotheses of this study. The methodology of the study involves detailed information on the subjects with the description of the settings, instruments used to measure quantitative and qualitative aspects of thermal comfort and cognitive performance, as well as the procedure of the study.

The fourth chapter presents the results of the research obtained from the quantitative and qualitative measurements including cognitive performance, with the statistical analysis. The results are shown in 4 major parts: (1) demographic information, (2) quantitative aspects of thermal comfort; (3) qualitative aspects of thermal comfort; and (4) difference in cognitive performance.

The fifth chapter discusses the results of this study by comparing them with the existing literature and relating to the hypotheses of this study. Afterward, the sixth chapter concludes the thesis by summarizing the aim and giving the focus points of the research. Thermal design guidelines, the limitations of the study and the approach to how the research can be improved with the further applications are also stated in this chapter (Figure 1).

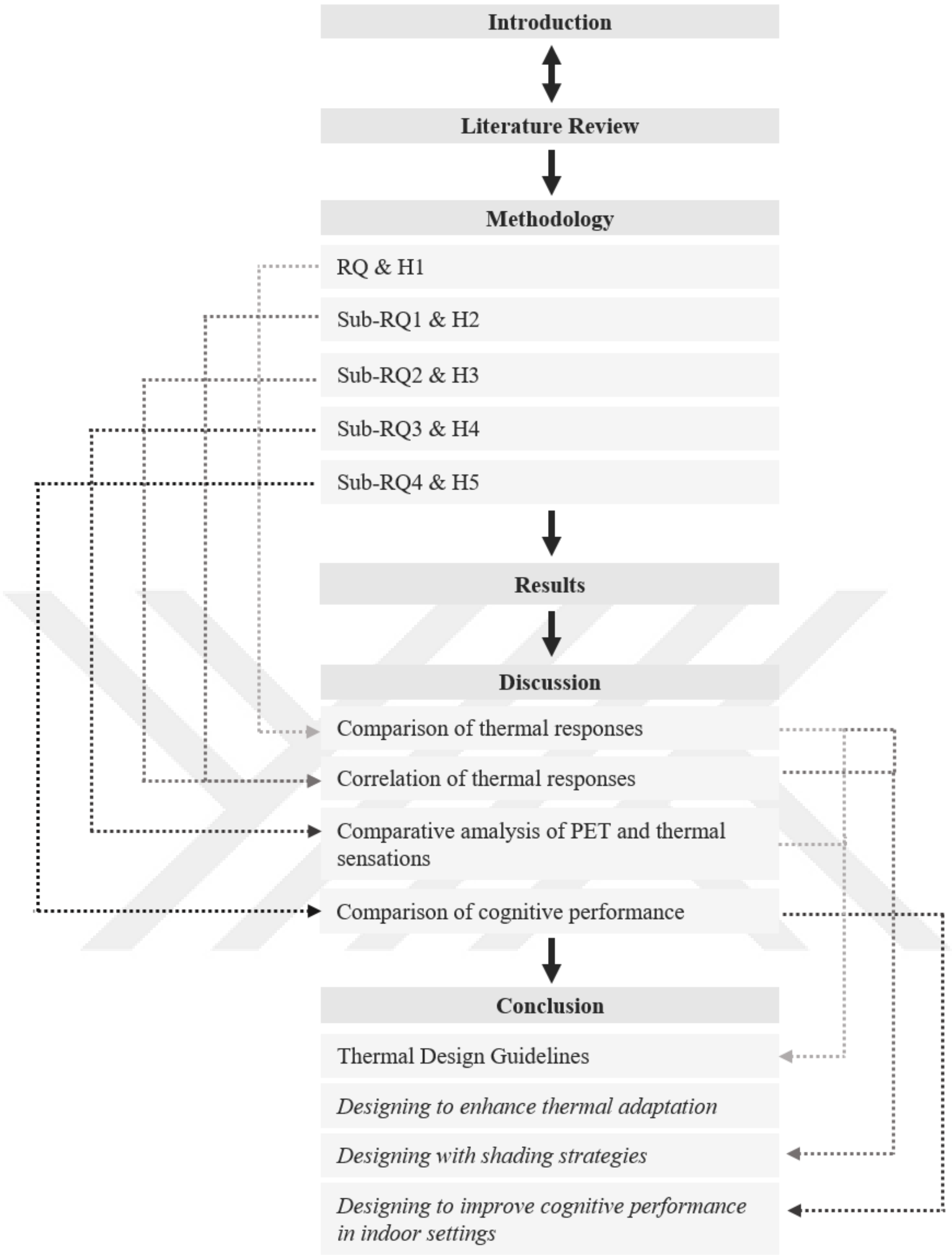

Figure 1. Connections between the sections of the thesis | Source: Author's figure.

CHAPTER 2

LITERATURE REVIEW

2.1. Climatic Aggravation upon Consolidated Urban Fabrics

Anthropogenic climate change is considered a profound global challenge for the 21st century since the Earth experiences a progressive increase in temperature. The mean air temperature is predicted to rise as a result of climate change, and heat waves are estimated to be more frequent, extreme, and prolonged (Schär et al., 2004). In comparison to a 1986–2005 baseline, the Intergovernmental Panel on Climate Change (IPCC) predicts that the global mean surface temperature would increase by 0.3-0.7°C to 2.6-2.8°C by 2100 (Collins et al., 2013). The National Oceanic and Atmospheric Administration (NOAA) also reports that the 10 warmest years on record on a global scale have arisen after 1998 (NOAA, 2022). Furthermore, over the next 40 years, heatwaves are predicted to become 5 to 10 times more frequent and severe, according to modeling studies (Barriopedro, Fischer, Luterbacher, Trigo, & García-Herrera, 2011).

Within the consolidated urban fabric, the lack of vegetation increases the heat storage in the ground layer and building materials, contributing to the greater level of air and surface temperature in urban areas compared to the rural surroundings (Oke, 1982), known as the ‘Urban Heat Island’ (UHI) effect. The intensity of the UHI is determined by both meso- and microscale variables, such as the size of the city, population density, and land use, as well as building density and vegetation distribution (Oke, 1981; Staiger, Laschewski, & Matzarakis, 2019). UHI intensity is an issue that must be approached with care in that it requires peri-urban/rural analysis against an urban setting, yet as cities expand the outer urban reference points may no longer be a good representation of non-urban conditions. The UHI has given high importance (Kim & Baik, 2002; Lee, 1992; Saitoh, Shimada, & Hoshi, 1996; Wilby, 2003) to human thermal comfort with ongoing urbanization patterns due to the reduction of living, and working productivity (Anupriya, 2016; Oke, 1982), making urban pollution more severe and affecting the health of citizens (Brown, Vanos, Kenny, & Lenzholzer, 2015; Rajagopalan, Lim, & Jamei, 2014; Tan et al., 2010). Therefore, human discomfort has become one of the most common concerns in the built environment as a result of increased exposure to extreme thermal conditions (Kjellstrom et al., 2016; Lin, Tsai, Liao, & Huang, 2013; Matthews, Wilby, & Murphy, 2017; Nikolopoulou & Lykoudis, 2006; Sheridan & Allen, 2015). Urban designers and architects have been in high demand because of the growing need for climate change adaptation measures assessment and quantification as a means of improving urban design and planning in response to the effects of climate change. (Matzarakis, 2021, 2022). Approaching certain urban morphological compositions and implementing various forms of vegetation, shade canopies, and water and vapour systems might improve thermal comfort and the local urban climate in outdoor contexts (Matzarakis, 2022; Nouri, 2015).

The intensity of the UHI effect shows an increase in Ankara, Turkey as seen in many cities around the world due to the rapid urbanization with increasing population density, the use of concrete and asphalt surfaces while decreasing vegetation distribution within the city (Çiçek & Doğan, 2006; Dihkan, Karsli, Guneroglu, & Guneroglu, 2018; Sensoy, Türkoğlu, Çiçek, Demircan, & Bölük, 2015; Yılmaz, 2019; Yüksel & Yılmaz, 2008). The UHI in many cities is considered greater at night than during the day, and in the winter than in the summer, and it is most noticeable when winds are weak (Oke, 2009). With regards to Ankara, it has been established that at the night, the urban context has a higher minimum temperature than the rural contexts because heated surfaces lose temperature more gradually (Sensoy et al., 2015).

2.2. Human Thermal Comfort

Thermal comfort has become one of the most important aspects in design decisions for both outdoor and indoor environments within the era of climate change. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has defined thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ASHRAE Standard 55, 2010: 3). Therefore, thermal comfort is accomplished when thermal balance between the body and the environment is attained, thus, ensuring that expectations of individuals pertaining to the conditions of their surroundings are matched as much as possible (Kalz, & Pfafferott, 2014). Furthermore, Givoni (1976) defined thermal comfort as the absence of discomfort feeling caused by heat or cold, and as a state including pleasantness. The definitions of thermal comfort do not define ‘state of mind’ or ‘satisfaction’, yet it is correct to say that comfort evaluation is a cognitive process that incorporates multiple factors affected by physical, physiological, psychological, and other aspects (Lin & Deng, 2008). For this reason, thermal comfort is influenced by different factors. There are two types of factors that affect human thermal comfort, which are environmental and personal factors. Environmental/meteorological factors as conditions of the thermal environment are mainly classified as air temperature, wind speed/air-speed, solar radiation, mean radiant temperature, and relative humidity. Personal parameters are primarily defined as metabolic rate and clothing level.

2.2.1. Environmental/Meteorological Factors

Air Temperature (Ta) with the unit of Celsius (°C) is the commonly used indicator of outdoor and indoor human thermal comfort within thermal environments. Ta is defined as “the temperature of the air at a point” (ASHRAE 55, 2017: 3). The effect of air temperature on human thermal comfort shows a variation depending on the climatic conditions of regions and seasons (Liu, Wu, Li, Cheng, & Yao, 2017; Munonye, 2020; Sahabi Abed & Matzarakis, 2017). Furthermore, convection is the exchange of heat between the body and the surrounding air (Sokolova, 2019). Therefore, thermal sensation of individuals in a given thermal environment is consequently influenced by changes in Ta (Chen, Hwang, Chang, & Lu, 2011; Gagge, Stolwijk, & Hardy, 1967; Nagano, Takaki, Hirakawa, & Tochihara, 2005; Wu, Liu, Zhang, Zhang, & Jiang, 2020; Zhang & Zhu, 2022). Considerably, different ranges of Ta could be perceived as comfortable or uncomfortable due to being difficult to control in especially outdoor contexts. As a result, only Ta has not been considered a sufficient indicator to wholesomely evaluate 'in-situ' human thermal comfort, especially in outdoor environments (Charalampopoulos & Nouri, 2019; Nouri, 2018).

Wind Speed (*V)* is also identified as an important parameter affecting human thermal comfort within outdoor context (Du et al., 2017; Fröhlich, Gangwisch, & Matzarakis, 2019; Hou, 2018; Rajagopalan et al., 2014). The utilisation of outdoor settings may be directly influenced by the mechanic force of *V*, or indirectly through its ability to manipulate of thermal conditions. (Kuttler, 2000). *V* might be influenced by structures in an environment such as buildings, which can enhance or diminish its mechanical effect and landscape amenities (Kabošová, Kmeť, & Katunský, 2020; Mironova, 2020; Ricci et al., 2022; Szkordilisz & Zöld, 2016; van Druenen, van Hooff, Montazeri, & Blocken, 2019). Air Speed (*Va*) is also considered the input parameter of human thermal comfort in an indoor context. *Va* is defined as "the rate of air movement at a point, without regard to direction" (ASHRAE Standard 55, 2017: 2).

Solar Radiation (SR) expressed with W/m^2 is defined as electromagnetic radiated energy obtained from the Sun, being the primary energy source of the Earth, as well as filtered out by the atmosphere before being taken in at the surface (Allaby, 2008). It is worth noting that, unlike the indoor environment, SR has a considerable impact on outdoor thermal comfort, which needs to be comprehensively well studied and examined. For this reason, the investigated impact of SR shows the large difference between indoor and outdoor environments (Arens, Humphreys, de Dear, & Zhang, 2010). SR is a modifiable climatic parameter through the use of some strategies to achieve comfortable thermal conditions, such as providing vegetation for shade in summer, and landscape amenities that enable access to SR during the winter (Gunawardena, Wells, & Kershaw, 2017; Lin, Li, & Brown, 2022). With regards to SR, Global Radiation (Grad) defined as the entire amount of SR collected on the ground (Shibley & Weaver, 1982) is used to measure the radiation fluxes in outdoor thermal environment studies (Nouri & Costa, 2017).

The other most important meteorological parameter influencing human thermal comfort and human energy balance is the Mean Radiant Temperature (Tmrt) with the unit of Celsius (°C), specifically during hot sunny conditions. Tmrt has been considered as the uniform temperature of an imagined environment in which radiant heat transmission from the human body is identical to radiant heat transmission in the existing uneven environment (Gagge, Fobelets, & Berglund, 1986; Matzarakis & Mayer, 2000; ISO, 1998). Tmrt generally shows a considerable variation in open space conditions. Globe Temperature (Tg) is, moreover, one of the most widely used measurement variables to asses heat stress, and is retrieved from a globe thermometer with a hollow copper sphere painted matte black. According to Coutinho (as cited in De Brito, Da Silva, De Souza, & Barros, 2019), and ISO (1998), Tg is one of the variables to calculate Tmrt, and corresponds to the temperature that provides an assessment of the thermal radiation level of the surfaces in a given environment.

Relative Humidity (RH) is an important thermal environment parameter influencing human physiology, thermal sensation, and comfort. RH is defined as “the ratio of the partial pressure (or density) of the water vapour in the air to the saturation pressure (or density) of water vapour at the same temperature and the same total pressure” (ASHRAE Standard 55, 2010; 3). Even though RH has a very little impact on human thermal comfort in a certain range (Baizhan Li, Yu, Liu, & Li, 2011; Jing, Li, Tan, & Liu, 2013) compared with other meteorological parameters, its effect on thermal comfort at high and low temperatures should not be overlooked. This is because changes in relative humidity can have a profound impact on the level of thermal comfort experienced in warm situations (Jing et al., 2013), and even increased air temperature can lead to discomfort in humidity (Palonen, Seppänen, & Jaakkola, 1993).

2.2.2. Personal Factors

As a personal factor affecting thermal comfort, The ASHRAE 55 Standard (2010:3) defines metabolic rate as "the rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface" in met units. Therefore, the degree of activity affects energy generation in the human body, resulting in influencing human thermal comfort. As presented in Table 1, diverse types of activities have related metabolic rates.

Table 1. Metabolic rates of different activities (ISO, 2005).

Activity	W/m^2	Met
Reclining	46	0.8
Seated, relaxed	58	1
Sedentary activity	70	1.2
Standing light activity	93	1.6
Standing medium activity	116	2
Walk on level:		
2 km/h	110	1.9
3 km/h	140	2.4
4 km/h	165	2.8
5 km/h	200	3.4

Clothing insulation expressed in clo units is also another personal factor affecting human thermal comfort and is defined as the thermal insulation that is provided by clothing (Schiavon & Lee, 2013). Clothing insulation could be differentiated based upon the climatic factors, culture, gender, and age (Chun, Kwok, Mitamura, Miwa, & Tamura, 2008; Havenith, Holmér, & Parsons, 2002; Kwon & Choi, 2012; Morgan & de Dear, 2003; Vecchi, Lamberts, & Candido, 2017). Clothing provides protection to the body from SR in hot temperatures. It may, therefore, prevent the body from expending excess body heat. To illustrate, clothing in hot areas may provide a cooling impact on air flow (Clark & Edholm, 1985).

2.3. Thermal Comfort Approaches

Thermal comfort models are classified as either quantitative or qualitative approach for assessing the thermal climate components because human thermal interaction with the environment involves both a physiological and psychological reaction. In a physiologically important aspect, a quantitative model expressed as 'Heat Balance Model' attempts to represent the responses of individuals to the thermal environment in terms of the physics and physiology of heat transfer (de Freitas & Grigorieva, 2015, 2017; Yao, Li, & Liu, 2009). In a qualitative model known as 'Adaptive Comfort Model' has been developed in accordance with the reactions of individuals in ways that tend to improve their comfort as a result of thermal discomfort within the thermal environment (Nicol & Humphreys, 2002). Nevertheless, the heat balance and adaptive comfort approaches to measuring thermal comfort are complementary instead of contradicting each other even if the two types of thermal models give different understandings of human thermal comfort (Brager & de Dear, 1998).

2.3.1. Heat Balance Model

The heat-balance model approach is based upon Fanger's studies (Fanger, 1970) with 1296 young students in a controlled climate chamber, through a steady-state heat transfer model. For individuals involved in near-sedentary activities under steady-state settings, the model was revealed to be an accurate method (Doherty & Arens, 1988). The participants with standardised clothing insulation and activities were exposed to different thermal environments including the four environmental parameters, Ta, *V*, RH, and Tmrt (Macpherson, 1962), to record their thermal sensation through the use of a 7-point ASHRAE thermal sensation scale. The model of Fanger (1970) incorporates heat balance theory with thermoregulation physiology to predict a diversity of comfort temperatures that are pleasant for individuals in a given setting (Djongyang, Tchinda, & Njomo, 2010). According to the model, the human body uses physiological processes, including sweating, and controlling blood flow to the skin, to maintain a balance between heat generated through metabolism and loss of heat from the body, that is, the major criterion for obtaining a neutral thermal experience is to maintain this heat balance (Charles, 2003).

Fanger (1967) conducted studies to investigate the physiological process of the human body when it is near neutral in order to predict the parameters under which thermal comfort would occur. Using data from the lab experiment, the comfort equation connected to 7-point ASHRAE thermal sensation scale was established to quantify thermal comfort (Fanger, 1972). With regards to the heat balance equation, thermal comfort was defined as the imbalance between the actual heat flow from the body in a given thermal environment and the required heat flow for neutral comfort in a given activity. The equation was developed to calculate The 'Predicted Mean Vote' (PMV) and also integrated into 'Predicted Percentage Dissatisfied' (PPD) index in order to provide individuals thermally comfortable indoor climatic conditions. The Klima Michel Model was developed by Jendritzky et al. (as stated in Mayer, 1993) through adapting this approach to outdoor conditions after taking into consideration more complicated outdoor radiation conditions and providing appropriate parameters. This model could get away with ignoring basic thermo-physiological regulating systems due to its only intention to calculate an integral index for the thermal component of climate rather than to provide a comprehensive representation of the thermal conditions of the human body (Höppe, 1999). For this reason, the 'Munich Energy balance Model for Individuals' (MEMI), which is a thermo-physiological heat-balance model, providing quantitative data on the individual heat fluxes and all essential thermoregulatory processes with dependence on the ambient conditions, was developed (Höppe 1984, 1994). The heat-balance model MEMI is based on the energy balance equation of the human body and is the basis for the calculation of the Physiologically Equivalent Temperature index.

Based upon heat balance model, several thermal indices have been developed and used to evaluate bio-climatic conditions for individuals. Some of the most commonly used thermal indices are Physiologically Equivalent Temperature (PET) (Höppe, 1999; Matzarakis, Mayer, & Iziomon, 1999; Mayer & Höppe, 1987), modified Physiologically Equivalent Temperature (mPET) (Chen, Fröhlich, Matzarakis, & Lin, 2017; Chen & Matzarakis, 2018), Universal Thermal Climate Index (UTCI) (Jendritzky, de Dear, & Havenith, 2012), rational Standard Effective Temperature (SET*) (Gagge et al., 1986; Spagnolo & de Dear, 2003), and Perceived Temperature (PT) (Staiger, Laschewski, & Grätz, 2012), and Predicted Mean Vote (PMV) (Fanger, 1972). The meteorological input parameters are required for calculating these thermal indices such as Ta, RH, *V*, and short and long wave radiation fluxes.

The PET index is described as the Ta at which, the human energy budget in an indoor context is sustained by skin temperature (T_{Sk}), core temperature (T_{Cr}), and perspiration rate (PR) being identical to those under the measured conditions (Höppe, 1993; Höppe, 1999; Mayer & Höppe, 1987). Thus, the heat balance of the human body within 80 W metabolic rate and a heat resistance of 0.9 clo (cloting insulation) is maintained (Höppe, 1999). The PET index requires the following meteorological parameters for calculation: Ta, RH, *V*, and short-and long wave radiation fluxes considered by their integral effect as Tmrt. The PET could be calculated through the use of the biometeorological model RayMan Pro software (Fröhlich et al., 2019; Matzarakis et al., 2006, 2007, 2010; Matzarakis & Fröhlich, 2018). The PET index offering the Celsius unit (°C) is especially 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, as well as it is easily interpreted and communicated to non-climatic professionals (Matzarakis, & Amelung, 2008).

2.3.2. Adaptive Comfort Model

Adaptation is defined as an organism's steady reduction in reactivity to repeated environmental stimuli by consciously or unconsciously involving all the processes to increase their comfort with the environment climate and their individual or collective needs (Brager & de Dear, 1998; de Dear & Brager, 1998; Nikolopoulou, Baker, & Steemers, 1999). The adaptive comfort approach was firstly proposed by Humphreys to explain the deviation between actual human sensation and predicted results obtained from heat balance model (Nicol & Humphreys, 1973). The adaptive comfort model presented a significant association between human and outdoor climate conditions, stating the principle that individuals respond to the thermal environment by modifying their behaviours based upon their thermal expectations and preferences. Therefore, the concept of the adaptive model provides a ‘give and take’ interaction between the environment climate and individuals by not considering a human as a passive recipient, yet instead, as an active agent collaborating with and changing to the human-environment approach (Brager & de Dear, 1998). Nikolopoulou and Steemers (2003) stated that the principle of adaptation would be effective in evaluating thermal comfort in outdoor environments. Within this framework, adaptive comfort concept could be classified into three main categories: Behavioural adjustment, physiological adaptation, and psychological adaptation (Brager & de Dear, 1998).

2.3.2.1. Behavioural Adaptation

Behavioural adaptation referred to physical adaptation (Nikolopoulou & Steemers, 2003) mainly includes all adjustments made by individuals consciously or unconsciously to modify heat and mass fluxes regulating thermal balance of the body. Therefore, an individual has a considerable opportunity because of taking an active role in sustaining their comfort in thermal environment. The classification of behavioural adaptation might be classified into three sub-categories as follows (Brager & de Dear, 1998):

- Personal adaptation includes the adjustments of oneself to the thermal environment by altering an item of clothing, activity level, changing body posture, hot and/or cold drink, and also changing the location for the purpose of seeking a more comfortable environment.
- Technological adaptation contains the interrelationship between a person and the thermal environment with the opportunity to change microclimatic parameters such as opening/closing windows or doors, and turning on an air-conditioner or heating devices.
- Cultural responses are related to organizational and social customs which refer to conditions prevailing in the environment such as having a siesta on the hot days and having a casual dress code.

Several experiments have been conducted in order to analyse adaptive behaviours of individuals as an adaptive process to improve one’s thermal comfort and sensation in a given outdoor and indoor environment. Based upon the experiments conducted in outdoor environments through the use of questionnaires and/or observations, Watanabe and Ishii (2016) stated that male and female pedestrians adapted themselves to the environment by the choice of ‘wearing hats or parasols’ in order to handle the influence of excessive heat stress during the hot season when standing at the traffic signals. Additionally, Yang, Wong, and Jusuf (2013) looked into the impact of thermal adaptation on human thermal sensation and adaptive behaviour preferences in hot thermal sensation in Singapore. This study concluded that ‘moving to shaded trees or shelters’ was the most preferred approach for behavioural adaptation to the outdoor environment. The study by Huang, Cheng, Gou, and Zhang (2019) also indicated that the adaptive behaviours of individuals showed differences with the regard to the summer and winter seasons on the university campus of Mianyang, China. The preference of ‘going to a shaded place’ and ‘staying under the sun’ was concluded to be the most significant adaptive strategies to improve thermal comfort levels in summer and winter, respectively. The study also revealed that the individuals tended more towards engaging and interacting with their encircling environment instead of making subjective changes. An example of this was reflected by ‘use umbrella’ being more highly sought, compared to ‘take off clothes’ to improve their thermal comfort. The researchers explained the reason behind this conclusion with the probability of having already the lowest clothing insulation (0.51 clo) in hot summers. Subsequently, Katzschner (2006) implied that individuals selected staying outside instead of seeking a shaded location in an interior setting in warm, and even heat-stressed outdoor thermal conditions.

Apart from interior design components such as physical space arrangement and type of furniture (İmamoğlu & Gürel, 2016; Maitland, Stratton, Foster, Braham, & Rosenberg, 2014; Martin, 2009; Sufar, Talib, & Hambali, 2012; Webb, Schaller, & Hunley, 2008), thermal conditions also influence the behaviours of individuals (Aparicio-Ruiz, Barbadilla-Martín, Guadix, & Muñuzuri, 2021; Karjalainen, 2009; Mustapa, Zaki, Rijal, Hagishima, & Ali, 2016; Rijal, Humphreys, & Nicol, 2015; Shrestha, Rijal, Kayo, & Shukuya, 2021; Zheng et al., 2022). Therefore, with regards to behavioural adaptation in indoor environments, the study by Kim, de Dear, Parkinson, and Candido (2017) concluded that in terms of environmental modifications (technological adaptation), ‘operating windows or doors’ was the dominant observed adaptive behaviour within the sample of Sydney household in residential buildings. This study also revealed that ‘changes in clothing insulation’ as a behavioural adaptation process was the more prominent and temperature-sensitive in residential buildings during spring and fall seasons, compared with summer and winter. Furthermore, window opening has been mostly researched as a part of the adaptation process in the existing literature and considered to be controlled by Ta, RH, and *V*, based upon assumptions on individual behaviours (Calì, Andersen, Müller, & Olesen, 2016; Shi et al., 2018; Yao & Zhao, 2017; Zhang & Barrett, 2012). In fact, access to the operable window is the fundamental prerequisite for the ASHRAE adaptive comfort model’s application (ASHRAE Standard 55, 2010). Rijal et al. (2007) developed and implemented an adaptive algorithm for window opening in building simulation in order to analyse window opening behaviour, and showed the impact of occupant behaviour on comfort and building energy use. The study concluded that ‘windows open’ had the lowest proportion in winter, and the highest in summer, shown to be a function of the outdoor and indoor temperature. The results obtained from the survey data also showed similar results to the Humphreys adaptive algorithm (Humphreys & Nicol, 2000), that is, the algorithm's representation of window open behaviour was proven to be more responsive to changes in building design characteristics than a non-adaptive method.

2.3.2.2. Physiological Adaptation

Physiological adaptation, called physiological acclimation in the context of thermal environment, represents physiological reactions to thermal environmental conditions, which result in a progressive reduction of the strain generated by such exposure (de Dear & Brager, 1998). Physiological adaptation could be classified into two sub-categories as follows:

- Genetic adaptation represents the modifications that are a part of the genetic inheritance of an individual, and develop at a time scale that extends beyond the lifespan of an individual, and even involves the period between generations.
- Acclimatization refers to the modifications in the settings of the physiological thermo-regulation system over days or weeks as a result of being exposed to a single or combined thermal environmental factors, yet it has a prolonged seasonal mechanism resulting from constant experiences.

In physiological acclimatization, which is an unconscious form of adaptation, the autonomic nervous system acts as an intermediary and has a direct impact on the human body's thermoregulation operating points (Brager & de Dear, 1998). Heat acclimatized people display a wide variety of cardiovascular reactions, including a decreased heart rate, increased blood volume, and greater peripheral blood flow when subjected to the same quantity of heat (Eichna, Bean, Ashe, & Nelson, 1945; Fox, 1974; Zhu, Liu, &Wargocki, 2020). Numerous research has been carried out in order to investigate physiological acclimation including distinctive age ranges, as an adaptive approach to improving the impacts of thermal environment on human thermal comfort. The analysis of physiological parameters has mainly based upon TSk, electrocardiograph (ECG), and electroencephalogram (EEG) (Cândido, de Dear, & Ohba, 2012; Liu, Zhong, & Wargocki, 2017; Liu, Wang, Liu, & Di, 2013; Schellen, Loomans, de Wit, Olesen, & Lichtenbelt, 2013; Schweiker et al., 2012; Wu et al., 2019; Yao, Lian, Liu, & Shen, 2008). Wu et al. (2019) compared the physiological responses of the elderly with middle-aged and young-aged individuals in a heated climate chamber. According to the study, with regards to physiological responses such as oral temperature, blood pressure, and heart rate, the elderly and middle-aged individuals were less susceptible to the thermal environment than college students which remained nearly constant with changes in Ta. With regards to winter season, Cândido et al. (2012) examined the influences of short-term physiological acclimatization of individuals being subjected to hot-humid thermal conditions on thermal perception and air movement preferences. Their T_{Cr} was increased by daily exercising. The three-day subsequent increase in T_{Cr} is assumed to be an effective short-term physiological acclimatization strategy in the study.

2.3.2.3. Psychological Adaptation

The psychological aspect of adaptation refers to a change in how an individual perceives and reacts to sensory information based upon previous experiences and expectations. Considerably, psychological factors impact the thermal perception of a thermal environment, and the alterations occurring in this context (de Dear & Brager, 1998). The six psychological factors suggested by (Nikolopoulou & Steemers, 2003) are described as follows:

- Naturalness defined by Griffiths, Huber, and Baillie (1987) is strongly related to the environment not involving artificiality, in which there seems to be progressing evidence that individuals could show higher tolerance a various range of changes in the physical environment.
- Experience is considerably associated with the human environment because of being a variable that an individual has during the thermal experiences. Past experience has a direct relationship with individual expectations and is classified into a short and long-term experience. Short-term experiences associated with memory could change an individual's expectations day to day. The scheme that individuals have formed in their thoughts is connected to the long-term experiences that individuals have had, which help them decide what course of action to take in various thermal conditions. In response to the

thermal conditions, changes in clothing, drinking of hot/cold drinks, and changing the location to sunnier or shady spaces are all well-established strategies for dealing with the changeable thermal environment.

- Expectations related to how the environment should be instead what they actually experience in a specified space greatly influence the perceptions of individuals. As several researchers have stated, expectations of certain thermal conditions are the major reason for individual satisfaction with a given thermal environment (Becker, Potchter, & Yaakov, 2003; Höppe, 2002). Naturally, when thermal conditions differed from what individuals had been experiencing on the preceding days, it resulted in variances in sensation votes of individuals and/or even complaints as a consequence of their altered expectations.
- Time of exposure refers to the variance in the length of time individuals are subjected to conditions that are perceived uncomfortable. The thermal perception of the environment is a crucial factor in determining how long individuals stay in a given environment.
- Perceived control represents providing opportunities through the behavioural adaptation of a site such as choices for changing the location of individuals to more sunny/shaded areas.
- Environmental stimulation mainly is an important aspect in outdoor environments that show few thermal constraints, being one of the reasons that individuals use these spaces.

Several studies have presented that psychological adaptation to thermal environment is required to provide greater use of outdoor spaces since human responses to the outdoor environment and actual human thermal sensation take precedence in determining the levels of individuals for thermal condition understanding (Amindeldar, Heidari, & Khalili, 2017; Chen, Xue, Liu, Gao, & Liu, 2018; Lin, de Dear, & Hwang, 2011; Nasir, Ahmad, & Ahmed, 2012; Marialena Nikolopoulou & Steemers, 2003; Yu, Yang, & Zhu, 2015; Zabetian & Kheyroddin, 2019). Lin et al. (2011) revealed that the preferred temperatures had a greater seasonal offset because the seasonal difference between neutral and preferred temperatures was distinctive. The reason behind this approach was explained with the conclusion that individuals might have used various adjectives to describe their preferred thermal conditions during different seasons. In hot summer settings, they might have defined their preferred thermal state as cooler than in cold winter conditions. In a similar alignment, the study by Chen, Wen, Zhang, and Xiang (2015) also argued that expectations and thermal comfort preference showed a change with the seasons, and even the climatic and regional diversity influenced thermal sensation of individuals. Furthermore, Nasir et al. (2012) indicated that individuals tended to adapt themselves psychologically to microclimatic conditions under the shade based upon their thermal experiences and perceptions.

On the other hand, psychological adaptation is an essential requirement for not the only outdoor environment, but also indoor context to determine the understanding in thermal comfort and sensation of occupants within buildings (Kalmár, 2016; Luo et al., 2016; Xiong, Zhou, Lian, You, & Lin, 2016; Y. Yang, Li, Liu, Tan, & Yao, 2015). Kalmár (2016) stated that the subjective sensation of individuals showed a decrease after a certain period of time in a warm indoor environment. This decrease in sensation was explained based upon the outdoor and indoor thermal histories of the individuals. The results also concluded that individuals from regions with warmer climatic conditions and being accustomed to air conditioning mechanisms had a preference for low indoor temperatures. With regards to the personal control within indoor contexts, Luo et al. (2016) examined the impact of personal control over space conditioning systems on the thermal comfort perception of occupants to identify the psychological influence of perceived control, and even the physical (behavioural) influence with the utilisation of the controllable approaches in a climate chamber. According to the findings, individuals with perceived control ability over thermal environment led to improvement in thermal comfort perception. They also showed better thermal sensation with higher thermal satisfaction in both warm and cold thermal conditions, proving the possibility to be the only effect of psychological impact.

2.4. Relationship between Outdoor Climate and Indoor Thermal Environment

In order to understand the reasons behind what indicators affect the indoor thermal environment, numerous studies have been conducted within indoor and outdoor contexts. However, some studies showed that outdoor climatic parameters had a prominent influence on the indoor thermal environments, mainly with regard to the outdoor Ta (Ta_{OUT}) (Adunola, 2014; de Dear & Brager, 1998; Humphreys, 1978; Humphreys, Rijal, & Nicol, 2013; Humphreys & Nicol, 2000; Mallick, 1996; Nicol & Humphreys, 2010), based upon the adaptive comfort approach, which the calculated indoor comfort temperatures could be related to outdoor thermal conditions to provide an adaptive comfort correlation (ASHRAE Standard 55, 2010; Manu, Shukla, Rawal, Thomas, & de Dear, 2016). Considerably, after the first quantitative relationship between outdoor temperature and indoor comfort temperature, founded by Humphreys (1978), several studies also argued that changes in the Ta_{OUT} led to a variation in the indoor Ta (Ta_{IN}) (Krüger & Zannin, 2004; Nicol, Raja, Allaudin, & Jamy, 1999; Pan et al., 2021; Yan, Yang, Zheng, & Li, 2016).

Furthermore, Ta_{OUT} could have the main influence on thermal adaptation in the identical indoor environments in terms of thermal preferences based upon different seasons (Cao, Zhu, Ouyang, Zhou, & Huang, 2011; Wang, Li, Ren, & He, 2014), and behavioural adjustments because of its effect on Ta_{IN} (Yan et al., 2016). According to the existing literature, thermal sensation of individuals within indoor settings is considerably affected by the outdoor temperature (Cao, Zhou, Huang, & Zhu, 2008). With regards to the literature, the Ta_{OUT} is not only the parameter affecting Ta_{IN}, but also it could result in considerable variations in indoor *Va* (Va_{IN}) within especially indoor settings with neutral ventilation (Manu et al., 2016), while a little correlation was found in the indoor settings with air-conditioning systems (de Dear & Brager, 1998).

Apart from Ta_{OUT}, and its effect on Ta_{IN} and Va_{IN}, outdoor RH (RH_{OUT}) has relatively an impact on indoor RH (RH_{IN}) that is not shown to strongly depend upon Ta_{OUT} (Halawa & van Hoof, 2012). However, RH_{OUT} is a weakly correlated indicator for RH_{IN} exposure compared to Ta (Nguyen, Schwartz, & Dockery, 2014; Pan et al., 2021). Radiation fluxes entering through windows, moreover, contribute to shaping the perceived thermal sensation of occupants in an indoor environment (Bauman & Arens, 1996; Hodder & Parsons, 2007, 2008), and can lead to thermal problems in terms of overheating or cold sensation in interior settings with unshaded glazing (Arens et al., 2015).

2.5. Relationship between Outdoor Climate and Thermal Comfort in Outdoor Thermal Environment

Over the past years, the effect of outdoor climatic parameters, especially Ta, *V*, Tmrt on outdoor human thermal comfort has been investigated to enhance comfort levels in outdoor contexts (Aljawabra, 2014; Andreou, 2013; Banerjee, Middel, & Chattopadhyay, 2020; Eliasson, Knez, Westerberg, Thorsson, & Lindberg, 2007; Li, Zhao, Peng, Wang, & Shui, 2020; Nikolopoulou, Baker, & Steemers, 2001; Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007; Thorsson, Lindqvist, & Lindqvist, 2004; Villadiego & Velay-Dabat, 2014). Even though Ta has been found the most predominant determinant of outdoor thermal comfort (Lin et al., 2011), the perception of *V*, Tmrt, and RH are also important measurements in outdoor environments (Lai et al., 2020). Thus, the identification of the importance of different outdoor climatic parameters has been taken into consideration since no single thermal climatic indicator could describe the comprehensive understanding of outdoor thermal comfort (Lin, 2009).

Due to the urban morphology, *V* and SR are also significant factors that affect human thermal comfort and adaptation (Herrmann & Matzarakis, 2012; Lin, Matzarakis, & Hwang, 2010). In several studies, SR, however, had the most significant effect on human thermal sensation in outdoor spaces (Elnabawi & Hamza, 2020; Yang et al., 2013; Yin et al., 2012), compared with *V* and RH. Yin et al. (2012) stated that excess SR showed a reduction in thermal comfort level of individuals during summer, resulting in changing adaptation strategies under intense SR. Apart from SR, the wind also contributes to improving thermal sensation and comfort related to heat-stressed seasons (Abreu-Harbich, Labaki, & Matzarakis, 2014; Ali-Toudert & Mayer, 2007; Andreou, 2013; Herrmann & Matzarakis, 2012; Lindberg & Grimmond, 2011; Al Sabbagh, Yannas, & Cadima, 2016; Walton, Dravitzki, & Donn, 2007). However, based upon the climatic characteristics of regions, increasing *V* could result in discomfort depending on Ta due to strong wind in northern climates (Nikolopoulou & Lykoudis, 2006), and even a decrease in *V* with the intense sunshine could lead to the improvement in thermal sensation in outdoor environment during the cold season (Amindeldar et al., 2017).

With regards to the qualitative aspect of thermal comfort, not only outdoor climatic parameters have a considerable impact on thermal comfort. Yet, also several studies had considered the strong relationships among outdoor thermal responses (Fransson, Västfjäll, & Skoog, 2007; Wang et al., 2018; Wang, de Groot, Bakker, Wörtche, & Leemans, 2017; Yang et al., 2013). The study by Viiladiego & Velay-Dabat (2014) stated that thermal sensation showed a relationship with *V*, RH, and SR sensations. The cases of the study also revealed that warm thermal sensation was related to perceiving the environment dry, low *V*, and high SR. Yet, these sensations could have not shown the same strong relationship with thermal sensation. Thus, solar radiation sensation was considered the predominant determinant of thermal sensation, while humidity sensation seemed to have less influence on thermal sensation (Villadiego & Velay-Dabat, 2014; Yang et al., 2013).

2.6. Impact of Shading Strategies on Thermal Comfort

Increasing the effect of shading in outdoor spaces is an effective adaptive strategy to improve human thermal comfort (Berkovic et al. 2012; Lee et al. 2018; Shashua-Bar et al. 2009, 2010; Wong & Jusuf, 2010). Shading effects obtained from the architectural elements, vegetation, and other landscape amenities, can decrease the incidence of SR, and sunlight, lower the ground surface temperature and reduce long and short-wave radiation effects (Ali-Toudert & Mayer, 2007; Ali-Toudert & Mayer, 2006; Emmanuel et al., 2007; Hwang et al., 2011; Klemm, Heusinkveld, Lenzholzer, & van Hove, 2015; Lin et al., 2010; Nouri, Costa, Santamouris, & Matzarakis, 2018). Numerous studies on outdoor thermal comfort and adaptation have been conducted to obtain information on various shading effects on human thermal comfort in university campuses, urban parks, and streets by using microclimatic measurements, and questionnaire surveys. Several researchers indicated that high temperatures in most outdoor open spaces lead to thermal discomfort for students due to a lack of shading area (Abdallah et al., 2020; Lee, Md Din, Iwao, Lee, & Anting, 2021). The shade from such amenities and vegetation increases thermal comfort and adaptation significantly in spring, summer, and autumn (Hwang et al., 2011; Middel, Selover, Hagen, & Chhetri, 2016), and provides more comfortable spaces than the outdoor spaces that receive direct sunlight (Elnabawi & Hamza, 2020; Othman, Zaki, Rijal, Ahmad, & Razak, 2021).

With regards to shading strategies, green infrastructures have been proposed as an effective measure for mitigating UHI effect in warming cities and improving the urban microclimate (Tan, Lau, & Ng, 2016) through its shadow and evapotranspiration impact (Aleksandrowicz, Vuckovic, Kiesel, & Mahdavi, 2017; Ekşi, Rowe, Wichman, & Andresen, 2017; Perini & Magliocco, 2014; Reis & Lopes, 2019). Therefore, landscape amenities, especially vegetation, are considered important shading strategies resulting in the reduction of SR intensity, and the modification of the reflected radiation from the ground and other surfaces within the outdoor context (Kotzen, 2003; Nouri, Fröhlich, Matos Silva, & Matzarakis, 2018). Green roof, moreover, contributes to decreasing the extreme effects of thermal conditions in urban context (Ekşi & Uzun, 2013). Subsequently, through computer models of Gothenburg, Sweden, an increase in vegetation cover ratio providing shade leads to a decrease in Tmrt (Lindberg & Grimmond, 2011). In order to understand the effects of different shading levels, Lin et al. (2010) investigated outdoor thermal conditions with different shading levels on a university campus in Taiwan in each season. The results showed that thermal discomfort was founded in barely shaded spaces with a high Sky-View Factor (SVF) during summer, while in highly shaded spaces with a low SVF during winter. Yet, the thermal comfort was maintained for the longest duration in the median shading levels (Lin et al., 2010).

In addition to green infrastructures, architectural elements such as canyons including buildings shade (Vanos et al., 2012; Yin, Lang, Xiao, & Xu, 2019), and the building-level strategies such as arcade design (Mazouz & Zerouala, 1998; Yin & Xiao, 2016) are important determinant as shading strategies in especially warming cities. Nouri et al. (2018) also discussed the influence of different shading strategies on human thermal comfort. This study identified that thermal comfort with regards to SR could be influenced according to the aspect ratio, symmetry, and orientation of canyons. The architectural blocks and arcade design in urban environments could also provide the lowest average PET value in relation to exposing direct sun or the ability of urban form to provide shade (Ali-Toudert & Mayer, 2007; Taleghani, Kleerekoper, Tenpierik, & van den Dobbelsteen, 2015). Even though the shading potential of green infrastructures and architectural elements did not show a significant variation in the study by Middel et al. (2016), Lee et al. (2018) revealed that the building shade strategy was assumed as the most effective shading strategy, followed by the use of tree and umbrella.

Furthermore, the use of different paving materials in outdoor spaces shows significant temperature differences, therefore the impact of pavement with a cooling feature as a shading strategy has been given importance in research on urban settings nowadays (Asimakopoulos et al., 2012; Livada, Santamouris, & Assimakopoulos, 2007; Santamouris, 2013) because of the effect of surface temperature (Tsurf) on the temperature of the surrounding air (Akbari, Davis, Dorsano, Huang, Winert, 1992; Asaeda, Ca, & Wake, 1996; Babić & Ce, 2012; Choi, Suh, & Park, 2014; Pomerantz, Ppn, & Akbari, 2000). With regards to the paving materials, surface shading with the use of grass has a considerable influence on the reduction of heating up through lowering temperature, compared to the materials exposed to direct sunlight (Djekic et al., 2018). For this reason, the differences in surface temperature (Tsurf) of materials used in outdoor environments were concluded in a study by Lin, Ho, and Huang

(2007) in subtropical Taiwan. The study indicated that asphalt concrete and concrete had a higher temperature than interlocking block/interlocking blocks with grass infilling and grass; thus, Tsurf was closely correlated to Ta, followed by Tg and SR (Lin et al. 2007). Nouri and Costa (2017) studied bioclimatic analysis in Rossio through meteorological equipment, easy-to-use software for urban design, and planning professionals, providing public space design solutions. The findings indicated that the highest Tsurf was provided from basalt paving, while the road surface with granite had the highest Tsurf in the shade.

2.7. Impact of Wind Strategies on Thermal Comfort

Excessive closely spaced buildings due to urbanization in today's megacities lead to limiting air circulation and undesirable low *V* at the pedestrian level (Ng, 2009; Tsang, Kwok, & Hitchcock, 2012; Yim, Fung, Lau, & Kot, 2009). Air pollution and heat exhaustion may build-up due to a lack of air movement in the summer months because of a lack of ventilation. Mean *V* less than 1.5 m/s, which is the minimum requirement by Hong Kong's Air Ventilation Assessment, might induce outdoor thermal discomfort for individuals, particularly during the hot summer months (Cheng, Ng, Chan, & Givoni, 2012; Ng, 2009). For this reason, numerous studies have been conducted in order to improve air circulation by concentrating *V* at the pedestrian level. Ceratin building forms, directions, and street canyons formed between buildings have been revealed as useful determinants in achieving acceptable wind conditions at the pedestrian level around buildings and open outdoor spaces (Jamieson, Carpenter, & Cenek, 1992; Kuo, Tzeng, Ho, & Lai, 2015; Rodríguez-Algeciras, Tablada, Nouri, & Matzarakis, 2021; Stathopoulos & Storms, 1986; Stathopoulos, Wu, & Bédard, 1992; Uematsu, Yamada, Higashiyama, & Orimo, 1992). Another suitable wind strategy to solve the thermal discomfort during the heated season with the possible use for recreational activities and passage ways has been identified as a ‘Lift-up’ shape supported by a central core, columns, or shear walls. This design can minimize the obstruction to wind flow and improve wind circulation (Du et al., 2017; Huang, Niu, Xie, Li, & Mak, 2020; Tse et al., 2017). In addition to such wind strategies, green vegetation is considered another resource to provide a comfortable wind environment in terms of not only decreasing *V*, but also improving human thermal comfort (He, Yang, & Ye, 2014; Xu, Hong, Jiang, An, & Zhang, 2019).

Nevertheless, several pedestrian level wind environment studies have indicated that strong winds around surrounding buildings are the main focus on the human thermal discomfort conditions due to the influence of building dimensions, shapes, orientations, density, spacing between buildings, street canyons through wind tunnel effect approach (Blocken, Stathopoulos, & Carmeliet, 2008; Blocken, Carmeliet, & Stathopoulos, 2007; Kubota, Miura, Tominaga, & Mochida, 2008; To & Lam, 1995). The excessive *V*, therefore, could result in a more uncomfortable thermal comfort level for individuals due to cold sensation, compared to windless open outdoor environments (Hou, 2018).

2.8. Cognitive Performance

Cognitive function, which is a fundamental term for human adaptation and survival, refers to the mental activities of ‘reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly, and learn from experience’ (Plomin, 1999). Perception, reasoning, memory, learning, attention, concentration, decision-making, and linguistic ability are considered the domains of cognitive functioning (Keough, 2014). The dynamic interrelationship between embodied systems and their environmental surroundings has been concentrated on contemporary cognition theories (Calvo & Gomila, 2009).

Numerous studies have investigated the factors affecting cognitive performance in relation to the mental processes of individuals. With regards to the studies, the possible effects on cognitive performance are evaluated as age (van Hooren et al., 2007), and education level (Dore, Elias, Robbins, Elias, & Brennan, 2007; Yao, Zeng, & Sun, 2009), physical activity (Brisswalter, Collardeau, & René, 2002; Pirrie & Lodewyk, 2012), and even indoor environmental quality involving indoor temperature, air quality, lighting and noise (Afacan & Demirkan, 2016; Chen & Schwartz, 2009; Hygge & Knez, 2001; Lercher, Evans, & Meis, 2003; Zhang & de Dear, 2017). In research contexts, standardized instruments designed using psychometric approaches to measuring several types of cognitive abilities are utilised to test cognitive performance of the individuals (Strauss, Sherman, & Spreen, 2006) such as the Wechsler Adult Intelligence Scale (WAIS-IV) (Lichtenberger & Kaufman, 2009) and the Cambridge Neuropsychological Test Automated Batteries (CANTAB) (Fray, Robbins, & Sahakian, 1996). In addition to these instruments, d2 test of attention (Brickenkamp & Zillmer, 1998), Stroop task (Stroop, 1935), Boston Naming Test (Kaplan, Goodclass, & Weintraub, 1983), the Uchida-Kraepelin test (UKT) (Kuraishi et al., 1957) also has been used as primary tasks to measure different types of mental abilities with either paper-based and computerized use possibilities.

Numerous field and laboratory investigations have been conducted to analyse the association between thermal comfort and human cognitive performance through evaluating adopted simulated tasks (Jiang et al., 2018; Lan, Wargocki, & Lian, 2011; Woo et al., 2022). Nevertheless, most studies have concentrated on the thermal comfort of the controlled indoor environment related to especially heat stress in relation to the cognitive performance, and the productivity of university, primary/secondary school students, office workers, and patients in hospital settings (Cui, Cao, Park, Ouyang, & Zhu, 2013; Gaoua, Racinais, Grantham, & El Massioui, 2011; Geng, Ji, Lin, & Zhu, 2017; Lan & Lian, 2009; Lan, Lian, & Pan, 2010; Sarbu & Pacurar, 2015; Wang et al., 2018; Wyon, 1974; Zhang & de Dear, 2017). An increase in the indoor temperature does not just influence the thermal comfort of individuals (ASHRAE Standard 55, 2010), but also cognitive performance within indoor contexts (Chen, Tao, & Liu, 2020; Fan, Liu, & Wargocki, 2019; Hocking, Silberstein, Lau, Stough, & Roberts, 2001).

Cui, Cao, Park, et al. (2013) evaluated the performance of university students through memory typing tasks under five temperature conditions. The study found that warm discomfort affected negatively performance, while temperature values between 22℃ (slightly cool) and 26℃ (a little higher than neutral) were the optimum temperature range for performance. In addition, Geng et al. (2017) concluded that ‘neutral’ and ‘slightly cool’ indoor thermal environments led to optimal productivity, and the increase in thermal sensation affected positively the productivity of university students. In contrast to the previous studies, the results of the study conducted by Wang et al. (2018) showed that ‘a slightly warm’ indoor thermal environment equated to optimal performance of 12-14 years students in a controlled environment in summer. Furthermore, an investigation of performance measurement under dynamic settings with airflow by establishing thermal conditions from “neutral” to “slightly warm” was carried out by Cui, Cao, Ouyang, and Zhu (2013). The study found no significant performance difference. Berg et al. (2015), moreover, showed no significant difference in some types of cognitive functions of patients such as attention, and psychomotor performances in warm conditions with heat stress.

Particularly, with regards to attention and concentration, the study by Zhang and de Dear (2017) stated that concentration performance of university students showed a considerable increase with the rise of temperature in temperature cycles starting at 22 °C. Subsequently, attention could be different among different ranges of temperatures (Lan, Xia, Hejjo, Wyon, & Wargocki, 2020). Attention performance at 16 °C was optimum, compared to the higher temperature values in the study by Hu & Maeda (2020). Contrary, several studies also implied that attention did not show a difference in various thermal environments (Maula et al., 2016; Tanabe & Nishihara, 2004).

CHAPTER 3

METHODOLOGY

3.1. Research Questions and Hypotheses

This study intends to evaluate the impacts of shaded outdoor spaces on thermal adaptation and link such results with cognitive performance of university students in classroom environments. In this respect, the following major research question was formulated:

RQ: How do different outdoor shading level experiences influence thermal adaptation of university students in outdoor and indoor classroom environments?

There are also other sub research questions in this study:

Sub-RQ1: Is there a difference in the impacts of different outdoor shading levels on outdoor thermal adaptation of university students?

Sub-RQ2: Is there an association between outdoor thermal responses in different outdoor shading levels and indoor thermal responses of university students?

Sub-RQ3: Is there a difference between quantitative and qualitative measurements of thermal comfort of university students?

Sub-RQ4: What is the difference in indoor concentration performance for students with different outdoor shading level experiences in classroom environments?

The following five hypotheses are proposed to meet the objectives of the study:

H1: Outdoor and indoor thermal adaptation of students with a shaded outdoor space experience differ from those with a sun-exposed outdoor space experience.

H2: The impact of a shaded outdoor space is significantly different from the impact of a sun-exposed outdoor space on outdoor thermal adaptation of university students.

H3: There is a significant relationship between outdoor thermal responses in different outdoor shading levels and indoor thermal responses of university students.

H4: There is a significant difference between quantitative and qualitative measurements of thermal comfort of university students.

H5: Indoor concentration performance of students with a shaded outdoor space experience is significantly higher than those with a sun-exposed outdoor space experience.

3.2. Subjects of the Study

This study was conducted following the approval of the ethics committee at Bilkent University in order to carry out with the students in Bilkent University before starting the field experiments (for the approval document, See Appendix A). This study recruited a total number of 58 undergraduate design students from the Interior Architecture and Environmental Design bachelors program at Bilkent University. The participants were aged between 18 and 23 years old.

Before the experiments, all the participants were briefly introduced to the subject of the study. The consent form including the purpose, procedure, benefits related to the study, and confidentiality issues on personal information was distributed to sign to be involved in the field experiments (for the consent form, See Appendix B). The participants were entirely on a voluntary basis with the right for withdrawing from the procedure at any phase of the field experiment. Since participants were not reimbursed for their involvement in this experiment, this study was not designed with the intention of paying money for participating in the field experiment.

3.3. Description of the Study Area

This study was carried out in the country Turkey located in Western Anatolia and bridges southeastern Europe and Asia. Turkey has a variety of climatic classifications as a result of being surrounded by three distinct seas, significant mountain ranges, and interior basins (Nouri et al. 2021). With regards to the Köppen-Geiger (KG) classification maps produced by Peel, Finlayson, and McMahon (2007) and Yılmaz and Çiçek (2018), Turkey has ranged between the B, C, D classifications, with a wide-ranging diversity between their sub-classifications.

Ankara is located in the Central Anatolia Region of Turkey at 40°N and 33°E, with a climatic KG classification of '*Dsb*' which is associated with a snow/cold climate with dry/warm summers (Peel et al. 2007). However, the newer map of KG for Turkey produced by Yılmaz and Çiçek (2018) indicated that Ankara is adjacent to '*Csa*' which identifies warm temperate with dry hot summer, and '*BSk*' which identifies cold semi-arid climate classification. With a substantially higher temperature threshold during the summer, KG in the case of Ankara can vary to '*Dsa*' within the depressions of the plateaus (Nouri et al. 2021; Yılmaz and Çiçek 2018). Mean temperatures of Ankara range from 0.2 °C in January to 23.4 °C in July, with an annual average of 11.9 °C (Turkish State Meteorological Service, 2021).

The field investigation was conducted in İ.D. Bilkent University given its enclosure of various microclimatic conditions. The university campus is located approximately 12 kilometres west of the centre of Ankara with over 300 hectares. The university is divided into three types of campuses: Main, middle, and east campus. In order to provide a particular analytical area within the campus, the Points of Interest (POI) methodology was intended to establish within this study through a similar approach undertaken by Nouri and Costa (2017). Two POIs, surrounding the Faculty of Art, Design, and Architecture (FADA), was considered as study areas on the main campus of Bilkent University (See Appendix C). Figure 2 presents the distribution of two defined POIs that would detect sequential microclimatic changes during the measurement period. POI 1 was defined as a shaded outdoor space, located between two buildings of the FADA that block direct solar radiation and have a possibility of wind tunneling effect due to the mass configuration (wide-narrow-wide) of two buildings (Nugrahanti, Lubis, & Kusyala, 2018). POI 2 was considered as a sun-exposed outdoor space that receives direct solar radiation in an open square during the measured period, used as a frequent gathering area for students.

In addition, the building of the FADA was selected because of containing various classrooms on each floor as a study area indoor thermal adaptation and cognitive performance examinations. Two classrooms (Classroom 1 and Classroom 2) with natural ventilation were considered classroom environments in the FADA building (Figure 3). These classrooms with approximately 210 m^2 have three windows façade and are located in the North-West direction on the third floor. Due to each classroom being divided with a partition wall within itself, the indoor examinations of this study were conducted on the one side of each classroom in order to prevent the differences in the two sides of the classroom from considerably affecting the results.

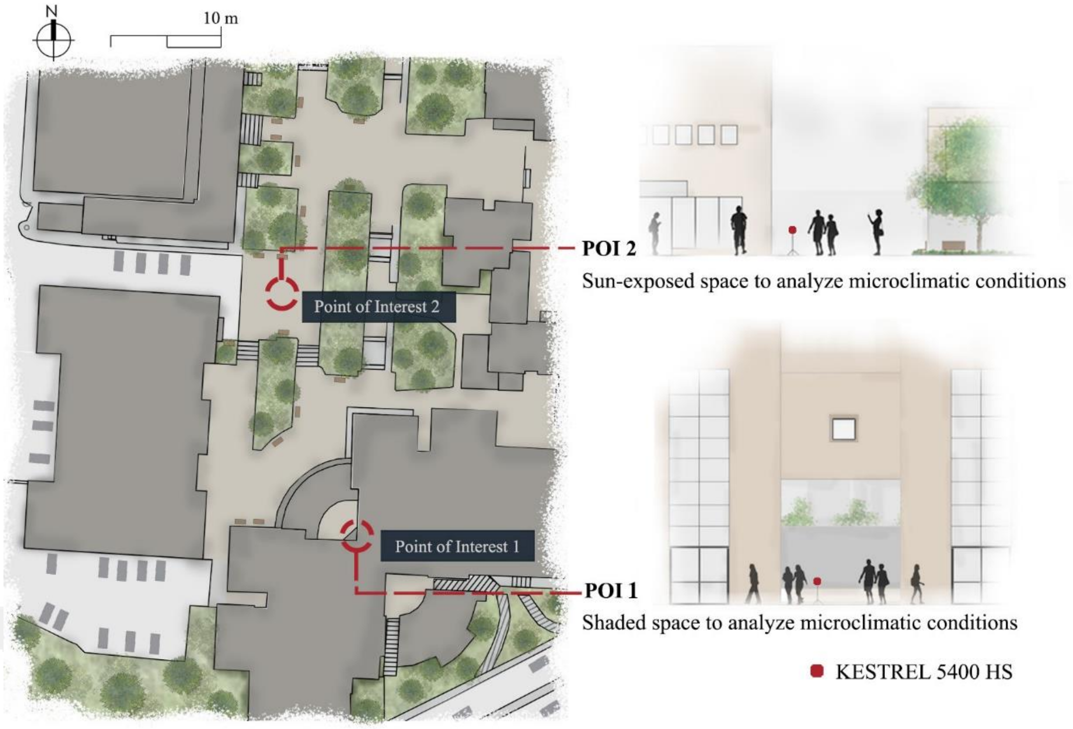

Figure 2. Point of Interests of view in the campus, illustrated by the author | Source: Author's rendering.

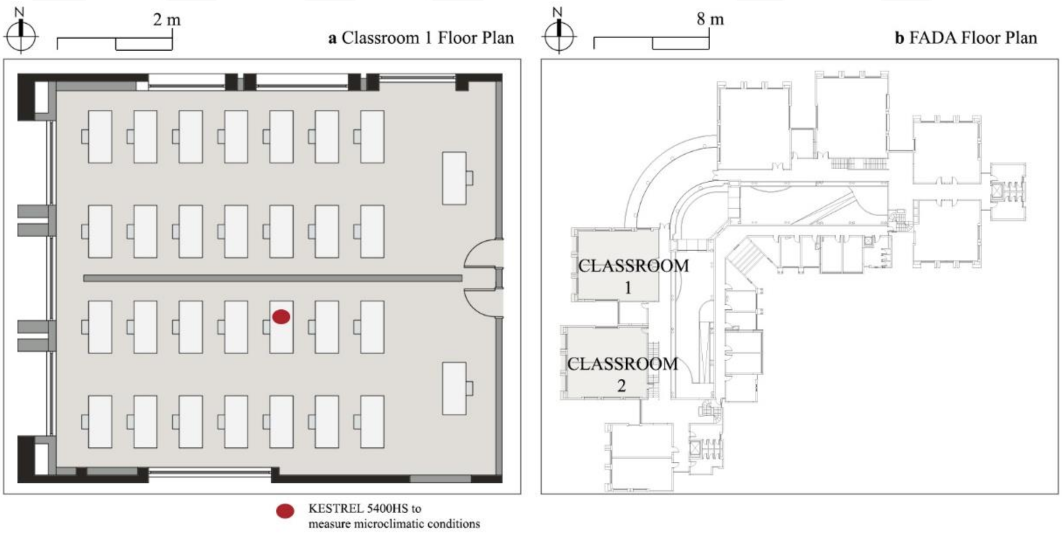

Figure 3. Illustration of the building and the Classroom 1-floor plan indicating the location of the in-situ station | Source: Author's illustrations.

Although numerous studies have investigated summer and winter seasons due to the characteristics of the thermal condition in the outdoor environment, this study was carried out in the autumn season as a result of human comfort levels changing considerably due to fluctuations in thermal sensation (Li et al. 2020). For this reason, the field experiments of the study were conducted on 11th October 2021 on a sunny day during the autumn season. On this day, the average daily mean and maximum temperature were 6-7°C higher than the monthly normal in Ankara. The field measurements were conducted between 15:00 and 16:30, symbolic of the end of the hotter hours of the day, and the period in which the local surface receives and absorbs heat at a greater rate than it can radiate it back to the encircling atmosphere, depending on cloud cover and wind speed. It presents the period with increased vulnerability to indoor temperatures within naturally ventilated buildings in Ankara (Nouri et al., 2021b).

3.4. Instruments

This study employed experimental research, questionnaires, and a cognitive task in the process of the field experiment. In this study, the thermal environmental condition of selected outdoor spaces was measured through *in-situ* portable trackers for microclimatic measurements (Appendix D), and PET was calculated through the software RayMan Pro for a quantitative thermal comfort approach. Subsequently, a questionnaire survey on human thermal responses for qualitative thermal comfort approach in both outdoor and indoor contexts (Appendix E), and a cognitive performance task, d2 test of attention, to evaluate cognitive performance of university students with a different experience of outdoor microclimatic conditions were used within the field experiment (Appendix F).

3.4.1. Quantitative Approach Measurement

This study used a quantitative approach to quantify microclimatic parameters of chosen experiment areas in order to analyse the thermo-physiological aspect of thermal comfort in the human bio-meteorological system. As presented in Table 1, *in-situ* outdoor (POI 1 and POI 2) and indoor (Classroom 1 and Classroom 2) measurements of four singular microclimatic variables were measured through the use of the portable Kestrel Heat Stress (KHS) trackers with the temporal resolution of 1-min at a 1.1 m height, which is the centre of gravity of the human body for standing subjects (ISO, 1998; Kuttler, 2000) to process into the Energy Balance Model (EBM) index (Höppe 1984, 1994) within this study. The four variables retrieved from *in-situ* $KHS_{O}/_{I}$ were Ta_{OUT} / Ta_{IN}, Tg_{OUT} / Tg_{OUT}, V_{OUT} / V_{IN}, and RH_{OUT} / RH_{IN}. These variables were chosen for this study because of their relevance in determining the thermophysiological influence on the human bio-meteorological system in light of retrieved environmental conditions. Furthermore, these singular variables provide a comprehensive understanding of the association to human thermoregulation dynamics and the approach to the human body (Nouri, Charalampopoulos, & Matzarakis, 2018). Specifically, two KESTREL 5400HS were used to measure these variables in the selected outdoor and indoor settings (Table 2). The real-time data logs from these portable trackers were wirelessly transferred through the use of the Kestrel LiNK application.

Table 2. Outdoor and indoor variable collection of in-situ measurements for study | Source: Author's table.

	Outdoor Collection Methodology				**Indoor Collection Methodology**	
Data Typology	*In-situ*		*In-situ*		*In-situ*	
Data Resolution	1 minute		1 minute		1 minute	
Station & Variable	KHS_{OUT}		KHS_{OUT}		KHS_{IN}	
	Var.	Unit	Var	Unit	Var	Unit
Study Part	Ta_{O}	[°C]	Ta_{O}	[°C]	Ta_{I}	[°C]
	Tg_{O}	[°C]	Tg_{O}	[°C]	Tg_{I}	[°C]
	V_{O}	[m/s]	V_{O}	[m/s]	V_{I}	[m/s]
	RH_{O}	[%]	RH_{O}	[%]	RH_{I}	[%]

In addition to these four preliminary microclimatic variables, $Tmrt_{OUT}$ / $Tmrt_{IN}$, which is used to measure the radiation fluxes was calculated in outdoor and indoor measurement sites. Outdoor/indoor Grad ($Grad_{IN}$ / $Grad_{OUT}$), was also retrieved from the handheld apparatus KKMOON SM206 to gather the highest values in outdoor and indoor measurement sites. In addition, outdoor/indoor Tsurf ($Tsurf_{OUT}$/$Tsurf_{IN}$) in POIs and classrooms were retrieved from the handheld apparatus BENETECH GM550. A 10-meter diameter was allowed to retrieve all of the temperatures of surrounding surfaces. The specifications of the equipment are presented in Table 3.

Table 3. Equipment specification used for the field study | Source: Author's table.

	Equipment Name and Model	Parameter	Unit	Accuracy	Resolution
Outdoor and Indoor	Kestrel 5400HS	Air temperature	°C	±0.5 °C	0.1 °C
		Globe temperature	°C	±1.4 °C	0.1 °C
		Relative humidity	%	±2%RH	0.1 %RH
		Wind speed	m/s	±3% (Larger of 3 % of reading)	0.1 m/s
	Kkmoon Sm206	Global radiation	W/m²	±10	0.1W/m²
Outdoor	Benetech Gm 550	Surface temperature	°C	1.5%	0.1°C

The study referred to the EBM index within the urban and interior contexts to determine the effects of the thermal condition on the human body. PET index (Mayer and Höppe 1987; Matzarakis et al. 1999), based upon the Munich Energy-balance Model for individuals (MEMI) (Höppe 1993, 1999) was considered an appropriate thermal index for thermo-physiological analysis in this study. EBM stress classification including the PET presented the most effective indices relevant in terms of the body-atmosphere balance (de Freitas & Grigorieva, 2017). Additionally, its unit (°C) makes results more apprehensible (Matzarakis et al., 1999). To state human Physiological Stress (PS) thresholds as identified by Matzarakis et al. (1999), the PET was calculated using the biometeorological model RayMan Pro © (Fröhlich et al., 2019; Matzarakis, Rutz, & Mayer, 2006, 2007, 2010; Matzarakis & Fröhlich, 2018). Based upon MEMI, Ta_{OUT} / Ta_{IN}, V_{OUT} / V_{IN}, and RH_{OUT} / RH_{IN}, were retrieved from the in-situ $KHS_{OUT}/_{IN}$. In addition to these variables, to calculate the PET index, $Tmrt_{OUT}$ / $Tmrt_{IN}$ was calculated through Tg_{OUT} / Tg_{IN}, retrieved from *in-situ* $KHS_{OUT}/_{IN}$, based on the following equation from the ISO 7726 standard (ISO, 1998) in order to relate it to the qualitative measurement of SR because of its comprehensive results for the PET calculation instead of $Grad_{OUT}/Grad_{IN}$:

$$\mathrm{Tmrt_{IN}} = \left[(\mathrm{Tg_{IN}} + 273)^4 + \frac{0.25 \times 10^8}{\varepsilon}\left(\frac{|\mathrm{Tg_{IN}} - \mathrm{Ta_{IN}}|}{D}\right)^{1/4} \times (\mathrm{Tg_{IN}} - \mathrm{Ta_{IN}})\right]^{1/4} - 273$$

and

$$\mathrm{Tmrt_{OUT}} = \left[(\mathrm{Tg_{OUT}} + 273)^4 + \frac{0.25 \times 10^8}{\varepsilon}\left(\frac{|\mathrm{Tg_{OUT}} - \mathrm{Ta_{OUT}}|}{D}\right)^{1/4} \times (\mathrm{Tg_{OUT}} - \mathrm{Ta_{OUT}})\right]^{1/4} - 273$$

where D is the globe diameter (0.025 in this study) and ε is its emissivity (0.95 for a black globe). Furthermore, a comparative chart was used to identify the PS grade (Table 4).

Table 4. Ranges of the Physiologically Equivalent Temperature (PET) for different grades of thermal perception and Physiological Stress (PS) on human beings; internal heat production: 80W, heat transfer resistance of the clothing: 0.9 clo, according to the authors (Matzarakis & Mayer, 1997) Source: adapted from the authors (Matzarakis et al., 1999).

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

3.4.2. Qualitative Approach Measurement

This section was aimed at determining psychological and behavioural aspects of thermal adaptation as a qualitative approach to thermal comfort that could support to complement the thermo-physiological analysis on the basis of similar studies (e.g. Abdallah et al., 2020; Hadianpour, Mahdavinejad, Bemanian, & Nasrollahi, 2018; Othman, Zaki, Rijal, Ahmad, & Razak, 2021; Wang et al., 2017). In the field experiment, separate thermal comfort questionnaire surveys for outdoor and indoor environments were distributed to 58 university students, and a total of 116 questionnaires, including 58 for outdoor environments, and 58 for indoor environments were collected within the study. 50 questionnaires were collected from the participants with experience POI 1, and 66 questionnaires from the participants with experience POI 2. The questionnaire surveys consisted of three major sections of questions:

The first section of the questionnaire survey gathered the demographical information of the participants. It included information on gender, age, nationality, residency duration in Ankara, and their location in outdoor environment in terms of being in a shaded or sun-exposed outdoor space. In addition, the clothing insulation of the participants was asked within this section, based upon ASHRAE Standard 55 (2010).

The second section asked participants to rate their current thermal responses. Overall thermal comfort vote (OTCV) was asked, using a four-level scale (Comfortable, slightly comfortable, slightly uncomfortable, comfortable) instead of the three-level scale used in the previous studies (Chen et al., 2015; Zhang, de Dear, & Hancock, 2019). Furthermore, this section also included the sensation, preference, and comfort votes of participants for Ta, *V*, and SR. Based on ASHRAE Standard 55 (ASHRAE Standard 55, 2010), Air Temperature Sensation Vote (ATSV) was evaluated on a seven-point scale (-3, cold; –2, cool; -1, slightly cool; 0, neutral; 1, slightly warm; 2, warm; 3, hot), which was the same scale used in Thermal Sensation Vote (TSV) in the previous studies (Mishra, Derks, Kooi, Loomans, & Kort, 2017; Wang et al., 2017). Similar to the study (Chen et al., 2015) Air Temperature Preference Vote (ATPV) was rated on a five-point scale (much colder, a bit colder, no change, a bit warmer, much warmer). Wind Speed and Solar Radiation Sensation Vote (WSSV and SRSV, respectively) were rated on a seven-point scale (Very low/Very weak, Low/Weak, Slightly low/Slightly weak, Neutral, Slightly high/Slightly strong, High/Strong, Very high/Very strong) instead of a five-point scale used in the studies (Abdallah et al., 2020; Othman et al., 2021). For evaluation of Wind Speed and Solar Radiation Preference Vote (WSPV, and SRPV, respectively), a five-point scale was used (Lower/Weaker, A bit lower/A bit weaker, No change, A bit higher/A bit stronger, Higher/Stronger) as similar to previous studies (Abdallah et al., 2020; Chen et al., 2015). The comfort vote for Ta, *V*, and SR (ATCV, WSCV, and SRCV, respectively) was evaluated using Yes/No answers.

The third section was designed to analyse the behavioural aspect of thermal adaptation in outdoor spaces with different shading levels, and also in indoor spaces. Instead of asking all types of adaptive behaviours under the main question as seen in the previous studies (e.g. Chen et al., 2015; Lin, 2009; Trebilcock, Soto-Muñoz, Yañez, & Figueroa-San Martin, 2017), this study divided adaptive behaviours into two parts, based upon changing their location (e.g. being in a more shaded location) and adjusting their own thermal state (e.g. taking off some clothing), and asked the participant into two forms of questions in the questionnaire.

In this study, the first section of the questionnaire was only answered in outdoor environments. Moreover, the second and third sections of the questionnaire survey were used in both outdoor and indoor parts of the questionnaire. Yet, the only difference between outdoor and indoor surveys was that in SR questions, the only thermal response asked to rate from the participants was their solar radiation preference in indoor space, whereas solar sensation, preference, and comfort were all rated in outdoor spaces.

3.4.3. Cognitive Performance: d2 Test of Attention

In this study, the standard version of the d2 Test of Attention was used to measure the cognitive performance of students because of its assessed construct and convergent validity (Bates & Lemay, 2004). The d2 is a one-page paper-pencil-based and time-limited test. The test aims at evaluating concentration and sustained attention (Brickenkamp & Zillmer 1998). The d2 test includes 14 lines with 47 characters, 658 in total. These stimuli contain the letters ‘d’ or ‘p’ with marks above and/or below. Yet, there are three targets in the stimuli: the letter ‘d’ with two marks above it, two marks below it, or one mark above while another below. It is required participants to make the cancelation with a cross (/) of the maximum number of target items (Brickenkamp, 1962; Brickenkamp & Zillmer, 1998; Culbertson & Sari, 1997). Participants have available 20 seconds for each line in which the researcher commands them to change the line to start the next line. The test was performed individually within this study, even though it has a possibility to be performed in groups.

As presented in Table 5, scoring of the d2 test of attention includes the following several measures of performance: (1) total number of items processed (TN); (2) errors of omission (E1); (3) errors of commission (E2); (4) total number of errors (E); (5) percentage of errors (E%); (6) a total number of items scanned minus the error (TN-E); (7) concentration performance (CP), and (8) the fluctuation rate (FR) (Brickenkamp & Zillmer, 1998) (Table 3). Similar to studies (e.g. Bektaş, 2019; Culbertson & Sari, 1997; da Silva-Sauer, Garcia, Ehrich de Moura, & Fernández-Calvo, 2022; Woo et al., 2022), the following parameters of the d2 test of attention were utilised within this study: TN, E%, TN-E, CP, and FR.

Table 5. The descriptions of the d2 test of attention parameters | Source: Author's table.

Abbreviations[1]	**Description of measures**	**Computation**[2]	**Cognitive measures Evaluated**[3]
TN	Total number of characters processed	Sum of number of characters processed before the final cancellation on each trial	Scanning speed
E %	Percent of errors	Total number of errors divided by the total number of characters processed	Selective scanning/ processing accuracy
TN-E	Total correctly processed	Total characters processed minus total errors made	Scanning/processing speed and accuracy to determine overall performance
CP	Concentration performance	Total number of correctly canceled minus total number incorrectly canceled	Scanning/processing speed
FR	Fluctuation rate	Maximum total items processed in a trial minus minimum total items processed in a trial	Variation in scanning/ processing speed

[1]Abbreviations used in the manual of the first USA edition (Brickenkamp & Zillmer, 1998)

[2] Brickenkamp & Zillmer, 1998

[3] Brickenkamp & Zillmer, 1998; Sinha, Bowers, & Woods, 2018

3.5. Procedure of the Study

In order to answer the research questions and test the proposed hypotheses of this study, the following experimental procedure was designed for this study (Figure 4).

The study consisted of two exposure periods, which were outdoor and indoor exposure periods. At first, the subjects were divided into 2 groups, expressed as Grp 1 and Grp 2, based upon their classroom environments, to experience either POI 1 or POI 2. In the outdoor exposure period, Grp 1 was exposed to POI 1 for 15 minutes, while Grp 2 was told to spend 15 minutes in POI 2 because of considered ~ 15-20 minutes as an appropriate thermal adaptation phase of the body to reach a steady-state (Arens, Zhang, & Huizeng, 2006; Goto & Toftum, 2002; Mishra et al., 2017; Wu & Mahdavis 2014). Based upon adaptive thermal comfort theory, an individual's perception of thermal comfort is impacted by an individual's recent thermal experience (Brager & de Dear, 1998). For this reason, the complementary subjective outdoor thermal comfort questionnaire was distributed to fill in to record their outdoor thermal perception with regard to analysing the impacts of experiencing different shading levels, after the adaptation phase to the exposed outdoor spaces.

Upon completing the outdoor questionnaire, Grp 1 and Grp 2 were told to move to the classroom environment for an indoor exposure period, and spend 15 minutes in their classrooms as a thermal adaptation phase. In order to evaluate indoor thermal perception based upon experienced outdoor shading levels and cognitive performance, a complementary subjective indoor thermal comfort questionnaire was then filled in classrooms and completed the d2 test of attention (for approximately 5 minutes), respectively. Outdoor and indoor microclimatic variables were measured during outdoor and indoor exposure periods, and filling in questionnaires surveys and d2 test of attention.

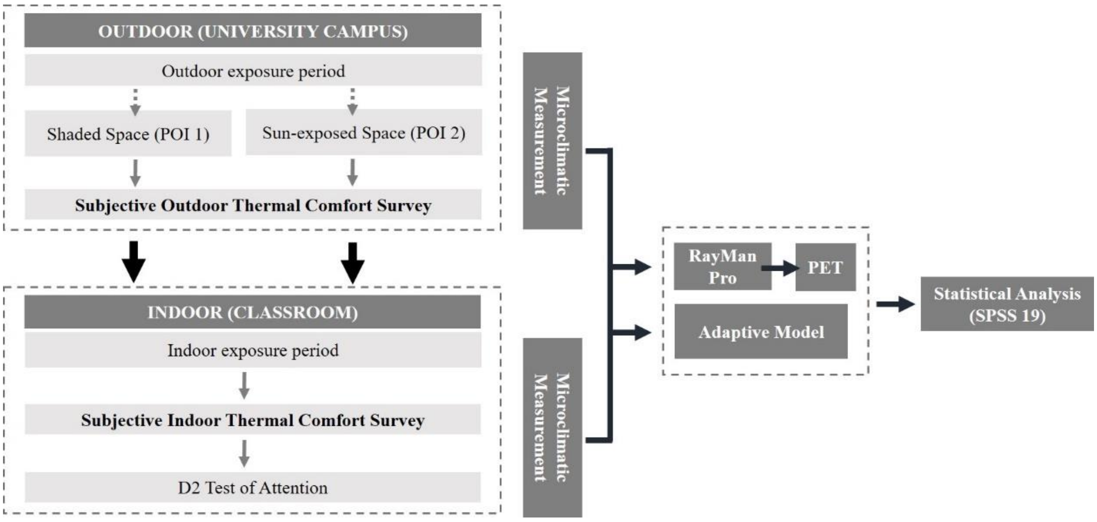

Figure 4. Experimental procedure of the study | Source: Author's figure.

CHAPTER 4

RESULTS

This chapter of the thesis represents the results and the statistical analysis of the data obtained for this study. The results obtained from the questionnaire surveys were analysed using IBM Statistical Package for the Social Sciences (SPSS) 19 Software. Distributions with a percentage of demographic information, thermal responses, and descriptive statistics of quantitative data, PET, and thermal responses were analysed. Subsequently, to interpret the results obtained from *in-situ* $KHS_{OUT}/_{IN}$ and the KKMOON SM206, the table indicates the mean, minimum and maximum values for measured microclimatic parameters in each site, and Climate-Tourism/Transfer-Information-Scheme (CTIS) (Matzarakis, 2014) were used in the study.

Similar to studies (e.g. Chen et al., 2018; Sharmin, Steemers, & Humphreys, 2019; Wang et al., 2018; Wang et al., 2017; Yang et al., 2013), because thermal response votes were recorded at the ordinal scale, the correlation among thermal responses votes, including OTCV, Ta, *V*, SR sensation, preference, and comfort, and also a correlation of d2 test of attention parameters with outdoor thermal responses were determined by applying Spearman's rho correlation test, which is the measure of a relationship between two variables in terms of the strength and direction (Argyrous, 1997), in POIs and classroom contexts. Afterward, an independent *t*-test analysis was conducted to compare the cognitive performance of students with different outdoor space experiences because the two groups under comparison are independent of each other, as in the previous studies (e.g. Liu, Jia, Cen, Ma, & Liu, 2020; Luo et al., 2016). The test was also used for parameters of the d2 test of attention to analyse differences in cognitive performance among groups with experience of different outdoor shading levels.

4.1. Demographic Findings

The data collected by the questionnaire were statistically analysed to determine several thermal comfort parameters and demographic information concerning the participants. The mean age of the participants was 21 years old with a standard deviation of 1.1 years. Most participants were university students in the age groups of 20-22 years old (84.0%), 18-19 years old (7.0%), and 23 years old (9.0%). Of twenty-five participants with experience of POI 1, 88.0% of them were females, and 12% of them were male. Of thirty-three participants with experience of POI 2, 63.6% of them were female, while 36.4% of them were male. Overall, among the participants 74.1% of the participants were female and 25.9% were male.

The results regarding the nationality of the participants indicated that, in overall, 48.3% of the participants were from Ankara, Turkey. There were not found any non-Turkish participants, and the amount of the participants from different cities in Turkey was distributed almost equally. Moreover, the mean residence time of the participants in Ankara was 12.9 years with a standard deviation of 8.4 years.

4.2. Quantitative Approach Analyses

4.2.1. Microclimatic Parameters in POIs and Classrooms

The microclimatic parameters in selected environments were measured to evaluate physiological aspects of thermal comfort. As seen in Figure 5 and Table 6, during the measurement period, Ta demonstrated a large difference between POI 1 and POI 2, as well as POI 2 and classrooms. Ta_{OUT} in POI 2 (Ta_{OUT}POI 2) was higher with a mean of 26.5°C in comparison to Ta_{OUT} in POI 1 (Ta_{OUT}POI 1) (21.2°C), Classroom 1 (22.5°C), and Classroom 2 (24.0°C). Additionally, there was a large difference in the mean *V* between POI 1 and POI 2, POI 1 and classrooms. V_{OUT} in POI 1 (V_{OUT}POI 1) revealed the highest mean value equating to 1.0 m/s. The measured RH patterns presented that the mean RH was almost the same in RH_{OUT} in POI 1 (RH_{OUT}POI 1) (41.0%), RH_{OUT} in POI 2 (RH_{OUT}POI 2) (34.0%), Classroom 1 (35.0%), and Classroom 2 (33.1%). The recording of Tg during measurement periods presented a great variation both between POI 1 and POI 2, and between POI 2 and classrooms. The highest mean Tg was recorded in Tg_{OUT} in POI 2 (Tg_{OUT}POI 2) (35.3°C) in comparison to Tg_{OUT} in POI 1 (Tg_{OUT}POI 1) (20.2°C), Classroom 1 (22.4°C), and Classroom 2 (22.5°C). Subsequently, the variation in Tmrt was large between POI 1 and POI 2, and POI 1 and classrooms. The $Tmrt_{OUT}$ in POI 2 ($Tmrt_{OUT}$POI 2) had the highest mean value with 43.4°C in comparison to $Tmrt_{OUT}$ in POI 1 ($Tmrt_{OUT}$POI 1) (22.0°C), Classroom 1 (22.4°C), and Classroom 2 (21.4°C).

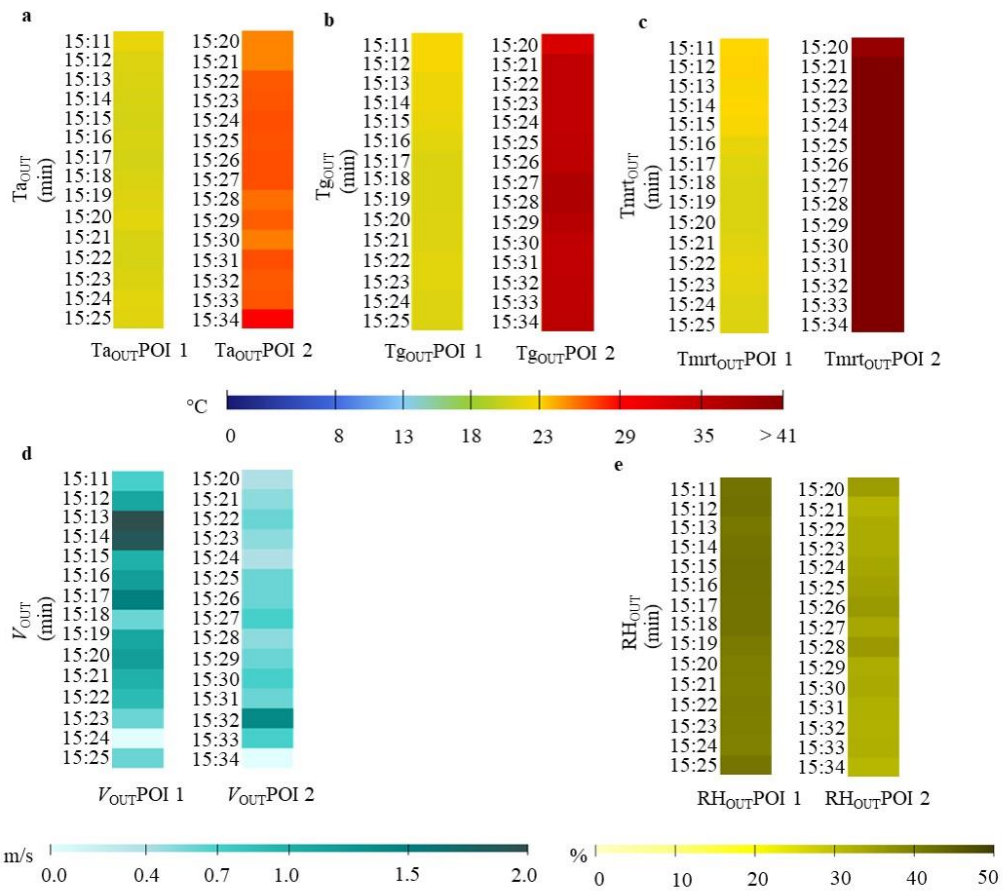

Figure 5. Variation results obtained from KHS_{OUT} between 15:11-15:20 for POI 1 and 15:19-15:34 for POI 2: (a) – Air Temperature, (b) – Globe Temperature, (c) – Mean Radiant Temperature, (d) – Wind Speed, and (e) – Relative Humidity. | Source from Author's chart.

Ta_{OUT}, outdoor air temperature; *$Ta_{OUT}POI$ 1*, outdoor air temperature in POI 1; *$Ta_{OUT}POI$ 2*, outdoor air temperature in POI 2; *Tg_{OUT},* outdoor globe temperature; *$Tg_{OUT}POI$ 1*, outdoor globe temperature in POI 1; *$Tg_{OUT}POI$ 2*, outdoor globe temperature in POI 2; *RH_{OUT},* outdoor relative humidity; *$RH_{OUT}POI$ 1*, outdoor relative humidity in POI 1; *$RH_{OUT}POI$ 2*, outdoor relative humidity in POI 2; *V_{OUT},* outdoor wind speed; *$V_{OUT}POI$ 1*, outdoor windspeed in POI 1; *$V_{OUT}POI$ 2*, outdoor wind speed in POI 2

Table 6. Mean results obtained from KHS in the POIs and classrooms during the measure periods | Source from Author's tables.

		POI 1 (shaded)	POI 2 (sun-exposed)	Classroom 1	Classroom 2
Ta (°C)	Mean	21.2	26.5	22.5	24.0
	Min.	20.9	25.3	22.2	23.1
	Max.	22.0	29.0	22.8	25.7

Table 6 (cont'd)

		POI 1 (shaded)	POI 2 (sun-exposed)	Classroom 1	Classroom 2
***V* (m/s)**	Mean	1.05	0.5	0.0	0.0
	Min.	0.0	0.0	0.0	0.0
	Max.	2.0	1.4	0.0	0.0
RH (%)	Min.	0.0	0.0	0.0	0.0
	Max.	2.0	1.4	0.0	0.0
	Max.	42.3	35.8	38.1	35.0
Tg (°C)	Mean	21.7	35.3	22.4	22.5
	Min.	21.3	35.1	22.0	22.2
	Max.	22.7	37.0	22.6	23.6
Tmrt (°C)	Mean	22.0	43.4	22.4	21.4
	Min.	21.3	39.1	21.9	19.3
	Max.	23.6	47.6	22.6	21.8
Grad (W/m²)		0.9	941	0.3	0.3

Ta, air temperature; *Tg*, globe temperature; *RH*, relative humidity; *V*, wind speed; *Tmrt*, mean radiant temperature

Subsequently, the variation in Grad was considerable between POI 1 and POI 2, and POI 2 and classrooms. The respective mean Grad in POI 2 had the highest value with 941 W/m², in comparison to POI 1 (0.9 W/m²), and classrooms (0.3 W/m²) (Table 4). As seen in Table 7, in POI 1, there were 2 different surface materials, which are granite and marble. Tsurf of granite ranged from 12.6°C to 13.2°C, and Tsurf of marble was 13.9°C. In POI 2, there were granite and cast iron in the manhole around the site. Tsurf of granite and manhole were 26.3°C, and 27.2°C, respectively. In the classrooms, Tsurf of granite was 20.0°C.

Table 7. Results of Tsurf of materials in site measurements | Source: Author's table.

	POI 1	POI 2	Classroom 1	Classroom 2
	Tsurf (°C)	**Tsurf (°C)**	**Tsurf (°C)**	**Tsurf (°C)**
Limestone	–	–	–	–
Granite	12.6 – 13.2	26.3	20.0	20.0
Marble	13.9	–	–	–
Cast iron	–	27.2	–	–

4.2.2. Thermal Comfort Analysis through the PET Index

To figure out the impacts of the identified microclimatic variables on the human biometeorological system, PET was determined by the corresponding meteorological parameters within POIs, and classrooms, with determining the metabolic rate of the participants 0.9 clo and 80 W in the RayMan model to analyse the human biometeorological system's response to the given microclimatic factors (Matzarakis et al., 2007). To assess the physiological stress levels in each POI and classroom during corresponding measurement periods, Figure 6 indicated the variation of Ta and PET values in POIs. Subsequently, in comparison to the physiological stress grades shown in Table 4, it was shown that the hottest PET value and physiological stress grade was varied in POI 2, with the mean PET equating to 33.2℃, resulting in 'Moderate Heat Stress.' Additionally, the lowest mean PET value and physiological stress grade was revealed in POI 1 with the mean PET equating to 18.7℃, indicating 'No Thermal Stress'. Classroom 1 and Classroom 2 resulted in-between 'No Thermal Stress' and 'Slight Heat Stress', with the mean PET value equating to 23.0℃, and 23.2℃, respectively.

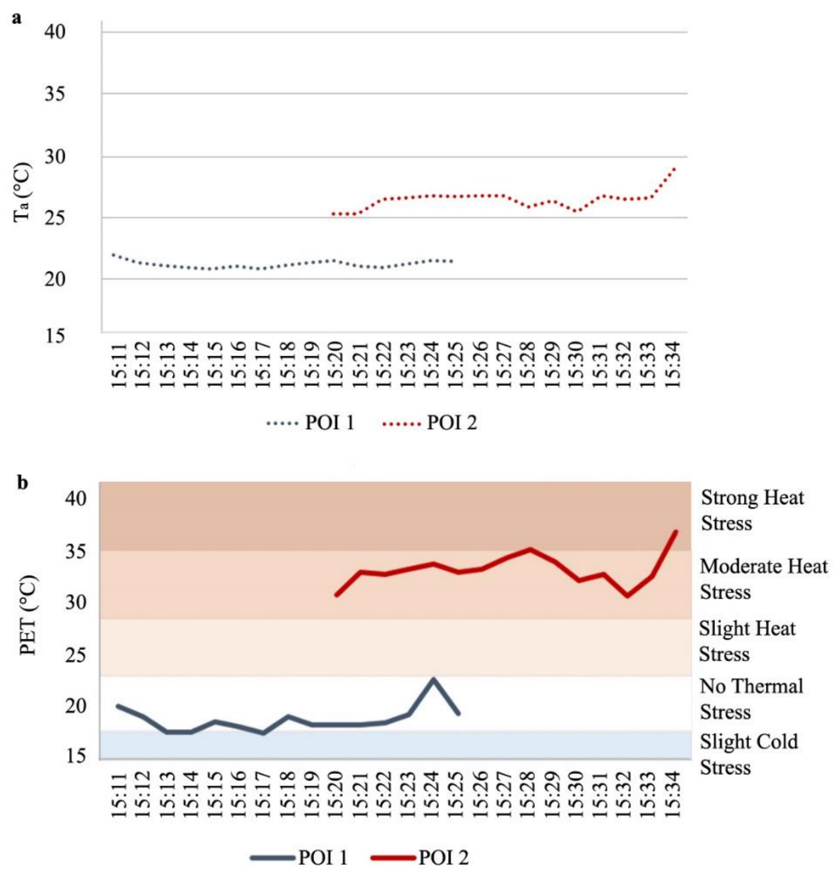

Figure 6. Variation of PET and physiological stress grades in POIs | Source: Author's graph.

4.3. Qualitative Approach Analyses with Subjective Thermal Responses

In order to understand the qualitative approach of thermal comfort with subjective thermal responses of students in the different environments, distributions with a percentage were analysed for OTCV, sensation, preference, and comfort votes of Ta, *V*, and SR in POIs, and classrooms. The distributions for each parameter were represented by illustrated bar charts. Furthermore, the correlation analysis among outdoor thermal responses, and between outdoor and indoor thermal responses was demonstrated to evaluate the qualitative approach to thermal comfort within this section.

4.3.1. Overall Thermal Comfort

As shown in Figure 7, according to the results retrieved from the questionnaire for demonstrating OTCV in POIs, 48% of students in POI 1 claimed outdoor OTCV ($OTCV_{OUT}$) condition is ‘slightly uncomfortable.’ On the other hand, the total percentage of ‘slightly comfortable’ and ‘comfortable’ votes were almost equal to ‘slightly uncomfortable’ votes. Subsequently, the votes of students in POI 2 were almost equally distributed between ‘slightly uncomfortable’ (31.3%), and ‘uncomfortable’ (28.1%). With regard to the indoor contexts, the majority of students in Grp 1 declared indoor OTCV ($OTCV_{IN}$) ‘comfortable’ (54.2%), while the votes of ‘comfortable’ (46.9%), and ‘slightly comfortable’ (43.8%) were almost equal percentages in Grp 2.

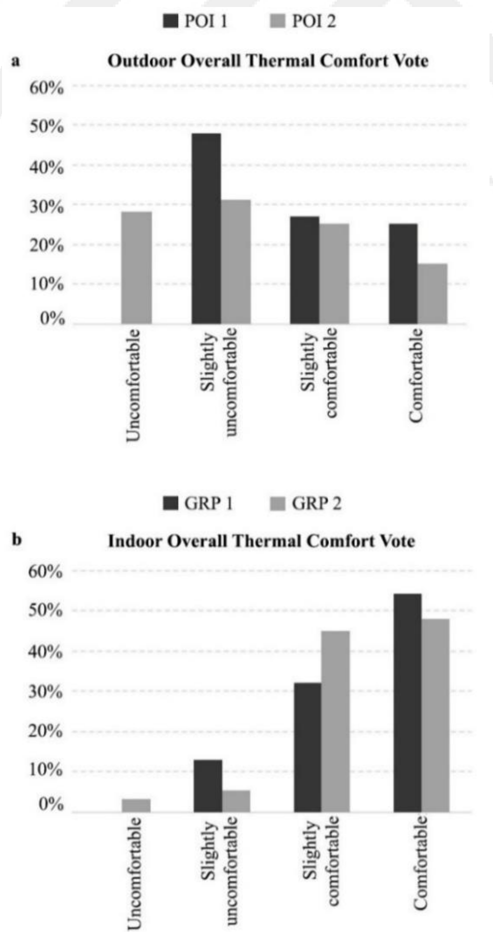

Figure 7. Distribution analysis of outdoor and indoor thermal responses for (a) outdoor, and (b) indoor | Source from Author’s charts.

4.3.2. Air Temperature

Figure 8 indicated the participant's data for outdoor ATSV ($ATSV_{OUT}$), ATPV ($ATPV_{OUT}$), and ATCV ($ATCV_{OUT}$) involved in the questionnaire in POI 1 and POI 2. The questionnaire results demonstrated a significant difference among POIs. In $ATSV_{OUT}$, the highest percentage was allocated to the students in POI 1 who voted 'slightly cool' (36.0%), 'cool' (32.0%), and 'neutral' (28.0%). However, in POI 2, most students voted they felt 'slightly warm' (33.3%), 'warm' (30.3%), and 'hot' (24.2%). Thus, it indicated that the majority of votes in POI 1 were clustered between the 'neutral' and 'cool' side of the scale, while on the 'warm' side in POI 2. Furthermore, in terms of $ATPV_{OUT}$, students who voted 'a bit warmer' (64.0%) represented the largest group in POI 1, while most students voted 'a bit colder' (67.7%) in POI 2 to have a better microclimatic condition. With regard to the question about $ATCV_{OUT}$, 76.0% of the students in POI 1 voted 'yes', while the majority of the students (66.7%) in POI 2 voted 'no'.

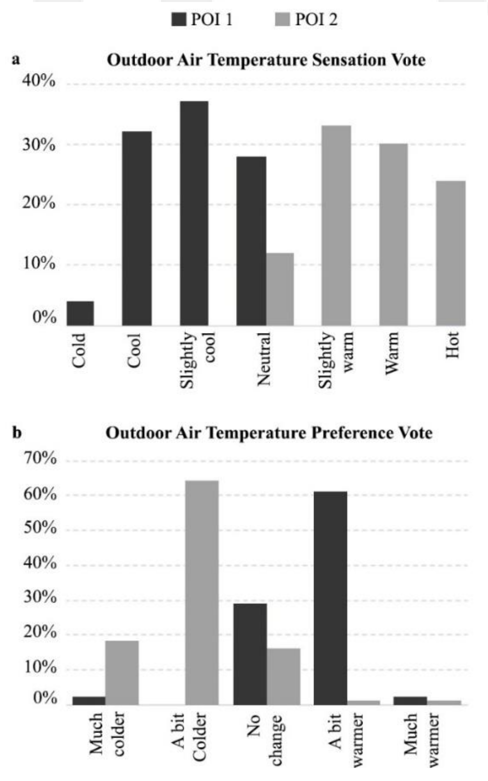

Figure 8. Distribution analysis of outdoor thermal responses of Ta: (a) ATSV, and (b) ATPV | Source from Author's charts.

After experiencing POI 1 and POI 2, participants were asked to answer their indoor ATSV ($ATSV_{IN}$), ATPV ($ATPV_{IN}$), and ATCV ($ATCV_{IN}$) in classrooms. In $ATSV_{IN}$, the percentage of 'neutral', represented the largest group in Grp 1 and Grp 2 and was higher in Grp 2 (54.5%) in comparison to Grp 1 (37.5%). Additionally, in $ATPV_{IN}$, the majority of votes in Grp 1 (50.0%), and Grp 2 (54.5%) were accumulated in 'no change'. Regarding $ATCV_{IN}$, the votes of 'yes' had the highest percentage in both Grp 1 (83.3%) and Grp 2 (87.9%) (Figure 9).

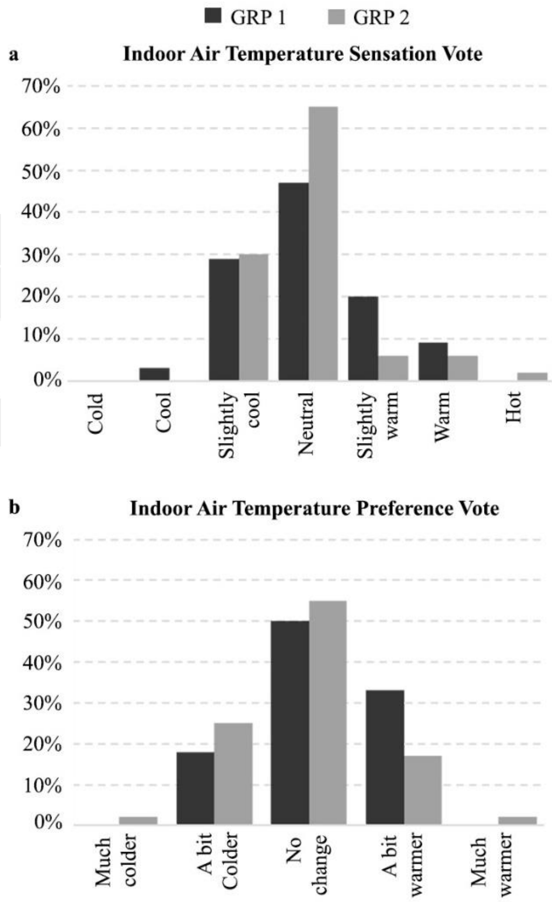

Figure 9. Distribution analysis of indoor thermal responses of Ta: (a) ATSV, and (b) ATPV | Source from Author's charts.

4.3.3. Wind Speed

As seen in Figure 10, in addition to Ta, the participants were questioned on the outdoor WSSV ($WSSV_{OUT}$), WSPV ($WSPV_{OUT}$), and WSCV ($WSCV_{OUT}$) in POIs. In $WSSV_{OUT}$, the greater percentage of students in POI 1 voted 'slightly high' (51.0%), while the votes were almost equally distributed between 'neutral' and 'very low' sides of the scale in POI 2. Subsequently, with regard to $WSPV_{OUT}$, 60.0% of students in POI 1 voted 'a bit lower' wind speed for a better condition, while the votes of 'no change' (45.5%) and 'a bit higher' (39.4%) indicated the highest proportion in comparison to the other votes. In $WSCV_{OUT}$, students who voted 'yes' represented the greatest group in both POI 1 and POI 2, being 56.0% and 69.7%, respectively.

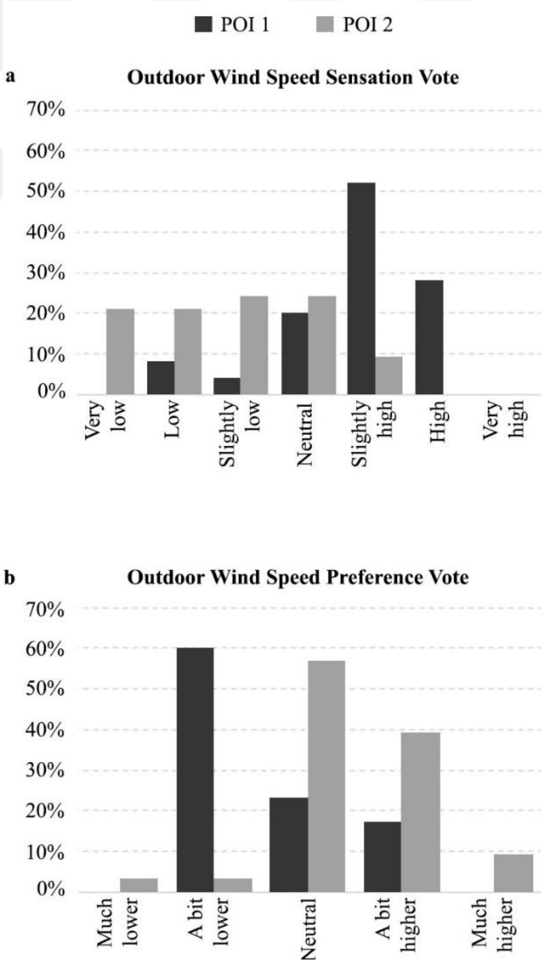

Figure 10. Distribution analysis of outdoor thermal responses for V: (a) WSSV, and (b) WSPV | Source from Author's charts.

With regards to the results retrieved from the classrooms, 62.5% of students in Grp 1 and 63.6% of students in Grp 2 declared the indoor WSSV ($WSSV_{IN}$) was 'neutral'. Moreover, in indoor WSPV ($WSPV_{IN}$), the percentage of 'no change', demonstrated the greatest group in both Grp 1 and Grp 2, was higher in Grp 1 (79.2%) than Grp 2 (56.3%). In terms of indoor WSCV ($WSCV_{IN}$), most students in Grp 1 and Grp 2 voted 'yes', being 83.3%, and 69.7%, respectively (Figure 11).

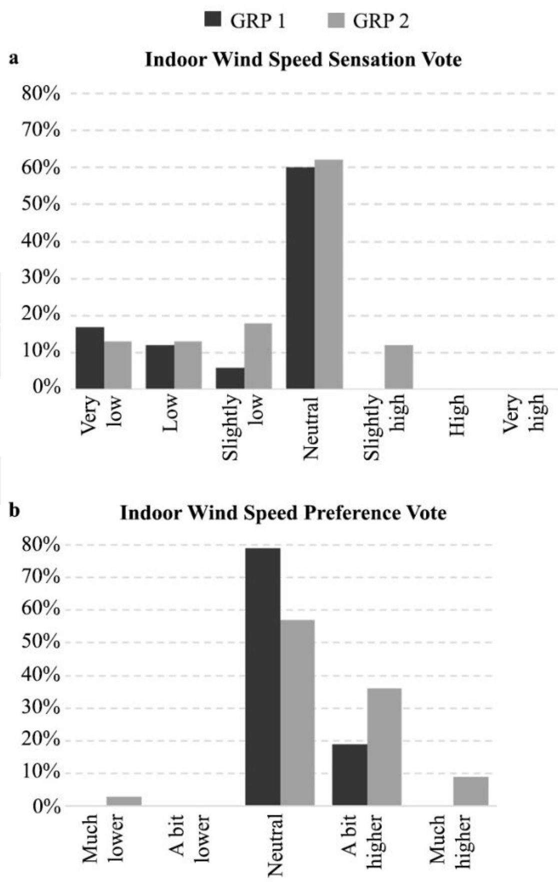

Figure 11. Distribution analysis of indoor thermal responses for V: (a) WSSV, and (b) WSPV | Source from Author's charts.

4.3.4. Solar Radiation

Figure 12 presented the participant's data on outdoor SRSV ($SRSV_{OUT}$), SRPV ($SRSPV_{OUT}$), and SRCV ($SRCV_{OUT}$) in POIs. Based upon the results, the responses to

SR were significantly different between POI 1 and POI 2. In $SRSV_{OUT}$, the majority of students in POI 1 accumulated 'weak' (68.0%), while the votes of students in POI 2 were almost equally distributed between 'slightly strong' (39.0%), and 'strong' (33.0%). With regard to $SRSPV_{OUT}$, 'a bit stronger' votes (60.0%) demonstrated the greatest percentage in POI 1, while the majority of students in POI 2 voted 'a bit weaker' (66.0%). Furthermore, in $SRCV_{OUT}$, most participants in POI 1 voted 'yes' (64.0%), while 'no' (66.0%) in POI 2.

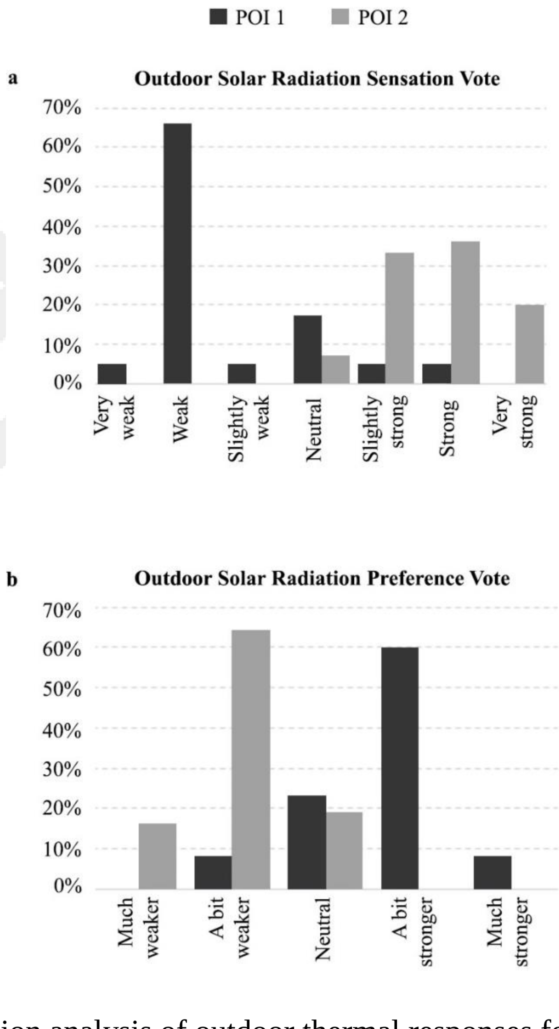

Figure 12. Distribution analysis of outdoor thermal responses for SR: (a) SRSV, and (b) SRPV | Source from Author's charts.

In the following phase of the study, participants were questioned about indoor SRPV ($SRPV_{IN}$) in classrooms after experiencing POI 1 and POI 2. The greatest percentage of Grp 1 (50.0%), and Grp 2 (61.0%) was distributed in the votes of 'no change'.

Almost half of the students in Grp 1, however, voted ‘a bit stronger’ with 42% (Figure 13).

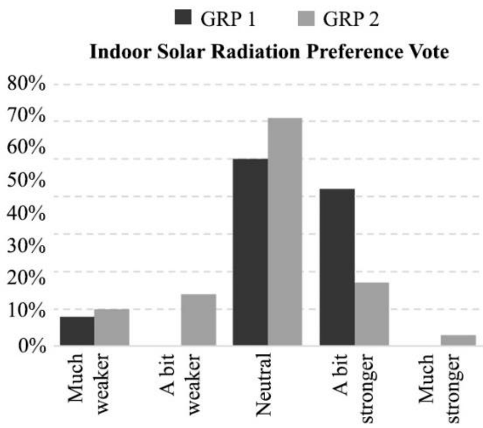

Figure 13. Distribution analysis of indoor thermal responses for SRPV | Source from Author’s chart.

4.3.5. Adaptive Behaviours

The questionnaire survey results of two types of adaptive behaviours in POIs are shown in Figure 14. According to the cross-tabulation analysis for Adaptive Behaviours (I) based upon adjusting thermal state, ‘having a hot/cold drink’ (48.0%) and ‘taking off some clothing’ (51.5%) were considered the most voted behavioural adaptive measure to improve current thermal comfort in POI 1 and POI 2, respectively, but the proportion was relatively close to ‘having a hot/cold drink’ (45.5%) in POI 2. With regards to the results retrieved for Adaptive Behaviours (II) identified as changing location, the majority of students in POI 1 and POI 2, claimed ‘being in a more sunny location’ (56.0%), and ‘being in a more shaded location’ (66.7%) as a dominant behaviour choice, respectively.

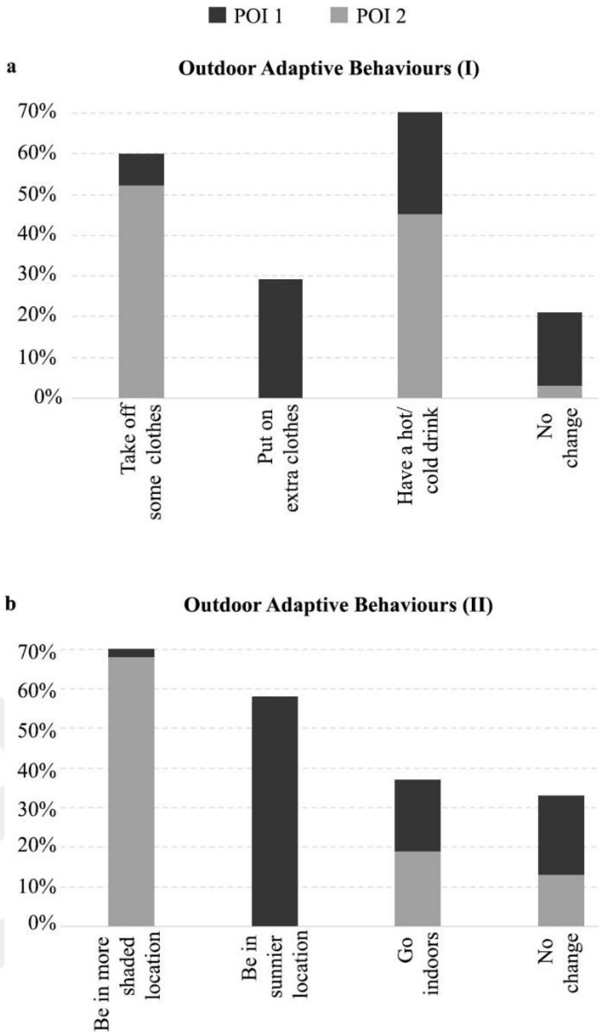

Figure 14. Distribution analysis of outdoor adaptive behaviours (I) and (II) in POIs | Source from Author's charts.

Moreover, in the following phase of the study, students were asked to choose behavioural preferences for adaptation in classrooms after experiencing POI 1 and POI 2. Based upon Adaptive Behaviours (I), the results revealed that 'opening windows' was the most preferred behavioural measure of students in Grp 1 (41.7%) and Grp 2 (36.4%). For Adaptive Behaviours (II), 'going outdoors' (33.3%), 'no changes' (33.3%), and 'being in more sunny location' (25.0%), were demonstrated almost equal distribution in Grp 1, while the majority of student in Grp 2 voted 'no change' (51.5%) in the classroom (Figure 15).

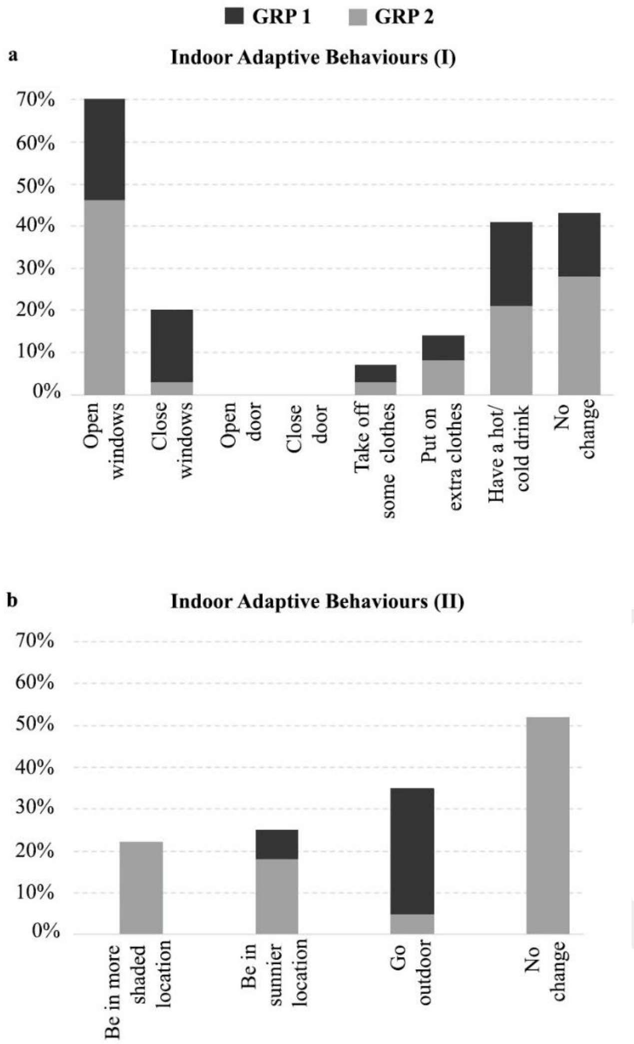

Figure 15. Distribution analysis of indoor adaptive behaviours (I) and (II) for Grp 1 and Grp 2 | Source from Author's charts.

4.3.6. Correlation Analysis among Outdoor Thermal Responses

4.3.6.1. Correlation among Sensation Votes

In order to evaluate the effects of outdoor thermal responses among each other, Table 8 represents the result of the Spearman correlation test among $ATSV_{OUT}$, $WSSV_{OUT}$, and $SRSV_{OUT}$ in POIs. It can be indicated that $WSSV_{OUT}$ as the only parameter significantly affecting $ATSV_{OUT}$ had a moderate negative correlation with ATSV ($r=-0.606$, $p < 0.05$) in POI 1, and $SRSV_{OUT}$ were not statistically correlated with

$ATSV_{OUT}$ ($p > 0.05$). This revealed that $ATSV_{OUT}$ tended to decrease with an increase in $WSSV_{OUT}$ at POI 1. On the other hand, based upon the corresponding results at POI 2, the only variable affecting $ATSV_{OUT}$ was $SRSV_{OUT}$ with a moderate positive correlation ($r=0.438$, $p < 0.05$), indicating that a higher $SRSV_{OUT}$ was associated with an increase in $ATSV_{OUT}$. Given that the strength in the effect of $WSSV_{OUT}$ in $ATSV_{OUT}$ in POI 1 was higher than $SRSV_{OUT}$ in POI 2.

4.3.6.2. Correlation between Overall Thermal Comfort and Sensation Votes

The correlation of $OTCV_{OUT}$ with $ATSV_{OUT}$, $WSSV_{OUT}$, and $SRSV_{OUT}$ was analysed in POIs. It can be seen in Table 8 that $ATSV_{OUT}$ showed the most significant influence on $OTCV_{OUT}$ in POI 1 with a moderate positive correlation ($r=0.627$, $p < 0.05$), followed by $WSSV_{OUT}$ ($r=-0.449$, $p < 0.05$), and $SRSV_{OUT}$ ($r=0.435$, $p < 0.05$). This indicated that $OTCV_{OUT}$ showed an increase with the increase of $ATSV_{OUT}$ and $SRSV_{OUT}$, as well as the decrease of $WSSV_{OUT}$. However, $OTCV_{OUT}$ in POI 2 was affected by only $ATSV_{OUT}$ and $SRSV_{OUT}$, with a correlation coefficient of, −0.531 and −0.442, respectively, while $WSSV_{OUT}$ did not have a significant influence on $OTCV_{OUT}$ ($p > 0.05$). This revealed that $OTCV_{OUT}$ tended to increase when $ATSV_{OUT}$ and $SRSV_{OUT}$ decreased.

Table 8. Correlation analysis among outdoor sensation responses and $OTCV_{OUT}$ | Source: Author's table.

		POI 1			**POI 2**		
		$ATSV_{OUT}$	$WSSV_{OUT}$	$SRSV_{OUT}$	$ATSV_{OUT}$	$WSSV_{OUT}$	$SRSV_{OUT}$
$ATSV_{OUT}$	Correlation Coefficient	1.00	-0.606**	0.205	1.00	-0.108	0.438*
	Sig. (2-tailed)	.	0.001	0.325	.	0.549	0.011
	N	25	25	25	33	33	33
$WSSV_{OUT}$	Correlation Coefficient	-0.606**	1.00	0.152	-0.108	1.00	-0.284
	Sig. (2-tailed)	0.001	.	0.469	0.549	.	0.110
	N	25	25	25	33	33	33

Table 8 (cont'd)

		POI 1			POI 2		
		$ATSV_{OUT}$	$WSSV_{OUT}$	$SRSV_{OUT}$	$ATSV_{OUT}$	$WSSV_{OUT}$	$SRSV_{OUT}$
$SRSV_{OUT}$	Correlation Coefficient	0.205	0.152	1.00	0.438*	-0.284	1.00
	Sig. (2-tailed)	0.325	0.469	.	0.011	0.110	.
	N	25	25	25	33	33	33
$OTCV_{OUT}$	Correlation Coefficient	0.627**	-0.449*	0.435*	-0.531**	-0.077	-0.442*
	Sig. (2-tailed)	0.001	0.024	0.030	0.002	0.677	0.011
	N	25	25	25	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

$ATSV_{OUT}$, outdoor air temperature sensation vote; $WSSV_{OUT}$, outdoor wind speed sensation vote; $SRSV_{OUT}$, outdoor solar radiation sensation vote; $OTCV_{OUT}$, outdoor overall thermal comfort vote.

4.3.6.3. Correlation between Overall Thermal Comfort and Comfort Votes

On the other hand, as seen in Table 9, the results of the correlation of $OTCV_{OUT}$ with $ATCV_{OUT}$, $WSCV_{OUT}$, and $SRCV_{OUT}$ indicated that $ATCV_{OUT}$ and $SRCV_{OUT}$ had a higher influence on $OTCV_{OUT}$ than $WSCV_{OUT}$ in POIs, with a correlation coefficient of 0.548, and 0.531 for POI 1, and 0.695, and 0.692 for POI 2, respectively. Considerably, these results also demonstrated that the effect of $ATCV_{OUT}$ and $SRCV_{OUT}$ in POI 1 was significantly higher than in POI 2.

Moreover, this study also analysed the correlations among $ATCV_{OUT}$, $WSCV_{OUT}$, and $SRCV_{OUT}$ in POIs in order to evaluate how much these parameters were related to one another. According to the results, $ATCV_{OUT}$ had a strong positive correlation with SRCV ($r=0.749$, $p < 0.05$), and a moderate positive correlation with $WSCV_{OUT}$ ($r=0.634$, $p < 0.05$) in POI 1. $WSCV_{OUT}$, however, was not statistically correlated with $SRCV_{OUT}$ in POI 1 ($p > 0.05$). These results show that $ATCV_{OUT}$ showed an increase with the increase of $SRCV_{OUT}$ and $WSCV_{OUT}$ in POI 1. With regard to the correlation in POI 2, the results show that $ATCV_{OUT}$ which was the only parameter have an effect on POI 2 had a strong correlation with $SRCV_{OUT}$ (r=0.861, $p < 0.05$), but a significant correlation was not found with $WSCV_{OUT}$ ($p > 0.05$). It can be indicated that only the increase of $SRCV_{OUT}$ lead to an improvement in $ATCV_{OUT}$ in POI 2.

Table 9. Correlation analysis between outdoor $OTCV_{OUT}$ and comfort votes | Source: Author's table.

		POI 1			**POI 2**		
		$ATCV_{OUT}$	$WSCV_{OUT}$	$SRCV_{OUT}$	$ATCV_{OUT}$	$WSCV_{OUT}$	$SRCV_{OUT}$
$OTCV_{OUT}$	Correlation Coefficient	0.548**	0.441*	0.531**	0.695**	0.394*	0.692**
	Sig. (2-tailed)	0.005	0.027	0.006	0.000	0.025	0.000
	N	25	25	25	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

$ATCV_{OUT}$, outdoor air temperature comfort vote; *$WSCV_{OUT}$*, outdoor wind speed comfort vote; *$SRCV_{OUT}$*, outdoor solar radiation comfort vote; *$OTCV_{OUT}$*, outdoor overall thermal comfort vote

4.3.6.4. Correlation between Sensation and Comfort Votes

Within the study, the correlation between sensation and comfort votes was evaluated in POIs (Table 10). The results of the correlation indicated that $ATSV_{OUT}$ was the only psychological measure that affected $ATCV_{OUT}$ in POIs, with a correlation coefficient of 0.500 in POI 1, and -0.553 in POI 2. It could be revealed from the result that $ATCV_{OUT}$ showed an increasing tendency when $ATSV_{OUT}$ increased in POI 1 and decreased in POI 2. Additionally, $WSCV_{OUT}$ in POI 1 was affected by $WSSV_{OUT}$ (r=-0.473) and followed by $ATSV_{OUT}$ (r=0.436), while $SRSV_{OUT}$ was the only variable affecting $WSCV_{OUT}$ in POI 2 with the correlation coefficient of -0.469. According to these results, $WSCV_{OUT}$ tended to increase with the increase of $ATSV_{OUT}$, and the decrease of $WSCV_{OUT}$ in POI 1, while the decrease of $SRSV_{OUT}$ in POI 2. With regards to $SRCV_{OUT}$, it was significantly correlated with $ATSV_{OUT}$ in POI 1 and POI 2, with a correlation coefficient of 0.512, and -0.480, respectively. In addition to $ATSV_{OUT}$, $SRSV_{OUT}$ also affected significantly $SRCV_{OUT}$ (r=0.504) in only POI 1. Therefore, it could be seen that $SRCV_{OUT}$ showed an increasing tendency when $ATSV_{OUT}$ and $SRSV_{OUT}$ increased in POI 1, and $ATSV_{OUT}$ decreased in POI 2.

Table 10. Correlation analysis between outdoor sensation and comfort votes | Source: Author's table.

		POI 1			**POI 2**		
		$ATCV_{OUT}$	$WSCV_{OUT}$	$SRCV_{OUT}$	$ATCV_{OUT}$	$WSCV_{OUT}$	$SRCV_{OUT}$
$ATSV_{OUT}$	Correlation Coefficient	0.500*	0.436*	0.512**	-0.553**	-0.112	-0.480**
	Sig. (2-tailed)	0.011	0.029	0.009	0.001	0.535	0.005
	N	25	25	25	33	33	33
$WSSV_{OUT}$	Correlation Coefficient	-0.289	-0.473*	-0.326	-0.194	0.302	-0.175
	Sig. (2-tailed)	0.161	0.017	0.111	0.280	0.088	0.338
	N	25	25	25	33	33	33
$SRSV_{OUT}$	Correlation Coefficient	0.283	-0.101	0.504*	-0.275	-0.469**	-0.189
	Sig. (2-tailed)	0.170	0.629	0.10	0.121	0.006	0.300
	N	25	25	25	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

$ATSV_{OUT}$, outdoor air temperature comfort vote; *$WSSV_{OUT}$*, outdoor wind speed comfort vote; *$SRSV_{OUT}$*, outdoor solar radiation comfort vote; *$ATCV_{OUT}$*, outdoor air temperature comfort vote; *$WSCV_{OUT}$*, outdoor wind speed comfort vote; *$SRCV_{OUT}$*, outdoor solar radiation comfort vote.

4.3.7. Correlation Analysis between Outdoor and Indoor Thermal Responses

In order to evaluate the impacts of outdoor thermal responses in POIs on indoor thermal responses of participants in a classroom environment based upon Grp 1 and Grp 2, Spearman’s correlation test was utilised. As seen in Table 11, the correlation analysis among sensation votes in Grp 1 indicates that $ATSV_{IN}$ showed only a significant relationship with $SRSV_{OUT}$, with a moderate positive correlation ($r=0.411$, $p < 0.05$). This revealed that $ATSV_{IN}$ tended to increase with the increase of $SRSV_{OUT}$. However, with regard to the correlation among sensation votes in Grp 2, $ATSV_{IN}$ significantly affected only outdoor ATSV (c), with a weak positive correlation ($r=0.379$, $p < 0.05$), indicating that $ATSV_{IN}$ had an increase when $ATSV_{OUT}$ increased.

Furthermore, $WSSV_{OUT}$ in Grp 1 was the only variable affecting $WSSV_{IN}$, with a moderate positive correlation ($r=0.427$, $p < 0.05$). Subsequently, based upon Grp 2, $ATSV_{OUT}$ showed the most significant correlation with $WSSV_{IN}$ with a correlation coefficient of -0.630, followed by $SRSV_{OUT}$ with a correlation coefficient of -0.442. With regards to these results, it can be demonstrated that $WSSV_{OUT}$ tended to increase with the increase of $WSSV_{IN}$ in Grp 1, while the decrease of $ATSV_{OUT}$ and $SRSV_{OUT}$ in Grp 2.

Within the study, the correlation between $OTCV_{IN}$ and outdoor sensation votes was also analysed based upon Grp 1 and Grp 2. $OTCV_{IN}$ did not show any correlation with $ATSV_{OUT}$, $WSSV_{OUT}$, and $SRSV_{OUT}$ ($p > 0.05$) in Grp 1, while the only variable affecting $OTCV_{IN}$ was $WSSV_{OUT}$ in Grp 2 with a correlation coefficient of 0.396. These results indicated that $OTCV_{IN}$ showed an increase with the increase of $WSSV_{OUT}$ in Grp 2 (Table 10). With regards to the correlation between sensation and comfort votes, the only correlation was found between $ATSV_{OUT}$ and $WSCV_{IN}$ in Grp 2 with a correlation coefficient of -0.383, while it was no found a correlation in Grp 1.

Table 11. Correlation analysis between outdoor and indoor thermal responses | Source: Author's table.

		GRP 1			GRP 2		
		$ATSV_{OUT}$	$WSSV_{OUT}$	$SRSV_{OUT}$	$ATSV_{OUT}$	$WSSV_{OUT}$	$SRSV_{OUT}$
$ATSV_{IN}$	Correlation Coefficient	-0.017	0.246	0.411*	0.379*	0.279	0.164
	Sig. (2-tailed)	0.936	0.246	0.046	0.030	0.116	0.360
	N	24	24	24	33	33	33
$WSSV_{IN}$	Correlation Coefficient	-0.311	0.427*	-0.188	-0.630**	0.019	-0.442**
	Sig. (2-tailed)	0.139	0.038	0.379	0.000	0.915	0.010
	N	24	24	24	33	33	33
$SRPV_{IN}$	Correlation Coefficient	0.049	-0.038	-0.130	-0.302	-0.135	0.014
	Sig. (2-tailed)	0.820	0.861	0.545	0.087	0.455	0.938
	N	24	24	24	33	33	33
$OTCV_{IN}$	Correlation Coefficient	0.301	-0.261	0.121	-0.161	0.396*	0.056
	Sig. (2-tailed)	0.153	0.217	0.573	0.379	0.025	0.761
	N	24	24	24	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

$ATSV_{IN}$ /$ATSV_{OUT}$, indoor/outdoor air temperature sensation vote; *$WSSV_{IN}$ / $WSSV_{OUT}$*, indoor/outdoor wind speed sensation vote; *$SRPV_{IN}$*, indoor solar radiation preference vote; *$SRSV_{OUT}$*, outdoor solar radiation sensation vote; *$OTCV_{IN}$*, indoor overall thermal comfort vote.

Furthermore, the results of the correlation between indoor preferences and outdoor sensation votes in Grp 1 and Grp 2 indicated that outdoor sensation votes did not show any statistical correlation with indoor preferences in Grp 1. On the other hand, $ATSV_{OUT}$ had the most significant effect on $WSPV_{IN}$ with a moderate positive correlation ($r=0.578$, $p < 0.05$). It was followed by $ATPV_{IN}$ with a moderate negative correlation ($r=-0.515$, $p < 0.05$). This revealed that the increase of $ATSV_{OUT}$ led to the increase of $WSPV_{IN}$ and the decrease of $ATPV_{IN}$ in Grp 2.

4.4. Difference in Cognitive Performance

In order to compare the cognitive performance of the participants, first, the parameters of d2 test of attention were calculated as described in the guidelines offered by Brickenkamp & Zillmer (1998). To understand the difference between the university students with experience POI 1 and the university students with experience POI 2, an independent *t*-test was used. Independent *t*-test indicated that university students with experience of different outdoor shading levels had significant differences in CP (p= 0.042) and FR (p= 0.041). Nevertheless, no significant difference in TN, E1, E2, and E% was found. With regards to the mean value of CP and FR, as indicated in Table 12, students in Grp 1 had a mean CP score of 182.8 (σ= 34.3), while the other students in Grp 2 reported a mean CP score of 167.6 (σ= 21.0). Regarding FR, the students in Grp 1 had a mean FR score of 16.5 (σ= 5.8), while the other students in Grp 2 reported a mean FR score of 19.3 (σ= 4.5). These results represented that CP of students in Grp 1 was higher than students in Grp 2, yet FR of students in Grp 1 was demonstrated lower than students in Grp 2.

Table 12. Results of independent t-test for differences in d2 test of attention between POI 1 and POI 2 | Source: Author's table.

	Grp1 (shaded experience)		**Grp2 (sun-exposed experience)**		***t***	***df***	***p* (2-tailed)**	**Mean diff.**
	Mean	**Std. Deviation**	**Mean**	**Std. Deviation**				
Total Number (TN)	508.64	85.933	487.06	65.675	-1.085	56	0.283	-21.579
Errors Percentage (E%)	6.294	4.1457	5.748	3.8437	-0.517	56	0.607	-0.5455
Total Correctly Processed Items (TN-E)	85.552	19.3290	82.288	15.6262	-0.711	56	0.480	-3.2641
Concentration Performance (CP)	182.80	34.381	167.61	21.018	-2.080	56	0.042	-15.194
Fluctuation (FR)	16.52	5.867	19.36	4.513	2.088	56	0.041	2.844

4.5. Correlation between Outdoor Thermal Responses and Cognitive Performance

In order to understand the correlation between outdoor thermal response in POIs and cognitive performance, the results were obtained from Spearman’s correlation. The only correlations were found in Grp 2, while there was no statistically significant correlation between outdoor thermal responses and the parameters of the d2 test of attention in Grp 1. Additionally, the only parameters having a correlation in the d2 test of attention were FR and TN. Spearman's correlation between $OTCV_{OUT}$ and FR rate indicated that $OTCV_{OUT}$ had a moderate negative correlation with FR in POI 2 ($r = -0.450$, $p < 0.05$). In addition, the analysis demonstrated that $ATSV_{OUT}$ had a moderate negative correlation with FR ($r = -0.418$, $p < 0.05$). These results reveal that FR had an increasing tendency with the decrease of $OTCV_{OUT}$, and $ATSV_{OUT}$ in Grp 2. In addition to FR, TN had a weak positive correlation with $SRCV_{OUT}$ ($r = 0.371$, $p < 0.05$), indicating that increase in $SRCV_{OUT}$ led to an improvement in TN for Grp 2 (for correlation table, See Appendix G).

CHAPTER 5

DISCUSSION

This chapter of the thesis discusses the findings obtained from the measurements of this study and associates these findings with the existing literature. The objective of this study is to investigate the influence of shaded outdoor spaces on thermal adaptation, relating these results to cognitive performance of university students in classroom environments. The importance of adaptation to climate change on thermal comfort and life quality in warming cities has been considered by many researchers from different disciplines (Matzarakis, 2021). However, there is a need for an interdisciplinary approach to associate separated disciplines on the topic of minimizing the adverse impact of climate change on humans (Nouri & Matzarakis, 2019). The results of the study raise the opportunity to establish interdisciplinary bridges between the four main fields, which are human thermal comfort, interior/landscape architecture, urban planning/design, and neuro-psychology, through the qualitative assessment of the relationship between outdoor and indoor, and quantitative aspects of thermal comfort within learning environments. Therefore, the results obtained from the quantitative and qualitative assessments should be approached as an evaluation of the probable improving effects of outdoor shaded spaces to the environments where learning and thermal comfort are an important part of warming cities due to climate change. In order to evaluate the results and test the hypotheses of this study, the discussion chapter was divided into four major focus points follows:

- Evaluate the differences in thermal responses and adaptive behaviours of students for indoor and outdoor environments in relation to microclimatic measurements
- Understand the relationships between indoor and outdoor thermal responses in students with different outdoor shading level experiences
- Compare the PET and thermal sensation in different groups
- Compare the cognitive performance of students with different outdoor shading level experiences

5.1. Comparison of Thermal Responses (in relation to Microclimatic Measurements)

In order to test the hypothesis 1 of this study (**H1:** Outdoor and indoor thermal adaptation of students with a shaded outdoor space experience differ from those with a sun-exposed outdoor space experience) in psychological aspects of thermal adaptation, within this study, the comparison of thermal responses in shaded, sun-exposed spaces and classroom environments was evaluated, based upon the measurements of each microclimatic parameters. The results of outdoor overall thermal comfort votes in the questionnaire showed that shade improved outdoor thermal comfort in comparison to sun-exposed outdoor spaces, as the previous studies (Berkovic et al., 2012; Chan, Chau, & Leung, 2017; Elnabawi & Hamza, 2020; Hanafi & Alkama, 2017; Lin et al., 2010; Middel et al., 2016; Pantavou, Theoharatos, Santamouris, & Asimakopoulos, 2013). The reason for that was the comfort level in the shade was found higher than in the sun-exposed space. However, the highest ratio of votes in the shade was identified as ‘slightly uncomfortable’ even though the total proportion of ‘slightly comfortable’ and ‘comfortable’ votes were higher than it. To understand the reasons behind these outcomes, sensation, preference, and comfort level were analysed for air temperature, wind speed, and solar radiation, which have been identified as the strongest parameters influencing outdoor thermal comfort (Amindeldar et al., 2017; Andreou, 2013; Fröhlich et al., 2019; Lee, Mayer, & Schindler, 2014; Lin, 2009; Mayer, Holst, Dostal, Imbery, & Schindler, 2008; Walton et al., 2007).

With regards to the results of air temperature responses, shade decreased the sensation to ‘slightly cool’ and ‘cool’ in the mean of outdoor air temperature equating to 21.2℃. Yet, the students preferred to be warmer despite feeling comfortable. Experiencing the sun-exposed outdoor space led to air temperature sensation in the mean of outdoor air temperature equating to 26.5℃ as ‘slightly warm’ and ‘hot’ with the colder preference to have better climatic conditions demonstrated by the study of Makaremi, Salleh, Jaafar, and GhaffarianHoseini (2012). Therefore, the current results were in alignment with the previous studies showing that shaded spaces decreased warm sensation (Middel et al., 2016; Othman et al., 2021; Watanabe et al., 2014). Even though these results were confirmed by the literature, air temperature sensation in the shaded outdoor space was lower than the previous studies that the most comfortable thermal conditions were founded on the ‘neutral’ thermal sensation in shade during the spring and autumn seasons (Hadianpour et al., 2018; Hwang et al., 2011). The reason behind the difference in satisfying sensation could be the resultant of different climatic conditions due to the regional characteristics in which the previous studies were conducted.

Furthermore, the existing literature recognized that wind speed is just as, if not more important than air temperature for thermal comfort studies (Du et al., 2017; Hou, 2018; Sangkertadi & Syafriny, 2017; Tse et al., 2017; Xie et al., 2018). Based upon the outcomes of this study, shade increased wind speed sensation to ‘slightly high’ in the mean of outdoor wind speed equating to 1.05 m/s, while wind speed sensation in the mean of outdoor wind speed of 0.5 m/s was perceived as ‘neutral’ and ‘slightly low’ in the sun-exposed outdoor space. Wind speed sensation in the shaded outdoor space was found higher than in the study of Othman et al. (2021) concluded that shade led to a ‘neutral’ wind speed sensation in higher air temperature. Despite the difference, wind speed conditions were satisfied in both spaces even though participants preferred lower wind speed in the shade. These outcomes indicated that the high and low wind speed in outdoor environments did not lead to uncomfortable thermal conditions. The finding obtained from shaded outdoor spaces were not consistent with the study by Hou (2018) concluded that high wind speed resulted in thermal discomfort during winter season. Conducting the studies in a different season could be the reason for the difference in the findings on the comfort level in high wind speed conditions.

Solar radiation has been proven to be an significant parameter influencing thermal comfort in outdoor contexts (Abreu-Harbich et al., 2014; Kotzen, 2003; Ndetto & Matzarakis, 2013; Norton et al., 2015; Pearlmutter, Berliner, & Shaviv, 2007). In alignment with this statement, the current findings indicated that shade had a probability to decrease solar radiation sensation to ‘weak’ when the mean value of outdoor mean radiant temperature equated to 22.0°C, but it was preferred to be stronger even though students were not unsatisfied. Contrarily, the mean of outdoor mean radiant temperature equating to 43.4°C was founded ‘slightly strong’ and ‘strong’, resulting in uncomfortable conditions with the preference of ‘a bit weaker’ in sun-exposed outdoor space. These results revealed that a lack and intensity of solar radiation led to a difference in the preference for solar radiation in thermal environments. Nevertheless, the excessive intense experience of solar radiation resulted in a more unsatisfied condition, compared with the lack of solar radiation in shaded outdoor environments.

With regards to indoor context, this study revealed that thermal responses for each microclimatic parameter measured in classrooms did not show any difference for all students. Considerably, the comfort level of air temperature and wind speed were found satisfying with ‘neutral’ sensations in Classroom 1 (the mean of indoor air temperature equating to 22.5°C; the mean of indoor wind speed equating to 0.0 m/s) and Classroom 2 (the mean of indoor air temperature equating to 24.0°C; the mean of indoor wind speed equating to 0.0 m/s) despite experiencing different outdoor shading levels. Moreover, the students did not want to change the conditions for each parameter. Yet, the preference for ‘ a bit stronger’ was relatively close to ‘no change’ in the mean of indoor mean radiant temperature equating to 22.4°C in Classroom 1 and 21.4°C in Classroom 2. These resulting choices could be linked to the inability of humans to differentiate single parameters since the main cause of the effect does not only associated with singular factors (Matzarakis, 2020). However, the preference results obtained from this study were not in alignment with the study of (Hwang, Lin, Chen, & Kuo, 2009) concluded that cooler thermal condition was the dominant preference although the majority of school children perceived the classroom to be neutral. Therefore, this study revealed that university students had different thermal condition preference compared to school children. Overall, the current study also determined that for each microclimatic parameter, classroom environments had more comfortable conditions than outdoor spaces in which they had experience in this study, compared to the findings related to outdoor spaces.

In order to test the hypothesis 1 of this study (**H1:** Outdoor and indoor thermal adaptation of students with a shaded outdoor space experience differ from those with a sun-exposed outdoor space experience) in behavioural aspects of thermal adaptation, the questionnaire survey used within this study especially questioned the desired thermal adaptive strategies of university students to be more comfortable in the thermal conditions for outdoor and indoor contexts. The most prevailing adaptive behaviour was found to be ‘be in a more sunny location’ and ‘have a hot or cold drink’ in the shaded space. ‘Being in a more shaded location’ and ‘taking off some clothing’ were, however, considered the most dominant behavioural adaptive strategies in the sun-exposed space. Therefore, the analysis revealed that thermal adaptation behaviours of students in the outdoor context showed a variation depending upon outdoor thermal conditions. In addition, the shade led to a need for changing the location to a sunnier space, as opposed to the study of Wang et al. (2018). Nevertheless, the study also confirmed the previous studies that people sought the shade to improve their thermal comfort in sun-exposed spaces with higher Ta (Eliasson et al., 2007; Martinelli, Lin, & Matzarakis, 2015; Marialena Nikolopoulou et al., 2001; Marialena Nikolopoulou & Lykoudis, 2007; Thorsson et al., 2004; Watanabe & Ishii, 2016; Xue, Liu, & Liu, 2021; Yang et al., 2013). Since the study was conducted in October, corresponding to the transition from the hot season, the students in the sun-exposed space may have perceived almost summer thermal conditions rather that the autumn, which could explain their preference for changing location to a more shaded area.

Subsequently, in classrooms, the most dominant adaptive behaviours were found to be ‘no change’ for their location and ‘open windows’ after experiencing shaded and sun-exposed outdoor space. This result showed that students did not tend to change their location in the classroom context as they did outdoors even though they experienced different outdoor shading levels. In addition, this outcome was aligned with previous studies that ‘open windows’ was the most common adaptive behaviour to have a comfortable thermal condition (Kim et al., 2017; Rijal et al., 2007; Schweiker & Wagner, 2016).

These results confirmed hypothesis 1 in both psychological and behavioural aspects of thermal adaptation for outdoor environments with regards to each microclimatic parameter. Nevertheless, psychological and behavioural adaptation did not show complete confirmation of hypothesis 1 for indoor environments. The reason behind this was that the students reported the same sensation and preference for indoor microclimate parameters and the same behavioral adaptation strategy to have better indoor thermal comfort.

5.2. Correlation of Thermal Responses

This part of the thesis was designed to test hypothesis 2 (**H2:** The impact of a shaded outdoor space is significantly different from the impact of a sun-exposed outdoor space on outdoor thermal adaptation of university students) with regards to correlations among outdoor thermal responses. Considerably, the current study represented that qualitative (psychological) thermal responses significantly affected thermal comfort apart from quantitative measurements as in the previous studies (Fransson et al., 2007; Wang et al., 2018; Wang et al., 2017; Yang et al., 2013). Yet, the effects of parameters varied based upon the shading level of outdoor conditions. The results obtained from the Spearman correlation test confirmed that the only parameter affecting outdoor air temperature sensation was outdoor wind speed sensation under shade, while outdoor solar radiation sensation was the only measurement for outdoor air temperature sensation under the sun. The outcomes were partly in accordance with previous studies that concluded thermal sensation significantly increased with the decrease in wind speed and the increase in solar radiation (Givoni et al., 2003; Krüger, Minella, & Rasia, 2011; Ng & Cheng, 2012; Wang et al., 2017; Yang et al., 2013). Within this study, however, the strength of associations mostly was higher than in these studies. The reasons behind the difference could be resultant from: (1) conducting in different countries with different KG classifications; and (2) using air temperature sensation vote in the current studies, while thermal sensation vote was used in these studies even if the same 7-point scale was used.

Moreover, the outcomes revealed that thermal responses influencing outdoor overall thermal comfort vote varied greatly depending on the shading levels of outdoor environments. With regards to the results, outdoor air temperature and solar radiation sensations were important determinants of human comfort under shade and sun. wind speed sensation, also, could be considered an essential component for overall thermal comfort in the only shaded outdoor space. These findings were not consistent with the study of Wang et al. (2017) that did not find a significant relationship among thermal comfort level, sensation, and wind speed sensation in summer. This difference could indicate that there might be a distinctive outcome between various seasons since the findings of the current study were related to the only autumn season. Wang et al. (2018), however, reported the increase in thermal comfort with the decrease in thermal sensation, and the increase in wind speed sensation. The results were partly aligned with this study, in terms of the results obtained in shaded space, while not in sun-exposed space. The reason for that could be that wind speed in the current study was recorded higher than in this study. Thus, the difference with Wang et al. (2018) had also a possibility to show that wind speed significantly influenced thermal perception of individuals in the shaded outdoor space.

In addition, the current research provided new insight into the relationships among outdoor overall thermal comfort, air temperature, wind speed, and solar radiation comfort that were not investigated in the existing literature. Within this study, the influences of outdoor air temperature and solar radiation comfort were higher than outdoor wind speed comfort under the shade and the sun even though the strength of associations under the shade was relatively higher than under the sun. These findings showed that outdoor air temperature comfort was the most significant parameter for outdoor overall thermal comfort in both types of space, followed by outdoor solar radiation and wind speed comfort. With regards to the relationship among outdoor air temperature, wind speed, and solar radiation comfort, outdoor air temperature comfort showed the greatest importance on outdoor wind speed and solar radiation comfort under the shade, while outdoor air temperature comfort under the sun was affected only by outdoor solar radiation comfort. It indicated that solar radiation comfort was an important determinant for air temperature comfort in both shaded and sun-exposed outdoor spaces.

This study also revealed that outdoor sensation in different microclimatic conditions had relatively different influences on outdoor air temperature, wind speed, and solar radiation comfort. With regards to outdoor air temperature comfort, air temperature sensation was the only most important determinant under both shaded and sun-exposed outdoor spaces with almost equal strength. Air temperature sensation was also a crucial measure of solar radiation comfort in both types of outdoor space, yet solar radiation sensation also affected solar radiation comfort in only the sun-exposed outdoor space. However, the parameters affecting outdoor wind speed comfort showed differences based upon the outdoor spaces with different shading levels. Air temperature sensation was, moreover, a psychological measure of wind speed comfort under the shaded outdoor space after wind speed sensation, while the only determinant influencing wind speed comfort was solar radiation sensation in the sun-exposed outdoor space. Overall, through the findings and the discussion of the difference between the impacts of outdoor shaded and sun-exposed spaces on thermal adaptation, H2 was supported within this study regarding the psychological aspect of thermal adaptation.

The hypothesis 3 (**H3:** There is a significant relationship between outdoor thermal responses in different outdoor shading levels and indoor thermal responses of university students), also, was tested through the statistical analysis and discussed to evaluate the findings of the study with previous studies in this part of the thesis. The existing literature has proven the effect of outdoor climatic factors, specifically air temperature, on the indoor environment (Adunola, 2014; Humphreys, 1978; Humphreys et al., 2013; Humphreys & Nicol 2000; Mallick, 1996; Nicol & Humphreys, 2010). The findings of this study, however, provided a new perspective by analysing the effects of outdoor thermal responses obtained from different microclimatic conditions on indoor thermal responses. Regarding the outcomes of this study, outdoor thermal responses obtained from students in shaded and sun-exposed outdoor spaces had a relationship with indoor thermal responses of students. However, the relationship between outdoor and indoor thermal responses varied based upon the experienced space in the outdoor context within the study. According to the responses of students with experience shade, outdoor solar radiation sensation was the only outdoor parameter influencing indoor air temperature sensation. The responses of students under the sun; however, showed that indoor air temperature sensation was affected by only outdoor air temperature sensation, which was consistent with the study of Adunola (2014) that outdoor air temperature influenced indoor air temperature. With regards to indoor wind speed sensation, outdoor wind speed sensation was the dominant qualitative measurement, based upon the responses of students under shade, while outdoor air temperature sensation showed the highest importance in affecting indoor wind speed sensation according to students with the sun-exposed outdoor space experience. Correspondingly, in order to understand the effect of outdoor thermal sensation on indoor overall thermal comfort, the relationship of indoor overall thermal comfort with outdoor air temperature, wind speed, and solar radiation sensations was analysed. Depending on the results, the only subjective measure of indoor overall thermal comfort was outdoor wind speed sensation for students under the sun. In addition to these analyses, the relationship between indoor preference votes and outdoor sensation votes was evaluated to understand how outdoor sensation affected indoor preferences for each microclimatic parameter in this study. However, the only relationship was found outdoor air temperature sensation and indoor wind speed comfort, based upon only students with the sun-exposed outdoor space experience. Therefore, experiencing a shaded outdoor space did not have any impact on indoor thermal preferences. Overall, these outcomes of this study confirmed H3. For this reason, the confirmation of H3 revealed that qualitative outdoor measurements of air temperature, wind speed, and solar radiation could be a crucial criterion to understand the expectation of university students in an indoor context; and even experiencing the sun-exposed outdoor space could have more impact on indoor thermal responses than the shaded outdoor space.

5.3. Comparative Analysis of PET and Thermal Sensations

To test hypothesis 4 (**H4:** There is a significant difference between quantitative and qualitative measurements of thermal comfort of university students) the PET values and thermal responses of students were compared in this study. The study established that the PET/PS levels in the selected spaces showed a considerable difference during the measurement period. With regards to comparing thermophysiological and psychological outcomes, the lowest PET values were recorded in the shaded outdoor space with the mean PET equating to 18.8℃, and the sensation also identified the space as ‘slightly cool.’ Contrarily, the sun-exposed space with the mean PET equating to 33.2℃ was identified as ‘slightly warm’ and ‘warm’ in thermal sensation votes, revealing the highest PET value. Therefore, the outputs of the study indicated that the shaded outdoor space reduced the PET due to diminished mean radiant temperature, which was aligned with the previous studies (Ali-Toudert & Mayer, 2007; Taleghani et al., 2015). The reduction of the PET was matched with interviewees expressing ‘slightly cool’. In classrooms, however, the sensation was determined as ‘neutral’ in the mean PET value of 23.0℃. Correspondingly, these results indicated that the sensation of students in the sun-exposed outdoor space was almost identical to the output of the human biometeorological model with PET (Matzarakis & Mayer, 1997) (Table 4). Yet, the actual sensations of students were revealed to be slightly higher in indoor contexts and to be slightly lower for the shaded outdoor space than those associated with the PET outputs. Therefore, H4 was confirmed with the indoor settings and the shaded outdoor space, while not for the sun-exposed outdoor space.

In addition to the results of the PET, the PS threshold grades varied differently in the shaded outdoor space in comparison to the sun-exposed space. The occurrence of

‘Moderate Heat Stress’ took place in sun-exposed space, while ‘No Thermal Stress’ was obtained in shaded space. Therefore, these outcomes indicated that even during the autumn season, human thermophysiological thresholds could still vary particularly during the hotter hours of the day as a result of mean radiant temperature fluctuations between the outdoor spaces.

With regards to surface temperature, although the surface temperature of the materials in outdoor and indoor settings was measured, surface temperature values were not included as they gave unreliable results given the high variability of materials in each Point of Interest and classroom. Thus, for this particular study, globe temperature was utilised to determine to mean radiant temperature and PET. This provided a more effective means to approach radiation impacts within each respective location.

5.4. Comparison of Cognitive Performance

In order to test H5 (**H5:** Indoor concentration performance of students with a shaded outdoor space experience is significantly higher than those with a sun-exposed outdoor space experience), the parameters of the d2 test of attention were compared and discussed regarding the results of the independent *t*-test between students with experience of different outdoor shading levels. The relationship between thermal comfort with temperature and cognitive performance has been researched for improving cognitive performance in prior studies (Bajc et al., 2019; Barbic et al., 2019; Riham Jaber, Dejan, & Marcella, 2017; Sarbu & Pacurar, 2015; Siqueira et al., 2017; Zhang & de Dear, 2017; Zhang et al., 2019). However, they mostly did not consider the effect of experiencing outdoor space with different thermal conditions on cognitive performance in indoor settings. To address such a gap, the current study provided new insight into the difference in cognitive performance between students who experienced a shaded outdoor environment subsequently and sun-exposed outdoor environment in classroom environments through the d2 test of attention. The previous studies concluded that the best cognitive performance was achieved in ‘neutral’ or ‘slightly cool’ (Geng et al., 2017), ‘neutral’ (Lan et al., 2010), and ‘slightly cool’ (Jensen et al., 2009; Lan et al., 2011) sensation votes. In addition, some studies found that in-between ‘slightly warm’ and ‘warm’, optimal performance was achieved (Wang et al., 2018; Wyon, 1974). The results of this study, however, showed a significant difference in concentration performance and fluctuation rate between students with experience in shaded and sun-exposed outdoor spaces. These differences were seen in classroom contexts where ‘neutral’ sensation votes were greatly distributed. Therefore, these results indicated that experiencing a shaded outdoor environment improved the concentration of students and decreased fluctuation rate in the classroom context. Such results could be attributable to two main factors, that: (1) the tasks given to the participants to measure cognitive performance in previous studies were different; and, (2) these studies were conducted only in indoor environments with changing the indoor microclimatic conditions by not considering experiencing outdoor spaces. Thus, the current study showed that experiencing the shade had a significant positive effect on the cognitive performance of students in an indoor environment during the autumn season. Overall, the findings of this study supported H5 because of revealing the significant difference in concentration performance, and even fluctuation rate.

Apart from H5, the findings of the study also revealed that experiencing the sun-exposed outdoor space could influence cognitive performance, only fluctuation rate, and the total number of items processed in d2 test of attention, within the classroom setting. However, the only important determinants affecting fluctuation rate of the students in Grp 2 were outdoor air temperature sensation and outdoor overall thermal comfort. These outcomes were partly consistent with the previous studies although these studies only focused on the effects of indoor thermal conditions on cognitive performance (Chen et al., 2020; Fan et al., 2019). Apart from the fluctiation rate, outdoor solar radiation comfort was another only measure that influenced the total number of items processed results of the students exposed to the sun-exposed outdoor space. For this reason, it could be indicated from these results that air temperature and solar radiation in outdoor environments were possible microclimatic parameters influencing cognitive performance within indoor settings.

CHAPTER 6

CONCLUSION

In conclusion, first, the main focal points of this study are presented to understand the overall perspective. Next, the thermal design guidelines are suggested to understand the contributions of this study to the design and scientific community. Finally, the limitations of the study on the methodology are explained with further research recommendations to enhance the contributions to the research field.

This research systematically investigated the impacts of shaded outdoor spaces on thermal adaptation and cognitive performance of university students within classroom settings in Ankara, Turkey in the autumn season. Both quantitative and qualitative aspects of thermal comfort were considered in this study. Existing literature has indicated that the shade in outdoor environments has a prevailing influence on reducing the adverse impacts of climate change, primarily thermal discomfort, within warming cities (Matzarakis, 2021; Nouri & Costa, 2017). The findings of the research supported that a shaded outdoor space improved outdoor thermal comfort, and even experiencing such space increased cognitive performance of university students during the autumn season. The main conclusions are summarized as follows:

This study revealed that both quantitative and qualitative aspects of thermal comfort provided an understanding of thermal adaptation of students in university campus settings. With regards to the quantitative aspects, mean Physiologically Equivalent Temperature showed a variation based upon the outdoor shading levels in outdoor environments. The considerable difference in the mean Physiologically Equivalent Temperature between shaded (18.7°C) and sun-exposed (33.2°C) outdoor spaces determined that shade had a possibility to enhance the opportunity to consider the different bioclimatic environments on the university campus, and find the different ways for thermal adaptation of students.

Furthermore, regarding psychological adaptation, this study implied that the impacts of the shaded outdoor space on outdoor thermal responses differentiated from the sun-exposed outdoor space in relation to microclimatic parameters. In a shaded outdoor area, students revealed a greater occurrence of thermally comfortable conditions, resulting in the opportunity to improve cognitive performance in the indoor classroom setting. In the shaded outdoor space, wind speed was considered the most influential measure for outdoor thermal comfort level after air temperature. Yet, outdoor wind speed sensation had not only an impact on outdoor thermal responses but also on indoor wind speed sensation. This provides great precedence to considering wind speed as a considerable parameter in even learning environments and their outdoor surroundings. Based upon the sun-exposed outdoor space, solar radiation indicated its noticeable influence on thermal comfort of students after air temperature, considering the adverse impact on thermal adaptation in both outdoor and indoor contexts. Therefore, even though air temperature could be taken into consideration as the primary measure of thermal comfort in both outdoor and indoor environments, wind speed in shaded outdoor spaces and solar radiation in sun-exposed spaces determined that there were important measures that could not be underestimated within this study.

This study also stated a considerable difference in behavioural adaptation of students with different outdoor shading levels experiences. With regards to adaptive behaviours in outdoor settings, the preference of students exposed to shaded and sun-exposed spaces as changing their location to the sunnier or shadier location might indicate the necessity to improve the design of such areas, including for the autumn season. Furthermore, the diversity of the undertaken analyses pointed out the association between outdoor quantitative and qualitative microclimatic parameters and indoor thermal comfort of students. Nevertheless, different outdoor site characteristics, such as shaded and sun-exposed within this study, impacted differently the indoor thermal comfort of students, providing the significance of examinations of interior design by considering different site experiences.

Finally, the progressive impact of experiencing shaded outdoor areas on concentration performance of students in classroom settings indicated that outdoor site-specific characteristics were a critical component that could be considered by architects and designers with respect to concentrating on both quantitative and qualitative aspects of thermal comfort in outdoor and indoor contexts. Moreover, the association between outdoor thermal responses and fluctuation rate of the students also indicated that not only indoor thermal environment was an influential measure for cognitive performance, but also the outdoor thermal environment could be considered an important component while designing learning environments.

Overall, even though a variety of undertaken examinations on thermal comfort studies was considered by the scientific community, this study builds upon the weaker links between its quantitative and qualitative aspects between indoor and outdoor contexts. Where, moreover, within an era of climate change and rapidly densifying urban fabrics, their contexts contribute to being increasingly susceptible to both existing and future heat-related stress factors. The case of Ankara in this study is a typical example of such risk factors and a beacon for a growing need for interdisciplinary practice for different disciplines that share common goals. An example of such goals is the ongoing need to ensure the efficacy of contemporary learning environments, whereby cognitive performance attributed are also investigated and associated with both outdoor and indoor relationships. This also has indicated its effects on cognitive performance within such learning environments by providing an interrelationship between different research fields to consider distinctive design layouts within outdoor and indoor contexts.

6.1. Association of Thesis Objectives, Methodology, and Results with the Literature and Scientific Community

This research was associated with the Turkish national Scientific and Technological Research Council of Turkey (TÜBİTAK), project, named "Human Thermal Comfort Thresholds within indoor and outdoor environments – Facing rising heat levels in an era of climate change, the case of Ankara, Turkey – (TCTA)", with project number: #120C077. The process of the thesis was systematically structured throughout the whole master's program (for the Gantt chart, see Appendix H). During the process, to continuously interrelate this research within the existing literature and receive crucial feedback from the scientific community, the methodology of this study was published in the European Meteorological Society (EMS) Annual Meeting 2021 in September 2021. An original research article manuscript from the results of the thesis, moreover, has been aimed at the Springer Journal Theoretical and Applied Climatology, *ISSN 0177-798X* (print).

6.2. Thermal Design Guidelines

This part of the thesis was designed to propose several important guidelines for a specific case study in Ankara to the architects and designers in outdoor and indoor contexts with regard to the discussion part of this study. For this reason, the stated guidelines considered the aim and evaluation of the results of this study are gathered into three main parts: designing to enhance thermal adaptation, designing with shading strategies, and designing to improve cognitive performance in indoor settings (Figure 16).

Evaluation of Results	Thermal Design Guidelines
	Designing to enhance thermal adaptation
Difference in thermal perception and adaptive behaviours in outdoor spaces with different shading levels	Using qualitative evaluation as a potential tool to analyse differences in thermal adaptation
Distinctive evaluation of thermal perception in qualitative measurement and thermal sensation with PET	Considering both qualitative and quantitative aspect of thermal comfort to combine human thermophysiological and human thermal perception
Correlation differences between outdoor and indoor thermal responses based upon experiences of different types of outdoor conditions	Giving importance to the proximity and types of outdoor microclimatic conditions with aspect of short-term thermal history during the process of interior design
	Designing with shading strategies
V as an important parameter affecting qualitative evaluation of thermal comfort in the shaded outdoor space	Considering the variation in V in outdoor environments during autumn season, apart from Tmrt
The significant impact of V_{OUT} in the perception of V_{IN}	Evaluating V_{OUT} for designing indoor environment with considering natural ventilation solutions that enhance convection effects upon humans within classroom environments
	Designing to improve cognitive performance in indoor settings
The positive impact of experiencing shaded outdoor space during break time on concentration performance of students in studio setting	Considering outdoor shading strategies that provide various opportunities during break times together with the proper use and placement of local amenities such suitable vegetation species and pergolas

Figure 16. Relationship between the evaluation of results and thermal design guidelines | Author's figure.

6.2.1. Designing to Enhance Thermal Adaptation

Qualitative aspect of thermal comfort have a potential tool to become a useful tool in the process of design decision-making in both outdoor and indoor contexts through the evaluation of thermal perception and adaptive behaviours of students within outdoor environments with different site characteristics. This can provide a growing interdisciplinary bridge for separated disciplines by concentrating on climate-sensitive actions. Thus, relating different disciplines can contribute to providing crucial solutions and guidelines to global climatic problems and their interrelations with different investigation fields. Nevertheless, in terms of university students' thermal adaptation on campus, landscape architects and urban designers/planners should note that the quantitative and qualitative components of thermal comfort provide distinct perspectives to enhance the design opportunities. As a result, design solutions for both outdoor and interior environments should be considered by concentrating on both quantitative and qualitative aspects to combine thermophysiological and human thermal perception for a particular environment.

Landspace architects and designers in urban planning should take into consideration that experiencing outdoor environments with different site characteristics can lead to distinctive thermal perception and preference for not only outdoor context, but also indoor context. For this reason, design decisions for indoor learning environments should be considered proximity and types of outdoor microclimatic conditions with the aspect of short-term thermal history. This design decision could greatly contribute to improving the indoor thermal adaptation of students.

6.2.2. Designing with Shading Strategies

The major contribution of shading strategies with buildings is the reduction of mean radiant temperature and global radiation compared to a sun-exposed space. Therefore, vegetation and/or architectural structures should be taken into consideration to reduce the intensity of mean radiant temperature and global radiation in outdoor environments through the consideration of seasonal impacts. It should be, however, noted that wind speed is another important parameter influencing human thermal perception in a shaded outdoor space. For this reason, not only focusing reduction of mean radiant temperature and global radiation but also the variation in wind speed should be considered for design decisions in outdoor environments during the autumn season.

Wind speed could not only affect outdoor thermal perception in a shaded outdoor space, and also have a significant impact on indoor wind speed sensation of students in a classroom context. For this reason, outdoor wind speed should be taken into consideration into designing indoor environments to have better thermal conditions. To illustrate, wind strategies within the actual outdoor environments should be designed and even improved with the changing influence of different seasons. It is because the discussion of the findings with existing literature indicated that seasonal change could lead to different wind speed comfort for individuals. Such sensation considerations can, moreover, be reflected upon building upon studies that consider natural ventilation solutions that enhance convection effects upon humans within classroom environments.

6.2.3. Designing to Improve Cognitive Performance in Indoor Settings

Apart from indoor thermal conditions, having experience of a shaded outdoor space influences positively cognitive performance, particularly concentration performance, of students in a classroom setting in comparison to a sun-exposed space during the autumn season. For this reason, decisions makers should consider outdoor shading strategies that provide various opportunities during break times in their design decisions. Such design decisions also invariably expand the consideration of different shading solutions, together with the proper use and placement of local amenities such as suitable vegetation species and pergolas.

6.3. Study Limitations and Suggestions for Further Studies

The outcomes of this study were specifically focused upon the case of Ankara, Turkey. However, the methodology framework of this study could be applied to other regions with different Köppen Geiger classifications in order to obtain thermal benchmarks of diverse outdoor and indoor spaces. Also, it should be emphasized that the results of the application of the study had some methodological limitations, these being that: (1) the current study was conducted during a mid-season. Through the availability of measuring quantitative and qualitative aspects in summer, spring, and winter, more relationships between thermal responses could be found, including between the seasons themselves; (2) the measurement period in the study was limited, therefore, there is the opportunity to expand the measurement period within a future study; (3) only two Point of Interest typologies including building shaded and sun-exposed open square outdoor locations were considered in this study. As a result, there is a crucial opportunity for a future study to consider different Point of Interest typologies that can shed more information upon the effects of outdoor local amenities upon the relationships delineated in this study; (4) the sample size was limited, therefore it could be enlarged using the methodology already established in this study to further explore the results presented by this research; (5) to measure the cognitive performance of university students, the d2 test of attention was utilized, but using different tasks such as Digit Span, and Simple Reaction Time, could provide the opportunity to evaluate more cognitive skills; (6) because the questionnaire surveys were prepared in English, there was a possible language barrier due to English not being a native language of the students, and finally (7) the age group was for young people, however a future study can also be undertaken to consider older age groups, providing more information upon age-related factors in thermal adaptation.

Further research could concentrate on a future investigation of such a study in more thermally efficient/current construction methods/codes, where the thermal resistance of the building shell provides more resistance to outdoor stimuli. The reason behind the possible implication is that the building used within this study was selected because of its increased vulnerability. Such an implication approach could give the possibility to provide building energy efficiency strategies with regards to the direct and/or latent relationships with outdoor thermal conditions. The other environmental factors, such as air quality, and glaring within indoor and outdoor contexts could be taken into consideration to interrelate environmental quality measures, and reveal each impact on human comfort. Along with environmental factors, the implications of various tree species and planting strategies as potential means to cast shade within the local urban environment could be considered due to their behaviours in distinct ways upon in-situ microclimates. Such a perspective could provide specific information in the development of landscape and urban design guidelines based upon shading strategies and climate adaptation in an era of climate change within warming cities. With regards to the specific case in Ankara, Bilkent University campus, particularly, has various range of tree species that could affect human thermal comfort in outdoor contexts, such as *Platanus orientalis, Prunus serrulta, Quercus rubra, Tilia rubra, Ulmus laevis, Picea pungens*. Furthermore, a complementing future study could be considered in Turkish since English is not the native language of the students, and even the interviews prepared structurally in addition to questionnaire surveys could be conducted in order to reveal other psychological impacts behind thermal comfort of students. Such a future study could also raise interesting results in analysing the vocabulary use and meaning between two different languages.

REFERENCES

Abdallah, A. S. H., Hussein, S. W., & Nayel, M. (2020). The impact of outdoor shading strategies on student thermal comfort in open spaces between education building. *Sustainable Cities and Society*, *58*, 102124. https://doi.org/10.1016/j.scs.2020.102124

Abreu-Harbich, L. V., Labaki, L. C., & Matzarakis, A. (2014). Thermal bioclimate as a factor in urban and architectural planning in tropical climates—The case of Campinas, Brazil. *Urban Ecosystems*, *17*(2), 489–500. https://doi.org/10.1007/s11252-013-0339-7

Adunola, A. O. (2014). Evaluation of urban residential thermal comfort in relation to indoor and outdoor air temperatures in Ibadan, Nigeria. *Building and Environment*, *75*, 190–205. https://doi.org/10.1016/j.buildenv.2014.02.007

Afacan, Y., & Demirkan, H. (2016). The influence of sustainable design features on indoor environmental quality satisfaction in Turkish dwellings. *Architectural Science Review, 59*(3), 229-238.

Akbari, H., Davis, S., Dorsano, J., Huang, S., Winert, S., 1992. *Cooling Our Communities e A Guidebook on Tree Planting and Light Colored Surfacing*. Washington, DC: U.S. Environmental Protection Agency Office of Policy Analysis Climate Change Division.

Al Sabbagh, N. I. H. A. L., Yannas, S. I. M. O. S., & Cadima, P. A. U. L. A. (2016). Improving pedestrian thermal sensation in Dubai. In PLEA 2016–36th International Conference on Passive and Low Energy Architecture, Cities, Buildings, People: Towards Regenerative Environments.

Aleksandrowicz, O., Vuckovic, M., Kiesel, K., & Mahdavi, A. (2017). Current trends in urban heat island mitigation research: Observations based on a comprehensive research repository. *Urban Climate*, *21*, 1–26. https://doi.org/10.1016/j.uclim.2017.04.002

Ali-Toudert, F., & Mayer, H. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. *Building and Environment*, *41*(2), 94–108. https://doi.org/10.1016/j.buildenv.2005.01.013

Ali-Toudert, F., & Mayer, H. (2007a). Thermal comfort in an east–west oriented street canyon in Freiburg (Germany) under hot summer conditions. *Theoretical and Applied Climatology*, *87*(1–4), 223–237. https://doi.org/10.1007/s00704-005-0194-4

Ali-Toudert, F., & Mayer, H. (2007b). Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. *Solar Energy*, *81*(6), 742–754. https://doi.org/10.1016/j.solener.2006.10.007

Aljawabra, F. F. (2014). *Thermal comfort in outdoor urban spaces: The hot arid climate*. University of Bath.

Allaby, M. (Ed.). (2008). *A dictionary of earth sciences* (3rd ed). Oxford University Press.

Amindeldar, S., Heidari, S., & Khalili, M. (2017). The effect of personal and microclimatic variables on outdoor thermal comfort: A field study in Tehran in cold season. *Sustainable Cities and Society*, *32*, 153–159. https://doi.org/10.1016/j.scs.2017.03.024

Andreou, E. (2013). Thermal comfort in outdoor spaces and urban canyon microclimate. *Renewable Energy*, *55*, 182–188. https://doi.org/10.1016/j.renene.2012.12.040

Anupriya, S. (2016). Exploratory study on the relation between urban landscapes and urban corridors for outdoor thermal comfort. *Procedia Technology*, *24*, 1801–1807. https://doi.org/10.1016/j.protcy.2016.05.224

Aparicio-Ruiz, P., Barbadilla-Martín, E., Guadix, J., & Muñuzuri, J. (2021). A field study on adaptive thermal comfort in Spanish primary classrooms during summer season. *Building and Environment*, *203*, 108089.

Arens, E., Hoyt, T., Zhou, X., Huang, L., Zhang, H., & Schiavon, S. (2015). Modeling the comfort effects of short-wave solar radiation indoors. *Building and Environment*, *88*, 3-9.

Arens, E., Zhang, H., & Huizenga, C. (2006). Partial- and whole-body thermal sensation and comfort—Part II: Non-uniform environmental conditions. *Journal of Thermal Biology*, *31*(1–2), 60–66. https://doi.org/10.1016/j.jtherbio.2005.11.027

Argyrous, G. (1997). *Statistics for Social Research*. Macmillan Education UK. https://doi.org/10.1007/978-1-349-14777-9

Asaeda, T., Ca, V. T., & Wake, A. (1996). Heat storage of pavement and its effect on the lower atmosphere. *Atmospheric Environment*, *30*(3), 413–427. https://doi.org/10.1016/1352-2310(94)00140-5

ASHRAE Standard 55. (2010). *Thermal Environmental Conditions for Human Occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. Standard 55, American Society of Heating, Refrigerating and Air-Conditioning. Atlanta, GA: ASHRAE.

ASHRAE Standard 55. (2017). *Thermal Environmental Conditions for Human Occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. Standard 55, American Society of Heating, Refrigerating and Air-Conditioning. Atlanta, GA: ASHRAE.

Asimakopoulos, D. A., Santamouris, M., Farrou, I., Laskari, M., Saliari, M., Zanis, G., Giannakidis, G., Tigas, K., Kapsomenakis, J., Douvis, C., Zerefos, S. C., Antonakaki, T., & Giannakopoulos, C. (2012). Modelling the energy demand projection of the building sector in Greece in the 21st century. *Energy and Buildings*, *49*, 488–498. https://doi.org/10.1016/j.enbuild.2012.02.043

Babić, S., & Ce, Me. (2012). Analysis of pavement surface heating in urban areas. *GRAĐEVINAR*, *64*(2). https://doi.org/10.14256/JCE.641.2011

Baizhan Li, Wei Yu, Meng Liu, & Nan Li. (2011). Climatic Strategies of Indoor Thermal Environment for Residential Buildings in Yangtze River Region, China. *Indoor and Built Environment*, *20*(1), 101–111. https://doi.org/10.1177/1420326X10394495

Bajc, T., Banjac, M., Todorovic, M., & Stevanovic, Z. (2019). Experimental and statistical survey on local thermal comfort impact on working productivity loss in university classrooms. *Thermal Science*, *23*(1), 379–392. https://doi.org/10.2298/TSCI170920160B

Banerjee, S., Middel, A., & Chattopadhyay, S. (2020). Outdoor thermal comfort in various microentrepreneurial settings in hot humid tropical Kolkata: Human biometeorological assessment of objective and subjective parameters. *Science of The Total Environment*, *721*, 137741. https://doi.org/10.1016/j.scitotenv.2020.137741

Barbic, F., Minonzio, M., Cairo, B., Shiffer, D., Dipasquale, A., Cerina, L., Vatteroni, A., Urechie, V., Verzeletti, P., Badilini, F., Vaglio, M., Iatrino, R., Porta, A., Santambrogio, M., Gatti, R., & Furlan, R. (2019). Effects of different classroom temperatures on cardiac autonomic control and cognitive

performances in undergraduate students. *Physiological Measurement*, *40*(5), 054005. https://doi.org/10.1088/1361-6579/ab1816
Barriopedro, D., Fischer, E. M., Luterbacher, J., Trigo, R. M., & García-Herrera, R. (2011). The hot summer of 2010: Redrawing the temperature record map of Europe. *Science*, *332*(6026), 220–224. https://doi.org/10.1126/science.1201224
Bates, M. E., & Lemay, E. P. (2004). The d2 Test of Attention: Construct validity and extensions in scoring techniques. *Journal of the International Neuropsychological Society*, *10*(03). https://doi.org/10.1017/S135561770410307X
Bauman, F. S, & Arens, E. A. (1996). Task/ambient conditioning systems: Engineering and application guidelines. UC Berkeley: Center for the Built Environment. Retrieved from https://escholarship.org/uc/item/0r36z48d.
Becker, S., Potchter, O., & Yaakov, Y. (2003). Calculated and observed human thermal sensation in an extremely hot and dry climate. *Energy and Buildings*, *35*(8), 747–756. https://doi.org/10.1016/S0378-7788(02)00228-1
Bektaş, F. (2019). Evaluation of d2 attention levels of orienteering national team athletes who are in education age. *Journal of Education and Training Studies*, *7*(6), 49. https://doi.org/10.11114/jets.v7i6.4204
Berg, R. J., Inaba, K., Sullivan, M., Okoye, O., Siboni, S., Minneti, M., Teixeira, P. G., & Demetriades, D. (2015). The impact of heat stress on operative performance and cognitive function during simulated laparoscopic operative tasks. *Surgery*, *157*(1), 87–95. https://doi.org/10.1016/j.surg.2014.06.012
Berkovic, S., Yezioro, A., & Bitan, A. (2012). Study of thermal comfort in courtyards in a hot arid climate. *Solar Energy*, *86*(5), 1173–1186. https://doi.org/10.1016/j.solener.2012.01.010
Blocken, B., Carmeliet, J., & Stathopoulos, T. (2007). CFD evaluation of wind speed conditions in passages between parallel buildings—Effect of wall-function roughness modifications for the atmospheric boundary layer flow. *Journal of Wind Engineering and Industrial Aerodynamics*, *95*(9–11), 941–962. https://doi.org/10.1016/j.jweia.2007.01.013
Blocken, B., Stathopoulos, T., & Carmeliet, J. (2008). Wind environmental conditions in passages between two long narrow perpendicular buildings. *Journal of Aerospace Engineering*, *21*(4), 280–287. https://doi.org/10.1061/(ASCE)0893-1321(2008)21:4(280)
Brager, G. S., & de Dear, R. J. (1998). Thermal adaptation in the built environment: A literature review. *Energy and Buildings*, *27*(1), 83–96. https://doi.org/10.1016/S0378-7788(97)00053-4
Brickenkamp, R. (1962). *Test of attention (test d2)*. Gottingen: Hogrefe.
Brickenkamp, R., & Zillmer, E. (1998). *Test d2 test of attention.* Oxford, UK: Hogrefe.
Brisswalter, J., Collardeau, M., & René, A. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine*, *32*(9), 555–566. https://doi.org/10.2165/00007256-200232090-00002
Brown, R. D., Vanos, J., Kenny, N., & Lenzholzer, S. (2015). Designing urban parks that ameliorate the effects of climate change. *Landscape and Urban Planning*, *138*, 118–131. https://doi.org/10.1016/j.landurbplan.2015.02.006
Calì, D., Andersen, R. K., Müller, D., & Olesen, B. W. (2016). Analysis of occupants' behavior related to the use of windows in German households.

Building and Environment, *103*, 54–69. https://doi.org/10.1016/j.buildenv.2016.03.024

Çalışkan, O., & Türkoğlu, N. (2015). Ankara'da termal konfor koşulların eğilimi ve şehirleşmenin termal konfor koşulları üzerine etkisi. *Coğrafi Bilimler Dergisi*, *12*(2), 119-132.

Cândido, C., de Dear, R., & Ohba, M. (2012). Effects of artificially induced heat acclimatization on subjects' thermal and air movement preferences. *Building and Environment*, *49*, 251–258. https://doi.org/10.1016/j.buildenv.2011.09.032

Cao, B., Zhou, X., Huang, L., & Zhu, Y. (2008). Field survey of human thermal adaptability in transition season and heating supply period. In Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge. UK.

Cao, B., Zhu, Y., Ouyang, Q., Zhou, X., & Huang, L. (2011). Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing. *Energy and Buildings*, *43*(5), 1051–1056. https://doi.org/10.1016/j.enbuild.2010.09.025

Chan, S. Y., Chau, C. K., & Leung, T. M. (2017). On the study of thermal comfort and perceptions of environmental features in urban parks: A structural equation modeling approach. *Building and Environment*, *122*, 171–183. https://doi.org/10.1016/j.buildenv.2017.06.014

Charles, K. E. (2003). Fanger's Thermal Comfort and Draught Models. In: IRC-RR-162 2003. Canada: Institute for Research in Construction, National Research Council of Canada.

Chen, C. P., Hwang, R. L., Chang, S. Y., & Lu, Y. T. (2011). Effects of temperature steps on human skin physiology and thermal sensation response. *Building and Environment*, *46*(11), 2387-2397.

Chen, J.-C., & Schwartz, J. (2009). Neurobehavioral effects of ambient air pollution on cognitive performance in US adults. *NeuroToxicology*, *30*(2), 231–239. https://doi.org/10.1016/j.neuro.2008.12.011

Chen, L., Wen, Y., Zhang, L., & Xiang, W.-N. (2015). Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai. *Building and Environment*, *94*, 644–653. https://doi.org/10.1016/j.buildenv.2015.10.020

Chen, L., Zhang, Y., Han, J., & Li, X. (2021). An investigation of the influence of ground surface properties and shading on outdoor thermal comfort in a high-altitude residential area. *Frontiers of Architectural Research*, *10*(2), 432–446. https://doi.org/10.1016/j.foar.2020.12.005

Chen, X., Xue, P., Liu, L., Gao, L., & Liu, J. (2018). Outdoor thermal comfort and adaptation in severe cold area: A longitudinal survey in Harbin, China. *Building and Environment*, *143*, 548–560. https://doi.org/10.1016/j.buildenv.2018.07.041

Chen, Y., Tao, M., & Liu, W. (2020). High temperature impairs cognitive performance during a moderate intensity activity. *Building and Environment*, *186*, 107372. https://doi.org/10.1016/j.buildenv.2020.107372

Chen, Y.-C., & Matzarakis, A. (2018). Modified physiologically equivalent temperature—Basics and applications for western European climate. *Theoretical and Applied Climatology*, *132*(3–4), 1275–1289. https://doi.org/10.1007/s00704-017-2158-x

Chen, Y.-C., Fröhlich, D., Matzarakis, A., & Lin, T.-P. (2017). Urban roughness estimation based on digital building models for urban wind and thermal

condition estimation—application of the SkyHelios model. *Atmosphere*, *8*(12), 247. https://doi.org/10.3390/atmos8120247
Cheng, V., Ng, E., Chan, C., & Givoni, B. (2012). Outdoor thermal comfort study in a sub-tropical climate: A longitudinal study based in Hong Kong. *International Journal of Biometeorology*, *56*(1), 43–56. https://doi.org/10.1007/s00484-010-0396-z
Choi, Y.-Y., Suh, M.-S., & Park, K.-H. (2014). Assessment of surface urban heat islands over three megacities in east asia using land surface temperature data retrieved from COMS. *Remote Sensing*, *6*(6), 5852–5867. https://doi.org/10.3390/rs6065852
Chun, C., Kwok, A., Mitamura, T., Miwa, N., & Tamura, A. (2008). Thermal diary: Connecting temperature history to indoor comfort. *Building and Environment*, *43*(5), 877–885. https://doi.org/10.1016/j.buildenv.2007.01.031
Çiçek, İ., & Doğan, U. (2006). Detection of urban heat island in Ankara, Turkey. *Il Nuovo Cimento C*, *29*(4), 399–409. https://doi.org/10.1393/ncc/i2005-10028-2
Clark, R. P., & Edholm, O. G. (1985). *Man and his thermal environment*. London: Edward Arnold.
Collins, M., Knutti, R., Arblaster, J., Dufresne, J. L., Fichefet, T., Friedlingstein, P., ... & Booth, B. B. (2013). Long-term climate change: projections, commitments and irreversibility. In Climate Change 2013-The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1029-1136). Cambridge University Press.
Cui, W., Cao, G., Ouyang, Q., & Zhu, Y. (2013). Influence of dynamic environment with different airflows on human performance. *Building and Environment*, *62*, 124–132. https://doi.org/10.1016/j.buildenv.2013.01.008
Cui, W., Cao, G., Park, J. H., Ouyang, Q., & Zhu, Y. (2013). Influence of indoor air temperature on human thermal comfort, motivation and performance. *Building and Environment*, *68*, 114–122. https://doi.org/10.1016/j.buildenv.2013.06.012
Culbertson, W. C., & Sari, D. A. (1997). Preliminary normative study of the d2 test with American children. *Archives of Clinical Neuropsychology*, *12*(4), 303–304. https://doi.org/10.1093/arclin/12.4.303b
da Silva-Sauer, L., Garcia, R. B., Ehrich de Moura, A., & Fernández-Calvo, B. (2022). Does the d2 Test of Attention only assess sustained attention? Evidence of working memory processes involved. *Applied Neuropsychology: Adult*, 1–9. https://doi.org/10.1080/23279095.2021.2023152
De Brito, F. B., Da Silva, L. B., De Souza, E. L., & Barros, T. S. (2019). Study of globe temperature relative to air temperature during cognitive activities in information technology laboratories. *Work*, *62*(3), 393-410.
de Dear, R. J., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions*, *104*(1), 145-67.
Dihkan, M., Karsli, F., Guneroglu, N., & Guneroglu, A. (2018). Evaluation of urban heat island effect in Turkey. *Arabian Journal of Geosciences*, *11*(8), 186. https://doi.org/10.1007/s12517-018-3533-3
Djekic, J., Mitkovic, P., Dinic-Brankovic, M., Igic, M., Djekic, P., & Mitkovic, M. (2018). The study of effects of greenery on temperature reduction in urban areas. *Thermal Science*, *22*(Suppl. 4), 988–1000. https://doi.org/10.2298/TSCI170530122D

Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. *Renewable and sustainable energy reviews*, *14*(9), 2626-2640.

Doherty, T., & Arens, E. A. (1988). Evaluation of the physiological bases of thermal comfort models. *ASHRAE Transactions*, *94*(1).

Dore, G. A., Elias, M. F., Robbins, M. A., Elias, P. K., & Brennan, S. L. (2007). Cognitive performance and age: norms from the maine-syracuse study. *Experimental Aging Research*, *33*(3), 205–271. https://doi.org/10.1080/03610730701319087

Du, Y., Mak, C. M., Liu, J., Xia, Q., Niu, J., & Kwok, K. C. S. (2017). Effects of lift-up design on pedestrian level wind comfort in different building configurations under three wind directions. *Building and Environment*, *117*, 84–99. https://doi.org/10.1016/j.buildenv.2017.03.001

Eichna, L. W., Bean, W. B., Ashe, W. F., & Nelson, N. (1945). Performance in relation to Environmental Temperature, Reactions of Normal Young Men to Hot, Humid (Simulated Jungle) Environment. *Bulletin of the Johns Hopkins Hospital*, *76*(1), 25-58.

Eliasson, I., Knez, I., Westerberg, U., Thorsson, S., & Lindberg, F. (2007). Climate and behaviour in a Nordic city. *Landscape and Urban Planning*, *82*(1–2), 72–84. https://doi.org/10.1016/j.landurbplan.2007.01.020

Elnabawi, M. H., & Hamza, N. (2020). A behavioural analysis of outdoor thermal comfort: a comparative analysis between formal and informal shading practices in urban sites. *Sustainability*, *12*(21), 9032. https://doi.org/10.3390/su12219032

Emmanuel, R., Rosenlund, H., & Johansson, E. (2007). Urban shading-a design option for the tropics? A study in Colombo, Sri Lanka: urban shading in the tropics. *International Journal of Climatology*, *27*(14), 1995–2004. https://doi.org/10.1002/joc.1609

Fan, X., Liu, W., & Wargocki, P. (2019). Physiological and psychological reactions of sub-tropically acclimatized subjects exposed to different indoor temperatures at a relative humidity of 70%. *Indoor Air*, *29*(2), 215–230. https://doi.org/10.1111/ina.12523

Fanger, P. O. (1967). Calculation of thermal comfort-introduction of a basic comfort equation. *ASHRAE Transacions*, *73*.

Fanger, P. O. (1970). *Thermal comfort: analysis and applications in environmental engineering*. Copenhagen: Danish Technical Press.

Fanger, P. O. (1972). *Thermal comfort: Analysis and applications in environmental engineering*. New York: McGraw-Hill.

Fox, R. H. (1974). Heat acclimatisation and the sweating response. Heat loss from animals and man (JL Monteith and LE Mount, eds.), 277-303.

Fransson, N., Västfjäll, D., & Skoog, J. (2007). In search of the comfortable indoor environment: A comparison of the utility of objective and subjective indicators of indoor comfort. *Building and Environment*, *42*(5), 1886–1890. https://doi.org/10.1016/j.buildenv.2006.02.021

Fröhlich, D., Gangwisch, M., & Matzarakis, A. (2019). Effect of radiation and wind on thermal comfort in urban environments—Application of the RayMan and SkyHelios model. *Urban Climate*, *27*, 1–7. https://doi.org/10.1016/j.uclim.2018.10.006

Gagge, A. P., Fobelets, A. P., & Berglund, L. (1986). A standard predictive index of human response to the thermal environment. *ASHRAE trans*, *92*(2), 709-731.

Gagge, A. P., Stolwijk, J. A. J., & Hardy, J. D. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. *Environmental research*, *1*(1), 1-20.
Gaoua, N., Racinais, S., Grantham, J., & El Massioui, F. (2011). Alterations in cognitive performance during passive hyperthermia are task dependent. *International Journal of Hyperthermia*, *27*(1), 1–9. https://doi.org/10.3109/02656736.2010.516305
Geng, Y., Ji, W., Lin, B., & Zhu, Y. (2017). The impact of thermal environment on occupant IEQ perception and productivity. *Building and Environment*, *121*, 158–167. https://doi.org/10.1016/j.buildenv.2017.05.022
Givoni, B. (1976). *Man, climate and architecture*. (2nd ed.). London: Applied Science Publishers.
Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N., & Becker, S. (2003). Outdoor comfort research issues. *Energy and Buildings*, *35*(1), 77–86. https://doi.org/10.1016/S0378-7788(02)00082-8
Goto, T., & Toftum, J. (2002). Thermal sensation and comfort with transient metabolic rates. *Indoor Air*, 6.
Griffiths, I. D., Huber, J. W., & Baillie, A. P. (1987). Integrating the environment. In Proceeding of the 1987 European Conference on Architecture. Kluwer Academic Publishers, The Netherlands.
Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of The Total Environment*, *584–585*, 1040–1055. https://doi.org/10.1016/j.scitotenv.2017.01.158
Hadianpour, M., Mahdavinejad, M., Bemanian, M., & Nasrollahi, F. (2018). Seasonal differences of subjective thermal sensation and neutral temperature in an outdoor shaded space in Tehran, Iran. *Sustainable Cities and Society*, *39*, 751–764. https://doi.org/10.1016/j.scs.2018.03.003
Hanafi, A., & Alkama, D. (2017). Role of the urban vegetal in improving the thermal comfort of a public place of a contemporary Saharan city. *Energy Procedia*, *119*, 139–152. https://doi.org/10.1016/j.egypro.2017.07.061
Havenith, G., Holmér, I., & Parsons, K. (2002). Personal factors in thermal comfort assessment: Clothing properties and metabolic heat production. *Energy and Buildings*, *34*(6), 581–591. https://doi.org/10.1016/S0378-7788(02)00008-7
He, B.-J., Yang, L., & Ye, M. (2014). Strategies for creating good wind environment around Chinese residences. *Sustainable Cities and Society*, *10*, 174–183. https://doi.org/10.1016/j.scs.2013.08.003
Herrmann, J., & Matzarakis, A. (2012). Mean radiant temperature in idealised urban canyons—Examples from Freiburg, Germany. *International Journal of Biometeorology*, *56*(1), 199–203. https://doi.org/10.1007/s00484-010-0394-1
Hocking, C., Silberstein, R. B., Lau, W. M., Stough, C., & Roberts, W. (2001). Evaluation of cognitive performance in the heat by functional brain imaging and psychometric testing. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 128(4), 719-734.
Hodder, S. G., & Parsons, K. (2007). The effects of solar radiation on thermal comfort. *International journal of biometeorology*, *51*(3), 233-250.
Hodder, S., & Parsons, K. (2008). The effects of solar radiation and black body re-radiation on thermal comfort. *Ergonomics*, *51*(4), 476-491.
Höppe, P. (1984). Die energiebilanz des menschen (PhD dissertation). Wissenschaft Mitteilung Meteorological Institute University Munchen. Munich, Germany.

Höppe, P. (1994). Die Wärmebilanzmodelle MEMI und IMEM zur Bewertung der thermischen Beanspruchung am Arbeitsplatz. Verh. Dtsch. Ges. Arbeitsmed. Umweltmed, 34, 153-158.
Höppe, P. (1999). The physiological equivalent temperature—A universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, *43*(2), 71–75. https://doi.org/10.1007/s004840050118
Höppe, P. (2002). Different aspects of assessing indoor and outdoor thermal comfort. *Energy and Buildings*, *34*(6), 661–665. https://doi.org/10.1016/S0378-7788(02)00017-8
Höppe, P. R. (1993). Heat balance modelling. *Experientia, 49*(9), 741-746.
Hou, Y. (2018, June). Effect of wind speed on human thermal sensation and thermal comfort. In AIP Conference Proceedings 1971. https://doi.org/10.1063/1.5041131
Hu, S., & Maeda, T. (2020). Productivity and physiological responses during exposure to varying air temperatures and clothing conditions. *Indoor Air*, *30*(2), 251–263. https://doi.org/10.1111/ina.12628
Huang, T., Niu, J., Xie, Y., Li, J., & Mak, C. M. (2020). Assessment of “lift-up” design’s impact on thermal perceptions in the transition process from indoor to outdoor. *Sustainable Cities and Society*, *56*, 102081. https://doi.org/10.1016/j.scs.2020.102081
Huang, Z., Cheng, B., Gou, Z., & Zhang, F. (2019). Outdoor thermal comfort and adaptive behaviors in a university campus in China’s hot summer-cold winter climate region. *Building and Environment*, *165*, 106414. https://doi.org/10.1016/j.buildenv.2019.106414
Humphreys, M. (1978). Outdoor temperatures and comfort indoors. *Batiment International*, *Building Research and Practice*, *6*(2), 92–92. https://doi.org/10.1080/09613217808550656
Humphreys, M. A., & Nicol, J. F. (2000). Outdoor temperature and indoor thermal comfort: raising the precision of the relationship for the 1998 ASHRAE database of field studies. *Ashrae Transactions*, *106*(2), 485-492.
Humphreys, M. A., Rijal, H. B., & Nicol, J. F. (2013). Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. *Building and Environment*, *63*, 40–55. https://doi.org/10.1016/j.buildenv.2013.01.024
Hwang, R.-L., Lin, T.-P., & Matzarakis, A. (2011). Seasonal effects of urban street shading on long-term outdoor thermal comfort. *Building and Environment*, *46*(4), 863–870. https://doi.org/10.1016/j.buildenv.2010.10.017
Hwang, R.-L., Lin, T.-P., Chen, C.-P., & Kuo, N.-J. (2009). Investigating the adaptive model of thermal comfort for naturally ventilated school buildings in Taiwan. International Journal of Biometeorology, 53(2), 189–200. https://doi.org/10.1007/s00484-008-0203-2
Hygge, S., & Knez, I. (2001). Effects of noise, heat and indoor lighting on cognitive performance and self-reported affect. *Journal of Environmental Psychology*, *21*(3), 291–299. https://doi.org/10.1006/jevp.2001.0222
İmamoğlu, Ç., & Gürel, M. Ö. (2016). “Good fences make good neighbors”: Territorial dividers increase user satisfaction and efficiency in library study spaces. *The Journal of Academic Librarianship, 42*(1), 65-73.
ISO. (1998). 7726, *Ergonomics of the thermal environment, instruments for measuring physical quantities*. Geneva: International Standard Organization.

ISO. (2005). ISO Standard 7730:2005. *Moderate Thermal Environments—Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort*. Geneva: International Organization for Standardization.

Jamieson, N. J., Carpenter, P., & Cenek, P. D. (1992). The effect of architectural detailing on pedestrian level wind speeds. *Journal of Wind Engineering and Industrial Aerodynamics*, *44*(1–3), 2301–2312. https://doi.org/10.1016/0167-6105(92)90020-B

Jendritzky, G. (1990). Bioklimatische Bewertungsgrundlage der Raume am Beispiel von mesoskaligen Bioklimakarten. Akad f Raumforsch u Landesplanung, 114, 7-69.

Jendritzky, G., de Dear, R., & Havenith, G. (2012). UTCI—Why another thermal index? *International Journal of Biometeorology*, *56*(3), 421–428. https://doi.org/10.1007/s00484-011-0513-7

Jendritzky, G., Sönning, W., & Swantes, H. J. (1979). Ein objektives Bewertungsverfahren zur Beschreibung des thermischen Milieus in der Stadt- und Landschaftsplanung ("Klima-Michel-Modell"). Hannover: Beiträge Akad. Raumforschung Landesplanung.

Jensen, K. L., Toftum, J., & Friis-Hansen, P. (2009). A Bayesian Network approach to the evaluation of building design and its consequences for employee performance and operational costs. *Building and Environment*, *44*(3), 456–462. https://doi.org/10.1016/j.buildenv.2008.04.008

Jiang, J., Wang, D., Liu, Y., Xu, Y., & Liu, J. (2018). A study on pupils' learning performance and thermal comfort of primary schools in China. *Building and Environment*, *134*, 102–113. https://doi.org/10.1016/j.buildenv.2018.02.036

Jing, S., Li, B., Tan, M., & Liu, H. (2013). Impact of relative humidity on thermal comfort in a warm environment. *Indoor and Built Environment*, *22*(4), 598–607. https://doi.org/10.1177/1420326X12447614

Kabošová, L., Kmeť, S., & Katunský, D. (2020). Wind flow around buildings of basic shapes with and without a wind-adaptive envelope. *Selected Scientific Papers - Journal of Civil Engineering*, *15*(1), 59–75. https://doi.org/10.1515/sspjce-2020-0007

Kalmár, F. (2016). Investigation of thermal perceptions of subjects with diverse thermal histories in warm indoor environment. *Building and Environment*, *107*, 254–262. https://doi.org/10.1016/j.buildenv.2016.08.010

Kalz, D. E., & Pfafferott, J. (2014). *Thermal comfort and energy-efficient cooling of nonresidential buildings* (pp. 2-8). Cham, Germany: Springer International Publishing.

Kaplan, E., Goodclass, H., & Weintraub, S. (1983). *Boston Naming Test*. Philadelphia: Lea and Febiger.

Karjalainen, S. (2009). Thermal comfort and use of thermostats in Finnish homes and offices. *Building and Environment*, *44*(6), 1237-1245.

Katzschner, L., Bosch, U., & Röttgen, M. (2006). Behaviour of people in open spaces in dependence of thermal comfort conditions. In Proceedings of 23rd Conference on Passive and Low Energy Architecture, PLEA2006. Geneva, Switzerland. Available online. http://web5.arch.cuhk.edu.hk/server1/staff1/edward/www/plea2018/plea/2006/Vol1/PLEA2006_PAPER714.pdf

Keough, N. (2014). Calgary, Sustainable. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 483–484). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_2939

Kim, J., de Dear, R., Parkinson, T., & Candido, C. (2017). Understanding patterns of adaptive comfort behaviour in the Sydney mixed-mode residential context. *Energy and Buildings*, *141*, 274–283. https://doi.org/10.1016/j.enbuild.2017.02.061

Kim, Y.-H., & Baik, J.-J. (2002). Maximum Urban Heat Island Intensity in Seoul. *Journal of Applied Meteorology*, *41*(6), 651–659. https://doi.org/10.1175/1520-0450(2002)041<0651:MUHIII>2.0.CO;2

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., & Hyatt, O. (2016). Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts. *Annual Review of Public Health*, *37*(1), 97–112. https://doi.org/10.1146/annurev-publhealth-032315-021740

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015). Street greenery and its physical and psychological impact on thermal comfort. *Landscape and Urban Planning*, *138*, 87–98. https://doi.org/10.1016/j.landurbplan.2015.02.009

Kotzen, B. (2003). An investigation of shade under six different tree species of the Negev desert towards their potential use for enhancing micro-climatic conditions in landscape architectural development. *Journal of Arid Environments*, *55*(2), 231–274. https://doi.org/10.1016/S0140-1963(03)00030-2

Krüger, E. L., & Zannin, P. H. T. (2004). Acoustic, thermal and luminous comfort in classrooms. *Building and Environment*, *39*(9), 1055–1063. https://doi.org/10.1016/j.buildenv.2004.01.030

Krüger, E. L., Minella, F. O., & Rasia, F. (2011). Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. *Building and Environment*, *46*(3), 621–634. https://doi.org/10.1016/j.buildenv.2010.09.006

Kubota, T., Miura, M., Tominaga, Y., & Mochida, A. (2008). Wind tunnel tests on the relationship between building density and pedestrian-level wind velocity: Development of guidelines for realizing acceptable wind environment in residential neighborhoods. *Building and Environment*, *43*(10), 1699–1708. https://doi.org/10.1016/j.buildenv.2007.10.015

Kuo, C.-Y., Tzeng, C.-T., Ho, M.-C., & Lai, C.-M. (2015). Wind tunnel studies of a pedestrian-level wind environment in a street canyon between a high-rise building with a podium and low-level attached houses. *Energies*, *8*(10), 10942–10957. https://doi.org/10.3390/en81010942

Kuraishi, S., Kato, M., & Tsujioka, B. (1957). Development of the “Uchida-Kraepelin psychodiagnostic test” in Japan. *Psychologia*, *1*(2), 104-109.

Kuttler, W. (2004). Stadtklima. Umweltwissenschaften und Schadstoff-Forschung, *16*(3), 187-199.

Kwon, J., & Choi, J. (2012). The relationship between environmental temperature and clothing insulation across a year. *International Journal of Biometeorology*, *56*(5), 887–893. https://doi.org/10.1007/s00484-011-0493-7

Lai, D., Lian, Z., Liu, W., Guo, C., Liu, W., Liu, K., & Chen, Q. (2020). A comprehensive review of thermal comfort studies in urban open spaces.

Science of The Total Environment, *742*, 140092. https://doi.org/10.1016/j.scitotenv.2020.140092
Lan, L., & Lian, Z. (2009). Use of neurobehavioral tests to evaluate the effects of indoor environment quality on productivity. *Building and Environment*, *44*(11), 2208–2217. https://doi.org/10.1016/j.buildenv.2009.02.001
Lan, L., Lian, Z., & Pan, L. (2010). The effects of air temperature on office workers' well-being, workload and productivity-evaluated with subjective ratings. *Applied Ergonomics*, *42*(1), 29–36. https://doi.org/10.1016/j.apergo.2010.04.003
Lan, L., Wargocki, P., & Lian, Z. (2011). Quantitative measurement of productivity loss due to thermal discomfort. *Energy and Buildings*, *43*(5), 1057–1062. https://doi.org/10.1016/j.enbuild.2010.09.001
Lan, L., Xia, L., Hejjo, R., Wyon, D. P., & Wargocki, P. (2020). Perceived air quality and cognitive performance decrease at moderately raised indoor temperatures even when clothed for comfort. *Indoor Air*, *30*(5), 841–859. https://doi.org/10.1111/ina.12685
Lee, D. O. (1992). Urban warming?- an analysis of recent trends in London's heat island. *Weather*, *47*(2), 50–56. https://doi.org/10.1002/j.1477-8696.1992.tb05773.x
Lee, H., Mayer, H., & Schindler, D. (2014). Importance of 3-D radiant flux densities for outdoor human thermal comfort on clear-sky summer days in Freiburg, Southwest Germany. *Meteorologische Zeitschrift*, *23*(3), 315–330. https://doi.org/10.1127/0941-2948/2014/0536
Lee, I., Voogt, J., & Gillespie, T. (2018). Analysis and comparison of shading strategies to increase human thermal comfort in urban areas. *Atmosphere*, *9*(3), 91. https://doi.org/10.3390/atmos9030091
Lee, Y. Y., Md Din, M. F., Iwao, K., Lee, Y. H., & Anting, N. (2021). Impact of thermal behaviour of different environmental conditions on ambient environment and thermal discomfort in Malaysia. *Indoor and Built Environment*, *30*(4), 520–534. https://doi.org/10.1177/1420326X19897956
Lercher, P., Evans, G. W., & Meis, M. (2003). Ambient noise and cognitive processes among primary schoolchildren. *Environment and Behavior*, *35*(6), 725–735. https://doi.org/10.1177/0013916503256260
Li, B., Liu, M., & McKinnell, K. G. (2006). Impact of urbanization on building energy consumption and the role of BEE design codes in China: A position statement. *Property Management*, *24*(3), 354–364. https://doi.org/10.1108/02637470610660200
Li, J., Zhao, L., Peng, Z., Wang, Z., & Shui, T. (2020). Study on outdoor thermal comfort in the transitional season of Hefei. *E3S Web of Conferences*, *165*, 01026. https://doi.org/10.1051/e3sconf/202016501026
Lin, J., Li, D., & Brown, R. D. (2022). Microclimatic landscape architecture: from theory to application. *Urban Science*, *6*(1), 9. https://doi.org/10.3390/urbansci6010009
Lin, T. P., Ho, Y. F., & Huang, Y. S. (2007). Seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan. *Building and environment*, *42*(12), 4124-4131.
Lin, T.-P. (2009). Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Building and Environment*, *44*(10), 2017–2026. https://doi.org/10.1016/j.buildenv.2009.02.004

Lin, T.-P., de Dear, R., & Hwang, R.-L. (2011). Effect of thermal adaptation on seasonal outdoor thermal comfort. *International Journal of Climatology*, *31*(2), 302–312. https://doi.org/10.1002/joc.2120

Lin, T.-P., Matzarakis, A., & Hwang, R.-L. (2010). Shading effect on long-term outdoor thermal comfort. *Building and Environment*, *45*(1), 213–221. https://doi.org/10.1016/j.buildenv.2009.06.002

Lin, T.-P., Tsai, K.-T., Liao, C.-C., & Huang, Y.-C. (2013). Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types. *Building and Environment*, *59*, 599–611. https://doi.org/10.1016/j.buildenv.2012.10.005

Lin, Z., & Deng, S. (2008). A study on the thermal comfort in sleeping environments in the subtropics—Developing a thermal comfort model for sleeping environments. *Building and Environment*, *43*(1), 70–81. https://doi.org/10.1016/j.buildenv.2006.11.026

Lindberg, F., & Grimmond, C. S. B. (2011). The influence of vegetation and building morphology on shadow patterns and mean radiant temperatures in urban areas: Model development and evaluation. *Theoretical and Applied Climatology*, *105*(3–4), 311–323. https://doi.org/10.1007/s00704-010-0382-8

Liu, G., Jia, Y., Cen, C., Ma, B., & Liu, K. (2020). Comparative thermal comfort study in educational buildings in autumn and winter seasons. *Science and Technology for the Built Environment*, *26*(2), 185–194. https://doi.org/10.1080/23744731.2019.1614426

Liu, H., Wu, Y., Li, B., Cheng, Y., & Yao, R. (2017). Seasonal variation of thermal sensations in residential buildings in the Hot Summer and Cold Winter zone of China. *Energy and Buildings*, *140*, 9–18. https://doi.org/10.1016/j.enbuild.2017.01.066

Liu, W., Zhong, W., & Wargocki, P. (2017). Performance, acute health symptoms and physiological responses during exposure to high air temperature and carbon dioxide concentration. *Building and Environment*, *114*, 96–105. https://doi.org/10.1016/j.buildenv.2016.12.020

Liu, Y., Wang, L., Liu, J., & Di, Y. (2013). A study of human skin and surface temperatures in stable and unstable thermal environments. *Journal of Thermal Biology*, *38*(7), 440–448. https://doi.org/10.1016/j.jtherbio.2013.06.006

Livada, I., Santamouris, M., & Assimakopoulos, M. N. (2007). On the variability of summer air temperature during the last 28 years in Athens. *Journal of Geophysical Research*, *112*(D12), D12103. https://doi.org/10.1029/2006JD008140

Luo, M., Cao, B., Ji, W., Ouyang, Q., Lin, B., & Zhu, Y. (2016). The underlying linkage between personal control and thermal comfort: Psychological or physical effects? *Energy and Buildings*, *111*, 56–63. https://doi.org/10.1016/j.enbuild.2015.11.004

Macpherson, R. K. (1962). The assessment of the thermal environment. A review. *Occupational and Environmental Medicine*, *19*(3), 151-164.

Maitland, C., Stratton, G., Foster, S., Braham, R., & Rosenberg, M. (2014). The Dynamic Family Home: a qualitative exploration of physical environmental influences on children’s sedentary behaviour and physical activity within the home space. *International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 1-12.

Makaremi, N., Salleh, E., Jaafar, M. Z., & GhaffarianHoseini, A. (2012). Thermal comfort conditions of shaded outdoor spaces in hot and humid climate of Malaysia. *Building and environment*, *48*, 7-14.
Mallick, F. H. (1996). Thermal comfort and building design in the tropical climates. *Energy and buildings*, *23*(3), 161-167.
Manu, S., Shukla, Y., Rawal, R., Thomas, L. E., & de Dear, R. (2016). Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). *Building and Environment*, *98*, 55–70. https://doi.org/10.1016/j.buildenv.2015.12.019
Martin, S. H. (2009). Environment-behaviour studies in the classroom. *Journal of Design & Technology Education*, *9*(2).
Martinelli, L., Lin, T.-P., & Matzarakis, A. (2015). Assessment of the influence of daily shadings pattern on human thermal comfort and attendance in Rome during summer period. *Building and Environment*, *92*, 30–38. https://doi.org/10.1016/j.buildenv.2015.04.013
Matthews, T. K. R., Wilby, R. L., & Murphy, C. (2017). Communicating the deadly consequences of global warming for human heat stress. *Proceedings of the National Academy of Sciences*, *114*(15), 3861–3866. https://doi.org/10.1073/pnas.1617526114
Matzarakis, A. (2014). Transfer of climate data for tourism applications-the climate-tourism/transfer-information-scheme. *Sustain Environ Res*, *24*(4), 273-280.
Matzarakis, A. (2021). Comments about urban bioclimate aspects for consideration in urban climate and planning issues in the era of climate change. *Atmosphere*, *12*(5), 546. https://doi.org/10.3390/atmos12050546
Matzarakis, A. (2022). Communication aspects about heat in an era of global warming—the lessons learnt by germany and beyond. *Atmosphere*, *13*(2), 226. https://doi.org/10.3390/atmos13020226
Matzarakis, A., & Amelung, B. (2008). Physiological equivalent temperature as indicator for impacts of climate change on thermal comfort of humans. In *Seasonal forecasts, climatic change and human health* (pp. 161-172). Springer, Dordrecht.
Matzarakis, A., & Fröhlich, D. (2018). Influence of urban green on human thermal bioclimate – application of thermal indices and micro-scale models. *Acta Horticulturae*, *1215*, 1–10. https://doi.org/10.17660/ActaHortic.2018.1215.1
Matzarakis, A., & Mayer, H. (1997). Heat stress in Greece. *International Journal of Biometeorology*, *41*(1), 34–39. https://doi.org/10.1007/s004840050051
Matzarakis, A., & Mayer, H. (2000). Atmospheric conditions and human thermal comfort in urban areas. In 11th Seminar on Environmental Protection "Environment and Health".
Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology*, *43*(2), 76–84. https://doi.org/10.1007/s004840050119
Matzarakis, A., Rutz, F., & Mayer, H. (2006). Modelling the thermal bioclimate in urban areas with the RayMan Model. In International Conference on Passive and Low Energy Architecture.
Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling radiation fluxes in simple and complex environments—Application of the RayMan model. *International Journal of Biometeorology*, *51*(4), 323–334. https://doi.org/10.1007/s00484-006-0061-8

Matzarakis, A., Rutz, F., & Mayer, H. (2010). Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model. *International Journal of Biometeorology*, *54*(2), 131–139. https://doi.org/10.1007/s00484-009-0261-0

Maula, H., Hongisto, V., Östman, L., Haapakangas, A., Koskela, H., & Hyönä, J. (2016). The effect of slightly warm temperature on work performance and comfort in open-plan offices—A laboratory study. *Indoor Air*, *26*(2), 286–297. https://doi.org/10.1111/ina.12209

Mayer, H. (1993). Urban bioclimatology. *Experientia*, *49*(11), 957-963.

Mayer, H., & Höppe, P. (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology*, *38*(1), 43–49. https://doi.org/10.1007/BF00866252

Mayer, H., Holst, J., Dostal, P., Imbery, F., & Schindler, D. (2008). Human thermal comfort in summer within an urban street canyon in Central Europe. *Meteorologische Zeitschrift*, *17*(3), 241–250. https://doi.org/10.1127/0941-2948/2008/0285

Mazouz, S., & Zerouala, M. S. (1998). Shading as a modulator for the design of urban layouts based on vernacular experiences. *Energy and Buildings*, *29*(1), 11–15. https://doi.org/10.1016/S0378-7788(97)00054-6

Middel, A., Selover, N., Hagen, B., & Chhetri, N. (2016). Impact of shade on outdoor thermal comfort—A seasonal field study in Tempe, Arizona. *International Journal of Biometeorology*, *60*(12), 1849–1861. https://doi.org/10.1007/s00484-016-1172-5

Mironova, J. (2020). Wind impact on low-rise buildings when placing high-rises into the existing development. *IOP Conference Series: Materials Science and Engineering*, *890*(1), 012055. https://doi.org/10.1088/1757-899X/890/1/012055

Mishra, A. K., Derks, M. T. H., Kooi, L., Loomans, M. G. L. C., & Kort, H. S. M. (2017). Analysing thermal comfort perception of students through the class hour, during heating season, in a university classroom. *Building and Environment*, *125*, 464–474. https://doi.org/10.1016/j.buildenv.2017.09.016

Morgan, C., & de Dear, R. (2003). Weather, clothing and thermal adaptation to indoor climate. *Climate Research*, *24*, 267–284. https://doi.org/10.3354/cr024267

Munonye, C. (2020). The influence of seasonal variation of thermal variables on comfort temperature in schools in a warm and humid climate. *OALib*, *07*(09), 1–13. https://doi.org/10.4236/oalib.1106753

Mustapa, M. S., Zaki, S. A., Rijal, H. B., Hagishima, A., & Ali, M. S. M. (2016). Thermal comfort and occupant adaptive behaviour in Japanese university buildings with free running and cooling mode offices during summer. *Building and Environment*, *105*, 332-342.

Nagano, K., Takaki, A., Hirakawa, M., & Tochihara, Y. (2005). Effects of ambient temperature steps on thermal comfort requirements. *International journal of biometeorology*, *50*(1), 33-39.

Nasir, R. A., Ahmad, S. S., & Ahmed, A. Z. (2012). Psychological adaptation of outdoor thermal comfort in shaded green spaces in Malaysia. *Procedia - Social and Behavioral Sciences*, *68*, 865–878. https://doi.org/10.1016/j.sbspro.2012.12.273

Ndetto, E. L., & Matzarakis, A. (2013). Effects of urban configuration on human thermal conditions in a typical tropical African coastal city. *Advances in Meteorology*, *2013*, 1–12. https://doi.org/10.1155/2013/549096
Ng, E. (2009). Policies and technical guidelines for urban planning of high-density cities – air ventilation assessment (AVA) of Hong Kong. *Building and Environment*, *44*(7), 1478–1488. https://doi.org/10.1016/j.buildenv.2008.06.013
Ng, E., & Cheng, V. (2012). Urban human thermal comfort in hot and humid Hong Kong. *Energy and Buildings*, *55*, 51–65. https://doi.org/10.1016/j.enbuild.2011.09.025
Nguyen, J. L., Schwartz, J., & Dockery, D. W. (2014). The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity. *Indoor air*, *24*(1), 103-112.
Nicol, F., & Humphreys, M. (2010). Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN15251. *Building and Environment*, *45*(1), 11–17. https://doi.org/10.1016/j.buildenv.2008.12.013
Nicol, J. F., & Humphreys, M. A. (1973). Thermal comfort as part of a self-regulating system. *Building Research and Practice*, *1*(3), 174–179. https://doi.org/10.1080/09613217308550237
Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*, *34*(6), 563–572. https://doi.org/10.1016/S0378-7788(02)00006-3
Nicol, J. F., Raja, I. A., Allaudin, A., & Jamy, G. N. (1999). Climatic variations in comfortable temperatures: the Pakistan projects. *Energy and buildings*, *30*(3), 261-279.
Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Building and Environment*, *41*(11), 1455–1470. https://doi.org/10.1016/j.buildenv.2005.05.031
Nikolopoulou, M., & Lykoudis, S. (2007). Use of outdoor spaces and microclimate in a Mediterranean urban area. *Building and Environment*, *42*(10), 3691–3707. https://doi.org/10.1016/j.buildenv.2006.09.008
Nikolopoulou, M., & Steemers, K. (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings*, 7.
Nikolopoulou, M., Baker, N., & Steemers, K. (1999). Thermal comfort in urban spaces: different forms of adaptation. In Proceedings of the REBUILD International Conference: The Cities of Tomorrow. Barcelona.
Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: Understanding the human parameter. *Solar Energy*, *70*(3), 227–235. https://doi.org/10.1016/S0038-092X(00)00093-1
NOAA National Centers for Environmental Information, State of the Climate: Global Climate Report for Annual 2021, published online January 2022, retrieved on April 5, 2022 from https://www.ncdc.noaa.gov/sotc/global/202113.
Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, *134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018

Nouri, A. S. (2015). A framework of thermal sensitive urban design benchmarks: potentiating the longevity of Auckland’s public realm. *Buildings*, *5*(1), 252–281. https://doi.org/10.3390/buildings5010252

Nouri, A. S. (2018). Addressing urban outdoor thermal comfort thresholds through public space design - A bottom-up interdisciplinary research approach for thermal sensitive urban design in an era of climate change: The Lisbon Case. (PhD Thesis). University of Lisbon.

Nouri, A. S., & Costa, J. P. (2017). Addressing thermophysiological thresholds and psychological aspects during hot and dry mediterranean summers through public space design: The case of Rossio. *Building and Environment*, *118*, 67–90. https://doi.org/10.1016/j.buildenv.2017.03.027

Nouri, A. S., Afacan, Y., Çalışkan, O., Lin, T.-P., & Matzarakis, A. (2021a). Approaching environmental human thermophysiological thresholds for the case of Ankara, Turkey. *Theoretical and Applied Climatology*, *143*(1–2), 533–555. https://doi.org/10.1007/s00704-020-03436-5

Nouri, A. S., Çalışkan, O., Charalampopoulos, I., Cheval, S., & Matzarakis, A. (2021b). Defining local extreme heat thresholds and indoor cooling degree necessity for vulnerable residential dwellings during the 2020 summer in Ankara–Part I: Air temperature. *Solar Energy*.

Nouri, A. S., Costa, J. P., Santamouris, M., & Matzarakis, A. (2018). Approaches to outdoor thermal comfort thresholds through public space design: A review. *Atmosphere*, *9*(3), 108.

Nouri, A.S., & Matzarakis, A. (2019). The maturing interdisciplinary relationship between human biometeorological aspects and local adaptation processes: an encompassing overview. *Climate*, *7*(12), 134. https://doi.org/10.3390/cli7120134

Nugrahanti, F. I., Lubis, I. H., & Kusyala, D. (2018). The impact of building mass configuration towards wind-driven natural ventilation in apartment in Jakarta. *IOP Conference Series: Earth and Environmental Science*, *213*, 012042. https://doi.org/10.1088/1755-1315/213/1/012042

Oke, T. R. (1981). Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. *Journal of Climatology*, *1*(3), 237–254. https://doi.org/10.1002/joc.3370010304

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1–24. https://doi.org/10.1002/qj.49710845502

Oke, T.R. (2009). *Boundary Layer Climates* (2nd ed., reprinted). London: Routledge.

Othman, N. E., Zaki, S. A., Rijal, H. B., Ahmad, N. H., & Razak, A. A. (2021). Field study of pedestrians’ comfort temperatures under outdoor and semi-outdoor conditions in Malaysian university campuses. *International Journal of Biometeorology*, *65*(4), 453–477. https://doi.org/10.1007/s00484-020-02035-3

Palonen, J., Seppänen, O., & Jaakkola, J. J. (1993). The effects of air temperature and relative humidity on thermal comfort in the office environment. *Indoor Air*, *3*(4), 391-397.

Pan, J., Tang, J., Caniza, M., Heraud, J. M., Koay, E., Lee, H. K., ... & Marr, L. C. (2021). Correlating indoor and outdoor temperature and humidity in a sample of buildings in tropical climates. *Indoor air, 31*(6), 2281-2295.

Pantavou, K., Theoharatos, G., Santamouris, M., & Asimakopoulos, D. (2013). Outdoor thermal sensation of pedestrians in a Mediterranean climate and a comparison with UTCI. *Building and Environment*, *66*, 82–95. https://doi.org/10.1016/j.buildenv.2013.02.014

Pearlmutter, D., Berliner, P., & Shaviv, E. (2007). Integrated modeling of pedestrian energy exchange and thermal comfort in urban street canyons. *Building and Environment*, *42*(6), 2396–2409. https://doi.org/10.1016/j.buildenv.2006.06.006

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Ko¨ppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.*, 12.

Perini, K., & Magliocco, A. (2014). Effects of vegetation, urban density, building height, and atmospheric conditions on local temperatures and thermal comfort. *Urban Forestry & Urban Greening*, *13*(3), 495–506. https://doi.org/10.1016/j.ufug.2014.03.003

Pirrie, A. M., & Lodewyk, K. R. (2012). Investigating links between moderate-to-vigorous physical activity and cognitive performance in elementary school students. *Mental Health and Physical Activity*, *5*(1), 93–98. https://doi.org/10.1016/j.mhpa.2012.04.001

Pomerantz, M., Ppn, B., & Akbari, H. (2000). The effect of pavements' temperatures on air temperatures in large cities. Lawrence Berkeley National Laboratory Report No. LBNL-43443, Berkeley, CA.

Rajagopalan, P., Lim, K. C., & Jamei, E. (2014). Urban heat island and wind flow characteristics of a tropical city. *Solar Energy*, *107*, 159–170. https://doi.org/10.1016/j.solener.2014.05.042

Ricci, A., Guasco, M., Caboni, F., Orlanno, M., Giachetta, A., & Repetto, M. P. (2022). Impact of surrounding environments and vegetation on wind comfort assessment of a new tower with vertical green park. *Building and Environment*, *207*, 108409. https://doi.org/10.1016/j.buildenv.2021.108409

Riham Jaber, A., Dejan, M., & Marcella, U. (2017). The effect of indoor temperature and CO_2 levels on cognitive performance of adult females in a university building in Saudi Arabia. *Energy Procedia*, *122*, 451–456. https://doi.org/10.1016/j.egypro.2017.07.378

Rijal, H. B., Humphreys, M., & Nicol, F. (2015). Adaptive thermal comfort in Japanese houses during the summer season: behavioral adaptation and the effect of humidity. *Buildings, 5*(3), 1037-1054.

Rijal, H. B., Tuohy, P., Humphreys, M. A., Nicol, J. F., Samuel, A., & Clarke, J. (2007). Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings. *Energy and Buildings*, *39*(7), 823–836. https://doi.org/10.1016/j.enbuild.2007.02.003

Rodríguez-Algeciras, J., Tablada, A., Nouri, A. S., & Matzarakis, A. (2021). Assessing the influence of street configurations on human thermal conditions in open balconies in the Mediterranean climate. *Urban Climate*, *40*, 100975.

Sahabi Abed, S., & Matzarakis, A. (2017). Seasonal regional differentiation of human thermal comfort conditions in Algeria. *Advances in Meteorology*, *2017*, 1–14. https://doi.org/10.1155/2017/9193871

Saitoh, T. S., Shimada, T., & Hoshi, H. (1996). Modeling and simulation of the Tokyo urban heat island. *Atmospheric Environment*, *30*(20), 3431–3442. https://doi.org/10.1016/1352-2310(95)00489-0

Sangkertadi, S., & Syafriny, R. (2017). Pair influence of wind speed and mean radiant temperature on outdoor thermal comfort of humid tropical environment. *Journal of Urban and Environmental Engineering*, *10*(2), 177–185. https://doi.org/10.4090/juee.2016.v10n2.177185

Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. *Renewable and Sustainable Energy Reviews*, *26*, 224–240. https://doi.org/10.1016/j.rser.2013.05.047

Santamouris, M. (2019). Urban Heat Island and Local Climate Change. In *Minimizing Energy Consumption, Energy Poverty and Global and Local Climate Change in the Built Environment: Innovating to Zero* (pp. 65–102). Elsevier. https://doi.org/10.1016/B978-0-12-811417-9.00003-9

Sarbu, I., & Pacurar, C. (2015). Experimental and numerical research to assess indoor environment quality and schoolwork performance in university classrooms. *Building and Environment*, *93*, 141–154. https://doi.org/10.1016/j.buildenv.2015.06.022

Schär, C., Vidale, P. L., Lüthi, D., Frei, C., Häberli, C., Liniger, M. A., & Appenzeller, C. (2004). The role of increasing temperature variability in European summer heatwaves. *Nature*, *427*(6972), 332–336. https://doi.org/10.1038/nature02300

Schellen, L., Loomans, M. G. L. C., de Wit, M. H., Olesen, B. W., & Lichtenbelt, W. D. van M. (2013). Effects of different cooling principles on thermal sensation and physiological responses. *Energy and Buildings*, *62*, 116–125. https://doi.org/10.1016/j.enbuild.2013.01.007

Schiavon, S., & Lee, K. H. (2013). Dynamic predictive clothing insulation models based on outdoor air and indoor operative temperatures. *Building and Environment*, *59*, 250-260.

Schweiker, M., & Wagner, A. (2016). The effect of occupancy on perceived control, neutral temperature, and behavioral patterns. *Energy and Buildings*, *117*, 246–259. https://doi.org/10.1016/j.enbuild.2015.10.051

Schweiker, M., Brasche, S., Bischof, W., Hawighorst, M., Voss, K., & Wagner, A. (2012). Development and validation of a methodology to challenge the adaptive comfort model. *Building and Environment*, *49*, 336–347. https://doi.org/10.1016/j.buildenv.2011.08.002

Sensoy, S., Türkoğlu, N., Çiçek, İ., Demircan, M., & Bölük, E. (2015). Urbanization effect on trends of extreme temperature indices in Ankara. In 7th Atmospheric Science Symposium. İstanbul: İstanbul Technical University, İstanbul Aydın University. Available online. https://www.mgm.gov.tr/FILES/iklim/yayinlar/2015/3.pdf

Sharmin, T., Steemers, K., & Humphreys, M. (2019). Outdoor thermal comfort and summer PET range: A field study in tropical city Dhaka. *Energy and Buildings*, *198*, 149–159. https://doi.org/10.1016/j.enbuild.2019.05.064

Shashua-Bar, L., Pearlmutter, D., & Erell, E. (2009). The cooling efficiency of urban landscape strategies in a hot dry climate. *Landscape and Urban Planning*, *92*(3–4), 179–186. https://doi.org/10.1016/j.landurbplan.2009.04.005

Shashua-Bar, L., Tsiros, I. X., & Hoffman, M. (2012). Passive cooling design options to ameliorate thermal comfort in urban streets of a Mediterranean climate (Athens) under hot summer conditions. *Building and Environment*, *57*, 110–119. https://doi.org/10.1016/j.buildenv.2012.04.019

Shashua-Bar, L., Tsiros, I. X., & Hoffman, M. E. (2010). A modeling study for evaluating passive cooling scenarios in urban streets with trees. Case study: Athens, Greece. *Building and Environment*, *45*(12), 2798–2807. https://doi.org/10.1016/j.buildenv.2010.06.008

Sheridan, S. C., & Allen, M. J. (2015). Changes in the frequency and intensity of extreme temperature events and human health concerns. *Current Climate Change Reports*, *1*(3), 155–162. https://doi.org/10.1007/s40641-015-0017-3

Shi, Z., Qian, H., Zheng, X., Lv, Z., Li, Y., Liu, L., & Nielsen, P. V. (2018). Seasonal variation of window opening behaviors in two naturally ventilated hospital wards. *Building and Environment*, *130*, 85–93. https://doi.org/10.1016/j.buildenv.2017.12.019

Shibley, R. G., & Weaver, D. F. (1982). A monograph on passive and low energy alternatives in the United States. In *Passive and Low Energy Alternatives I* (pp. 15-71). Pergamon.

Shrestha, M., Rijal, H. B., Kayo, G., & Shukuya, M. (2021). A field investigation on adaptive thermal comfort in school buildings in the temperate climatic region of Nepal. *Building and Environment*, *190*, 107523.

Sinha, P., Bowers, D., Woods, A. J. (2018). D2 test of attention. In: J.S. Kreutzer, J. DeLuca, B. Caplan (Eds.). *Encyclopedia of Clinical Neuropsychology*, (pp. 1039-1043). New York: Springer.

Siqueira, J. C. F., da Silva, L. B., Coutinho, A. S., & Rodrigues, R. M. (2017). Analysis of air temperature changes on blood pressure and heart rate and performance of undergraduate students. *Work*, *57*(1), 43–54. https://doi.org/10.3233/WOR-172533

Sokolova, I. (2019). Temperature Regulation. In *Encyclopedia of Ecology* (pp. 633–639). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11129-7

Spagnolo, J., & de Dear, R. (2003). A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *Building and Environment*, *38*(5), 721–738. https://doi.org/10.1016/S0360-1323(02)00209-3

Staiger, H., Laschewski, G., & Grätz, A. (2012). The perceived temperature – a versatile index for the assessment of the human thermal environment. Part A: Scientific basics. *International Journal of Biometeorology*, *56*(1), 165–176. https://doi.org/10.1007/s00484-011-0409-6

Staiger, H., Laschewski, G., & Matzarakis, A. (2019). Selection of appropriate thermal indices for applications in human biometeorological studies. *Atmosphere*, *10*(1), 18. https://doi.org/10.3390/atmos10010018

Stathopoulos, T., & Storms, R. (1986). Wind environmental conditions in passages between buildings. *Journal of Wind Engineering and Industrial Aerodynamics*, *24*(1), 19–31. https://doi.org/10.1016/0167-6105(86)90070-X

Stathopoulos, T., Wu, H., & Bédard, C. (1992). Wind environment around buildings: A knowledge-based approach. *Journal of Wind Engineering and Industrial Aerodynamics*, *44*(1–3), 2377–2388. https://doi.org/10.1016/0167-6105(92)90028-9

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology, 18*(6), 643.

Sufar, S., Talib, A., & Hambali, H. (2012). Towards a better design: physical interior environments of public libraries in peninsular Malaysia. *Procedia-Social and Behavioral Sciences, 42*, 131-143.

Szkordilisz, F., & Zöld, A. (2016). Effect of vegetation on wind-comfort. *Applied Mechanics and Materials*, *824*, 811–818. https://doi.org/10.4028/www.scientific.net/AMM.824.811

Taleghani, M., Kleerekoper, L., Tenpierik, M., & van den Dobbelsteen, A. (2015). Outdoor thermal comfort within five different urban forms in the

Netherlands. *Building and Environment*, *83*, 65–78. https://doi.org/10.1016/j.buildenv.2014.03.014
Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A. J., Li, F., & Chen, H. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology*, *54*(1), 75–84. https://doi.org/10.1007/s00484-009-0256-x
Tan, Z., Lau, K. K.-L., & Ng, E. (2016). Urban tree design approaches for mitigating daytime urban heat island effects in a high-density urban environment. *Energy and Buildings*, *114*, 265–274. https://doi.org/10.1016/j.enbuild.2015.06.031
Tanabe, S., & Nishihara, N. (2004). Productivity and fatigue. *Indoor Air*, *14*(s7), 126–133. https://doi.org/10.1111/j.1600-0668.2004.00281.x
Thorsson, S., Honjo, T., Lindberg, F., Eliasson, I., & Lim, E.-M. (2007). Thermal comfort and outdoor activity in Japanese urban public places. *Environment and Behavior*, *39*(5), 660–684. https://doi.org/10.1177/0013916506294937
Thorsson, S., Lindqvist, M., & Lindqvist, S. (2004). Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. *International Journal of Biometeorology*, *48*(3), 149–156. https://doi.org/10.1007/s00484-003-0189-8
To, A. P., & Lam, K. M. (1995). Evaluation of pedestrian-level wind environment around a row of tall buildings using a quartile-level wind speed descripter. *Journal of Wind Engineering and Industrial Aerodynamics*, *54–55*, 527–541. https://doi.org/10.1016/0167-6105(94)00069-P
Trebilcock, M., Soto-Muñoz, J., Yañez, M., & Figueroa-San Martin, R. (2017). The right to comfort: a field study on adaptive thermal comfort in free-running primary schools in Chile. *Building and Environment*, *114*, 455–469. https://doi.org/10.1016/j.buildenv.2016.12.036
Tsang, C. W., Kwok, K. C. S., & Hitchcock, P. A. (2012). Wind tunnel study of pedestrian level wind environment around tall buildings: Effects of building dimensions, separation and podium. *Building and Environment*, *49*, 167–181. https://doi.org/10.1016/j.buildenv.2011.08.014
Tse, K. T., Zhang, X., Weerasuriya, A. U., Li, S. W., Kwok, K. C. S., Mak, C. M., & Niu, J. (2017). Adopting 'lift-up' building design to improve the surrounding pedestrian-level wind environment. *Building and Environment*, *117*, 154–165. https://doi.org/10.1016/j.buildenv.2017.03.011
Turkish State Meteorological Service. (2021). İllere ait mevsim normalleri (1991-2020). Retrieved from https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler istatistik.aspx?m=ANKARA.
Uematsu, Y., Yamada, M., Higashiyama, H., & Orimo, T. (1992). Effects of the corner shape of high-rise buildings on the pedestrian-level wind environment with consideration for mean and fluctuating wind speeds. *Journal of Wind Engineering and Industrial Aerodynamics*, *44*(1–3), 2289–2300. https://doi.org/10.1016/0167-6105(92)90019-7
van Druenen, T., van Hooff, T., Montazeri, H., & Blocken, B. (2019). CFD evaluation of building geometry modifications to reduce pedestrian-level wind speed. *Building and Environment*, *163*, 106293. https://doi.org/10.1016/j.buildenv.2019.106293
van Hooren, S. A. H., Valentijn, A. M., Bosma, H., Ponds, R. W. H. M., van Boxtel, M. P. J., & Jolles, J. (2007). Cognitive functioning in healthy older adults aged 64–81: a cohort study into the effects of age, sex, and education. *Aging*,

Neuropsychology, and Cognition, *14*(1), 40–54. https://doi.org/10.1080/138255890969483
Vanos, J. K., Warland, J. S., Gillespie, T. J., Slater, G. A., Brown, R. D., & Kenny, N. A. (2012). Human energy budget modeling in urban parks in Toronto and applications to emergency heat stress preparedness. *Journal of Applied Meteorology and Climatology*, *51*(9), 1639–1653. https://doi.org/10.1175/JAMC-D-11-0245.1
Vecchi, R. D., Lamberts, R., & Candido, C. M. (2017). The role of clothing in thermal comfort: How people dress in a temperate and humid climate in Brazil. *Ambiente Construído*, *17*(1), 69–81. https://doi.org/10.1590/s1678-86212017000100124
Villadiego, K., & Velay-Dabat, M. A. (2014). Outdoor thermal comfort in a hot and humid climate of Colombia: A field study in Barranquilla. *Building and Environment*, *75*, 142–152. https://doi.org/10.1016/j.buildenv.2014.01.017
Walton, D., Dravitzki, V., & Donn, M. (2007). The relative influence of wind, sunlight and temperature on user comfort in urban outdoor spaces. *Building and Environment*, *42*(9), 3166–3175. https://doi.org/10.1016/j.buildenv.2006.08.004
Wang, D., Xu, Y., Liu, Y., Wang, Y., Jiang, J., Wang, X., & Liu, J. (2018). Experimental investigation of the effect of indoor air temperature on students' learning performance under the summer conditions in China. *Building and Environment*, *140*, 140–152. https://doi.org/10.1016/j.buildenv.2018.05.022
Wang, Y., de Groot, R., Bakker, F., Wörtche, H., & Leemans, R. (2017). Thermal comfort in urban green spaces: A survey on a Dutch university campus. *International Journal of Biometeorology*, *61*(1), 87–101. https://doi.org/10.1007/s00484-016-1193-0
Wang, Z., Li, A., Ren, J., & He, Y. (2014). Thermal adaptation and thermal environment in university classrooms and offices in Harbin. *Energy and Buildings*, *77*, 192–196. https://doi.org/10.1016/j.enbuild.2014.03.054
Watanabe, S., & Ishii, J. (2016). Effect of outdoor thermal environment on pedestrians' behavior selecting a shaded area in a humid subtropical region. *Building and Environment*, *95*, 32–41. https://doi.org/10.1016/j.buildenv.2015.09.015
Watanabe, S., Nagano, K., Ishii, J., & Horikoshi, T. (2014). Evaluation of outdoor thermal comfort in sunlight, building shade, and pergola shade during summer in a humid subtropical region. *Building and Environment*, *82*, 556–565. https://doi.org/10.1016/j.buildenv.2014.10.002
Webb, K. M., Schaller, M. A., & Hunley, S. A. (2008). Measuring library space use and preferences: Charting a path toward increased engagement. *portal: Libraries and the Academy*, *8*(4), 407-422.
Wilby, R. L. (2003). Past and projected trends in London's urban heat island. *Weather*, *58*(7), 251–260. https://doi.org/10.1256/wea.183.02
Wong, N. H., & Jusuf, S. K. (2010). Study on the microclimate condition along a green pedestrian canyon in Singapore. *Architectural Science Review*, *53*(2), 196–212. https://doi.org/10.3763/asre.2009.0029
Woo, J., Rajagopalan, P., & Andamon, M. M. (2022). An evaluation of measured indoor conditions and student performance using d2 Test of Attention. *Building and Environment*, 108940. https://doi.org/10.1016/j.buildenv.2022.108940

Wu, Q., Liu, J., Zhang, L., Zhang, J., & Jiang, L. (2020). Study on thermal sensation and thermal comfort in environment with moderate temperature ramps. *Building and Environment*, *171*, 106640.

Wu, Y., Liu, H., Li, B., Kosonen, R., Kong, D., Zhou, S., & Yao, R. (2019). Thermal adaptation of the elderly during summer in a hot humid area: Psychological, behavioral, and physiological responses. *Energy and Buildings*, *203*, 109450. https://doi.org/10.1016/j.enbuild.2019.109450

Wu, Y.-C., & Mahdavi, A. (2014). Subject Assessment of Thermal Transition in a Museum: A Case Study. In Proceedings of the 2nd ICAUD International Conference in Architecture and Urban Design. Tirana, Albania: Epoka University.

Wyon, D. P. (1974). The effects of moderate heat stress on typewriting performance. *Ergonomics*, *17*(3), 309–317. https://doi.org/10.1080/00140137408931356

Xie, Y., Huang, T., Li, J., Liu, J., Niu, J., Mak, C. M., & Lin, Z. (2018). Evaluation of a multi-nodal thermal regulation model for assessment of outdoor thermal comfort: Sensitivity to wind speed and solar radiation. *Building and Environment*, *132*, 45–56. https://doi.org/10.1016/j.buildenv.2018.01.025

Xiong, J., Zhou, X., Lian, Z., You, J., & Lin, Y. (2016). Thermal perception and skin temperature in different transient thermal environments in summer. *Energy and Buildings*, *128*, 155–163. https://doi.org/10.1016/j.enbuild.2016.06.085

Xu, M., Hong, B., Jiang, R., An, L., & Zhang, T. (2019). Outdoor thermal comfort of shaded spaces in an urban park in the cold region of China. *Building and Environment*, *155*, 408–420. https://doi.org/10.1016/j.buildenv.2019.03.049

Xu, S., Cheng, B., Huang, Z., & Shen, C. (2022). An investigation on the thermal environment of residential courtyards in the cold area of Western Sichuan Plateau. *Buildings*, *12*(1), 49. https://doi.org/10.3390/buildings12010049

Xue, J., Liu, W., & Liu, K. (2021). Influence of Thermal Environment on Attendance and Adaptive Behaviors in Outdoor Spaces: A Study in a Cold-Climate University Campus. *International Journal of Environmental Research and Public Health*, *18*(11), 6139. https://doi.org/10.3390/ijerph18116139

Yan, H., Yang, L., Zheng, W., & Li, D. (2016). Influence of outdoor temperature on the indoor environment and thermal adaptation in Chinese residential buildings during the heating season. *Energy and Buildings*, *116*, 133–140. https://doi.org/10.1016/j.enbuild.2015.12.053

Yang, W., Wong, N. H., & Jusuf, S. K. (2013). Thermal comfort in outdoor urban spaces in Singapore. *Building and Environment*, *59*, 426–435. https://doi.org/10.1016/j.buildenv.2012.09.008

Yang, Y., Li, B., Liu, H., Tan, M., & Yao, R. (2015). A study of adaptive thermal comfort in a well-controlled climate chamber. *Applied Thermal Engineering*, *76*, 283–291. https://doi.org/10.1016/j.applthermaleng.2014.11.004

Yao, M., & Zhao, B. (2017). Window opening behavior of occupants in residential buildings in Beijing. *Building and Environment*, *124*, 441–449. https://doi.org/10.1016/j.buildenv.2017.08.035

Yao, R., Li, B., & Liu, J. (2009). A theoretical adaptive model of thermal comfort – Adaptive Predicted Mean Vote (aPMV). *Building and Environment*, *44*(10), 2089–2096. https://doi.org/10.1016/j.buildenv.2009.02.014

Yao, S., Zeng, H., & Sun, S. (2009). Investigation on status and influential factors of cognitive function of the community-dwelling elderly in Changsha City. *Archives of Gerontology and Geriatrics*, *49*(3), 329–334. https://doi.org/10.1016/j.archger.2008.11.007

Yao, Y., Lian, Z., Liu, W., & Shen, Q. (2008). Experimental study on physiological responses and thermal comfort under various ambient temperatures. *Physiology & Behavior*, *93*(1–2), 310–321. https://doi.org/10.1016/j.physbeh.2007.09.012

Yılmaz, E. (2019). Mobil ölçümlerle Ankara şehir ısı adası. *Coğrafi Bilimler Dergisi*, *17*(2), 281–317. https://doi.org/10.33688/aucbd.600933

Yılmaz, E., & Çiçek, İ. (2018). Detailed Köppen-Geiger climate regions of TurkeyTürkiye'nin detaylandırılmış Köppen-Geiger iklim bölgeleri. *Journal of Human Sciences*, *15*(1), 225. https://doi.org/10.14687/jhs.v15i1.5040

Yim, S. H. L., Fung, J. C. H., Lau, A. K. H., & Kot, S. C. (2009). Air ventilation impacts of the "wall effect" resulting from the alignment of high-rise buildings. *Atmospheric Environment*, *43*(32), 4982–4994. https://doi.org/10.1016/j.atmosenv.2009.07.002

Yin, J., Zheng, Y., Wu, R., Tan, J., Ye, D., & Wang, W. (2012). An analysis of influential factors on outdoor thermal comfort in summer. *International Journal of Biometeorology*, *56*(5), 941–948. https://doi.org/10.1007/s00484-011-0503-9

Yin, S., & Xiao, Y. (2016). Scale Study of Traditional Shophouse Street in South of China Based on Outdoor Thermal Comfort. *Procedia Engineering*, *169*, 232–239. https://doi.org/10.1016/j.proeng.2016.10.028

Yin, S., Lang, W., Xiao, Y., & Xu, Z. (2019). Correlative impact of shading strategies and configurations design on pedestrian-level thermal comfort in traditional shophouse neighbourhoods, Southern China. *Sustainability*, *11*(5), 1355. https://doi.org/10.3390/su11051355

Yu, Z. (Jerry), Yang, B., & Zhu, N. (2015). Effect of thermal transient on human thermal comfort in temporarily occupied space in winter – A case study in Tianjin. *Building and Environment*, *93*, 27–33. https://doi.org/10.1016/j.buildenv.2015.07.006

Yüksel, Ü. D., & Yılmaz, O. (2008). Ankara kentinde kentsel isi adasi etkisinin yaz aylarinda uzaktan algilama ve meteorolojik gözlemlere dayali olarak saptanmasi ve değerlendirilmesi. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 23*(4).

Zabetian, E., & Kheyroddin, R. (2019). Comparative evaluation of relationship between psychological adaptations in order to reach thermal comfort and sense of place in urban spaces. *Urban Climate*, *29*, 100483. https://doi.org/10.1016/j.uclim.2019.100483

Zhang, F., & de Dear, R. (2017). University students' cognitive performance under temperature cycles induced by direct load control events. *Indoor Air*, *27*(1), 78–93. https://doi.org/10.1111/ina.12296

Zhang, F., de Dear, R., & Hancock, P. (2019). Effects of moderate thermal environments on cognitive performance: A multidisciplinary review. *Applied Energy*, *236*, 760–777. https://doi.org/10.1016/j.apenergy.2018.12.005

Zhang, S., & Zhu, N. (2022). Gender differences in thermal responses to temperature ramps in moderate environments. *Journal of Thermal Biology*, *103*, 103158.

Zhang, Y., & Barrett, P. (2012). Factors influencing the occupants' window opening behaviour in a naturally ventilated office building. *Building and Environment*, *50*, 125–134. https://doi.org/10.1016/j.buildenv.2011.10.018

Zhang, Y., Wang, J., Chen, H., Zhang, J., & Meng, Q. (2010). Thermal comfort in naturally ventilated buildings in hot-humid area of China. *Building and*

Environment, *45*(11), 2562–2570. https://doi.org/10.1016/j.buildenv.2010.05.024

Zheng, P., Wang, C., Liu, Y., Lin, B., Wu, H., Huang, Y., & Zhou, X. (2022). Thermal adaptive behavior and thermal comfort for occupants in multi-person offices with air-conditioning systems. *Building and Environment*, *207*, 108432

Zhu, M., Liu, W., & Wargocki, P. (2020). Changes in EEG signals during the cognitive activity at varying air temperature and relative humidity. *Journal of exposure science & environmental epidemiology*, *30*(2), 285-298.

APPENDICES

APPENDIX A. THE ETHICAL PERMISSION BY THE BİLKENT UNIVERSITY ETHICAL COMMITTEE

Bilkent Üniversitesi
Akademik İşler Rektör Yardımcılığı

Tarih : 11 Ekim 2021

Gönderilen : Betül Gündoğdu

Danışman : Andre Santos Nouri

Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı

Konu : *"Investigating the ..."* çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 11 Ekim 2021 tarihli görüşme sonucu, *"Investigating the impacts of shaded outdoor spaces on thermal adaptation and cognitive performance of university students in classroom environments"* 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 Özaktaş	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Doç.Dr. Çiğdem Gündüz Demir	Bilgisayar Mühendisliği	Yedek Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2021_10_11_02

Bilkent Üniversitesi, 06800 Bilkent, Ankara • Telefon: (312) 290 12 13 • (312) 290 12 14 • Faks: (312) 266 41 52

APPENDIX B. CONSENT FORM

CONSENT FORM

Title: Investigating the Impacts of Outdoor Shaded Spaces on Thermal Adaptation and Cognitive Performance of University Students in Classroom Environments

Investigator	Advisor
Betül Gündoğdu, M.F.A. Student	Asst. Prof. Dr. Andre Santos Nouri
İ.D. Bilkent University	İ.D. Bilkent University
Interior Architecture and Environmental Design	Interior Architecture and Environmental Design
betul.gundogdu@bilkent.edu.tr	andre.nouri@bilkent.edu.tr
(+90) 505 605 21 11	FA Building, No:309, Bilkent University

You are invited to be a participant in a research study. You were selected as a possible participant because you are university students aged above 18 years old. Please read this form and ask any questions you may have before agreeing to participate in this study.

The Purpose of the Research: The aim of the study is twofold: (1) to evaluate the effect of outdoor shaded spaces upon thermal comfort; and, (2) link such results upon the cognitive performance of university students in a classroom environment with natural ventilation.

Description of the Research: You will be divided into 2 groups decided as experiencing shaded and unshaded outdoor space in the break time while micro-climatic variables are measured in both spaces. During this time, you will answer a paper-based thermal comfort questionnaire. 20 minutes later after entering the classroom, you will answer a paper-based thermal comfort questionnaire again, and attention test while micro-climatic variables are measured in the classroom.

Risks and Discomforts: There is no risk in participating in this study.

Benefits: The results of this research may give a guideline to designers, architects, interior architects, urban planners and decision-makers related to governement to understand the human-environment relationship based on the results of this study.

Participation: Your participation is based on voluntariness. You may withdraw at any time by informing the investigator, without stating any reason and without any penalty. Also, the investigator may exclude you if required. Your decision whether or not to participate will not affect your current or future relations with Bilkent University and academic evaluations in any way.

Confidentiality: All answers of participants will be kept strictly confidential. Only investigator and the advisor will have access to the information. The results will be used in a master thesis, its associated oral presentation, and any other dissemination associated this research within an academic community.

Statement of Consent:

"I have informed about the research and have got answers to all questions I asked. I assent to participate in this research."

Participant:

Name, last name:……………………………………………………..

Adress:……………………………………………………………………………………………………
………

Date:

Signature:

Signature of Investigator:

APPENDIX C. MEASUREMENT SITE PHOTOS OF THE STUDY

Photo 1. POI 1 (Shaded Outdoor Space)

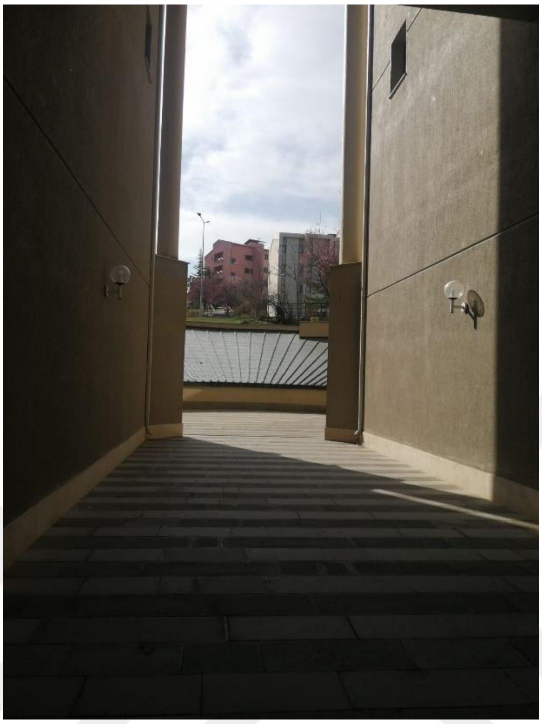

Photo 2. POI 2 (Sun-exposed Outdoor Space)

APPENDIX D. *IN-SITU* PORTABLE TRACKERS

Kestrel 5400HS (Table 3)

Kkmoon Sm206 (Table 3)

Benetech Gm 550 (Table 3)

APPENDIX E. THE QUESTIONNAIRE SURVEY

THERMAL COMFORT QUESTIONNAIRE

Date: …./…./2021
Time: ……….......

This study aims to investigate the impacts of outdoor shaded spaces on your thermal adaptation and link the results upon cognitive performance in classroom environments. The questionnaire consists of 3 main sections: Personal Information, Outdoor Thermal Comfort with Adaptive Behaviors, and Indoor Thermal Comfort with Adaptive Behaviours. The data obtained from the questionnaire is going to be used in a Master's Thesis in the Department of Interior Architecture and Environmental Design, İ.D. Bilkent University.

Thank you for your participation.

PERSONAL INFORMATION

1.Gender:

Male ☐ Female ☐ Do not want to answer ☐

2.How old are you? ....

3. Where are you from? ....

4. How long have you been in Ankara? ....

5. What is your location at the moment?

Shaded area ☐ Sun-exposed area ☐

6. Using the list below, please check each item of clothing that you are wearing right now.

Short-Sleeve Shirt	☐	Dress	☐	Socks	☐
Long-Sleeve Shirt	☐	Shorts	☐	Boots	☐
T-shirt	☐	Athletic Sweatpants	☐	Shoes	☐
Long-Sleeve Sweatshirt	☐	Trousers	☐	Sandals	☐
Sweater	☐	Undershirt	☐		
Vest	☐	Long Underwear Bottoms	☐		
Jacket	☐	Long Sleeve Coveralls	☐		
Knee-Lengt Skirt	☐	Overalls	☐		
Ankle-Length Skirt	☐	Slip	☐		

OUTDOOR THERMAL COMFORT

(Please tick off only one box with X for each question)

How would you rate your overall thermal comfort?

Comfortable ☐ Slightly comfortable ☐ Slightly uncomfortable ☐ Uncomfortable ☐

TEMPERATURE

1. How do you feel about the temperature at the moment?

Cold	Cool	Slightly cool	Neutral	Sligthly warm	Warm	Hot
☐	☐	☐	☐	☐	☐	☐

2. How do you prefer the temperature to be at the moment?

Much colder	A bit colder	No change	A bit warmer	Much warmer
☐	☐	☐	☐	☐

3. Do you feel comfortable about the temperature at the moment?

Yes	No
☐	☐

WIND SPEED

1. How do you feel about the wind speed at the moment?

Very high	High	Slightly high	Neutral	Sligthly low	Low	Very low
☐	☐	☐	☐	☐	☐	☐

2. How do you prefer the wind speed to be at the moment?

Higher	A bit higher	No change	A bit lower	Lower
☐	☐	☐	☐	☐

3. Do you feel comfortable about the wind speed at the moment?

Yes	No
☐	☐

SOLAR RADIATION

1. How do you feel about the sunshine at the moment?

Very strong	Strong	Slightly strong	Neutral	Sligthly weak	Weak	Very weak
☐	☐	☐	☐	☐	☐	☐

2. How do you prefer the sunshine to be at the moment?

Stronger	A bit stronger	No change	A bit weaker	Weaker
☐	☐	☐	☐	☐

3. Do you feel comfortable about the sunshine at the moment?

Yes	No
☐	☐

OUTDOOR ADAPTIVE BEHAVIOURS

(Please tick off only one box with X for each question)

1.What could you do to feel more comfortable at the moment?

- Take off some clothing ☐
- Putting on extra clothes ☐
- Having a hot/cold drink ☐
- No changes ☐

2.What could you do to feel more comfortable at the moment?

- Be in more shaded location ☐
- Be in more sunny location ☐
- Go indoors ☐
- No changes ☐

INDOOR THERMAL COMFORT

(Please tick off only one box with X for each question)

How would you rate your overall thermal comfort?

Comfortable ☐ Slightly comfortable ☐ Slightly uncomfortable ☐ Uncomfortable ☐

Are you sitting 1 meter away from window? Yes ☐ No ☐

TEMPERATURE

1. How do you feel about the temperature at the moment?

Cold	Cool	Slightly cool	Neutral	Sligthly warm	Warm	Hot
☐	☐	☐	☐	☐	☐	☐

2. How do you prefer the temperature to be at the moment?

Much colder	A bit colder	No change	A bit warmer	Much warmer
☐	☐	☐	☐	☐

3. Do you feel comfortable about the temperature at the moment?

Yes	No
☐	☐

AIR SPEED

1. How do you feel about the air speed at the moment?

Very high	High	Slightly high	Neutral	Sligthly low	Low	Very low
☐	☐	☐	☐	☐	☐	☐

2. How do you prefer the air speed to be at the moment?

Higher	A bit higher	No change	A bit lower	Lower
☐	☐	☐	☐	☐

3. Do you feel comfortable about the air speed at the moment?

Yes	No
☐	☐

SOLAR RADIATION

How do you prefer the sunshine to be at the moment?

Stronger	A bit stronger	No change	A bit weaker	Weaker
☐	☐	☐	☐	☐

INDOOR ADAPTIVE BEHAVIOURS

(Please tick off only one box with X for each question)

1.What could you do to feel more comfortable at the moment?

Open windows	☐	Take off some clothing	☐
Close windows	☐	Putting on extra clothes	☐
Open door	☐	Having a hot/cold drink	☐
Close door	☐	No changes	☐

2.What could you do to feel more comfortable at the moment?

Be in more shaded location	☐
Be in more sunny location	☐
Go outdoor	☐
No changes	☐

APPENDIX F. D2 TEST OF ATTENTION

APPENDIX G. CORRELATION BETWEEN OUTDOOR THERMAL RESPONSES AND COGNITIVE PERFORMANCE

			Grp 1					Grp 2				
			TN	E%	TN-E	CP	FR	TN	E%	TN-E	CP	FR
Spearman's rho	$OTCV_{OUT}$	Correlation Coefficient	-0.213	-0.153	-0.087	-0.222	-0.033	0.327	0.222	0.007	-0.052	-0.450**
		Sig. (2-tailed)	0.307	0.466	0.680	0.286	0.875	0.067	0.223	0.969	0.778	0.010
		N	25	25	25	25	25	33	33	33	33	33
	$ATSV_{OUT}$	Correlation Coefficient	-0.007	-0.034	0.019	-0.162	-0.195	0.083	-0.036	-0.072	0.079	-0.418*
		Sig. (2-tailed)	0.973	0.873	0.927	0.438	0.351	0.645	0.844	0.689	0.664	0.016
		N	25	25	25	25	25	33	33	33	33	33
	$ATPV_{OUT}$	Correlation Coefficient	0.264	0.297	0.146	0.114	0.010	-0.157	-0.115	-0.007	-0.112	0.265
		Sig. (2-tailed)	0.202	0.149	0.487	0.587	0.962	0.382	0.524	0.968	0.535	0.136
		N	25	25	25	25	25	33	33	33	33	33
	$ATCV_{OUT}$	Correlation Coefficient	-0.137	0.026	0.007	-0.306	-0.059	0.342	0.193	0.065	0.081	-0.307
		Sig. (2-tailed)	0.515	0.902	0.975	0.137	0.780	0.052	0.282	0.720	0.653	0.083
		N	25	25	25	25	25	33	33	33	33	33
	$WSSV_{OUT}$	Correlation Coefficient	0.037	-0.210	0.018	0.219	0.226	-0.325	-0.225	-0.041	0.024	-0.221
		Sig. (2-tailed)	0.862	0.315	0.932	0.294	0.277	0.065	0.208	0.820	0.894	0.216
		N	25	25	25	25	25	33	33	33	33	33
	$WSPV_{OUT}$	Correlation Coefficient	0.022	0.063	0.030	-0.193	-0.068	0.226	0.294	-0.023	-0.159	0.098
		Sig. (2-tailed)	0.915	0.765	0.887	0.356	0.748	0.206	0.097	0.900	0.375	0.589
		N	25	25	25	25	25	33	33	33	33	33
	$WSCV_{OUT}$	Correlation Coefficient	-0.179	0.095	-0.152	-0.319	-0.152	0.003	-0.035	-0.094	0.208	-0.159
		Sig. (2-tailed)	0.391	0.651	0.470	0.120	0.469	0.985	0.848	0.601	0.245	0.377
		N	25	25	25	25	25	33	33	33	33	33
	$SRSV_{OUT}$	Correlation Coefficient	0.088	-0.163	0.170	0.073	0.087	0.001	-0.012	0.049	-0.100	0.281
		Sig. (2-tailed)	0.676	0.437	0.416	0.728	0.681	0.994	0.946	0.785	0.579	0.113
		N	25	25	25	25	25	33	33	33	33	33
	$SRPV_{OUT}$	Correlation Coefficient	-0.051	-0.147	-0.139	0.032	0.043	0.287	0.100	0.056	0.140	-0.181
		Sig. (2-tailed)	0.809	0.485	0.509	0.881	0.838	0.111	0.587	0.760	0.445	0.323
		N	25	25	25	25	25	33	33	33	33	33
	$SRCV_{OUT}$	Correlation Coefficient	-0.070	-0.116	0.064	-0.197	0.035	0.371*	0.143	0.202	0.146	-0.291
		Sig. (2-tailed)	0.741	0.581	0.762	0.345	0.869	0.036	0.435	0.268	0.424	0.106
		N	25	25	25	25	25	33	33	33	33	33

APPENDIX H. GANTT CHART FOR THE PROCESS OF THE THESIS