MERVE MÜNEVVER AHAN

INVESTIGATING THE RELATIONSHIP OF OUTDOOR HEAT STRESS UPON INDOOR THERMAL COMFORT AND QUALITATIVE SELF-SLEEP EVALUATION: THE CASE OF ANKARA

Bilkent University 2022

INVESTIGATING THE RELATIONSHIP OF OUTDOOR HEAT STRESS UPON INDOOR THERMAL COMFORT AND QUALITATIVE SELF-SLEEP EVALUATION: THE CASE OF ANKARA

A Master's Thesis

by

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June 2022

To my family,

Recep

INVESTIGATING THE RELATIONSHIP OF OUTDOOR HEAT STRESS UPON INDOOR THERMAL COMFORT AND QUALITATIVE SELF-SLEEP EVALUATION: THE CASE OF ANKARA

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

by
Merve Münevver Ahan

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

THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
İHSAN DOĞRAMACI BİLKENT UNIVERSITY
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By Merve Münevver Ahan

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

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ABSTRACT

INVESTIGATING THE RELATIONSHIP OF OUTDOOR HEAT STRESS UPON INDOOR THERMAL COMFORT AND QUALITATIVE SELF-SLEEP EVALUATION: THE CASE OF ANKARA

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June 2022

Recently, the necessity of exploring the relationship between sleep quality and the thermal environment has amplified regarding increasing heat stress risk on the human body due to climate change, particularly in vulnerable-uninsulated buildings of Ankara. Within this scope, this study investigated occupants' sleep quality and thermal comfort in insulated and uninsulated buildings under three local extreme heat event thresholds: (1) typical summer day (TSD_{25}), (2) very hot day (VHD_{33}), and lastly, (3) heat wave event (HWE_{31}). Within a two-tiered approach to thermal comfort evaluations, the physiological thermal comfort of occupants was identified through the calculation of Physiologically Equivalent Temperature (PET) from the climatic data of local meteorological stations. On the other hand, the psychological thermal comfort and sleep quality of participants were evaluated by questionnaires during each heat event. The results of this study demonstrated that PET_{Out} reached 43.5 °C, which indicates the extreme heat stress within PS grades during the VHD_{33}s. The PET values were consistently higher in uninsulated buildings than in insulated buildings. Also, most of the mean psychological thermal comfort votes (TCVs) and sleep quality votes (SQVs) were better in uninsulated buildings than in insulated ones during TSD_{25} and HWE_{31}s, while it was the opposite within extreme conditions of VHD_{33}s. The outputs of this study contribute to interdisciplinary efforts to attenuate the existing and impending risks of climate change on human life by defining the influence of increasing outdoor heat stress on indoor spaces, thermal comfort, and the sleep quality of occupants.

Keywords: Thermal comfort, Sleep quality, PET, Outdoor heat stress, Extreme heat thresholds, Ankara

ÖZET

DIŞ MEKAN ISI STRESİNİN İÇ MEKAN TERMAL KONFOR VE NİTEL BİREYSEL UYKU KALİTESİ DEĞERLENDİRMESİ İLE İLİŞKİSİNİN İNCELENMESİ: ANKARA ÖRNEĞİ

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Tez Danışmanı: Öğr. Dr. Andre Santos Nouri

Haziran 2022

Son zamanlarda iklim değişikliğine bağlı olarak insan vücudu üzerindeki artan ısı stresi riski düşünüldüğünde, özellikle Ankara'nın hassas-yalıtımsız binalarında, uyku kalitesi ve termal çevre ilişkisinin araştırılması daha da kritik bir hale gelmiştir. Bu kapsamda, bu çalışma yalıtımlı ve yalıtımsız binalarda, sakinlerinin uyku kalitesi ve ısıl konforlarını üç yerel aşırı sıcaklık olayı eşiği altında: (1) tipik yaz günü (TYG_{25}), (2) çok sıcak gün ($ÇSG_{33}$) ve son olarak (3) sıcak hava dalgası olayı (SHD_{31}), araştırmıştır. İki kademeli termal konfor değerlendirme yaklaşımının ilk aşamasında, yerel meteoroloji istasyonlarının iklim verileri ile Fizyolojik Eşdeğer Sıcaklık (FES) değerleri hesaplanarak bina sakinlerinin fizyolojik termal konforları belirlenmiştir. Öte yandan, katılımcıların psikolojik termal konforları ve uyku kaliteleri, her bir ısı olayı sırasında anketler aracılığı ile değerlendirilmiştir. Bu çalışmanın sonuçları dış mekan FES değerlerinin, $ÇSG_{33}$'ler sırasında, fizyolojik stres sınıfında aşırı ısı stresi derecesine eşdeğer olan 43.5 °C'ye ulaştığını göstermiştir. FES değerleri, yalıtımlı binalara nazaran yalıtımsız binalarda sürekli olarak daha yüksek değerlerde

seyretmiştir. Ayrıca, ortalama psikolojik termal konfor oylarının (TKO) ve uyku kalitesi oylarının (UKO) çoğu, yalıtımsız binalarda, TYG_{25} ve SHD_{31} olaylarında yalıtımlı binalara göre daha iyiyken, $ÇSG_{33}$'lerin ekstrem koşullarında durum tam tersi şekildedir. Bu çalışmanın çıktıları, artan dış ortam ısı stresinin iç mekanlar ve bina sakinlerinin termal konfor ve uyku kaliteleri üzerindeki etkisini tanımlayarak, iklim değişikliğinin insan yaşamı üzerindeki mevcut ve olası risklerini azaltmaya yönelik disiplinler arası çabalara katkıda bulunmaktadır.

Anahtar Kelimeler: Termal konfor, Uyku kalitesi, Dış mekan ısı stresi, Ekstrem ısı eşikleri, Ankara

ACKNOWLEDGEMENTS

First of all, I would like to express my endless gratitude to my supervisor Asst. Prof. Dr. Andre Santos Nouri for his invaluable guidance and inspiring perspective. His intellectual knowledge, experience, and constructive criticism have enabled me to think more critically at each step in the creation of this thesis. Also, his supportive attitude and calm voice motivated me to learn more and work harder with pleasure. His thoughtful approach and encouragement helped me to get out of my comfort zone and be confident in myself. I would also like to thank him for giving importance not only to my academic development but also to my spirit.

I would also like to acknowledge my committee members Assoc. Prof. Dr. Yasemin Afacan and Prof. Dr. Sevgi Yilmaz, for their constructive feedback on my dissertation. Furthermore, my sincere gratitude goes to Prof. Dr. Andreas Matzarakis for his time and comprehensive advice that illuminated the scope of this research.

I would also thank the Bilkent Main Campus Houses dwellers for contributing to my research process by allocating their time. This thesis would not have been possible without their help. Also, special thanks to the Bilkent Housing Office and Bilkent University Directorate of Construction and Technical Works for providing the necessary tools and information for this research. I would also thank Assoc. Prof. Dr. Onur Çalışkan for contributing to this research by providing the necessary data.

I convey special thanks to Betül Gündoğdu for her accompany by sharing the same troubles and feelings with me during the thesis process. I also wish to thank İpek, Fulya, and Samah, for the valuable friendships that Bilkent brought to me. I would also like to thank my dearest friends, Kübra, Sena, Sinem, and Abdüllatif, who made me smile when I had difficulties. Last but not least, I would like to thank my dear husband, Recep Erdem Ahan, who contributed to this thesis with his improving comments. I would also like to thank him for always being there for me with his unique companionship, eternal understanding, and lovely smile.

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LIST OF ABBREVIATIONS

AMS	Ankara’s Meteorological Station
ASV	Air Speed Sensation Vote
CCDI	Climate Change Detection Indices
CTIS	Climate-Tourism/Transfer-Information-Scheme
EBM	Energy Balance Model
HSV	Humidity Sensation Vote
HWE_{31}	Heat Wave Event
KG	Köppen-Geiger
KHS	Kestrel Heat Stress
MEMI	Munich Energy-Balance Model for Individuals
MRT	Mean Radiant Temperature (°C)
MRT_{In}	Indoor Mean Radiant Temperature (°C)
MRT_{20}	Tropical Nights
NREM	Non-Rapid Eye Movement
Oct	Octas
PET	Physiologically Equivalent Temperature (°C)
PET_{In}	Indoor Physiologically Equivalent Temperature (°C)
$PET_{In}PRE$	Indoor Physiologically Equivalent Temperature in Pre-2000 Buildings (°C)
$PET_{In}POST$	Indoor Physiologically Equivalent Temperature in Post-2000 Buildings (°C)
PET_{Out}	Outdoor Physiologically Equivalent Temperature (°C)
PS	Physiological Stress

REM	Rapid Eye Movement
RH_{In}	Indoor Relative Humidity (%)
$RH_{In}PRE$	Indoor Relative Humidity in Pre-2000 Buildings (%)
$RH_{In}POST$	Indoor Relative Humidity in Post-2000 Buildings (%)
RH_{Out}	Outdoor Relative Humidity (%)
SQV	Sleep Quality Vote/Ratio
Ta_{In}	Indoor Air Temperature (°C)
$Ta_{In}PRE$	Indoor Air Temperature in Pre-2000 Buildings (°C)
$Ta_{In}POST$	Indoor Air Temperature in Post-2000 Buildings (°C)
Ta_{Out}	Outdoor Air Temperature (°C)
Tcr	Core Body Temperature
TCV	Thermal Comfort Vote
Tg_{In}	Indoor Globe Temperature (°C)
TSD_{25}	Typical Summer Day
Tsk	Skin Temperature
TSV	Thermal Sensation Vote
TÜBİTAK	Turkish National Scientific and Technological Research Council
V_{In}	Indoor Air Speed (M/S)
V_{Out}	Outdoor Wind Speed (M/S)
VHD_{33}	Very Hot Day

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Considering that 45% of the global population suffers from sleep impairments and their negative impacts on life quality, the recent prevalence of sleep quality investigations can be understandable (Imagawa & Rijal, 2015; “World Sleep Day,” 2017). To address the global issue of poor sleep quality, it is necessary to employ local approaches encircling both indoor and outdoor conditions since an appropriate sleeping environment is a key factor in enhancing sleep quality and quantity (Caddick, Gregory, Arsintescu, & Flynn-Evans, 2018; Kallawicha, Boonvisut, Chao, & Nitmetawong, 2021; X. Zhang, Luo, Xie, & Liu, 2021). The comfortable indoor environment is formulated by four main components: thermal comfort, illumination, acoustic, and air quality (Demirkan & Afacan, 2018; N. Zhang, Cao, & Zhu, 2018). On the other hand, given that sleep is regulated by the circadian rhythm of body temperature (Pigeon & Grandner, 2013; Szymusiak, 2018), it is possible to signify that thermal comfort has a major role in initiating and maintaining sleep (Jhaveri, Trammell, & Toth, 2007; Xu, Lian, Shen, Lan, & Sun, 2021).

Several studies manifested the impacts of indoor thermal parameters, i.e., air temperature (Ta) and relative humidity (RH), on sleep quality (Budiawan & Tsuzuki, 2021; Haskell et al., 1981; Y. Liu et al., 2014; Okamoto-Mizuno et al., 1999; Pan et al., 2012; Sagot et al., 1987; Song et al., 2020; Tsuzuki et al., 2015; N. Zhang et al., 2019). However, the influence of outdoor thermal conditions on the sleep quality of occupants was disregarded within the existing literature (Minor, Bjerre-Nielsen, Jonasdottir, Lehmann, & Obradovich, 2022). When considering the risks of increased outdoor heat stress in indoor spaces and human sleep due to growing climate change and global warming, the inclusion of outdoor thermal conditions in indoor sleep quality investigations gains prominence. On top of that, most of the abovementioned studies were confined to utilizing meteorological factors, which are descriptive for ambient conditions but insufficient in identifying the heat stress on the human body. Within this context, involving outdoor thermal conditions and thermal indices in detecting the heat stress on the human body and exploring their associations with sleep quality can help to elaborate the human-centered design standards within the interdisciplinary area.

In the case of Ankara, the adverse effects of outdoor heat stress can entail more risk in vulnerable indoor environments, particularly in uninsulated residential settings (Nouri, Çalışkan, Charalampopoulos, Cheval, & Matzarakis, 2021). When considered thermal insulation was not obligatory until 2000 in Turkey (Esiyok, 2006), and the number of buildings constructed before 2000 was 384,489 in Ankara (Özkan, 2018), it is possible to reckon that uninsulated-vulnerable buildings are still widely used in Ankara. Within the easier transition of heat stress from outdoors to indoors in these uninsulated buildings, the sleep quality of a high number of occupants is at risk.

The local vulnerability can be eliminated by detecting the local risk factors depending on the global climatic change. Numerous studies designated the vulnerability of the city of Ankara to outdoor heat stress in terms of urban heat island effects (Akkose, Meral Akgul, & Dino, 2021; Çalışkan & Türkoğlu, 2014; Çiçek & Doğan, 2006; Karaca, Tayanç, & Toros, 1995; Türkoğlu, Çalışkan, Çiçek, & Yılmaz, 2012). Nevertheless, these studies examining the vulnerability of Ankara depending on climatic risk factors overlooked three crucial points: (i) handling the thermal comfort on both psychological and physiological sides; (ii) assessing the vulnerability within both outdoor and indoor environments; and, (iii) addressing the heat stress on occupants of Ankara using local extreme heat event thresholds. Therefore, investigating the sleep quality by filling the given gaps in exploring the bottom-up heat load on the human body can help extinguish the climatic risks on citizens of Ankara. Particularly understanding the local extreme weather conditions can provide to generate solutions or mitigation strategies towards risks of these extreme local conditions due to climate change (Rifkin, Long, & Perry, 2018). Additionally, on a larger scale, it can contribute to the interdisciplinary approach to designing healthy living environments, which concerns interior architects, architects, urban planners, meteorologists, and decision-makers.

1.2. Aim of the Study

The main objective of this study is to identify the existing local risk factors that will be exacerbated by effects of climate change in Ankara. In particular, the present study investigates the sleep quality and thermal comfort of occupants through an initial approach of examining their alterations under different local extreme heat events. This preliminary approach improves the comprehensiveness of the existing literature by including the interrelation between outdoor and indoor thermal conditions and their influence on heat stress on the human body. Furthermore, this study inquiries about the thermal comfort of occupants by performing a two-tiered approach, including psychological and physiological assessments. In the context of physiological thermal comfort, this study examines the heat stress on the human body utilizing thermal indices contrary to previous studies that investigate sleep quality regarding only ambient thermal conditions. Finally, this study explores these local risks by comparing thermal comfort and sleep quality of occupants between insulated and uninsulated residential settings to deepen the concept of vulnerability to the local climatic risk factors in Ankara.

1.3. Structure of the Thesis

The present thesis is structured around six main chapters, as delineated in Figure 1. The first chapter explains the motivation and aim of this research. Chapter 2 provides insight into the available scientific knowledge of the main terms of the study; thermal comfort, sleep quality, and the relationship between thermal comfort and sleep quality based on existing literature. In addition, thermal index, and outdoor heat stress approaches, unprecedented in investigating sleep quality depending on thermal comfort, are described in the third subsection of Chapter 2. Chapter 3 covers the methodological base of this research. This section begins by identifying the research questions and hypotheses of this dissertation. Then, the details of the study area and two-tiered procedure, including physiological and psychological evaluations, are introduced based on existing methods in the literature. The fourth chapter presents the results of these two-tiered assessments. In Chapter 5, the findings of the study are discussed with regard to existing knowledge on thermal comfort and sleep quality reached by previous studies. Also, the management solutions for heat stress, limitations of the research process, and recommendations for further studies were elucidated in Chapter 5. Finally, Chapter 6 encapsulates the concluding remarks of this study.

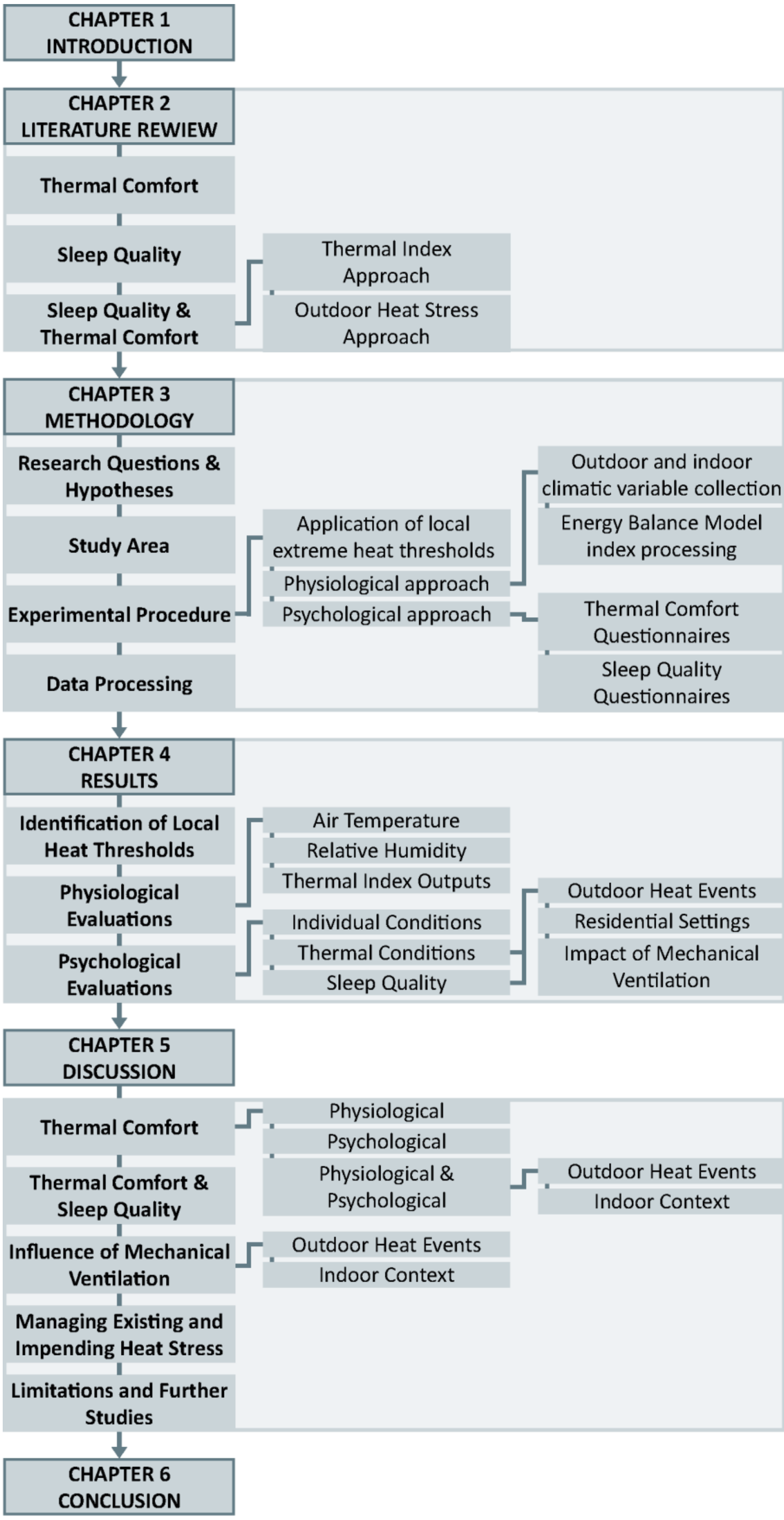

Figure 1. Thesis structure flow diagram indicating the organization of chapters and sub-sections (Illustration by the author, 2022).

CHAPTER 2

LITERATURE REVIEW

2.1. Sleep Quality

Sleep plays an integral role in human life since one-third of human life is spent within sleep. Sleep can be identified as an individual practice interrelated with psychological and physiological aspects of the human body (Yi, Shin, & Shin, 2006). Psychologically, sleep indicates a revocable behaviour of rest and diminished consciousness (Carskadon & Dement, 2011)). On the physiological side, sleep is described through the repetition of a cycle including two main stages, Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM), which are diverged according to the sleep depth, the existence of eye movement, brain waves, and muscular ton (Åkerstedt, Nilsson, & Kecklund, 2009; Brinkman, Reddy, & Sharma, 2021). Within the adults, NREM forms approximately the %80 of sleep, and REM corresponds to %20 of the sleep process. In particular, NREM sleep comprises four sub-phases, beginning with the lightest phase 1, continuing with deeper phase 2, and finishing with the deepest phases 3 and 4. Subsequent to NREM-phase 4, REM sleep initiates to complete the one sleep cycle, which takes place 4 or 5 times in total on an average sleep period (Brinkman et al., 2021; Doroshenkov, 2007; Šušmáková & Krakovská, 2008).

The psychological and physiological well-being of sleep is assessed through the term sleep quality (Cao, Lian, Du, Miyazaki, & Bao, 2021; Dongmei, Mingyin, Shiming, & Minglu, 2012). Mainly sleep quality is disclosed psychologically by deepness and calmness of sleep and physiologically by total time, delay, and the number of awakenings within sleep (Buysse Charles F Reynolds Ill, Monk, Berman, & Kupfer, 1988; Krystal & Edinger, 2008). Having a decent sleep quality contributes to every aspect of human life, from the health of individuals to the functioning of society. Within an individual’s life, sleep quality helps maintain health by protecting and detoxicating the brain, enhancing memory and learning, regulating emotions, balancing metabolism, defeating fatigue, and restoring the body's energy (Dongmei et al., 2012; Maquet, 2001; Vyazovskiy, 2015; Wölfling & Claßen, 2021; Xie et al., 2013; N. Zhang et al., 2019). On the other hand, poor sleep quality causes overall health impairment encompassing cardiovascular system, immune system, cognitive function, metabolism, circadian rhythm, loss of appetite, obesity, diabetes 2, and reduced learning and memory (Imagawa & Rijal, 2015; Malow, 2004; Möller-Levet et al., 2013; Mullington et al., 2003; Pannain et al., 2012; Zheng et al., 2019). Additionally, problematic sleep entails a risk of generating mental illnesses such as anxiety and depression (Hill, Burdette, & Hale, 2009; Lustberg & Reynolds, 2000). In the context of society, in addition to increased mortality and morbidity rates, poor sleep quality causes a significant reduction in socio-economic efficacy due to decreased work efficiency, productivity, and performance (Bixler, 2009; Cao et al., 2021; Leger, Bayon, Laaban, & Philip, 2012). Furthermore, suboptimal sleep can imperil the health and safety of the society by inducing major disasters of humanity, such as the Chernobyl explosion (Folkard & Lombardi, 2006; Folkard, Lombardi, & Tucker, 2005; Wells & Vaughn, 2012).

2.2. Thermal Comfort

With the increasing effects of climate change on all scales of human life, thermal comfort has become one of the most popular research topics for various disciplines, including health, product design, architecture, urban planning, meteorology, and decision making. Given the multivariate structure of thermal comfort, it can be described through three aspects of the human body; psychology, thermophysiology, and energy (Höppe, 2002). Psychologically, thermal comfort is a mental situation that states being pleased with the thermal environment (ASHRAE, 2010). Within the physiological side, thermal comfort signifies a state of the human body feeling not too hot or too cold but neutral, which is disclosed by the minimum reaction in the thermoregulatory system (Habibi, 2012). The mechanism of the thermoregulatory system is operated through thermoreceptors located in the skin and brain. When the human body is exposed to too low temperatures, skin thermoreceptors show reactions such as freezing or draughting. On the other hand, brain thermoreceptors respond with sweating when too hot temperatures are felt (E. Mayer, 1993). As a final definition of thermal comfort, the energy approach can be explained by the balance of mutual heat fluxes between the human body and its environment. In particular, the heat balance is determined by the alterations of core (Tcr) and skin temperatures (Tsk) depending on environmental conditions such as Ta, humidity, velocity, and mean radiant temperature (MRT) (Fanger, 1986; Rosenfelder, Koppe, Pfafferott, & Matzarakis, 2016). Although the human body can sustain a stable heat balance usually by changing blood flow and sweating in a warm environment and producing heat and shivering in the cold, it loses balance when body temperature surpasses certain limits due to too hot or too cold environmental conditions. For instance, in a too hot environment, the blood and heat flow between the Tcr and Tsk accelerates to regulate its thermal comfort at first. However, as the Ta rises, the body retains the heat due to increased Tcr and can reach critical degrees such as 42 °C (Olesen, 1982).

In addition to meteorological factors mentioned above, heat exchange of the human body and thermal comfort is affected by demographic, individual, and environmental factors. As demographical aspects, age and gender can impact thermal comfort due to different metabolic conditions between individuals (Kingma, Frijns, & Lichtenbelt, 2012; Rupp, Vásquez, & Lamberts, 2015). In the case of age, the diminished functioning of a given thermoregulatory system and activity levels result in higher thermal neutral temperatures in older adults (Afacan, 2015; del Ferraro, Iavicoli, Russo, & Molinaro, 2015; Havenith, 2001; Hoof & Hensen, 2006).

Similarly, previous studies demonstrated that women are thermal comfortable in warmer environments (Cao et al., 2021; Lan et al., 2008; Nakano et al., 2002; Pan et al., 2012). In addition to age and gender, individual factors such as clothing, short and long-term thermal history, thermal adaptation, and thermal expectation can influence occupants' thermal sensation and comfort (Humphreys, Nicol, & Raja, 2007; Nikolopoulou & Steemers, 2003; Parmeggiani, 1987). Having a longer thermal history in a specific climatic region facilitates the thermal adaptation in that climate because the thermal expectation of people changes according to thermal conditions they are exposed to for a long time (Gautam, Rijal, Imagawa, Kayo, & Shukuya, 2020; He, An, Hong, Huang, & Cui, 2020; Lam et al., 2021; Yafei Wang, de Groot, Bakker, Wörtche, & Leemans, 2017). Besides, short-term thermal history impacts the thermal comfort of occupants (Amin, Teli, James, & Bourikas, 2016; Ji, Cao, Luo, & Zhu, 2017). Previous studies designated that people who experienced warmer thermal environments marked a higher thermal neutral temperature and lower thermal sensations (Chun, Kwok, Mitamura, Miwa, & Tamura, 2008; Y. Zhang, Chen, Wang, & Meng, 2016).

Finally, the thermal comfort of occupants is affected by two particular characteristics of the building envelope, heat insulation and ventilation types, since these environmental factors have a crucial role in heat transition between outdoor and indoors (Bouchlaghem, 2000; Hansen, Bjarløv, Peuhkuri, & Harrestrup, 2018; Kaynakli, 2012; Kubota, Chyee, & Ahmad, 2009; Lotfabadi & Hançer, 2019; Roulet, 2001; Wallace, Emmerich, & Howard-Reed, 2002). Regarding physiological impacts of building insulation, previous studies confirmed that uninsulated buildings have poor thermal performance compared to insulated buildings (Amirzadeh, Strand, Hammann, & Bhandari, 2018; Dikmen, 2011; Pal, 2018). The thermal performance of buildings can affect the thermal load on the human body and, subsequently, psychological thermal comfort. However, the number of studies investigating the psychological thermal comfort depending on the building insulation is limited in the existing literature. Piasecki et al. (2020) studied the subjective indoor environmental quality in a thermally retrofitted building and revealed lower psychological thermal comfort in an uninsulated version of the building. Similar results were demonstrated by Afacan & Demirkan (2016), who also investigated the indoor environmental quality but, depending on sustainable design features, found that insulation increased the thermal satisfaction of participants. Besides thermal insulation, ventilation type, i.e., natural and mechanical ventilation such as air conditioning, can affect physiological and psychological thermal comfort. Natural ventilation through window opening can rise the exchange of Ta and relative humidity (RH) between exterior and interior spaces (Kubota et al., 2009; Wallace et al., 2002) and can cause alterations in thermal comfort. Similarly, air conditioning can change the thermal conditions of indoor environments, the short-term thermal history, and the thermal comfort of occupants, as manifested by Chun et al. (2008), who revealed that air conditioning increases the thermal sensations votes.

2.3. The Relationship Between Thermal Comfort and Sleep Quality

The human body uses the circadian rhythm of Tcr to regulate sleep. To prepare for sleep, the body decreases the Tcr by sending warm blood from the body core to the skin. Warm blood transfers its heat to the skin and causes an increase in the Tsk. At the skin, the body loses its heat and initiates sleep (Ko & Lee, 2018; Kräuchi, Cajochen, & Wirz-Justice, 1998; Murphy & Campbell, 1997; Okamoto-Mizuno & Mizuno, 2012; Raymann, Dick, & van Someren, 2005; Zheng et al., 2019). Since the net heat loss of the body is affected by many indoor climatic factors (Takahashi et al., 2014; van Someren, 2000), it is crucial to provide an optimal indoor thermal environment to improve sleep quality (Dongmei et al., 2012; Kallawicha et al., 2021; Li Lan & Lian, 2016).

In the literature, many studies have been conducted to examine the impact of indoor thermal parameters on sleep. For instance, Haskell et al. (1981) studied the effects of high and low Ta on human sleep stages and found that lower REM sleep, the last sleep stage when the human thermoregulatory system impairs (Sagot et al., 1987), and higher wakefulness at 37 °C compared to the 29 °C. Similar findings were also reported by Okamoto-Mizuno et al. (1999), who investigated the effect of humid heat on human sleep stages. The results demonstrated a considerable decrease in the REM and NREM stage 3 sleep in 35 °C Ta with 75% RH compared to the indoor conditions with 29 °C Ta and 50% RH. In the study of Zhang et al. (2019), a 29 °C pre-sleep environment provided longer REM and NREM stage 3 sleep compared to those with 23 °C and 26 °C Ta. In addition to studies focused on sleep stages, the influence of Ta on overall sleep quality was also investigated by many researchers. In a study based on both subjective and physiological measurements, Pan et al. (2012) suggested that Ta substantially affects sleep quality. Lan et al. (2014) revealed that lower sleep onset latency, higher slow-wave sleep, and higher subjective sleep quality in a 30 °C sleep environment than at 26 °C.

2.3.1. Thermal Index Approach

Given that thermal comfort is affected by demographic, individual, and environmental factors in addition to meteorological parameters, it is possible to note that indoor Ta and RH are not the only factors affecting thermal load on the human body and, subsequently, sleep quality. Within this scope, exploring the thermal load on the human body can help understand the overall thermal comfort of humans and its effects on sleep quality. The thermal load and heat balance of the human body and their relation to sleep quality can be measured through the utilization of thermal indices (de Freitas & Grigorieva, 2015; Nouri, Afacan, et al., 2021; Staiger, Laschewski, & Matzarakis, 2019). Several studies have been carried out to comprehend the relationship between overall thermal comfort and sleep quality using thermal indices (Cao et al., 2022; Dewasmes, Telliez, & Muzet, 2000; Dongmei, Zhongping, Ning, & Mengjie, 2017; Irshad, Khan, Algarni, Habib, & Saha, 2018; Tsang, Mui, & Wong, 2021). Nonetheless, these studies focused on the Predicted Mean Vote, Predicted Percentage of Dissatisfied, and Standard Effective Temperature, which are thermal indices only suitable for indoor measurements (Nouri, Costa, Santamouris, & Matzarakis, 2018). On the other hand, the Physiologically Equivalent Temperature (PET) index is suitable for both indoor and outdoor assessments of physiological thermal comfort (Höppe, 1999; Matzarakis, Rutz, & Mayer, 2007).

PET index is an Energy Balance Model (EBM) index that can be calculated by using Ta in relation to the energy balance of the human body is regulated by Tcr, Tsk, and sweating rate (Höppe, 1999; Nouri, Afacan, et al., 2021). The PET index is one of the most sensitive EBM thermal indices to the change of Ta (Charalampopoulos, 2019; de Freitas & Grigorieva, 2015, 2017). Nevertheless, there is a limited number of studies that use the PET index (Höppe, 1999; Matzarakis & Mayer, 1997; H. Mayer & Höppe, 1987) to understand the thermal load on the human body and its relationship with sleep quality. Nastos & Matzarakis (2008) investigated sleep disturbances upon human-biometeorology and found increased sleep disturbances due to high PET values. Samson et al. (2017) looked into the evolution of human sleep associated with technological and cultural innovations of Hadza hunter-gatherers sleeping in grass huts, using PET to measure heat stress. The results demonstrated that grass huts served as a shield from outdoor heat stress and provided less thermal variation in the sleeping environment.

2.3.2. Outdoor Heat Stress Approach

To understand the whole thermal load on the human body, outdoor heat stress must be taken into account in addition to the indoor thermal conditions since urban energy balance is constituted by both anthropogenic and climatic heat fluxes (Oke, 1988). Furthermore, considering the outdoor climatic conditions encircle and influence the indoor thermal environment, exploring the interrelationship between outdoor and indoor conditions is necessary. The impact of climatic conditions on the indoor thermal environment subsequently also influences the sleep quality of occupants (Kayaba et al., 2014), who spend 90% of their life indoors (Walikewitz, Jänicke, Langner, & Endlicher, 2018). More specifically, the urban heat island effect and the increasing frequency of heat waves due to climate change results in higher energy consumption for cooling in summer, thermal discomfort, and health problems (Akkose et al., 2021; Santamouris, 2015; Zemtsov et al., 2020). Additionally, higher nocturnal air temperatures from urban heat islands (Kownacki, Gao, Kuklane, & Wierzbicka, 2019; Roaf, Crichton, & Nicol, 2009) can disturb the sleep quality of occupants.

As mentioned in section 2.2., the human biometeorological system can regulate thermal comfort until receiving excessive heat stress. Therefore, detecting, understanding, and bargaining for extreme heat stress risks can help avoid exposure to a higher thermal load on the human body. Extreme heat stress can be explored using extreme heat events based on local climatic factors such as Ta, RH, daily minimum and maximum temperatures, and excursion from local standards (Ellis & Nelson, 1978; Luber & McGeehin, 2008; Nouri, Charalampopoulos, & Matzarakis, 2022; Rooney, McMichael, Kovats, & Coleman, 1998). Within the case of Ankara, three outdoor heat stress events were defined currently based on Climate Change Detection Indices (CCDI), which are a typical summer day (TSD_{25}), a very hot day (VHD_{33}), and a heat wave event (HWE_{31}) (Nouri, Çalışkan, et al., 2021).

CHAPTER 3

METHODOLOGY

3.1. Research Questions and Hypotheses

This study aimed to explore the level of local vulnerability in terms of occupants' thermal comfort and sleep quality to climatic risk factors in Ankara. Within this context, the following research questions were inquired, and the corresponding hypotheses were formulated to investigate the objectives of this study:

RQ_1: How are occupants' thermal comfort and sleep quality affected by different local extreme heat events?

H_{1a}: The physiological thermal comfort of occupants will be higher in TSD_{25}, then in a HWE_{31}s, and will be lowest during a VHD_{33}s.

H_{1b}: The psychological thermal comfort of occupants will be higher in TSD_{25}, then in a HWE_{31}s, and will be lowest during a VHD_{33}s.

H_{1c}: The sleep quality of occupants will be higher during a TSD_{25}, then in a HWE_{31}s, and will be lowest during a VHD_{33}s.

RQ_2: How occupants' thermal comfort and sleep quality are affected by pre-sleep mechanical ventilation during each local extreme heat event?

H_2: Utilization of mechanical ventilation before sleep will not improve the psychological thermal comfort and sleep quality of occupants during all local extreme heat events.

3.2. Study Area

This study was conducted during the summer of 2021, between the months of June and September, in Ankara. Ankara is located at the latitude of 39° 55′ 31″ N and the longitude of 32° 51′ 58″ E. The local climate of Ankara is Continental-Mediterranean which means dry and hot summers (Karaca et al., 1995). Also, within Köppen-Geiger (KG) classification, the climate of the Ankara region was defined as *'Dsb'*, which indicates a cold climate and dry-warm summers, as demonstrated in Table 1 (Peel et al., 2007). However, further research revealed that the actual KG class of Ankara is *'Dsa'*, which also states a cold climate but dry and hot summers (Nouri, Afacan, et al., 2021). In addition, *'BSk'* and *'Csa'* classes, which show cold-semi-arid climate and dry-hot summers, respectively, were detected for the contiguous regions of Ankara.

Table 1. Description of KG classes within Ankara (Nouri, Afacan, et al., 2021; Peel, Finlayson, & Mcmahon, 2007).

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

MAT, mean annual temperature; T_{hot}, temperature of the hottest month; T_{cold}, temperature of the coldest month; T_{mon10}, of months where the temperature is above 10; MAP, mean annual precipitation;

P_{sdry}, precipitation of the driest month in summer; P_{wdry}, precipitation of the driest month in summer; P_{wwet}, precipitation of the wettest month in winter; $P_{threshold}$, 2 number × MAT (Nouri, Afacan, et al., 2021; Peel et al., 2007).

In particular, this study was conducted in Bilkent's University-Main Campus, more specifically within the housing (Lojman) area of the campus (Figure 2). The study area was selected regarding its inclusion of both vulnerable-uninsulated and insulated residential typologies, which are pre-2000 and post-2000 buildings (Figure 3 & 4). In addition, given the Covid-19 Pandemic precautions, the study area was limited to this specific region of Ankara.

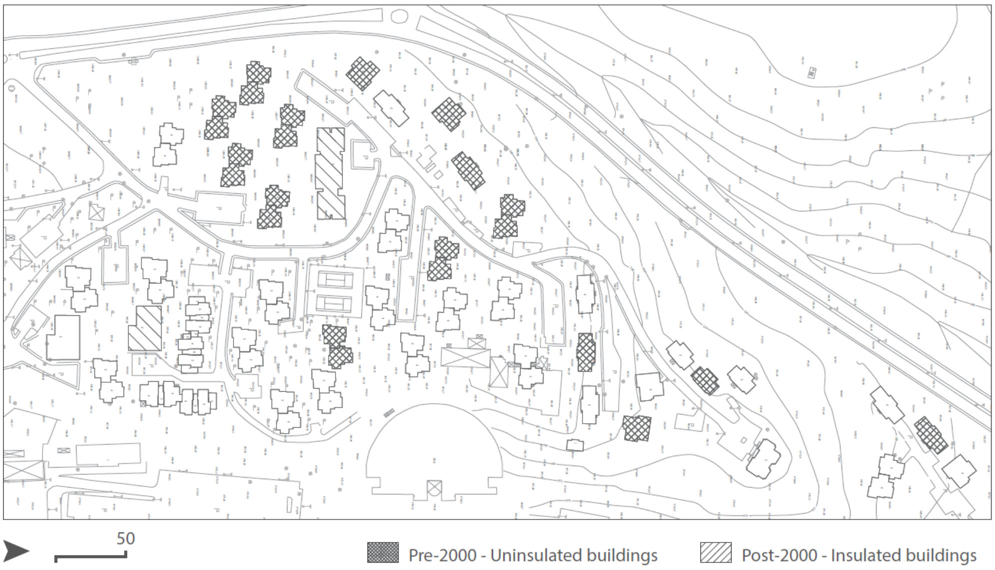

Figure 2. Study area map revealing the location of two residential construction typologies; uninsulated and insulated (Illustration by the author, 2022).

Figure 3. Block and apartment floor plans of pre-2000 buildings, and location of KHS within residential setting (Nouri et al., 2022).

Figure 4. Block and apartment floor plans of post-2000 buildings, and location of KHS within residential setting (Illustration by the author, 2022).

Measurements and questionnaires were performed in 15 pre-2000 and two post-2000 buildings. Pre-2000 buildings were three or four-storey buildings with an average of 50 m^2 residential units. They were constructed before 2000 with a traditional reinforced concrete system without thermal insulation (Esiyok, 2006). The external wall system was comprised of only internal and external cement plasters, and gas concrete briquette (Bilkent University Directorate of Construction and Technical Works, 1985). On the other hand, post-2000 buildings were four-storey buildings with an average of 54.3 m^2 residential units. They were constructed after 2000 with thermal insulation, in line with Thermal Insulation in Buildings" (TS-825) standard. In contrast to the pre-2000 buildings, the external wall of post-2000 buildings includes 20 cm stone wool heat insulation, waterproof membrane, and travertine facade cladding (Bilkent University Directorate of Construction and Technical Works, 2021).

3.3. Experimental Procedure

This research was operated with a two-tiered approach, one physiological analysis, and the other psychological analysis, to understand the interrelationship between outdoor and indoor assessments of urban conditions (Figure 5). Within the physiological evaluations, outdoor and indoor climatic variables were collected to understand the physiological thermal comfort of dwellers from both urban and interior scales. Additionally, the outdoor climatic variables were utilized to verify the occurrence of local extreme heat thresholds; TSD_{25}, VHD_{33}, and HWE_{31}. On the psychological side, thermal comfort and sleep quality questionnaires were conducted during the given local extreme heat events in each residential setting.

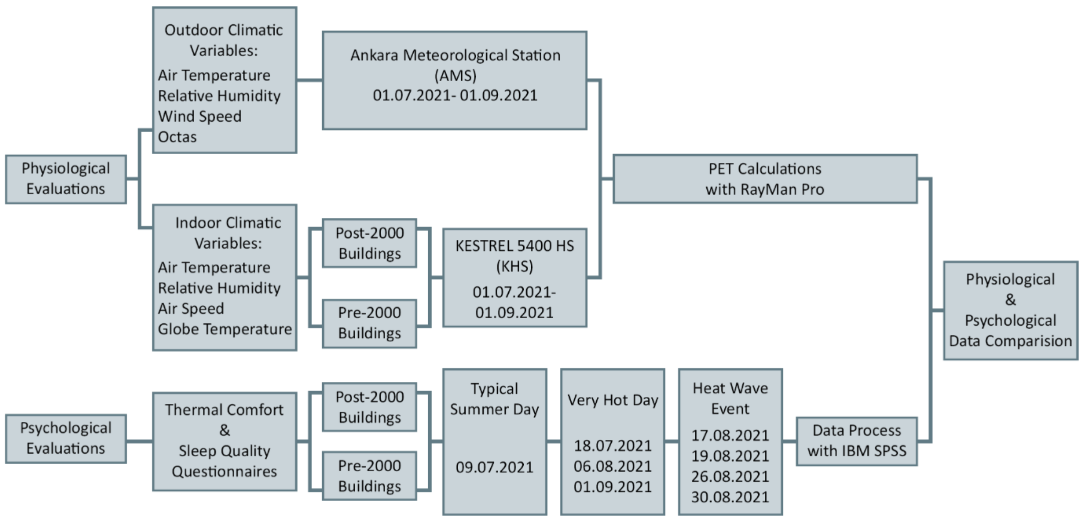

Figure 5. Research framework diagram demonstrating the two-tiered methodological approach of the study (Illustration by the author, 2022).

3.3.1. Application of Local Extreme Heat Thresholds

Within this study, different types of heat events were evaluated to consider the implication of outdoor heat events upon investigated sleep quality patterns. Such an approach interlaces with the growing need to consider outdoor conditions upon indoor conditions, as suggested by several studies (Basu & Samet, 2002; Gustin, McLeod, & Lomas, 2018; Kownacki et al., 2019; Nouri et al., 2022; Rosenfelder et al., 2016; Walikewitz et al., 2018; White-Newsome et al., 2012). Limited work has been undertaken which could otherwise inform interdisciplinary approaches towards human health with regards to heat risk management in Ankara (Akkose et al., 2021; Çalışkan & Türkoğlu, 2014; Çiçek & Doğan, 2006; Nouri, Afacan, et al., 2021; Nouri, Çalışkan, et al., 2021; Türkoğlu et al., 2012; Yılmaz, 2019)

The application of extreme heat events was decided according to the percentile-based descriptions of locally adapted CCDIs, i.e., cool days, cool nights, warm days, and warm nights (Nouri, Çalışkan, et al., 2021). The adaptation of CCDIs for Ankara was operated regarding yearly Ta data of Ankara between 2008 and 2020 through the R-based script RClimDex. Accordingly, three extreme heat events utilized in this research are TSD_{25}, VHD_{33}, and HWE_{31}, which indicate the risks of local heat stress on occupants of Ankara. TSD_{25} is the day when the maximum daily Ta exceeds 25 °C. VHD_{33} signifies the days when the maximum daily Ta is more than 33 °C (95th percentile), and HWE_{31} occurs when the daily Ta is higher than 31 °C (90th percentile) for six successive days (Can et al., 2019; Demirtaş, 2018; Kuglitsch et al., 2010; Luber & McGeehin, 2008).

3.3.2. Physiological Approach

Within this study, three local meteorological stations were used to collect outdoor and indoor climatic variables at various resolutions, including Ta and RH, which are known as the most important climatic factors affecting the sleep quality according to existing studies (W. te Liu et al., 2022; Okamoto-Mizuno et al., 1999; Okamoto-Mizuno, Tsuzuki, Mizuno, & Iwaki, 2005; Tsuzuki et al., 2015; Xu et al., 2021; Yan et al., 2022). In addition to these variables, the EMB index was applied to determine further impacts upon the human biometeorological system (Nouri, Çalışkan, et al., 2021; Nouri et al., 2022).

3.3.2.1. Outdoor and Indoor Climatic Variable Collection

In this study, outdoor and indoor meteorological parameters data were continually collected every day from 1 July to 1 September 2021. As outdoor meteorological parameters, hourly data of air temperature (Ta_{Out}), relative humidity (RH_{Out}), wind speed (V_{Out}), and cloud cover (Oct) were provided by Ankara Meteorological Station (AMS) ($MS_{\#17130}$). As indoor meteorological parameters, air temperature (Ta_{In}PRE and Ta_{In}POST), relative humidity (RH_{In}PRE and RH_{In}POST), airspeed (V_{In}), and Globe Temperature (Tg_{In}) were collected in 10 minutes resolution at 1.1 m above the ground through 2 Kestrel Heat Stress Stations (KHS) (Figure 6) that installed in two different residential settings (i.e., pre-2000 and post-2000 buildings) (Table 2). Additionally, the Mean Radiant Temperature (MRT) was calculated by Oct for outdoor and Tg_{In} for indoor meteorological data. The MRT_{In} was calculated using the following equation, as identified in ISO-7726-1998 (as cited in Nouri et al., 2022).

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

Where: Tg_{In} is indoor Globe Temperature, Ta_{In} is indoor Air Temperature, D= 0.025 m, and ε = 0.95 (i.e., matt black)

Table 2. Specifications of Kestrel Heat Stress (KHS) 5400 station. (Product Specifications for Kestrel 5400 Heat Stress Trackers Sensors, 2020)

Climatic Variable	**Accuracy**	**Resolution**	**Specification Range**
Air Temperature (Ta_{In})	0.5 °C	0.1 °C	-29.0 to 70.0 °C
Wind/Air Speed (V_{In})	> of 3% of reading	0.1 m/s	0.6 to 40.0 m/s
Relative Humidity (RH_{In})	2%	0.1 %	10 to 90% (25°C noncondensing)
Globe Temperature (Tg_{In})	1.4 °C	0.1 °C	-29.0 to 60.0 °C

Figure 6. Kestrel Heat Stress (KHS) 5400 station (https://kestrelinstruments.com/kestrel-5400-heat-stress-tracker-pro)

3.3.2.2. Energy Balance Model Index Processing

To scrutinize the physiological stress (PS) level of the human body, the PET index was calculated through outdoor and indoor climatic variables. The PET is an EBM thermal index based on the Munich Energy Balance Model for Individuals (MEMI) (Höppe, 1984, 1993) and is used to determine the impact of the thermal environment on the human body by using heat balance between them. PET is appropriate for this study because of its extensive usage in the field (Charalampopoulos, 2019; Nouri, Charalampopoulos, et al., 2018), suitability for both indoor and outdoor calculations (Höppe, 1999; Matzarakis et al., 2007), and utilization of °C as a unit of measurement (Nouri, Charalampopoulos, et al., 2018). Also, the PET can be calculated with easily obtainable data, which are air temperature, air velocity, air humidity, and radiation (Höppe, 1999; Matzarakis, 1999; Nouri, 2013).

Outdoor and indoor PET values (PET_{Out}, $PET_{In}PRE$ for pre-2000 buildings, and $PET_{In}POST$ for post-2000 buildings) were calculated through the use of the biometeorological model RayMan Pro (Matzarakis & Fröhlich, 2018; Matzarakis et al., 2007; Matzarakis, Rutz, & Mayer, 2010) software which can compute the short and longwave radiation of human heat balance for local thermal environments. Outdoor and indoor meteorological parameters were imported to RayMan Pro to examine the PS grades (Table 3) on occupants of Ankara.

Table 3. Ranges of the thermal index Physiologically Equivalent Temperature (PET) for different grades of Thermal Perception and Physiological Stress on human beings; internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (according to Matzarakis & Mayer, 1997) | Source: (Adapted from, Matzarakis et al., 1999).

PET	Thermal Perception	Physiological Stress
<4ºC	Very Cold	Extreme Cold Stress
	Cold	Strong Cold Stress
8ºC	Cool	Moderate Cold Stress
13ºC	Slightly Cool	Slight Cold Stress
18ºC	Comfortable	No Thermal Stress
23ºC	Slightly Warm	Slight Heat Stress
29ºC	Warm	Moderate Heat Stress
35ºC	Hot	Strong Heat Stress
>41ºC	Very Hot	Extreme Heat Stress

3.3.3. Psychological Approach

Psychological thermal comfort and sleep quality of occupants were evaluated through questionnaires during each heat stress event, as displayed in Figure 5. Totally, ninety-nine questionnaires were conducted with the voluntary dwellers of pre-2000 and post-2000 buildings. In particular, 17, 15, and 16 participants from pre-

2000 buildings, and 19, 16, and 16 participants from post-2000 buildings attended psychological evaluations during TSD_{25}, VHD_{33}, and HWE_{31} events, respectively.

Each survey/heat event day was chosen according to the weekly weather predictions of AMS ($MS_{\#17130}$), and subjects were briefed one week before each survey day through an email. The participants were asked to fill out the questionnaire on the morning of the day after the heat events by considering their previous night's thermal conditions and sleep quality. Also, the subjects were informed about the process through the validated consent form by the Bilkent University Ethics Committee.

Psychological assessment of thermal load on the human body and sleep quality requires a comprehensive approach, including several factors such as demographic conditions, bed insulation, ventilation, thermal sensation, thermal comfort, thermal expectation, and thermal adaptation (Budiawan & Tsuzuki, 2021; Lai et al., 2020; Y. Liu et al., 2014; Yingying Wang, Liu, Song, & Liu, 2015; H. Zhang, 2003; X. Zhang et al., 2021). Therefore, the questionnaire sheet is structured around four main parts; (1) general participant information, (2) sleeping conditions and behaviors, (3) climatic perception orientated, and lastly, (4) sleep quality orientated (Figure 7). In the first part, the subjects were asked for individual information such as age, gender, having a sleep disorder, and being outdoor during the last 24 hours. The following part includes questions about sleeping conditions, i.e., sleepwear level, bed covering level, mechanical ventilation usage (with air conditioning or other devices), and window opening behavior, of the participants. In the third part, subjects were requested to self-evaluate their thermal comfort and thermal sensations in terms of overall comfort, air temperature sensation, humidity sensation, and airspeed sensation, with a 7-point scale assessment in accordance with ASHRAE Standard (2010). Within the last part, participants' sleep quality was measured through a 5-point scale of sleep quality questions consisting of sleep calmness, ease of falling asleep, ease of awakening, freshness after awakening, sleep satisfaction questions, and adapted sleep sufficiency and frequency of awakening questions.

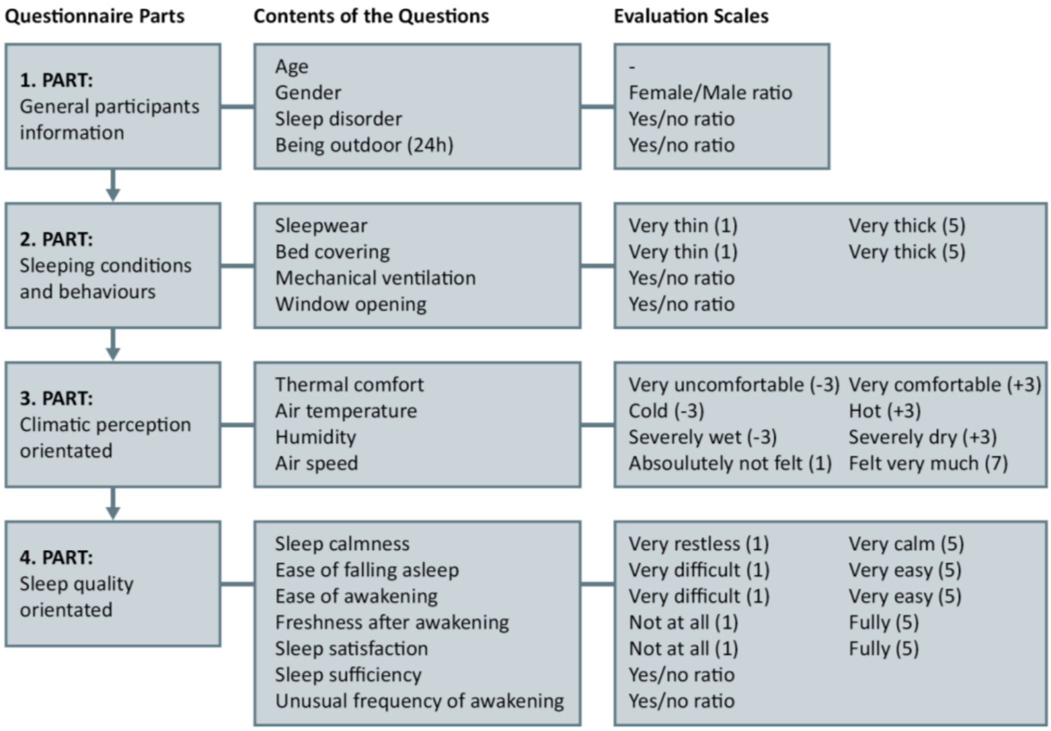

Figure 7. Psychological Approach Flow Diagram explaining the division of questionnaire parts that are cross-examined against question contents and evaluation scales (Illustration by the author, 2022).

3.3.3.1. Thermal Comfort Questionnaires

In the third part of the questionnaire, participants were asked to assess their psychological thermal sensations and comfort to compare with the physiological thermal comfort of occupants, as shown in Figure 7. Overall thermal comfort was voted through a 7-point scale based on Cao et al. (2021) and Tsuzuki et al. (2008). Also, corresponding to Ta_{In} of the physiological side, air temperature sensation was evaluated through the ASHRAE 7-point scale (2010) standard (Lan et al., 2014; Y. Liu et al., 2014; Pan et al., 2012; Song et al., 2015, 2020; Tsang et al., 2021; Wang et al., 2015; N. Zhang et al., 2018, 2019). Similarly, humidity sensations were assessed to compare with the physiological RH measurements. Besides, airspeed sensations were voted to investigate the effect of ventilation on thermal sensations. Both humidity and airspeed sensation questions and their 7-point scale evaluation types were adapted from several studies (Budiawan & Tsuzuki, 2021; Morito, Tsuzuki, Mori, & Nishimiya, 2017; Zaki et al., 2021; X. Zhang et al., 2021).

3.3.3.2. Sleep Quality Questionnaires

Within the last part of the questionnaire (Figure 7), participants were requested to evaluate their sleep quality to explore the alterations in indoor sleep quality of occupants by using the PET index in relation to outdoor heat stress events. As being the most-used sleep quality questions; sleep calmness, ease of falling asleep, ease of awakening, feeling refreshed after awakening, and sleep satisfaction were evaluated by a 5-point scale (Cao et al., 2021; Pan et al., 2012; Song et al., 2020; N. Zhang et al., 2019; X. Zhang et al., 2021). In addition, to learn the subjects' overall sleep evaluation and its relationship with specific heat events, sleep sufficiency, and unusual frequency of awakening, questions were adapted (Akerstedt, Hume, Minors, & Waterhouse, 1997; Li Lan et al., 2014; Y. Liu et al., 2014; Tsang et al., 2021; Yingying Wang et al., 2015; Zaki et al., 2021; N. Zhang et al., 2018; Zheng et al., 2019; Zilli, Ficca, & Salzarulo, 2009)

3.4. Data Processing

The physiological evaluations of Ta, RH, and PET values for particular heat events and identification of local heat thresholds through daily Ta_{Out} were represented through Climate-Tourism/Transfer-Information-Scheme (CTIS) heatmaps. For an illustration of daily Ta and PET datasets, PS grades were used for comparison purposes. In addition, for benchmarking indoor thermal conditions in pre-2000 and post-2000 buildings upon outdoor heat stress during pre-sleep and sleep periods, tables were utilized that demonstrate the average, maximum and minimum values of Ta, RH, and PET between the hours of 18:00 and 05:00. Within the psychological assessments, the mean values (Y. Liu et al., 2014; Song et al., 2015) and ratio of answers were processed through frequency tables under the descriptive statistics in IBM SPSS version 26.

CHAPTER 4

RESULTS

4.1. Identification of Local Heat Thresholds

To validate the physiological heat stress risks of outdoor heat events on indoor thermal comfort and sleep quality, the local heat stress thresholds were identified using daily Ta values of Ankara at 1-hour resolution for 01.07.2021-02.09.2021. Based on CCDIs, TSD_{25}, VHD_{33}, and HWE_{31} events were detected as the local extreme heat events of Ankara, as illustrated in Figure 8. Additionally, monthly tropical nights (MTR_{20}) were also elicited to emphasize the high night-time outdoor heat stress risk during July and August.

The first and foremost result obtained by the CTIS heatmap revealed that at least one extreme heat event occurred on each day during July and August without exception. Furthermore, the concurrent occurrence of extreme heat events provided to comprehend the amplified vulnerability of indoors to outdoor heat stress. For example, when considering 10 of 24 TSD_{25} events overlapped with the days missed meeting the HWE_{31} threshold by less than 1 °C, it was possible to verify that almost half of the TSD_{25}s had the potential to be a part of heat waves. More critically, it was noted that except first three days of July, all VHD_{33}s, including 21 VHD_{33}s and seven potential VHD_{33}s, were also part of HWE_{31}s. It was also found that 60% of these days that witness both VHD_{33} and HWE_{31} events also include MTR_{20}. In other words, the identification of local heat thresholds of Ankara for July and August confirmed the extreme outdoor heat stress risks on vulnerable indoors during particular heat event-survey dates, which were designated in Figure 8.

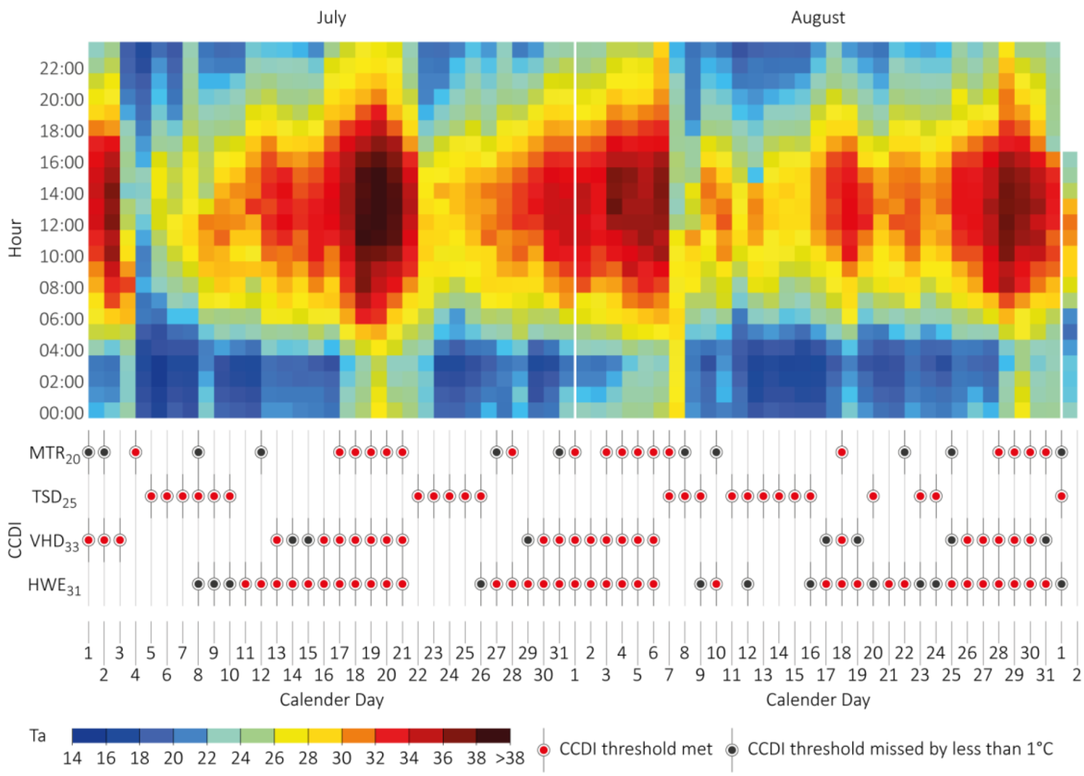

Figure 8. CTIS heatmap for identification of extreme heat events in Ankara urban center using daily Ta data with 1 h resolution, between 01.07.2021-and 02.09.2021 (Produced in CTIS program by author, 2022).

4.2. Physiological Evaluations

The undertaken analysis was conducted to understand the relationship between outdoor and indoor Ta, RH, and PET, using hourly and average meteorological datasets for TSD_{25}, VHD_{33}, and HWE_{31} events. The TSD_{25} surveys were completed in one day. However, the VHD_{33}s and HWE_{31}s surveys were filled during different heat event days, given the decreased frequency of these heat events in comparison to typical summer conditions. Thus, VHD_{33}s and HWE_{31}s results were obtained using average hourly PET, Ta, and RH values. These hourly data of Ta, RH, and PET were represented through CTIS heatmaps to show the hourly course of given data. The Ta and PET heatmap keys were determined according to the PS grades to be able to compare the heat load data with heat stress grades.

4.2.1. Air Temperature

When considering measured Ta values, it was possible to identify that they were always higher in the pre-2000 buildings than those from post-2000, as presented in Figure 9. This difference became more dramatic during the pre-sleep and during sleep periods, as displayed in Table 4. With regards to the TSD_{25}, at 00:00, Ta_{Out} was lower than Ta_{In} values with 21.6 °C, while Ta_{In}PRE was 26.5 °C and Ta_{In}POST was 26.7 °C (Figure 9). Then between the hours of 00:00 and 12:00, Ta_{Out}, Ta_{In}PRE, and Ta_{In}POST presented a variation of +8.4 K, +1.3 K, and +0.4 K, respectively. From 12:00 to 18:00, Ta_{Out} decreased by -6.6 K, while Ta_{In}PRE increased by +0.9 K, and the Ta_{In}POST slightly decreased by -0.1 K. The drop of average Ta_{Out} and Ta_{In}POST continued by -2.3 K and -0.2 K respectively during the nocturnal period, i.e., between 18:00 and 05:00. In contrast, Ta_{In}PRE kept rising by +1.0 K (Table 4).

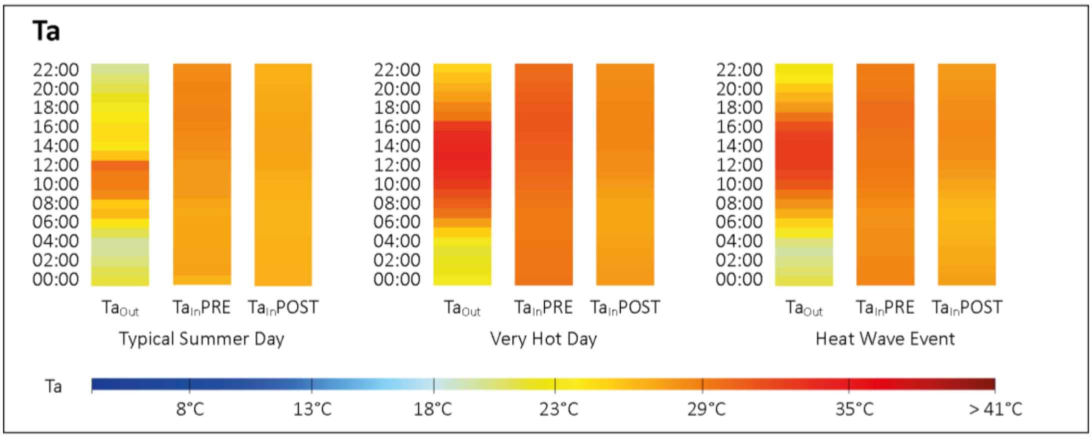

Figure 9. CTIS heatmaps for Ta values of pre-2000 and post-2000 buildings during the TSD_{25}, VHD_{33}, and HWE_{31} events (Produced in CTIS program by author, 2022).

Table 4. Average, maximum, and minimum values of Ta_{Out}, $Ta_{In}PRE$, and $Ta_{In}POST$ for before sleep and sleep hours during TSD_{25}, VHD_{33}, and HWE_{31} events.

		Ta_{Out}				$Ta_{In}PRE$				$Ta_{In}POST$			
		18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00	18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00	18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00
TSD_{25}	Average	22.3	20.0	17.7	20.0	28.7	28.3	29.6	29.7	26.9	26.6	26.7	26.7
	Maximum	23.4	20.7	18.3	22.5	28.8	28.4	30.0	29.8	27.0	26.7	26.8	26.8
	Minimum	24.1	21.3	17.2	17.3	28.7	28.2	29.0	29.7	26.8	26.6	26.7	26.7
VHD_{33}	Average	27.5	25.0	22.9	23.2	30.7	30.0	29.9	29.7	28.4	28.2	27.7	27.4
	Maximum	28.7	25.9	23.6	23.2	30.9	30.1	30.0	29.8	28.5	28.3	27.9	27.5
	Minimum	26.7	24.1	22.4	21.9	30.5	30.0	29.8	29.7	28.3	28.1	27.6	27.2
HWE_{31}	Average	26.5	22.9	20.3	20.3	29.5	29.1	28.9	28.7	28.0	27.6	27.2	26.8
	Maximum	27.7	24.0	21.1	22.3	29.9	29.1	29.0	28.8	28.2	27.8	27.5	26.9
	Minimum	25.4	21.9	19.6	18.8	29.2	29.1	28.8	28.6	27.9	27.5	27.0	26.7

TSD_{25}, typical summer day when the maximum daily Ta exceeds 25 °C; VHD_{33}, very hot day when the maximum daily Ta exceeds 33 °C; HWE_{31} heat wave event when the daily Ta exceeds 31 °C for six successive days; Ta_{Out}, outdoor air temperature; $Ta_{In}PRE$, air temperature in pre-2000 buildings; $Ta_{In}POST$, air temperature in post-2000 buildings.

As delineated in Figure 9, Ta_{Out}, $Ta_{In}PRE$, and $Ta_{In}POST$ values were highest during the VHD_{33}s compared with TSD_{25} and HWE_{31}s. Within the VHD_{33}s, at 00:00, Ta_{Out}, $Ta_{In}PRE$, and $Ta_{In}POST$ values were 23.2 °C, 29.7 °C, and 27.8 °C respectively. At 12:00, Ta values surpassed those of the morning hours by up to +10.7 K, +0.6 K, and +0.4 K. Until 18:00, Ta_{Out} showed a significant drop by -5.2 K, while on the contrary, $Ta_{In}PRE$ and $Ta_{In}POST$ presented a slight increase by +0.7 K and +0.4 K respectively. Between the hours 18:00 and 05:00, the average Ta_{Out} values indicated higher variation than $Ta_{In}PRE$ and $Ta_{In}POST$ values by -4.3 K, -1.0 K, and -1.0 K, as depicted in Table 4. It was also notable to state that the difference between average $Ta_{In}PRE$ and $Ta_{In}POST$ increased by +0.5 K. between 21:00 and 05:00.

In the case of HWE_{31}s, Ta values were lower than VHD_{33}s but higher than TSD_{25}. Figure 9 demonstrates that, at 00:00, Ta_{Out} was 21.4 °C, $Ta_{In}PRE$ was 28.7 °C, and $Ta_{In}POST$ was 27.4 °C. Around 12:00, Ta_{Out} designated a considerable rise by +11.1 K, while $Ta_{In}PRE$ and $Ta_{In}POST$ values showed a small increase by +0.6 K and +0.5

K. Until 18:00, even though the Ta_{Out} decreased by -4.7 K, Ta_{In}PRE and Ta_{In}POST values kept rising to +0.7 K and +0.3 K, respectively. As presented in Table 4, all average Ta values reached lower values throughout the nocturnal period. Notably, during the hours between 21:00 and 23:00, the difference between average Ta_{In}PRE and Ta_{In}POST was 1.5 °C, and this difference raised by +0.4 K during the sleep period until 05:00.

To sum up, the relationship between the hourly course of Ta_{Out}, Ta_{In}PRE, and Ta_{In}POST were similar during all three heat events. Ta_{Out} always had lower values than Ta_{In}PRE and Ta_{In}POST in the mornings. Then, all Ta values increased during the afternoon, and Ta_{Out} values became considerably higher than the Ta_{In}PRE and Ta_{In}POST values until 18:00. However, after 18:00, all Ta values began to decrease, but the amount of decrease was consistently higher for Ta_{Out}, while almost always, Ta_{In}PRE and Ta_{In}POST values declined only slightly. Exceptionally, the Ta_{In}PRE values slightly increased during the TSD_{25} night. Also, when the Ta_{In}PRE and Ta_{In}POST were compared, it was revealed that the difference between them kept rising during the pre-sleep and sleep periods.

4.2.2. Relative Humidity

As one of the most investigated meteorological factors influencing thermal comfort and sleep quality, RH was examined through the CTIS heatmap (Figure 10) and the average nocturnal period values table (Table 5). The results indicated that both RH_{Out} and RH_{In} values were highest during the TSD_{25} compared with the VHD_{33}s and HWE_{31}s, as shown in Figure 10. Within the case of TSD_{25}, at 00:00, the RH_{Out} was 61.0 % and had higher values than RH_{In}PRE and RH_{In}POST, which were 34.1 % and 50.8 %, respectively. Until 12:00, RH_{In}POST kept slightly increasing by +3.8 K, while on the contrary, RH_{Out} and RH_{In}PRE showed a drop by -26.0% and -4.5%. At 18:00, despite a significant increase in RH_{Out} by up to +22.0 K, RH_{In}PRE and RH_{In}POST values did not increase and presented a reverse variation by -4.7 K and -

1.8 K, respectively. As demonstrated in Table 5, between 18:00 and 05:00, all average RH values showed a slight increase by +3.0 K, +0.9 K, and +3.3 K.

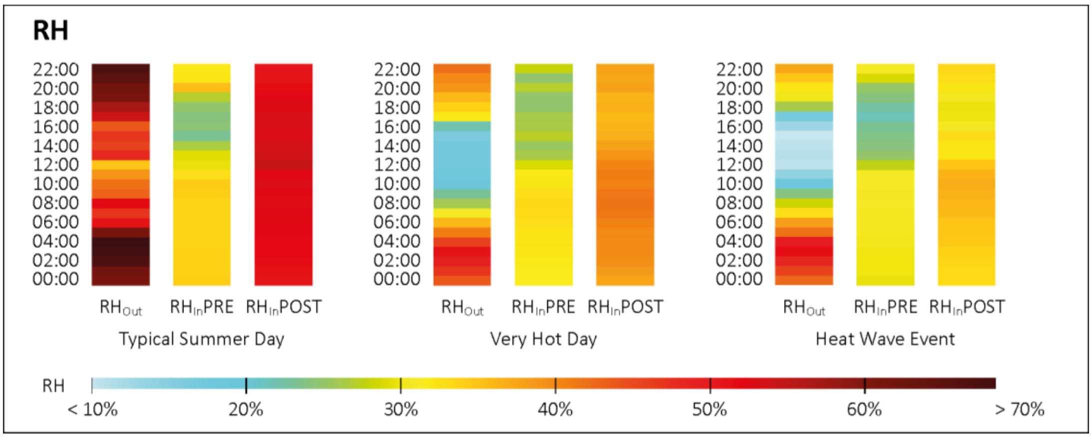

Figure 10. CTIS heatmaps for RH values of pre-2000 and post-2000 buildings during the TSD_{25}, VHD_{33}, and HWE_{31} events (Produced in CTIS program by author, 2022).

Table 5. Average, maximum, and minimum values of RH_{Out}, $RH_{In}PRE$, and $RH_{In}POST$ for before sleep and sleep hours during TSD_{25}, VHD_{33}, and HWE_{31} events.

		RH_{Out}				$RH_{In}PRE$				$RH_{In}POST$			
		18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00	18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00	18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00
TSD_{25}	Average	60.0	67.0	75.0	63.0	29.1	31.9	29.2	30.0	52.2	51.8	54.9	55.5
	Maximum	62.0	69.0	77.0	76.0	35.5	32.1	29.6	31.0	52.8	53.9	55.1	55.8
	Minimum	57.0	65.0	73.0	49.0	24.9	31.7	28.9	29.2	51.6	50.8	54.8	55.4
VHD_{33}	Average	36.0	42.4	49.2	49.3	25.5	27.1	30.4	31.2	37.0	37.9	38.0	39.0
	Maximum	39.0	45.0	50.0	51.0	27.0	28.8	30.8	31.5	38.0	38.5	38.3	38.9
	Minimum	34.0	40.0	48.0	48.0	24.8	24.8	29.8	31.0	36.3	37.3	37.6	38.5
HWE_{31}	Average	29.5	37.9	45.3	47.0	23.9	30.4	31.6	31.2	30.8	33.5	34.8	35.3
	Maximum	32.2	41.2	47.5	49.7	25.2	31.7	31.7	31.4	32.2	34.3	35.3	35.5
	Minimum	26.2	35.0	43.0	43.5	22.4	28.7	31.6	31.2	29.7	32.7	34.2	35.2

TSD_{25}, typical summer day when the maximum daily Ta exceeds 25 °C; VHD_{33}, very hot day when the maximum daily Ta exceeds 33 °C; HWE_{31} heat wave event when the daily Ta exceeds 31 °C for six successive days; RH_{Out}, outdoor relative humidity; $RH_{In}PRE$, relative humidity in pre-2000 buildings; $RH_{In}POST$, relative humidity in post-2000 buildings.

Along the VHD_{33}s, at 00:00, RH_{Out} was 44.3%, $RH_{In}PRE$ was 31.5 %, and $RH_{In}POST$ was 37.6% which were considerably lower than those of TSD_{25}. At 12:00, RH_{Out} marked a considerable decrease of -27.0 K, while $RH_{In}PRE$ and

$RH_{In}POST$ indicated a slight variation by -2.6 K and +2.8 K, respectively. During 18:00, RH_{Out} reaches higher values by up to +16.3 K. On the contrary, $RH_{In}PRE$ and $RH_{In}POST$ presented a small drop of -4.0 K and -3.7 K. Nevertheless, the average RH_{Out}, $RH_{In}PRE$, and $RH_{In}POST$ values for the nocturnal period (Table 5) revealed that all RH values raised by+13.3 K, +5.7 K, and +2.0 K between 18:00 and 05:00.

Similar to the TSD_{25} and VHD_{33s}, within the $HWE_{31}s$, the RH_{Out} had a higher value of 42.5% than $RH_{In}PRE$ (29.6%) and $RH_{In}POST$ (33.1%) at 00:00 too. Albeit, at 12:00, RH_{Out} presented a significant decrease by -32.0 K, while $RH_{In}PRE$ and $RH_{In}POST$ slightly variated by -2.0 K and +1.9 K. Around 18:00, it was witnessed that RH_{Out} raised by +15.8 K. In comparison, $RH_{In}PRE$ and $RH_{In}POST$ varied only by -5.2 K and -5.3 K. For pre-sleep and sleep period, the vulnerability of indoors became more dramatic at the nocturnal period as manifested through the increase of $RH_{Out,}$ $RH_{In}PRE$ and $RH_{In}POST$ by +17.5 K, +7.3 K, and +4.5 K (Table 5), between 18:00 and 05:00.

4.2.3. Thermal Index Outputs

In addition to the investigated Ta and RH, this study used PET thermal index to understand the physiological thermal load on the human body and its relationship with sleep quality. Figure 11 displays the hourly change of $PET_{Out,}$ $PET_{In}PRE$, and $PET_{In}POST$ during local extreme heat events. In TSD_{25}, at 00:00, with 17.3 °C, PET_{Out} was lower than PET_{In} values, while both $PET_{In}PRE$ and $PET_{In}POST$ were 27.5 °C. Nonetheless, until 12:00, PET_{Out} surpassed PET_{In} values by +16.3 K, and $PET_{In}PRE$ and $PET_{In}POST$ values presented a slight variation by +0.7 K and +0.4 K. Until 18:00, $PET_{In}PRE$ increased by +0.8 K, while PET_{Out} and $PET_{In}POST$ decreased by -14.0 K, -0.1 K respectively. For the nocturnal period, Table 6 revealed that, between 18:00 and 05:00, the variation of average PET_{Out} was higher by -2.7 K, than $PET_{In}PRE$ and $PET_{In}POST$ which varied by +0.9 K and -1.0 K respectively.

Therefore, the average $PET_{In}PRE$ and $PET_{In}POST$ remained higher than PET_{Out} between 18:00 and 05:00. Moreover, when the $PET_{In}PRE$ and $PET_{In}POST$ were compared, it was seen that the difference between them increased by +1.1 K between 21:00 and 05:00.

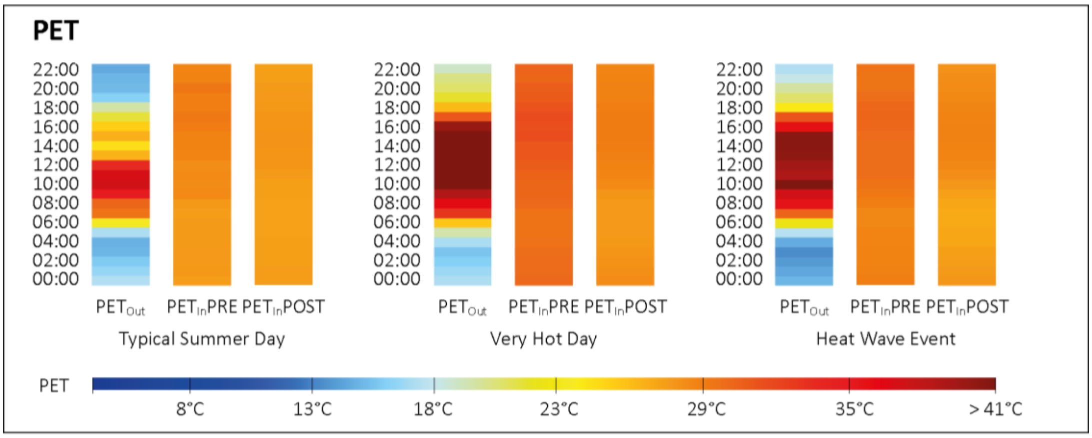

Figure 11. CTIS heatmaps for PET values of pre-2000 and post-2000 buildings during the TSD_{25}, VHD_{33}, and HWE_{31} events (Produced in CTIS program by author, 2022).

Table 6. Average, maximum, and minimum values of PET_{Out}, $PET_{In}PRE$, and $PET_{In}POST$ for before sleep and sleep hours during TSD_{25}, VHD_{33}, and HWE_{31} events.

		PET_{Out}				$PET_{In}PRE$				$PET_{In}POST$			
		18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00	18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00	18:00-20:00	21:00-23:00	00:00-02:00	03:00-05:00
TSD_{25}	Average	16.9	14.4	12.4	14.2	29.1	28.7	30.0	30.0	27.7	27.4	27.6	27.6
	Maximum	19.6	15.0	12.7	16.7	29.4	28.8	30.3	30.1	27.8	27.5	27.6	27.7
	Minimum	15.2	13.8	12.0	11.5	29.0	28.6	29.5	30.0	27.6	27.4	27.6	27.6
VHD_{33}	Average	22.9	19.0	17.3	18.4	30.9	30.3	30.2	30.0	28.9	28.7	28.3	27.9
	Maximum	26.2	20.3	18.0	20.5	31.2	30.4	30.3	30.1	29.0	28.8	28.5	28.1
	Minimum	20.8	18.0	16.7	16.6	30.7	30.3	30.2	30.1	28.8	28.6	28.2	27.8
HWE_{31}	Average	21.5	17.2	15.1	15.1	29.8	29.5	29.4	29.1	28.4	28.0	27.7	27.3
	Maximum	24.1	18.1	15.9	16.7	30.2	29.6	29.5	29.2	28.6	28.2	27.9	27.4
	Minimum	19.7	16.4	14.4	13.6	29.5	29.5	29.3	29.0	28.3	27.9	27.5	27.1

TSD_{25}, typical summer day when the maximum daily Ta exceeds 25 °C; VHD_{33}, very hot day when the maximum daily Ta exceeds 33 °C; HWE_{31} heat wave event when the daily Ta exceeds 31 °C for six successive days; PET_{Out}, outdoor physiological equivalent temperature; $PET_{In}PRE$, physiological equivalent temperature in pre-2000 buildings; $PET_{In}POST$, physiological equivalent temperature in post-2000 buildings.

In the case of VHD_{33}s, PET_{Out}, PET_{In}PRE, and PET_{In}POST values were consistently higher than the ones in TSD_{25} and HWE_{31}. At 00:00, the PET_{Out} was 17.2 °C, PET_{In}PRE was 30.1 °C, and PET_{In}POST was 28.3 °C (Figure 11). Until 12:00, PET_{Out} reached 43.5 °C, which indicates the extreme heat stress within PS grades. Meanwhile, PET_{In}PRE and PET_{In}POST showed notably smaller variations by +0.7 K and +0.5 K, respectively. In contrast to the afternoon, at 18:00, PET_{Out} decreased significantly by -17.3 K, while PET_{In}PRE and PET_{In}POST began to increase by +0.4 K and +0.2 K. As shown in Table 6, all average PET values declined throughout the pre-sleep and sleep periods. It was crucial to signify that, between 18:00 and 05:00, the PET_{Out} varied by -4.5 K, while PET_{In}PRE and PET_{In}POST showed slight variation by -0.9 K and -1.0 K. Thus, although the PET_{In}PRE and PET_{In}POST values were lower than PET_{Out} during the diurnal period, they remained higher than PET_{Out} in the nocturnal period. Also, when the residential settings were compared between 21:00 and 05:00, it was found that the difference between PET_{In}PRE and PET_{In}POST denoted an increase by +0.5 K.

Within the HWE_{31}s, at 00:00, PET_{Out} was 15.0 °C and lower than PET_{In}PRE and PET_{In}POST, which were 29.0 °C and 27.8 °C, respectively (Figure 11). At the hour of 12:00, PET_{Out} increased to 39.4 °C, which corresponds to strong heat stress in PS grades (Table 3). In the same period, PET_{In}PRE and PET_{In}POST altered only by +0.7 K and +0.7 K. Between the hours of 12:00 and 18:00, PET_{Out} marked a notable drop by -15.3 K. On the contrary, PET_{In}PRE and PET_{In}POST stayed in higher values by variations of +0.5 K and +0.1 K, respectively. As articulated in Table 6, and similar to VHD_{33}s, all PET values declined between 18:00 and 05:00 by variations of -6.4 K, -0.7 K, and -1.1 K respectively. More critically, from 21:00 to 05:00, the difference between PET_{In}PRE and PET_{In}POST was raised by +0.3 K.

In brief, the hourly and average PET values verified that generally, PET_{Out} values were lower than PET_{In}PRE and PET_{In}POST values in the morning but surpassed them and reached elevated PS grades during the afternoon. Nevertheless, when it comes to the nocturnal period, PET_{In}PRE and PET_{In}POST became markedly higher than PET_{Out} again. Besides, the difference between PET_{In}PRE and PET_{In}POST increased persistently between 21:00 and 05:00 during all outdoor heat events, with higher values of $PET_{In}PRE$.

4.3. Psychological Evaluations

The results of psychological evaluations were derived from the four-part analysis into the qualitative attributes from the questionnaires undertaken during identified local thresholds; TSD_{25}, VHD_{33}, and HWE_{31}. Within this scope, the results of parts 1 and 2 will be summarized under individual conditions, while the results of parts 3 and 4 will be launched at psychological evaluation of thermal conditions and evaluation of sleep quality sections.

4.3.1. Individual Conditions

As presented in Figures 12, 13, 14, and Table 7, it was possible to determine the individual conditions of participants from each residential setting for all heat events in Ankara. With regards to the demographic information of participants, it was revealed that the subjects' ages were consistently higher in pre-2000 buildings than in post-2000 buildings during all heat events (Figure 12). The gender ratio was always balanced between residential settings, as displayed in Figure 13. None of the participants had sleep disorders. Moreover, as the last component of part 1, being outdoor ratios were illustrated in Figure 14, which signified that the ratio of subjects that had been outdoors during 24 hours before the survey day was continually higher in pre-2000 buildings than in post-2000 buildings.

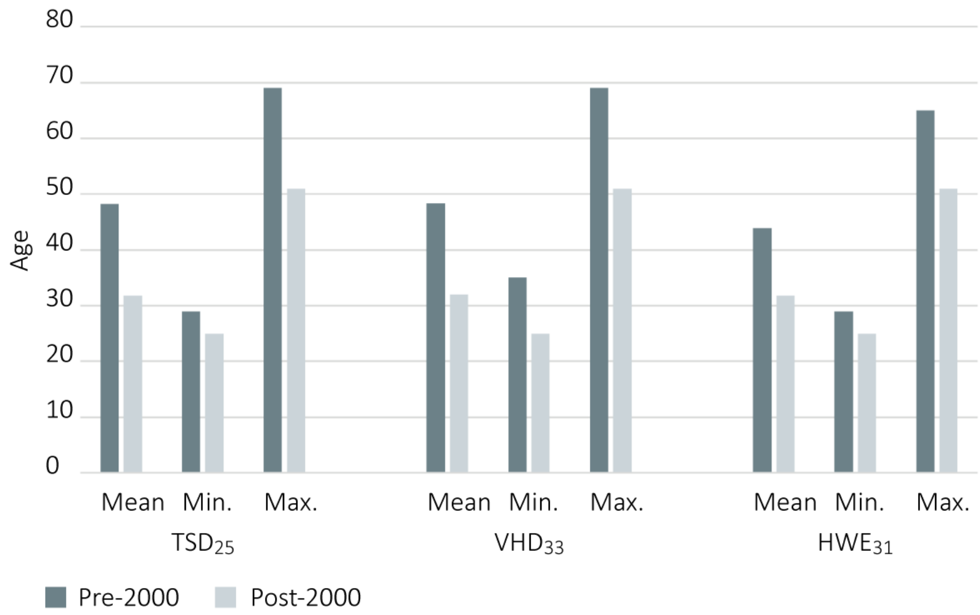

Figure 12. Mean, Minima, and Maxima of Ages for Participants of Pre- and Post-2000 Buildings During Outdoor Heat Events.

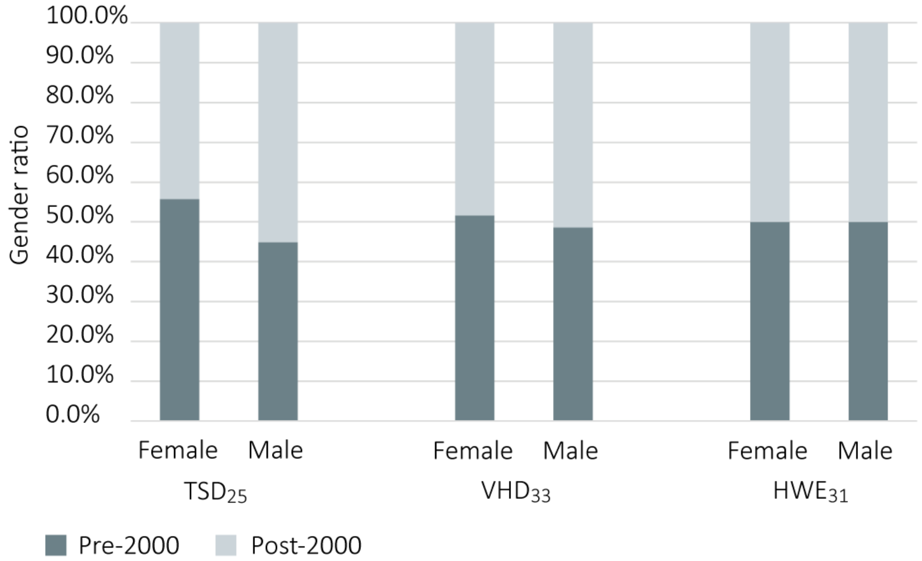

Figure 13. Gender Ratio for Participants of Pre- and Post-2000 Buildings During Outdoor Heat Events.

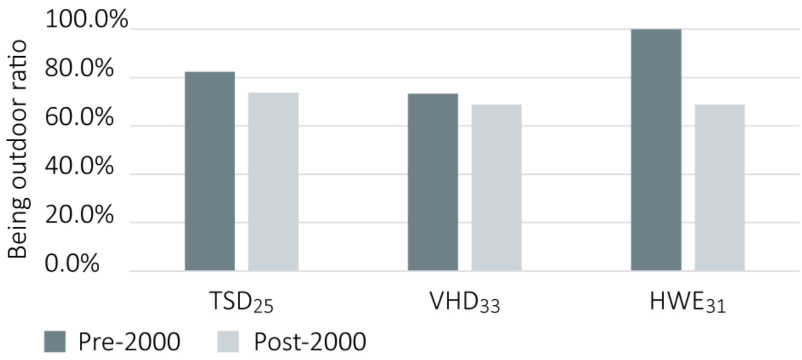

Figure 14. Being Outdoor Ratio for Participants of Pre- and Post-2000 Buildings During Outdoor Heat Events.

Table 7 enabled to be informed about participants' sleeping conditions and behaviour during each heat event. Regarding mean votes, it was possible to verify that both sleepwear and bed covering levels were always higher in pre-2000 buildings than post-2000 buildings during all heat events (only except for similar sleepwear levels during HWE_{31}). On the contrary, the window opening ratio was always higher in the post-2000 buildings than in the pre-2000 buildings. During all heat events, some participants used mechanical ventilation such as air conditioners. During the TSD_{25}, the ratio of participants who used mechanical ventilation before sleeping was higher in pre-2000 buildings than the post-2000 buildings, while there was a reverse situation during the VHD_{33} and HWE_{31} events.

Table 7. Mean bed insulation values and ventilation ratios for Participants of Pre- and Post-2000 Buildings During Outdoor Heat Events.

	TSD_{25}		VHD_{33}		HWE_{31}	
	Pre-2000	Post-2000	Pre-2000	Post-2000	Pre-2000	Post-2000
Mean sleepwear level	2.71	2.05	2.27	2.13	1.88	1.88
Mean bed covering level	3.24	2.58	2.53	2.25	2.40	2.06
Window opening ratio (Yes)	29.4%	47.4%	53.3%	75.0%	56.3%	75.0%
Mechanical ventilation ratio (Yes)	11.8%	5.3%	6.7%	12.5%	18.8%	25.0%

4.3.2. Psychological Evaluation of Thermal Conditions

4.3.2.1. Comparison of Outdoor Heat Events

The results of psychological thermal comfort evaluations from questionnaires inclusive of mechanical ventilation users were indicated in Table 8. Considering mean thermal comfort votes (TCV), it was possible to confirm for both residential settings that the thermal comforts of participants were highest during the TSD_{25} and lowest during the HWE_{31}s. On the other hand, the mean thermal sensation vote (TSV) was highest during the HWE_{31}s in both pre-2000 and post-2000 buildings. The mean humidity sensation vote (HSV) was highest within HWE_{31}s in pre-2000 buildings while highest during VHD_{33}s in post-2000 buildings. The mean airspeed sensation vote (ASV) was highest during the VHD_{33}s for each residential setting.

Table 8. Psychological thermal comfort evaluation results from questionnaires inclusive of users of mechanical ventilation.

	TSD_{25}		**VHD_{33}**		**HWE_{31}**	
	Pre-2000	Post-2000	Pre-2000	Post-2000	Pre-2000	Post-2000
Mean TCV	1.41	1.11	0.20	0.63	-0.31	-0.69
Mean TSV	0.18	0.16	0.40	-0.12	1.06	1.56
Mean HSV	0.24	0.42	0.27	0.06	-0.06	0.25
Mean ASV	3.00	3.16	3.07	3.69	2.50	3.19

TCV, Thermal Comfort Vote; TSV, Thermal Sensation Vote; HSV, Humidity Sensation Vote; And ASV, Airspeed Sensation Vote.

4.3.2.2. Comparison of Residential Settings

Comparing the TCVs of residential settings revealed that pre-2000 building participants had higher TCVs during TSD_{25} and HWE_{31}s than those of post-2000, while the reverse was the case for the VHD_{33}s. The mean TSVs were slightly higher in pre-2000 buildings during TSD_{25} and significantly higher in pre-2000 buildings during VHD_{33}s and post-2000 buildings during HWE_{31}s. The mean HSVs were higher in pre-2000 buildings during the TSD_{25} and HWE_{31}s while higher in post-2000 buildings during the VHD_{33}s. The ASVs were consistently higher in post-2000 buildings during all heat events. It was also worth noting that the difference between residential settings in ASVs was higher during the VHD_{33}s.

4.3.2.3. Impact of Mechanical Ventilation

The results of physiological thermal comfort evaluations from questionnaires noninclusive users of mechanical ventilation were displayed in Table 9. Compared to the previous results that included users of mechanical ventilation, TCVs of both residential settings increased during all heat events. Mainly, since TCVs increased more in post-2000 buildings than in pre-2000 buildings during the VHD_{33}s and HWE_{31}s, the difference between residential settings increased for VHD_{33}s and decreased during HWE_{31}s. On the other hand, the overall TSVs decreased when the users of mechanical ventilation were excluded, except TSV of pre-2000 buildings in TSD_{25}. In particular, the difference in TSVs between residential settings showed an increase in VHD_{33}s and a drop in HWE_{31}s. When the results of HSVs were examined, it was seen that the difference between HSVs declined in VHD_{33}s and raised in HWE_{31}s. Lastly, the difference in ASVs between pre-and post-2000 buildings steadily decreased for all heat events, most during the VHD_{33}s.

Table 9. Psychological thermal comfort evaluation results from questionnaires noninclusive of users of mechanical ventilation.

	TSD_{25}		**VHD_{33}**		**HWE_{31}**	
	Pre-2000	Post-2000	Pre-2000	Post-2000	Pre-2000	Post-2000
Mean TCV	1.47	1.17	0.29	0.86	-0.15	-0.33
Mean TSV	0.20	0.11	0.36	-0.29	0.92	1.25
Mean HSV	0.27	0.44	0.21	0.07	-0.08	0.42
Mean ASSV	3.00	3.06	3.21	3.57	2.54	2.92

TCV, thermal comfort vote; TSV, thermal sensation vote; HSV, humidity sensation vote; and ASV, airspeed sensation vote.

4.3.3. Evaluation of Sleep Quality

4.3.3.1. Comparison of Outdoor Heat Events

When considering sleep quality evaluations, as demonstrated in Figure 15, it was possible to determine the mean votes of each sleep quality parameter for the two residential settings during the different respective heat events. Within the overall inspection of sleep quality evaluations in pre-2000 buildings, it was found that sleep quality votes/ratios (SQV) were highest during TSD_{25}, except the sleep sufficiency that was highest within VHD_{33}s. Also, unusual frequency of awakening ratios (answer of Yes) was lowest during the TSD_{25} in pre-2000 buildings. On the other side, in post-2000 buildings, the highest votes for calmness of sleep, ease of falling asleep, and the lowest ratio of the unusual frequency of awakening were witnessed in TSD_{25}. Additionally, the sleep sufficiency ratio and mean ease of awakening, freshness after awakening, and sleep satisfaction votes were highest during VHD_{33}s in post-2000 buildings.

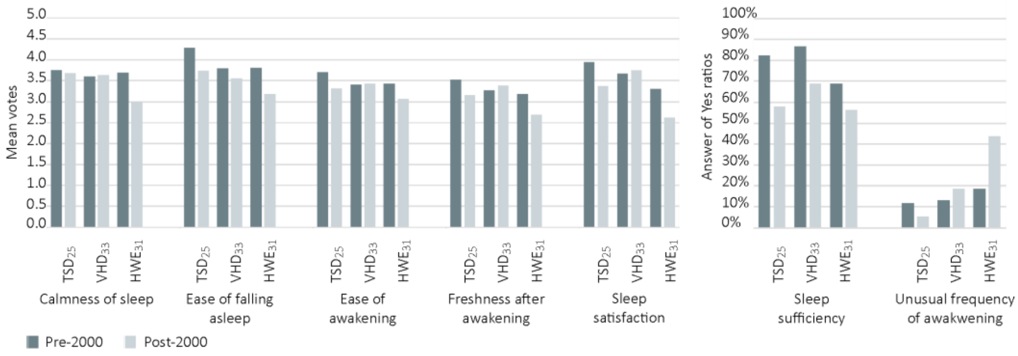

Figure 15. Sleep quality evaluation results from questionnaires inclusive of users of mechanical ventilation.

4.3.3.2. Comparison of Residential Settings

The comparison of the sleep quality evaluations between residential settings indicated that the sleep sufficiency ratio, mean calmness of sleep, and the ease of falling asleep votes were consistently higher in pre-2000 buildings during all outdoor heat events. Exceptionally the mean calmness of sleep votes were similar between residential settings during VHD_{33}s. Besides, the other SQVs, i.e., the mean ease of awakening, freshness after awakening, and sleep satisfaction, were higher for pre-2000 buildings during the TSD_{25} and HWE_{31}s while they were higher in post-2000 buildings during the VHD_{33}s. As of last, the frequency of unusual awakenings votes was higher in pre-2000 buildings during TSD_{25} than in post-2000 buildings, while it was the opposite for VHD_{33}s and HWE_{31}s.

4.3.3.3. Impact of Mechanical Ventilation

When users of mechanical ventilation were excluded (Figure 16), the mean values of sleep quality parameters improved more in favour of post-2000 buildings compared to pre-2000 ones during the TSD_{25} and VHD_{33}s, while the reverse was the case in HWE_{31}s. Within TSD_{25}, the differences in mean calmness of sleep, freshness after awakening, sleep satisfaction votes, and sleep sufficiency ratios between residential settings decreased, while the difference in unusual frequency of awakening increased. In the case of VHD_{33}s, the mean calmness of sleep and ease of falling asleep votes, and sleep sufficiency ratio declined in pre-2000 buildings and raised in post-2000 buildings. Consequently, the difference between these votes/ratios of residential settings marked an increase. Additionally, the difference in ease of awakening, freshness after awakening, and sleep satisfaction votes between the two residential settings also increased. Finally, the unusual frequency of awakening ratio increased in pre-2000 buildings and decreased in post-2000 buildings. During the HWE_{31}s, all sleep quality parameters except ease of falling asleep and ease of awakening raised in pre-2000 buildings and decreased in post-2000 buildings.

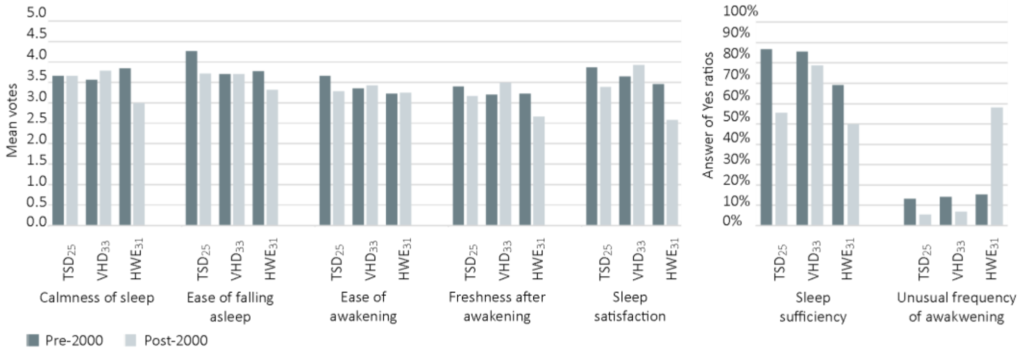

Figure 16. Sleep quality evaluation results from questionnaires noninclusive of users of mechanical ventilation.

CHAPTER 5

DISCUSSION

The results of the 99 interviews and physiological measurements demonstrated the various impacts of three outdoor heat events, i.e., TSD_{25}, VHD_{33}s, and HWE_{31}s, on thermal comfort, thermal sensation, and sleep quality of occupants in insulated and uninsulated residential settings. Within this scope, there were five observations in this study, these being: (i) the participants' physiological thermal load (considering PET_{Out}, PET_{In}, Ta_{Out}, Ta_{In}) was highest during the VHD_{33}s, then HWE_{31}s, and was lowest in TSD_{25} in both residential settings; while both RH_{Out} and RH_{In} values were highest during TSD_{25}; (ii) even though PET_{Out}, PET_{In}, Ta_{Out}, Ta_{In} values increased in the afternoon concurrently, during the pre-sleep and sleep period, the PET_{Out} and Ta_{Out} values decreased substantially while their indoor equivalents remained higher; (iii) within outdoor heat events context, psychological TCVs were highest during TSD_{25}, then during VHD_{33}s and were the lowest in HWE_{31}s in both residential settings; (v) among the outdoor heat events, the majority of psychological SQVs were highest within TSD_{25} in uninsulated buildings, while they were highest during VHD_{33}s in insulated buildings; (iv) within the indoor context, the majority of the psychological TCVs and SQVs were better in uninsulated buildings than in insulated ones during TSD_{25} and HWE_{31}s, while it was the opposite within VHD_{33}s; and, (vi) when users of mechanical ventilation were excluded, most of the psychological TCVs and SQVs improved in favour of the insulated buildings during VHD_{33}s.

5.1. Thermal Comfort

5.1.1. Physiological Thermal Comfort

Within the disclosed findings of physiological evaluations of thermal conditions, it was revealed that PET and Ta values showed a similar behaviour within both the outdoor heat events context and the residential context. The comparison of PET and Ta values between outdoor heat events showed that PET_{Out}, PET_{In}, Ta_{Out}, and Ta_{In} were consistently highest during VHD_{33}s, then during HWE_{31}s and were lowest in TSD_{25}. In addition, considering the PET_{Out} values reached the PS level of Extreme Heat Stress only during the VHD_{33}s, it was crucial to assert that the vulnerability of indoors and the thermal load of the human body reached their peak during VHD_{33} events. These findings affirmed the first hypothesis of this study, **H_{1a}**, "*The physiological thermal comfort of occupants will be higher in TSD_{25}, then in a HWE_{31}s, and will be lowest during a VHD_{33}s.*".

When discussing the general hourly course of PET and Ta values for all outdoor heat events, it was confirmed that PET_{In} and Ta_{In} values were higher than PET_{Out} and Ta_{Out} values in the morning, while the situation was the opposite in the afternoon. Even though PET_{Out} and Ta_{Out} surpassed the PET_{In} and Ta_{In} during the diurnal period, they become significantly lower than PET_{In} and Ta_{In} throughout the pre-sleep and sleep periods. The slower drop of PET_{In} and Ta_{In} than the rapid decrease of PET_{Out} and Ta_{Out} can be explained by the high heat retention capacity within the mass walls of building structures (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006; Shaviv, Yezioro, & Capeluto, 2001). Furthermore, the rise of PET_{Out} and Ta_{Out} was highest during VHD_{33}s, amplifying the implication of vulnerability of indoors and the heat stress on the human body were utmost during the VHD_{33} events.

With regards to the indoor context, it was noted that PET_{In}PRE and Ta_{In}PRE were persistently higher than the PET_{In}POST and Ta_{In}POST, respectively, during all outdoor heat events. More importantly, the difference between $PET_{In}PRE$ and $PET_{In}POST$ and the difference between $Ta_{In}PRE$ and $Ta_{In}POST$ kept rising throughout the pre-sleep and sleep periods during each outdoor heat event. These findings agreed with the previous studies that identified lower thermal performance in uninsulated buildings (Amirzadeh et al., 2018; Dikmen, 2011; Pal, 2018).

The RH results demonstrated the opposite behaviour of Ta and PET within the context of both outdoor heat events and indoor. In the case of outdoor heat events, it was seen that both RH_{Out} and RH_{In} values were notably highest during TSD_{25}, which can be understandable considering the lowest PET and Ta occurred during the TSD_{25}. Although there has been no standard and consensus on the acceptable RH limit in the current literature, it was possible to note that the general measured RH_{Out} and RH_{In} values did not exceed 70%, whereas higher values were found as unacceptable for thermal comfort by previous studies (Djamila, Chu, & Kumaresan, 2014; Jing, Li, Tan, & Liu, 2013; Kong et al., 2019).

5.1.2. Psychological Thermal Comfort

The highest psychological TCVs were during the TSD_{25} for both residential settings during all heat events. Nonetheless, the pre-sleep physiological thermal conditions were not similar between pre-2000 and post-2000 buildings during TSD_{25}. More specifically, pre-2000 buildings’ participants felt thermally comfortable when the average Ta was 28.3 °C, RH was 31.9%, and PET was 28.7 °C in the pre-sleep period (21:00-23:00). As for post-2000 buildings, subjects felt thermally comfortable when the average Ta was 26.6 °C, RH was 51.8%, and PET was 27.4 °C before sleep. Cao et al. (2022) and N. Zhang et al. (2019) also reported that subjects felt thermally comfortable when Ta was 26 °C before sleep.

5.1.3. Relationship Between Physiological and Psychological Thermal Comfort

As mentioned in 5.1.1, PET_{Out}, PET_{In}, Ta_{Out}, and Ta_{In} values were lowest during TSD_{25}, then HWE_{31}s and VHD_{33}s. So, it can be understandable that the highest TCVs and the lowest TSVs were within TSD_{25} in both residential settings. However, the lowest TCVs and the highest TSVs were not expected to be during HWE_{31}s instead of VHD_{33}s. The reason for this unforeseen difference between physiological and psychological results might be that the VHD_{33}s were intertwined with HWEs during the 2021 summer in Ankara, as was also demonstrated for the 2020 summer in Ankara (Nouri, Çalışkan, et al., 2021). Hence, despite the accuracy of its first part, hypothesis $\mathbf{H_{1b}}$, "*The psychological thermal comfort of occupants will be higher during a TSD_{25}, then in a HWE_{31}s, and will be lowest during a VHD_{33}s.*" was rejected.

In the case of the residential context, the PET_{In}PRE and Ta_{In}PRE values were higher than PET_{In}POST and Ta_{In}POST values, respectively, during all heat events. Nevertheless, psychological TCV and TSV outcomes were unanticipated during TSD_{25} and HWE_{31}s. Even though the PET_{In}PRE and Ta_{In}PRE values were higher than PET_{In}POST and Ta_{In}POST invariably, the TCVs were higher in pre-2000 buildings than in post-2000 buildings during TSD_{25} and HWE_{31}s. Similar results were also obtained by Ealiwa et al. (2001) who investigated the occupants' thermal comfort in Ghademes, Libya during summer. Their findings showed that even though the equivalent measurements indicated discomfortable conditions, participants evaluated their thermal environments as comfortable.

Moreover, in pre-2000 buildings, the mean TSVs were slightly higher within TSD_{25} and relatively lower during HWE_{31}s. These findings disagree with the previous studies that signified the necessity of insulation to achieve thermal comfort (Hansen et al., 2018; Kaynakli, 2012; Lotfabadi & Hançer, 2019) and studies that identified lower psychological thermal comfort (Piasecki et al., 2020) in uninsulated buildings.

There can be four possible explanations for these unexpected psychological results within TSD_{25} and HWE_{31}s in pre-2000 buildings: (i) higher mean age; (ii) higher bed insulation levels; (iii) longer thermal history; and, (iv) lower window opening behaviour. Considering older adults' higher thermal neutral temperatures (Schaudienst & Vogdt, 2017; Schellen, van Marken Lichtenbelt, Loomans, Toftum, & de Wit, 2010) and higher mean age in pre-2000 buildings, it was possible to relate the higher TCVs in pre-2000 buildings with age during TSD_{25} and HWE_{31}s. Secondly, perpetually higher sleepwear and bed covering levels of pre-2000 buildings participants can create an isolated bed microclimate which can result in less sensitivity to the ambient thermal conditions during sleep (Bischof et al., 1993; Y. Liu et al., 2014; Okamoto-Mizuno & Tsuzuki, 2010; Song et al., 2015; van Someren, 2006).

In addition to the higher mean age and bed insulation level, past experiences in various environments, such as indoors and outdoors, can influence the thermal sensations (Nikolopoulou & Steemers, 2003). Particularly thermal history can affect occupants' thermal comfort (Brager & De Dear, 1998; Ji et al., 2019; Vargas & Stevenson, 2014). Regarding the higher being outdoor ratios of pre-2000 buildings' subjects, they were exposed to outdoor heat stress more than the subjects of post-2000 buildings. In this case, associating the higher TCVs of pre-2000 buildings' subjects to their short-term warmer thermal history (24h) was possible since previous exposure to a warm environment decreases the thermal sensations, as resulted by Fadeyi (2014), Kalmár (2016), and Y. Zhang et al., (2016). Contingently, long-term thermal history can provoke lower air temperature sensations (Amin et al., 2016; Chun et al., 2008; Jowkar, de Dear, & Brusey, 2020). However, given the temporal scope of this particular study to the events within the stipulated season, such associations between longer-term thermal history and thermal comfort remain an important topic for future study. Finally, a higher window opening ratio in post-2000 buildings can influence the unexpected TCVs on TSD_{25}, and HWE_{31}s since window opening increases the Ta and RH transmission between outdoor and indoor environments (Kubota et al., 2009; Wallace et al., 2002).

5.2. Relationship Between Pre-sleep Thermal Comfort and Sleep Quality

When exploring the SQVs in each residential setting, it was revealed that most of the mean SQVs revealed better evaluations in pre-2000 buildings during TSD_{25}, among all heat events. Exceptionally, the mean sleep sufficiency ratios were highest during VHD_{33}s. On the other hand, in post-2000 buildings, the majority of SQVs were highest within the VHD_{33}s. Only the ease of falling asleep votes and unusual frequency of awakening ratios presented better evaluations during the TSD_{25} in post-2000 buildings. These better sleep quality evaluations of post-2000 buildings' participants were not expected because of the extreme conditions of VHD_{33}s, i.e., the highest PET_{Out}, PET_{In}, Ta_{Out}, and Ta_{In} values among heat events. Nevertheless, the same pre-sleep PET_{In}PRE value during the TSD_{25} and PET_{In}POST value during the VHD_{33}s, i.e., 28.7 °C, can explain these unexpected results. Furthermore, Ta_{In}PRE in TSD_{25} was 28.3 °C, and Ta_{In}POST in VHD_{33}s was 28.2 °C during the pre-sleep period. These findings revealed that the pre-sleep thermal load of uninsulated pre-2000 buildings in TSD_{25} was the same as that in insulated post-2000 buildings in VHD_{33}s, which indicated the integral role of insulation in reducing heat exchange between indoor and outdoor environments (Halawa et al., 2018; Jelle, 2011; Ozel, 2011). Consequently, hypothesis **H_{1c}**, which suggested that "*The sleep quality of occupants will be higher during a TSD_{25}, then in a HWE_{31}s, and will be lowest during a VHD_{33}s.*" was rejected because outdoor conditions affect indoor conditions distinctly due to heat insulation. On the other hand, within the same dates/times, the average RH_{In} presented different values, such as RH_{In}PRE in TSD_{25} was 31.9%, and RH_{In}POST in VHD_{33}s was 37.9%. These findings verified the effectiveness of PET thermal index rather than utilization of Ta and RH alone in assessing and understanding occupants' sleep quality, in addition to the previous knowledge that PET is a convenient representative of the impacts of climatic factors on human health due to its associations with human thermoregulatory system and circadian rhythm (Matzarakis & Amelung, 2008).

Comparing the residential settings in each heat event, the SQVs were higher in pre-2000 buildings than in post-2000 buildings within TSD_{25} (except for the unusual frequency of awakening ratio) and HWE_{31}s. On the contrary, during the VHD_{33}s, the majority of SQVs were higher in post-2000 buildings. Furthermore, these higher SQVs of pre-2000 buildings' participants within TSD_{25} and HWE_{31}s were not anticipated because of the consistently higher thermal load in pre-2000 buildings. However, the parallel TCVs during each heat event signified that the occupants' psychological thermal comfort affects their sleep quality regardless of having up-to-code building insulation methods.

Albeit, higher mean age and mean bed insulation levels in pre-2000 buildings can influence these unexpected SQVs. Exposure to heat results in poor sleep quality for older adults (L. Lan, Tsuzuki, Liu, & Lian, 2017; Tsuzuki et al., 2015). Nevertheless, previous studies showed that healthy older adults tend to evaluate their sleep quality as acceptable, although their physiological sleep measurements indicated the opposite (Buysse et al., 1991; Vitiello, Larsen, & Moe, 2004; Zilli et al., 2009). This inconsistency was explained by older adults' lower expectations for their sleep quality. Besides that, bed insulation can improve the sleep quality of occupants (Y. Liu et al., 2014; Zaki et al., 2021) by restraining bed microclimate (Muzet et al., 1984; Song et al., 2015) and keeping skin temperature at thermal neutral range (Troynikov, Watson, & Nawaz, 2018).

5.3. Influence of Mechanical Ventilation on Thermal Comfort and Sleep Quality Evaluations

The results that include users of mechanical ventilation showed that TCVs and most of the SQVs were better in the pre-2000 buildings during TSD_{25} and HWE_{31}s, while it was the reverse within VHD_{33}s. When the users of mechanical ventilation were excluded, this situation continued. However, the majority of the TCVs, TSVs, and SQVs improved in favour of post-2000 buildings, especially during VHD_{33}s, which verifies hypothesis **H_3**, "*Utilization of mechanical ventilation before sleep will not* *improve the psychological thermal comfort and sleep quality of occupants during all local extreme heat events*."

All TCVs were increased in each residential setting when users of mechanical ventilation were excluded during each heat event. In detail, the difference in TCVs between residential settings did not change in TSD_{25}, and it decreased during HWE_{31}s. However, during VHD_{33}s, mean TCV slightly increased in pre-2000 buildings while it notably increased in post-2000. Thus, when users of mechanical ventilation were excluded, the difference between TCVs increased in VHD_{33}s in favour of post-2000 buildings. Besides, almost all TSVs decreased within the results non-inclusive of users of mechanical ventilation. Only the TSV in pre-2000 within TSD_{25} increased barely. Similar results were pointed out by Chun et al. (2008), who investigated the relationship between thermal history and indoor comfort. They revealed that air-conditioning increased the TSVs.

A similar improvement was seen in all SQVs in VHD_{33}s when the users of mechanical ventilation were excluded. Within the VHD_{33}s results that include users of mechanical ventilation, mean ease of awakening, freshness after awakening, and sleep satisfaction votes were higher in post-2000 buildings. When the users of mechanical ventilation were excluded from these results, the difference in these SQVs between residential settings increased. Moreover, the previous results showed that the ease of falling asleep, and sleep sufficiency ratio was higher, and the unusual frequency of awakening ratio and mean sleep calmness vote was lower in pre-2000 buildings during VHD_{33}s. However, in the users of mechanical ventilation excluded results, calmness of sleep increased in post-2000 buildings and decreased in pre-2000 buildings. Also, mean ease of falling asleep votes become equal between residential settings. Sleep sufficiency ratios remained higher in pre-2000 buildings, but the difference between residential settings decreased remarkably. Finally, the unusual frequency of awakening ratios become higher in pre-2000 buildings and lower in post-2000 buildings. When considering that these improvements in SQVs were primarily in favour of insulated buildings, it was ascertained that mechanical ventilation was a temporary and ineffective tool to enhance sleep environments and sleep quality in uninsulated buildings. Particularly, it was insufficient to provide an optimal thermal environment for sleep within the extreme conditions of VHD_{33}s in uninsulated buildings.

Given that both TCVs and SQVs were improved within the results not involving users of mechanical ventilation compared to those involving users of mechanical ventilation, it was possible to point out that the utilization of mechanical ventilation such as air conditioners in a pre-sleep period did not contribute to thermal comfort and sleep quality of occupants. Fujii et al. (2015) also reported that using air conditioning before going to bed did not improve subjects' sleep quality. Sekhar & Goh (2011) found that naturally ventilated bedrooms provide a better sleep environment than air-conditioned bedrooms.

5.4. Management of Existing and Impending Heat Stress Events in Ankara to Address Human Sleep Quality in an Urban Context

In light of existing literature and the outcomes of this study, several strategies can be generated to ensure sleep quality standards by managing current and impending heat stress risks in Ankara. First of all, a comprehensive base should be created by detecting the local vulnerability in terms of climatic risk factors, built environment, and occupants to recognize and comprehend the local needs. Thus, local, human-centered and innovative solutions can be integrated with that solid knowledge base to improve occupants' quality of life and safety as urban fabrics continue to warm up in an era of climate change.

Within the research and development process of the local base, the utilization of bottom-up approaches can elaborate the understanding of local vulnerability. For instance, considering both exterior and interior environments are effective on human health (Matzarakis & Mayer, 2000; Nouri & Matzarakis, 2019), both outdoor and indoor meteorological factors should be addressed in investigating indoor thermal comfort and sleep quality, contrary to the previous studies that used only indoor thermal parameters (Budiawan & Tsuzuki, 2021; Haskell et al., 1981; Y. Liu et al., 2014; Okamoto-Mizuno et al., 1999; Pan et al., 2012; Sagot et al., 1987; Song et al., 2020; Tsuzuki et al., 2015; N. Zhang et al., 2019). However, individual meteorological factors are insufficient to describe the relationship between the human body and thermal environments (Jendritzky, de Dear, & Havenith, 2012; Matzarakis & Amelung, 2008). Therefore, the assessments of outdoor and indoor thermal parameters should be supported by a thermal index approach to explore the influence of these climatic factors on the human body through bidirectional heat fluxes between the human body and the environment.

In addition to bottom-up academic investigation methods, an interdisciplinary approach can advance the development of local knowledge base efforts. Within this interdisciplinary approach, professionals in the decision-making, administration, urban planning, architecture, education, and health fields can work together to create a local inventory of vulnerable construction typologies. It is possible to multiply the perspectives of vulnerability for local risk management. However, given the focus and results of this research, investigation of vulnerability in terms of heat insulation, ventilation types, and risk groups of dwellers gains prominence. Detection and mapping the number, age, and locations of insulated and uninsulated buildings can help prioritize the urgent urban areas for the urban transformation processes in relation to existing and future microclimatic vulnerability.

Similarly, identifying ventilation types, i.e., natural or mechanical ventilation, can help to generate energy-efficient and thermally comfortable built environments concerning the outdoor-indoor transitions. As an example, the usage of air conditioners is gradually increasing worldwide due to higher air temperatures (Biardeau, Davis, Gertler, & Wolfram, 2020). Nonetheless, as revealed by this study, utilization of mechanical ventilation such as air conditioners did not improve thermal comfort nor sleep quality of the occupants. In fact, air conditioners do not benefit people, but they damage the indoors and outdoors by releasing CO_2 and waste heat (Cheung & Jim, 2019; de Munck et al., 2013; Salamanca, Georgescu, Mahalov, Moustaoui, & Wang, 2014). More critically, air-conditioning can increase the vulnerability of human health to heat stress (Farbotko & Waitt, 2011). Thus, considering the costs and benefits of air-conditioning, controlling the usage amount of air-conditioning with regulations and education, and providing and encouraging alternative environmental solutions based on scientific knowledge can be the initial interferences of administrations.

In addition to the detection of insulation and ventilation facilities in built environments, the vulnerability of dwellers should be determined to produce particular and efficient solutions to heat stress risks. For instance, as one of the most important findings of this study and existing literature, aged people tend to evaluate their thermal comfort as comfortable even though their physiological results indicate the opposite conditions. Nevertheless, even though older adults perceive warmer environments as comfortable, their bodies keep exposed to heat stress, as verified by the lower SQVs of pre-2000 buildings in extreme conditions of VHD_{33}s. Therefore, increasing local heat stress is still a risk factor for elderlies regardless of their psychological preferences. Within this scope, detecting vulnerable age groups can contribute to handling the heat stress risks factors associated to the elderly. For instance, elderly adults may not be able, or wish, to effectively address certain risk factors pertaining to heat exposure given the aforementioned factors regarding habituation and accustomization patterns. Hence, initiating a health warning system (Matzarakis, Laschewski, & Muthers, 2020) for Ankara can be helpful to inform about the upcoming local extreme heat events, their risks to specific groups, and actions to be taken. Furthermore, considering that heat stress endangers more extensive risk groups in terms of age, sex, socioeconomic factors, living environment, and diseases (Kovats & Hajat, 2008), the application of a health warning system constitutes an urgency to mitigate the impacts of current and impending local extreme heat events in Ankara.

CHAPTER 6

CONCLUSION

This study aimed to investigate the occupants' thermal comfort and sleep quality depending on the local outdoor heat stress events by comparing the indoor conditions of insulated and uninsulated buildings. A two-tiered approach, including psychological and physiological assessments, was performed to detect the occupants' overall thermal comfort. Within the physiological thermal comfort evaluations, the utilization of the PET thermal index, in addition to meteorological factors, helped to comprehend the thermal load on the human body during local extreme heat events. Additionally, examining the interrelationship between outdoor and indoor thermal environments highlighted the local vulnerability of indoor spaces toward climatic risk factors. On the psychological side, questionnaires contributed to understanding occupants' existing thermal comfort and sleep quality as an individual practice in terms of various factors affecting the sleeping environment, such as extreme heat events, heat insulation, bed insulation, and mechanical ventilation.

The results of this study pointed out that occupants' thermal comfort and sleep quality altered during local extreme heat events. Particularly, the physiological thermal comfort of participants was highest within the TSD_{25} and lowest in VHD_{33} events. In the residential context, physiological thermal comfort was consistently higher in insulated buildings when compared to uninsulated ones during all local extreme heat events. On the other hand, the participants' psychological thermal comfort and sleep quality showed more complicated behaviours depending on demographic, individual, and environmental factors. In other words, age, bed insulation, thermal history, and mechanical ventilation compensated for the thermal comfort and sleep quality in uninsulated buildings during the TSD_{25} and HWE_{31} events. However, their compensation was insufficient during the VHD_{33}s, which has the highest heat stress level within both outdoors and indoors.

These results delineate that analyzing both outdoor and indoor conditions and their bidirectional interactions is a prerequisite for comprehending occupants' overall heat stress, thermal comfort, and sleep quality. Notably, the findings of this study accentuate the vulnerability of indoor spaces within still-occupied uninsulated buildings towards extreme outdoor heat stress events in Ankara’s hot and dry climate. Moreover, this study reveals that individual efforts such as air-conditioning or window openings are insufficient and ineffective ways to create thermally comfortable sleep environments and improve sleep quality. Yet, instead of individual, temporary, and detrimental air-conditioner usage, locally adapted design standards and strategies should provide permanent solutions for indoor thermal comfort and qualified sleep environments. Within this context, this study emphasizes the importance of an interdisciplinary approach, including health, education, architecture, urban planning, meteorology, administration, and policy-making fields, in designing, achieving, and sustaining comfortable, health, and safe urban fabrics.

6.1. Limitations and Future Studies

Within the undertaken study, the thermal comfort and sleep quality of occupants were evaluated against local heat stress events for Ankara, utilizing the thermal index approach within both outdoor and indoor contexts. Besides, the two-tiered approach, including both physiological and psychological measurements, was used in this study. The thermal comfort of occupants was evaluated through both physiological and psychological data. However, the sleep quality results were based only on subjects' psychological evaluations due to Covid-19 pandemic risks. Thus, there is the opportunity to further evaluate sleep quality in a subsequent study where such physiological aspects are considered during the local heat events in Ankara.

Even though thermal comfort and sleep are individual practices eventually, exploring the local influencing factors can help advance the understanding of them, which conduce to improving these personal experiences in a social context. Within this scope, further examination of the following issues can elaborate on the current effort to improve human life. Firstly, considering the mutual interaction of sleep and diet (Frank et al., 2017; Grandner, Jackson, Gerstner, & Knutson, 2013), complementing the undertaken methodology with evaluations of dietary habits, including meals, drinks, and nutrition intakes, is recommended for future studies. Secondly, the inclusion of longer-term thermal history in psychological evaluations in terms of climatic background and residence time can facilitate comprehending the impact of thermal adaptation, expectation, and comfort of occupants (Jowkar et al., 2020; Lam et al., 2021). Moreover, regarding the trend of increasing summer days in Turkey (Erlat & Türkeş, 2013), discovering the thermal comfort and sleep quality within a more extended period and performing the present methodology in different seasons to compare the impacts of extreme conditions are suggested for future studies. Additionally, detecting the extreme cold thresholds of Ankara and investigating the thermal comfort and sleep quality under cold thresholds can enhance the existing knowledge on local vulnerability towards global climatic risk factors.

6.2. Associations of Thesis Aims, Methodological Approach and Findings with the Existing Literature and Scientific Community

The present thesis was structured and designed within the scope of Bilkent University Interior Architecture and Environmental Design Master of Fine Arts Program, with the respective disseminations and milestones as detailed in Appendix

D. The methodological instruments, and the presentation in the scientific community of this study were associated to the Turkish National Scientific and Technological Research Council (TÜBİTAK), project, called “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. Additionally, the methodological approach of this study was introduced at the European Meteorological Society Annual Meeting 2021 (EMS2021) to strengthen the substance of the research. Besides, the findings of the study are intended to be published in the Springer Journal Theoretical and Applied Climatology (Print ISSN: *0177-798X*).

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APPENDICES

APPENDIX A

BILKENT UNIVERSITY ETHICS COMMITTEE APPROVAL FORM

Bilkent Üniversitesi
Akademik İşler Rektör Yardımcılığı

Tarih : 28 Haziran 2021

Gönderilen : Merve Münevver Ahan

Danışman : Andre Santos Nouri

Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı

Konu : *"Investigation of ..."* çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 28 Haziran 2021 tarihli görüşme sonucu, *"Investigation of the Relationship between Outdoor Heat Events and Sleep Quality in Ankara"* 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_06_28_01

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

(Form Student_EN*)

Ethics form for graduate and undergraduate students - human participants

Note - group projects fill in one copy with all your names on it. Consult your project supervisor for advice before filling in the form.

Your name(s): Merve Münevver Ahan
Project Supervisor: Asst. Prof. Dr. Andre Santos Nouri

A. Write your name(s) and that of your supervisor above.
B. Read section 2 that your supervisor will have to sign. Make sure that you cover all these issues in section 1. Discuss what you are going to put on the form with your project supervisor.
C. Sign the form and get your project supervisor to complete section 2 and sign the form.

1. Project Outline (to be completed by student(s))

(i) Full Title of Project:

Investigation of the Relationship between Outdoor Heat Events and Sleep Quality in Ankara

(ii) Aims of project:

The aim of the project is to understand the relationship between the indoor thermal thresholds and sleep quality shall be undertaken through the use of: (i) the Physiologically Equivalent Temperature (PET) calculated from climatic variables retrieved from the residential units at a 10 minute temporal resolution; (ii) questionnaires to acquire qualitative responses from local residents; and, (iii) local urban climatic data, retrieved from Ankara's meteorological station (WMO #17130) at an hourly temporal resolution.

(iii) What will the participants have to do? (brief outline of procedure; please draw attention to any manipulation that could possibly be judged as deception; ***for survey work, a copy of the survey should be attached to this form*****):**

This research will be conducted through the fill in questionnaires by participants who live in Bilkent Main Campus Houses. The questionnaires will be filled out both online or manually regarding the preference of participants. The online questionnaire will be delivered and collected through e-mail and the hardcopy questionnaires will be delivered by hand. Participants should fill the questionnaires 3 times in terms of the scope of the research. The questionnaire includes 4 parts as can be seen in the attachments.

(iv) What sort of people will the participants be and how will they be recruited? In the case of children state age range. (***Any participant who has not lived through his/her 18th birthday is considered to be a child!*****)**

People aged above 18 and who lives in Bilkent Main Campus Houses will be recruited by asking their voluntary participation by face to face conversations and e-mail.

*If you are testing children or other vulnerable individuals, state whether all applicants have CRB** clearance* ____

(v) What sort stimuli or materials will your participants be exposed to? Tick the appropriate boxes and then explain the form that they take in the space below, please draw attention to any content that could conceivably upset your participants).
Questionnaires[X]; Pictures[ ]; Sounds [ ]; Words[x]; Caffeine[ ]; Alcohol[ ]; Other[ ].

The participants need to answer the questionnaires.
Thermal Comfort Assessment Questionnaire, Morito, Tsuzuki, Mori & Nishimiya, 2017
Sleep Quality Assessment Questionnaire, Pan, Lian & Lan, 2012; Lan, Pan, Lian, Huang & Lin, 2014; Zhang, Cao & Zhu, 2019

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* Adapted from *www.york.ac.uk/depts/psych/www/research/ethics/HumanProjForm.doc*
** Criminal Records Bureau – Please attach relevant clearance documentation.

1

Anli

(vi) Consent Informed consent must be obtained for all participants before they take part in your project. The form should clearly state what they will be doing, drawing attention to anything they could conceivably object to subsequently. It should be in language that the person signing it will understand. It should also state that they can withdraw from the study at any time and the measures you are taking to ensure the confidentiality of data. If children are recruited from schools you will require the permission of the head teacher, and of parents. Children over 14 years should also sign an individual consent form themselves. When testing children you will also need Criminal Records Bureau clearance. Testing to be carried out in any institution (prison, hospital, etc.) will require permission from the appropriate authority. (Please include documentation for such permission.)

Who will you seek permission from?

All volunteer participants will be asked to sign a consent form before answering the questions.

Please attach the consent form you will use. Write the "brief description of study" in the words that you will use to inform the participants here.

This research aims to understand the relationship between sleep quality and the thermal comfort of occupants in Bilkent Main Campus Houses. I will ask you to answer the questions about your sleep quality, your thermal comfort and your conditions during sleep such as your clothing and insulation level. The questionnaires need to be answered in the morning to evaluate the sleep quality and thermal comfort of your previous night. The questionnaires are required to be answered at 3 different times in terms of the scope of the research.

(vii) Debriefing - how and when will participants be informed about the experiment, and what information you intend to provide? If there is any chance that a participant will be 'upset' by taking part in the experiment what measures will you take to mitigate this?

The necessary information about the research such as the aim, method, requests, risks, benefits of the research and the security of personal information will be provided to all participants through a consent form before the experiment. Also, the participants will be informed about their participation based on voluntariness, and they will not get any penalty if they quit or be excluded from the study. The participants will be selected through random sampling. The interviewees that agree to participate will be informed days beforehand in the scope of local climate conditions that shall be retrieved from the local meteorological station (with the WMO N#17130).

(viii) What procedures will you follow in order to guarantee the confidentiality of participants' data? Personal data (name, addresses etc.) should only be stored if absolutely necessary and then only in such a way that they cannot be associated with the participant's experimental data.

All answers of participants will be kept strictly confidential, such that only I and my advisor will have access to the information. A locked cabinet in my advisor office will be used for data retention. The results that got by analyzing the data will be used as a written report in a master thesis, its associated oral presentation, and any other dissemination associated this research within an academic milieu. The confidential details of the project will not be declared to the public by any means that identifies the personal information of participants.

(vii) Give brief details of other special issues the ethics committee should be aware of.

There is not any special issue.

(viii) Tick any of the following that apply to your project

[x] it uses Bilkent facilities;
[ ] it uses stimuli designed to be emotive or aversive;
[ ] it requires participants to ingest substances (e.g., alcohol);
[x] it require participants to give information of a personal nature;
[ ] it involves children or other vulnerable individuals;
[ ] it could put you or someone else at risk of injury.

Student's signature: .... date: 18.06.2021

(all students must sign if this is a group project, please initial all other pages)

The signatures here signify that researchers will conform to the accepted ethical principles endorsed by relevant professional bodies, in particular to

Declaration of Helsinki (WMA):
http://www.wma.net/en/30publications/10policies/b3/index.html

Ethical Principles of Psychologists and Code of Conduct (APA):
http://www.apa.org/ethics/code2002.html

Ethical Standards for Research with Children (SCRD):
http://www.srcd.org/about-us/ethical-standards-research

2. Supervisor's assessment (supervisor to complete - circle yes or no)

Yes/No - I confirm that I have secured the resources required by this project, including any workshop time, equipment, or space that are additional to those already allocated to me.

Yes/No - The design of this study ensures that the dignity, welfare and safety of the participants will be ensured and that if children or other vulnerable individuals are involved they will be afforded the necessary protection.

Yes/No - All statutory, legislative and other formal requirements of the research have been addressed (e.g., permissions, police checks)

Yes/No - I am confident that the participants will be provided with all necessary information before the study, in the consent form, and after the study in debriefing.

Yes/No - I am confident the participant's confidentiality will be preserved.

Yes/No - I confirm that students involved have sufficient professional competency for this project.

Yes/No - I consider that the risks involved to the student, the participants and any third party are insignificant and carry no special supervisory considerations. If you circle "no" please attach an explanatory note.

No/Yes - I would like the ethics committee to give this proposal particular attention. (Please state why below)

Supervisor's signature: .... **date:** 27/06/21

<u>Please e-mail an electronic version of this word processed form (without signatures) along with other application material to the committee to start the evaluation process.</u> Paper copies of all application material, (properly signed where indicated, and initialed on all other pages) should be sent after possible modifications suggested by the committee are finalized.

Bilkent University does not allow the use of students of research investigators as participants. Students who have the potential of being graded by the investigators during or following the semester(s) in which the study is being carried out should not participate in the study. Students may not receive any credit for any university course, with the exception of the GE250/GE251 courses, for their participation. The GE250 and GE251 (Collegiate Activities I and II) courses include an optional activity which encompasses volunteering as a participant in a research project.

3

APPENDIX B

CONSENT FORM

Date:

CONSENT FORM

"Investigating the Relationship of Outdoor Heat Stress Upon Indoor Thermal Comfort and Qualitative Sleep Evaluation: The Case Ankara"

Investigator
Merve Münevver Ahan, Master Student
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FA Building, No:309, Bilkent University

The Purpose of the Research
This research aims to understand the relationship between sleep quality and the thermal comfort of occupants in Bilkent Main Campus Houses.

Description of the Research:
I will ask you to answer the questions about your sleep quality, your thermal comfort and your conditions during sleep such as your clothing and insulation level. The questionnaires need to be answered in the morning to evaluate the sleep quality and thermal comfort of your previous night. The questionnaires are required to be answered at 3 different times in terms of the scope of the research. Dependent on climatic conditions, the participants will be informed days before to fill the questionnaires because of the nature of this research.

Risks and discomforts
There is no risk to participating in this research.

Benefits
The results of this research may benefit other people such as designers, architects, urban planners and decision-makers to understand the human-environment relationship and to creating more livable places 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.
The academic evaluations or services are given to university-related participants (students, staff or their relatives) will not be affected positively or negatively from accepting or refusing to attend the research, or if withdrawing or being excluded from the study for any reason.

Confidentiality
All answers of participants will be kept strictly confidential, such that only I and my advisor will have access to the information. A locked cabinet in my advisor office will be used for data retention. The results that got by analyzing the data will be used as a written report in a master thesis, its associated oral presentation, and any other dissemination associated this research within an academic milieu. The confidential details of the project will not be declared to the public by any means that identifies the personal information of participants.

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

Name of Participant: ______________________________
Sign of Participant: ______________________________
Address of Participant: ______________________________
____
____

Sign of Investigator: ______________________________

APPENDIX C

QUESTIONNAIRE SHEET

Date:

"Investigating the Relationship of Outdoor Heat Stress Upon Indoor Thermal Comfort and Qualitative Sleep Evaluation: The Case Ankara"

This research aims to understand the relationship between sleep quality and the thermal comfort of occupants in Bilkent Main Campus Houses.

This questionnaire sheet includes 24 questions. There are no correct or incorrect answers.

PART 1: This part includes personal information questions.

1) Your Building Number:		
2) Age:		
3) Gender:		
4) Do you have any sleep disorder?		
	Yes	No
5) Have you been in outdoors or not in the past 24 hours?		

PART 2: This part includes questions about your sleep behaviours. So, please answer these questions the following morning.

Please mark your sleep behaviours for last night.

	Very Thin	Thin	Moderate	Thick	Very Thick
6) What was your level of sleepwear?					
7) How was your bed covering?					

	Yes	No
8) Did you use an air conditioner or other devices to adjust indoor temperature?		
9) Did you open your windows close to/in bedroom during the night?		

PART 3: This part includes questions about the relationship between you and your environment.

Please rate your overall **thermal comfort** sensation level before sleep.							
	Very Uncomf ortable (-3)	Uncomfortab le (-2)	Slightly Uncomfortab le (-1)	Neutr al (0)	Slightly Comfortab le (+1)	Comfortab le (+2)	Very Comfortab le (+3)
10) Overall Thermal Comfort Sensation Vote							

Date:

Please rate your **air temperature sensation** before sleep.							
	Cold (-3)	Cool (-2)	Slightly Cool (-1)	Neutral (0)	Slightly Warm (+1)	Warm (+2)	Hot (+3)
11) The sensation of Temperature Vote							

Please rate your **humid sensation** before sleep.							
	Severely Wet (-3)	Wet (-2)	Slightly Wet (-1)	Neutral (0)	Slightly Dry (+1)	Dry (+2)	Severely Dry (+3)
12) The sensation of Humidity Vote							

Please rate your **airspeed sensation** before sleep.							
	Absolutely Not Felt (1)	Not Felt (2)	Slightly Not Felt (3)	Unspecified (4)	Slightly Felt (5)	Felt (6)	Felt Very Much (7)
13) The sensation of Air Speed Vote							

PART 4: This part includes questions about your sleep quality. So, please answer these questions <u>the following morning.</u>

Please rate your sleep quality for last night.					
	Very Restless (1)	Quite Restless (2)	Neither Calm Nor Restless (3)	Fairly Calm (4)	Very Calm (5)
14) How was your sleep yesterday?					
	Very Difficult (1)	Quite Difficult (2)	Neither Easy Nor Difficult (3)	Fairly Easy (4)	Very Easy (5)
15) How easy was it to fall a sleep yesterday?					
	Very Difficult (1)	Quite Difficult (2)	Neither Easy Nor Difficult (3)	Fairly Easy (4)	Very Easy (5)
16) How easy was it to wake up today?					
	Not at all (1)	Not Much (2)	Moderately (3)	Fairly (4)	Fully (5)
17) Did you feel refreshed after awakening?					
	Not at all (1)	Not Much (2)	Moderately (3)	Fairly (4)	Fully (5)
18) Did you feel satisfied after last night sleep?					

Date:

	Yes	No
19) Do you think you get enough sleep?		

	Yes	No
20) Was your frequency of awakening more than usual?		

If your answer was yes for the previous question (20), please answer the following question (21). If your answer is no, you do not have to answer the following question.

	Never	1 or 2 times	3 or 4 times	More (#)
21) Frequency of nighttime awakening for last night?				

	Yes	No
22) In general, and related to your state of mind, do you feel that your sleep quality was affected by another factor?		

23) If your answer is yes for the previous question (22), you are welcome to provide more information as you feel comfortable:

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	Yes	No
24) If you answered yes to question (22), pertaining again to your state of mind, do you feel that last night's climatic conditions further exacerbated the discussed factor that affected your sleep quality?		

Do you have anything else that you want to share about your sleep and thermal comfort?

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Date:

Do you have comments or suggestions on this research and questionnaires?

APPENDIX D

GANTT CHART of RESEARCH PROCESS

<table>
<tr><th>Year</th><th>Time Period</th><th colspan="2">Main Process</th><th>Background</th><th>Presentation & Submissions</th></tr>
<tr><td rowspan="12">2021</td><td>JANUARY</td><td colspan="2">Literature Review</td><td rowspan="13">Improving & Updating Literature Review</td><td></td></tr>
<tr><td>FEBRUARY</td><td colspan="2" rowspan="3">Determination of methodological approach</td><td></td></tr>
<tr><td>MARCH</td><td></td></tr>
<tr><td>APRIL</td><td>Abstract Submit to EMS2021</td></tr>
<tr><td>MAY</td><td>Specifications of questionnaires</td><td>Conducting pilot study</td><td></td></tr>
<tr><td>JUNE</td><td>Bilkent Ethics Committee Approval application</td><td>Seeking participants for questionnaires.</td><td></td></tr>
<tr><td>JULY</td><td rowspan="2">Indoor meteorological data measurements</td><td rowspan="2">Conducting questionnaires</td><td></td></tr>
<tr><td>AUGUST</td><td></td></tr>
<tr><td>SEPTEMBER</td><td colspan="2">Outdoor meteorological data request from AMS (MS#17130)</td><td>EMS 2021 Presentation</td></tr>
<tr><td>OCTOBER</td><td rowspan="3">Data process with IBM SPSS version 26</td><td rowspan="3">Determining the structure of the manuscript</td><td></td></tr>
<tr><td>NOVEMBER</td><td></td></tr>
<tr><td>DECEMBER</td><td>IAED 590 Seminar in Research Topics Presentation</td></tr>
<tr><td>2022</td><td>JANUARY</td><td>PET calculations with Rayman Pro</td><td>Starting to write manuscript</td><td></td></tr>
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FEBRUARY	Creation of figures	Writing & revising the manuscript	
MARCH	Revising figures		Presentation for Prof. Dr. Andreas Matzarakis
APRIL		Writing & revising Thesis	
MAY			
JUNE	Pre-delivery of thesis	MFA thesis defense	Article submission to Theoretical and Applied Climatology Journal
JULY	Final delivery of thesis		