UNIVERSIDAD POLITÉCNICA DE MADRID

Escuela Técnica Superior de Arquitectura de Madrid

Departamento de Urbanística y Ordenación del Territorio

Park Cooling Effect and Its Physical and Psychological Impact on Thermal Comfort

Case study: Retiro Park, Madrid

Doctoral Thesis

Author:

Farshid Aram

Architect and Urban Designer

Supervisor

Dr. Ester Higuera Garcia. PhD Architect

2020

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Sustainability and Urban Regeneration program

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Arquitectura de Madrid**

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**Departamento de Urbanística y
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This doctoral thesis is presented as a compendium of publications, following the requirements of the Technical University of Madrid approved by the Governing Council of 30th November 2017. It consists of the following sections:

- A. Abstract
- B. Introduction: interest of research, objectives and hypothesis
- C. Methodology: approach and methodology, organization and content
- D. Publications: collection of publications
- E. Summary and analysis of results
- F. Conclusions and future lines of research
- G. Bibliography

The three articles in section “D” must meet the following requirements: the doctoral candidate must be the first of the authors, the articles must appear in the JCR or SJR rankings in positions Q1 or Q2, the maximum number of authors must be six and the director or co-director of the thesis must be co-author in at least one of the articles.

The research results have already been published in five articles. All of them in journals indexed in the Scimago Journal & Country Rank (SJR). The list of publications that make up this thesis can be seen publication part (next page).

Publications

Included in this thesis are five published papers (Chapter D), all of which were peer-reviewed and co-authored with other researchers. My contribution to each paper is outlined at the front of the relevant chapter. The bibliographic and status for these papers, including all authors, are outlined below.

Article 1 :Scopus (SJR): Q1

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Additional publications not included in the thesis

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Refereed journal articles

- **F.Aram**, E. Solgi, & G. Holden, “*The role of green space in increasing social interactions in neighborhoods with periodic markets,*” the journal of **Habitat International**. vol. 84, pp. 24-32, 2019. (Scopus: Q1)
- S. Mansurnia, B. Bahrami, L. Mahmoudi Farahani & **F. Aram**, “*Understanding children's perceptions and activities in urban public spaces: the case study of Zrebar lake waterfront,*” the journal of **Urban Studies**. SAGE Publications Ltd, 2020. (Scopus: Q1)
- M. Faroughi, M. Karimimoshaver, **F. Aram**, E. Solgi, A. Mosavi, N. Nabipour, & K. Chau, “*Computational modeling of land surface temperature using remote sensing data to investigate the spatial arrangement of buildings and energy consumption relationship,*” the journal of **Engineering Applications of Computational Fluid Mechanics**. vol. 14, p. 254-270, 2020. (Scopus: Q1)
- S. Fathi, H. Sajadzadeh, F. M. Sheshkal, **F. Aram**, Gergo Pinter, Imre Felde, & Amir Mosavi. “*The Role of Urban Morphology Design on Enhancing Physical Activity and Public Health,*” **International Journal of Environmental Research and Public Health**. vol.17, p. 2359, 2020. (Scopus: Q2)
- M. Chahardowli, H. Sajadzadeh, **F. Aram**, & Amir Mosavi. “*Survey of Sustainable Regeneration of Historic and Cultural Cores of Cities,*” **Energies**, vol. 13(11), p. 2708, 2020. (Scopus: Q1)
- R. Khakian, M.Karimimoshaver, **F. Aram**, S.Zoroufchi Benis, A. Mosavi, & A. R.. Varkonyi-Koczy. “*Modeling Nearly Zero Energy Buildings for Sustainable Development in Rural Areas,*” **Energies**, vol. 13(10), p. 2593, 2020. (Scopus: Q1)
- M.Karimimoshaver, H. Hajivaliei, M. Shokri, S. Khalesro, **F. Aram**, & S. Shamshirband. “*A model for locating tall buildings through a visual analysis approach,*” **Applied Sciences**, vol. 10 (17), p. 6072, 2020. (Scopus: Q1)

Refereed conference papers

- S. Nosratabadi, A. Mosavi, R. Keivani, S. Ardabili & **F. Aram**, “*State of the Art Survey of Deep Learning and Machine Learning Models for Smart Cities and Urban Sustainability,*” 18th International Conference on Global Research and Education Inter-Academia – 2019, Springer, Cham.

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List of Abbreviation

AEMET	Agencia Estatal de Meteorología.
AMMA	Aram Mental Map Analyzer (software)
CED	Cooling Effect Distance
CEI	Cooling Effect Intensity
PCE	Park Cooling Effect
PCI	Park Cool Island
PET	Physiological Equivalent Temperature
PMV	Predicted Mean Vote
PTC	Perceived Thermal Comfort
SET*	Standard Effective Temperature
UCI	Urban Cool Island
UGS	Urban Green Space
UHI	Urban Heat Island
UTCI	Universal Thermal Climate Index

A. ABSTRACT

Resumen

Uno de los temas más debatidos es el calentamiento global de las ciudades y los problemas que surgen de él para las personas. Debido al fenómeno de la isla de calor urbana, el problema del calor en las zonas, especialmente en las ciudades densamente pobladas, es mucho más tangible y ha amenazado la vida de los ciudadanos. Uno de los problemas de la isla de calor urbano es su efecto sobre la salud y el bienestar de los ciudadanos, física y mentalmente. Una de las formas más efectivas de mitigar el calor urbano y la isla de calor urbana es aumentar y los espacios verdes urbanos (a pequeña y gran escala), que ya han sido propuestos por muchos estudios. La investigación ha demostrado que, entre la infraestructura verde urbana, los parques de gran escala, gracias a la diversidad y la cantidad de vegetación, tienen un efecto más significativo en la reducción de la temperatura, que este efecto no solo reduce la temperatura dentro del parque, sino que también puede reducir la temperatura en los alrededores del parque. . Los dos indicadores principales que se utilizan para medir el efecto de enfriamiento pasivo de los parques urbanos son la intensidad del efecto de enfriamiento y la distancia del efecto de enfriamiento. Según la investigación realizada en este campo, se ha demostrado que, en general, los parques con un área de más de 10 hectáreas son capaces de reducir la temperatura del aire a 350 metros, en aproximadamente de 1 a 2 grados centígrados.

Dado que España es uno de los países europeos más cálidos con un clima mediterráneo, es oportuno hacer frente a los efectos del calor urbano y para garantizar la salud y el bienestar de los ciudadanos en los espacios públicos. En consecuencia, para investigar el efecto de enfriamiento del parque y su impacto en el confort térmico físico y psicológico de los ciudadanos, se seleccionó el Parque del Retiro, de 125 hectáreas situado en el centro de Madrid, la capital de España, como un estudio de caso. Los datos de la investigación comenzaron a principios del verano y se recopilaron cada dos semanas, los días 22 de junio, 10 y 24 de julio, 10 y 24 de agosto y 10 de septiembre de 2018. Esta investigación fue un estudio experimental y se realizó a través del método de medición in situ y luego los datos se analizaron utilizando modelos computacionales. Los datos en este estudio incluyen datos microclimáticos y un cuestionario. Los datos microclimáticos se recopilaron utilizando equipos móviles estándar para verificar la temperatura, el viento y la humedad, en tres distancias desde cada uno de los bordes norte, oeste y sur del parque. Simultáneamente con la recopilación de datos microclimáticos, los datos del cuestionario se recopilaron realizando entrevistas a 423 ciudadanos (residentes y trabajadores) de los nueve sitios investigados. El análisis de datos microclimáticos se realizó con el software RayMan para calcular la temperatura fisiológica equivalente como un indicador de confort térmico fisiológico (physiological equivalent temperature-PET). Los datos del cuestionario también se analizaron utilizando métodos estadísticos y programas SPSS. Además, para analizar los mapas cognitivos, se diseñó y utilizó el programa especial llamado Aram Mental Map Analyzer (AMMA).

En las proximidades de los lados norte, oeste y sur del Parque Retiro, hay tres islas de calor urbano a una distancia de 665, 855 y 520 metros del parque, respectivamente. Los resultados de este estudio revelaron que el efecto de enfriamiento de este parque contribuye a reducir la temperatura de su área de 150-380 metros en el lado norte en promedio a 0.9 °C en comparación con el área ubicada en el isla de calor urbano adyacente (665 metros). La reducción de la temperatura en el lado occidental a una distancia de 445-600 metros en promedio fue de 2.7 °C en comparación con el área de isla de calor urbana. Además, estas reducciones de temperatura en el rango sur fueron similares a los de la parte norte, por lo que el efecto de enfriamiento del parque hizo que la temperatura en las áreas adyacentes al parque disminuyera en promedio 130-280 metros desde el parque en 1.25 °C en comparación . La distancia de 520 metros. Por lo tanto, el efecto del enfriamiento del Parque del Retiro puede reducir la temperatura en un

promedio de 1.6 °C dentro de una distancia de unos 420 metros, en las tres direcciones investigadas.

La variación de la intensidad del efecto de enfriamiento a diferentes distancias del parque afectó directamente la cantidad del confort térmico desde una perspectiva física y psicológica. Los resultados del confort físico térmico basado en el índice de PET indicaron que en distancias donde el efecto de enfriamiento del parque es más intenso, la tasa de PET debería reducirse. El índice de PET promedio en los lados norte, oeste y sur disminuyó en 1.3 °C (4.1%), 3.5 °C (8.7%) y 3.1 °C (7.3%) en comparación con las áreas adyacentes a las islas de calor urbano, respectivamente. Según estos resultados, las personas sintieron un mayor confort térmico en áreas cercanas al parque en un promedio de 6.7%.

Los resultados de los datos del cuestionario se consideraron como un indicador del confort térmico percibido (perceived thermal comfort -PTC) y, en función de la puntuación de estos datos, que tenía la forma de Likert (1-5), se reveló que en las áreas donde el efecto de enfriamiento del parque fue notable: los residentes tenían más PTC en un promedio de 7.2%, en comparación con las áreas alejadas del parque en las isla de calor urbanas adyacentes. Además, los resultados de otra parte del cuestionario, en forma de mapas cognitivos, mostraron que, en promedio, el 59.4% de los 423 encuestados se refirieron al parque como un lugar donde tenían el mayor confort térmico en comparación con otros lugares públicos.

Los resultados de este estudio mostraron que los grandes parques urbanos tienen un papel importante en la creación de confort térmico para el enfriamiento pasivo desde una perspectiva fisiológica y psicológica para los ciudadanos. Dado el cambio climático y el aumento de la temperatura en los centros urbanos densamente poblados, se espera que se desarrollen de manera sostenible las ciudades y las comunidades urbanas en el futuro, aumentando el efecto de enfriamiento de los parques urbanos y las soluciones prácticas para expandir y crear tales espacios verdes. Considerando que la isla urbana de calor es un efecto dinámico, en el tiempo, será preciso en futuras investigaciones, realizar simulaciones considerando el factor tiempo, para que se puedan establecer correctas medidas de prevención frente al Cambio Climático, del efecto refrescante de los parques en la temporada estival.

Abstract

One of the most controversial issues has been global warming and the problems it has posed to human societies. Owing to the phenomenon of urban heat island (UHI), the problem of heat in urban areas, especially in densely populated cities, is much more tangible and has threatened the lives of citizens. One of the issues of urban heat island is its adverse effect on people's thermal comfort both from physical and mental perspectives. Developing urban green spaces on small and large scales is considered as an effective way to deal with urban heat and UHIs, which has been proven by many studies. Research has shown that among urban green infrastructures, large-scale parks and green spaces have a more significant effect on temperature reductions, so that this effect not only reduces the temperature inside of parks, but it can also reduce the temperature outside of parks. Two main indicators generally utilized to measure the cooling effect of urban parks are the cooling effect intensity (CEI) and the cooling effect distance (CED). According to studies conducted in this field, in general, parks with an area of more than 10 hectares are capable of decreasing the air temperature to 350 meters by about 1 to 2 degrees.

Given that Spain is one of the warmest European countries with a Mediterranean climate, in order to ensure the health and well-being of citizens, taking people's thermal comfort into account is of paramount importance. Therefore, to explore the cooling effect of parks and their impacts on citizens' physical and psychological thermal comfort, 125-hectare Retiro Park in the center of Madrid, was selected as a case study. Research data collection began in the early summer and was conducted every two weeks for 6 days (22 June, 10, and 24 July, 10 and 24 August, and 10 September). This experimental study has been conducted through field measurements and then data have been analyzed using computational modeling. The data in this study include microclimatic data and questionnaires. Microclimatic data were collected using standard mobile equipment to check the temperature, wind, and humidity on three distances from each of the northern, western, and southern edges of the park. Simultaneously with the collection of microclimatic data, the data of the questionnaire were collected as face-to-face interviews from 423 citizens of the nine investigated sites. Microclimatic data analyses were performed using RayMan software to calculate physiological equivalent temperature (PET) as a physiological thermal comfort indicator. Questionnaire data were also analyzed using statistical methods and SPSS programs. To analyze cognitive maps the special program called Aram Mental Map Analyzer (AMMA) was also designed and utilized.

In the vicinity of the northern, western, and southern sides of Retiro Park, there is the UHI of Madrid at the distance of 665, 855, and 520 meters, respectively. The results of this study demonstrated that the cooling effect of this park can reduce the temperature of the 150-380 meter area on its northern side on average by 0.9°C compared to the area located in the UHI adjacent (665 meters). The average temperature reduction on the western side in the distance of 445-600 meters from park was 2.7°C compared to the area of UHI. Furthermore, these temperature changes in the southern side were akin to the northern side, so that the cooling effect of the park resulted in a 1.25°C temperature reduction in 130-280 meters from the park compared to 520 meters. Overall, the cooling effect of Retiro Park can reduce the temperature by an average of 1.6°C within the distance of 420 meters, in the three investigated directions.

The CEI variations at different distances from the park directly affected on thermal comfort from physical and psychological perspectives. The results of physical thermal comfort based on the PET index indicated that the greater the park cooling effect the more the PET rate. The average PET index on the northern, western, and southern sides decreased by 1.3°C (4.1%), 3.5°C (8.7%), and 3.1°C (7.3%), respectively, compared to the areas adjacent to the UHI. Based on the results,

residents in areas close to the park felt an average of 6.7% more thermal comfort perception from physical view.

The results of the questionnaire were considered as an indicator of perceived thermal comfort (PTC) and based on the score of this data, which was in the form of Likert (1-5), it was determined that the residents perceive more thermal comfort (7.2 %) in the surrounding areas of the park compared to the adjacent heat islands. Additionally, the results of another part of the questionnaires, which were in the form of cognitive maps, showed that on average, 59.4% of the 423 respondents referred to the park as a place where they had the highest thermal comfort compared to other public places.

The results of this study represented the noticeable impact of large urban parks on creating thermal comfort for citizens. Given climate change and temperature increases in densely populated urban centers, to achieve sustainable developments in cities and urban communities, some factors such as urban park cooling effect and practical solutions to expand and create such green spaces require more attention. Considering that the UHI is a dynamic effect, over time, it will be necessary for future investigations to carry out simulations considering the time factor, so that correct prevention measures can be established through the cooling effect of the parks against climate change in the summer season.

B. INTRODUCTION

B.1. Problem statement and justification of research

B.1.1. Urban heat island problems and urban green spaces

The climate is changing rapidly; Earth's temperature is rising due to increasing amount of greenhouse gases in the atmosphere (IPCC, 2018; Ng and Ren, 2017). These changes disrupt the daily lives of human societies, which, in addition to financial losses, create many problems and are considered to be a serious threat to human health, safety and security (Demuzere and et al., 2014; Heltberg et al., 2009; Ebi and Paulson, 2007). In addition, the increase in air temperature in urban areas is more than rural areas under a phenomenon called urban heat island (UHI) (Taha et al.1988; Oke, 1982). The UHI is shaped by various factors, including the absorption of sunlight energy by surfaces of buildings and pavements of streets and materials (dark surfaces), the imposition of heat in the city and the reduction of green space in urban spaces (O'Malley et al., 2015; Kaloustian and Diab., 2015; Xi et .al, 2012; Priyadarsini et al., 2008). Also, an increase in the population living in cities and an increase in high energy consumption exacerbate this phenomenon (Mirzaei, 2015; Battista et al., 2016). According to research projects, 60-80% of energy resources are consumed in cities (Kamal-Chaoui and Roberts, 2009), and considering that it is anticipated that the urban population will increase from 54% in 2016 to 60% in 2030 (UN, 2016), the UHI will be a major challenge to urban life.

Rising urban heat and the increase in the number and size of urban heat islands (UHIs) directly affect the health of citizens (Patz et al., 2005; McMichael, Woodruff, and Hales, 2006). Increase in air temperature is directly related to increase in mortality due to heat exposure during summers with very high temperatures (Vutcovici, Goldberg, and Valois 2014; Harlan et al., 2006). Moreover, according to some studies, rising temperatures affect not only physical health but also mental health (Kuo, 2015). Studies have shown that some aggressive behaviors are associated with temperature increase (Anderson, 2001). Also, heat waves have been associated with psychological and behavioral disorders (Hansen et al., 2008).

Many studies have been done on the ways to reduce UHI in different parts of the world (Rosenfeld et al., 1998; Azevedo and Leal, 2017; EPA, 2008; Wang et al., 2016; Huang et al., 1990). In general, we can summarize used methods in the following sections: Using vegetation including trees, shrubs and lawns at different scales, using water bodies and use

of materials with high albedo values for Pavement and other ground surfaces (Santamouris, 2013; Taha et al., 1988; Gunawardena et al., 2017; Moyer et al., 2017).

The use of green spaces is considered as an effective way to reduce the heat islands and its role has been proven in many research projects (Zölch et al., 2016; Norton et al., 2015; Chow and Brazel, 2012; Wong and Yu, 2005). In this context, various research projects have been conducted in relation to different forms of green spaces.

The majority of investigations on the effect of features and dimensions of green spaces on UHI have been conducted in the past ten years (Akbari and Kolokotsa, 2016). Accordingly, urban parks were considered as an effective solution to confront UHI, compared to other urban green spaces due to their vast area and diversity of vegetation, which caused significant effects on cooling the environment and thermal comfort (Givoni, 1991), and urban parks were first introduced as "Parks cool Island (PCI)" (Cao et al., 2010) and later "Urban Cool Island (UCI)" (Martins et al., 2016; Yu et al., 2017) in the literature of urban studies and sustainability.

Park Cooling Effect (PCE) generally refers to a phenomenon that in an urban area due to the presence of park and urban green space with regard to the area, shape and quality of the green space, the temperature increase not only decreases in the green space itself but also affects the surrounding environment and cools it. Considering the climate change (IPCC, 2017) and the raising the temperature (Dimoudi et al. 2013), especially in cities, due to the phenomenon of UHI in recent years (Mohajerani, Bakaric, and Jeffrey-Bailey 2017), we are witnessing hot summers in urban areas, especially in the capitals and large cities, hence regarding to PCEs impacts, it will be considered as a highly effective solution against heat islands in new development plans (Skelhorn, Levermore, and Lindley 2016; Mariani et al. 2016).

Furthermore, over the years, the value of parks and green spaces for cities and their benefits for the health and welfare of citizens has been discussed and proven in many studies (Hunter et al., 2019; (Shen, Sun, and Che 2017; Bertram & Rehdanz, 2015; Twohig-Bennett and Jones, 2018). In general, green spaces are an essential part of the urban landscape, as they are crucial for the stability and sustainability of cities (Belmeziti, Cherqui, and Kaufmann 2018). Hence, designing and building green spaces should be a

key part of any urban plan that aims to create sustainable cities with healthy communities (Shashua-Bar, Pearlmutter, and Erell 2009; Buyadi et al., 2015; Lee, Mayer, and Chen 2016). Considering the impact of PCE, this effect can be felt not only in the park itself but also within a radius around the park, leading to improved thermal comfort and well-being in the neighborhood as well (Hamada and Ohta, 2010; Yan, Wu, and Dong 2018).

B.1.2. Research Gap

One of the most important issue in the UHI effect is human health, which includes physical and mental health. Many studies have been carried out on the importance of it regarding the effect of heat on the health and thermal comfort of the human body (Hirashima et al., 2016; Salata et al. 2016; Ng and Cheng, 2012). Following the manifestation of the consequences of climate change, the subject of thermal comfort in outdoors has attracted the attention of many researchers, especially those working in the fields of climate, urban development, and environmental research (Chen and Ng, 2012; Jamei et al., 2016; Lai et al., 2019). Human thermal comfort depends on several factors including climate, air temperature, relative humidity, solar radiation, and air movements (Rupp, Vásquez, and Lamberts, 2015). Ultimately, people's perception of environmental conditions also depends on non-climatic factors such as clothing type, coping ability, age, gender, physical appearance, subcutaneous fat, fitness, diet, and skin color (Djongyang et al., 2010; van Hoof and Hensen, 2007).

Over the years, researchers have introduced various indexes for measuring outdoor thermal comfort. Among the existing thermal comfort indexes, the Physiological Equivalent Temperature (PET) which has been derived from the human energy balance, not only meets the aforementioned requirement but also takes the features of human physiology into account (Matzarakis, Mayer, and Iziomon, 1999; Krüger, Rossi, and Drach, 2017; Matzarakis a Amelung, 2008; Taleghani et al., 2015). Highly suitable for urban and environmental studies, PET is and is one of the four most widely used indexes in outdoor thermal comfort research (Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Universal Thermal Climate Index (UTCI), Standard Effective Temperature (SET*)). PET has also been used in a wider range of climatic regions than other indexes (Potchter et al., 2018).

According to studies conducted on the subject of thermal comfort in open spaces, another factor that can significantly influence the results of such studies is people's cognition and mental images of their environment (Knez & Thorsson, 2006; Nikolopoulou, Baker, and Steemers, 2001). Numerous studies have shown that different people have vastly different perceptions of thermal comfort and temperature preferences and also differ in their behavioral and physiological coping and their psychological habits or their expectations from the climate (Nikolopoulou and Steemers, 2003; Knez and Thorsson, 2008; Lenzholzer, Klemm, and Vasilikou 2018; Ruggiero et al., 2019). These differences make it difficult to study people's perceptions of the thermal comfort of their environment (Nikolopoulou, 2011). However, using methods like surveying to ask people how they feel about temperature and thermal conditions can provide a broad picture of people's perceived thermal comfort and satisfaction with the thermal conditions of their environment (Hadavi, Kaplan, and Hunter, 2018; Klemm, Heusinkveld, Lenzholzer, and van Hove, 2015).

In studies conducted in different parts of the world, researchers have used PET index to measure the thermal comfort inside the large urban parks (Chen et al., 2015; Sun et al., 2017; Mahmoud, 2011; Cohen, Potchter, and Matzarakis 2012), but there seems to be a gap in the research literature regarding of the impact of this effect on the perceived thermal comfort from a psychological perspective.

Contrary to the issue of physiological thermal comfort, there have been very few studies concerning thermal comfort from a psychological view. Studies in this section were based on data collected from questionnaires and cognitive maps, which tried to measure the effect of thermal comfort on the citizens' fluency inside of the park (Klemm, Heusinkveld, Lenzholzer, Jacobs, et al., 2015; Nasir et al., 2012). The necessity of using new methods and more advanced techniques in the analysis of cognitive maps is very necessary and important for a more accurate examination of the effect of thermal comfort on the citizens' comfort. In addition, another gap in the existing literature is that previous studies (thermal comfort assessment from physiological and psychological view) have been mostly focused on the space inside the park itself and neglected the consequent impacts on the spaces around the park.

B.1.2.1. Research Gap in Madrid

The UHI effect is even more important for cities with hot summers such as those with a Mediterranean climate (Vardoulakis et al., 2013; Tsitoura, Michailidou, and Tsoutsos, 2016). Research on several cities with Mediterranean climate has shown that most UHIs emerge in the center of these cities during summer. In a study in Thessaloniki, Greece (Giannaros and Melas, 2012), the results showed that the center of the city had the highest discomfort index in the summer and was 1-1.5°C hotter than other parts. However, areas with the highest percentage of green space had a lower temperature than other parts. In a study conducted in Tel Aviv (2006), results showed that during summer, residents experience significant discomfort in urban spaces because of high temperatures. This study reported that the maximum daily average temperature is about 29.0°C, but the presence of a 28-hectare park in the center of the city with favorable vegetation had caused a 2°C temperature decrease in the surrounding area (Potchter, Cohen, and Bitan, 2006).

Spain, which has a Mediterranean climate, is very sensitive to climate change, as in other Mediterranean regions (Carmen and León, 2017; Ward et al. 2016) (Figure 1). The rugged terrain geographic location of Spain has created significant climatic changes; researchers have indicated that since 1970, the average annual temperature has been increasingly widespread, as evidenced by the warming of the weather in winter (Rodríguez et al., 2014; Chust et al., 2011). Also, the average temperature in Spain over the past 100 years has

Figure1 . Mean land surface temperatures in summer from 2000 to 2013 (left side) and in the hot July 2006 (right side) for selected European cities; data source: Ward et al. 2016.

slightly increased compared to the rest of the Europe, 1 °C compared with 0.9 °C (Abanades et al. 2007). Other data also show that the average temperature rise in Spain in the last century, with a temperature of 1.5 - 1.2 °C, is higher in the same period than the average temperature rise in the world 0.74 °C and Europe 1°C (EEA, 2017).

The studies conducted in Madrid the capital of Spain, reveal that Madrid is facing to UHI impacts (Sobrino et al., 2013). The UHI effects in 1985 made the center of Madrid 4°C hotter by comparison with peripheral areas (Román López et al., 2017). Furthermore, the recent study has shown that temperature difference could be up to 8°C during the hot summer of Madrid (Núñez Peiró et al. 2016).

In spite of the studies done on the bioclimatic urbanism of Madrid (Higueras García, 2006) and investigation conducted in order to tackle the UHI effects in buildings (Núñez Peiró, Sánchez-Guevara Sánchez, and Neila González, 2017; Higueras García et al., 2009) and urban public spaces (Tumini et al., 2016), one can claim that the importance of parks and the creation of PCE have not been addressed. It was first introduced in 1992 on the Retiro Park in Madrid in relation to parks and green spaces and its effects on cooling (Almendros Coca, 1992). Considering this, it is very important to consider and use the new methods of reducing the temperature like as PCE creation in urban areas, including Madrid in order to provide healthier society in point of physical and psychological view.

There have been numerous studies on large urban parks and their effects on thermal comfort, but the majority of these studies have examined thermal comfort within parks and their differences from other outdoor spaces. Also, the studies that have assessed the cooling effect of green spaces have only examined the temperature differences between the area around the park and the park itself. Given the importance of the urban heat problem, especially in cities with Mediterranean climate which experience hot summers, this study aimed to investigate the cooling effect of a large urban park on its surroundings (specifically the central park of Madrid which borders UHI) in order to more precisely determine the effect of such green spaces on thermal comfort from physiological and psychological perspectives (as major factors of human health).

B.2. Hypothesis, research questions and objectives

According to the previous studies and the research gaps, there are three main questions to prove it in this research:

- Are urban green spaces, especially urban parks, able to reduce the surrounding area temperature in hot summer?
- Can urban parks reduce air temperature while providing thermal comfort through their cooling effects at different distances?
- To what extent does PCE affect perceived thermal comfort as psychologically? In fact, is the PCE able to play an effective role in recognizing these spaces in the minds of citizens as a place that provides thermal comfort?

Concerning the cooling effect of urban green spaces, the research hypothesis is that urban parks, due to their scale and characteristics, are able to provide thermal comfort for citizens not only in the park but also in the surrounding environment. Thermal comfort created from both physiological and psychological perspectives is debatable, and it is necessary that both of these factors work together to examine the full concept of thermal comfort, especially in the hot months of the year and areas close to hot urban areas (heat islands) in order to determine the extent of their impact.

The main objective of this study is to investigate the cooling effect of an urban park located in the city center and the proximity of the UHI, and its impact on the thermal comfort from a physiological and psychological perspective.

Concerning the main purpose stated, it is necessary to consider three sub-objectives first of all:

- Identifying and categorizing urban green spaces and getting acquainted with their characteristics regarding the amount of cooling effect in order to select a suitable urban green space for this research in Madrid.

- Identifying, selecting, and using appropriate new methods and tools to collect data and analyze the amount of thermal comfort perceived by citizens physiologically and psychologically.
- Investigating and analyzing the range of change in thermal comfort perception (physiologically and psychologically) based on the intensity of the cooling effect of the park at different distances from it.

In order to achieve the intended objectives, experimental research was used in which the characteristics of large urban green spaces were first considered to produce a cooling effect and also the latest version of the map of the UHI of Madrid in 2015 ([Núñez Peiró, Sánchez-Guevara Sánchez, and Neila González, 2017](#)) Was used and Retiro Park located in the center of Madrid with an area of more than 125 hectares was selected as a case study. Adjacent to the park is one central UHI that surrounded the north, west, and south of Retiro Park. Accordingly, to investigate the severity of the cooling effect of Retiro Park and its effect on thermal comfort in adjacent areas to the UHI in the three neighborhoods of Salamanca in the north, Cortes in the west and Pacífico in the south, the research locations were selected. The study locations in each of the mentioned neighborhoods in three different distances from the park have been selected according to the previous research in the places where the intensity of the cooling effect of the park has changed ([Núñez Peiró, Sánchez-Guevara Sánchez, and Neila González, 2017](#)). In total, in this study, 9 places around the park were selected at different distances. As urban structure and morphology, materials used in buildings, roads, and vegetation were among the factors influencing the measurement of the cooling effect of parks, efforts have been made to ensure that the points selected in this study in each of the three research neighborhoods have similarity in terms of spatial configuration, material, and vegetation.

The data collected in this study were of two types: (I) Microclimate data including air temperature, humidity, and wind speed, which were measured inside the Retiro Park and at all 9 location on six days starting from the summer of 2018: June 22, July 10 & 24, August 10 & 24, and September 10. (II) Survey data, which were collected by a questionnaire measuring citizens' age, gender, clothing, activities, perceived thermal

comfort and, also cognitive maps whereby citizens were asked to specify the places where they feel the most thermal comfort.

Given the role of urban green spaces in mitigating UHI and creating thermal comfort in cores of cities, they have a fundamental impact on the quality of life of citizens and sustainable development of urban environments. In this study with regard to the collected data, we examined the cooling effect of a large central park (Retiro Park) in Madrid at different distances from the edges of park (Minimum: 130m, Average: 447m, and Maximum: 855m) and the consequent impact on thermal comfort from physiological and psychological perspectives.

C. METHODOLOGY

C.1. Methodology and thesis structure

This research is based on four stage and is aimed at achieving the ultimate goal of the research. In fact, the first three stages are organized respectively according to the fulfillment of the three sub-objectives mentioned in the previous chapter, so that during the process of these three stages, the final step is taken to achieve the last stage. The stages of formation of this research and its content are presented in Figure 2.

Figure2 . Methodology

The process of the steps performed and the articles related to each stage are as follows:

C.1.1. Identification and classification of the urban green spaces cooling effects

In the first stage of this research, in order to classify and identify the methods that were used to investigate the cooling effect of green spaces and also to determine the characteristics of this effect, all the research that has been conducted on this issue since 2010 was reviewed in a comprehensive study. In this study, the effective and important role of urban green spaces and large-scale parks was clarified. In fact, this study has shown that large-scale urban parks above

10 hectares play an effective role in creating a cooling effect and counteracting UHI and they can affect their surrounding area of up to 350 meters and reduce the air temperature between 1 and 2 degrees Celsius. Based on the findings of this study, Retiro Park was selected as the study case of this research due to its 125 hectare area and its location in the city center and its proximity to the UHI of Madrid (Figure 3 and 4).

Figure3 . Location of Retiro Park within the Madrid's UHI, Source: Núñez Peiró et al., 2017

Figure4 . Night isotherms in Madrid, July 15, 2015. Source: Núñez Peiró et al., 2017

The results of the studies were published as thematic literature of this research and in the form of a review article.

- **Aram, F.,** Higuera García, E., Solgi, E., & Mansournia, S. (2019). *Urban green space cooling effect in cities*. Heliyon. Elsevier Ltd. <https://doi.org/10.1016/j.heliyon.2019.e01339>

C.1.2. Experimental collection of data and considering analytical methods for thermal comfort assessment

In the second stage, according to the results obtained from the first stage, Retiro Park was selected to investigate the impact of this park on thermal comfort in three areas of north, west, and south where the UHI of Madrid is located (Figure 5). In each of these neighborhoods, three points were considered at the different distances and appropriate methods were selected to collect and analyze the required data in line with the purpose of this study. As mentioned in the previous chapter, the data are in two forms: microclimatic data and data from the questionnaire.

Figure5 . The Location of selected areas

All data (both microclimatic and survey) were collected on clear sunny days. At each intersection, data collection was performed over a 10 minute period, during which one group collected temperature data and the other group conducted the survey. Since the Minimum and Maximum temperature inside the park in the summer of 2017 had been observed, on average,

between 05:23 and 14:04 CEST (AEMET, 2018), all stages of data collection were scheduled to start after 10:30 in morning and ended by average 15:00 at noon.

Air temperature (T_a) and relative humidity (RH) were measured by a mobile microclimate station (HOBO MX2301A Temperature/RH Data Logger, produced by Onset Computer Corporation Co., MA, USA) with an accuracy of $\pm 2.5\%$ for RH and $\pm 0.2^\circ\text{C}$ for T_a . Wind speed (WS) was measured by a Proster digital anemometer model MS6252a. All measurement devices were installed 1.5 meters above the ground (Figure 6). A fisheye lens (Sigma 8 mm circular) was used to assess the sky view and take fisheye photographs. T_a and RH data were automatically logged at 1-min intervals and averaged over every 10 minutes. Wind speed data were also recorded manually at 1-min intervals and averaged over every 10 minutes. Climatic data including T_a and RH were also collected from the AEMET station (Agencia Estatal de Meteorología) located inside the Retiro.park.

Figure6 . The measurement devices

Throughout the study, researchers surveyed a total of 145 individuals in the northern part (49 responders in N1, 45 responders in N2, 51 responders in N3), 145 individuals in the western part (47 responders in W1, 50 responders in W2, 48 responders in W3), and 133 individuals in the southern part (46 responders in S1 , 43 responders in S2, 44 responders in S3), who were randomly chosen from among people either living or working in the area(total, 423 responders). Surveys were conducted during the same 10 minutes in which the microclimate measurements were being made (on average, 7 people per intersection per day). Respondents were from both genders and different age groups (excluding children) and had different activity levels (sitting,

standing, and walking). The citizens' perceived thermal comfort was measured by a researcher-made questionnaire consisting of two sections: questions and cognitive maps.

The cognitive map section of the questionnaire was a map of the area between the edge of the Retiro Park and the heat islands to its north, west and, south according to the places of investigation in three parts, on which citizens were asked to mark the areas where they normally feel thermal comfort. To avoid bias, this map was drawn so that the park would make up only a small portion of the map. The obtained cognitive maps were analyzed with the software AMMA (Aram Mental Map Analyzer). In this analysis, the maps on which the park was marked were awarded a score of 100 and the maps on which there was no mention of the park were given a score of 0.

The questions section of the questionnaire itself consisted of two parts. The first part consisted of the questions enquiring directly about the perceived thermal comfort of the respondent. These questions were designed based on the 5-item Likert scale with scores ranging from 1 (Very Low) to 5 (Very High) (Table 1). The questions included in this section were: 1. How thermally comfortable do you feel (neither too hot nor too cold)? 2. How hot do you feel? 3. How much do you feel the cooling effect of the Retiro Park? 4. How heat-tolerant are you? The responses to this part of the questionnaire were analyzed in SPSS using statistical methods.

Table1 , The questions section of the questionnaire

Años:	Género:	¿Desde cuando vives aquí?:				
Preguntas	Muy bajo	bajo	Medio	alto	Muy alto	
1-¿te sientes en confort térmico? ¿Sin frío y sin calor?						
2- ¿Sientes calor?						
3- ¿Notas la sensación de frescor del parque del retiro?						
4-¿Las altas temperaturas son llevaderas?						
Que ropa llevas puesta		Que actividad estas realizando				
T-Shirt ☐ Shorts ☐ Tank top ☐ Gym cloths ☐ Shirt ☐ Pants ☐ Dress ☐ Slip ☐ Suit ☐ Jeans ☐ Skirt ☐ Sweater ☐		Vivo ☐ Para Caminar ☐ Sentado ☐ Trabajand ☐ Corriendo ☐ En pie ☐				

The second part of this section was dedicated to demographic and personal information, including age, gender, type of clothing, and activities. Given the importance of information collected in this part of the questionnaire for the calculation of PET (Matzarakis, Rutz, and Mayer, 2010), for each respondent, the type of clothing was quantified based on the Clo index and the type of activity was quantified based on relevant standards (Streinu-Cercel, Costoiu, and Mârza, 2008).

It should be mentioned that due to the importance of the analysis of mental maps and the need to use new methods, Aram Mental Map Analyzer (AMMA) software was invented by the author of this study to analyze mental maps. This program provided reliable and credible results during the executive projects, and in this research, this software was used in the discussion of data analysis and was considered as an important part of the methodology of this research. Since this program is considered as an innovative and new method of this research, an article was published to introduce and describe how it works.

- **Aram, F., Solgi, E., Higuera García, E., Mohammadzadeh, S. D., Mosavi, A., & Shamshirband, S. (2019).** *Design and validation of a computational program for analysing mental maps: Aram mental map analyzer.* Sustainability (Switzerland), 11(14). <https://doi.org/10.3390/su11143790>

The results obtained from the analysis of the questionnaires were analyzed by SPSS and AMMA and by using RayMan software, microclimatic data along with the personal information of the respondents (gender, age, clothing, activity, etc.) was calculated for each individual in order for the PET calculation (Figure 7).

Figure7 . Structure of data analyzing by each software

C.1.3. Analyzing the results of collected data in investigated areas

In the third stage of this research, the results obtained from the analysis of the questionnaires were considered in this study as a measure of thermal comfort from a psychological point of view and were described as Perceived Thermal Comfort (PTC). The data obtained from the calculation of RayMan software as PET index were considered as physiological comfort measurement criteria. All of this data was examined and analyzed in each of the three northern, western, and southern areas of the park. Three articles, each covering an area around Retiro Park, were published as achievements of this stage.

Article on the northern area:

- **Aram, F.**, Solgi, E., Higuera García, E., Mosavi, A., & Várkonyi-Kóczy, A. R. (2019). *The cooling effect of large-scale urban parks on surrounding area thermal comfort*. *Energies*, 12(20). <https://doi.org/10.3390/en12203904>

Article on the western area:

- **Aram, F.**, Solgi, E., Baghaee, S., Higuera García, E., Mosavi, A., & Band, S. S. (2020). How Parks Provide Thermal Comfort Perception in the Metropolitan Cores; a Case Study in Madrid Mediterranean Climatic Zone. *Climate Risk Management*, 30, 100245. <https://doi.org/10.1016/j.crm.2020.100245>

Article on the southern area:

- **Aram, F.**, Solgi, E., Higuera García, E., & Mosavi, A. (2020). Urban heat resilience at the time of global warming: evaluating the impact of the urban parks on outdoor thermal comfort. *Environmental Sciences Europe*, 32(1), 117. <https://doi.org/10.1186/s12302-020-00393-8>

C.1.4. Summarizing the results of collected data in three investigated areas

In the fourth stage, the results obtained in all three other stages, especially the results of the third stage, were summarized and evaluated and conclusions were presented. Also, at this stage, according to the final results obtained from the effect of Retiro Park on thermal comfort from a physiological and psychological point of view, the necessary suggestions for the development and expansion of this research in the future were presented.

D. PUBLICATIONS

Article 1. State of the art

Statement of Contribution to Co-Authored Published Paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

F.Aram, E. Higuera Garcia, E. Solgi, & S. Mansournia, "*Urban Green Space Cooling Effect in Cities*," *Heliyon*, Volume 5, Issue 4, April 2019. (doi:10.1016/j.heliyon.2019.e01339)

The main purpose of this paper is to answer the first sub-objective; “Identifying and categorizing urban green spaces and getting acquainted with their characteristics regarding the amount of cooling effect in order to select a suitable urban green space for this research”.

My contribution to the paper involved: literature review, interpretation and analyses of experimental and theoretical results, writing and editing the manuscript.

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Review Article

Urban green space cooling effect in cities

Farshid Aram^a, Ester Higuera García^a, Ebrahim Solgi^{b,*}, Soran Mansournia^c

^a Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid-UPM, Madrid, 28040, Spain

^b School of Engineering and Built Environment, Griffith University, Australia

^c Faculty of Architecture and Urbanism, University of Art, Tehran, Iran

* Corresponding author.

E-mail address: ebrahim.solgi@griffithuni.edu.au (E. Solgi).

Abstract

Urban green spaces are considered an appropriate way to reduce urban heat island effects and provide comfort to the nearby occupants. In addition to cooling the actual space, urban green spaces are also able to influence the surrounding area, and this phenomenon is called the urban green space cooling effect. The most important issues with regard to the cooling effects of urban green spaces are the intensity and density of the cooling, which can play a major role for urban designers and planners in dealing with urban heat island. This article reviews the latest studies that have examined the cooling effects of urban green spaces in recent years. Based on the method of evaluation of their samples, the studies are divided into three groups. The first category consists of research into a set of urban green spaces in one part of or in an entire city, mainly conducted through remote sensing and satellite maps. The second category investigates city parks or several urban parks with recognizable shapes and locations. In this section, information was mainly gathered by virtue of field observations. The third category relates to studies in which a part of urban space according to different scenarios of green space placement was modeled by simulation. The results of the present study illustrate that the highest cooling effect distance and cooling effect intensity are for large urban parks with an area of more than 10 ha; however, in addition to the area, the natural elements and qualities of the urban

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green spaces, as well as climate characteristics, highly inform the urban green space cooling effect.

Keywords: Energy, Environmental science

1. Introduction

The intensified accumulation of greenhouse gases in the Earth's atmosphere has led to rapid changes in global temperature trends and climate (IPCC, 2017; Ng and Ren, 2017). While disrupting our daily lives and causing financial losses, these changes are further expected to have serious safety, security, and health implications (Demuzere et al., 2014; Heltberg et al., 2008; Ehi and Paulson, 2007; Khanian et al., 2018). In urban areas, this issue has been exacerbated by another modern phenomenon called the Urban Heat Island (UHI) effect (Taha et al., 1988; Oke, 1982). Owing to UHI effect, an urban area can be on average 1.0–6.0 °C warmer than the nearby non-urban regions (Dimoudi et al., 2013). For example, USGCRP (2017) reported that because of UHI effect, American cities experience 0.5–4.0 °C higher daytime air temperatures and 1.0–2.5 °C higher night-time air temperatures than the nearby rural areas.

The UHI effect has several causes, including the increased absorption of sunlight by dark-colored surfaces of buildings, the physical properties of the materials commonly used in urban areas, the imposition of heat in the urban space due to the urban morphology which affects shading and air movement, the urban compactness which stems from density, plot ratio, land-use and travel proximity, and the deficiency in urban green spaces (Giridharan and Emmanuel, 2018; O'Malley et al., 2015; Kaloustian and Diab, 2015; Xi et al., 2012; Priyadarsini et al., 2008). This phenomenon is also exacerbated by the growing size of the city dwelling human population and the increasing rate of energy consumption (Mirzaei, 2015; Battista et al., 2016). Research has shown that cities currently account for 60–80% of the world's total energy consumption (Kamal-Chaoui and Roberts, 2009). It was also indicated that distance from UHI is a key factor affecting heating and cooling loads and thus the effect of urbanization on energy demand (Kolokotroni et al., 2010). Since it has been estimated that the ratio of world urban population to total population is set to increase from 54% in 2016 to 60% in 2030 (UN, 2016), UHI can be expected to become a major challenge in the future urban life.

There is an extensive body of literature on the available strategies to reduce the UHI effect (Aflaki et al., 2017; Rosenfeld et al., 1998; Azevedo and Leal, 2017; EPA, 2008; Wang et al., 2016; Huang et al., 1990). In general, the methods currently available for this purpose can be categorized into four groups: the use of vegetation cover like trees, shrubs and lawns at different scales (Gago et al., 2013; Mackey et al., 2012), the stack night ventilation (Kolokotroni et al., 2006), the use of waterbodies

(Gunawardena et al., 2017; Moyer and Hawkins, 2017; Daniel et al., 2018), and the use of materials with high albedo rating for pavement and other ground surfaces (Pacheco-Torgal, 2015; Santamouris, 2013; Li et al., 2013a,b; Taha et al., 1988).

The effectiveness of green infrastructure in reducing urban thermal islands is already proven through measurements (field measurements, scale models, and thermal remote sensing), and computer simulation (Farhadi et al., 2019; Lai et al., 2019; Zölch et al., 2016; Norton et al., 2015; Chow and Brazel, 2012; Wong and Yu, 2005). The literature related to this subject consists of broad investigations into green infrastructure of different shapes and scales (Wang and Banzhaf, 2018), including small local parks (Ca et al., 1998; Aram et al., 2019), large urban parks (Petralli et al., 2009; Buyadi et al., 2015), urban forests (Oke et al., 1989; Brandt et al., 2016), urban gardens (Mazhar et al., 2015), green roofs (Santamouris, 2014; Alcazar et al., 2016; Besir and Cuce, 2018), green facades (Demuzere et al., 2014; Manso and Castro-Gomes, 2015), and street trees (Lobaccaro and Acero, 2015; Shahidan et al., 2010; Klemm et al., 2015).

The majority of investigations into the effect of features and dimensions of urban green spaces (UGSs) on UHI have been conducted over the past ten years (Akbari and Dionysia, 2016). According to a review study published in 2010 (Bowler et al.), green infrastructure (trees, parks, forests, and green roofs) have a higher level of thermal comfort than other urban spaces. This is especially true for larger parks and urban forests (UGS), which can have up to 0.94 °C lower daytime temperatures. Another recent review study has shown that thermal comfort and the UHI reduction effect of a UGS depends on its size and shape. According to this study, the cooling effect of an UGS is directly correlated with its vegetation cover and tree shade area (Jamei et al., 2016). In a recent review paper by Taleghani (2018), among the strategies for reducing the effect of UHI, the role of effective UGSs has been emphasized. By taking six Urban Parks Studies (UGS) into account, it has also been demonstrated that these spaces play a major role in UHI reductions.

Hence, thanks to their vast area and diverse vegetation cover, urban parks have a much more significant cooling and thermal comfort impact than small green spaces (Givoni, 1991). As a result, these parks have become known as effective counter-measures against the UHI effect. In the urban studies and sustainability literature, the cold aura around urban parks has become known as "Park Cool Island" (PCI) (Cao et al., 2010; Spronken Smith and Oke, 1998) and lately, as "Green Space Cool Island" (GCI) (Martins et al., 2016; Du et al., 2017). A recent study by Bartesaghi Koc et al. (2018) showed that from all the studies conducted on the cooling effect of green infrastructure, the contribution of the cooling effect of parks and UGSs was 10.9% (PCIs: 6.7% and GCIs 4.2%). PCI or GCI generally refers to the cooling impact of an UGS not only on the area within the park but on the surrounding area as well. Modern development planning science considers the UGS cooling effect to be a highly effective solution for dealing with thermal islands.

Although the growing public and academic attention to UHI has encouraged research into this subject, the studies and findings in relation to the cooling effect of UGSs are yet to be summarized in a review. While there are some review studies on the cooling effect of urban parks, they are not specific and also cover other green infrastructure such as street trees, green roofs and green facade (Bowler et al., 2010; Jamei et al., 2016; Taleghani, 2018). The present study aims to review and categorize the recent studies carried out regarding the relation of characteristics of UGSs to their cooling effect, in order to facilitate the study of data collection and analysis methods commonly used in this area, and thus assist future planning and development attempts to use urban parks and urban gardens for creating the cooling effect and countering the UHI effect.

2. Main text

2.1. Research methodology

This paper is a systematic review of recent research on the utilization of UGSs for creating a cooling effect. Initially, a search was conducted for all articles that discuss urban greening at any scale with the purpose of creating thermal comfort and a cooling effect. Among these articles, those that included case studies on UGSs, in turn including parks, gardens and local green spaces were shortlisted. Since one section of the latest review study on the impact of green spaces on UHI (2010) (Bowler et al.) was dedicated to urban parks and green spaces, the articles published before 2010 were excluded. The remaining recent articles were first studied in greater detail.

Studies on the relation of UGSs to their cooling effect can be classified into three categories: (i) studies that investigate the combined impact of a group of UGSs and provide no specific information about the characteristics of individual green spaces; (ii) studies that contain specific information about the region and location of the cases studied; (iii) studies in which the cooling effect of UGSs has been examined using computer simulation based on several scenarios regarding the specifications of the green space. After reorganizing the data into the aforementioned categories, articles in the same category were compared in terms of quantitative and qualitative data and findings, including the number, shape, size, and dimensions of green spaces, the type of vegetation cover, and the resulting cooling effect. Consequently, the results of this review will be presented in three sections.

2.2. Cooling effect of a group of urban green spaces

In this section, the studies that have investigated the combined impact of a group of UGSs on a certain part or the entire domain of a city (Table 1) are examined. In general, the objective of these studies is to determine how effective is a group of urban green spaces in reducing UHI and cooling the environment. Given the well-known

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Table 1. Summary of studies investigating the cooling effect of a group of UGSs.

Ref	Location (Köppen and Geiger Climate classification, Kottek et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Cao et al. (2010)	Nagoya, Japan (Cfa)	May 25, July 10, October 30	92 parks compared with the surrounding area	Trees, grass, shrubs, soil, water, low albedo surfaces, high albedo surfaces	0.1ha to 41.9 ha	Identifying the role of park parameters (e.g., park size, land-use types, and shapes) in the PCI phenomenon	<ul style="list-style-type: none"> Remotely sensed ASTER LST data and IKONOS image Multivariate Regression 	Cooling effects rely on the park characteristics and seasonal radiation conditions. Also, trees, shrubs and compactness of park benefit the PCI in spring and summer.
Du et al. (2017)	Shanghai, China (Cfa)	February	68 green spaces	Including trees and shrubs, lawn, different buildings and water body	1.12 ha to 205.32 ha	Indicating the role of UGS for implementing cooling effect and distinguishing efficient relevant elements in CEI and CED	<ul style="list-style-type: none"> LST image ArcGIS version 10.1 MATLAB 2014 Pearson correlation 	GCI impacts are contingent upon green space itself and its surrounding features. Furthermore, raising vegetation and water body fractions or reducing impervious surfaces helps to improve GCI impacts.
Lan et al. (2015)	Beijing, China (Dwa)	September 22	30 parks compared to city center	Trees and shrubs	18.42 km ² in total	Developing an alternative method for calculating the cooling extent of green parks by using remote sensing	<ul style="list-style-type: none"> Remote sensing, LST map Dry and wet bulb thermometers (24st) 	The area around a park that benefits from the cooling effect increases with park size.
Yu et al. (2017)	Fuzhou, China (Cfa)	From January to July	435 green patches (connected, and disconnected with water bodies)	329 patches: tree- based (280) and grassland-based (49)	0.02 ha to 296.7 ha	Quantifying which form of greenspace has the greatest cooling effect: simple or complex shape, large or small areas	<ul style="list-style-type: none"> LST map, ArcGIS hierarchical cluster analysis (CHA) 	Compact greenspaces in the shape of a circle or square provide significant cooling effects in terms of intensity and efficiency

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Table 1. (Continued)

Ref	Location (Köppen and Geiger Climate classification, Kottick et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Feyisa et al. (2014)	Addis Ababa, Ethiopia (Cwb)	October 4–18	21 green areas: public parks, green spaces around building and private parks.	Green areas with dense tree vegetation (canopy cover of at least 60%)	0.85–22.3 ha	Identifying the physical characteristics of USG which determine cooling efficiency and examining its extent of extension	<ul style="list-style-type: none"> • NDT index • ArcGIS version 10.0 • Regression model 	Appropriate choice of species, geometry and size of parks may improve efficiency of urban cooling
Anjos and Lopes (2017)	Aracaju, Brazil (As)	July 19 to October 10	UGS around 7 urban climate stations in different parts of the city	Vegetated area: from 2.2% to 53% Water bodies: From 0 to 50%	Not mentioned	Assessing the UHI and PCI effects based on an urban climatological network	<ul style="list-style-type: none"> • Climatic sensor • Local Climate Zone map 	Most UHI and PCI intensities do not develop only in the light winds and clear sky. But these factor have remarkable impact
Brown et al. (2015)	Kuala Lumpur, Malaysia (Af); Lahore, Pakistan (Bsh); Alice Springs, Australia (Bwh); Kyoto, Japan (Cfa); Toronto, Canada (Dfb)	10 years data	Five different zones were compared	Five sites in five different climate zones	Various sizes	Recognizing the effect of microclimate modifications on thermal comfort caused by elements in the landscape	<ul style="list-style-type: none"> • Simulated by human thermal comfort model COMFA 	Decreasing air temperatures through a 'cool island park' is a moderately effective strategy
Chang and Li (2014)	Taipei, Taiwan (Cfa)	August to September and December to February	60 urban parks were surveyed and compared with the surrounding area	Trees, shrubs and pavement	Various sizes	Exploring details related to the planning and design of city parks such that they may effectively cool surrounding urban areas	<ul style="list-style-type: none"> • Thermal sensor • Stationary regression method 	Parks and other open spaces should be designed with less than 50% paved area and at least 30% trees, shrubs, and other shadings.

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Table 1. (Continued)

Ref	Location	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Chen et al. (2014)	Beijing, China (Dwa)	May 22, July 9, October 13 and November 14	Measured 6 types of UGS: wood-land, shrub land, grassland, cropland, rivers, lakes	UGS covering 35% of the overall study area	Total size: 6450 ha	Focusing on the effects of spatial patterns of urban green patches on their own surface cooling effect	<ul style="list-style-type: none"> LST map & QuickBird (QB) image Regression analyses 	In addition to patch size, the other elements such as shape, edge or connectivity have cooling effects
Sun and Chen (2017)	Beijing, China (Dwa)	July 5 and July 29	Five types of UGS: Impervious land (IL), forest land (FL), grass land (GL), water body (WB), and bare land (BL).	Ringroad 5 of the city	Total size: 108.86 km ²	Investigating the dominant combinations of landscape conversions (2012), and quantifying the change of mean LST	<ul style="list-style-type: none"> ENVJ software QuickBird (2002) and IKONOS (2012) TM images 	Greater focus on protecting natural forests in cities might provide greater benefits for climate mitigation.
Buyadi et al. (Dec 2013)	Shah-Alam, Malaysia (Af)	February 21 and January 21	Study site situated in center of the city with various kind of land use and green spaces	Water bodies, high dense trees, mixed vegetation	Total size: 8530 ha	Surveying the influence of development on UGS and UHI	<ul style="list-style-type: none"> LST map NDVI assessment 	Decreasing the vegetation land cover in open spaces has a direct correlation to increasing UHI
Li et al. (2013a,b)	Beijing, China (Dwa)	September 8 and October 4	Seven landscape Metrics, based on easily calculated, interpretable, and little redundancy	Not mentioned	0.52 ha to 0.89 ha	Examining the effects of spatial resolution on the relationship between LST and the spatial pattern of greenspace	<ul style="list-style-type: none"> ENVJ 4.6 QuickBird, SPOT, and TM imagery Pearson and partial Pearson correlation 	The relationship between LST and the abundance of greenspace was negative, but with the spatial configuration of UGS varied by spatial resolution

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Table 1. (Continued)

Ref	Location (Köppen and Geiger Climate classification, Kottek et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Kong et al. (2014)	Nanjing, China (Cfa)	June 13	Part of the city includes the urbanized area of Nanjing and part of its suburbs	Impervious surface, water body, agricultural land, forest vegetation, and barren land	Total size: 9200 ha	Investigating the sensitivity of the cooling effect associated with greenspace to changes in scale.	<ul style="list-style-type: none"> Correlation analyses IKONOS image 	CEI and characteristics formed by greenspace patterns, and increasing vegetation provide cooling effect
Zhang et al. (2014)	Beijing, China (Dwa)	June to August	6387 green space	Trees, shrubs, grass, tree-shrubs, scrub- grass	Total size: 22,556 ha	Measuring the ecological benefits of the cooling effect associated with the use of green spaces	<ul style="list-style-type: none"> Empirical model (11 weather stations) 	The cooling effect and the environmental benefits of UGS largely depend on the green space's structure and size
Muriani et al. (2016)	Milan, Italy (Cfb)	33 years data (1981–2014)	Five metropolitan sites	Different sites in various zones (rural, urban parks, sites located in canyons of the urban plateau, and urban peaks)	Not mentioned	Describing the behavior of the surface energy balance (SEB) and establishing a frequency distribution climatology of the sensible fraction (SF) index	<ul style="list-style-type: none"> Weather stations and remotely sensed data SEB model 	The cooling effect of urban parks can be improved through ameliorating and optimizing single park structure components

utility of remote sensing methods in urban ecological studies (Wilson et al., 2003), most of the research in this category has employed satellite imagery data from sources such as LST map, QuickBird, IKONOS, and ASTER for convenient analysis of the effect of green spaces over large expanses. Some of the studies to be discussed in this section have also utilized field observations, temperature measurements, or temperature sensors for better examination of cooling effect intensity (CEI) and cooling effect distance (CED).

The first article to be discussed in this category is a study conducted on 30 parks in Beijing, where it was found that the size of the parks has an impact on cooling effect creation. The parks investigated in this study had an average CED of between 85m and 284m, and could reduce the average temperature by about 2.3–4.8 °C (Lin et al., 2015). A more recent study on 435 green spaces in another city in China (Fuzhou) showed that CEI of a park is a function of not only its size, but also its shape and quality. This study found that circular or rectangular compact green spaces play a more significant role in cooling effect, and that the area of a green space and the diversity of its vegetation also directly affect the level of cooling. For example, they reported that the CED of a space with an area of 2.3 ha and Δ LST of 0.93 °C was 59.62m, but the CED of a space with an area of 35.78 ha and Δ LST of 4.43 °C reached as high as 279.19 m. The green spaces examined in this study had an average CEI of 1.78 °C and average CED of 104m (Yu et al., 2017). In a similar study, the impact of the geometric shape of 21 UGSs in Addis Ababa on the resulting cooling effect was investigated. This study found a negative relationship between CEI and Shape Index (SI), and a positive relationship between CED and SI, and park size. Among the cases investigated in this study, the one with great cooling impact had a CEI of 6.72 °C and a CED of 240m (Feyisa et al., 2014).

After studying 92 parks in Nagoya, Cao et al. (2010) found that PCI varies not only with physical factors but also with the season. They reported that in spring, summer and autumn, the largest park studied (41.9 hectares) had a peak CEI of 6.50 K, 6.82 K and 2.46K respectively, and the studied parks as a whole had an average CEI of 1.30 K, 1.16 K and 0.43K respectively. Ultimately, this study concluded that the highest cooling effect occurs in summer and autumn. However, a recent study conducted in Aracaju reported that in both hot and cold seasons, CEI remains within the range of 1.5–2.0 °C, though the intensity of UHI varies with season (Anjos and Lopes, 2017).

A recent analysis in 2017 of 68 green spaces found that in addition to areas and complex shapes that play an important role in creating the cooling effect, another factor termed water body, was also effective in CEI and CED indices. In this study, it was also found that among the green space areas surveyed (1.12 ha–205.32 ha), the area of 1.12 ha had the lowest CED and CEI which were respectively 90m and 0.78 °C; however, the area of 129.46 ha had the highest CED and CEI which were 1610 m and 9.35 °C, respectively (Du et al., 2017).

2.3. Cooling effect of particular urban green spaces with known specifications

This section discusses the articles where the location and characteristics (size and shape) of the studied UGSs are specifically mentioned. To enable more accurate examination of the cooling effect of green spaces, the articles in this category are further divided into three subcategories based on the size and type of the case studied: (i) large-scale urban parks with areas of more than 20 ha, (ii) medium-sized urban parks with areas of between 0.1 and 12 hectares; and (iii) local and small parks with areas of less than 0.1 hectares.

2.3.1. Large-sized urban parks

Research in this subcategory has studied large urban parks mostly located in city centers (Table 2). The cooling effect of large urban parks has long been of paramount interest to urban planners (Almendros Coca, 1992; Ca et al., 1998). Thanks to their vast area and location in the heart of the city, these parks often have a significant impact on the temperature of urban spaces (Jauregui, 1990). The cooling effect of these parks is closely associated with their CED and CEI, which depends on several factors, including park size and shape, type and amount of vegetation cover, and regional climate.

A study conducted by Hamada and Ohta (2010) in Nagoya found that during summers, areas adjacent to Heiwa Park (147 ha) had up to 1.9 °C lower temperature than other areas. They reported that in summers, this park had a CED of 200–300 meters during night hours and 300–500 meters during day hours. In another study (Doick et al., 2014), the average night-time CED of Kensington Gardens (111 ha) in London over the period between August and December (5 months) was found to vary between 20 and 440 meters. According to this study, this park reduces the summer nighttime temperatures by an average of 1.1 °C and a maximum of 4 °C.

Besides CED and CEI, some studies of large parks have investigated the Physiological Equivalent Temperature (PET), which is an indicator of human comfort under temperature variations (Matzarakis et al., 1999; Matzarakis and Amelung, 2008), to measure the cooling effect of green spaces. A study conducted in Shanghai, China, showed that on a hot sunny day (August 21st, 2:00 pm), the *Yuan Dynasty Relics Park* (102 ha) decreased the PET by an average of 2 °C and a maximum of 15.6 °C (Sun et al., 2017). Another study conducted in Shanghai (Chen et al., 2015) reported that the cooling effect created by *Zhongshan Park* (21.42 ha) located in the city center resulted in a PET of 15–29 °C during winter. In a similar study by Mahmoud (2011), it was shown that during the hot months of summer, the cooling effect of *Cairo's central Park* (26.01 ha) results in a daytime PET of 22–30 °C and a nighttime PET of 21–29 °C.

Table 2. Summary of studies investigating the cooling effect of large-sized urban parks.

Ref	Location (Köppen classification, Kottick et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Hamaoka and Ohta (2010)	Nagoya, Japan (Cfa)	March and August	One park compared with urban areas	forest, lawn, ponds, fields, spaces containing monuments and buildings	147 ha	Clarifying the range of the cool-island effect of a green area on an urban area, as well as the relationship between vegetation and air temperatures	<ul style="list-style-type: none"> with temperature and humidity sen- sors 24 fixed mea- surement sites 	The range of the cooling effect as well as the relationship between the vegetation cover and air temperature throughout the year
Doick et al. (2014)	London, UK (Cfb)	August to December (nights)	One large park	Water body, mixed grass land and trees landscapes, and formal avenues and gardens	111 ha	Providing empirical evidence for the extent of cooling of London's UHI with one large greenspace	<ul style="list-style-type: none"> Mobile measurement A developed correlation 	Using meteorological stations close to urban greenspace can lead to underestimation of urban heat island intensity due to the cooling effect of the greenspace.
Sun et al. (2017)	Beijing, China (Dwa)	August 21	One park, Comparison of entire park with uncovered sites in the park	Grass, 10 & 20 m trees, hardened ground, water body and buildings	102 ha	Assessing the impacts of these parameters on thermal comfort improving effect of UGSs.	<ul style="list-style-type: none"> PET Index Simulation by ENVi-met and Rayman Regression method Stationary 	The most significant influencing factor on the moderation of thermal comfort is the higher trees, while hardened ground exhibits a negative impact
Chen et al. (2015)	Shanghai, China (Cfa)	November to January	One park, The squares in the park were compared	Surrounded by trees and benches	21.42 ha	Examining the relationship between outdoor micro- meteorological conditions and people's thermal comfort perception	<ul style="list-style-type: none"> PET index Mobile micro meteorological stations 	Visitors' thermal sensations and space use were more significantly affected by the micro- meteorological factors in winter compared with autumn

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Table 2. (Continued)

Ref	Location (Köppen classification, Kottek et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Mahmoud (2011)	Cairo, Egypt (Bwh)	December and June	One big park near the city center (compact urban fabric of the old city core)	9 different zones: peak, spine, entrance, fountain, lake, canopy, pavement,	26.01 ha	Assessing microclimatic and human comfort conditions in various zones within an urban park.	<ul style="list-style-type: none"> Field measurement campaign (thermal index PET and TSV) RayMan 	The results of this study contribute to the practice of providing appropriate thermal comfort in urban parks to attract visitors in summer and winter seasons.
Buyadi et al. (Nov 2013)	Shah-Alam, Malaysia (Af)	Not mentioned	One big national park	Forest reserved and protected	1,507 ha	Investigating the effects of land use changes on the surface temperature of a big national park	<ul style="list-style-type: none"> GIS Remote sensing images 	The vegetation areas can provide positive impacts on regulating high temperatures in urban areas.
Yan et al. (2018)	Beijing, China (Dwa)	Summer months	One big Central park	Park has hills, forest, lakes, wetland and other natural landscapes	680 ha	Investigating the cooling effect of big park on thermal environment of surrounding urban area	<ul style="list-style-type: none"> Field measurement Mobile micro meteorological stations 	The cooling effect of the big park influences not only within the park but extends beyond the park's border.

2.3.2. Medium-sized urban parks

The articles to be reviewed in this section (Table 3) can be divided into two groups: works where only a single park has been studied, and works where several parks of different sizes have been compared with each other. The articles belonging to the second group have utilized different criteria for comparison, most notably the park size, shape, location, and the type and quality of its vegetation cover (Bacci et al., 2002; Spronken Smith and Oke, 1998).

In a study conducted in London (Vaz Monteiro et al., 2016), eight city center parks with areas ranging from 0.2 ha to 12.1 ha were studied to determine the impact of park size on CEI and CED. In short, this study showed that green spaces with areas of 0.5–2 ha can only cause up to 0.3 °C temperature reduction over 40m distance, but the temperature reduction caused by green spaces with areas of 3–5 ha can extend over a 70–120 m distance and reach as low as 0.7 °C. It was also reported that larger green spaces with areas of up to 12.1 ha can decrease temperature by 1 °C over 180–330 m distances. In a study conducted in Tel Aviv (Cohen et al., 2012), the cooling effects of 10 urban parks with different sizes (0.2–0.36 ha) and different vegetation quality and diversity were compared. This study found that parks with dense vegetation cover have the greatest effectiveness in terms of cooling and thermal comfort. The greatest cooling effect was observed in summer, when the parks managed to reduce the temperature by up to 3.8 °C, resulting in a PET of 18 °C. In comparison, a smaller effect was observed in winter, when temperature reduction was 2 °C and the resulting PET was 10 °C.

Other studies on green spaces of medium-sized are focused on the cooling effect of a single park. In these works, comparisons have been made either between differently vegetated parts of a single park, or between the park as a whole and the surrounding spaces. Research on a 0.24 ha urban park in Lisbon showed that during hot summer days, the air within this park is up to 6.9 °C cooler than the surrounding area. This research highlighted other factors such as sunlight exposure, geometric shape, and wind speed as determinants of cooling effect (Oliveira et al., 2011). A similar study by Skoulika et al. (2014) on a 6 ha park in Athens reported that wind can have a significant impact on the magnitude of cooling effect. The CEI of this park was found to be between -0.7K and -8.8K during night hours, and between -0.2K and -2.6K during day hours.

2.3.3. Small parks

Besides large and medium-sized parks, small parks can also play a role in creating a cooling effect. Generally, studies on the cooling effect of UGSs are more focused on large and medium-sized green spaces; however, among the articles in this area, in a study, the role of small parks is also mentioned. According to this study

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Table 3. Summary of studies investigating the cooling effect of medium-sized and small urban parks.

Ref	Location (Köppen and Geiger Climatic classification, Kotték et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Vaz Monteiro et al. (2016)	London, UK (Cfb)	June 20 to October 2, (nights)	8 Parks situated in central of city	Tree canopy (47% _174%) and grass (68%_91%)	0.2 ha to 12.1 ha	Modeling the extent of the local air cooling service and finding related greenspace area	<ul style="list-style-type: none"> Geographic Information System (ArcMap 10 – Esri) 	For the ranges of areas studied, the distance over which cooling is experienced increases linearly by increasing green areas. The relationships between cooling amount and areas are non-linear.
Cohen et al. (2012)	Tel Aviv, Israel (Csa)	June 15 to July 15 and January	10 sites: three urban parks, three street canyons, two urban squares and a lawn in the tissue of the city	Varied vegetation coverages (a variety of tree types and sizes, shrubs and lawn, and paved areas)	2000 m ² to 3600 m ²	Examining the diurnal and seasonal climatic behavior of green and bare urban spaces; and studying their impact on human thermal comfort	<ul style="list-style-type: none"> Meteorological stations and relative humidity sensors RayMan and PET calculations 	The cooling effect caused by urban vegetation is much higher in summer than in winter and at midday than at nighttime.
Oliveira et al. (2011)	Lisbon, Portugal (Csa)	6 days of 2006 and 2007 (August and September)	One garden in densely urbanized area	Deciduous trees, small lakes, large trunks and well developed crowns predominate (85%)	0.24 ha	Investigating the thermal performance of a small green space and its influence on the weather parameters of the surrounding atmosphere	<ul style="list-style-type: none"> Motive measurement RayMan 	The thermal performance of green areas is contingent upon some factors, like the climatic envelop and locations of study areas.

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Table 3. (Continued)

Ref	Location (Köppen and Geiger Climatic classification, Kottak et al., 2006)	Month	Green site & comparator	Features of green site	Size	Purpose	Methods/ Instruments	Conclusion
Skoulika et al. (2014)	Athens, Greece (Csa)	July 29 to September 2	One park surrounded by a very dense area with medium size residential and commercial buildings	Covered by grass, various types of bushes, low trees (olives, acacias, etc.), dense medium and high size trees	60,000 m ²	Understanding and analyzing the relative climatic conditions in the park compared to the reference urban areas, and evaluate its climatic contribution	<ul style="list-style-type: none"> Field measurement (The nine fixed temperature and humidity stations) Mobile sensors 	<p>The park has an important mitigation impact on its surroundings (3.3 K). Increased wind speeds increase the mitigation potential beyond the park limit</p>
Park et al. (2017)	Seoul, South Korea (Dwa)	Aug 9, 16, 27 and Sep 6, 7, 11	6 Small green space within urban blocks	Different shape types: polygonal, linear, single, and mixed.	300 m ² to 650 m ²	Understanding the cooling effect of SGs on urban block units based on their types (four types) and structures	<ul style="list-style-type: none"> Choose district by either local climate zone (LCZ) model Air temperature logger (Testo 174H) 	<p>Small green areas can bring a positive benefit by increasing the cooling effects in urban blocks, and configuration of green space (polygonal and mixed types) plays a more important role.</p>

conducted by Park et al. (2017) in Seoul, small green spaces with an area of 300 m² can result in 1 °C temperature reduction and slightly larger parks with an area of 650 m² can reduce the temperature by up to 2 °C. This study found that the CEI of a park correlates with its size, and accurately predicted that a 1500 m² green space would reduce the temperature by up to 3.6 °C. This study also showed that polygonal lands with combined vegetation cover can reduce the temperature by up to 4 °C (Table 3).

2.4. Cooling effect predicted in computer simulations

This section reviews the studies conducted more recently following the popularization of computer analysis, the use of ENVI-met and FLUENT software (CFD model), in urban biochemical studies (Table 4). The articles covered in this section have employed ENVI-met and CFD simulations to predict the cooling effect of green spaces with different shapes, dimensions, and placements in different scenarios.

One of the first works in which the cooling effect of green spaces was analyzed with ENVI-met was a study conducted in 2012, where the impact of replacing Hong Kong sidewalk pavements with green materials was simulated in various climatic scenarios. This study found that planting sidewalk trees in urban spaces result in a better cooling effect than building green surfaces such as green roofs (Ng et al., 2012). A similar study in Manchester also found that mature trees have a significant impact on the pavement surface temperature. The simulation results of this study showed that adding 5% mature tree density would reduce the surface temperature by 1.0 °C, and even adding 5% density saplings would result in 0.5 °C temperature reduction in urban areas (Skelhorn et al., 2014).

In another recent study (Lin and Lin, 2016), ENVI-met software was used to simulate eight scenarios regarding the placement of green spaces in Taipei City. Of these eight scenarios, three were dedicated to the placement of 6 hectares of green space, and the remaining five assessed the placement of 36 hectares of green space. In these simulations, the impact of park sizes and placement was studied. Ultimately, the results showed that the larger the size of the UGS, the greater will be the cooling effect. In this study, the best result in terms of cooling performance was achieved by using a combination of smaller parks placed alongside a larger green space.

Utilizing a three-dimensional CFD model in Ljubljana in Slovenia by Vidrih and Medved (2013), the study indicated that the summertime cooling effect of different parts of a 1.96 ha park is depended on its leaf area index (LAI). They also reported that in areas where LAI_{sp} (planting density of 45 trees with an age of 50 years, per hectare) is 3.16, CEI reaches -4.8 °C, but in the extremities of the park, where LAI_{sp} is 1.05, CEI reaches -1.2 °C.

Table 4. Summary of studies investigating the cooling effect predicted in computer simulations.

Ref	Location (Köppen and Geiger Climatic classification, Kottek et al., 2006)	Month	Simulated Factor	Simulated Item	Purpose	Methods/ Instruments	Conclusion
Ng et al. (2012)	Hong Kong, China (Cfa)	May 9	different greenery percentages around high rise buildings	Green space within the city center with high building density	Establishing a compact site in the center consisting of mixed commercial and residential buildings	<ul style="list-style-type: none"> Mobile meteorological station ENVI-net PET Index 	Greening and more significantly tree planting must be positioned nearer to the area where human activities are concentrated
Skelton et al. (2014)	Manchester, UK (Cfb)	July 13	Five study areas with retail, office, and residential buildings surrounded by UGS	Vegetation, mature trees and new trees	Indicating the impact of greenspace types on temperature, and assessing the utility of ENVI-net in cooling effect	<ul style="list-style-type: none"> ENVI-net Button temperature sensors Radiation shields 	UGS elements like mature trees have impact on the mitigation of high temperatures. On the other hand, asphalt has a significant negative effect
Lin and Lin (2016)	Taipei, Taiwan (Cfa)	July 2	Evaluation of 8 park spatial arrangement scenarios	simulating differing greenery percentages	Characterizing the influence of the spatial arrangement of urban parks on local temperature reduction.	<ul style="list-style-type: none"> ENVI-net 	A larger total park area, a greater number of parks, a greater area of the largest park, more evenly distributed park spaces, and more park diversity lead to more dramatic outdoor cooling effects
Maddal et al. (2015)	Phoenix, USA (Bwh)	June 23	Eight simulation scenarios for the neighborhood	varying tree canopy cover, from 0% to 30% using a mix of native and non-native trees	Quantifying the thermal impact of two heat mitigation aspects: urban forestry, cool roof initiatives.	<ul style="list-style-type: none"> ENVI-net 	Increased tree coverage reduces air temperatures, but the magnitude of this impact, even with a 25% tree canopy cover, may not be sufficient to offset increased temperatures due to climate change.
Vidrih and Medved (2013)	Ljubljana, Slovenia (Cfb)	July	One urban park	Simulating different scenarios in 140m *140m area	Investigating the impact of the density and size (age) of trees, air temperatures and wind velocities on UGS	<ul style="list-style-type: none"> Three-dimensional CFD modelling 	The park cooling effect was determined according to local conditions on the surface of park elements on a selected extreme summer days.

2.5. Summary and discussion

The present paper reviewed the recent articles related to the impact of UGS on the creation of cooling effect, reduction of UHI, and provision of thermal comfort in urban environments. In the past ten years, the growing attention to the importance of green spaces, and especially parks, in the creation of cooling effect has led to the publication of many research works with different methodologies and at different scales in relation to this subject. Given the high number and variety of articles published on this subject, we categorized the works based on methodology and scale of research. Although the literature contains a number of review studies on the subject of urban parks and green spaces (Bowler et al., 2010; Jamei et al., 2016; Taleghani, 2018; Bartesaghi Koc et al., 2018), they have taken a comprehensive perspective and investigated the articles on the entirety of green infrastructure. Hence, in these studies, the research on urban parks and green spaces has been reviewed as a part of an extensively broader literature and there is no detailed categorization in regard to the methods and findings of the studies specifically focused on this subject. Considering this gap in the literature and the importance of UGS cooling effect for urban planning, we attempted to address the lack of a review study in literature in regard to UGSs and their impact on cooling effect.

In the first section of this paper, we reviewed the articles on the combined impact of a group of UGSs on a part or the entire area of a city. The studies covered in this section were mostly based on remote sensing methods, with the exception of a few works that utilized field observations as well.

The next section of this study was dedicated to the articles where the location, size, and shape of the studied UGSs are specifically mentioned. These articles are mainly based on the studies of one or several specific parks, using field data collected from temperature sensors installed in and around the case, and/or by collecting PET data from residents to estimate the cooling effect. Some of these studies have also employed ENVI-met software, satellite imagery and remote sensing data for deeper analysis. For better categorization, these articles were divided into three subcategories based on the size of the studied case. A summary of results reported by these articles is presented in Table 5 and Fig. 1.

The last category of articles included the studies that have heavily utilized computer simulation. While being a relatively new method in this line of research, computer simulation has greatly facilitated the qualitative analyses that put more emphasis on the effect of vegetation type and quality and the placement of green spaces, rather than CED and CEI measurements. Although simulation is a convenient and quick method of analysis, it is not as accurate and reliable as the study of aerial maps and field observations, and is only suitable for developing initial hypotheses and assumptions and studying how the change of scenarios and variables affect the

Table 5. Summary of studies investigating the cooling effect of particular UGSs with known specifications.

Size	General features
Big Size Parks	<ul style="list-style-type: none"> • Mature and tall trees with high percent of canopy • Water body • Different zones and landscapes with various vegetation types
Medium Size Parks	<ul style="list-style-type: none"> • Different size of trees (medium and high) • various vegetation types • small water body
Small Green Spaces	<ul style="list-style-type: none"> • Low tree diversity • Low vegetation diversity • Has an enclosure space

a Big Size Parks		147 ha CED= 200-300m CEI _{max} ≈ 1.9 °C		21.42 ha CED= NM CEI≈ 1-2°C
	111 ha CED≈ 20-440 m CEI ≈1.1°C - 4 °C		26.01 ha CED= NM CEI≈ 1°C
	102 ha CED≈ NM CEI≈ 2°C		1,507 ha CED≈ NM CEI≈ NM
b Medium Size Parks		0.2 ha CED≈ 0 m CEI ≈0.34 °C		2.9 ha CED≈ 45-149 m CEI ≈0.59 °C
	0.3 ha CED= 1 m CEI ≈0.32 °C		3.8 ha CED= 10-85 m CEI ≈0.77 °C
	0.8 ha CED= 22-44 m CEI ≈0.57°C		10.1 ha CED≈ 173-179 m CEI ≈0.66 °C
	2.5 ha CED≈ 46-218 m CEI ≈0.42 °C		12.1 ha CED≈ 329-328 m CEI ≈0.98 °C
c Small Green Spaces		0.07 ha CEI ≈1.7°C		0.06 ha CEI ≈1.5°C
	0.01 ha CEI ≈0.5°C		0.2 ha CEI ≈4.1°C
	0.3ha CEI ≈4.5°C		0.093 ha CEI ≈2°C

Fig. 1. (a) 6 parks were investigated at this scale. (b) 21 parks were investigated at this scale. But, the information of Vaz Monteiro et al. (2016) study having both CEI and CED is illustrated. (C) 6 parks were investigated at this scale.

responses. As a result, the articles included in this section lack specific CED and CEI measurements. Overall, it can be concluded that each of the above methods has a set of unique features, which make it preferable for research at certain scales or with certain purposes.

Although the impact of UGS cooling effect has been researched at different scales and for different climates, the number and geographical distribution of studies in this field do not match the importance of the subject. The majority of past studies on this subject have been carried out in Eastern Asia, and their results cannot be generalized to other regions. Also, the majority of these studies are focused either on large and central parks or medium-sized parks, and have largely overlooked the smaller and local green spaces. Although it is known that larger parks have greater cooling effect, the only study that has investigated the effect of small parks (Park et al., 2017) has demonstrated the noticeable cooling effect of small parks on their surroundings, which indicates the necessity of further research into this matter.

It is also notable that the reviewed articles have overlooked some aspects of the subject in favor of a focus on the size of green spaces. While, some of these works have studied factors such as shape index (SI) (Feyisa et al., 2014), leaf area index (LAI) (Vidrih and Medved, 2013), wind speed (Skoulika et al., 2014), Δ LST of surfaces (Yu et al., 2017), seasonal changes (Anjos and Lopes, 2017), vegetation type (Cohen et al., 2012; Skelhorn et al., 2014; Middel et al., 2015), and sunlight exposure (Oliveira et al., 2011), none of them have examined the collective effect of that may influence the CED and CEI of a green space. In addition, most of these studies have ignored the role of natural and artificial objects and elements typically found within parks, such as waterbodies and urban furniture. A study on urban design and planning solutions to reduce the effects of urban heating was carried out by Kleerekoper et al. (2012) in the Netherlands, emphasizing on the use of various solutions, such as green space and waterbodies alongside each other. Furthermore, the other recent article that has considered the effect of the different qualitative and quantitative green space elements is the study of Xu et al. (2017), and there is still a huge gap in the research literature in regard to this issue.

Furthermore, only a few studies have considered the actual size of the vegetated area within green spaces. In other words, most studies, and especially those that have employed remote sensing methods, have assumed the entire area of green space (including sidewalks and buildings) as vegetated surface; a simplifying assumption that can undermine the accuracy of research. Another problem observed in the reviewed articles is the size mismatch between the studied cases, which may undermine the quality of comparisons, and thus the research power to discover the factors influencing the temperature reduction. In view of the above issues, it is

imperative for future research to pay further attention to the specifications of the cases to be studied and to the selection of proper methodology according to research objectives and scale.

3. Conclusion

With steadily growing impacts of global warming, cities are increasingly struggling with new problems such as intensified UHI effect. Further academic attention to the impact of UGS on UHIs can provide city planners with viable strategies to address this issue. In this paper, we reviewed and categorized recent articles in this field of study. In summary, all of the reviewed articles agreed on the fact that UGSs, including parks, play a key role in reducing UHI, creating cooling, and providing thermal comfort for citizens.

In the reviewed articles, the impact of green spaces and their specifications were investigated through different approaches including the use of field observation and temperature sensors for accurate CEI and CED measurement and the use of satellite maps and remote sensing methods to investigate the collective impact of a group of UGSs on large expanses of a city. A good agreement was observed between the results derived from satellite imagery data and those obtained from field studies. From the results reported by these groups of research, it can be concluded that large parks with areas of more than 10ha have the highest average CED and CEI; that is, a 1–2 °C temperature reduction that extends over a 350m distance from the park boundary.

A relatively new method in this field of research is computer simulation, which allows research and analysis variables to be adjusted as desired. Given the unique merits and characteristics of the above methods and the success of previous attempts to combine field examinations with simulation or with remote sensing data, consideration of all these methods in line with research objectives and specifications can facilitate future research into cooling effect.

Since the majority of studies on cooling effect of UGS have been published in the last ten years, and this subject can be considered a relatively new branch of urban sustainability research, future studies are expected to cover broader geographic and climatic spectra and to focus their comparisons on carefully selected cases with similar characteristics such as size and shape. Future studies are also recommended to develop and test new advanced methods for this particular line of research and also incorporate the natural and artificial features commonly found in urban spaces into their analyses, in order to identify and evaluate the impact of all variables of UGS that play a role in temperature reduction through cooling effect.

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Article 2. Methodology: Analyzing Mental Map

Statement of Contribution to Co-Authored Published Paper

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The main purpose of this paper is to introduce new methods for analyzing thermal comfort perception of people, according to the second sub-objective of the research; "Identifying, selecting, and using appropriate new methods and tools to collect data and analyze the amount of thermal comfort perceived by citizens physiologically and psychologically".

My contribution to the paper involved: Fabrication, conducting the experiment, data collection, the computer programming and analysis of results, writing and editing the manuscript.

Article

Design and Validation of a Computational Program for Analysing Mental Maps: Aram Mental Map Analyzer

Farshid Aram ¹, Ebrahim Solgi ², Ester Higuera García ¹, Danial Mohammadzadeh S. ^{3,4}, Amir Mosavi ^{5,6,7,†} and Shahaboddin Shamshirband ^{8,9,*}

¹ Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid-UPM, 28040 Madrid, Spain

² School of Engineering and Built Environment, Griffith University, Gold Coast 4215, Australia

³ Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad 9177948974, Iran

⁴ Department of Elite Relations with Industries, Khorasan Construction Engineering organization, Mashhad 9185816744, Iran

⁵ Faculty of Health, Queensland University of Technology, Brisbane QLD 4059, Australia

⁶ Kando Kalman Faculty of Electrical Engineering, Obuda University, 1034 Budapest, Hungary

⁷ School of the Built Environment, Oxford Brookes University, Oxford OX3 0BP, UK

⁸ Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh 758307, Vietnam

⁹ Faculty of Information Technology, Ton Duc Thang University, Ho Chi Minh City 758307, Vietnam

* Correspondence: shahaboddin.shamshirband@tdtu.edu.vn

† Current address: Centre for Accident Research Road Safety-Queensland, Queensland University of Technology, Brisbane QLD 4059, Australia.

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Abstract: Considering citizens' perceptions of their living environment is very helpful in making the right decisions for city planners who intend to build a sustainable society. Mental map analyses are widely used in understanding the level of perception of individuals regarding the surrounding environment. The present study introduces Aram Mental Map Analyzer (AMMA), an open-source program, which allows researchers to use special features and new analytical methods to receive outputs in numerical data and analytical maps with greater accuracy and speed. AMMA performance is contingent upon two principles of accuracy and complexity; the accuracy of the program is measured by Accuracy Placed Landmarks (APL) and General Orientation (GO), which respectively analyses the landmark placement accuracy and the main route mapping accuracy. Also, the complexity section is examined through two analyses Cell Percentage (CP) and General Structure (GS), which calculates the complexity of citizens' perception of space based on the criteria derived from previous studies. AMMA examines all the dimensions and features of the graphic maps and its outputs have a wide range of valid and differentiated information, which is tailored to the research and information subject matter that is required.

Keywords: Smart urban planning; sustainable urban development; mental maps; smart cities; quantitative analysis; environmental psychology; landmark; sustainable society

1. Introduction

Involving people in urban projects and the use of citizen's views are the key factors for sustainable urban society development [1–3]. People's participation occurs in a variety of ways [4,5]. Considering people's perceptions and their cognition of the environment that they live in can play a key role in successful urban planning based upon people's actual needs [6–8]. The feelings and expectations of

people regarding space and their living space, with regard to their cultural and social characteristics, have always held researchers' interests [9–11].

When studying the mentality and perception of people with regard to city and urban spaces, one of the common methods is synchronizing their conceptual mapping of the city into a map that provides a tangible model of the city. These maps were first introduced by Tolman as cognitive maps in 1948 [12] and express the subjective and abstract representations of the individual from the environment [13]. Images that take this form include elements derived from the individual's direct experience from a location and information from the environment, which include the place structure or appearance, its relative position and its values. These mental images are types of guiding maps [14] and are in fact, images of the distances and directions formed in the memory [15]. Lines, points and zones are the most important elements that are referred to most in research as the map's main components.

Kevin Lynch [16] developed this approach as the city's image and examined the city's imagery capacity in terms of understanding and remembering structural elements (path, edge, node, landmark and district). Lynch's research on American cities has made this method renowned and made it the basis of considerable other research [16]. Peter Gould utilized a similar method named mental maps to assess the spatial preferences of individuals on surfaces [17] and other researchers, such as Golledge, have referred to these maps as cognitive maps that emphasize the priority of places in people's imagery, as well as establishing relationships between places [18].

Norberg-Schultz [19] identified these maps as places, paths and territories where places are points similar to Lynch's nodes and landmarks where major events occur. Paths are permanent elements that shape the city's overall structure and territories are similar to Lynch's districts. Territories have elements that are defined by an "enclosed space" and play the role of paths and places. In various studies, the names of maps drawn by citizens that depict the geographical, urban, residential or even architectural spaces are in the form of cognitive maps [20,21] sketch maps [22] and map drawing [23]. All of the mentioned studies refer to the same two-dimensional maps derived from the perception of individuals of their surroundings.

1.1. Why Is It Important to Analyze the Mental Map?

The study of mental maps as a scientific method constitutes the focus of knowledge on the impact of the environment on the perceptions and minds of individuals [24], including environmental psychology, urban planning and human geography [25]. However, mental maps are not without issues due to their qualitative nature and the absence of a constant pattern for accurately measuring the perception of space [26] but are still considered as a reliable and practical scientific method [27].

The study of mental maps is not only used to address the structural and physical characteristics of space that affect perception [28,29] but can be deeply rooted in the spatial behaviour of the environment [30–32] and used to obtain valuable information on the sense of people's enjoyment of existence within the space [33]. Through mental maps, the prediction of individuals' decision making and spatial selection [34–36] will be possible, in addition to evaluating individuals' routing and navigation [37–39].

The utility of cognitive maps and their role as a mnemonic and metaphorical device [40]; are precisely one of the other benefits of these maps, as shapers of the world and local attitudes and perspectives [41]. Cognitive maps are therefore a means to structure and store knowledge [42].

Moreover, other commonly applied features of mental maps include understanding the differences in spatial perception of different age groups, from children [43] to elderly aged [44], as well as different genders [45,46].

Kitchin [47] referred to the applied worth and practical values of mental maps in various sciences in a relevant study, including cartography and remote sensing, geographical educational issues, crime solving, concerning the planning of suitable living environments, Geographical Information Systems (GISs), search and rescue, advertising, as well as designing and understanding computer interfaces and databases.

The subjective analysis method does not impose a predetermined structure on data and therefore this, it is possible to obtain understanding in a more descriptive and detailed way compared to open-ended questionnaires or in-depth interviews. Furthermore, it is possible to extract experiences that define and shape the meaning of the place by obtaining human imagery. Thus, mental maps within scientific studies have specific functionality due to their objective representation and are effective in scientific and practical advancement due to their correct and precise analysis.

1.2. The Significant Factors for Analyzing Mental Maps

The issue of peoples' perception of their surroundings, the manner and processes in which people make connections with their surroundings and the ways in which these connections affect people are questions raised by many researchers which are not covered in the field of urban and environmental studies. Fundamental studies related to mental maps in the field of urbanization have been developed by theorists of this technique and include the studies of Donald Appleyard's [48] mental role grouping and research by Walsh, Krauss and Regnier [49] regarding the complexity and accuracy of landmarks.

In general, there are different perspectives on peoples' perception of their surroundings. Regarding a perspective based on the theories of Lynch [16] and Appleyard [50], landmarks are considered as the starting point for peoples' perception of their surroundings which is within a network of paths. In a review by Evans, Marrero and Butler [51], it is clear that over time, peoples' perception of landmarks do not change but their location accuracy varies. Also, in another assessment by Hart and Moor [52], Siegel and White [53], it was shown that gradually, people had an improved and more accurate perception of other paths and nodes. In fact, paths are recognized more clearly as linking networks for landmarks over time and reflect the perceptions of people on the shape and structure of their surroundings [54,55].

Overall, landmarks and paths can be considered as the main contributor to the perceptual image of the surrounding environment. Landmarks in urban spaces are a three dimensional sign that shape the inhabitant's knowledge of the urban space [56,57]. Paths and their shapes, as a two dimensional structure, create a network of spatial information in the human mind regarding the surrounding environment [20].

In a study conducted by Koseoglu and Onder [58], an effective way to measure an individual's perceptions of the environment is introduced through two variables examining the landmarks and the complexity of the spatial layout, which is, in fact, the complexity of the two dimensional spatial design concerning space and paths. However, the functionality of landmarks refers to the three dimensional information of a space. In this regard, as mentioned in numerous studies, the analysis of landmark locations and the main structure of cities and paths depicted by citizens is described as the most important part of mental maps analysis, according to which peoples' perception of the environment is evaluated [59–61].

The purpose of analysing map drawings in addition to checking the accuracy of landmark locations which is a milestone in individuals' perception of the environment is to evaluate individuals' perception of the structure and shape of space by comparing trajectories drawn with the actual state to provide an overview of how individuals perceive the environment [21]. However, given that these maps are merely a simple and abstract representation of reality, the analysis and assessment of these maps is challenging [62]. Notwithstanding, based on these two important items, that is, landmarks and paths, mental maps can be analysed more accurately.

2. Methods of Mental Map Analysis

The analysis of mental maps is done quantitatively and qualitatively or as a quantitative-qualitative combination. Qualitative methods are mostly based on the logic and conclusions of researchers and empirical knowledge, therefore, considering that the purpose of this research is based on a software and computational solution, thus quantitative methods are implemented in this research.

Computational methods were initially considered by researchers and they have always aimed to analyse mental maps quantitatively and through valuation [63] for more precise evaluation. In this

regard, one of the first attempts was studies conducted by Appleyard [48] where the complex perception of individuals is rated based on the drawings of mental maps and has been regarded as the one of the most prominent studies on mental maps.

Another prominent method in this regard is the Bi-dimensional Regression (BDR) method which was first introduced in the geography field by Tobler [64]. BDR is a statistical and numerical method in which the similarity between two points is examined geographically. This method may be used to assess the analysis of mental maps and to compare the points drawn by the respondents and the actual points [65]. In another study conducted by Symington, Charlton and Brunsdon [66], this method also applies to the analysis of paths and the structure of the perceived environment. By using the coordinates of the paths, it is possible to analyse mental maps through the depicted paths.

With the advent of computers and data analysis based on computer methods regarding the analysis of mental maps, researchers have aimed to analyse mental maps faster and more accurately through computer methods. One of the first studies in this field was conducted by Sheetz et al. [24], which proposed that mental maps can be evaluated by Group Support System (GSS) for more rapid and accurate analysis. Furthermore, in recent years, considering the many capabilities of GIS in environmental and urban studies [67–69] measures have been taken to analyse people's perception towards urban environments using the tools within this program [70–72]. In the context of analysing mental maps in a computational manner, in research conducted by Trowbridge et al. [73], the Georeferencing ArcGIS tool was used to evaluate the accuracy of the mental maps based on the metric distances of the main map, which actually evaluated the accuracy of landmark locations by overlapping the mental map with the city's main map.

In another method presented by Tomko and Winter [74], five lynch elements [16] that is, node, path, edge, landmark and district, along with the innovative element of this research; restricted district, are classified based on two characteristics: 1. Accessibility (accessible and inaccessible) and 2. Dimensionality (0D, 1D and 2D) according to Table 1. They presented a new model on peoples' perception of the city image based on the type of transportation used (car, train and water transport). The output of these calculations determine the relationship between the factors via graphs and show the different images of the city from the perspective of different individuals travelling with different transportation within the city, as well as the differences between these images.

Table 1. Combinations of accessibility and dimensionality of Lynch's original five elements of the city form and the added restricted district [74].

Dimensions	Accessible	Non-Accessible
0	Node	Landmark
1	Path	Edge
2	District	Restricted district

In reality, what is being discussed as common methods of analysing mental maps, is the valuation and evaluation of the references of important points and places from the perspective of citizens and the comparison of depictions with the main structure and paths of the city. According to the mentioned topics, as the most important objective of AMMA software formation, it was attempted to initially analyse and assess landmarks and paths depicted by the respondents in a simple software environment that is solely for analysing and assessing mental maps to obtain precise numerical outputs and analytical maps. Also, as a secondary objective, during another stage and based on the needs of other research in assessing the mental complexity of citizens, this software has made it possible to assess mental maps based on the studies conducted in this field.

3. Aram Mental Map Analyzer

It is noteworthy that when analysing mental maps, it is vital to know what features are depicted by citizens for suitable analysis. An important note about these maps is that in addition to peoples'

perception of the environment, the power and syntax of depiction are equally as important regarding mental maps thus various maps are evident from individuals which are depicted differently. In general, most individuals typically depict the curve paths as straight [75] or the angles are mostly drawn as rectangular [76]. Another important point is that lack of scalability regarding mental maps, which makes distances differ from reality such that the distance between landmarks are either too great or much less [77].

For this purpose, the AMMA mechanism is designed so that in a simple environment, the mental maps can easily be transferred to the software environment (main map) with all their drawing features using graphical tools in order to address mental map features based on the locations of landmarks and depicted paths for the accurate analysis of individuals' perceptions towards their surroundings using common patterns derived from the mentioned maps. AMMA is programmed in MATLAB and its data processing method is based on image processing as a raster data. As seen, it is possible for the user to mark spots on the main city map using the tools provided in the software environment on the basis of depicted maps and to present results as numerical data and analytical maps. In essence, the main function of the AMMA software is the conversion of qualitative data resulting from mental maps into numerical data along with an analytical map in the form of individually or generally depicted maps. Generally, it can be said that the program has two inputs: the main map of the study area (as the basis for numerical calculations) and the mental maps (qualitative data). Firstly, by using the tools in the software the researchers implement the information (determination of the region, landmarks and paths) on the main map. Afterwards, the mental maps (qualitative data) are entered into the software and the drawings of the questioners (mental maps) are transferred to original maps using the software tools. Based upon the analyses outlined in the following sections (Sections 3.1 and 3.2), they are extracted as numerical outputs. Additionally, in the form of colour spectral diagrams (based on calculations), graphical outputs are presented.

The software environment is such that the city map entered into the software as image files (JPG, TIFF or PNG) is in the form of a grid and each unit of the grid conforms to a binary code that is valued if marked. This valuation takes place on the city map in two stages. In the first stage, the expert enters presuppositions regarding landmark points and main paths into the software (these presuppositions are based on the expert's previous studies and research hypothesis) and stored in the software memory. In the second stage, considering the depicted mental maps, the map is marked individually where these marks are based on depictions by respondents and are compared by the expert with data from the previous stage. The output is in the form of numerical data according to the level of overlap based on the opinion of the expert. At this stage, the data of each mental map is stored in the software memory, in addition, the information is also stored in the user's folder. All marks entered into the software based on the mental maps are stored as layers in the software memory so a general analysis is provided in addition to the singular analysis of individual maps.

At the end of the analysis process, according to the information provided by the depicted maps, two types of output are presented. 1- an excel file consisting of a table that contains all the analysis in the form of numerical data and 2- analytical maps, that, in addition to singular map analysis, provide a general analysis of all the depicted maps that show which spaces are the basis of individuals' perceptions and also depictions which will be explained in more detail in the following sections.

3.1. AMMA Structure

The mental image of citizens related to the environment is diverse but obtaining a common pattern is of importance in the field of mental maps research. The AMMA software is programmed on this basis to consider landmark points and paths depicted in mental maps as turning points regarding sketch maps analysis as well as examining the mental complexity of individuals. In this regard, this program is based on two main structures: 1- accuracy and 2- complexity of mental maps (Figure 1). The analysis of the precision of mental maps actually focuses on depicted landmarks and paths by respondents and encompasses two factors that is, General Orientation (GO) and Accuracy Place Landmarks (APL).

Mental maps complexity analysis also consists of two factors, that is, General Structure (GS) and Cell Percentage (CP), which assess the degree of individuals' mental complexity based on studies by Appleyard [48], Walsh, Krauss and Reigner [49].

Figure 1. AMMA structure chart.

3.1.1. Accuracy

As previously noted, the landmark points and paths are considered as turning points and anchors of mental maps analysis and a correct evaluation and analysis of these two factors lead to an understanding of how people perceive space. Accordingly, this program aims to extract these two factors appropriately from the sketch maps using suitable tools and solutions. For this purpose, there are two analytical methods in this software; APL and GO.

In APL analysis, it discovers how well the inhabitants refer to the landmarks and the importance of each landmark in urban spaces. For this purpose, initially, within the software environment on the main city map, the prominent points of the area are determined according to the expert's perspective or previous studies (urban planning, architect, psychologist, sociologist, etc.). Then, based on sketch maps, it is determined how many of these landmarks are marked by the inhabitants. Data is scored in this section in terms of percentage. Individual analysis shows the percentage of prominent points and landmarks entered into the software by the expert which the citizens have responded to. Also, general analysis in this section in the form of graphical maps determines the number of overall referrals to each of the landmarks and the significance of these landmarks.

Another important point is that the definition of landmarks in this stage is the responsibility of the expert because the landmark in this section may include the path (the way which residents move along. For example: attractive roads, sidewalks, etc.), district (the section of a city, characterized based on the special feature. For example, university campuses, historical city centres), node (remarkable points which the paths reach together. For example, crowded intersections, plazas, etc.), edge (dividing lines between two surfaces. For example, hedge, seashores, etc.) [16] or in particular points that are required for research. For example, in research that studies the marketing impact on people's perception, key points are supermarkets and shopping centres or in study on thermal comfort, the key points are places where people feel warm [78–80]. Furthermore, regarding social studies on safety, places may be considered that have the most sense of safety and night lighting. In general, the landmark points are entered to the software according to the research conducted by the expert and sketch maps are analysed accordingly.

In GO analysis, the level of citizen referrals to the main paths is determined and the obtained data is calculated by comparisons with the paths determined by the expert. In this section, GO analysis shows the level of referred main paths as percentages. Here, initially, the main paths are entered into the software by the expert, which, according to the expert's perspective, can be based on the path

characteristic such as the width and length or other path features which the expert has used as a basis for research. For example, paths can be identified as main paths by the expert which have the most connectivity previously analysed in the Space Syntax software.

The prominent point regarding this software is that the expert (based on previous studies or on the basis of considered research hypothesis) can identify the locations or paths that are deemed more important by people compared to other paths and points according to the research subject this may be contrary to the expectation of the researcher. Thus, at the end of the software analysis, maps are presented as outputs where all points and paths marked by the respondents are presented as an overlay of all maps which highlight the most prominent and least important spaces in the form of a colour spectrum that may or may not have been predicted by the expert. In this regard, the researcher is able to achieve scientific results based on previous hypothesis and studies or may consider new hypothesis for their research.

3.1.2. Complexity

The complexity of mental maps is one the analysis assessed by the AMMA software. In this assessment, the level of mental complexity of individuals is investigated based on individual characteristics and to this end, two fundamental studies in this field have been utilized for analysis; CP analytical method and the GS method.

In the CP analytical method, the overall drawings (paths and landmarks) are assessed. In order to measure the amount of reflected information in each map, the number of surface units referred to by the respondents are measured. In this method, first implemented by Walsh, Krauss and Reigner [49], initially, a chessboard type grid is placed on the main map of the research and the number of units in the whole domain is labelled S. On the other hand, according to the information given on each map, the number of referred units by the respondent is shown as S1. The ratio of S1 to S represents the percentage of information provided on the map by the respondent, which is shown by the CP index.

Finally, the GS components are examined. This component refers to the complexity of citizens' perception of space. In this section, based on Appleyard's scoreboard [48], the expert accredits scores to mental maps based on depicted characteristics. In this table, Appleyard divides the mental complexity of individuals in two groups of spatial and linear depictions and assigns scores for each of the drawings, as follows.

In regard to Appleyard's valuable studies on citizen's mental maps, which is the basis of scientific studies in this field, this analysis has been proposed as a software option for researchers who tend to compare their research with Appleyard's perspective for comparisons with Appleyard's table according (Figure 2) to mental maps characteristics and to enter their scores in the software's relevant section.

In this software, only the GS index is based on Appleyard's default studies and other software components including APL, GO and CP are entered into the software based on field studies and field observations conducted by the expert. Finally, the software computes three components based on specified points and paths by the expert. GS related data is manually entered in the application environment.

3.2. Environment and Features of AMMA

The AMMA software environment is designed to be very simple and easy to use. In general, the software environment consists of 7 sections, two of which are related to the software input that is, the main area map assessed and the mental map. In fact, the main map and mental maps as inputs should be prepared and imported during running the software. That is, firstly, the main map of the city is entered and then landmarks and paths are identified by an expert on those, afterwards the mental maps are entered respectively, based on which the main map is stacked and saved, then the next map will be inserted and so on. Other sections include Modify Tools, Analyse Option, Result Panel, Export Options, Manual Options (Figure 3). The entry of maps and input data consists of 8 stages, the process of which is described in Figure 4.

Figure 2. Applyard rating chart for assessment of mental complexity in AMMA.

Figure 3. Environment of AMMA and its options.

Figure 4. Process of AMMA to input the maps and data to analyzing. 1&2. The main map of the area is entered, by clicking on the icon Load Map (JPG, TIFF or PNG file). 3. Gridding the map entered in the AMMA by the option "Grid on/off," as well as it is possible to change the grid size through "Grid Size" option. 4. Drawing the districts of the study area on the map as a pen called "Draw Boundary." We can also change the line thickness as much as we want. After drawing the scope, by clicking on the icon Save Image the grids located in the district of the study area are counted and saved. 5. In the main map the landmarks are determined by an option called "Mark Place". To save points in software we click Save Image icon. Then, it is observed that coloured points are disappeared and save to AMMA. 6. Another option called "Mark Orientation" works like "Mark Place" option and enables us to specify the main orientation of the map including the main crossing streets or paths with different colours

(pink). 7. In this step, the citizens' mental map is entered through pressing "Load Mental Map" button to import mental map of responders to begin the analysis process. After entering the citizens' mental maps, we spot the map based on the mental map of citizens through an option called "Fill Grid." 8. In this step, we score the structure of mental maps based on the Appleyard's model, the scoring is manually inserted while there is an icon called GS Guide so that users can score more accurately. 9. Here, respondents' information including age and gender are entered for a more detailed review and analysis of the data. At last the button "save Image" should be pressed to save the data and disappear the information of pervious responder to import new mental map.

The output of AMMA is twofold. Output is in the form of numerical data and analytical maps. In numerical output, which is an Excel file, all the data for mental maps analysis are numerical and categorized by the researcher and through the use of this data, a variety of maps and graphs are produced based on the research subject (Figure 5).

Figure 5. Example of an Excel file of AMMA and the sample of charts that could be stemmed from that.

Software analytical maps also consist of three sections:

1- Analytical maps are specific to each mental map, including mental map image, places referred to according to the main mental map image and finally a table containing numerical data and general characteristics of the individual interviewed. These maps are commonly used for individual analysis and comparison of mental maps (Figure 6).

2- HIST of all analytical maps. In this map, all mental maps are placed on top of one another in the form of various layers and locations that overlap each other and are displayed as a colour spectrum based on the number of overlaps. By using this, it is determined which places are most referenced by citizens and the number of references is also indicated according to the map key (Figure 7).

Figure 6. Analytical maps of each mental map for individual analysis.

Figure 7. Sample of HIST of all analytical maps.

3- HIST of all Places. In this map, all mental maps are placed on one another again but this time, only the places designated as landmarks by the expert are assessed and finally, the number of times these places have been referred to is determined. Through this map, the significance and value of the landmark points entered to the software by the expert is determined (Figure 8).

Figure 8. Sample of HIST of all Places map.

3.3. Validating Experiments

In order to test the validity of the software, it was utilized in a real project related to the urban structure of the Gelal River route in the city of Khorramabad, to assess the validity of AMMA. For this purpose, 30 mental map questionnaires were distributed in three areas as different ages and genders randomly (A, B and C) and each region was divided into two sections (Figure 9). Part A is located in the northern part of the city and covers the area between the Sakhrei and the QUE parks. This area is considered as a recreational area for the leisure time of Khorramabad residents. Part B is located in the central part of the city between the Shohada Bridge and Daraei Bridge and is considered a part of the city's busy and crowded area. Part C is located in the southern part of the city, which is considered as the historical area of Khorramabad. Ghaleh Falak al-Falak, which is 1300 years old, and Safavi Bridge, which is about 300 years old, are located in this area. This section includes the area between Hajji Bridge and Safavid Bridge.

Figure 9. Khorramabad map and the regions in which questionnaires were distributed (Left) and the result of the AMMA from mental maps of residents (Right).

In the mental map questionnaire, people were asked to draw a map of their city including the route of the Gelal River.

Prior to collecting mental maps, in a survey that was conducted separately through 384 questionnaires (as multiple choice questions) in the same three areas, it was shown that in the area named Shohada Bridge located in area B, the highest score was achieved in terms of various indexes (functional, physical, social and environmental). Also, it was shown that from the perspective of women, area C scored the lowest in terms of the four questionnaire components and in contrast, the highest score accredited by women was for area A. Furthermore, the last question of the collected questionnaires was titled: "which part of your neighbourhood would you like to spend more time in?" In area A, from 131 questionnaires, 63.4% stated with "Zibakenar," in area B, from 125 questionnaires, 83.6% responded with "Shohada Bridge" and in area C, from 128 questionnaires, 71% referred to the Ghaleh Falak al-Falak green space, which includes a historic cast.

Thirty mental maps were collected for AMMA testing and analysis, which was done only for software testing; however, interesting results were obtained, some of which are consistent with previous results, including the fact that the Shohada Bridge area was referred to and drawn the most by citizens such that it was the most referenced place within the software (22 times) in the form of a colour spectrum (Cream colour) (Figure 10). It was interesting that 12 women who had drawn their mental maps had referenced area C urban spaces the least and in contrast, most area A drawings were related to the mental maps drawn by women. In addition, based on software results, the three areas of Zibakenar, Shohada Bridge and Ghaleh Falak al-Falak were the most referred to places by citizens with 18 references equally (pink colour). (Figure 11).

Figure 10. HIST of all mental maps of thirty Khorramabad residents that shows 22 responders have drawn the Shohada Bridge area (output of AMMA) (Right) and the location of Shohada bridge in Khorramabad (Left).

Based on these results, it can be deduced that information collected via mental maps in a random manner for a limited statistical society (30 people) solely to test software credibility was consistent with expectations. Additionally, other results were provided including level of citizens' mental complexity, neglected points, landmarks' value and so forth.

Figure 11. HIST of all Places map of Khorramabad residents (output map of AMMA).

4. Discussion and Summary

Based on the outputs and results obtained from the software implementation experience, the software analysis has been validated for scientific research. By utilizing analytical maps along with AMMA numerical outputs provided as Excel files, various analyses and interpretations can be deduced from mental maps such as the results obtained from the case study concerning women's favourite places and the impact of environment quality on the mentality of individuals. These specific features are provided by AMMA, through which mental maps can be processed faster and more accurately according to the research subject.

What is dealt with regarding the analysis of mental maps is the differing drawings from various individuals with various perceptions. Therefore, obtaining common patterns by simplifying and transferring depicted points and paths drawn on the main map and comparing them with one another will aid in suitable analysis. This is possible with the drawing tools available in AMMA.

Drawing tools can accurately transfer perceptual information in the software environment [81–83] and the user is able to easily transfer mental maps in the program environment on to the main drawing map. By utilizing this feature, the issue of turning and marking landmarks using rectangular boxes (which are only located at the perimeter of the landmark and are not flexible in coinciding with the original landmark) is resolved [84]. Also, given that all numerical calculations are based on gridding conducted on the main map, marking could only take place within each grid. Otherwise in the regions on the main map where angles, skews or curves exist, marking could not be achieved on the main map in exact accordance to mental maps (Figure 12). Thus, considering this software feature, calculations are done more accurately. It should also be noted that, although the hexagonal grids, as opposed to square grids, are recommended for calculating the quantitative calculations of the mental maps, and considering the geometric properties [85], this is true when within the grids are supposed to be spotted. However, the spotting in AMMA is graphical and the grids only have a computational role.

Figure 12. Difference between AMMA marking (right) and marking on each grid (left).

Moreover, calculations completed in computational methods such as BDR is based on the calculation of the position of the location drawn by the actual position of the location based on numerical calculations compared to the urban structure in the mind of the citizen. However, in AMMA, by using a much simpler method of transferring respondent drawings to the main map, in addition to landmark locations within the drawn city and based on referred points within the citizen's drawings, calculations take place. In this case, the urban structure drawn by citizens is more tangible and comparable. In fact, it can simply be said that by using the Mark Place and Mark Orientation options the landmarks and main paths consequently can be drawn by the experts on the main map. Then, by inserting mental maps and matching them with the original map (using the Load Mental Map options) the ability to move the ranges drawn on the mental map (including landmarks and paths) can be provided. Mental map information then is implemented on the main map and analysed on the basis of inputs given by the expert to the mental maps. In this case, it is not necessary to enter numerical coordinates of the sign or path (as in the BDR method) and the user only marks the landmarks or paths (based on mental map) on the original map for analysing.

5. Limitations

Despite the benefits of the current technique, AMMA also has limitations. First, AMMA does not examine the feelings people have towards a place. This issue, which was neglected from the outset in mental maps, has always made individual's feelings towards their surroundings unclear when analysing mental maps with individual perception. These feelings may include five senses or a sense of identity that are formed based on the memories individuals have concerning the environment. Nevertheless, next software versions attempts to include information concerning individuals' feelings towards their environment and relevant valuation such as when placing marks on the main map based on mental maps, it will also be possible to determine individuals' feelings towards landmarks by valuation on various levels (from very little to very much) based on the research subject.

Another noteworthy point is that despite the features of AMMA drawing tools, these tools also have limitations including the fact that drawing takes place based on the movement of the mouse. This may entail vibration or unwanted movement, when, for example, a path or location is referred to by many respondents in the final software analysis, which is in the form of various multi-layers of mental maps, the path and landmark edges will be shown as multi-colours and sliced (Figure 13).

Other features that are considered software limitations are the dimensions and image of the original map which should be in a square shape (e.g., 4in*4in) and JPG, TIFF or PNG format. Although, considering that scaling the original map takes place within this program by the user based on grid dimensions and size, there will not be any issues if the mentioned dimensions do not coincide. Furthermore, only the form of the original map will be slightly pulled or condensed because the criterion is the created grids and the percentage that they are filled with.

Figure 13. The landmark with multi-colours and sliced edges.

Grid networking is one of the advantages of AMMA, through which quantitative calculations are carried out and there are no issues concerning scale-matching. As with the Space Syntax software, the grid dimensions are regulated based on the size and dimensions of the map, as well as block size. However, this process may be time consuming since grid matching is based on desired size according to the size and dimensions of city blocks or buildings which results in confusion for the user. Nevertheless, in AMMA grids, it attempts to minimize limitations compared to Space Syntax limitations so that the user is able to use the mouse and tools available to enlarge and shrink the grids thus expediting grid matching.

In some other systems, the grid network is not seen as orderly. In this case, despite the distorted image displayed on the screen, the image within the software is calculated correctly and there are no computational or operational issues, such that only the image on the screen may be seen as irregular. Despite the disadvantages mentioned above, these disadvantages do not affect the analysis of mental maps and the reduction of the credit quality of AMMA and output data is accurately provided to researchers.

6. Conclusions

Mental maps are valuable methods of presenting individuals' perceptions of their surroundings. Despite vast applications in various studies, in the computational and quantitative analysis field, sufficient research has not been conducted. Peoples' perception method assessment known as "image of the city" has been raised from the outset as Lynch's elements but considering that the most common mental maps drawn by people consist of landmarks as a three dimensional image and paths as a two dimensional image from the environment structure, these two factors have been focused on for recent research in order to analyse mental maps.

Even though among computational methods, emphasis has been places on landmarks and landmark position calculations, a quantitative method has been presented in AMMA to assess paths and the main environment structure. The most important section of AMMA regarding mental map accuracy and validity are in the form of APL and GO analysis which assess landmark points and paths forming the main environment structure respectively. These methods are presented as valid evaluating techniques for the accurate analysis of mental maps by researchers. Citizens' mental complexity are also items assessed in AMMA in addition to mental maps analysis via the CP and GS method analysis. The availability of this section along with the main AMMA section have entailed unique results for the

program which provides the means for comprehensive mental maps analysis. As such, AMMA is a modern and credible method for mental maps analysis and it is hoped that this program will be useful for researchers active in the perceptual and environmental studies field due to the features available in this program. In order to increase the efficiency and responsiveness of computer programs they need to be upgraded over different time periods, which is always possible through reprogramming. Accordingly, it can be said that AMMA has the ability to meet the new study requirements in this area through plugins and options that will be considered as the future plans of the AMMA program.

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Article 3. Case study (North part of Retiro Park)

Statement of Contribution to Co-Authored Published Paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

F. Aram, E. Solgi, E. Higuera García, A. Mosavi, & A. R. Várkonyi-Kóczy, "*The cooling effect of large-scale urban parks on surrounding area thermal comfort*," the journal of *Energies*, Volume 12, Issue 20, October 2019. (DOI: 10.3390/en12203904)

The main purpose of this paper is to answer the third sub-objective of the study in the northern side of the Retiro Park; "Investigating and analyzing the range of change in thermal comfort perception (physiologically and psychologically) based on the intensity of the cooling effect of the park at different distances from it".

My contribution to the paper involved: literature review, data analysis, writing and editing the manuscript.

Article

The Cooling Effect of Large-Scale Urban Parks on Surrounding Area Thermal Comfort

Farshid Aram ¹ , Ebrahim Solgi ², Ester Higuera García ¹, Amir Mosavi ^{3,4,5,*} and Annamária R. Várkonyi-Kóczy ^{3,6}

¹ Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid-UPM, 28040 Madrid, Spain

² School of Engineering and Built Environment, Griffith University, Gold Coast 4222, Australia

³ Institute of Automation, Kalman Kando Faculty of Electrical Engineering, Obuda University, 1034 Budapest, Hungary

⁴ Faculty of Health, The Queensland University of Technology, Brisbane, QLD 4059, Australia

⁵ School of Built the Environment, Oxford Brookes University, Oxford OX30BP, UK

⁶ Department of Mathematics and Informatics, J. Selye University, 94501 Komarno, Slovakia

* Correspondence: amir.mosavi@kvk.uni-obuda.hu

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Abstract: This empirical study investigates large urban park cooling effects on the thermal comfort of occupants in the vicinity of the main central park, located in Madrid, Spain. Data were gathered during hot summer days, using mobile observations and a questionnaire. The results showed that the cooling effect of this urban park of 125 ha area at a distance of 150 m could reduce air temperatures by an average of 0.63 °C and 1.28 °C for distances of 380 m and 665 meters from the park. Moreover, the degree of the physiological equivalent temperature (PET) index at a distance of 150 meters from the park is on average 2 °C PET and 2.3 °C PET less compared to distances of 380 m and 665 m, respectively. Considering the distance from the park, the correlation between occupant perceived thermal comfort (PTC) and PET is inverse. That is, augmenting the distance from the park increases PET, while the extent of PTC reduces accordingly. The correlation between these two factors at the nearest and furthest distances from the park is meaningful (p -value < 0.05). The results also showed that large-scale urban parks generally play a significant part in creating a cognitive state of high-perceived thermal comfort spaces for residents.

Keywords: cooling effect; urban park; thermal comfort; physiological equivalent temperature; perceived thermal comfort; urban heat island; air temperature; sustainable cities; smart cities; urban health; global warming; urban green spaces; sustainable urban development; climate change mitigation and adaptation; urban resilience

1. Introduction

Due to climate change and the growing urbanization, the heat in cities is rising rapidly [1,2]. Today, heat has adversely affected urban life across the world [3], including urban areas of the Mediterranean climate [4,5]. The increase in temperature in urban areas, especially densely populated areas has given rise to the phenomenon of urban heat islands (UHI) [6,7], which can threaten the health and comfort of citizens [8,9]. The green urban spaces have been researched by numerous studies as an adaptive strategy to reduce the effect of urban heat and improve the health of citizens, by considering thermal comfort [10,11] as well as their socio-economic role [12]. Various studies have been conducted on the effects of various types of green infrastructures aiming at reducing urban heat and thermal discomfort [13,14], which include different scales and forms such as small local parks [15], large urban parks [16], urban gardens [17], green roofs [18,19], green walls [20,21] and street trees [22,23]. This study emphasizes the cooling effect of large urban parks.

The studies conducted on large urban parks have shown that such parks have a significant effect on air temperature reduction and UHI [24–26], which is especially noticeable during the summer [27,28]. However, it is noteworthy that the temperature drop does not only take place within the park but also surrounding areas [29]. The cooling effect of urban parks, referred to as a park cooling island (PCI) [30], is known to affect the surrounding environment depending on the area of the green space and quality of green coverage [31,32]. Two relevant indices to measure the cooling effect of urban parks are the cooling effect distance (CED) and cooling effect intensity (CEI) [33], which have been extensively used in various scales and climates [34–36].

Studies on the cooling effect of urban parks in different regions have shown that large scale urban parks with areas over 10 ha can have an average of 1 to 2 °C effect on surrounding areas that are an average of 350 meters away [33]. In general, air temperature reductions in urban parks are typically up to 0.5–4 °C and may even cause up to 5–7 °C reduction [37]. Despite the cooling effect of urban parks on their surroundings, such an outcome is not merely dependent on the traits of the green space [38]. The morphology of the surrounding area of parks, the sky view factor (SVF), the spatial configuration of the location, and the covered area, also affect the perception of the cooling effect of urban parks and thermal comfort [37,39].

Numerous studies have been carried out on the cooling effect of urban parks. However, research pertaining to the extent of this effect on thermal comfort perception from psychological and physical perspectives is limited. This gap necessitates examining the cooling effect of urban parks on the aforementioned parameters at different intervals from the park to determine factors that may be applied in sustainable urban development.

2. Park Cooling Effect and Thermal Comfort Perception

A set of thermal indices was investigated in two experimental (effective temp (ET), resultant temp (RT), humid operative temp (HOP), operative temp (OP) and wind chill index (WCI)) and analytical (index of thermal stress (ITS), heat stress index (HIS), effective temp (ET*), stand. effective temp (SET*), out. stand. eff. temp (OUT_SET), predicted mean vote (PMV), perceived temp (PT) and physiological equivalent temperature (PET)) groups [40–43]. The basis of these analytical indices was the energy balance (produced and wasted human energy). The main issue of thermal indices pertains to the average thermal comfort assessment and climate conditions of each area [44]. The result of various studies on validating other indices shows that examples such as SET and PET have a high correlation (89%) with thermal comfort in open spaces [45]. Most studies in recent years have utilized SET, PMV and PET to predict comfort levels in open spaces [46–48].

PET enables the comparison of the full effect of thermal conditions about the outside environment with individual experience [49,50]. PET is one of the recommended indices in urban and regional urban planning around the world, used to predict thermal changes of urban or regional clusters [51]. This index has shown a significant correlation to thermal comfort in various climatic conditions in open urban spaces as validation [52]. One of the prominent influencing factors on PET condition is the T_{mrt} (mean radiant temperature) climate variable. The indices mentioned above provide a single image of a set of individual and climate variables and enable the comparison of comfort conditions in various environments (due to global factors) [53].

In studies conducted to investigate the thermal comfort of urban parks, the PET index is commonly used. In a study conducted on a warm sunny day in Beijing, China (21 August, 2 pm) [54], it was shown that the effect of the Yuan Dynasty Relics green space with 102 ha area, in close approximately to the area of Retiro Park, reduces the PET by an average of 2 °C and a maximum of 15.6 °C. Another study conducted at Zhongshan Park in Shanghai city center with an area of 21.42 ha, showed that the PCI led to thermal comfort during Shanghai's winter as well as summer and had a PET of 15–29 °C [55]. Additionally, a study conducted at the Central Park of Cairo with an area of approximately 26.01 ha [56] showed that parks had a significant effect in enhancing thermal comfort during summer, which, based on this effect, entailed a PET value of 22–30 °C throughout the day.

While the cooling effect of urban parks has generally been recognized as a strategy for mitigating urban heat and providing thermal comfort [57,58], the extent of perceived thermal comfort stemming from the cooling effect of urban parks is difficult to predict, necessitating investigations of people's attitudinal and bodily experiences concerning physical thermal conditions at various intervals in the surrounding areas of these parks [59,60]. The degree of perceived thermal comfort by an occupant, which is caused by the cooling effect of urban parks, is dependent on factors such as individual behavioral and psychological traits, in addition to distance and cooling effect intensity [61–63]. Individual demographic traits include age, gender, and physical characteristics such as height and weight of occupants [64,65]. Psychological traits include the individual's experience of being in the environment and their thermal expectations and tolerance [66,67]. Behavioral aspects include the extent of being covered (in terms of clothes) and the type of activities conducted by the individual [68].

A common method to determine the extent of thermal comfort experienced by occupants is the use of surveys [69]. Essentially, by using such survey methods as open, semi-open, or multiple-choice questions [70], individuals can be asked about their thermal comfort experiences [71]. In order to measure the human thermal comfort perception level, cognitive mapping can be utilized in combination with questionnaires. Employing this method and asking residents to identify places where they feel more comfortable from a thermal point of view provided a more comprehensible image of the residents' thermal comfort level for understanding [72,73]. In recent years, utilizing questionnaires and asking direct questions about the perceived comfort of citizens alongside micro-climatic perceptions have yielded valuable results [74].

Many studies have been conducted on the cooling effect of urban parks, particularly their CEI and CED effects. However, less research has been carried out on the thermal comfort of this effect at different distances from the park. Additionally, few studies on the cooling effect of urban parks on thermal comfort have mainly investigated through physiological indices. As both psychological and physical perspectives together provide the complete concept of thermal comfort, it, therefore, necessitates examining the extent of thermal comfort created by urban green spaces from either perspective.

The purpose of this study is to investigate the cooling effect of the large urban park and its effect on the thermal comfort of occupants in the areas around the park. This study focuses on the perceived thermal comfort (PTC) and physiological equivalent temperature (PET) of locations, at a defined distance from the park and similar in terms of urban aspects and influential factors such as floor coverings, enclosures, street canyon and vegetation, whilst responding to the following research questions:

- What is the extent of the large urban park cooling effect on thermal comfort based on PET?
- What is the extent of the large urban park cooling effect on occupants' PTC?
- What is the relationship between the measured PTC and the measured occupant PET?

3. Materials and Methods

3.1. Location and Selection of the Sites

This research was located in Madrid (40°25'08" N; 3°41'31" O), the capital of Spain with a population of 3,223,334 and population density of 5265.91 /km², and a hot-summer Mediterranean climate (Csa) according to the Köppen classification [75]. The average annual temperature in downtown Madrid is 19.9 °C during the day and 10.1 °C at night. The warmest month of the year is July, with an average temperature of 32.1 °C during the day. Then August, June and September are the hottest months with average daily temperatures of 31.3 °C, 38.2 °C and 26.4 °C, respectively [76]. Retiro Park has an area of approximately 125 ha. It is the largest and oldest park in the center of Madrid with rich plant diversity. One of the prominent issues of this study was the method of selecting distances from Retiro Park. Although studies have not been conducted on the average cooling effect of Retiro Park, an updated UHI map of Madrid was presented in 2015 by Núñez Peiró et al. [77], where the effect of Retiro Park was made evident based on the temperature color spectrum. Essentially, the UHI map of

Madrid from 26 July 2015 represents the effect of Retiro Park in counteracting to the effect of UHI in the northern, eastern and southern areas of the park [78].

In order to accurately assess the cooling effect of Retiro Park on its surrounding areas, it was necessary to select places on a micro-scale with common features that are located at various distances from the park. The northern area of Retiro Park, due to its well-organized form, has more regular urban-type compared to other areas (east and south). Based on the temperature zones of the updated thermal map of Madrid's urban heat islands in 2015 [79], three street crossings (intersections) located in the Salamanca and Recoletos neighborhoods in the north of Retiro Park along the Lagasca Street, were chosen. These sites were located at 150 meters, 380 meters and 665 meters from the park at Lagasca intersection with the Conde de Aranda, Jorge Juan and Hermosilla streets, giving zones of different temperature ranges (yellow, orange and red; Figure 1). These types of selected local intersections represent most of Retiro Park's northern area intersections (Figure 2). Based on this map [77,79], each of the three intersections A, B and C had a temperature difference of about $0.8\text{ }^{\circ}\text{C}$.

Figure 1. Madrid's urban heat island (UHI) map on 26 July 2015 [77,79] and the selected northern region of the Retiro Park. Intersection A is in the yellow zone, intersection B is in the orange zone and intersection C is in the red zone, close to one of the UHIs of Madrid.

Figure 2. The northern region map of Retiro Park and the location of the selected sites. Point A is located 150 meters away from the park; point B is located 380 meters away from the park and point C is located 665 m away from the park.

All three assessed intersections were selected based on a common geometric configuration. The considered geometric configuration included an enclosure, sky view factor (SVF), and street height and width (Figure 3, Table 1). The considered material structure included the ground surface coverage material, pavement material and building facade material, which were similar in all three regions; the ground surface material in all three regions was asphalt; the pavement material was gray tiles and the building material is mostly red-colored bricks and bright cement (Figure 3). The presence of green spaces in the street canyon was highly significant in terms of micro-climatic issues [80]. In this regard, vegetation was also considered as well as the aforementioned parameters (Table 1), so the selected regions were also similar in terms of this parameter (Figure 3).

Figure 3. Street view of the three intersections (A–C) as well as fisheye shots.

Table 1. The geometric configuration of the intersections and street trees properties in three investigated intersections.

Part	Street Canyons					Street Trees			
	Width N_S (M)	Width W_E (M)	H/W Ratio N_S (–)	H/W Ratio W_E (–)	SVF ^a	Number of trees	Mean Tree Height (m)	Mean Crown Diameter (m)	Crown Shape ^b
A	15	12	1.23	1.54	0.17	26	12.74	5	Cone
B	15	15	1.28	1.33	0.2	30	12.34	6	Cone
C	15	15	1.2	1.23	0.2	25	12.66	5	Cone

a. Calculated by Ray Man 1.2; b. Crown Shape Classification by Park et al. [15].

There were two priorities in selecting the intersections. Firstly, the points were selected according to Madrid's UHI map (Figure 1) where the distances were of different temperature ranges, and secondly, locations were selected that shared the greatest similarity in terms of physical and structural traits. In this vein, three sites A, B and C were selected to extract data, in accordance with the goals of this study.

3.2. Microclimate Parameter Measurements

Micro-climatic measurements were conducted during six days in hot summer, on 22 June, 10 and 24 of July, 10 and 24 August and 10 September 2018. Data extraction started from 22 June and was spaced at roughly every two weeks, targeting sunny and calm days (no clouds) up to the end of summer (10 September). T_a and relative humidity (RH) were collected during the six days, were measured by mobile microclimate stations (HOBO MX2301A Temperature/RH Data Logger, manufactured by Onset Computer Corporation, MA, USA) with precision T_a ; ± 0.2 °C and RH; $\pm 2.5\%$ between 10:40 and 12:10 CEST (Central European Summer Time). The data was collected at one-minute intervals, and the weather data collection duration at each location was 10 minutes (Table 2).

Table 2. Intersection mean values for air temperature (T_a), relative humidity (RH) and wind speed (WS) on all measurement days (10:40–12:10 CEST).

Date	Part	Time	Mean T_a , °C	Mean RH %	Mean WS, m/s
22 June	C	10:40–10:50	29.26	29.1	1.43
	B	11:00–11:10	28.87	29.27	1.15
	A	11:30–11:40	27.81	32.04	0.80
10 July	C	11:15–11:25	29.8	33.96	1.43
	B	11:42–11:52	29.7	22.1	1.16
	A	12:00–12:10	29.4	29.71	1.36
24 July	C	10:40–10:50	29.45	21.71	1.36
	B	11:10–11:20	28.1	30.25	1.43
	A	11:30–11:40	27.74	30.56	1.43
10 August	C	10:40–10:50	25.12	18.16	1.43
	B	11:00–11:10	23.77	41.05	1.72
	A	11:20–11:30	23.22	43.45	2.47
24 August	C	10:50–11:00	26.63	38.81	2.35
	B	11:15–11:25	26.2	38.13	1.13
	A	11:35–11:45	26.05	37	1.29
10 September	C	10:45–10:55	23.41	56.71	1.5
	B	11:15–11:25	23.13	52.45	1.36
	A	11:35–11:45	21.73	51.15	1.91

The devices were placed 1.5 meters from the ground and covered by a radiation shield. The wind speed (WS) was determined by a Proster Digital Anemometer MS6252a placed at the same distance. The type of ground coverings, walls and types of and distance to vegetation that affect the temperature conditions were checked according to field studies; high-resolution images were taken by a Canon Eos 600D, 5184 pixels $\times$ 3456 pixels digital camera. Aerial images were taken from Google Earth, 2018–2019. Fisheye images were taken at three intersections using a fisheye (Sigma 8 mm circular) lens. Additionally, the weather data of Retiro Park were collected via the AEMET (Agencia Estatal de Meteorología) fixed station [76] located inside the park. These parameters were previously identified to show the effect of urban parks on thermal comfort [54].

3.3. The Questionnaire Survey

A random semi-structured survey was conducted on 145 pedestrians (nA: 49, nB: 45 and nC: 51) at intersections where microclimatic data were collected (workplace and residential). The interviewees comprised different gender and age groups (with the exception of children), and were active at different levels. Table 3 shows detailed information on the number and characteristics of individuals, on different days and intersections.

Data extraction from the surveys took place during the period of determining micro-climatic parameters at three intersections A, B and C (more and less than 10 minutes). Questions were divided into three sections.

The second section comprised four questions about the degree of thermal comfort perception during the interview. The questions were short and designed as five options (very high = 5 to very low = 1). Research questions concerning the level of individual thermal comfort included: (Q1) How much thermal comfort do you feel? (not too hot, not too cold); (Q2) How warm do you feel? (Q3) What is the extent of thermal comfort perceived through Retiro Park? (Q4) How much heat can you tolerate in this location?

The third section included open personal questions such as gender, height, weight, level of activity and type of clothing.

Table 3. The proportional percentages questionnaire data in the three investigated intersections on all the measured days.

Variable	Categories	Percentage (%)		
		A	B	C
Age	13–21	2.0	2.2	11.8
	22–30	26.5	20.0	13.7
	31–45	40.8	26.7	31.4
	46–60	16.3	24.4	29.4
	61–85	14.3	26.7	13.7
Gender	Men	67.3	73.3	51
	Women	32.7	26.7	49
Q1	Very low (1)	0	0	0
	Low (2)	10.2	6.7	9.8
	Medium (3)	28.6	57.8	43.1
	High (4)	42.9	31.1	35.3
	Very high (5)	18.4	4.4	11.8
Q2	Very low (5)	5.9	4.4	0
	Low (4)	23.5	31.1	18.4
	Medium (3)	33.3	26.7	22.4
	High (2)	27.5	28.9	38.8
	Very high (1)	9.8	8.9	20.4
Q3	Very low (1)	4.1	2.2	13.7
	Low (2)	8.2	20.0	25.5
	Medium (3)	28.6	31.1	27.5
	High (4)	42.9	31.1	25.5
	Very high (5)	16.3	15.6	7.8
Q4	Very low (1)	2.0	0	3.9
	Low (2)	10.2	15.6	25.5
	Medium (3)	30.6	60.0	35.3
	High (4)	42.9	13.3	23.5
	Very high (5)	2.0	0	3.9

Essentially, the questionnaire questions were designed so that in a short period (10 minutes), pedestrians in the neighborhood of different age and gender groups could be interviewed to extract information about their level of perceived thermal comfort (Figure 4). The total score from the questions is presented as an indicator of the perceived thermal comfort (PTC). However, the inquiry of PTC was ambiguous for occupants, so this question was addressed by asking how comfortable do you feel in terms of temperature (not too hot not too cold)? For the second inquiry, the question that was also directly asked was how much heat do you feel? Therefore, data relevant to this question was considered in reverse form to determine the perceived thermal comfort index (very high = 1 to very low = 5). It should be noted that in order to accurately derive the research data, prior to the start of summer on 22 May, 18 experimental micro-climatic data and questionnaires (six questionnaires at each intersection) were compiled (10 minutes at each intersection) in order to address the issues and queries of questionnaire gaps and to identify bio-climatic notions amidst the main questionnaire compilation stage.

3.4. Analyzing the Thermal Comfort Parameters

3.4.1. Physiological Parameters

In order to analyze thermal comfort and derive PET, the relevant parameters should be calculated. The calculation of parameters for PET assessment includes clo, level of activity, SVF and T_{mrt} . In this study, Ray Man 1.2 [81,82] software was used to derive SVF, T_{mrt} and PET. The calculation of clo, which pertains to the extent of being covered for an individual, was based on its computational indices [83]. Given that each clothing item has its own index, the clo for each person was based on the collected data. The greatest extent of clothing coverage for participants was a T-shirt with trousers (34%), shirt with trousers (25.4%) and the least was shorts with a t-shirt (22.6%), which were of 61 clo, 65 clo and 40 clo,

respectively. Determination of activity levels was based on individual activity in the environment. Every activity had an indicator, walking 115 W/m^2 , sitting 60 W/m^2 , standing 70 W/m^2 , and fast walking 220 W/m^2 [84] (Table 4).

Figure 4. The average frequency of questionnaire data (Questions 1–4) at three intersections. Intersection A is gray, intersection B is orange and intersection C is blue.

Table 4. Clothing and activity level of responders in the three investigated intersections.

Variable	Percentage (%)														
	Hot Summer Days														
	22 June			10 July			24 July			10 August			24 August		
	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3
<i>Clothing</i>															
Shirt and Normal Pants - 65 clo	40	40	33.3	44.4	33.3	25	30	33.3	10	0	20	0	0	16.6	28.5
Tshirt and normal pants - 61 clo	20	20	33.3	22.2	22.2	37.5	30	44.4	50	30	40	50	33.3	16.6	57.1
shirt and Shorts - 45 clo	0	0	0	11.1	0	0	10	0	0	10	10	0	16.6	16.6	0
Tshirt and Shorts (or skirt) - 40 clo	40	20	16.6	11.1	33.3	0	20	22.2	20	50	10	40	50	33.3	14.3
Dress - 35 clo	0	0	0	11.1	11.1	12.5	10	0	10	10	10	0	0	0	0
Suilet - 90 clo	0	0	16.6	0	0	12.5	0	0	10	0	10	10	0	16.6	0
Others	0	20	0	0	0	12.5	0	0	0	10	0	0	0	0	0
<i>Activity</i>															
Wiking - 115 W/m^2	60	10	66.6	55.5	77.8	50	40	44.4	60	30	50	80	50	66.6	57.1
Standing - 70 W/m^2	20	0	16.6	44.4	22.2	12.5	50	44.4	20	40	30	10	16.6	33.3	14.3
Sitting - 60 W/m^2	20	0	16.6	0	0	37.5	10	0	20	30	20	10	33.3	0	28.5
Jogging - 220 W/m^2	0	0	0	0	0	0	0	11.1	0	0	0	0	0	0	0

SVF calculation was conducted by importing fisheye images in the RayMan software, and 3D simulation of spatial geometry and environment vegetation in the Obstacle section of the software. The SVF index is one of the effective parameters in deriving the thermal comfort of the environment [85].

The PET index was considered a vital indicator in studying thermal comfort and has been used in numerous studies as a reliable indicator in deriving the thermal comfort of the external environment [46]. T_{mrt} and PET were derived based on extracted micro-climatic data (Table 5), and SVF data derived via the Ray Man software (Table 1).

3.4.2. Psychological Parameters

SPSS software was utilized, according to the statistical data obtained from the questionnaire to examine the significance of the data in three selected intersections, and also to examine the significance of the relationships between various indices with PTC [86,87]. In order to examine cognitive maps more accurately, AramMMA software was used [88]. In this program, all the cognitive maps were overlapped, and then according to the color spectrum, it determined which locations had the most point of reference (Figure 5). Each color represents the number of pointing a location (for example red means one time or purple means 12 times). In order to convert the qualitative data of cognitive maps into quantitative data, inside the AramMMA software, the Retiro area was rated, so that 100 percent of the score was dedicated to the maps that noted parks, while zero percent was considered for those that

did not mention to the park. By using the cognitive map analyses, the importance of park cooling effect on resident psychological thermal comfort in different parts of the Retiro Park was represented.

Table 5. Values of the T_{mrt} ($^{\circ}\text{C}$) and average values for physiological equivalent temperature (PET ; $^{\circ}\text{C}$) in part A, B and C.

Date	Part	Mean PET , $^{\circ}\text{C}$	T_{mrt} , $^{\circ}\text{C}$
22 June	C	35.3	48.4
	B	35.8	48.7
	A	33.7	48
10 July	C	36.3	49.4
	B	36.5	49.3
	A	35.8	49.3
24 July	C	35.7	49
	B	33.9	47.7
	A	33.5	47.6
10 August	C	28.9	43.8
	B	26.8	43.1
	A	24.3	42.7
24 August	C	29.1	44.4
	B	28.6	44.5
	A	26.9	44.3
10 September	C	26.1	40.6
	B	26.2	41
	A	23.1	39.8

Figure 5. Cognitive map analyses using the AramMMA software [88] during six hot summer days of 2018.

4. Results

Data was gathered during six days in hot summer, on 22 June, 10 and 24 July, 10 and 24 August and 10 September at three different intersections at different distances from the northern area of Retiro Park (Table 2). The selected data collection time interval was generally between 10:40 and 12:10 CEST (the exact time of each intersection is given in Table 2). This time was chosen since it was between the maximum and minimum temperatures in the park, so the temperature data extracted at points A, B and C were close to the average park temperature (mid-temperature taken by the AEMET weather station [76] on the data extraction days; Table 6). Based on Figure 6, the temperature range for points A, B and C (gray rectangle) was between the maximum and minimum extracted park temperature (linear range). It is noteworthy that among the three areas, the average temperature of point A was closer to the average temperature of the park (mid-temperature; Table 6) compared to the other points. AEMET data showed that the lowest and highest temperatures pertaining to the data extraction days in the Retiro Park were related to the 4:50–6:00 and 13:40–14:40 CEST timeframes.

Table 6. Mean values for air temperature (T_a), in the three intersection (10:40–12:10 CET) and values for air temperature (T_a), relative humidity (RH) and wind velocity (W) in the Retiro Park on all the measurement days.

Date	T_a °C			Retiro Park ^b T_a °C			Time of T_a in Retiro Park ^b		HR % Park ^b	Wind in Park ^b
	Part A	Part B	Part C	Min	Mid	Max	Min	Max		
22 June 2018	27.81	28.87	29.26	21.6	27.7	33.8	04:50	14:40	22.95	1.7
10 July 2018	29.4	29.7	29.8	21.5	28.4	35.2	06:00	13:50	22.95	2.2
24 July 2018	27.74	28.1	29.45	19.8	26.4	33.0	05:00	13:50	22.94	1.9
10 August 2018	23.22	23.77	25.12	17.5	24.4	31.3	05:40	13:40	36.8	2.2
24 August 2018	26.05	26.2	26.63	20.6	26.8	33.0	05:30	14:20	19.25	1.4
10 September 2018	21.73	23.13	23.41	17.3	22.8	28.3	05:20	13:45	33.55	1.9

a. Field measurement, b. AEMET data.

Figure 6. The diagram shows the temperature range of the three intersections A, B and C measured and the temperature range of Retiro Park during the six days of hot summer 2018 in Madrid.

Gray rectangles: Temperature range at three intersections (bottom side: T_a A, top Side: T_a C).

Linear range: The temperature range of the park is based on AEMET (bottom line: T_a mid of park, top line: T_a Max of the park).

The mean T_a for points A, B and C are 25.99 °C, 26.62 °C and 27.27 °C, respectively. The T_a difference over the measurement days between distance of 150 m (A) and 380 m (B) from the park was about 0.63 °C, between B and C (distance of 665 m) was about 0.65 °C and for the difference between A and C, the temperature difference was about 1.28 °C. According to the results, as the distance from the park increases, the temperature and its difference with areas closer to the park will be greater.

4.1. Assessment of the Park's Cooling Effecting on Thermal Comfort Indices

In this section, PET data and questionnaire results were used to assess the cooling effect of Retiro Park on thermal comfort. PET data are derived based on the indices standard and the perceived thermal effect is obtained based on the average questionnaire and cognitive maps data. By using both these data, the extent of thermal comfort originating from the Retiro Park cooling effect at distances A, B and C could be deduced as physiological and psychological points of view.

4.1.1. Comparison of the Park Cooling Effect Significance on PET at Different Distances from the Park

In a more accurate analysis using SPSS software, a one-way ANOVA was used to analyze the relationship between distances A, B and C from the park and the relevant PET differences. Upon every variance analysis and in the case of significant mean difference (the significant level of a p -value less than 0.05), Tukey test, which is a series of post-hoc tests, were used to accurately determine which of the average of a variable has a significant difference [89]. Essentially, by using this test, the thermal comfort relationship was deduced based on the PET index, which was obtained using the Ray Man software on distances A, B and C.

The results of the ANOVA test (Table 7) show that concerning the PET index, there was a lower significant error rate (0.05) and 95% confidence level of a significant difference between average PET data in each of the A, B and C points (p -value = 0.029). Therefore, Tukey's post-hoc tests were used to determine whether there is a significant difference between each of the A, B and C intersections.

Table 7. ANOVA PET analyses in the three investigated selected points.

	Sum of Squares	df	Mean Square	F	p -Value
Between Groups	151.731	2	75.865	3.645	0.029
Within Groups	2955.708	142	20.815		
Total	3107.439	144			

The results of this studied grouping test are presented in Table 8. According to this table, it can be stated that there was a significant relationship between the mean PET index at points A and C but the mean PET index between point B with points A and C did not entail a significant difference. The mean PET for A, B and C was 29.3 °C, 31.3 °C and 31.6 °C, respectively. Essentially, it can be stated that the PET index difference among intersections A and C was explicit and significant (p -value = 0.036). The mean of this index in A had a difference of 2.3 °C with C, while the difference between A with B was about 2 °C, which was not considered significant in terms of the Tukey test (p -value = 0.09).

4.1.2. Comparison of the Significance of the Questionnaire Dataset PTC at Different Distances from the Park

In order to compare the significance of the PTC at different distances from the park, the mean dataset extracted from the questionnaire for each section was derived as the PTC. The questions answered by citizens via the questionnaire were about how they felt about the ambient temperature and the effect of Retiro Park on such feelings in the form of four questions (Table 3).

Table 8. Tukey PET analyses in the three investigated intersections (A, B and C).

(I) Part	(J) Part	Mean Difference (I–J)	Std. Error	p-Value	95% Confidence Interval		Part	N	Subset for alpha = 0.05	
					Lower Bound	Upper Bound			1	2
A	B	−1.99624	0.94199	0.090	−4.2274	0.2349	A	49	29.3327	
	C	−2.28303 *	0.91265	0.036	−4.4447	−0.1214	B	45	31.3289	31.3289
B	A	1.99624	0.94199	0.090	−0.2349	4.2274	C	51		31.6157
	C	−0.28680	0.93311	0.949	−2.4969	1.9233				
C	A	2.28303 [†]	0.91265	0.036	0.1214	4.4447	Sig.		0.084	0.949
	B	0.28680	0.93311	0.949	−1.9233	2.4969				

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

Based on the results of the ANOVA statistical test (Table 9) and a lower significance error level (p -value < 0.05), there was 95% confidence pertaining to a significant difference between mean thermal comfort index (PTC) in each of the A, B and C regions (p -value = 0.032). Thus, Tukey's post-hoc test was used to determine the significant difference between each of the intersections.

Table 9. ANOVA perceived thermal comfort (PTC) analyses in the three investigated selected points.

	Sum of Squares	df	Mean Square	F	p-Value
Between Groups	2.318	2	1.159	3.517	0.032
Within Groups	46.809	142	0.330		
Total	49.128	144			

Since the rating of questions was from very low to very high in the form of numbers 1 to 5, Table 10 shows that the average of the total questions during the 6 days for A, B and C was approximately 3.3, 2.9 and 2.8, such that area A was of the highest share indicating more thermal comfort experienced by people in this area. In interpreting the table above, it can be stated that there was a significant difference between the mean PTC index at points A and C (p -value < 0.05), but the mean PTC at point B with points A and C had no significant difference. Based on this relationship, it is also clear that with an increase in distance from the green area, the perceived comfort experienced by citizens was reduced; thus there was an inverse correlation between increased distance and PTC.

Table 10. Tukey PTC analyses in the three investigated intersections (A, B and C).

(I) Part	(J) Part	Mean Difference (I–J)	Std. Error	p-Value	95% Confidence Interval		Part	N	Subset for alpha = 0.05	
					Lower Bound	Upper Bound			1	2
A	B	0.35417	0.14270	0.062	−0.0165	0.7248	C	51	2.8417	
	C	0.45000 *	0.14270	0.017	0.0793	0.8207	B	45	2.9375	2.9375
B	A	−0.35417	0.14270	0.062	−0.7248	0.0165	A	49		3.2917
	C	0.09583	0.14270	0.783	−0.2748	0.4665				
C	A	−0.45000 [†]	0.14270	0.017	−0.8207	−0.0793	Sig.		0.783	0.062
	B	−0.09583	0.14270	0.783	−0.4665	0.2748				

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

4.1.3. Comparing the Cognitive Maps Significance at Different Distances from the Park

The meaningfulness of the cognitive maps data with the distance from the park was evaluated using the ANOVA test. The analysis of this section was performed by using a AramMMA software for analyzing cognitive maps. In this analysis, the maps pointing to the Retiro park were distinguished from maps that did not mention the park. In fact, 100 percent of the score was dedicated to the maps noting parks, while zero percent was considered for those that did not mention to the park. The result of the ANOVA test (Table 11) illustrated that there was an acceptable agreement (95%) between the correlation of cognitive maps and the distance from the park (p -value < 0.05).

Table 11. ANOVA cognitive maps analyses in the three investigated selected points.

	Sum of Squares	df	Mean Square	F	p-Value
Between Groups	36,309.751	2	18,154.876	8.948	0.000
Within Groups	288,104.042	142	2028.902		
Total	324,413.793	144			

Owing to the agreement, in each of the A, B and C regions the Tukey test was used separately, and the results were as follows. As illustrated (Table 12), 87.7%, 60% and 50.9% of the respondents in the A, B and C areas, respectively, referred to the park. As expected, the highest level of cognitive mapping from the park is in the vicinity of the park area (150 to 380 meters). Nevertheless, in the C region, with 665 meters distance from the park, more than half of the respondents claimed that the site was comfortable thermally thus preferring to spend more time there. The difference between A and C was also meaningful (p -value = 0.000). The good agreement of this relationship depicts the impact of the Retiro park (as a place with a high level of thermal comfort) on the resident's mental images and psychological dimensions.

Table 12. Tukey cognitive maps analyses in the three investigated intersections (A, B and C).

(I) Part	(J) Part	Mean Difference (I-J)	Std. Error	p-Value	95% Confidence Interval		Part	N	Subset for alpha = 0.05	
					Lower Bound	Upper Bound			1	2
A	B	27.75510 *	9.30015	0.009	5.7273	49.7829	C	51	50.9804	
	C	36.77471 *	9.01047	0.000	15.4330	58.1164	B	45	60.0000	
B	A	-27.75510 *	9.30015	0.009	-49.7829	-5.7273	A	49		87.7551
	C	9.01961	9.21244	0.591	-12.8005	30.8397				
C	A	-36.77471 *	9.01047	0.000	-58.1164	-15.4330	Sig.		0.589	1.000
	B	-9.01961	9.21244	0.591	-30.8397	12.8005				

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

4.1.4. Comparison of the Significance of the Questionnaire Dataset PTC with PET

For a closer assessment of the effect of Retiro Park on thermal comfort, the PET index and PTC by citizens were compared on the basis of the total data extracted from the questionnaire. Mainly, this PET analysis, which is a standard index for perceived thermal comfort, was compared with the personal opinion of people about their perceptions concerning the thermal comfort of the environment. SPSS software was used to assess the correlation test as well as other statistical tests.

Based on the results of the Pearson correlation test (Table 13), the relationship between the PET index with thermal comfort in the selected points of A and C was significant (p -value < 0.05) and was of inverse correlation (-0.404 and -0.379). Due to the medium correlation coefficient (medium = -0.3 to -0.5) [90–92], the relationship between the PET index and the PTC in area A (p -value = 0.004) was more significant than that of area C (p -value = 0.006). Moreover, the significance of PET index relationship with perceived thermal comfort in area B (p -value = 0.061) was not accepted (p -value > 0.05).

Table 13. Pearson correlation analyses between PET and PTC.

		Part	PET
A	PTC	Pearson Correlation	-0.404 *
		p -value (2-tailed)	0.004
		N	49
B	PTC	Pearson Correlation	-0.281
		p -value (2-tailed)	0.061
		N	45
C	PTC	Pearson Correlation	-0.379 *
		p -value (2-tailed)	0.006
		N	51

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

4.2. Relations Between Thermal Comfort Indices (Physiological and Psychological)

Regarding the results, by increasing the distance from the park at intersections B and C, despite physical and structural similarities to the intersection the A, there was an increase in air temperature (T_a), and consequently, the extent of PET and T_{mrt} also changed accordingly.

The data pertaining to the perceived thermal comfort (PTC) acquired from the questionnaire was rated from 1 to 5 (1 = very low to 5 = very high) and at points A, B and C during six days were on average approximately 3.3, 2.9 and 2.8, respectively (Table 10). At point A, residents experienced higher thermal comfort compared to the other points. Essentially, the level of PTC at this location was medium to high according to citizens' opinions (medium = 3), whereas for B and C, the average perceived thermal comfort for the data extraction days was lower than medium. Furthermore, the results show that the extent of PTC at intersection A was more significant in all the days (Figure 7). It is noteworthy that based on statistical data, the perceived thermal comfort was correlated to PET and was of inverse correlation, such that its graph behavior was inversely correlated with the PET graph (Figures 7 and 8). For example, on 10th August, where the PET value was at a minimum at point A (PET 24.3 °C), the relevant perceived thermal comfort was at a maximum (3.6) or on 10th July, at point C, the PET was 36.3 °C, which was higher compared to other points and days which was inversed in the perceived thermal comfort graph and the least value of this index was at point C with a value of 2.4. In addition to the similar behaviors of PET, T_{mrt} , T_a and PTC parameters at each intersection during the six days of assessment (Figures 7 and 8), the credibility of the data and calculations conducted in this study were approved.

Figure 7. The average data for questionnaire data titled PTC at each three intersections A, B and C during six days.

Figure 8. The relationship among mean PET (gray), mean T_a (blue) and T_{mrt} (orange), at each three intersections A, B and C during six days.

Based on the results, it can be said that Retiro Park played an essential role in providing thermal comfort to the citizens during the summer days in downtown Madrid, which was physically and psychologically debatable. As mentioned, Madrid has a Mediterranean climate that is characterized by hot summers. Studies in the Mediterranean climate have shown how urban green spaces can reduce the impact of urban heat [93,94]. A study carried out in Greece, Athens [95], found that the urban park on the western margin of Athens during the hot summer days could reduce daytime air temperature between 0.2 °C and 2.6 °C. In a similar study conducted in Lisbon, another Mediterranean city during the six days of summer 2007 and 2008 [96], the results showed that a 0.24 ha urban park was able to reduce the air temperature inside the park to 6.9 °C compared to its surrounding air temperatures. These studies and the studies mentioned in the first part of the article indicate that large-scale parks affect their surroundings through cooling down their environment. This is significant for Retiro Park due to its variety of vegetation and vegetation density compared to previous studies. The cooling effect of the park can cool over a distance of 350 m in its northern part, with a dense and regular texture, between 0.06 and 1.28 °C compared to the 655 m range near Heat Island.

As noted earlier, little is known about the cooling effect of urban parks on thermal comfort, and most of the studies have focused on the CED and CEI levels. However, in the Mediterranean areas, a study was carried out in Israel investigating the thermal comfort of urban parks using the PET index.

In this study conducted by Cohen, Potchter and Matzarakis [97], a total of 10 urban parks of various areas (0.2 to 0.36 ha) were assessed in Tel Aviv. Although the investigated parks were smaller in terms of area compared to Retiro Park, the results illustrated that parks with richer vegetation density had greater cooling effects and thermal comfort, and could reduce temperatures by up to 3.8 °C whilst bringing PET to 18 °C during hot summer.

This study proved how important this is in areas with hot summers. However, in this study and other studies on the thermal comfort of large urban parks, less attention was paid to the thermal comfort from a psychological point of view. In this study, in addition to assessing CED and CEI of a park and thermal comfort from the physiological point of view (PET), mental thermal comfort through questionnaires (PTC) and cognitive maps were also investigated. Based on the results, the significance of both PTC and PET indices was confirmed. The two indices were inversely correlated, and when the cooling effect was reduced by the distance from the park, the PET rate increased and the PTC level decreased, which indicates the impact of the cooling effect of the large urban park on the thermal comfort from both psychological and physical perspectives.

In this regard, the role of large urban parks was tangible in providing thermal comfort for citizens and it is necessary to pay more attention to various levels of urban planning and sustainable development.

5. Conclusions

This study examined the potential of large urban parks in providing thermal comfort for citizens living within the park perimeter. The results extracted amidst six hot summer days in Madrid show that large urban parks exhibit a cooling effect. Considering the significance of the mean T_a difference between the distance of 150 m and 665 m from the park (p -value < 0/05), as well as the lower temperature of about 1.28 °C pertaining to the distance closest to the park compared to distances further away from the park (under equal conditions), in addition to the insignificant mean T_a difference at the distance of 380 m compared to 150 m and 665 m (p -value > 0/05), we found that the cooling effect of the large urban park at distances close to the park (under 380 meters) had a significant role in temperature reduction.

Accordingly, the level of PET would increase as the distance from the park increased, and residents would perceive less thermal comfort compared to distances closer to the park. The degree of PET index at a distance of 150 meters from the park was on average 2 °C PET and 2.3 °C PET less compared to distances of 380 meters and 665 meters respectively. The PTC of citizens was acquired based on the average obtained data from the questionnaire, which showed that people in the vicinity of the park experienced more thermal comfort. For the other two regions of the park, which were more distant, less thermal comfort was experienced (less than average).

The results of the cognitive maps analyses demonstrated that large parks played a significant role in thermal comfort improvement affecting people's mental map. For people, such parks are a space where they feel more comfortable, thereby spending more time to enjoy the desirable temperature. Although the resultant mental maps were closer to residents in the vicinity of parks, the results demonstrated that at long distances to the park (665 meters) those locations still had a psychological dimension in offering thermal comfort (more than 50%).

PET and PTC as the main variables of this research were inversely correlated such that when the distance from the park was increased, the PET was increased and thermal comfort was decreased. The correlation between the two indices was significant in the nearest and furthest distance from the park (p -value < 0.05) and the highest correlation coefficient of the two indices pertains to the distance closest to the park (150 meters). Essentially, this indicates the high level of perceived thermal comfort from the citizens' point of view as well as the PET compared to distant locations.

As a result, the cooling effect of a large urban park was a suitable solution to improve people's thermal comfort (as physiological and psychological perspectives) either within the park area or in the vicinity of the park. The results of this study clarified that in areas close to the park, such an effect on thermal comfort is more perceptible. Thus, in order to enhance the cooling effect of large urban parks, it is necessary to implement urban design and planning solutions (qualitative and quantitative) to provide more favorable conditions for the lives of citizens.

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Article 4. Case study (West part of Retiro Park)

Statement of Contribution to Co-Authored Published Paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

F. Aram, E. Solgi, S. Baghaee, E. Higuera García, "*How Parks Provide Thermal Comfort Perception in the Metropolitan Cores; A Case Study in Madrid Mediterranean Climatic Zone*", the journal of *Climate Risk Management*, Volume 30, September 2020. (DOI: 10.1016/j.crm.2020.100245)

The main purpose of this paper is to answer the third sub-objective of the study in the western side of the Retiro Park; "Investigating and analyzing the range of change in thermal comfort perception (physiologically and psychologically) based on the intensity of the cooling effect of the park at different distances from it".

My contribution to the paper involved: literature review, data analysis, writing and editing the manuscript.

How parks provide thermal comfort perception in the metropolitan cores; a case study in Madrid Mediterranean climatic zone

Farshid Aram^a, Ebrahim Solgi^b, Sepideh Baghaee^a, Ester Higuera García^a, Amir Mosavi^{c,d,*}, Shahab S. Band^{e,f,*}

^a Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid-UPM, Madrid 28040, Spain

^b School of Engineering and Built Environment, Griffith University, Gold Coast 4222, Australia

^c School of Economics and Business, Norwegian University of Life Sciences, 1430 Ås, Norway

^d Kalman Kando Faculty of Electrical Engineering, Obuda University, Budapest 1034, Hungary

^e Future Technology Research Center, College of Future, National Yunlin University of Science and Technology, 123 University Road, Section 3, Douliou, Yunlin 64002, Taiwan, ROC

^f Institute of Research and Development, Duy Tan University, Da Nang 550000, Vietnam

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ABSTRACT

The combined effects of global warming and increasing urban heat islands (UHIs) on air temperature and heat stress in cities are notable physical and mental health implications for citizens. With research having shown the effective role of urban green spaces in decreasing urban heat, this study investigated the cooling effect of a large urban park on thermal comfort outside the park area, from psychological and physiological perspectives. The studied park is located in the center of Madrid and adjacent to UHI. The study was performed by conducting field measurements and a survey with questionnaires. The measurements made on six summer days (with two-week intervals) showed that the park's cooling effect could decrease the air temperature by 2.4–2.8 °C right up to the edge of the heat island (600 m), and decrease the physiological equivalent temperature (PET) by about 3.9 °C. By decreasing air temperature and PET, this park was also shown to increase the perceived thermal comfort (PTC) of the citizens from the psychological perspective in the defined area of effect. This perceived thermal comfort was found to have a significant inverse relationship with PET (P-value <0.05). The examination of cognitive maps drawn by citizens showed that out of the 145 respondents, 68.3% marked the park as the area that they perceive as having the greatest thermal comfort, and prefer as the place to spend time enjoying thermal comfort, irrespective of its distance from their location.

1. Introduction

Rising air temperatures and heat stress in cities are increasingly important issues for urban management (IPCC, 2014), especially

* Corresponding authors at: School of Economics and Business, Norwegian University of Life Sciences, 1430 Ås, Norway (A. Mosavi). Institute of Research and Development, Duy Tan University, Da Nang 550000, Vietnam (Shahab S. Band).

E-mail addresses: amir.mosavi@kvk.uni-obuda.hu (A. Mosavi), shamshirbandshahaboddin@duytan.edu.vn, shamshirbands@yuntech.edu.tw (S.S. Band).

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considering that with growing urbanization in upcoming decades, the likely increased incidence of such problems will indeed affect welfare and thermal comfort of citizens (Brown et al., 2015; Haines et al., 2006; Seto et al., 2011). The psychological and behavioral factors involved in outdoor urban areas differ from those in the discussion of indoor thermal comfort (Nikolopoulou and Lykoudis, 2007; Spagnolo and de Dear, 2003; Lin, 2009). Optimal thermal comfort in open urban spaces can have a positive effect on the livability of a city and also play an important role in enhancing the quality of the social and environmental life of its citizens (Martinelli et al., 2015; Lai et al., 2014). Therefore, the urban heat issue, as one of the most important factors in measuring thermal comfort, is of particular importance for urban life (Oke 1982).

Rising urban heat and the increase in the number and size of urban heat islands (UHIs) directly affect the health of citizens (Patz et al., 2005; McMichael et al., 2006; Błażejczyk et al., 2018; Jedlovec et al., 2017). An increase in air temperature is directly related to an increase in mortality due to heat exposure during summers with very high temperatures (Harlan et al., 2006; Vutcovici et al., 2014; Lemonsu et al., 2015; Gao et al., 2020). Moreover, according to some studies, rising temperatures affect not only physical health but also mental health (Kuo, 2015). Studies have shown that some aggressive behaviors are associated with temperature increase (Anderson, 2001). Also, heat waves have been associated with psychological and behavioral disorders (Hansen et al., 2008).

Urban green spaces are among the most important determinants of the welfare and well-being of an urban community (Lai et al., 2019; Aram et al., 2019a; Faroughi et al., 2020). Parks and landscapes not only have a significant impact on the health of a community but also mitigate the UHI effects (Nichol, 1996; Mariani et al., 2016; Ahmadpoor and Shahab, 2020), leading to decreased temperature and increased air humidity (Robitu et al., 2006). In a study by Bowler et al. (2010), the author compared the cooling effect of 24 parks in different climates and found that because of their shading and evaporation effects, parks have a cooling effect and decrease the average temperature by 1 °C compared to areas without vegetation. This study also observed that large parks have lower temperatures and a better cooling effect than other green infrastructures (Bowler et al., 2010). The cooling effects of the parks are characterized by two major indices, cooling effect distance (CED) and cooling effect intensity (CEI), which depend on various factors such as the size, spacing, and shape of parks, type and density of their vegetation, and the regional climate (Aram et al., 2019b). According to a study conducted on one of Tokyo's largest parks (Sinjyuku-Gyoen), with an area of 58.3 ha, the mean temperature difference between built spaces in the park and in the city in summer is about 1 °C (Sugawara et al., 2014). Another study on a 525-hectare park in Mexico City showed that in dry and warm seasons, the minimum daily temperature in the park is 3–4 °C cooler than in built areas of the city (Jauregui, 1990). Overall, large parks have a significant cooling effect on the temperatures of urban spaces (Yan et al., 2018; Doick et al., 2014). This effect is even more important for cities with hot summers such as those with a Mediterranean climate (Vardoulakis et al., 2013; Tsitoura et al., 2016). Research on several cities with Mediterranean climate has shown that most UHIs emerge in the center of these cities during summer. In a study in Thessaloniki, Greece (Giannaros and Melas, 2012) where the temperature difference of 7 stations in different parts of the city was investigated in relation to thermal comfort, the results showed that the station located in the center of the city had the highest discomfort index in the summer and was 1–1.5 °C hotter than other stations. However, the station with the highest percentage of green space had a lower temperature than other stations. In a study conducted in Tel Aviv (2006), results showed that during summer, residents experience significant discomfort in urban spaces because of high temperatures. This study reported that the maximum daily average temperature is about 29.0 °C, but the presence of a 28-hectare park in the center of the city with favorable vegetation had caused a 2 °C temperature decrease in the surrounding area (Potchter et al., 2006).

1.1. Outdoor thermal comfort

Outdoor thermal comfort can be described as the condition in which the person feels neither hot nor cold and refers to the temperature at which the person feels comfortable (Staiger et al., 2012; ASHRAE, 2013). According to this definition, thermal comfort is a subjective feeling formed by one's presence in a place or environment and can vary from one person to another (Nikolopoulou and Lykoudis, 2006).

Compared to indoors, thermal comfort outdoors is more challenging to analyze, because there are several extra-temporal and spatial variables that may affect this thermal comfort, and more interactions between the physical environment and physiological and psychological mechanisms (Nikolopoulou, 2011). In essence, thermal comfort is an essential physiological condition that maintains the function of the human organism but can also be defined as the mental state that expresses satisfaction with the thermal environment (ASHRAE, 2010). Therefore, there are two aspects involved in the concept of thermal comfort: physiological and psychological, and to achieve optimal comfort conditions, we need to understand the interactions between these two aspects (Nikolopoulou and Steemers, 2003; Lenzholzer and van der Wulp, 2010).

1.1.1. Physiological approach

For the body to function properly, a constant deep core temperature of about 37 °C has to be maintained. Balancing the heat lost to the environment and the heat received from the environment with the base metabolic rate is an important aspect of thermal comfort. This basic heat balance equation, which defines the heat exchange between the human body and the surrounding environment, constitutes the basis of current thermal standards developed based on the physiological responses of the human body (ISO, 2005; ASHRAE, 2004).

Several biometrical indices have been developed to describe the level of human thermal comfort by linking the microclimate condition and human thermal sensation (Irwin, 2004). These indices are based on the assumption that when exposed to a climatic condition, people gradually move toward thermal equilibrium; this trend can be analyzed with the help of numerical solutions to energy balance equations governing thermoregulation (Nagano and Horikoshi, 2011). There are various indices for evaluating thermal comfort in outdoor spaces. These indices, which have been derived from the human energy balance, include: Predicted Mean Vote

(PMV) (Fanger, 1973), Effective Temperature (ET) (Fanger, 1973), Standard Effective Temperature (SET*) (Gagge et al., 1986) Out-SET* (Pickup and De Dear, 2000), and Physiological Equivalent Temperature (PET) (Höppe, 1999). In addition, there are some indices for evaluating the outdoor thermal comfort of a specific climate. The Mediterranean climate is a case in point: Mediterranean Outdoor Comfort Index (MOCI) (Salata et al., 2016, 2018). In general 165 indices have been developed in order to assess human thermal and most of them are usually used for indoor spaces while PET, PMV, SET* are mainly intended for outdoor spaces (VDI, 1998; Potchter et al., 2018).

Derived from the human energy balance, the PET is one of the most popular and widely used indices for evaluating outdoor thermal comfort (Matzarakis et al., 1999). The RayMan model introduced by Matzarakis et al. (Matzarakis et al., 2010) can be used to calculate the radiation fluxes within urban structures based on certain parameters, including T_a , Wind Velocity and Solar Radiation, of the surrounding environment (Nasir et al., 2012). PET is widely popular because it is measured in degrees Celsius (°C), which makes it more easily comprehensible for researchers and professionals, including urban planners. Today, this index is a globally accepted measure for thermal analyses (Potchter et al., 2018). Basically, PET converts the analysis of a complex outdoor climatic environment to a simple physiologically equivalent indoor scenario so that it can be easily understood and interpreted (Ali-Toudert and Mayer, 2006; Cheng et al., 2012; Lin, 2009).

1.1.2. Psychological approach

Besides physiology, psychological factors are also important for subjective evaluation of outdoor thermal comfort (Nikolopoulou et al., 2001). Each person perceives their surroundings in their own way and their response to a physical stimulus may not be directly related to the magnitude of that stimulus, but rather to the information they have about that particular situation. Therefore, psychological factors can have a significant impact on human thermal perception of a space and the changes occurring in that space (Katzschner, 2006; Lenzholzer and Koh, 2010; Thorsson et al., 2004).

Despite the important role of psychological factors in thermal comfort, they have not received sufficient attention. Also, some researchers were initially critical of paying much attention to this aspect, arguing that it is impossible to understand the exact nature of each person's feelings and perceptions (Auliciems, 1981; Westerberg and Glaumann, 1990; Mansournia et al., 2020). Nevertheless psychological factors that influence thermal comfort have recently been increasingly researched. In a survey where instantaneous thermal comfort in public places across Europe was measured through interviews, the results showed that the temperature that people consider comforting varies from country to country and also from person to person (Knez et al., 2009). Other studies on psychological factors and their impact on thermal experience have also shown a relationship between thermal comfort and personal characteristics such as culture and place of origin (Thorsson et al., 2007; Knez and Thorsson, 2006).

The primary means for assessing psychological factors is interview and questionnaire (Ng and Cheng, 2012). In a study by Knez and Thorsson (2006), psychological factors related to two sites with similar thermal conditions were investigated by conducting interviews (Knez and Thorsson, 2006). Nasir et al. (2012) used a combination of questionnaires and interviews to study the psychological adaptation of thermal comfort in Malaysia (Nasir, Ahmad, and Ahmed, 2012). Nikolopoulou et al. and Klemm et al. studied the subjective response of people to outdoor spaces by interviewing them and observing their activities and behaviors (Nikolopoulou et al., 2001; Klemm et al., 2015a, 2015b). In addition to conducting interviews to measure the perceived level of thermal comfort, some researchers have used mental maps in combination with questionnaires for research in this area. Mental or cognitive maps are among the primary tools for analyzing people's experiences of spaces and therefore, the basic means for gaining urban knowledge (Aram et al., 2019a, 2019c, 2019d; Ahmadpoor and Shahab, 2019; Ahmadpoor and Smith, 2020). In a study carried out in the Netherlands, a combination of interviews and cognitive maps was used to identify the variables affecting the psychological of thermal comfort (Klemm et al., 2015b). Lenzholzer (2008) also used cognitive maps as well as interviews to examine the thermal comfort perception from the psychological point of view (Lenzholzer, 2008). Researchers who have used this method believe that asking people to identify places where they feel more comfortable provides a more comprehensible picture of their thermal perceptions (Aram et al., 2019d).

There have been numerous studies on large urban parks and their effects on thermal comfort, but the majority of these studies have examined thermal comfort within parks and their differences from other outdoor spaces. Also, the studies that have assessed the cooling effect of green spaces have only examined the temperature differences between the area around the park and the park itself. Given the importance of urban heat problems, especially in cities with Mediterranean climates, which experience hot summers, this study aimed to investigate the cooling effect of a large urban park on its surroundings (in Madrid historical core with organic urban configurations) in order to more precisely determine the effect of such green spaces on thermal comfort from physiological and psychological perspectives. It should also be noted that a study was carried out in the northern part (which has structured urban configurations) of Madrid central park (Aram et al., 2019d). This study was limited to both being in the morning time and near the park's mid-range temperature. Thus, there was a research gap in studying thermal comfort perception during the hottest hours. However, the present study has been conducted during the time and temperature close to the maximum park temperature to have a more detailed study of thermal comfort in summer and the times when the temperature reaches its maximum.

2. Methodology

2.1. Measuring sites

This research was performed in Madrid (40°25'08"N; 3°41'31"W) the capital of Spain with a population of 6,617,513 and a population density of 5265.91 person/km². Madrid has Mediterranean climate, and according to Köppen-Geiger classification falls in the category of "hot dry-summer (Csa)" climate (Kottek et al., 2006). In the downtown of Madrid, the average annual temperature is

19.9 °C during the day and 10.1 °C at night. July is the warmest month of the year, with an average temperature of 32.1 °C during the daytime. Then August, June, and September with average daily temperatures of 31.3 °C, 38.2 °C, and 26.4 °C respectively, are the hottest months (AEMET, 2018). The studies conducted in Madrid reveal that it is facing to UHI impacts (Sobrino et al., 2013). The UHI effects in 1985 made the center of Madrid 4 °C hotter by comparison with peripheral areas (Román et al., 2017). Furthermore, the study in 2016 has shown that temperature difference could be up to 8 °C during the hot summer of Madrid (Núñez Peiró et al. 2016). The green space examined in this study was Parque del Retiro or Retiro Park which, with an area of about 125 ha, is one of the largest parks in the center of Madrid.

Investigation of the cooling effect was performed in the western part of the Retiro Park. According to the latest report on Madrid's UHI map (Núñez Peiró et al., 2017), this area falls in the domain of Atocha heat island. The area also belongs to the historical part of central Madrid and the Antón Martín district, which is one of Madrid's hotspots, 855 m away from the west side of the park (Sánchez-Guevara Sánchez et al., 2017).

Fig. 1. Map of UHIs of Madrid on July 26, 2015 (Núñez Peiró et al., 2017) and selected area at the west side of the Retiro Park. Node A is positioned in the yellow zone, Node B is in the orange zone, and Node C is in the red zone near one of Madrid's UHI.

For a more precise examination of the area using the 2015 map of Madrid's UHI (Núñez Peiró et al., 2017), other open spaces at different distances from the park and with different temperature ranges needed to be studied. When selecting these points, an attempt was made to choose the open spaces with the highest similarity to Antón Martín district in terms of spatial and qualitative features. The places selected for this purpose were the open space at the intersection of Moratín Street and María Street and the open space of the CaixaForum building (at the intersection of Almadén and La Alameda streets) positioned respectively 600 and 445 m west of the park. For easier reference, the points positioned 445 m, 600 m, and 855 m away from the edge of the park are named A, B, and C, respectively (Fig. 1).

All three of the mentioned areas are urban Nodes and open spaces formed by the intersection of several roads. Node A is rectangular shaped and Nodes B and C are triangular, with respective areas of 300 m², 265 m², and 260 m². Although Node A differs from Node B and C in both shape and area, the three points are generally similar in terms of enclosure, sky view factor (SVF), vegetation, flooring type (stone pavement and gray tiles), and adjacent buildings (mostly red brick and stone). It should be noted that the examined area contains no green space or park (small or large), other than Retiro Park (Table 1; Fig. 2).

The data of this study included microclimatic data and questionnaire data, which was collected on six hot summer days of 2018: June 22, July 10 & 24, August 10 & 24, and September 10. For all three nodes, measurements began in early summer and were repeated approximately every two weeks on the days that were sunny and clear (without clouds) until September 10. Measurements were made at noon between 12:15 and 13:45 CET when the air temperature in Madrid reaches its highest level (AEMET, 2018). The temperature measurement time and the time for collecting questionnaires was ten minutes.

2.2. Microclimate measurements

Microclimatic measurements were conducted in the form of dynamic experiment, all data including air temperature (T_a) and relative humidity (RH) were collected using a mobile microclimate station (HOBO MX2301A Temperature / RH Data Logger, manufactured by Onset Computer Corporation, MA, USA) with an accuracy of ± 0.2 °C for T_a and $\pm 2.5\%$ for RH. Wind velocity (WS) was measured using the Proster digital anemometer ms6252a. HOBO MX2301A was equipped with a shield (M-RSA) and all devices were installed 1.5 m above the ground. A fisheye lens (Sigma 8 mm circular) was used to assess the sky view and take fisheye photographs. T_a and RH data were automatically recorded every one minute and wind speed data were manually recorded every one minute; both were averaged over every 10 min. For more accurate comparison and closer examinations, climatic data including T_a and RH were also collected from the AEMET station (Agencia Estatal de Meteorología) located within Retiro Park (Fig. 3).

2.3. Questionnaire survey

Over the six days of measurement, at the same time as collecting the microclimatic data (10 min), researchers randomly conducted semi-structured interviews (Klemm et al., 2015b; Aram et al., 2020) with some occupants of the sites (both workers and residents) and collected a total of 145 questionnaires (Node A: 47, Node B: 50, Node C: 48 N). Respondents were active at different levels and included both genders and a wide range of age groups (excluding children). As the data collection and questionnaire completion were conducted at noon and in hot summer hours, for the convenience of the respondents, they filled out the forms in shady environments. Detailed information on the number and characteristics of respondents at each day of interview at each Node is presented in Table 2.

The questionnaire items were designed in three parts. The first part was designed to examine the respondent's cognitive image of thermal comfort in the area. In this part, respondents were provided with a map of the western neighborhood of Retiro Park - from the western edge of the park to the Antón Martín district - and asked to mark the areas where they would feel thermal comfort. To prevent unintended bias in responses, this map was drawn so that the park area would occupy a small portion of the map and not attract more attention than other areas. The resulting mental maps were examined using the software Aram Mental Map Analyzer (AMMA) (Aram et al., 2019a, 2019c, 2019d). In this software, the park area was introduced as the base point and given a score of 100, and other areas were not scored. Thus, the awarded score was 100 if the park area was marked and zero otherwise (no matter what other points were marked). In this way, after averaging the scores, the percentage of people specifically mentioning the park was obtained (Fig. 3).

The second part of the questionnaire included four brief questions about the perceived thermal comfort at the place of encounter; *How thermally comfortable do you feel in this place (neither hot nor cold)?; How hot do you feel in this place?; How much do you feel the cooling effect of Retiro Park in this place?; How tolerable is the heat of this place for you?*

The answers to these questions were designed based on a 5-point Likert scale (Very high = 5, high = 4, Medium = 3, Low = 2, Very

Table 1
Geometric configuration of the nodes and street trees properties in three investigated nodes.

Part	Node features						Street trees			
	Distance from park/m	Number of street legs	H/W Ratio	Area/ m ²	Shape	SVF ^a	Number of trees	Mean Tree Height (m)	Mean Crown Diameter (m)	Crown Shape ^b
A	445	4	1.11	300	Rectangular	0.4	3	1.8	0.5	Cone
B	600	5	1.12	265	Triangular	0.4	3	9.1	5.4	Cone
C	855	3	1.06	260	Triangular	0.3	5	3.2	2.7	Cone

^a Calculated by RayMan 1.2.

^b Crown Shape Classification by Park et al. (2017).

Fig. 2. Street views of the three investigated nodes (A, B and C), 3D aerial view, and fisheye shots.

Fig. 3. Methodology structure.

low = 1). The total scores of the responses to these

questions were considered as a measure of perceived thermal comfort and were statically analyzed in SPSS. It should be noted that the answers to the second question were scored in

reverse order (Very high = 1, High = 2, Medium = 3, Low = 4, Very low = 5) (Fig. 3).

The third part of the questionnaire included open-ended personal questions about age, height, weight, gender, activity level, and clothing type. These questions were included in the questionnaire because these factors can affect the person's physiological

Table 2

The proportional percentages questionnaire data in the three investigated Nodes (nA:47, nB:50, nC:48) on all the measured days.

Percentage (%)	Categories	Variable	Percentage (%)	
C	B	A	C	
2	8	0	2	Age
19	20	2	19	
31	30	11	31	
23	20	23	23	
25	22	36	25	
62	50	43	62	Gender
38	50	57	38	
2	0	2	2	Q1
19	14	9	19	
48	42	53	48	
25	36	32	25	
6	8	4	6	
4	2	4	4	Q2
23	44	9	23	
33	22	40	33	
25	24	38	25	
15	8	9	15	
2	6	2	2	Q3
27	20	13	27	
33	38	34	33	
25	20	32	25	
13	16	19	13	
13	8	4	13	Q4
27	44	11	27	
25	36	60	25	
27	10	21	27	
8	2	4	8	
				Clothing
15	10	11	15	
23	24	21	23	
13	6	6	13	
31	46	38	31	
19	12	21	19	
0	2	2	0	
				Activity
50	82	66	50	
31	16	9	31	
15	0	26	15	
4	2	0	4	
				AMMA results
43.8	32	19.1	43.8	
56.3	68	80.9	56.3	

temperature and need to be clarified before assessing the PET index. The parameters that needed to be determined for PET calculations were the clothing level (clo), type of activity, and SVF. In this study, this index was determined using the software RayMan 1.2 (Fröhlich et al., 2019; Matzarakis et al., 2010) (Fig. 3).

In the studied areas, the most frequent types of clothing were T-shirts with shorts, T-shirts with trousers, and dresses, with values of 40, 61, and 30, respectively. Also, the most frequent activities were walking, standing, and sitting, which according to standards, have activity values of 115, 70 and 60, respectively (Streinu-Cercel et al., 2008) (Table 2).

Another parameter needed for PET calculations was SVF (Matzarakis et al., 2010). This index was determined using the software RayMan by creating a 3d simulation of the spatial geometry and vegetation characteristics of the environment in the obstacle menu and importing the fisheye images into the software. Using this method, SVF of Nodes A, B, and C was calculated as 0.4, 0.4, and 3.0, respectively (Table 1).

3. Results

There were noticeable differences between the microclimatic data collected from Nodes A, B, and C during the data collection period (Table 3). The average temperature of Node C located 855 m away from the western edge of the park during 6 days of data collection (33.9 °C) were respectively 2.8 °C and 2.4 °C hotter than that of Nodes A (31.1 °C) and B (31.5 °C), which are positioned 445 m and 600 m away from the park.

Further, the temperature data obtained from the AEMET station in Retiro Park (AEMET, 2018) showed that on June 22, July 10 & 24, August 10 & 24, and September 10, air temperatures at Nodes A and B were within the range of average and maximum temperatures within the park, but at Node C (Antón Martín) this was only true on July 10 and July 24 (on the rest of the days air

temperature exceeded the maximum temperature inside the park). The results also showed that the temperature data obtained from Node A (CaixaForum) were the closest to the average temperature data of inside the park (Tables 3 and 4; Fig. 4).

Since one of the main determinants of the PET index is air temperature and the sites were selected for highest similarity in terms of other influencing variables (vegetation, enclosure, built environment materials, and data collection time), temperature changes caused by the cooling effect of the park directly affected the PET index. The results showed that the average PET value during the data collection days at the point 855 m away from the park was 41.3 °C, which was 3.9 °C higher than the corresponding figure at points 600 m and 445 m away from the park (37.4 °C). This indicates that residents of the Antón Martín district (Node C) were feeling lower thermal comfort than those of the other two areas.

For more accurate examination of the level of thermal comfort perceived by the citizens, the average score of the items included in the questionnaire was used as a measure of perceived thermal comfort (PTC) at each area at each of the six days. As mentioned earlier, each answer was awarded a score between 1 and 5 (Very high = 5 to Very low = 1). This average score was calculated to 3.13 for the CaixaForum area (Node A), 3.05 for the Moratín area (Node B), and 3.01 for the Antón Martín area (Node C). Accordingly, the CaixaForum area and Antón Martín area had the highest and lowest levels of perceived thermal comfort, respectively.

To assess the impact of the park's cooling effect on psychological and physiological variables, the Pearson correlation test was used to analyze the relationship between PTC and PET (Table 5). According to the results of the correlation test, the only significant relationship between PET and thermal comfort was an inverse relationship at a distance of 445 m from the park (P-value < 0.05). In other words, the relationships of PET with thermal comfort in other distances were insignificant (P-value > 0.05). Basically, this test showed that decreasing PET near the park in the CaixaForum area coincides with a notable increase in PTC which is statistically significant. Therefore, the important finding from the correlation test was the existence of a significant inverse relationship between PET and PTC.

Also, the data obtained from AMMA were used to examine the perceived thermal comfort based on cognitive maps. The results of this software showed that out of 145 respondents, 99 (68.28%) marked the park as a place of thermal comfort. Residents of the area 445 m away from the park had the highest rate (80.9%) of marking Retiro Park as a place where they would feel thermal comfort. At the other two points, which were 600 m and 855 m away from the park, this rate was 68% and 56.3%, respectively. These results suggest that the impact of Retiro Park on the respondents' perceptions of thermal comfort is so strong that more than half of the respondents (56.3%) who were farther away from the park (855 m) preferred this park as a place to spend time and enjoy thermal comfort.

Also, using AMMA, the obtained cognitive maps were converted into an analytical map with a color spectrum representing the number of people marking each given point as a place of thermal comfort. This map is displayed in Fig. 5. This figure shows that, on all of the examined days, Retiro Park is the site most frequently marked by the citizens.

4. Discussion

The results show that in the hot summer months of Madrid, Retiro Park plays an important role in bringing thermal comfort to the surrounding area; a role that can be discussed from both physiological and psychological perspectives.

In the six examined summer days (June 22, July 10 & 24, August 10 & 24, and September 10), the maximum temperatures inside the park (according to the AEMET station) were occurring in the time range between 13:40 and 14:40 CET. As shown in Table 4, the average temperature inside the park and outside it up to a distance of about 600 m (Nodes A and B) was 2.4 °C cooler than the point 855 m away from the park (Node C), and this is while the measurements of Nodes A and B were performed at 12:55–13:45 CET and 12:35–13:20 CET (close to the time of maximum temperature inside the park) but those of Node C were carried out at 12:15–12:55

Table 3

Nodes mean values for Wind velocity (WS), relative humidity (RH), air temperature (T_a), and physiological equivalent temperature (PET) on the all measurement days (12:15–13:45 CET).

Date	Nodes	Time	Mean WS, m/s	Mean RH, %	Mean T_a , °C	Mean PET, °C
22 Jun	A	13:00–13:10	2.16	20.13	31.64	37.2
	B	12:40–12:50	1.57	20.05	33.17	39.3
	C	12:15–12:25	2.5	24.96	35.5	43.1
10 July	A	13:35–13:45	1.37	20.13	34.23	41.1
	B	13:10–13:20	1.57	21.8	34.5	42.2
	C	12:45–12:55	2.25	22.34	34.69	42.0
24 July	A	13:00–13:10	1.15	22.36	30.87	37.8
	B	12:40–12:50	2.53	20.22	31.03	35.7
	C	12:15–12:25	2.23	24.47	32.57	38.9
10 Aug	A	12:55–13:05	2.36	28.81	33.14	43.0
	B	12:35–12:45	1.81	28.09	33.64	40.6
	C	12:15–12:25	1.64	30.47	34.33	43.0
24 Aug	A	13:30–13:40	1.31	27.82	30.77	36.6
	B	13:10–13:20	1.52	27.07	30.86	36.6
	C	12:40–12:50	1.54	22.01	34.96	42.8
10 Sept	A	13:15–13:25	1.43	41.3	25.62	29.1
	B	12:50–13:00	1.33	40.79	25.84	29.9
	C	12:20–12:30	1.3	33.95	32.33	38.8

Table 4The values for air temperature (T_a) relative humidity (RH) and wind velocity (W) in the Retiro Park on all the measurement days (AEMET, 2018).

Date	Retiro park ^a T_a (°C)			Time of T_a in Retiro park ^a		HR % of park ^a	Wind in park ^a
	Min	Mid	Max	Min	Max		
22.06.2018	21.6	27.7	33.8	04:50	14:40	22.95	1.7
10.07.2018	21.5	28.4	35.2	06:00	13:50	22.95	2.2
24.07.2018	19.8	26.4	33.0	05:00	13:50	22.94	1.9
10.08.2018	17.5	24.4	31.3	05:40	13:40	36.8	2.2
24.08.2018	20.6	26.8	33.0	05:30	14:20	19.25	1.4
10.09.2018	17.3	22.8	28.3	05:20	13:45	33.55	1.9

Fig. 4. The diagram demonstrates the temperature range of the three Nodes A, B & C and the temperature range of the Retiro Park. Gray rectangles: temperature range at three Nodes (bottom side: T_a Node A, top Side: T_a Node C) Gray rectangles: temperature range at three Nodes (bottom side: T_a Node A, top Side: T_a Node C) Linear range: the temperature range of the park is based on AEMET (2018) (bottom line: T_a Min of the park, top line: T_a Max of the park).

Table 5

Pearson Correlation analyses between PTC and PET.

Part			GENERAL Q (PTC)
A	PET	Pearson Correlation	-0.316 ^a
		P-value. (2-tailed)	0.031
		N	47
B	PET	Pearson Correlation	-0.142
		P-value. (2-tailed)	0.326
		N	50
C	PET	Pearson Correlation	-0.152
		P-value. (2-tailed)	0.303
		N	48

Fig. 5. Cognitive map analyses using the Aram Mental Map Analyzer (AMMA) during six summer days of 2018.

CET, that is, 1–1.5 h before the time of maximum temperature in the park. Considering the magnitude of temperature decline around the park, temperature difference has also affected the PET and caused the Antón Martín area, which is nearest to the UHI, to have 9.5% higher PET than both CaixaForum (A) and Moratín (B) (41.05 °C vs. 37.4 °C).

Overall, research in this area has shown that urban parks that are larger than 10 ha can affect the average temperature of the surrounding area by 1–2 °C up to a radius of 350 m (Aram et al., 2019b; Yan et al., 2018; Bowler et al., 2010). According to the results of this study, Retiro Park has even a higher cooling effect with a CED of about 600 m and a CEI of more than 2.4 °C, which can be attributed to its large area and vegetation diversity.

Over the years, the cooling effect of urban parks on the air temperature both within and around the park has been extensively researched. But the studies on this effect on PET and body physiology in the area around the park are limited. These studies have been conducted in different parts of the world, including Asia, Africa, and the Middle East.

A study in Shanghai, China showed that Zhongshan Park in the center of this city, with an area of 21.42 ha, is indeed improving thermal comfort, and its cooling effect increases the PET index to 15–29 °C (Chen et al., 2015). In a study by Sun et al. (2017) in Beijing,

China, it was found that the Yuan Dynasty Relics Park with an area of 102 ha, which is nearly as large as the park examined in this study (Retiro Park), can reduce the PET on a warm sunny day (August 21) by an average of 2–15.6 °C.

A study carried out by Mahmoud (2011) in Cairo reported that the central park of the city, with an approximate area of 26.01 ha, has an effect on the residents' thermal comfort during the summer. The results of the study showed that during the day, the park reduces the PET in the range of 22–30 °C. In another study in Tel-Aviv, Israel, where 10 urban parks with different areas were surveyed (Cohen et al., 2012), the results showed that parks with high vegetation density and diversity had a stronger cooling effect and could reduce the temperature by 3.8 °C in summer. It was also found that parks have a direct effect on thermal comfort can increase PET to 18 °C.

Despite the many merits of these studies, they have not addressed the range of the cooling effect and the PET difference in areas around the park that have similar spatial characteristics. Furthermore, these studies have focused on PET, thus largely ignoring the issue of perceived thermal comfort from a psychological perspective, and this is while, when combined together, physiological and psychological factors can provide a more comprehensive definition of thermal comfort. In order to analyze the cooling effect of a large urban park on thermal comfort in the area around it with organic urban configuration, this study not only examined the PET index, but also used a questionnaire measuring an index called PTC and cognitive maps to investigate the people's perception of thermal comfort caused by the cooling effect of the park from a psychological perspective during the hottest hours.

The relationship between PET and PTC illustrates the importance of the presence of a large park in the middle of a city for the outdoor thermal comfort of citizens. In the case of this study, this effect of the park is so strong that there has been a reduction in the impact of UHI up to a distance of 600 m away from the park. It is important to note that the studied area has the same texture and physical properties as the area in the heat island (dense urban), which means in the absence of the park, the temperature increase due to the heat island effect would have profoundly affected the physical and mental health of the citizens living and working in the central part of Madrid.

5. Conclusion

Large urban parks play a major role in providing citizens with thermal comfort from both physiological and psychological perspective, especially in areas with hot summers. The results of this study showed that in hot summer days of Madrid, which has a Mediterranean climate, because of the large urban park (125 ha) located in the center of this city, two areas at distances of 445 m and 600 m from the park have respectively 8.3% and 7.1% lower air temperature than a similar area positioned 885 m away from the park near a UHI. It was also found that this temperature decline has an impact on the PET index, causing the people in these ranges (445 m and 600 m) to have 3.9 °C (9.5%) lower PET by average.

The results showed that with the decrease in temperature and consequently the decrease in PET in the areas around the park, people living and working in these areas exhibit higher levels of perceived thermal comfort (PTC). More specifically, thanks to the cooling effect of the studied park, the average PTC within a 600 m distance of the park is about 1.3–3.8% higher than the area near UHI.

The analysis of cognitive maps also showed that Retiro Park plays an important role in creating a sense of thermal comfort in the citizens around the park. In fact, these analyses demonstrated how profound the cooling effect of the park is in citizens' minds. This effect is so strong that out of 145 respondents surveyed in three areas, 68.3% marked Retiro Park as the place they prefer to spend time enjoying thermal comfort. It is important to note that the park was the first choice of respondents in all of the three examined areas, even 56% of people at a distance of 855 m away from the park. According to the results of this study, the cooling effect of large central parks in areas with hot summers, including those with a Mediterranean climate, can play a key role in preventing the creation and growth of UHIs in high density and heavily populated areas. In the absence of such green spaces, there is a strong possibility that central parts of the city experience rising temperatures in the form of UHIs, with dire impacts on the physical and mental health of citizens.

Despite the promising results reported on the essential role of Retiro Park as the largest central park in Madrid, still remain several research questions yet to be answered. For instance, investigation on the thermal comfort of the other sides of the park adjacent to the UHI at the other times of the day would be essential. In addition, conducting further studies for investigation of the impact of urban green spaces, particularly large parks, in the center of urban areas would be vital considering extensive global warming and the rapid urbanization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Article 5. Case study (South part of Retiro Park)

Statement of Contribution to Co-Authored Published Paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

F. Aram, E. Solgi, , E. Higuera García, " *Urban heat resilience at the time of global warming: evaluating the impact of the urban parks on outdoor thermal comfort*", the journal of *Environmental Sciences Europe*, Volume 32, Issue 1, September 2020. (DOI: 10.1186/s12302-020-00393-8)

The main purpose of this paper is to answer the third sub-objective of the study in the southern side of the Retiro Park; "Investigating and analyzing the range of change in thermal comfort perception (physiologically and psychologically) based on the intensity of the cooling effect of the park at different distances from it".

My contribution to the paper involved: literature review, data analysis, writing and editing the manuscript.

RESEARCH

Urban heat resilience at the time of global warming: evaluating the impact of the urban parks on outdoor thermal comfort

Farshid Aram¹, Ebrahim Solgi², Ester Higuera Garcia¹ and Amir Mosavi^{3,4,5*}

Abstract

Background: In densely populated urban centers, increased air temperature due to urban heat island (UHI) effect can undermine the thermal comfort and health of citizens. Research has shown that large urban parks can mitigate the effect of UHIs and improve thermal comfort, especially in the warmer months of the year when temperature changes are more noticeable. This study investigated the cooling effect intensity (CEI) of the Retiro Park in the center of Madrid at three different distances from its southern edge and the impact of this cooling effect on thermal comfort from physiological and psychological perspectives. This investigation was performed by measuring microclimate data and conducting a survey simultaneously during the summer days.

Results: The results showed that the CEI of the park varies with distance from its edge. Because of this effect, air temperature within the 130 m and 280 m distance of the park was, respectively, 1.6 °C and 0.9 °C lower than the temperature at the 520 m distance (the nearest heat island). After examining the effect of the park in terms of physiological equivalent temperature (PET), it was found that the PET at the 130 m and 280 m distance of the park was 9.3% and 5.4% less than the PET in the heat island domain. More than 81% of the respondents (in all three areas) had a mental image of the park as the place where they would experience the highest level of outdoor thermal comfort, and this rate was higher in the areas closer to the park. The analysis of citizens' responses about perceived thermal comfort (PTC) showed that citizens in areas with higher CEI had perceived a higher degree of thermal comfort from the psychological perspective.

Conclusion: This study demonstrates the significant role of large urban parks located in the core of the populated cities in providing thermal comfort for citizens from both physiological and psychological perspectives. Additionally, the results of this study demonstrated that among the environmental (natural and artificial) factors around the park (topography, urban structure, etc.), the aspect ratio has the greatest impact on thermal comfort.

Keywords: Urban park, Urban heat island, Thermal comfort perception, Cooling effect intensity, Urban configuration, Environmental factors

Background

Climate change has had visible effects on many human communities all over the world, but these effects are more deeply felt in large, densely populated cities [19,

35]. Research has shown that urban areas are typically warmer than their rural counterparts; a difference that can be attributed to the phenomenon known as urban heat island effect (UHI) [67, 83, 90]. This effect is strong enough to cause major physical and mental health problems for citizens [16, 52, 55, 85]. Urban green spaces not only beautify the urban landscape but also moderate urban climate by increasing humidity and lowering air temperature [18, 97]. Over the years, the value of parks

*Correspondence: amir.mosavi@kvk.uni-obuda.hu

³ Kalman Kando Faculty of Electrical Engineering, Obuda University, Budapest 1034, Hungary

Full list of author information is available at the end of the article.

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and green spaces for cities and their benefits for the health and welfare of citizens has been discussed and proven in many studies [15, 34, 79, 86]. In general, green spaces are an essential part of the urban landscape, as they are crucial for the stability and sustainability of cities [7, 9–11, 14, 76]. Hence, designing and building green spaces should be a key part of any urban plan that aims to create sustainable cities with healthy communities [19, 51, 75, 78]. Urban green spaces are known to have a cooling effect on air temperature [24, 25]. Typically, this effect can be felt not only in the park itself but also within a radius around the park, leading to improved thermal comfort in the neighborhood [31, 92, 95].

Thermal comfort has received much attention because of its great impact on the quality of life of citizens [21, 50]. According to CIBSE, human thermal comfort refers to the temperature conditions that satisfy at least 80% of individuals [22]. Human thermal comfort depends on several factors including climate, air temperature, humidity, sunlight, and air movements [74]. Ultimately, people's perception of environmental conditions also depends on non-climatic factors such as clothing type, coping ability, age, gender, physical appearance, subcutaneous fat, fitness, diet, and skin color [23, 87].

Serious research on the subject of thermal comfort began in 1956 with the study of conditions of human thermal comfort in indoor spaces and later expanded to outdoors [68]. What makes the assessment of outdoor thermal comfort different from the analysis of indoor thermal comfort, besides the scale of work, is the massive difference between the thermal needs of different individuals, which vary with the region and study conditions [54, 64]. Following the manifestation of the consequences of climate change, the subject of thermal comfort in outdoors has attracted the attention of many researchers, especially those working in the fields of climate, urban development, and environmental research [21, 37, 50]. Over the years, researchers have introduced various indexes for measuring outdoor thermal comfort, which include Predicted Mean Vote (PMV) [26], Standard Effective Temperature (SET*) [29], which was later developed into OUT-SET* [70], Man-Environment heat Exchange (MENEX) [17], Physiological Equivalent Temperature (PET) [33], Comfort Formula (COMFA) [39], and Universal Thermal Climate Index (UTCI) [38] among others.

To analyze thermal comfort in urban environments, the measure of analysis should take into account the local climatic conditions and the four main climatic factors that affect human thermal comfort, i.e. air temperature, humidity, wind speed, and solar radiation [49, 61, 77]. Among the existing thermal comfort indexes, the PET, which has been derived from the human energy balance,

not only meets the aforementioned requirement but also takes the features of human physiology into account [48, 57, 58]. Highly suitable for urban and environmental studies, PET is and is one of the four most widely used indexes in outdoor thermal comfort research (PET, PMV, UTCI, SET*). PET has also been used in a wider range of climatic regions than other indexes [71].

ASHRAE defines thermal comfort not solely as an environmental and physiological phenomenon but also as a condition of mind that expresses satisfaction with the thermal environment [6, 12]. In this definition, the term "condition of mind" refers to the fusion of mental and physiological conditions in the concept of thermal comfort [5]. Numerous studies have shown that different people have vastly different perceptions of thermal comfort and temperature preferences and also differ in their behavioral and physiological coping and their psychological habits or their expectations from the climate [45, 53, 65, 73]. These differences make it difficult to study people's perceptions of the thermal comfort of their environment [62]. However, using methods like surveying to ask people how they feel about temperature and thermal conditions can provide a broad picture of people's perceived thermal comfort and satisfaction with the thermal conditions of their environment [30, 42].

According to studies conducted on the subject of thermal comfort in open spaces, another factor that can significantly influence the results of such studies is people's cognition and mental images of their environment [44, 63]. Since people's mental conditions play a key role in their cognition of the environment [56], these conditions can have massive impacts on their thermal perception of the environment and consequently their comfort conditions [3, 46, 80]. Indeed, the response of a human to an external stimulus depends on the "information" that the individual has in and about that particular situation [60]. People's cognition and perception of their environment can be studied by the use of environmental psychology methods and instruments. One of the most common of these instruments is cognitive maps [32, 41, 89]. These maps can represent people's knowledge of places and their importance in people's minds, and can, therefore, be used in outdoor comfort studies to gain an insight into how important people believe a place is in terms of contribution to thermal comfort [7, 9–11]. In other words, these maps can help us examine the citizens' perception of places based on their role in creating thermal comfort [43].

Given the role of urban green spaces in mitigating urban heat and creating thermal comfort in built-up spaces, they have a fundamental impact on the quality of life of citizens and sustainable development of urban environments. Previous research on the role of the

central park in Mediterranean climates and the city of Madrid has conducted two studies regarding the cooling effect of parks on thermal comfort [7–11]. In one study, the northern part of the park with structured urban configuration was examined in the morning [7, 9–11], while in the other study, the western part of the park, located in the historical area (organic urban configuration) was examined at noon [8]. These investigations do not discuss the role of elements that can affect the intensity and distance of the cooling effect and consequently the thermal comfort. Therefore, the present study, in the continuation of two other studies, not only examines the area located on the southern side of the park, but also discuss the role of effective environmental (natural and artificial) factors (such as wind pressure, topography, urban texture, and ratio) to cover to the gap in previous studies. In this study, considering the influential factors outside of the park, we examined the cooling effect of a large central park at different distances and the consequent impact on thermal comfort from physiological and psychological perspectives.

Methods

The measuring sites

This study was performed in Madrid, Spain (40°25′08″N; 3°41′31″W), which according to Köppen–Geiger classification, has a “Hot-summer Mediterranean” climate [47]. The case chosen for examining the effect of large urban green spaces on thermal comfort was the Retiro Park, which, with an area of about 125 ha, is one of the largest parks in the center of Madrid. The area of interest was in the southern side of

this park, where according to the Madrid’s UHI maps, there is a heat island at the 520 m distance from the edge of the park [66].

According to the UHI of Madrid [66], there is a heat island near the Granada-Narciso Serra district located 520 m away from the southern edge of the park (marked red in Fig. 1) [72]. For a more precise examination of the cooling effect of the park, two areas at the intersection of Gutenberg-Valderribas-Fuenterriabía and Torrejón-Agustín Querol, which are located in the orange and yellow zones at the 280 m and 130 m distance from the park, were also included in the study. All selected intersections are physically and structurally identical. For easier reference, hereafter, the Torrejón-Agustín Querol intersection (150 m) is called intersection A, the Gutenberg-Valderribas-Fuenterriabía intersection (280 m) as called intersection B, and the Granada-Narciso Serra intersection (520 m) is called intersection C.

The southern side of the Retiro Park has a regular and grid-like texture mostly consisting of seven-story buildings. The façade of most buildings in this area is made of red brick. The roads of the area are asphalt and the sidewalks are mostly made of bright colored mosaic tiles (Fig. 2).

The data collected in this study were of two types: (I) microclimate data including air temperature, humidity, and wind speed, which were measured inside the Retiro Park and at all three intersections on 6 days starting from the summer of 2018: June 22, July 10 and 24, August 10 and 24, and September 10. (II) Survey data, which were collected by a questionnaire measuring citizens’ perceived thermal comfort and also cognitive maps whereby

citizens were asked to specify the places where they feel the most thermal comfort.

All data (both microclimate and survey) were collected on clear sunny days. At each intersection, data collection was performed over a 10 min period, during which one group collected temperature data and the other group conducted the survey. Since the peak temperature inside the park in the summer of 2017 had been observed, on average, between 13:28 and 15:08 CEST [1], all stages of data collection were scheduled to start after 13:30.

Microclimate measurements

Air temperature (T_a) and relative humidity (RH) were measured by a mobile microclimate station (HOBO MX2301A Temperature/RH Data Logger, produced by Onset Computer Corporation Co., MA, USA) with an accuracy of $\pm 2.5\%$ for RH and $\pm 0.2^\circ\text{C}$ for T_a . Wind speed (WS) was measured by a Proster digital anemometer model MS6252a. All measurement devices were installed 1.5 m above the ground. A fisheye lens (Sigma 8 mm circular) was used to assess the sky view and take fisheye photographs. T_a and RH data were automatically logged at 1-min intervals and averaged over every 10 min. Wind speed data were also recorded manually at 1-min intervals and averaged over every 10 min. It should be mentioned that the wind direction differed in measuring days (22 Jun, N; 10 Jul, NNE; 24 Jul, SW; 10 Aug, NNE; 24 Aug, N; 10 Sep, N), due to this issue assessing the role of wind direction was inconclusive. Climatic data including T_a and RH were also collected from the AEMET station

(Agencia Estatal de Meteorología) located inside the Retiro Park [1].

Survey

Throughout the study, researchers surveyed a total of 133 individuals ($N_{\text{node A}}=46$, $N_{\text{node B}}=43$, $N_{\text{node C}}=44$), who were randomly chosen from among people either living or working in the area. Surveys were conducted during the same 10 min in which the microclimate measurements were being made (on average, seven people per intersection per day). Respondents were from both genders and different age groups (excluding children) and had different activity levels (sitting, standing, and walking). The citizens' perceived thermal comfort was measured by a researcher-made questionnaire consisting of two sections: questions and cognitive maps.

The cognitive map section of the questionnaire was a map of the area between the southern edge of the Retiro Park and the heat islands to its south, on which citizens were asked to mark the areas where they normally feel thermal comfort. To avoid bias, this map was drawn so that the park would make up only a small portion of the map. The obtained cognitive maps were analyzed with the software AMMA [9]. In this analysis, the maps on which the park was marked were awarded a score of 100 and the maps on which there was no mention of the park were given a score of 0 (Table 1).

The questions section of the questionnaire itself consisted of two parts. The first part consisted of the questions enquiring directly about the perceived

Table 1 The proportional percentages questionnaire data in the three investigated intersection ($N_{\text{node A}} = 46$, $N_{\text{node B}} = 43$, $N_{\text{node C}} = 44$) on all the measured days

Variable	Categories	Percentage (%)		
		A	B	C
Age	13–21	19.6	23.3	15.9
	22–30	21.7	11.6	6.8
	31–45	30.4	30.2	34.1
	46–60	13	23.3	20.5
	61–85	15.2	11.6	22.7
Gender	Men	47.8	55.8	56.8
	Women	52.2	44.2	43.2
Q1	Very low (1)	0	2.3	4.5
	Low (2)	13	14	31.8
	Medium (3)	37	41.9	34.1
	High (4)	39.1	34.9	27.3
	Very high (5)	10.9	7	2.3
Q2	Very low (5)	8.7	18.6	18.2
	Low (4)	45.7	34.9	47.7
	Medium (3)	37	37.2	25
	High (2)	6.5	4.7	9.1
Q3	Very high (1)	2.2	4.7	0
	Very low (1)	6.5	4.7	9.1
	Low (2)	19.6	27.9	29.5
	Medium (3)	15.2	30.2	36.4
	High (4)	34.8	25.6	20.5
	Very high (5)	23.9	11.6	4.5

thermal comfort of the respondent. These questions were designed based on the five-item Likert scale with scores ranging from 1 (very low) to 5 (very high) (Table 1). The questions included in this section were: (1) How thermally comfortable do you feel (neither too hot nor too cold)? (2) How hot do you feel? (3) How much do you feel

the cooling effect of the Retiro Park? (4) How heat-tolerant are you?

The responses to this part of the questionnaire were analyzed in SPSS using statistical methods such as One-Way Analysis of Variance (ANOVA) to compare the PET values of the three examined nodes on the south side of the Retiro Park.

The second part of this section was dedicated to demographic and personal information, including age, gender, type of clothing, and activities. Given the importance of information collected in this part of the questionnaire for the calculation of PET [59], for each respondent, the type of clothing was quantified based on the Clo index and the type of activity was quantified based on relevant standards [81] (Table 1).

Results

As mentioned, the data of this study were collected on 6 days, with approximately 14-day intervals, starting from the summer of 2018. During the data collection days, the min, mid, and max temperatures inside the park, which were measured by the AEMET station [1], were 32.4 °C, 26.1 °C, and 19.7 °C on average (Table 2). As expected (from Madrid's 2015 UHI), the selected intersections had different temperatures depending on their distances from the park (Table 3). The Torrejón-Agustín Querol intersection, which was closest to the park (130 m), had the closest average temperature (33.7 °C) to the average temperature inside the park (32.4 °C). In comparison, the Gutenberg-Valderribas-Fuenterrob intersection at a distance of 280 m from the park and the Granada-Narciso Serra intersection at a distance of 520 m from the park had higher average temperatures (34.4 °C and 35.3 °C) (Fig. 3).

Considering these temperature differences, PET and PTC were also predicted to be different. After determining the PET of each respondent (based on gender,

Table 2 The individual and average values for air temperature (T_a) relative humidity (RH) and wind velocity (W) in the Retiro Park on all the measurement days

Date	Retiro parka T_a (°C)			Time of T_a in Retiro parka		HR % of park*	Wind in park*
	Min	Mid	Max	Min	Max		
22.06.2018	21.6	27.7	33.8	04:50	14:40	22.95	1.7
10.07.2018	21.5	28.4	35.2	06:00	13:50	22.95	2.2
24.07.2018	19.8	26.4	33	05:00	13:50	22.94	1.9
10.08.2018	17.5	24.4	31.3	05:40	13:40	36.8	2.2
24.08.2018	20.6	26.8	33	05:30	14:20	19.25	1.4
10.09.2018	17.3	22.8	28.3	05:20	13:45	33.55	1.9
Average	19.7	26.1	32.4	05:23	14:04	26.4	1.9

* AEMET data

Table 3 Intersection mean values for air temperature (T_a), relative humidity (RH), mean radiant temperature (T_{mrt}), wind speed (WS), PET and PTC on the all measurement days (13:30–15:20 CEST)

Date	Intersection	Time	Mean WS, m/s	Mean RH, %	Mean T_a , °C	Mean ^a T_{mrt} , °C	Mean PET, °C	Mean PTC
22 Jun	A	14:15–14:25	2.16	15.2	34.6	50.7	40.5	3.25
	B	13:55–14:05	2.68	15	36.97	53.5	43.8	3.44
	C	13:35–13:45	1.96	16.7	36.07	53.7	44.9	3.15
10 July	A	15:10–15:20	1.73	15.03	35.17	48.6	40.6	2.75
	B	14:50–15:00	1.68	16.17	35.9	51.9	42.8	2.96
	C	14:15–14:25	2.18	17.66	37.18	52.8	45	2.48
24 July	A	14:30–14:40	2.56	15.35	32.71	47.8	36.8	3.15
	B	14:10–14:20	3.01	15	33.08	49.2	37.4	3.01
	C	13:40–13:50	1.88	16.7	35.29	52.1	42.2	2.76
10 Aug	A	14:20–14:30	1.73	27.27	33.73	48.8	39.7	2.94
	B	14:00–14:10	2.11	29.31	35.28	50.8	41.7	2.74
	C	13:30–13:40	1.72	26.71	35.39	52	42.6	2.38
24 Aug	A	14:55–15:05	3	15.78	35.56	47.7	40.3	3.35
	B	14:35–14:45	2.19	15.87	35.81	49	41.6	3.03
	C	14:15–14:25	1.13	17.87	36.38	50.8	43.2	2.88
10 Sept	A	15:10–15:20	1.43	27.76	31.63	42.3	34.8	3.46
	B	14:45–14:55	1.33	28.16	31.65	43.8	35.6	3.25
	C	14:15–14:25	1.1	36.41	32.44	46.1	37.9	3.08
Average	A	14:42–14:52	2.10	19.40	33.70	47.65	38.43	3.16
	B	14:15–14:25	2.17	19.92	34.42	49.70	39.98	3.07
	C	13:51–14:01	1.60	22.01	35.26	51.25	42.29	2.79

^a The mean radiant temperature (T_{mrt}) has been calculated by RayMan 1.2

age, clothing type, and weather conditions at the time of the survey) with the software RayMan 1.2 [28], the average PET at distances of 130, 280, and 520 m from the park was calculated to 38.4 °C, 40.0 °C, and 42.3 °C, respectively. This suggests that thanks to the cooling effect of the park, citizens at the 130 m and 280 m distance from the park have, respectively, 3.9 °C PET and 2.3 °C PET less than those at the 520 m distance from the park (closer to the heat island) (Table 3).

The investigation of psychologically perceived thermal comfort, which was done with the help of questions and cognitive maps, showed that the cooling effect of the park has had a positive impact on the minds of citizens, as people living or working closer to the park were feeling more thermally comfortable than others who were farther away from the park and closer to one of the heat islands. After processing the respondent's answers to direct questions about their perception of thermal comfort (at the moment of the survey), which were scored from 1 to 5 (very low = 1, low = 2, medium = 3, high = 4, very high = 5), the results showed that the mean score decreased from 3.16 for intersection A, which was 130 m away from the park, to 3.07 for intersection B, which was 280 m away from the park, and finally to the sub-average score of

2.88 for intersection C, which was 580 m away from the park (Table 3).

The analysis of the obtained cognitive maps with the AMMA software showed that out of 133 respondents, 108 people or about 81% marked the park. This means that the majority of citizens know Retiro Park as the place where they would feel the highest degree of thermal comfort. As expected, it was found that the people at the Andrés Torrejón-Agustín Querol intersection had the highest rate of reference to the park (91.3%). In comparison, 81.4% of people at the Gutenberg-Valderribas-Fuenterriabía intersection and 70.5% of people at the Granada-Narciso Serra intersection mentioned the park. The last figure is still quite high considering the relatively long distance of the Granada-Narciso Serra intersection from the park. The results of the AMMA analysis of the obtained maps were also plotted in the form of color spectra showing the places most frequently marked by citizens. These plots also show that on every data collection day, the Retiro Park was more frequently mentioned than any other public space in the study area (Fig. 4).

Since the two main variables of this study were PET and PTC, statistical tests were used to find out whether there is any significant difference between the three nodes in terms of these indexes.

PET differences between the three nodes

One-Way Analysis of Variance (ANOVA) was used to compare the PET values of the three investigated area on the southern side of the Retiro. After this analysis, in cases where there were significant differences between means ($P < .05$), Tukey's honest significance test, which is a Post Hoc test, can be used to find the source of significant difference between response levels [13] (Table 4).

Since the results of ANOVA showed a significant difference between the average PETs of nodes A, B, and C (P -value $< .05$), Tukey's test was used to determine which of the response levels had a significant difference (Tables 5 and 6).

The above results can be interpreted as the presence of a significant difference between the average PETs of all three points, i.e. A, B and C, located respectively at the 130, 280 and 520 m distance from the park. Based on these statistical results, it can be confidently claimed that the cooling effect of the Retiro Park reduces PET and increases thermal comfort in nearby areas.

PTC differences between the three nodes

As mentioned earlier, the data collected by the questions included in the questionnaire were used to determine PTC. As with PET, ANOVA Analysis was used to compare PTC in the three nodes in the southern neighborhoods of the Retiro Park (Table 7).

Since the results of ANOVA showed a significant difference between PTC in different nodes (P -value $< .05$), again, Tukey's test was used to identify the source difference between the response levels. The results of this test are provided in the tables below (Table 8 and 9).

The above results suggest that there is a significant difference between average thermal comfort in the Andrés Torrejón-Agustín Querol intersection (intersection A), which is 130 m away from the park and the Granada-Narciso Serra intersection (intersection C), which is farther away from the park and closer to the heat island. This test proves that the cooling effect of the park is well perceived by the people living or working close to the park, causing them to have a significantly different level of PTC than those living or working further away from

Table 4 ANOVA PET analyses in the three investigated selected points

	Sum of squares	df	Mean square	F	P-value
Between groups	338.465	2	169.233	24.256	.000
Within groups	906.988	130	6.977		
Total	1245.453	133			

the park. However, the effective factors which have a significant role in the intensity and distance of park cooling effect and consequently its thermal comfort should be discussed.

Discussion

Research has shown that because of factors such as low albedo [91], extensive shading [82], and moisture generation and evaporation from leaf surfaces [88], the space within a park often has a lower ambient air temperature than the surrounding environments [69, 93]. The results of the present study showed that during the data

Table 5 Multiple Comparisons Tukey PET analyses in the three investigated intersections

(I) Intersection	(J) Intersection	Mean difference (I - J)	Std. error	P-value	95% confidence interval	
					Lower bound	Upper bound
A	B	-1.55111 ^a	.56029	.018	-2.8795	-.2227
	C	-3.86057 ^a	.55699	.000	-5.1811	-2.5400
B	A	1.55111 ^a	.56029	.018	.2227	2.8795
	C	-2.30946 ^a	.56641	.000	-3.6523	-.9666
C	A	3.86057 ^a	.55699	.000	2.5400	5.1811
	B	2.30946 ^a	.56641	.000	.9666	3.6523

^a The mean difference is significant at the .05 level**Table 6** Tukey PET analyses in the three investigated intersections (A, B and C)

Tukey HSD				
Intersection	N	Subset for alpha = .05		
		1	2	3
A	46	38.4326		
B	43		39.9837	
C	44			42.2932
P-value		1.000	1.000	1.000

Table 7 ANOVA PTC analyses in the three investigated selected points

	Sum of squares	df	Mean square	F	P-value
Between groups	1.790	2	.895	3.299	.040
Within groups	35.272	130	.271		
Total	37.062	133			

collection days (June 22, July 10 and 24, August 10 and 24, and September 10), the average maximum temperature of the Retiro Park at noon hours (13:40–14:40) was

32.4 °C, but at the same time, the average air temperature at the distance of 520 m from the park was about 35.3 °C. Studies carried out in various parts of the world have shown that large urban parks (> 10 ha) can reduce the air temperature by an average of 1–2 °C within a radius of 350 m [7]. In the present study, it was found that the cooling effect of the Retiro Park on the neighborhoods to its south has led to a 0.9 °C reduction in air temperature within the 280 m distance and a 1.6 °C reduction in air temperature within the 130 m distance of this park (compared to air temperature in the nearest heat island), which is in areas closer to the park. At a distance of 130 m, it was 1.6. Indeed, the findings of this study confirm that the Retiro Park, like other large parks, generates a cooling effect that can reduce the temperature of its surrounding area. However, the focus of this study was the impact of this cooling effect on the thermal comfort of citizens from both physiological and psychological perspectives; a matter that was explored with the help of well-established tests and standards.

Influential factors on park cooling effect

Other studies in the northern [7, 9–11] and western [8] sides of Retiro Park in Madrid have shown that the park cooling effect can reduce the air temperature during

Table 8 Multiple Comparisons Tukey PTC analyses in the three investigated intersections

(I) Intersection	(J) Intersection	Mean Difference (I - J)	Std. error	P-value	95% confidence interval	
					Lower bound	Upper bound
A	B	.08784	.11049	.707	-.1741	.3498
	C	.27693 ^a	.10984	.034	.0165	.5373
B	A	-.08784	.11049	.707	-.3498	.1741
	B	.18909	.11170	.212	-.0757	.4539
C	A	-.27693 ^a	.10984	.034	-.5373	-.0165
	B	-.18909	.11170	.212	-.4539	.0757

^a The mean difference is significant at the .05 level

Table 9 Tukey PTC analyses in the three investigated intersections (A, B and C)

Intersection	N	Subset for alpha = .05	
		1	2
C	44	2.8807	
B	43	3.0698	3.0698
A	46		3.1576
P-value		.206	.708

the summer days at a distance further from the park (Fig. 6). That is, in the northern area, the cooling effect of the park up to a distance of 665 m can reduce the

air temperature compared to the area located in UHI between 0.6 and 1.3 °C [7, 9–11]. This effect is also able to reduce the air temperature in the western part of the park to the range of located at 855 m (adjacent to UHI) between 2.4 and 2.8 °C [8]. Owing to these changes, it is questionable that what role environmental factors play in the distance and intensity of the cooling effect of the park in its surroundings. The environmental natural and artificial factors around the park (wind, topography, urban configuration, aspect ratio, etc.) have a significant role in park cooling effect [94, 96]. Because the prevailing wind direction was shifty during data collection, it was not considered in this study, but other

Fig. 5 Urban configuration of the northern area, western area, and southern area of Retiro Park **Fig. 6** The topographic map (right) and UHI map of Madrid [66] (left)

important environmental factors such as urban structure and topography were discussed.

Urban configuration

The northern area (Salamanca) and the southern area (Pacífico) of Retiro Park both have a structured urban configuration. The Cortes neighborhood is located on the western side of the park situated in the old part of Madrid and has an organic structure (Fig. 5). Based on the previous research about the role of urban texture in reducing air temperatures [27, 84, 98] and the results of this study, organic urban structures due to its structural features, can improve airflow, thereby reducing air temperatures. Accordingly, it can be said that the cooling effect of the park is paramount in the western area than in other areas (855 m).

Topography

Furthermore, the topographic map of Madrid showed that the two northern and western areas of Retiro Park are at a higher altitude than the southern area. This difference in height in Pacífico area (southern area) varies between 40 and 60 m compared to the western area and 55 to 70 m compared to the northern area (Fig. 6; right map). By comparing the topographic map with UHI map, the impact of height on the intensity and the distance of the park cooling effect was illustrated (Fig. 6). Being in a lower elevation area according to studies on the effect of topography on urban heat [2, 40] can make an urban area warmer. Thus, it can be said that the southern area of the park is warmer than the northern and western areas due to the difference in height (average 35 m), as a result, the distance of the cooling effect in the urban fabric is less than that of the other two areas.

Aspect ratio

However, the most important finding of this study is thermal comfort. On the northern side of Retiro Park, the PET amount of in the area where there is a park cooling effect is on average 2 °C to 2.3 °C less than the area located in UHI [7, 9–11]. On the western side, the rate of PET reduction where the park cooling effect exists is 3.9 °C. According to the results of this study, the cooling effect in the south of Retiro Park has resulted in PET with on average between 2.3 and 3.9 °C less than the area located on UHI. Since this difference in the southern part of the park is akin to other areas, it illustrates that the topographic factor and urban structure cannot be considered as effective variables on thermal comfort. As the southern area, in spite of the differences in height and the urban structures, in terms of perceived thermal comfort, has similar behaviour to other areas. The data collected in all three ranges were performed at the points where

the aspect ratio (H/W) was most similar to each other [7–11]. As the buildings of all three areas had the same height system (buildings of 5–6 floors), and the dimensions of the streets in the places where the data were collected (especially the northern and southern areas) were very similar, these similarities are also reflected in the PET difference. Aspect ratio (H/W), which is an important factor in the intensity of sunlight and shading, is among influential elements on perceived thermal comfort [4, 36]. Since the nature of such studies is to ask people and receive information from them, the respondents were overshadowed at all stages of data collection. Accordingly, the effect of aspect ratio (H/W) on the thermal comfort of residents has played a more noticeable role than other factors.

The elements inside a park can also play a significant role in the CEI of that park [82]. However, considering the limitations of this study and since its main goal was to prove the cooling effect of the park on the thermal comfort of citizens from physiological and psychological perspectives, we did not investigate the impact of internal components of the park. In previous studies, the effect of the quality of vegetation, water features, and other elements within the park on thermal comfort inside the park has been explored [91], but future studies need to accurately examine the effect of these factors on thermal comfort outside the park so that the results can be used to improve the design of urban parks for stronger cooling effects and increased thermal comfort generation in the surrounding urban landscape.

These days in the field of urban planning the issue of sustainable development and the 2030 Agenda for Sustainable Development has been of paramount importance. The results of this study indicated that the development and expansion of urban green spaces can be effective in achieving the Sustainable Development Goals (SDGs). According to this study, among 17 SDGs goals, the third goal (good health and well-being), the eleventh goal (sustainable cities and communities), and the thirteenth goal (climate action) are achievable. Given the potential of urban green space cooling effects in providing thermal comfort and the importance of sustainable development, appropriate programs to develop and improve the quality and quantity of green spaces are required.

Conclusion

In the present study, it was found that the cooling effect of the Retiro Park on the neighborhoods to its south varies with the distance from the park and diminishes at the distance of 520 m, which falls in the domain of a heat island. The cooling effect intensity (CEI) of the park is higher in the areas closer to the park, causing a 1.6 °C

reduction in air temperature within the 130 m distance and a 0.9 °C reduction in air temperature within the 280 m distance of the park compared to Granada-Narciso Serra intersection (520 m away from the park).

The results showed that any increase or decrease in the CEI of the Retiro Park will change the level of thermal comfort of citizens who live or work near the park from both physiological and psychological perspectives. The amount of PET within the 130 m distance of the park was 4% less than the PET at the 280 m distance and 9.3% less than the PET at the 520 m distance, which means citizens within this distance of the park enjoy higher physiological thermal comfort. Also, the PET at the 280 m distance from the park was 5.4% less than the PET at the 520 m distance.

The analysis of cognitive maps obtained from citizens to study the impact of the park's cooling effect on their perception of thermal comfort showed that more than 81% of respondents had a mental image of the park as the place that would provide them with the highest degree of thermal comfort. This rate was above 81% and 91% in the two districts that were nearest to the park and did not fall below 70.5% in the district that was farther from the park. The total score of the questionnaire, which was used as a direct measure of PTC, showed that citizens in the area with the highest CEI had the highest perception of thermal comfort from the psychological perspective and citizens in the area with the lowest CEI had the lowest PTC.

The results of this study demonstrate the critical role of large urban parks in generating thermal comfort for citizens from both physiological and psychological perspective. Considering the ongoing and upcoming effects of climate change on the temperature of densely populated urban centers, future studies need to focus on finding practical solutions to strengthen the cooling effect of urban parks and expand their area of effect in line with the objectives of sustainable urban development.

Abbreviations

UHI: Urban heat island; CEI: Cooling effect intensity; PET: Physiological equivalent temperature; PTC: Perceived thermal comfort.

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Authors' contributions

Conceptualization, FA and EH; methodology, FA and ES; software, FA and AM; validation, FA, ES and EH; formal analysis, FA and AM; investigation, FA; data curation, AM and ES; writing—original draft preparation, FA and ES; writing—review and editing, EH and AM; visualization, FA and AM; supervision, EH, AM, and ES. All authors read and approved the final manuscript.

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Ethics approval and consent to participate

In this study, the data are anonymized. Authors would like to confirm that all procedures performed in the research involving participants were in accordance with the ethical standards of the national research committee of Universidad Politécnica de Madrid and its later amendments or comparable ethical standards. The data and also the approval of the ethics committee of Universidad Politécnica de Madrid will be available upon request.

Consent for publication

Authors consent for the publication.

Availability of data and materials

Data are available upon request.

Competing interests

The authors declare that they have no competing interests.

Author details

¹ Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid-UPM, 28040 Madrid, Spain. ² School of Engineering and Built Environment, Griffith University, Gold Coast 4222, Australia. ³ Kalman Kardo Faculty of Electrical Engineering, Obuda University, Budapest 1034, Hungary. ⁴ School of Economics and Business, Norwegian University of Life Sciences, 1433 Ås, Norway. ⁵ Thuringian Institute of Sustainability and Climate Protection, 07743 Jena, Germany.

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E. ANALYSIS AND SUMMARY OF RESULTS

This chapter presents a summary of each of the stages into which this work is organized and the discussion of results.

E.1. Stage 1. Identification and classification of the urban green spaces cooling effects types and their attributes in order to choose a Case study

This stage includes base studies in which the types of green spaces and their characteristics were assessed to obtain the necessary information to select an appropriate case study for this research.

This part of research reviewed the recent articles related to the impact of urban green spaces (UGSs) on the creation of cooling effect, reduction of UHI, and provision of thermal comfort in urban environments. In the past ten years, the growing attention to the importance of green spaces, and especially parks, in the creation of cooling effect has led to the publication of many research works with different methodologies and at different scales in relation to this subject. Given the high number and variety of articles published on this subject, we categorized the works based on methodology and scale of research. Although the literature contains a number of review studies on the subject of urban parks and green spaces ([Bowler et al., 2010](#); [Jamei et al., 2016](#); [Taleghani, 2018](#); [Bartesaghi Koc, Osmond, and Peters, 2018](#)), they have taken a comprehensive perspective and investigated the articles on the entirety of green infrastructure. Hence, in these studies, the research on urban parks and green spaces has been reviewed as a part of an extensively broader literature and there is no detailed categorization in regard to the methods and findings of the studies specifically focused on this subject. Considering this gap in the literature and the importance of the UGS cooling effect for urban planning, in this phase we attempted to review the specific literature in regard to UGSs and their impact on cooling effect.

In the reviewed articles, the impact of green spaces and their specifications were investigated through different approaches including the use of field observation and temperature sensors for accurate cooling effect intensity (CEI) and cooling effect distance (CED) measurement as two main criteria of UGS cooling effect and the use of satellite maps and remote sensing methods to investigate the collective impact of a group of UGSs on large expanses of a city. In addition, a relatively new method in this field of research is a computer simulation, which allows research and analysis variables to be adjusted as desired.

In the first step, we reviewed the articles on the combined impact of a group of UGSs on a part or the entire area of a city. The studies covered in this part were mostly based on remote sensing methods, with the exception of a few works that utilized field observations as well.

The next step of this study was dedicated to the articles where the location, size, and shape of the studied UGSs are specifically mentioned. These articles are mainly based on the studies of one or several specific parks, using field data collected from temperature sensors installed in and around the case, and by collecting PET data from residents to estimate the cooling effect. Some of these studies have also employed ENVI-met software, satellite imagery and remote sensing data for deeper analysis. For better categorization, these articles were divided into three subcategories based on the size of the studied case. A summary of results reported by these articles is presented in [Table 2](#).

Table2 , Summary of studies investigating the cooling effect of particular UGSs with known specifications

Size	General features	Shape	Characteristics	Shape	Characteristics
a Big Size Parks	<ul style="list-style-type: none"> • Mature and tall trees with high percent of canopy • Water body • Different zones and landscapes with various vegetation types		147 ha CED $\approx$ 200-300m CEI $_{max}$ $\approx$ 1.9 °C		21.42 ha CED $\approx$ NM CEI $\approx$ 1-2°C
		111 ha CED $\approx$ 20-440 m CEI $\approx$ 1.1°C - 4 °C		26.01 ha CED $\approx$ NM CEI $\approx$ 1°C
		102 ha CED $\approx$ NM CEI $\approx$ 2°C		1,507 ha CED $\approx$ NM CEI $\approx$ NM
		0.2 ha CED $\approx$ 0 m CEI $\approx$ 0.34 °C		2.9 ha CED $\approx$ 45-149 m CEI $\approx$ 0.59 °C
b Medium Size Parks	<ul style="list-style-type: none"> • Different size of trees (medium and high) • various vegetation types • small water body		0.3 ha CED $\approx$ 1 m CEI $\approx$ 0.32 °C		3.8 ha CED $\approx$ 10-85 m CEI $\approx$ 0.77 °C
		0.8 ha CED $\approx$ 22-44 m CEI $\approx$ 0.57°C		10.1 ha CED $\approx$ 173-179 m CEI $\approx$ 0.56 °C
		2.5 ha CED $\approx$ 46-218 m CEI $\approx$ 0.42 °C		12.1 ha CED $\approx$ 329-328 m CEI $\approx$ 0.98 °C
		0.07 ha CEI $\approx$ 1.7°C		0.06 ha CEI $\approx$ 1.5°C
c Small Green Spaces	<ul style="list-style-type: none"> • Low tree diversity • Low vegetation diversity • Has an enclosure space		0.01 ha CEI $\approx$ 0.5°C		0.2 ha CEI $\approx$ 4.1°C
		0.3ha CEI $\approx$ 4.5°C		0.093 ha CEI $\approx$ 2°C

The last category of articles included the studies that have utilized computer simulation. While being a relatively new method in this line of research, computer simulation has greatly

facilitated the qualitative analyses that put more emphasis on the effect of vegetation type and quality and the placement of green spaces, rather than CED and CEI measurements. Although simulation is a convenient and quick method of analysis, it is not as accurate and reliable as the study of aerial maps and field observations, and is only suitable for developing initial hypotheses and assumptions and studying how the change of scenarios and variables affect the responses. As a result, the articles included in this section lack specific CED and CEI measurements. Overall, it can be concluded that each of the above methods has a set of unique features, which make it preferable for research at certain scales or with certain purposes.

The result of this stage revealed that large urban parks, due to their vast area and vegetation diversity, have a more cooling effect. According to the studies, large parks with an area of more than ten hectares have an average cooling effect of 1-2 ° C, affecting an average of 350 m a distance; thereby creating thermal comfort in the area around.

According to the results of the review, in this research, it was intended to choose large urban park by area more than 10 ha for examining of the maximum expected PCE, in addition with regard to the classification of cooling effect assessment methods, the field measurement due to accuracy and proportion for the specific case study, has been selected as the method of this study among remote sensing methods and computer simulation methods.

In this study we measured the cooling effect of the Retiro Park during the six hot summer of Madrid on 22 June, 10 and 24 July, 10 and 24 August and 10 September 2018 from 10:30 AM to 3:30 PM Central European Summer Time (CEST), in the three areas of the north, west and south of the Retiro Park. Regarding the urban heat island (UHI) map of Madrid in 2015 (Núñez Peiró, Sánchez-Guevara Sánchez, & Neila González, 2017; Núñez Peiró et al., 2016), the places were selected as data collection sites. In fact, the selected places were located between the Park Retiro and the UHI of Madrid. In each of the selected regions (North, West, and South of the Retiro Park) three locations were selected in different distances. Thus, during the hot summer days 9 points around the Retiro Park were surveyed (Figure 8).

As can be seen in Figure 8, the North, West, and South regions are named N, W and, S, respectively. In each of these regions, three locations were identified as 1 to 3 and were located in different temperature ranges such that N1, W1, S1 in the temperature range of yellow and at a distance of 150, 445 and 130 m from the park respectively. N2, W2, S2 are located in the orange temperature range and 380, 600 and 280 m from the Retiro Park respectively. N3, W3,

S3 were placed in a red temperature range, and the distance between these points from park were respectively 665, 855 and 520 m.

Figure8 . Madrid's UHI map on 26 July 2015 (ABIO, 2018). The selected northern, western and southern points of the Retiro Park. Parts N1, W1 and S1 are in the yellow zone, Parts N2, W2 and S2 are in the orange zone and parts N3, W3 and S3 are in the red zone, close to one the thermal islands of Madrid.

The investigation area in the northern side of Retiro Park is located in the Salamanca neighborhood. The northern area of Retiro Park, due to its well-organized form, has more regular urban-type compared to other areas (east and south). Based on the temperature zones of the updated thermal map of Madrid's urban heat islands in 2015 (Núñez Peiró, Sánchez-Guevara Sánchez, and Neila González, 2017), three intersections located in the Salamanca neighborhoods in the north of Retiro Park along the Lagasca Street, were chosen. These sites were located at 150 meters (N1), 380 meters (N2) and 665 meters (N3) from the park at Lagasca intersection with the Conde de Aranda, Jorge Juan and Hermosilla streets, giving zones of different temperature ranges (yellow, orange and red; Figure 8). These types of selected local intersections represent most of Retiro Park's northern area intersections.

All three assessed intersections were selected based on a common geometric configuration. The considered geometric configuration included an enclosure, sky view factor (SVF), and street height and width. The considered material structure included the ground surface coverage material, pavement material and building facade material, which were similar in all three regions; the ground surface material in all three regions was asphalt; the pavement material was gray tiles and the building material is mostly red-colored bricks and bright cement (Figure 9). The vegetation was also considered as well as the aforementioned parameters, so the

Figure9 . Street view of the three intersections; N1, N2 and N3, as well as fisheye shots

selected regions were also similar in terms of this parameter.

The investigation area in the western side of Retiro Park is located in the Cortes neighborhood close to the historical core of Madrid, this area falls in the domain of Atocha heat island. The Antón Martín district, which is one of Madrid's hotspots, 855 meters (W3) away from the west side of the park (Sánchez-Guevara Sánchez, Núñez Peiró, & Neila González, 2017). When selecting these points, an attempt was made to choose the open spaces with the highest similarity to Antón Martín district in terms of spatial and qualitative features. The places selected for this purpose were the open space at the intersection of Moratín Street and María Street and the open space of the CaixaForum building (at the intersection of Almadén and La Alameda streets) positioned respectively 600 (W2) and 445 (W1) meters west of the park.

All three of the mentioned areas are urban Nodes and open spaces formed by the intersection of several roads. Node W1 is rectangular shaped and Nodes W2 and W3 are triangular, with respective areas of 300m², 265m², and 260m². Although Node W1 differs from Node W2 and

W3 in both shape and area, the three points are generally similar in terms of enclosure, sky view factor (SVF), vegetation, flooring type (stone pavement and gray tiles), and adjacent buildings (mostly red brick and stone). It should be noted that the examined area contains no green space or park (small or large), other than Retiro Park (Figure 10).

Figure10 . Street views of the three investigated nodes; W1, W2 and W3, and fisheye shots

The investigation area in the southern side of Retiro Park is located in the Pacífico neighborhood. According to the Madrid's UHI map (Núñez Peiró, Sánchez-Guevara Sánchez, and Neila González, 2017), there is a heat island near the Granada-Narciso Serra district located 520m away from the southern edge of the park (Román et al., 2017). For a more precise examination of the cooling effect of the park, two areas at the intersection of Gutenberg-Valderribas-Fuenterrabía and Torrejón-Agustín Querol, which are located in the orange and yellow zones at the 280m and 130m distance from the park, were also included in the study. All selected intersections are physically and structurally identical.

The southern side of the Retiro Park has a regular and grid-like texture mostly consisting of 7-story buildings. The façade of most buildings in this area is made of red brick. The roads of the area are asphalt and the sidewalks are mostly made of bright colored mosaic tiles (Figure 11).

Figure 11 . Street views of the three investigated intersections; S1, S2 and, S3 and fisheye shots

E.2. Stage 2. Experimental collection of data and considering analytical methods for thermal comfort assessment from physiological and psychological perspective

Due to the selection of the Retiro Grand Park as a case study, and studies on the classification of PCE measurement methods, the field measurement method was determined to perform this study. The microclimatic data including wind speed, air temperature, humidity, as well as individual characteristics of the type of clothing, type of activity, gender, age, weight and height were required to evaluate the degree of thermal comfort in physiological terms. It was also necessary to psychologically assess the level of thermal comfort in the environment in which they were perceived in order to assess their psychological well-being. Also, the use of cognitive maps as a method used in environmental psychology can provide us with an accurate image of how people perceive urban spaces that have thermal comfort.

According to the purpose of this study, there were two important criteria for analysis and study, which included the study of thermal comfort in terms of physical and psychological perspective. The PET (physiological equivalent temperature) physical index was used to assess thermal comfort. All microclimatic data (temperature, wind speed and humidity) as well as questions related to individual characteristics in the questionnaire (age, sex, clothing, activity, etc.) were collected to evaluate this indicator.

The PTC (perceived thermal comfort) index was considered to assess psychological comfort. All data related to the questionnaire questions, which directly asked people about the level of perceived thermal comfort, were used to evaluate this index. Data related to mental maps in the questionnaire were also used to assess the influence of the cooling effect of Retiro Park on dwellers' perceptions and mentality.

Both microclimatic and survey were collected on clear sunny days. At each investigated location, data collection was performed over a 10 minute period, during which one group collected temperature data and the other group conducted the survey. Microclimatic data of the Retiro Park has been collected through the fixed station of AEMET inside the park. It should be mentioned that the wind direction were differed in measuring days (22 Jun, N; 10 Jul, NNE; 24 Jul, SW; 10 Aug, NNE; 24 Aug, N; 10 Sep, N), due to this issue assessing the role of wind direction was inconclusive.

The temperature data have been conducted over a period of six days and approximately every two weeks. During the field measurement, the sky was flat and without clouds (sunny). Air temperature (T_a), relative humidity (RH), and Wind speed (WS) were collected by mobile microclimate station. All equipments were installed at a distance of 1.5 m from the ground (Table 3 and Figure 12). Fish-eye photos were also taken by a fisheye camera to assess Sky View Factor (SVF). T_{mrt} data and Fish-eye images to evaluate the PET index were calculated by Ray man 1.2 (Matzarakis, Rutz, and Mayer, 2010).

In fact, the Ray man output, which is in the form of a PET, is based on other calculations, such as the T_{mrt} and the SVF, which is initially calculated by the software.

The SVF calculation consists of the following three equations: (Hämmerle et al., 2011a; b; 2014).

Formula 1

$$\Psi_s = \sum_{i=1}^n \sin^2 \cdot \beta_i \cdot \left(\frac{a_i}{360^\circ} \right)$$

Formula 2

$$\omega_{proj} = \sin(\varphi) \cdot \left(\frac{\varphi}{90^\circ} \right)^{-1}$$

Formula 3

$$\omega_{planar} = \omega_{proj} \cdot \cos(\varphi)$$

The T_{mrt} calculation consists of the following six equations:

Formula 4, (Thorsson et al. 2007)

$$T_{mrt} = \left[(T_g + 273.15)^4 + \frac{1.1 \cdot 10^8 \cdot v^{0.6}}{\varepsilon_g \cdot diam_g} \cdot (T_g - T_a) \right]^{0.25} - 273.15$$

Formula 5, (Verein Deutscher Ingenieure (VDI), 1998)

$$\overline{P_h} = \alpha_{abs,p} \cdot \sum_{i=1}^6 P_{sw,p} \cdot Pr_i + \varepsilon_{lw,p} \cdot \sum_{i=1}^6 P_{lw,p} \cdot Pr_i$$

Formula 6, (Chen, Lin, and Matzarakis, 2014; Krüger, Minella, and Matzarakis, 2014)

$$T_{mrt} = \sqrt[4]{\frac{\overline{P_h}}{\varepsilon_{lw,p} \cdot \sigma}} - 273.15$$

Formula 7, (Matzarakis, Rutz, & Mayer, 2010; Matzarakis et al. 2007; Lindberg, Holmer, and Thorsson, 2008)

$$P_s = \sigma \cdot A_s \cdot T_s^4 + \alpha_{abs,s} \cdot D_s$$

Formula 8,

$$\varepsilon_{lw,p} \cdot \sigma \cdot (T_{mrt}^4 - T_{cl}^4) = \sum_{i=1}^n (\varepsilon_{lw,p} \cdot \varepsilon_{lw,i} \cdot \sigma \cdot T_{s,i}^4 + \alpha_{abs,s,i} \cdot D_{s,i}) \cdot Pr_{p,i} - \varepsilon_{lw,p} \cdot \sigma \cdot T_{cl}^4$$

Formula 9,

$$T_{mrt} = \left[\sum_{i=1}^n \cdot \left(\varepsilon_{lw,i} \cdot T_{s,i}^4 + \frac{\alpha_{abs,s,i} \cdot D_{s,i}}{\varepsilon_{lw,p} \cdot \sigma} \right) \cdot Pr_{p,i} \right]^{0.25}$$

The PET calculation consists of the following below equations:

Formula 10, (Höppe, 1999)

$$M + Wo + R + C + E_{sk} + E_{res} + E_{sw} + S = 0$$

Table 3, Mean values for air temperature (Ta), relative humidity (RH) and wind velocity (W) in the three Part of Retiro Park (10:40–15:20 CEST)

Date	Part	Time	Mean Wind, m/s	Mean RH, %	Mean Ta, °C	T _{mrt} ^a , °C	Mean PET ^a , °C
22 Jun	N3	10:40-10:50 am	1.43	29.1	29.26	48.4	35.3
	N2	11:00-11:10 am	1.15	29.27	28.87	48.7	35.8
	N1	11:30-11:40 am	0.80	32.04	27.81	4 8	33.7
	W3	12:15-12:25 pm	2.5	24.96	35.5	54.1	43.1
	W2	12:40-12:50 pm	1.57	20.05	33.17	51.8	39.3
	W1	13:00-13:10 pm	2.16	20.13	31.64	50.3	37.2
	S3	13:35-13:45 pm	0.96	16.7	36.07	53.7	44.9
	S2	13:55-14:05 pm	2.68	15	36.97	53.5	43.85
	S1	14:15-14:25 pm	2.16	15.2	34.6	50.7	40.58
10 July	N3	11:15-11:25am	1.43	33.96	29.8	49.4	36.3
	N2	11:42-11:52 am	1.16	22.1	29.7	49.3	36.5
	N1	12:00-12:10 am	1.36	29.71	29.4	49.3	35.8
	W3	12:45-12:55 pm	2.25	22.34	34.69	53	42.0
	W2	13:10-13:20 pm	1.57	21.8	34.5	52.6	42.2
	W1	13:35-13:45 pm	1.87	20.13	34.23	51.6	41.1
	S3	14:15-14:25 pm	2.18	17.66	37.18	52.8	44.8
	S2	14:50-15:00 pm	1.68	16.17	35.9	51.9	43.0
	S1	15:10-15:20 pm	1.73	15.03	35.17	48.6	40.6
24 July	N3	10:40-10:50am	1.36	21.71	29.45	49	35.7
	N2	11:10-11:20 am	1.43	30.25	28.1	47.7	33.9
	N1	11:30-11:40 am	1.43	30.56	27.74	47.6	33.5
	W3	12:15-12:25 pm	2.23	24.47	32.57	51.3	38.9
	W2	12:40-12:50 pm	2.53	20.22	31.03	49.6	35.7
	W1	13:00-13:10 pm	1.15	22.36	30.87	49.7	37.8
	S3	13:40-13:50 pm	1.88	16.7	35.29	52.1	42.2
	S2	14:10-14:20 pm	3.01	15	33.08	49.2	37.6
	S1	14:30-14:40 pm	2.56	15.35	32.71	47.8	36.9
10 Aug	N3	10:40-10:50 am	1.43	18.16	25.12	43.8	28.9
	N2	11:00-11:10 am	1.72	41.05	23.77	43.1	26.8
	N1	11:20-11:30 am	2.47	43.45	23.22	42.7	23.4
	W3	12:15-12:25 pm	1.64	30.47	34.38	52.5	42
	W2	12:35-12:45 pm	1.81	28.09	33.64	51.6	40.5
	W1	12:55-13:05 pm	2.36	28.81	33.14	59	42.9
	S3	13:35-13:45 pm	0.96	16.7	36.07	53.7	44.9
	S2	13:55-14:05 pm	2.68	15	36.97	53.5	44.2
	S1	14:15-14:25 pm	2.16	15.2	34.6	50.7	40.5
24 Aug	N3	10:50-11:00am	2.35	38.81	26.63	44.4	28.8
	N2	11:15-11:25 am	1.13	38.13	26.2	44.5	29.3
	N1	11:35-11:45 am	1.29	37	26.05	44.3	27.3
	W3	12:40-12:50 pm	1.54	22.01	34.96	52.2	42.8
	W2	13:10-13:20 pm	1.52	27.07	30.86	48.1	36.7
	W1	13:30-13:40 pm	1.31	27.82	30.77	47.5	36.5
	S3	14:15-14:25 pm	2.18	17.66	37.18	52.8	45
	S2	14:50-15:00 pm	1.68	16.17	35.9	51.9	42.8
	S1	15:10-15:20 pm	1.73	15.03	35.17	48.6	40.6
10 Sep	N3	10:45-10:55 am	1.5	56.71	23.41	40.6	26.1
	N2	11:15-11:25 am	1.36	52.45	23.13	41	25.8
	N1	11:35-11:45 am	1.91	51.15	21.73	39.8	22.2
	W3	12:20-12:30 pm	1.3	33.95	32.33	49.1	38.7
	W2	12:50-13:00 pm	1.33	40.79	25.84	43.1	29.7
	W1	13:15-13:25 pm	1.43	41.3	25.62	42.7	28.8
	S3	13:40-13:50 pm	1.88	16.7	35.29	52.1	42
	S2	14:10-14:20 pm	3.01	15	33.08	49.2	37.4
	S1	14:10-14:20 pm	2.56	15.35	32.71	47.8	36.8

The questionnaire items were designed in three parts. The first part was designed to examine the respondent's cognitive image of thermal comfort in the area. In this part, respondents were provided with a map according to the selected part in northern, western and southern neighborhood of Retiro Park and asked to mark the areas where they would feel thermal comfort (Figure 13). To prevent unintended bias in responses, this map was drawn so that the park area would occupy a small portion of the map and not attract more attention than other areas (Figure 14). The resulting mental maps were examined using the software Aram Mental Map Analyzer (AMMA). In this software, the park area was introduced as the base point and given a score of 100, and other areas were not scored. Thus, the awarded score was 100 if the park area was marked and zero otherwise (no matter what other points were marked). In this way, after averaging the scores, the percentage of people specifically mentioning the park was obtained.

The second part of the questionnaire included four brief questions about the perceived thermal comfort at the place of encounter; How thermally comfortable do you feel in this place (neither hot nor cold)?; How hot do you feel in this place?; How much do you feel the cooling effect of Retiro Park in this place?; How tolerable is the heat of this place for you?

The answers to these questions were designed based on a 5-point Likert scale (Very high = 5, high = 4, Medium = 3, Low = 2, Very low = 1). The total scores of the responses to these questions were considered as a measure of perceived thermal comfort and were statically analyzed in SPSS. It should be noted that the answers to the second question were scored in reverse order (Very high = 1, High = 2, Medium = 3, Low = 4, Very low = 5).

The third part of the questionnaire included open-ended personal questions about age, height, weight, gender, activity level, and clothing type. These questions were included in the questionnaire because these factors can affect the person's physiological temperature and need to be clarified before assessing the PET index. The parameters that needed to be determined for PET calculations were the clothing level (clo), type of activity, and SVF. In this study, this index was determined using the software RayMan 1.2 (Fröhlich, Gangwisch, and Matzarakis, 2019; Matzarakis, Rutz, and Mayer, 2010).

In the studied areas, the most frequent types of clothing were T-shirts with shorts, T-shirts with trousers, and dresses, with Clo values of 40, 61, and 30, respectively. Also, the most frequent activities were walking, standing, and sitting, which according to standards, have

activity values of 115, 70 and 60, respectively (Streinu-Cercel, Costoiu, and Mârza, 2008) (Table 4).

Figure12 . The process of installing the equipment and collecting microclimatic data

Figure13 . Collecting the questionnaire data

A total of 423 questionnaires have been collected during the six days of 22 June, 10, 10 and 24 July, 10 and 24 August, and 10 September 2018, with part A, 145 (A1= 49, A2= 45 and A3= 51), part B, 145 (B1= 47, B2= 50 and B3= 48) and the part C, 133 (C1= 46, C2= 43, and C3= 44). The questionnaires data were analyzed by SPSS software and statistical methods. Aram Mental Map Analyzer software (AMMA) was also used to analyze mental maps.

The figure displays three overlapping maps of the Politécnica area in Bogotá, Colombia, each showing a different questionnaire form overlaid on it. The forms contain demographic and environmental perception questions.

Form 1 (Left):

Años: _____ Género: _____

1- ¿te sientes en confort térmico?

2- ¿Sientes calor?

3- ¿Notas la sensación de frescor del parque del retiro?

4- ¿Las altas temperaturas con llevaderas?

5- ¿O te cambiarías de ropa?

Que ropa llevas puesta

T-shirt ☐ Shorts ☐ Tank top ☐ Dress ☐ Gym clothes ☐
 Shirt ☐ Pants ☐ Skirt ☐ Slip ☐
 Suit ☐ Jeans ☐ Sweater ☐

Form 2 (Middle):

Años: _____ Género: _____

1- ¿te sientes en confort térmico?

2- ¿Sientes calor?

3- ¿Notas la sensación de frescor del parque del retiro?

4- ¿Las altas temperaturas con llevaderas?

5- ¿O te cambiarías de ropa?

Que ropa llevas puesta

T-shirt ☐ Shorts ☐ Tank top ☐ Dress ☐ Gym clothes ☐
 Shirt ☐ Pants ☐ Skirt ☐ Slip ☐
 Suit ☐ Jeans ☐ Sweater ☐

Form 3 (Right):

Años: _____ Género: _____

1- ¿te sientes en confort térmico?

2- ¿Sientes calor?

3- ¿Notas la sensación de frescor del parque del retiro?

4- ¿Las altas temperaturas con llevaderas?

5- ¿O te cambiarías de ropa?

Que ropa llevas puesta

T-shirt ☐ Shorts ☐ Tank top ☐ Dress ☐ Gym clothes ☐
 Shirt ☐ Pants ☐ Skirt ☐ Slip ☐
 Suit ☐ Jeans ☐ Sweater ☐

Figure14 . Different Types of the questionnaire for three investigated area

Table4 , The proportional percentages questionnaire data in the three investigated areas (North, West and, South) on all the measured days.

Variable	Categories	Percentage (%)								
		N1	N2	N3	W1	W2	W3	S1	S2	S#
<i>Age</i>	13-21	2.0	2.2	11.8	0	8	2	19.6	23.3	15.9
	22-30	26.5	20.0	13.7	2	20	19	21.7	11.6	6.8
	31-45	40.8	26.7	31.4	11	30	31	30.4	30.2	34.1
	46-60	16.3	24.4	29.4	28	20	23	13.0	23.3	20.5
	61-85	14.3	26.7	13.7	36	22	25	15.2	11.6	22.7
<i>Gender</i>	Men	67.3	73.3	51	43	50	62	47.8	55.8	56.8
	Women	32.7	26.7	49	57	50	38	52.2	44.2	43.2
<i>Q1</i>	Very low (1)	0	0	0	2	0	2	.0	2.3	4.5
	Low (2)	10.2	6.7	9.8	9	14	19	13.0	14.0	31.8
	Medium (3)	28.6	57.8	43.1	53	42	48	37.0	41.9	34.1
	High (4)	42.9	31.1	35.3	32	36	25	39.1	34.9	27.3
	Very high (5)	18.4	4.4	11.8	4	8	6	10.9	7.0	2.3
<i>Q2</i>	Very low (5)	5.9	4.4	0	4	2	4	8.7	18.6	18.2
	Low (4)	23.5	31.1	18.4	9	44	23	45.7	34.9	47.7
	Medium (3)	33.3	26.7	22.4	40	22	33	37.0	37.2	25.0
	High (2)	27.5	28.9	38.8	38	24	25	6.5	4.7	9.1
	Very high (1)	9.8	8.9	20.4	9	8	15	2.2	4.7	.0
<i>Q3</i>	Very low (1)	4.1	2.2	13.7	2	6	2	6.5	4.7	9.1
	Low (2)	8.2	20.0	25.5	13	20	27	19.6	27.9	29.5
	Medium (3)	28.6	31.1	27.5	34	38	33	15.2	30.2	36.4
	High (4)	42.9	31.1	25.5	32	20	25	34.8	25.6	20.5
	Very high (5)	16.3	15.6	7.8	19	16	13	23.9	11.6	4.5
<i>Q4</i>	Very low (1)	2.0	0	3.9	4	8	13	.0	.0	6.8
	Low (2)	10.2	15.6	25.5	11	44	27	34.8	23.3	6.8
	Medium (3)	30.6	60.0	35.3	60	36	25	32.6	32.6	34.1
	High (4)	42.9	13.3	23.5	21	10	27	19.6	27.9	34.1
	Very high (5)	2.0	.0	3.9	4	2	8	6.5	9.3	13.6
<i>Clothing</i>	Shirt and Normal Pants- 65 clo	21.1	32.2	22.8	11	10	15	21.3	6.5	13.6
	Tshirt and normal pants_61 clo	46.3	29.4	28.1	21	24	23	8.5	37.0	29.5
	shirt and Shorts-45 clo	1.7	4.4	9.8	6	6	13	6.4	6.5	6.8
	Tshirt and Shorts (or skirt)-40 clo	16.8	22.6	28.5	38	46	31	31.9	30.4	31.8
	Dress-35 clo	3.8	3.5	5.2	21	12	19	23.4	13.0	13.6
	Suiet-90 clo	8.2	4.4	1.9	2	2	0	2.1	2.2	0.0
<i>Activity</i>	Walking- 115 w	59.0	70.4	48.5	66	82	50	80.4	73.9	77.3
	Standing-70 w	15.6	24.4	30.4	9	16	31	13.0	15.2	18.2
	Sitting- 60 w	25.4	3.3	21.1	26	0	15	6.5	17.4	4.5
	Jogging-220 w	0.0	1.9	0.0	0	2	4	0.0	0.0	0.0
<i>AMMA results</i>										
	Park Not Mentioned (0)	12.2	40	49	19.1	32	43.8	8.7	18.6	29.5
	Park mentioned (100)	87.8	60	51	80.9	68	56.3	91.3	81.4	70.5

E.3. Stage 3. Analyzing the results of collected data in three investigated area

At this phase, the results of the data collected in all three surveyed areas in the north, west and south of Retiro Park, where the UHI of Madrid was located, were analyzed and summarized. As mentioned former, since the most important features of the cooling effect of the park are CEI and CED, therefore, first of all, the intensity of the cooling effect of Retiro Park at different distances from its northern, western and southern sides was investigated. According to these two features of Retiro Park, the influence of the park's cooling effect on thermal comfort from a psychological and physical point of view was investigated.

The results of the investigation indicated that during measurement days, the average amount of air temperature increased according to distance increase from the park. Air temperature (T_a) during measurement days in N1, N2, and N3 were average 25.8°C, 26.6°C and 27.1°C respectively. T_a in Part W1, W2, and W3 were 31.1°C, 31.3°C and 33.9°C, respectively. In addition in part C, similar to the other parts the T_a increased by distance from the park by average 33.7°C, 34.4°C, and 35.3°C in C1, C2, and C3 respectively (Table 5).

Table 5, Mean values for air temperature (T_a), relative humidity (RH) and wind velocity (W) in the three part of Retiro Park on all measurement days (10:40–15:20 CET)

Date	Part	Distance from Retiro Park, m	Mean T_a , °C	Mean PET ^a , °C	T_{mrt}^a , °C
Mean of Total day	A1	150	25.8	29.3	47.7
	A2	380	26.6	31.3	49.7
	A3	665	27.1	31.6	42.6
	B1	445	31.1	37.2	49.3
	B2	600	31.3	37.7	50.4
	B3	855	33.9	41.0	51.9
	C1	130	33.7	38.4	47.4
	C2	280	34.4	40.0	49.2
	C3	520	35.3	42.3	51.0

All steps of data collection were scheduled to start after 10:30 in morning and ended by average 15:00 at noon due to the Minimum and Maximum temperature inside the park in the summer of 2017 had been observed, on average, between 05:23 and 14:04 CEST (AEMET, 2018).

The first area to be measured was the neighborhood on the north side of the park (Salamanca), which typically lasted from 10:30 a.m. to 11:40 a.m. According to data from the AEMET Station, the temperature data from the northern range were close to the average daily mean temperature inside Retiro Park (26.1) during 6 days of measurement (Table 6).

Table 6 , The individual and average values for air temperature (Ta) relative humidity (RH) and wind velocity (W) in the Retiro Park on all the measurement days.

Date	Retiro park ^a T _a (°C)			Time of T _a in Retiro park ^a		HR % of park ^a	Wind in park ^a
	Min	Mid	Max	Min	Max		
22.06.2018	21.6	27.7	33.8	04:50	14:40	22.95	1.7
10.07.2018	21.5	28.4	35.2	06:00	13:50	22.95	2.2
24.07.2018	19.8	26.4	33.0	05:00	13:50	22.94	1.9
10.08.2018	17.5	24.4	31.3	05:40	13:40	36.8	2.2
24.08.2018	20.6	26.8	33.0	05:30	14:20	19.25	1.4
10.09.2018	17.3	22.8	28.3	05:20	13:45	33.55	1.9
Average	19.7	26.1	32.4	05:23	14:04	26.4	1.9

^a AEMET data

Due to the fact that the data were collected in two western and southern neighborhoods from 12:15 to 15:00 on average, the data from these areas were close to the average maximum temperature inside the park (32.4). In fact, these results showed that due to the change of daylight hours and the temperature inside the park, the intensity of the park's effect on the surrounding environment also changed, and similar behavior was observed in all measured areas at different distances of the park.

According to the results, using SPSS, the Pearson correlation test has been conducted to analyze the significance of the distance from the park and the air temperature and PET also. The results of this study revealed that T_a was correlated in all three areas by P-value <0.05. There is also a significant correlation in the overall survey in all areas (P-value <0.05). In fact, the test demonstrated the impact of distance from the park on the temperature (Table 7).

Table 7, Pearson correlation test, Distance with T_a

			T _a
Dis	Pearson Correlation		.178
	P-value		.000
	N		423
			T _a
North Dis	Pearson Correlation		.193
	P-value		.020
	N		145
West Dis	Pearson Correlation		.431
	P-value		.000
	N		145
South Dis	Pearson Correlation		.375
	P-value		.000
	N		133

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

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

E.3.1. Physical impact of Retiro Park on thermal comfort

Air Temperature has a key role in thermal comfort. Therefore, by altering the T_a by the distance from the park, the PET index as well the radiant temperature (T_{mrt}) also changes. These two indicators were calculated by Ray Man software1.2 (Matzarakis, Rutz, and Mayer, 2010). PET in North side of Retiro Park was averaged by 29.3°C in N1, 31.3°C in N2 and 31.6°C in N3. The PET index in western part W1, W2 and W3 was 37.2°C, 37.7°C, and 41.0°C, respectively. In the region of southern side of park, in S1, S2, and S3 amount of PET was 38.4, 40.0, and 42.3 respectively. T_{mrt} in N1, N2 and N3 was 47.7°C, 49.7°C, and 42.6°C respectively, in W1, W2 and W3, was 49.3°C, 50.4°C and 51.9°C respectively, and in S1, S2, and S3, the extent of T_{mrt} was 47.4°C, 49.2°C, and 51.0°C respectively (Table 5).

In a more accurate analysis using SPSS software, one way Anova was used to analyze the relationship between distances from the park and the relevant PET differences in nine investigated location in northern, western and southern side of park.

In the north side of the Retiro Park, upon every variance analysis and in the case of significant mean difference (the significant level of P-value less than 0.05), Tukey test, which is a series of post-hoc tests, were used to accurately determine which of the average of variable has a significant difference (Barnett, Neter, and Wasserman 1975). Essentially, by using this test, the thermal comfort relationship was deduced based on the PET index (Table 8).

Table8 , Anova PET analysis on the northern side of Retiro Park.

	Sum of Squares	df	Mean Square	F	P-value
Between Groups	151.731	2	75.865	3.645	0.029
Within Groups	2955.708	142	20.815		
Total	3107.439	144			

The results of the Anova test (Table 8) shows that concerning the PET index, there is lower significant error rate (0.05) and 95% confidence level of a significant difference between average PET data in each of the A, B and C points (P-value =0.029). Therefore, Tukey's post-hoc tests were used to determine whether there is a significant difference between each of the N1, N2 and N3 intersections (Table 9).

Table9 , Tukey PET analysis on the northern side of Retiro Park (N1, N2 and N3).

(I) Part	(J) Part	Mean		P-value	95% Confidence Interval		Subset for alpha = 0.05			
		Difference (I-J)	Std. Error		Lower Bound	Upper Bound	Part	N	1	2
N1	N2	-1.99624	.94199	.090	-4.2274	.2349	N1	49	29.3327	
	N3	-2.28303*	.91265	.036	-4.4447	-.1214	N2	45	31.3289	31.3289
N2	N1	1.99624	.94199	.090	-.2349	4.2274	N3	51		31.6157
	N3	-.28680	.93311	.949	-2.4969	1.9233				
N3	N1	2.28303*	.91265	.036	.1214	4.4447	Sig.		.084	.949
	N2	.28680	.93311	.949	-1.9233	2.4969				

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

The results of this studied grouping test are presented in [Table 9](#). According to this table, it can be stated that there is a significant relationship between the mean PET index at points N1 and N3. The mean PET for N1, N2 and N3 is 29.3 °C, 31.3 °C and 31.6 °C respectively. Essentially, it can be stated that the PET index difference among intersections N1 (150m) and N3 (665 m) is explicit and significant (P-value =0.036).

The results in western side of the Retiro Park showed that the average PET value during the data collection days at the point 855m away from the park was 41.3°C, which was 3.9°C higher than the corresponding figure at points 600m and 445m away from the park (37.4°C). This indicates that residents of the Antón Martín district (Node C) were feeling lower thermal comfort than those of the other two areas. The ANOVA Analysis was used to compare PET in the three nodes in the western neighborhoods of the Retiro Park ([Table 10](#)).

Table10 , Anova PET analysis on the western side of Retiro Park.

	Sum of Squares	df	Mean Square	F	P-value
Between Groups	430.836	2	215.418	15.053	.000
Within Groups	2032.068	142	14.310		
Total	2462.904	144			

Since the results of ANOVA showed a significant difference between PET in different nodes (P-value<0.05), again, Tukey's test was used to identify the source difference between the response levels. The results of this test are provided in the tables below ([Table 11 and 12](#)).

Table11 , Multiple Comparisons Tukey PET analysis on the western side of Retiro Park (W1, W2 and W3).

(I) Intersection	(J) Intersection	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
W1	W2	.53362	.76856	.767	-1.2867	2.3540
	W3	-3.35847*	.77628	.000	-5.1971	-1.5198
W2	W1	-.53362	.76856	.767	-2.3540	1.2867
	W3	-3.89208*	.76442	.000	-5.7026	-2.0815
W3	W1	3.35847*	.77628	.000	1.5198	5.1971
	W2	3.89208*	.76442	.000	2.0815	5.7026

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

Table12 , Tukey PET analysis on the western side of Retiro Park (W1, W2 and W3).

Subset for alpha = 0.05			
Intersection	N	1	2
W1	47	37.6936	
W2	50	37.1600	
W3	48		41.0521
P-value		.768	1.000

The above results suggest that there was a significant difference between average PET in the node W1, which is 445m away from the park and the node W3, which is farther away from the park and closer to the heat island (855m).

The ANOVA analysis was used to compare the PET values of the three examined points on the south side of the Retiro Park as well. After this analysis, in cases where there were significant differences between means ($P < 0.05$), Tukey's honest significance test, which is a Post Hoc test, can be used to find the source of significant difference between response levels (Barnett, Neter, and Wasserman 1975) (Table 13).

Table13 , Anova PET analysis on the southern side of Retiro Park.

	Sum of Squares	df	Mean Square	F	P-value
Between Groups	338.465	2	169.233	24.256	.000
Within Groups	906.988	130	6.977		
Total	1245.453	133			

Since the results of ANOVA showed a significant difference between the average PETs of nodes S1, S2, and S3 (P-value <0.05), Tukey's test was used to determine which of the response levels had a significant difference (Tables 14 and 15).

Table14 , Multiple Comparisons Tukey PET analysis on the southern side of Retiro Park (S1, S2 and S3).

(I) Intersection	(J) Intersection	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
S1	S2	-1.55111*	.56029	.018	-2.8795	-.2227
	S3	-3.86057*	.55699	.000	-5.1811	-2.5400
S2	S1	1.55111*	.56029	.018	.2227	2.8795
	S3	-2.30946*	.56641	.000	-3.6523	-.9666
S3	S1	3.86057*	.55699	.000	2.5400	5.1811
	S2	2.30946*	.56641	.000	.9666	3.6523

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

Table15 , Tukey PET analysis in the three on the southern side of Retiro Park (S1, S2 and S3).

Tukey HSD				
Intersection	N	Subset for alpha = 0.05		
		1	2	3
S1	46	38.4326		
S2	43		39.9837	
S3	44			42.2932
P-value		1.000	1.000	1.000

The above results can be interpreted as the presence of a significant difference between the average PETs of all three points, i.e. S1, S2 and S3, located respectively at the 130, 280 and 520m distance from the park. Based on these statistical results, it can be confidently claimed that the cooling effect of the Retiro Park reduces PET and increases thermal comfort in nearby areas.

In addition, by using the Pearson correlation test, it was found that the PET index was significant in general at all three parts by P-value <0.05. The correlation of this index with the distance from the park showed that the increasing or decreasing distance from the park has a direct correlation with the perceived thermal comfort as a physiological point of view (Table 16).

Table16 , Pearson correlation test, Distance with PET

			PET
Dis	Pearson Correlation		.218
	P-value		.000
	N		423
			PET
North	Dis	Pearson Correlation	.190
		P-value	.022
		N	145
West	Dis	Pearson Correlation	.366
		P-value	.000
		N	145
S	Dis	Pearson Correlation	.521
		P-value	.000
		N	133

E.3.2. Psychological impact of urban park on thermal comfort

In order to survey the thermal comfort perception, two methods were considered: mental maps and the questionnaire question of the level of perception of the cooling effect of the Retiro Park that called perceived thermal comfort (PTC). The Aram Mental Map Analyzer (AMMA) software was used to investigate mental maps. By this software, we rated the park and introduced the park as landmark point. Based on the analysis of AMMA, the map in which the park was plotted was a score of 100 and maps in which the park was not sketched 0 score intended. Accordingly, this analysis of the AMMA software indicated that in each area, the residents near Retiro Park had the highest levels of Retiro Park drawing. In Salamanca neighborhood, during the measurement days, the highest amount of drawing is related to the N1 within 150 meters of the park by 87.8%. While in district N2 and N3 pedestrians mentioned to the park by 60% and 50.9 % respectively, and the rest of the responders did not mention the park in these parts.

In the Cortes neighborhood and Pacífico neighborhood (western and southern part of the park), the pattern was similar to the northern part of the park. The highest proportion of the park was related to the vicinity of the park, in part W1 by 80.9% and part S1 by 91.3 %, residents marked Retiro Park. Based on these results, and according to the expectations of the pedestrians, in identifying the areas where thermal comfort is perceived, in general, the park is a place where most citizens feel a thermal comfort. As shown in [Table 17](#), Retiro Park, even more, a far distance from the park, on average more than 50 percent of the citizens have been considered. In fact the results indicated that, despite the distance from the park, the Retiro Park has been

recognized by people as a place with high thermal comfort. This issue was more prominent in near areas of the park (Table 17).

Table17 , The Percentage of mentioned Retiro Park in the northern, western and southern side of park (analyzed by AMMA)

AMMA Results	North part			West part			South part		
	N1	N2	N3	W1	W2	W3	S1	S2	S3
Park Not Mentioned (0)	12.2	40	49.1	19.1	32	43.8	8.7	18.6	29.5
Park mentioned (100)	87.8	60	50.9	80.9	68	56.3	91.3	81.4	70.5

Analyzing the HIST of all analytical maps, carried out by AMMA software, corroborated that, Retiro Park in all regions (North, West, and South) has the highest portion compared with other places as a place where more thermal comfort Have been perceived. In fact, this analysis overlaps all of the drawings and, based on the color spectrum, determines which places make the most contribution to the drawing. Each color indicates the number of times the place has been mentioned (Figure 15 and 16). For example, the red color indicates that the location is drawn once, or the violet color indicates that 12 times that location marked by responders.

The investigation of psychologically perceived thermal comfort, which was done with the help of questions and cognitive maps, showed that the cooling effect of the park has had a positive impact on the minds of citizens, as people living or working closer to the park were feeling more thermally comfortable than others who were farther away from the park and closer to one of the heat islands. After processing the respondent's answers to direct questions about their

Figure15 . The Mental Maps analyzes during the three summer days, in North, West and South of Retiro Park

Figure16 . The Mental Maps analyzes during the three summer days, in North, West and South of Retiro Park

perception of thermal comfort (at the moment of the survey), which were scored from 1 to 5 (Very low = 1, Low = 2, Medium = 3, High = 4, Very high = 5), the results showed the average of the total questions during the 6 days in the Salamanca area for N1, N2 and N3 is approximately 3.3., 2.9 and 2.8, such that area N1 is of the highest share indicating more thermal comfort experienced by people in this area. This average score in the Cortes neighborhood was calculated to 3.13 for the CaixaForum area (Node W1), 3.05 for the Moratín area (Node W2), and 3.01 for the Antón Martín area (Node W3). Accordingly, the W1 area had the highest levels of perceived thermal comfort, respectively. In addition in the Pacífico neighborhood, the mean score decreased from 3.16 for intersection S1, which was 130m away from the park, to 3.07 for intersection S2, which was 280m away from the park, and finally to the sub-average score of 2.88 for intersection S3, which was 580m away from the park.

In general, the results of the questionnaire revealed that residents in all three areas of Retiro Park in the vicinity of the park (N1, W1, and C1) had the highest contribution of the cooling effect perception of Retiro Park. It should be mentioned that according to the results cooling effect of Retiro was understandable up to the distances that UHI located around the park, although it is less than the nearest parts of the park.

To assess the impact of the park's cooling effect on psychological and physiological variables, the Pearson correlation test was used to analyze the relationship between PTC and PET (Table 5). According to the results, the correlation between these two factors not only in general but also in each part by P-value <0.05 is meaningful (P-value North= 0.00, P-value West= 0.043, P-value South= 0.001) (Table 18). Basically, this test showed that decreasing PET near the park coincides with a notable increase in PTC which is statistically significant. Therefore, the important finding from the correlation test was the existence of a significant inverse relationship between PET and PTC.

Table18 , Pearson correlation test, results of the questionnaire (thermal comfort perception) with PET

			Thermal Comfort Perception
PET	Pearson Correlation		-.449
	P-value		.000
	N		423
			Thermal Comfort Perception
A	PET	Pearson Correlation	-.518
		P-value	.000
		N	145
B	PET	Pearson Correlation	-.169
		P-value	.043
		N	145
C	PET	Pearson Correlation	-.297
		P-value	.001
		N	133

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

In addition, the results of this study showed that the PET data and the level of PTC have the inverse correlation and are related to each other in all regions (Figure 17).

Thermal Comfort Perception: Very high = 5, high = 4, Medium = 3, Low = 2, Very low = 1

Figure 17. The relation between mean physiological equivalent temperature (PET) and thermal comfort perception in the three investigated region in Madrid, Spain on 22 June, 10 & 24 July, 10 & 24 August, and 10 September 2018.

E.4. Stage 4. Summarizing the results of collected data in three investigated area

This study examines the potential of large urban parks in creating thermal comfort for citizens living within the park perimeter. The results extracted amidst 6 hot summer days (June 22, July 10 & 24, August 10 & 24, and September 10), in Madrid revealed that Retiro Park exhibits a

cooling effect that provided thermal comfort from both psychological and physical perspective. Overall, research in this area has shown that urban parks that are larger than 10ha can affect the average temperature of the surrounding area by 1-2°C up to a radius of 350m.

In the northern part of park in Salamanca neighborhood, considering the significance of the mean T_a difference between the distance of 150 m and 665 m from the park, as well as the lower temperature of about 1.28 °C pertaining to the distance closest to the park compared to distances further away from the park (under equal conditions), the results revealed that the cooling effect of the large urban park at distances close to the park (under 380 meters) has a significant role in temperature reduction. In the western part of Retiro Park, the average temperature inside the park and outside it up to a distance of about 600m (Nodes W1 and W2) was in average 2.3°C cooler than the point 855m away from the park (Node W3). The cooling effect intensity of the park in Southern side of the park is higher in the areas closer to the park, causing a 1.6°C reduction in air temperature within the 130m distance and a 0.9°C reduction in air temperature within the 280m distance of the park compared to S3 intersection (520m away from the park) (Figure 18).

Figure18, The distance of the Retiro park cooling effect in the studied area

Over the years, the cooling effect of urban parks on the air temperature both within and around the park has been extensively researched. But the studies on this effect on PET and body physiology in the area around the park are limited. These studies have been conducted in different parts of the world, including Asia, Africa, and the Middle East (Chen et al., 2015; Sun et al., 2017; Mahmoud, 2011; Cohen, Potchter, and Matzarakis 2012).

Despite the many merits of these studies, they have not addressed the range of the cooling effect and the PET difference in areas around the park that have similar spatial characteristics. Also, these studies have been fully concentrated on PET, thus largely ignoring the issue of perceived thermal comfort from a psychological perspective, and this is while, when combined together, physiological and psychological factors can provide a more comprehensive definition of thermal comfort.

Considering these gaps and the importance of this subject, the present study examined the cooling effect of the Retiro Park on the neighborhoods to the area around it (north, west and, south) during hot summer days and the consequent impact on the thermal comfort of citizens from both physiological and psychological perspectives. The PET index was used to quantify the physiological aspect of this impact. The psychological aspect of the subject was explored with the help of a researcher-made questionnaire and through the analysis of cognitive maps. Since the questions included the questionnaire directly asked the citizens about their perceived thermal comfort, the total score of the questionnaire was defined as the measure of perceived thermal comfort (PTC).

Accordingly, the results indicated that on the northern side of Retiro the amount of PET will increase as the distance from the park increases, and residents will perceive less thermal comfort from the physiological perspective compared to distances closer to the park. The degree of PET index at a distance of 150 meters from the park is on average 2 °C PET and 2.3 °C PET less compared to distances of 380 meters and 665 meters respectively. At the western side of Retiro park Considering the magnitude of temperature decline around the park, temperature difference has also affected the PET and caused the W3 area, which is nearest to the UHI, to have 3.9°C higher PET than both average amounts of W1 and W2 (41.05°C vs. 37.4°C). Furthermore, the results showed that any increase or decrease in the intensity of the Retiro Park cooling effect will change the level of thermal comfort of citizens who live or work near the southern side of the park. The amount of PET within the 130m distance of the park

was 1.6°C less than the PET at the 280m distance and 3.9°C less than the PET at the 520m distance, which means citizens within this distance of the park enjoy higher physiological thermal comfort. Also, the PET at the 280m distance from the park was 2.3°C less than the PET at the 520m distance.

The PTC of citizens was acquired based on the average obtained data from the questionnaire which showed that in general people in the vicinity of the park experience more thermal comfort. For the other regions of the park which were more distant, less thermal comfort was experienced (less than average).

In addition, the results of the cognitive maps analyses demonstrated that large parks play a significant role in thermal comfort improvement affecting people's mental maps. For people, such parks are a space where they feel more comfortable, thereby spending more time to enjoy the desirable temperature. Although the resultant mental maps in were closer to residents in the vicinity of parks (87.8 % in the northern part, 80.9% in the western part, and 91.3% in the southern part), the results demonstrated that at long distances to the park still have a psychological dimension in offering thermal comfort (more than 50% in the northern part, 56% in the western part, and 70% in the southern part).

Analysis of PET and PTC data related to the examined days showed that these two indices have identical behaviors not only in general but also in every day and at every distance from the park. These two indices were found to have an inverse relationship, in the sense that as we move away from the park, PET increases and PTC decreases. Variations of these two indices were more pronounced on hotter summer days and near the park.

The relationship between PET and PTC illustrates the importance of the presence of a large park in the core of a city for the outdoor thermal comfort of citizens. In the case of this study, this effect of the park is so strong that there has been a reduction in the impact of UHI. It is important to note that the studied area has the same texture and physical properties as the area in the heat island (dense urban), which means in the absence of the park, the temperature increase due to the UHI effect would have profoundly affected the physical and mental health of the citizens living and working in the central part of Madrid. In fact, the obtained PET and PTC values showed that within distance from the park, where the cooling effect intensity (CEI) is significant, citizens feel more thermal comfort than in other areas where the park's cooling effect is not as strong (near the UHI).

The trends of PET and PTC values clearly illustrate the cooling effect of the park at different distances from its edges in north, west, and, south during all days of measurement. Since PET is in degrees Celsius (like air temperature), the areas with higher CEI (N1, W1 and, S1) have fewer PET values. For PTC, which was measured on the Likert scale on the range of 1 to 5, higher values indicate higher levels of perceived thermal comfort; a feeling that was more frequent in the areas near the park, where its cooling effect is strong. The analysis of cognitive maps showed that in areas with peak CEI, citizens are more likely to perceive the Retiro Park as a place of thermal comfort.

To sum up, the results of this study show that in the hot summer months of Madrid, Retiro Park plays an important role in bringing thermal comfort to the surrounding area; a role that can be discussed from both physiological and psychological perspectives.

F. CONCLUSIONS AND FUTURE RESEARCH

F.1. Conclusion

This study was set out to explore the potential of large urban parks in providing thermal comfort for citizens. Nine sites were selected from the northern, western, and southern of Retiro Park at the center of Madrid which was on the basis of the previously conducted research. In this study, micro-climatic measurements and data collections including questionnaires questioner collecting (with mental maps) were conducted for 6 days on 22 June, 10 & 24 July, 10 & 24 August, and 10 September 2018.

Studies carried out in various parts of the world have shown that large urban parks (>10 ha) can reduce the air temperature by an average of 1-2°C within a radius of 350 m. The results of the presented study showed that Retiro Park, with an area of 125 ha, has a significant role in creating comfort and health of citizens. The cooling effect of Retiro Park can reduce the temperature of the surrounding area by an average of 1.6°C to a distance of 420 meters.

Residents in the vicinity of the park are more exposed to the park's cooling effect, and given that they feel more thermal comfort based on the PET index. During the six days of the hot summer in the northern, western and, southern side of Retiro park up to distances of 330, 600 and 280 m from the park, the PET was reduced by 1.3°C (4.1%), 3.5°C (8.7 %) and 3.1°C (7.1%), respectively, compared with the distance of 520-855 m from the park (where the UHI of Madrid was located). The correlation of distance from the park with T_a and PET was significant. Based on the results, increasing or reducing the distance from the park had a direct impact on PET and T_a . The findings of this study confirm that Retiro Park, generates a cooling effect that can reduce the temperature of its surrounding area. However, finding the impact of this cooling effect on thermal comfort of citizens from both physiological and psychological perspectives was the focus of this study accomplished through validated tests and standards.

Analysis of the questionnaires demonstrated how the cooling effect of the park can provide thermal comfort from psychological point of view. The PTC index had an inverse correlation with PET index. In addition, based on the analysis of the mental maps, most citizens considered Retiro Park as a place where they perceived more thermal comfort. That is, the total score of the questionnaires, which was used as a direct measure of PTC, showed that citizens in the area with the highest CEI compared to the citizens in the area adjacent of the UHI, had an average of 7.2 % more perception of thermal comfort from the psychological perspective.

The analyses of cognitive maps also showed that Retiro Park plays an important role in creating a sense of thermal comfort in the citizens around the park. These analyses demonstrated how profound the cooling effect of the park is in citizens' minds so that out of 423 respondents surveyed in three areas, 71.9% marked Retiro Park as the place they prefer to spend time. It is important to note that the park was the first choice of respondents in all of the nine examined areas, even people in the vicinity of the UHI (N3: 51%, W3: 56.6%, S3: 70.5 %).

The results of this study demonstrate the critical role of Retiro park in generating thermal comfort for citizens from both physiological and psychological perspective. Accordingly, the cooling effect of large central parks in areas with hot summers, including those with a Mediterranean climate, can play a key role in preventing the creation and growth of UHIs in high density and heavily populated areas. In the absence of such green spaces, there is a strong possibility that central parts of the city experience rising temperatures in the form of UHIs, with dire impacts on the physical and mental health of citizens. Considering these results, future studies and urban plans should be designed and carried out with even more attention to the impact of urban green spaces, especially large parks, in the center of urban areas. In addition, given to the ongoing and upcoming effects of climate change on the temperature of densely populated urban centers, future studies need to focus on finding practical solutions to strengthen the cooling effect of urban parks.

F.2. Hypothesis Verification

According to the analysis carried out to obtain the goal of this research, the hypothesis of this research which is " Concerning the cooling effect of urban green spaces, the research hypothesis is that urban parks, due to their scale and characteristics, are able to provide thermal comfort for citizens not only in the park but also in the surrounding environment. Thermal comfort created from both physiological and psychological perspectives is debatable, and it is necessary that both of these factors work together to examine the full concept of thermal comfort, especially in the hot months of the year and areas close to hot urban areas (heat islands) in order to determine the extent of their impact" was proved through statistical methods and mental map analyses. Statistical analyses showed that the CEI of Retiro Park was able to reduce the ambient temperature, such that this decrease in temperature had a meaningful

relationship with increasing distance from the park in all surveyed areas (north, west, and south) (P-value <0.05). This decrease in temperature was directly related to the decrease in PET (physiological comfort index) (P-value <0.05). That is, by increasing CEI in areas close to parks, the temperature decreased while the rate of thermal comfort increased. For a more detailed study of the PET index in three limited studies, this study was conducted separately. The results showed that in all these areas and in each of the studied area, there is a meaningful relationship between increasing or decreasing cooling effect and the PTC of landscapes. This relationship has been proven by statistical tests (P-value <0.05). Furthermore, the effective role of park cooling effects (PCE) in increasing thermal comfort from a psychological perspective using statistical analyses and cognitive maps was proved. A comprehensive analysis indicated that both perspectives of thermal comfort had a meaningful inverse relationship with each other. In each of the three ranges examined, this relationship was proved separately with P-value <0.05 .

It should also be noted that the results of this study has been published in scientific journals, on the official website of UPM University (July 2019), as well as more than 10 leading Spanish news agencies under the title of “El Retiro de Madrid, un oasis urbano” que actúa como climatizador frente al calor”.

F.3. Future research

Although the environments examined in this study were physically, socially, and culturally identical and the times chosen for measurements were close to the time of peak temperature inside the park, further studies with a more detailed examination of geographical features (slope, height, etc.) and urban fabric are needed to completely differentiate the impact of the park’s cooling effect from other environmental factors. In previous studies, the effect of the quality of vegetation, water features, and other elements within the park on thermal comfort inside parks has been explored (Xu et al., 2017), but future studies need to accurately examine the effect of these factors on thermal comfort outside the park so that the results can be used to improve the design of urban as well as outdoor thermal comfort. These days in the field of urban planning the issue of sustainable development and the 2030 Agenda for Sustainable Development has been of paramount importance. The results of this study indicated that the

development and expansion of urban green spaces can be effective in achieving the Sustainable Development Goals (SDGs). According to this study, among seventeen SDGs goals, the third goal (good health and well-being); the eleventh goal (sustainable cities and communities); and the thirteenth goal (climate action), are achievable. Given the potential of urban green space cooling effects in providing thermal comfort and the importance of sustainable development, appropriate programs to develop and improve the quality and quantity of green spaces are required.

Considering that as this research has been based on the previous research of the ABIO research group, especially the studies conducted on the Madrid's UHI, the continuation of this research will be in line with the goals of the ABIO research projects in future. All points investigated within the UHI is located near the fixed stations of the ABIO research group that makes comparing the results of this research in the coming years with regard to new information and data feasible. It is also worth noting that since the issue UHIs is a dynamic, in future research, it is necessary to examine the changes and the behavior of the UHIs and the cooling effect of the parks simultaneously in order to plan more accurately. Necessary documents should also be reviewed during different periods and conditions (e.g., new phenomena such as the spread of COVID19 are expected to affect climate issues). Continuous studies and the preparation of new and up-to-date reports and maps can be continued following the results of this research that can be used in short-term and long-term planning.

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APPENDIX

Measurement data- Northern side

																			measurement data										Mental map data				
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	Tmrt	PEV	PET	SET	Time	Date	QD	QC	QB	QA	Part	Distance	CP	APL	GO	Age	Gender									
110	0.65	1	61	Man	1.43 m/s	29.1	29.26	48.4	2.5	35.4	27.3	10:40-10:50 am	22-Jun	2	4	3	3	A3	665	2.5	0	0.0	61	Man									
110	0.65	2	41	Woman	1.43 m/s	29.1	29.26	48.4	2.5	35.3	27.1	10:40-10:50 am	22-Jun	3	4	3	2	A3	665	0.8	0	0.0	41	Woman									
70	0.61	3	25	Man	1.43 m/s	29.1	29.26	48.4	2.5	35.4	29.2	10:40-10:50 am	22-Jun	3	4	3	3	A3	665	1.3	0	0.0	25	Man									
58	0.61	4	31	Woman	1.43 m/s	29.1	29.26	48.4	2.4	35.3	29.8	10:40-10:50 am	22-Jun	5	1	5	3	A3	665	7.8	100	13.8	31	Woman									
110	0.95	5	28	Man	1.43 m/s	29.1	29.26	48.4	2.5	35.4	27.6	10:40-10:50 am	22-Jun	4	3	4	3	A3	665	2.5	0	0.1	28	Man									
110	0.4	6	43	Woman	1.43 m/s	29.1	29.26	48.4	2.6	35.3	26.9	10:40-10:50 am	22-Jun	2	1	4	4	A3	665	1.7	0	0.0	43	Woman									
110	0.61	7	40	Woman	1.15 m/s	29.27	28.87	48.7	2.6	35.7	27.7	11:00-11:10 am	22-Jun	3	4	3	3	A2	380	8.4	0	17.1	40	Woman									
110	0.65	8	73	Man	1.15 m/s	29.27	28.87	48.7	2.6	35.8	27.9	11:00-11:10 am	22-Jun	4	3	4	4	A2	380	15.4	100	28.7	73	Man									
110	0.65	9	71	Man	1.15 m/s	29.27	28.87	48.7	2.6	35.8	27.9	11:00-11:10 am	22-Jun	2	3	4	4	A2	380	18.1	100	27.1	71	Man									
110	0.59	10	47	Woman	1.15 m/s	29.27	28.87	48.7	2.6	35.7	27.7	11:00-11:10 am	22-Jun	3	4	3	3	A2	380	3.5	0	46.3	47	Woman									
110	0.4	11	30	Man	1.15 m/s	29.27	28.87	48.7	2.7	35.9	27.9	11:00-11:10 am	22-Jun	3	4	4	3	A2	380	8.9	100	14.2	30	Man									
70	0.4	12	24	Man	0.80 m/s	32.04	27.81	48	2.1	33.7	27.6	11:30-11:40 am	22-Jun	3	2	3	3	A1	150	4.1	100	0.1	24	Man									
110	0.65	13	29	Man	0.80 m/s	32.04	27.81	48	2.2	33.8	26.3	11:30-11:40 am	22-Jun	4	3	4	3	A1	150	6.4	100	1.9	29	Man									
110	0.65	14	67	Man	0.80 m/s	32.04	27.81	48	2.2	33.8	26.1	11:30-11:40 am	22-Jun	3	4	4	5	A1	150	4.1	100	0.4	67	Man									
58	0.61	15	39	Woman	0.80 m/s	32.04	27.81	48	1.6	33.6	28.6	11:30-11:40 am	22-Jun	4	4	3	4	A1	150	6.0	100	1.0	39	Woman									
110	0.4	16	39	Woman	0.80 m/s	32.04	27.81	48	2	33.6	25.4	11:30-11:40 am	22-Jun	2	5	3	3	A1	150	5.8	100	10.7	39	Woman									
																							CP	APL	GO	Age	Gender						
110	0.34	1	55	Woman	1.43 m/s	33.96	29.76	49.4	3	36.3	28	11:15-11:25 am	10-Jul	4	3	4	3	A3	665	3.9415	100	0	55	Woman									
110	0.61	2	39	Woman	1.43 m/s	33.96	29.76	49.4	2.8	36.3	28	11:15-11:25 am	10-Jul	2	4	4	3	A3	665	2.4826	0	0	39	Woman									
58	0.61	3	24	Man	1.43 m/s	33.96	29.76	49.4	2.8	36.4	30.9	11:15-11:25 am	10-Jul	3	1	3	5	A3	665	2.5055	0	0	24	Man									
110	0.65	4	51	Woman	1.43 m/s	33.96	29.76	49.4	2.8	36.3	28	11:15-11:25 am	10-Jul	1	2	4	2	A3	665	6.0702	100	0	51	Woman									
110	0.42	5	49	Woman	1.43 m/s	33.96	29.76	49.4	2.9	36.3	28	11:15-11:25 am	10-Jul	1	2	4	2	A3	665	3.585	100	0	49	Woman									
58	0.61	6	19	Man	1.43 m/s	33.96	29.76	49.4	2.8	36.4	30.9	11:15-11:25 am	10-Jul	2	3	2	3	A3	665	5.6626	100	0	19	Man									
70	0.9	7	52	Man	1.43 m/s	33.96	29.76	49.4	2.7	36.2	30.2	11:15-11:25 am	10-Jul	3	4	3	3	A3	665	3.6899	0	0	52	Man									
58	0.65	8	39	Woman	1.43 m/s	33.96	29.76	49.4	2.7	36.3	30.2	11:15-11:25 am	10-Jul	3	2	4	3	A3	665	4.634	100	0.0166	39	Woman									
110	0.65	9	62	Man	1.16 m/s	22.17	29.7	49.3	2.7	36.5	28.3	11:42-11:52 am	10-Jul	3	4	3	3	A2	380	4.5044	100	0	62	Man									
110	0.65	10	80	Man	1.16 m/s	22.17	29.7	49.3	2.7	36.5	28.3	11:42-11:52 am	10-Jul	4	3	4	3	A2	380	7.7587	100	0	80	Man									
70	0.61	11	35	Man	1.16 m/s	22.17	29.7	49.3	2.7	36.5	30.2	11:42-11:52 am	10-Jul	3	5	3	3	A2	380	2.2274	0	0	35	Man									
70	0.4	12	27	Man	1.16 m/s	22.17	29.7	49.3	2.8	36.6	30.2	11:42-11:52 am	10-Jul	4	5	4	3	A2	380	2.8672	0	0	27	Man									
110	0.32	13	42	Man	1.16 m/s	22.17	29.7	49.3	2.9	36.7	28.4	11:42-11:52 am	10-Jul	3	5	4	4	A2	380	0.8068	0	0	42	Man									
110	0.65	14	50	Woman	1.16 m/s	22.17	29.7	49.3	2.7	36.4	28	11:42-11:52 am	10-Jul			4	4	A2	380	2.5875	0	31.529	50	Woman									
110	0.4	15	50	Man	1.16 m/s	22.17	29.7	49.3	2.8	36.6	28.3	11:42-11:52 am	10-Jul		3	4	4	A2	380	0.6971	0	0	50	Man									
110	0.4	16	18	Man	1.16 m/s	22.17	29.7	49.3	2.9	36.6	28.3	11:42-11:52 am	10-Jul	3	4	5	5	A2	380	4.6265	100	0	18	Man									
110	0.61	17	41	Man	1.16 m/s	22.17	29.7	49.3	2.7	36.5	28.3	11:42-11:52 am	10-Jul	3	4	3	3	A2	380	3.739	100	0	41	Man									
110	0.61	18	75	Man	1.36 m/s	29.71	29.4	49.3	2.6	35.9	27.8	12:00-12:10 am	10-Jul	3	3	4	2	A1	150	3.7914	100	0	75	Man									
110	0.61	19	45	Man	1.36 m/s	29.71	29.4	49.3	2.6	35.9	27.8	12:00-12:10 am	10-Jul	4	4	2	4	A1	150	7.461	100	25.031	45	Man									
110	0.65	20	16	Man	1.36 m/s	29.71	29.4	49.3	2.6	35.9	27.8	12:00-12:10 am	10-Jul	4	4	4	4	A1	150	3.8791	100	0	16	Man									
70	0.65	21	40	Man	1.36 m/s	29.71	29.4	49.3	2.6	35.9	29.6	12:00-12:10 am	10-Jul	3	4	4	2	A1	150	4.5587	100	0	40	Man									
70	0.65	22	43	Man	1.36 m/s	29.71	29.4	49.3	2.6	35.8	29.7	12:00-12:10 am	10-Jul	4	4	4	2	A1	150	4.6684	100	5.7094	43	Man									
110	0.65	23	60	Woman	1.36 m/s	29.71	29.4	49.3	2.6	35.7	27.5	12:00-12:10 am	10-Jul	3	4	3	3	A1	150	7.3675	100	24.403	60	Woman									
110	0.47	24	40	Woman	1.36 m/s	29.71	29.4	49.3	2.7	35.8	27.4	12:00-12:10 am	10-Jul	1	1	2	4	A1	150	4.8534	100	0	40	Woman									
70	0.41	25	40	Woman	1.36 m/s	29.71	29.4	49.3	2.8	35.8	29.4	12:00-12:10 am	10-Jul	4	4	2	4	A1	150	5.5468	100	14.516	40	Woman									
70	0.35	26	34	Woman	1.36 m/s	29.71	29.4	49.3	2.8	35.8	29.4	12:00-12:10 am	10-Jul	4	4	2	4	A1	150	4.1284	100	0	34	Woman									
																							CP	APL	GO	Age	Gender						
70	0.61	1	65	Man	1.36 m/s	21.71	29.45	49	2.6	35.7	29.4	10:40-10:50 am	24-Jul	2	2	2	3	A3	665	4.4038	100	0	65	Man									
70	0.61	2	60	Woman	1.36 m/s	21.71	29.45	49	2.3	35.6	29.4	10:40-10:50 am	24-Jul	4	5	3	4	A3	665	4.4172	100	0	60	Woman									
110	0.9	3	57	Man	1.36 m/s	21.71	29.45	49	2.5	35.7	27.7	10:40-10:50 am	24-Jul	2	5	4	4	A3	665	5.5546	100	0	57	Man									
58	0.61	4	58	Woman	1.36 m/s	21.71	29.45	49	2.1	35.6	30.1	10:40-10:50 am	24-Jul	3	4	5	3	A3	665	4.5048	100	0	58	Woman									
110	0.4	5	42	Man	1.36 m/s	21.71	29.45	49	2.7	35.8	27.3	10:40-10:50 am	24-Jul	3	4	4	5	A3	665	8.2393	100	20.278	42	Man									
110	0.61	6	36	Man	1.36 m/s	21.71	29.45	49	2.6	35.7	27.5	10:40-10:50 am	24-Jul	3	5	4	2	A3	665	2.0651	0	0	36	Man									
110	0.41	7	48	Woman	1.36 m/s	21.71	29.45	49	2.7	35.6																							

		CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender	
	110	0.61	1	50	Woman	1.43 m/s	18.16	25.12	43.8	0.9	28.9	21.8	10:40-10:50 am	10-Aug		2	2	3	3	A3	665		3.0989	0	0.921	50	Woman	
	110	0.4	2	45	Man	1.43 m/s	18.16	25.12	43.8	1	28.7	20.7	10:40-10:50 am	10-Aug		3	4	2	4	A3	665		4.215	100	0	45	Man	
	110	0.95	3	44	Man	1.43 m/s	18.16	25.12	43.8	1.5	29.4	23.3	10:40-10:50 am	10-Aug		2	3	2	3	A3	665		4.3156	100	0	44	Man	
	58	0.61	4	36	Man	1.43 m/s	18.16	25.12	43.8	0.8	29	24.6	10:40-10:50 am	10-Aug		2	2	3	4	A3	665		4.3225	100	0	36	Man	
	70	0.61	5	62	Man	1.43 m/s	18.16	25.12	43.8	0.9	29	23.9	10:40-10:50 am	10-Aug		4	1	1	3	A3	665		4.8231	0	0.1493	62	Man	
	110	0.61	6	18	Man	1.43 m/s	18.16	25.12	43.8	1.3	29	22	10:40-10:50 am	10-Aug		3	2	3	3	A3	665		7.9549	100	2.227	18	Man	
	110	0.4	7	17	Man	1.43 m/s	18.16	25.12	43.8	1.1	28.7	20.7	10:40-10:50 am	10-Aug		3	3	2	4	A3	665		2.3208	0	0.0554	17	Man	
	110	0.61	8	18	Woman	1.43 m/s	18.16	25.12	43.8	1	28.9	21.8	10:40-10:50 am	10-Aug		5	3	5	5	A3	665		4.6786	100	0	18	Woman	
	110	0.4	9	26	Woman	1.43 m/s	18.16	25.12	43.8	0.7	28.6	20.6	10:40-10:50 am	10-Aug		3	3	4	3	A3	665		2.3072	0	0	26	Woman	
	110	0.4	10	17	Man	1.43 m/s	18.16	25.12	43.8	1.1	28.7	20.7	10:40-10:50 am	10-Aug		2	3	3	4	A3	665		7.0848	100	0.1307	17	Man	
	110	0.61	11	38	Woman	1.72 m/s	41.05	23.77	43.1	0.5	26.8	20.4	11:00-11:10 am	10-Aug		3	3	2	4	A2	380		5.5187	100	0	38	Woman	
	110	0.65	12	40	Man	1.72 m/s	41.05	23.77	43.1	0.9	26.9	20.5	11:00-11:10 am	10-Aug		2	4	2	4	A2	380		5.361	100	0	40	Man	
	70	0.61	13	52	Man	1.72 m/s	41.05	23.77	43.1	0.5	26.9	22.5	11:00-11:10 am	10-Aug		3	3	1	2	A2	380		5.702	100	0	52	Man	
	110	0.4	14	55	Man	1.72 m/s	41.05	23.77	43.1	0.5	26.5	18.9	11:00-11:10 am	10-Aug			3	2	3	A2	380		4.1783	100	0	55	Man	
	58	0.65	15	85	Woman	1.72 m/s	41.05	23.77	43.1	-2.3	27	23	11:00-11:10 am	10-Aug		3	2	2	3	A2	380		10.708	100	0.3362	85	Woman	
	70	0.45	16	30	Woman	1.72 m/s	41.05	23.77	43.1	-1.1	26.5	20.9	11:00-11:10 am	10-Aug			3	1	4	A2	380		6.2728	100	23.09	30	Woman	
	110	0.61	17	65	Woman	1.72 m/s	41.05	23.77	43.1	0.4	26.8	20.4	11:00-11:10 am	10-Aug		2	2	2	5	A2	380		7.5865	100	0	65	Woman	
	70	0.9	18	52	Man	1.72 m/s	41.05	23.77	43.1	0.9	27.5	24.1	11:00-11:10 am	10-Aug		3	2	4	4	A2	380		1.416	0	0	52	Man	
	58	0.35	19	30	Woman	1.72 m/s	41.05	23.77	43.1	-2.6	26.6	20.8	11:00-11:10 am	10-Aug		4	4	5	4	A2	380		5.2363	100	0	30	Woman	
	110	0.61	20	32	Man	1.72 m/s	41.05	23.77	43.1	1	26.9	20.5	11:00-11:10 am	10-Aug		3	5	3	3	A2	380		4.4318	100	0	32	Man	
	110	0.4	21	33	Man	2.47 m/s	43.45	23.22	42.7	0.1	23.4	16.2	11:20-11:30 am	10-Aug		4	2	1	4	A1	150		4.3241	100	0	33	Man	
	58	0.45	22	30	Woman	2.47 m/s	43.45	23.22	42.7	-3.1	24.6	18.8	11:20-11:30 am	10-Aug		4	2	1	4	A1	150		4.3071	100	0	30	Woman	
	58	0.61	23	31	Man	2.47 m/s	43.45	23.22	42.7	-0.1	24.7	21.2	11:20-11:30 am	10-Aug			3	2	5	A1	150		4.475	100	0	31	Man	
	110	0.4	24	34	Man	2.47 m/s	43.45	23.22	42.7	0.6	24.2	18.4	11:20-11:30 am	10-Aug			3	2	4	A1	150		6.2067	100	23.137	34	Man	
	110	0.4	25	48	Woman	2.47 m/s	43.45	23.22	42.7	-0.7	23.4	16.1	11:20-11:30 am	10-Aug		3	3	2	4	A1	150		5.8755	100	0	48	Woman	
	70	0.3	26	29	Woman	2.47 m/s	43.45	23.22	42.7	-2.9	24.2	16.8	11:20-11:30 am	10-Aug			3	1	4	A1	150		6.5994	100	0.7247	29	Woman	
	70	0.4	27	34	Man	2.47 m/s	43.45	23.22	42.7	-0.6	24.4	18.2	11:20-11:30 am	10-Aug		4	3	1	3	A1	150		4.4601	100	0	34	Man	
	70	0.61	28	36	Man	2.47 m/s	43.45	23.22	42.7	0.1	24.4	20.4	11:20-11:30 am	10-Aug		3	3	2	4	A1	150		4.7946	100	0	36	Man	
	58	0.61	29	42	Man	2.47 m/s	43.45	23.22	42.7	-0.2	24.8	21.2	11:20-11:30 am	10-Aug		4	4	2	5	A1	150		9.3483	100	0.044	42	Man	
	70	0.4	30	36	Man	2.47 m/s	43.45	23.22	42.7	-0.6	24.4	18.2	11:20-11:30 am	10-Aug			3	4	2	5	A1	150		13.195	100	13.005	36	Man
Act		CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender	
	58	0.65	1	47	Woman	2.35 m/s	38.81	26.63	44.4	-0.1	29.2	24.8	10:50-11:00am	24-Aug		4	2	2	5	A3	665		10.94	100	40.86	47	Woman	
	110	0.61	2	53	Woman	2.35 m/s	38.81	26.63	44.4	1.2	29.1	22	10:50-11:00am	24-Aug		3	2	2	5	A3	665		6.7901	100	0.2723	53	Woman	
	70	0.65	3	43	Man	2.35 m/s	38.81	26.63	44.4	1.2	29.2	24.1	10:50-11:00am	24-Aug		2	4	3	3	A3	665		6.5849	100	0.0039	43	Man	
	110	0.61	4	62	Woman	2.35 m/s	38.81	26.63	44.4	1.1	29.1	22	10:50-11:00am	24-Aug		3	2	2	4	A3	665		6.3943	100	0	62	Woman	
	110	0.61	5	62	Man	2.35 m/s	38.81	26.63	44.4	1.4	29.2	22.2	10:50-11:00am	24-Aug		3	1	2	4	A3	665		2.2428	0	0	62	Man	
	110	0.61	6	59	Man	2.35 m/s	38.81	26.63	44.4	1.4	29.2	22.2	10:50-11:00am	24-Aug		2	3	2	3	A3	665		2.6445	0	0	59	Man	
	58	0.4	7	38	Man	2.35 m/s	38.81	26.63	44.4	0.7	28.8	23.5	10:50-11:00am	24-Aug		4	2	3	3	A3	665		5.0275	100	0	38	Man	
	110	0.9	8	54	Man	1.13 m/s	38.13	26.2	44.5	1.6	29.3	23.3	11:15-11:25 am	24-Aug		3	2	2	3	A2	380		4.5388	100	0	54	Man	
	110	0.61	9	61	Man	1.13 m/s	38.13	26.2	44.5	1.3	28.8	21.8	11:15-11:25 am	24-Aug		2	3	4	2	A2	380		9.7962	100	0.0786	61	Man	
	70	0.4	10	27	Man	1.13 m/s	38.13	26.2	44.5	0.8	28.4	22.4	11:15-11:25 am	24-Aug		2	2	3	3	A2	380		4.1705	0	0	27	Man	
	70	0.45	11	39	Woman	1.13 m/s	38.13	26.2	44.5	-0.3	28.3	22.3	11:15-11:25 am	24-Aug		3	3	2	3	A2	380		6.9344	100	0	39	Woman	
	110	0.65	12	43	Man	1.13 m/s	38.13	26.2	44.5	1.4	28.8	21.8	11:15-11:25 am	24-Aug		3	3	3	3	A2	380		0.5445	0	0	43	Man	
	110	0.4	13	62	Woman	1.13 m/s	38.13	26.2	44.5	0.6	28.2	20.2	11:15-11:25 am	24-Aug		3	4	2	4	A2	380		5.4464	100	0.0849	62	Woman	
	58	0.61	14	56	Man	1.29 m/s	37	26.05	44.3	0.6	27.3	23.3	11:35-11:45 am	24-Aug		4	3	2	3	A1	150		7.2619	100	0	56	Man	
	110	0.61	15	29	Man	1.29 m/s</																						

Measurement data- Western side

Measurement datas																				Mental map data				
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date	QD	QC	QB	QA	Part	Dis	CP	APL	GO	Age	Gender
70	0.4	1	35	Man	2.5 m/s	24.96	35.5	54.1	5	43.5	35.6	12:15-12:25 pm	22-Jun		4	4	4	B3	855m	15.2995	100	1.49906	35	Man
70	0.61	2	50	Woman	2.5 m/s	24.96	35.5	54.1	5.5	42.8	34.3	12:15-12:25 pm	22-Jun	5	5	3	3	B3	855m	16.1641	100	0.934101	50	Woman
70	0.65	3	28	Man	2.5 m/s	24.96	35.5	54.1	4.4	43	34.6	12:15-12:25 pm	22-Jun	2	2	4	3	B3	855m	3.7139	0	0	28	Man
110	0.4	4	34	Man	2.5 m/s	24.96	35.5	54.1	4.6	43.6	33.6	12:15-12:25 pm	22-Jun	2	2	5	2	B3	855m	13.0334	100	0.095317	34	Man
110	0.61	5	34	Woman	2.5 m/s	24.96	35.5	54.1	4.4	42.8	32.3	12:15-12:25 pm	22-Jun	2	2	4	3	B3	855m	16.2816	100	2.74099	34	Woman
110	0.61	6	27	Woman	1.57 m/s	20.05	33.17	51.8	3.5	39.1	29.3	12:40-12:50 pm	22-Jun	1	5	3	5	B2	600m	16.0191	100	0.634334	27	Woman
70	0.61	7	66	Woman	1.57 m/s	20.05	33.17	51.8	4.1	39.1	31.3	12:40-12:50 pm	22-Jun		5	3	5	B2	600m	16.9767	100	2.38672	66	Woman
110	0.3	8	28	Woman	1.57 m/s	20.05	33.17	51.8	4.1	39.5	29.9	12:40-12:50 pm	22-Jun	2	3	4	3	B2	600m	15.4372	100	1.6157	28	Woman
110	0.4	9	46	Woman	1.57 m/s	20.05	33.17	51.8	3.9	39.4	29.6	12:40-12:50 pm	22-Jun	2	4	4	2	B2	600m	0.88714	0	0	46	Woman
110	0.37	10	19	Woman	1.57 m/s	20.05	33.17	51.8	3.8	39.4	29.6	12:40-12:50 pm	22-Jun	2	4	4	2	B2	600m	14.9472	100	1.20834	19	Woman
110	0.61	11	44	Man	2.16 m/s	20.13	31.64	50.3	2.9	37.2	28.1	13:00-13:10 pm	22-Jun	3	3	3	3	B1	445m	2.2056	0	4.21722	44	Man
58	0.3	12	89	Woman	2.16 m/s	20.13	31.64	50.3	3.4	37.2	30.6	13:00-13:10 pm	22-Jun	4	4	4	4	B1	445m	21.8382	100	18.516	89	Woman
58	0.65	13	39	Woman	2.16 m/s	20.13	31.64	50.3	3.2	37	30.6	13:00-13:10 pm	22-Jun	3	4	4	3	B1	445m	19.5957	100	14.8365	39	Woman
110	0.3	14	47	Woman	2.16 m/s	20.13	31.64	50.3	3.4	37.1	27.8	13:00-13:10 pm	22-Jun	3	5	2	4	B1	445m	16.0701	100	1.56792	47	Woman
110	0.4	15	15	Man	2.16 m/s	20.13	31.64	50.3	3.1	37.3	28.1	13:00-13:10 pm	22-Jun	4	3	4	3	B1	445m	16.6444	100	0.796142	15	Man
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date	QD	QC	QB	QA	Part	Dis	CP	APL	GO	Age	Gender
110	0.45	1	64	Man	2.25 m/s	22.34	34.69	53	4.3	42.2	32.4	12:45-12:55 pm	10-Jul	5	4	3	3	B3	855m	2.2022	0	0	64	Man
110	0.61	2	68	Man	2.25 m/s	22.34	34.69	53	3.9	41.7	31.7	12:45-12:55 pm	10-Jul	2	5	4	5	B3	855m	14.0482	100	0	68	Man
70	0.4	3	70	Man	2.25 m/s	22.34	34.69	53	4.8	42.2	34.4	12:45-12:55 pm	10-Jul	4	5	2	3	B3	855m	15.7097	100	0	70	Man
110	0.4	4	24	Man	2.25 m/s	22.34	34.69	53	4.3	42.2	32.4	12:45-12:55 pm	10-Jul	5	4	4	3	B3	855m	15.0489	100	0	24	Man
110	0.65	5	66	Woman	2.25 m/s	22.34	34.69	53	4.3	41.5	31.3	12:45-12:55 pm	10-Jul	4	2	3	3	B3	855m	14.54	100	0.002189	66	Woman
110	0.3	6	28	Woman	2.25 m/s	22.34	34.69	53	5	42.2	32.6	12:45-12:55 pm	10-Jul	2	2	4	2	B3	855m	5.1946	0	2.04644	28	Woman
70	0.45	7	75	Man	2.25 m/s	22.34	34.69	53	4.5	41.9	33.9	12:45-12:55 pm	10-Jul	4	4	5	1	B3	855m	2.2932	0	0	75	Man
70	0.65	8	42	Man	2.25 m/s	22.34	34.69	53	4.1	41.7	33.6	12:45-12:55 pm	10-Jul		3	4	3	B3	855m	17.4226	100	0.010961	42	Man
70	0.3	9	34	Woman	2.25 m/s	22.34	34.69	53	6.1	42.2	34.6	12:45-12:55 pm	10-Jul	3	2	4	3	B3	855m	3.2617	0	3.30796	34	Woman
70	0.4	10	30	Woman	1.57 m/s	21.8	34.5	52.6	5.6	42.1	34.7	13:10-13:20 pm	10-Jul	3	3	4	3	B2	600m	3.5947	0	28.2805	30	Woman
110	0.4	11	56	Man	1.57 m/s	21.8	34.5	52.6	4.3	42.4	33.1	13:10-13:20 pm	10-Jul	3	4	3	3	B2	600m	3.2309	0	0	56	Man
110	0.4	12	31	Woman	1.57 m/s	21.8	34.5	52.6	4.6	42.1	32.7	13:10-13:20 pm	10-Jul	4	2	4	4	B2	600m	13.5998	100	0	31	Woman
70	0.4	13	58	Man	1.57 m/s	21.8	34.5	52.6	4.7	42.3	35	13:10-13:20 pm	10-Jul	3	3	3	4	B2	600m	15.8914	100	0	58	Man
110	0.3	14	26	Woman	1.57 m/s	21.8	34.5	52.6	4.9	42.3	33.3	13:10-13:20 pm	10-Jul	3	3	4	3	B2	600m	14.4999	100	0	26	Woman
110	0.61	15	50	Man	1.57 m/s	21.8	34.5	52.6	3.9	42	32.2	13:10-13:20 pm	10-Jul	1	2	4	3	B2	600m	17.5098	100	0	50	Man
110	0.45	16	73	Woman	1.57 m/s	21.8	34.5	52.6	4.9	42.1	32.7	13:10-13:20 pm	10-Jul	2	2	2	3	B2	600m	16.4888	100	0	73	Woman
110	0.3	17	61	Woman	1.57 m/s	21.8	34.5	52.6	5.2	42.3	33.3	13:10-13:20 pm	10-Jul	3	2	2	4	B2	600m	17.4058	100	0	61	Woman
110	0.65	18	57	Man	1.57 m/s	21.8	34.5	52.6	3.9	42	32.2	13:10-13:20 pm	10-Jul	2	3	4	2	B2	600m	2.8928	0	0.57212	57	Man
110	0.65	19	32	Man	1.87 m/s	20.13	34.23	51.6	3.5	40.7	30.9	13:35-13:45 pm	10-Jul	3	5	3	4	B1	445m	15.0868	100	0.149786	32	Man
70	0.3	20	72	Woman	1.87 m/s	20.13	34.23	51.6	5.9	41.2	33.9	13:35-13:45 pm	10-Jul	3	2	3	3	B1	445m	14.2675	100	0.002231	72	Woman
58	0.45	21	16	Woman	1.87 m/s	20.13	34.23	51.6	5	40.8	33.8	13:35-13:45 pm	10-Jul	3	4	3	3	B1	445m	3.3687	100	0	16	Woman
58	0.4	22	33	Man	1.87 m/s	20.13	34.23	51.6	4.5	41.2	34.4	13:35-13:45 pm	10-Jul	3	1	5	3	B1	445m	15.8542	100	0.004015	33	Man
58	0.45	23	21	Man	1.87 m/s	20.13	34.23	51.6	4.2	41	34	13:35-13:45 pm	10-Jul	4	3	3	3	B1	445m	15.5696	100	0	21	Man
110	0.3	24	46	Woman	1.87 m/s	20.13	34.23	51.6	4.7	41.2	31.8	13:35-13:45 pm	10-Jul	2	2	4	3	B1	445m	13.6017	100	0	46	Woman
58	0.4	25	17	Man	1.87 m/s	20.13	34.23	51.6	4.4	41.2	34.4	13:35-13:45 pm	10-Jul	1	3	5	1	B1	445m	5.2449	100	0	17	Man
58	0.4	26	18	Man	1.87 m/s	20.13	34.23	51.6	4.4	41.2	34.4	13:35-13:45 pm	10-Jul		3	4	2	B1	445m	14.5756	100	0	18	Man
58	0.4	27	29	Man	1.87 m/s	20.13	34.23	51.6	4.4	41.2	34.4	13:35-13:45 pm	10-Jul	4	4	4	2	B1	445m	15.9776	100	0	29	Man
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date	QD	QC	QB	QA	Part	Dis	CP	APL	GO	Age	Gender
110	0.3	1	50	Woman	2.23 m/s	24.47	32.57	51.3	4	39	29.7	12:15-12:25 pm	24-Jul	3	4	4	3	B3	855m	16.1797	100	0	50	Woman
110	0.61	2	23	Man	2.23 m/s	24.47	32.57	51.3	3.3	38.8	29.5	12:15-12:25 pm	24-Jul	4	3	2	4	B3	855m	3.6435	0	2.56388	23	Man
70	0.61	3	40	Man	2.23 m/s	24.47	32.57	51.3	3.4	38.8	31.4	12:15-12:25 pm	24-Jul	4	3	3	3	B3	855m	17.3808	100	0	40	Man
200	0.4	4	19	Woman	2.23 m/s	24.47	32.57	51.3	3.8	38.8	25.9	12:15-12:25 pm	24-Jul	3	5	5	4	B3	855m	16.5785	100	0.021083	19	Woman
200	0.3	5	58	Woman	2.23 m/s	24.47	32.57	51.3	3.9	38.9	26	12:15-12:25 pm	24-Jul	3	5	5	5	B3	855m	16.615	100	0.042072	58	Woman
70	0.4	6	38	Man	2.23 m/s	24.47	32.57	51.3	3.7	39.1	31.7	12:15-12:25 pm	24-Jul	4	3	5	5	B3	855m	16.1854	100	0.084415	38	Man
58	0.65	7	68	Man	2.23 m/s	24.47	32.57	51.3	3.6	38.8	32.1	12:15-12:25 pm	24-Jul	1	4	4	2	B3	855m	16.534	100	0.015374	68	Man
70	0.4	8	32	Man	2.23 m/s	24.47	32.57	51.3	3.7	39	31.7	12:15-12:25 pm	24-Jul	1	2	5	2	B3	855m	0.51156	0	0	32	Man
70	0.45	9	32	Man	2.23 m/s	24.47	32.57	51.3	3.5	38.9	31.5	12:15-12:25 pm	24-Jul	2	3	5	2	B3	855m	16.079	100	0.14821	32	Man
110	0.3	10	78	Woman	2.23 m/s	24.47	32.57	51.3	4.1	39	29.7	12:15-12:25 pm	24-Jul	3	3	4	3	B3	855m	18.1545	100	0.024503	78	Woman
110	0.4	11	27	Man	2.53 m/s	20.22	31.03	49.6	2.9	35.9	26.7	12:40-12:50 pm	24-Jul	3	3	4	4	B2	600m	1.3507	0	0	27	Man
110	0.4	12	46	Man	2.53 m/s	20.22	31.03	49.6	2.8	35.9	26.7	12:40-12:50 pm	24-Jul	3	3	2	3	B2	600m	0.36636	0	0	46	Man
200	0.4	13	72	Man	2.53 m/s	20.22	31.03	49.6	3.3	35.9	23.4	12:40-12:50 pm	24-Jul	2	3	4	4	B2	600m	16.1483	100	0.003935	72	Man
7																								

Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	Tmrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender
70	0.37	1	45	Woman	1.64 m/s	30.47	34.38	52.5	5.8	42	34.9	12:15-12:25 pm	10-Aug		2	4	3	3	B3	855m		15.6797	100	0	45	Woman
70	0.4	2	60	Man	1.64 m/s	30.47	34.38	52.5	4.8	42.2	35.2	12:15-12:25 pm	10-Aug		4	3	3	2	B3	855m		0.74621	0	0	60	Man
58	0.3	3	45	Woman	1.64 m/s	30.47	34.38	52.5	6.6	42.2	36.3	12:15-12:25 pm	10-Aug		3	3	2	2	B3	855m		18.3859	100	0	45	Woman
58	0.65	4	85	Man	1.64 m/s	30.47	34.38	52.5	4.7	41.8	35	12:15-12:25 pm	10-Aug		4	1	3	4	B3	855m		2.7729	0	0	85	Man
110	0.45	5	56	Man	1.64 m/s	30.47	34.38	52.5	4.1	42.1	32.8	12:15-12:25 pm	10-Aug		2	3	1	2	B3	855m		15.7185	100	0.004044	56	Man
110	0.45	6	59	Man	1.64 m/s	30.47	34.38	52.5	4.1	42.1	32.8	12:15-12:25 pm	10-Aug		5	2	2	4	B3	855m		0.22882	0	0	59	Man
70	0.3	7	71	Woman	1.64 m/s	30.47	34.38	52.5	6.5	42.2	35.5	12:15-12:25 pm	10-Aug		4	3	3	3	B3	855m		3.4663	0	0	71	Woman
110	0.45	8	22	Woman	1.64 m/s	30.47	34.38	52.5	4.6	42.1	32.8	12:15-12:25 pm	10-Aug		2	3	3	2	B3	855m		1.7114	0	0	22	Woman
110	0.65	9	32	Woman	1.64 m/s	30.47	34.38	52.5	4.2	41.7	32	12:15-12:25 pm	10-Aug		2	3	3	4	B3	855m		1.0828	0	0	32	Woman
110	0.61	10	24	Man	1.64 m/s	30.47	34.38	52.5	3.9	41.9	32.4	12:15-12:25 pm	10-Aug			2	3	3	B3	855m		1.3501	0	0	24	Man
110	0.61	11	41	Man	1.81 m/s	28.09	33.64	51.6	3.6	40.5	31.1	12:35-12:45 pm	10-Aug		1	1	2	4	B2	600m		15.3737	100	0	41	Man
110	0.4	12	35	Man	1.81 m/s	28.09	33.64	51.6	4	40.9	31.8	12:35-12:45 pm	10-Aug		2	4	2	3	B2	600m		15.1827	100	0	35	Man
110	0.4	13	25	Man	1.81 m/s	28.09	33.64	51.6	4	40.9	31.8	12:35-12:45 pm	10-Aug			4	3	4	B2	600m		18.1516	100	0	25	Man
110	0.37	14	25	Woman	1.81 m/s	28.09	33.64	51.6	4.2	40.6	31.4	12:35-12:45 pm	10-Aug			5	3	3	B2	600m		15.6413	100	0	25	Woman
110	0.95	15	24	Woman	1.81 m/s	28.09	33.64	51.6	3.4	40	30.3	12:35-12:45 pm	10-Aug		3	3	2	2	B2	600m		15.5415	100	0	24	Woman
110	0.4	16	52	Woman	1.81 m/s	28.09	33.64	51.6	4.3	40.6	31.4	12:35-12:45 pm	10-Aug		2	3	2	4	B2	600m		5.7911	0	36.0608	52	Woman
110	0.4	17	36	Man	1.81 m/s	28.09	33.64	51.6	4	40.9	31.8	12:35-12:45 pm	10-Aug		2	3	2	3	B2	600m		15.728	100	0	36	Man
110	0.4	18	43	Man	1.81 m/s	28.09	33.64	51.6	4	40.9	31.8	12:35-12:45 pm	10-Aug		5	3	4	3	B2	600m		0.44811	0	22.9787	43	Man
110	0.61	19	62	Man	1.81 m/s	28.09	33.64	51.6	3.6	40.5	31.1	12:35-12:45 pm	10-Aug		3	3	2	2	B2	600m		17.9307	100	0	62	Man
110	0.61	20	43	Man	1.81 m/s	28.09	33.64	51.6	3.6	40.5	31.1	12:35-12:45 pm	10-Aug		2	2	3	2	B2	600m		17.7931	100	0	43	Man
110	0.37	21	65	Woman	2.36 m/s	28.81	33.14	59	4.9	42.9	33.3	12:55-13:05 pm	10-Aug		3	4	4	3	B1	445m		20.0887	100	10.7483	65	Woman
110	0.37	22	43	Woman	2.36 m/s	28.81	33.14	59	4.7	42.9	33.3	12:55-13:05 pm	10-Aug		2	2	2	3	B1	445m		2.4058	0	0.951123	43	Woman
110	0.3	23	29	Woman	2.36 m/s	28.81	33.14	59	5.1	43.2	34	12:55-13:05 pm	10-Aug			3	3	3	B1	445m		16.3001	100	0	29	Woman
110	0.4	24	35	Woman	2.36 m/s	28.81	33.14	59	4.7	42.9	33.3	12:55-13:05 pm	10-Aug			3	3	4	B1	445m		1.9126	0	0	35	Woman
110	0.4	25	52	Woman	2.36 m/s	28.81	33.14	59	4.8	42.9	33.3	12:55-13:05 pm	10-Aug		3	3	4	3	B1	445m		1.6087	0	0	52	Woman
110	0.45	26	34	Man	2.36 m/s	28.81	33.14	59	4.3	43.2	33.7	12:55-13:05 pm	10-Aug		5	4	2	4	B1	445m		5.9065	0	0	34	Man
110	0.4	27	29	Man	2.36 m/s	28.81	33.14	59	4.3	43.2	33.7	12:55-13:05 pm	10-Aug		5	4	3	4	B1	445m		0.65532	0	0	29	Man
58	0.4	28	23	Woman	2.36 m/s	28.81	33.14	59	6	42.9	36.1	12:55-13:05 pm	10-Aug		3	3	3	5	B1	445m		16.131	100	0.011821	23	Woman
110	0.61	29	26	Man	2.36 m/s	28.81	33.14	59	3.9	42.6	32.8	12:55-13:05 pm	10-Aug		3	4	3	4	B1	445m		15.9947	100	0	26	Man
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	Tmrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender
110	0.4	1	25	Man	1.54 m/s	22.01	34.96	52.2	4.4	42.8	33.5	12:40-12:50 pm	24-Aug		2	2	3	4	B3	855m		15.8514	100	0	25	Man
110	0.61	2	23	Woman	1.54 m/s	22.01	34.96	52.2	4.3	42.8	33.1	12:40-12:50 pm	24-Aug		2	2	3	3	B3	855m		16.0199	100	0.015874	23	Woman
110	0.3	3	40	Woman	1.54 m/s	22.01	34.96	52.2	4.7	43	33.8	12:40-12:50 pm	24-Aug			3	3	3	B3	855m		2.9788	0	86.3729	40	Woman
110	0.4	4	43	Man	1.54 m/s	22.01	34.96	52.2	4.4	42.8	33.5	12:40-12:50 pm	24-Aug		4	4	2	4	B3	855m		0.30611	0	0	43	Man
110	0.4	5	25	Man	1.54 m/s	22.01	34.96	52.2	4.4	42.8	33.5	12:40-12:50 pm	24-Aug		3	3	2	3	B3	855m		16.4837	100	0	25	Man
110	0.4	6	59	Man	1.54 m/s	22.01	34.96	52.2	4.4	42.8	33.5	12:40-12:50 pm	24-Aug		3	2	4	3	B3	855m		0.40624	0	0	59	Man
110	0.4	7	61	Woman	1.52 m/s	27.07	30.86	48.1	3	36.5	27.8	13:10-13:20 pm	24-Aug		4	3	2	4	B2	600m		1.5083	0	0	61	Woman
70	0.65	8	40	Woman	1.52 m/s	27.07	30.86	48.1	3	36.4	30.1	13:10-13:20 pm	24-Aug		3	4	2	5	B2	600m		17.936	100	0.001772	40	Woman
70	0.9	41	Man	1.52 m/s	27.07	30.86	48.1	3	36.7	30		13:10-13:20 pm	24-Aug			4	3	4	B2	600m		16.5142	100	0.001925	41	Man
110	0.45	10	83	Woman	1.52 m/s	27.07	30.86	48.1	3.2	36.5	28.3	13:10-13:20 pm	24-Aug		2	2	5	2	B2	600m		16.95	100	0.1294	83	Woman
110	0.61	11	33	Man	1.52 m/s	27.07	30.86	48.1	2.8	36.6	28.1	13:10-13:20 pm	24-Aug			3	5	3	B2	600m		15.6785	100	0	33	Man
110	0.4	12	35	Man	1.52 m/s	27.07	30.86	48.1	3	36.7	28.1	13:10-13:20 pm	24-Aug		3	2	2	3	B2	600m		3.1578	0	0.211395	35	Man
110	0.4	13	28	Woman	1.31 m/s	27.82	30.77	47.5	3	36.5	28.2	13:30-13:40 pm	24-Aug		2	3	5	4	B1	445m		1.9177	0	0	28	Woman
110	0.4	16	28	Woman	1.31 m/s	27.82	30.77	47.5	3	36.5	28	13:30-13:40 pm	24-Aug		4	2	3	3	B1	445m		2.3879	0	2.4361	28	Woman
110	0.61	17	38	Man	1.31 m/s	27.82	30.77	47.5	2.8	36.6	28.2	13:30-13:40 pm	24-Aug		4	3	3	3	B1	445m		18.5244	100	0	38	Man
110	0.4	18	42	Woman	1.31 m/s	27.82	30.77	47.5	3	36.5	28	13:30-13:40 pm	24-Aug			3	3	3	B1	445m		22.0881	100	13.0629	42	Woman
110	0.65	19	43	Man	1.31 m/s	27.82	30.77	47.5	2.8	36.6	28.2	13:30-13:40 pm	24-Aug			4	3	3	B1	445m		20.3017	100	7.16176	43	Man
110	0.4	20	43	Man	1.31 m/s	27.82	30.77	47.5	3	36.7	28.3	13:30-13:40 pm	24-Aug			4	4	3	B1	445m		20.3017	100	7.16176	43	Man
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	Tmrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender
110	0.61	1	74	Man	1.3 m/s	33.95	32.33	49.1	3.3	38.8	30.2	12:20-12:30 pm	10-Sep		4	2	2	3	B3	855m		4.7407	100	88.1166	74	Man
110	0.3	2	78	Woman	1.3 m/s	33.95	32.33	49.1	4	38.9	30.6	12:20-12:30 pm	10-Sep		2	3	2	4	B3	855m		6.8956	0	25.4631	78	Woman
58	0.61	3	52	Woman	1.3 m/s	33.95	32.33	49.1	4	38.7	32.6	12:20-12:30 pm	10-Sep		3	4	3	4	B3	855m		0.24021	0	0	52	Woman
58	0.4	4	70	Man	1.3 m/s	33.95	32.33	49.1	4	38.9	33.3	12:20-12:30 pm	10-Sep		3	3	3	3	B3	855m		0.71015	0	18.5682	70	Man
70	0.4	5	44	Man	1.3 m/s	33.95	32.33	49.1	3.7	39	32.5	12:20-12:30 pm	10-Sep		4	5	2	4	B3	855m		18.0233	100	0	44	Man
110	0.61	6	48	Man	1.3 m/s	33.95	32.33	49.1	3.3	38.8	30.2	12:20-12:30 pm	10-Sep		4	4	2	4	B3	855m		1.7822	0	13.8884	48	Man
58	0.61	7	47	Man	1.3 m/s	33.95	32.33	49.1	3.6	38.8	32.8	12:20-12:30 pm	10-Sep		3	4	1	3	B3	855m		15.7495	100	0	47	Man
58	0.65	8	50	Man	1.3 m/s	33.95	32.33	49.1	3.5	38.7	32.7	12:20-12:30 pm	10-Sep		3	4	2	3	B3	855m		15.9573	1			

Measurement data- Southern side

																					Measurement datas													Mental map data				
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mtrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis	CP	APL	GO	Age	Gender													
70	0.4	1	17	Man	0.96 m/s	16.7	36.07	53.7	5.2	44.9	38	13:35-13:45 pm	22-Jun		3	4	5	2	C3	520m	5.1695	100	0	17	Man													
70	0.61	2	14	Man	0.96 m/s	16.7	36.07	53.7	4.6	44.5	36.6	13:35-13:45 pm	22-Jun		3	5	4	2	C3	520m	7.6438	100	0	14	Man													
110	0.65	3	80	Man	0.96 m/s	16.7	36.07	53.7	4.4	44.5	34.7	13:35-13:45 pm	22-Jun		5	5	3	5	C3	520m	1.4237	0	0	80	Man													
110	0.61	4	64	Man	0.96 m/s	16.7	36.07	53.7	4.4	44.5	34.7	13:35-13:45 pm	22-Jun		3	2	3	3	C3	520m	5.1557	100	0	64	Man													
110	0.4	5	53	Man	0.96 m/s	16.7	36.07	53.7	4.9	44.9	36	13:35-13:45 pm	22-Jun		1	3	3	3	C3	520m	5.3542	100	0	53	Man													
110	0.61	6	56	Man	2.68 m/s	15	36.97	53.5	4.3	43.8	33.4	13:55-14:05 pm	22-Jun		4	4	4	4	C2	280	9.5242	100	0	56	Man													
110	0.61	7	67	Man	2.68 m/s	15	36.97	53.5	4.3	43.8	33.4	13:55-14:05 pm	22-Jun		3	5	4	4	C2	280	8.0077	100	0	67	Man													
110	0.61	8	62	Woman	2.68 m/s	15	36.97	53.5	5	43.6	33.1	13:55-14:05 pm	22-Jun		3	4	4	4	C2	280	6.8312	100	0	62	Woman													
58	0.4	9	34	Woman	2.68 m/s	15	36.97	53.5	7	44.2	36.5	13:55-14:05 pm	22-Jun		4	4	3	4	C2	280	4.9974	100	0	34	Woman													
58	0.61	10	57	Man	2.16 m/s	15.2	34.6	50.7	4.1	40.5	33.1	14:15-14:25 pm	22-Jun		3	5	2	4	C1	130m	0.55337	0	0	57	Man													
110	0.4	11	17	Man	2.16 m/s	15.2	34.6	50.7	4	40.9	31	14:15-14:25 pm	22-Jun		1	5	3	4	C1	130m	6.1388	100	0	17	Man													
110	0.65	12	83	Woman	2.16 m/s	15.2	34.6	50.7	4	40.3	30.2	14:15-14:25 pm	22-Jun		1	5	5	3	C1	130m	8.1943	100	0	83	Woman													
110	0.4	13	14	Man	2.16 m/s	15.2	34.6	50.7	4	40.9	31	14:15-14:25 pm	22-Jun		1	5	3	2	C1	130m	6.6398	100	10.1432	14	Man													
110	0.65	14	88	Woman	2.16 m/s	15.2	34.6	50.7	4.1	40.3	30.2	14:15-14:25 pm	22-Jun		4	5	4	4	C1	130m	5.8571	100	0	88	Woman													
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mtrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis	CP	APL	GO	Age	Gender													
110	0.4	1	31	Man	2.18m/s	17.66	37.18	52.8	5	45	34.7	14:15-14:25 pm	10-Jul		3	4	4	4	C3	520m	7.8222	100	0	31	Man													
70	0.45	2	61	Man	2.18m/s	17.66	37.18	52.8	5.7	44.9	36.6	14:15-14:25 pm	10-Jul		5	3	4	4	C3	520m	6.7089	100	5.43582	61	Man													
110	0.4	3	38	Man	2.18m/s	17.66	37.18	52.8	5	45	34.7	14:15-14:25 pm	10-Jul			3	4	2	C3	520m	5.4442	100	0	38	Man													
70	0.4	4	13	Man	2.18m/s	17.66	37.18	52.8	5.3	44.9	36.6	14:15-14:25 pm	10-Jul		2	4	5	3	C3	520m	6.8332	100	0	13	Man													
110	0.65	5	61	Woman	2.18m/s	17.66	37.18	52.8	4.8	44.1	33.1	14:15-14:25 pm	10-Jul		1	3	5	1	C3	520m	0.17286	0	6.87732	61	Woman													
110	0.4	6	23	Man	2.18m/s	17.66	37.18	52.8	4.9	45	34.7	14:15-14:25 pm	10-Jul		2	2	4	3	C3	520m	5.7	100	0	23	Man													
110	0.4	7	34	Man	2.18m/s	17.66	37.18	52.8	5	45	34.7	14:15-14:25 pm	10-Jul		2	3	5	2	C3	520m	1.14	0	0	34	Man													
110	0.61	8	43	Man	1.68 m/s	16.17	35.9	51.9	4	42.8	32.6	14:50-15:00 pm	10-Jul		3	4	3	3	C2	280	5.682	100	0	43	Man													
110	0.4	9	16	Man	1.68 m/s	16.17	35.9	51.9	4.5	43.3	33.6	14:50-15:00 pm	10-Jul		4	2	3	4	C2	280	9.4602	100	0	16	Man													
110	0.4	10	48	Woman	1.68 m/s	16.17	35.9	51.9	5	43	33.2	14:50-15:00 pm	10-Jul			3	3	3	C2	280	5.3279	100	0	48	Woman													
110	0.65	11	61	Man	1.68 m/s	16.17	35.9	51.9	4.1	42.8	32.6	14:50-15:00 pm	10-Jul		4	1	3	4	C2	280	5.4892	100	0	61	Man													
110	0.45	12	49	Woman	1.68 m/s	16.17	35.9	51.9	5	43	33.2	14:50-15:00 pm	10-Jul		1	5	5	4	C2	280	6.295	100	0	49	Woman													
110	0.4	13	42	Man	1.68 m/s	16.17	35.9	51.9	4.5	43.3	33.6	14:50-15:00 pm	10-Jul		1	5	5	5	C2	280	6.1961	100	0	42	Man													
110	0.61	14	40	Woman	1.68 m/s	16.17	35.9	51.9	4.4	42.6	32	14:50-15:00 pm	10-Jul		3	4	3	3	C2	280	5.9882	100	0	40	Woman													
110	0.3	15	43	Woman	1.68 m/s	16.17	35.9	51.9	5.4	43.3	33.8	14:50-15:00 pm	10-Jul		2	2	4	3	C2	280	5.0737	0	0	43	Woman													
110	0.65	16	54	Man	1.73 m/s	15.03	35.17	48.6	3.7	40.6	30.7	15:10-15:20 pm	10-Jul		2	2	4	4	C1	130m	8.1714	100	1.65539	54	Man													
110	0.65	17	31	Woman	1.73 m/s	15.03	35.17	48.6	3.9	40.4	30.4	15:10-15:20 pm	10-Jul			4	4	3	C1	130m	5.69	100	0	31	Woman													
110	0.3	18	38	Woman	1.73 m/s	15.03	35.17	48.6	4.7	40.9	31.3	15:10-15:20 pm	10-Jul		2	1	5	5	C1	130m	5.4712	100	0	38	Woman													
110	0.3	19	42	Woman	1.73 m/s	15.03	35.17	48.6	4.7	40.9	31.3	15:10-15:20 pm	10-Jul		3	1	5	5	C1	130m	5.867	100	0	42	Woman													
110	0.95	20	30	Woman	1.73 m/s	15.03	35.17	48.6	3.5	40.1	32.7	15:10-15:20 pm	10-Jul		3	2	5	2	C1	130m	5.5692	100	0	30	Woman													
110	0.37	21	31	Woman	1.73 m/s	15.03	35.17	48.6	4.3	40.7	30.9	15:10-15:20 pm	10-Jul		4	4	4	3	C1	130m	7.8129	100	0	31	Woman													
110	0.4	22	35	Woman	1.73 m/s	15.03	35.17	48.6	4.3	40.7	30.9	15:10-15:20 pm	10-Jul		2	4	4	2	C1	130m	5.7459	100	0	35	Woman													
110	0.61	23	62	Woman	1.73 m/s	15.03	35.17	48.6	4	40.4	30.4	15:10-15:20 pm	10-Jul		3	2	4	4	C1	130m	5.3478	100	0	62	Woman													
110	0.61	24	19	Man	1.73 m/s	15.03	35.17	48.6	3.6	40.6	30.7	15:10-15:20 pm	10-Jul		4	5	3	4	C1	130m	5.503	100	0	19	Man													
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mtrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis	CP	APL	GO	Age	Gender													
110	0.61	1	45	Man	1.88m/s	16.7	35.29	52.1	3.9	42.2	32	13:40-13:50 pm	24-Jul		3	2	4	2	C3	520m	8.0391	100	0	45	Man													
110	0.4	2	53	Man	1.88m/s	16.7	35.29	52.1	4.4	42.6	32.8	13:40-13:50 pm	24-Jul		3	3	3	4	C3	520m	5.8815	100	0	53	Man													
110	0.61	3	40	Woman	1.88m/s	16.7	35.29	52.1	4.2	42	31.6	13:40-13:50 pm	24-Jul		2	3	4	2	C3	520m	5.5492	100	0	40	Woman													
70	0.61	4	60	Woman	1.88m/s	16.7	35.29	52.1	5.2	41.9	33.6	13:40-13:50 pm	24-Jul		4	3	4	4	C3	520m	5.4119	100	0	60	Woman													
110	0.61	5	55	Man	1.88m/s	16.7	35.29	52.1	3.9	42.2	32	13:40-13:50 pm	24-Jul		2	2	4	4	C3	520m	5.0737	100	0	55	Man													
110	0.3	6	57	Woman	1.88m/s	16.7	35.29	52.1	5.3	42.6	33	13:40-13:50 pm	24-Jul		3	3	4	4	C3	520m	5.3168	100	0	57	Woman													
110	0.65	7	80	Man	1.88m/s	16.7	35.29	52.1	4	42.1	32	13:40-13:50 pm	24-Jul		2	2	4	2	C3	520m	5.4267	100	0	80	Man													
110	0.37	8	32	Woman	1.88m/s	16.7	35.29	52.1	4.7	42.4	32.4	13:40-13:50 pm	24-Jul		3	3	4	3	C3	520m	5.2435	100	0	32	Woman													
110	0.61	9	43	Woman	1.88m/s	16.7	35.29	52.1	4.2	42	31.6	13:40-13:50 pm	24-Jul		2	2	5	2	C3	520m	3.6427	0	2.18849	43	Woman													
58	0.61	10	54	Woman	3.01 m/s	15	33.08	49.2	3.5	37.4	30.4	14:10-14:20 pm	24-Jul		3																							

Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender
110	0.65	1	68	Man	1.72 m/s	26.71	35.39	52	4.1	42.6	32.8	13:30-13:40 pm	10-Aug		3	2	4	2	C3	520m		0.38026	0	22.2973	68	Man
70	0.37	2	52	Woman	1.72 m/s	26.71	35.39	52	6.2	42.8	35.4	13:30-13:40 pm	10-Aug		5	1	4	3	C3	520m		7.8753	100	0	52	Woman
110	0.61	3	63	Man	1.72 m/s	26.71	35.39	52	4.1	42.6	32.8	13:30-13:40 pm	10-Aug		2	3	3	2	C3	520m		3.977	0	20.3343	63	Man
110	0.4	4	47	Woman	1.72 m/s	26.71	35.39	52	5	42.8	33.3	13:30-13:40 pm	10-Aug		2	3	4	3	C3	520m		5.7939	100	0	47	Woman
110	0.4	5	20	Man	1.72 m/s	26.71	35.39	52	4.5	43.1	33.8	13:30-13:40 pm	10-Aug		1	2	4	4	C3	520m		8.2235	100	0	20	Man
110	0.3	6	18	Woman	1.72 m/s	26.71	35.39	52	5.2	43	34	13:30-13:40 pm	10-Aug		2	2	4	2	C3	520m		1.5734	0	39.1917	18	Woman
70	0.4	7	36	Man	1.72 m/s	26.71	35.39	52	4.9	43	35.7	13:30-13:40 pm	10-Aug		3	3	4	3	C3	520m		5.7136	100	0	36	Man
58	0.65	8	72	Man	1.72 m/s	26.71	35.39	52	4.8	42.5	35.4	13:30-13:40 pm	10-Aug		1	1	5	2	C3	520m		1.3473	0	0	72	Man
110	0.61	9	86	Man	2.11 m/s	29.31	35.28	50.8	4	41.7	31.9	14:00-14:10 pm	10-Aug		3	3	3	3	C2	280		0.45285	0	0	86	Man
58	0.3	10	23	Woman	2.11 m/s	29.31	35.28	50.8	6.8	42.1	36.1	14:00-14:10 pm	10-Aug		3	2	4	2	C2	280		1.8538	0	12.0929	23	Woman
110	0.3	11	30	Woman	2.11 m/s	29.31	35.28	50.8	5.5	42.1	33.3	14:00-14:10 pm	10-Aug		2	3	4	4	C2	280		6.6289	100	0	30	Woman
58	0.4	12	53	Man	2.11 m/s	29.31	35.28	50.8	5	42.1	35.4	14:00-14:10 pm	10-Aug		3	4	4	3	C2	280		7.6004	100	19.0619	53	Man
110	0.65	13	33	Man	2.11 m/s	29.31	35.28	50.8	3.8	41.5	31.6	14:00-14:10 pm	10-Aug		2	3	3	3	C2	280		8.0077	100	0	33	Man
110	0.45	14	33	Man	2.11 m/s	29.31	35.28	50.8	4.4	42.2	32.7	14:00-14:10 pm	10-Aug		2	2	4	2	C2	280		8.7216	100	9.86891	33	Man
110	0.61	15	18	Woman	2.11 m/s	29.31	35.28	50.8	4.4	41.5	31.9	14:00-14:10 pm	10-Aug		2	2	4	2	C2	280		5.6198	100	0	18	Woman
110	0.4	16	42	Man	1.73 m/s	27.27	33.73	48.8	3.8	39.7	30.7	14:20-14:30 pm	10-Aug		4	3	4	2	C1	130m		5.7293	100	0	42	Man
110	0.37	17	24	Man	1.73 m/s	27.27	33.73	48.8	3.8	39.7	30.7	14:20-14:30 pm	10-Aug		3	4	2	4	C1	130m		5.7955	100	0	24	Man
70	0.3	18	25	Woman	1.73 m/s	27.27	33.73	48.8	3.9	39.5	30.3	14:20-14:30 pm	10-Aug		3	4	2	5	C1	130m		5.5723	100	0	25	Woman
110	0.3	19	42	Woman	1.73 m/s	27.27	33.73	48.8	4.3	39.6	30.6	14:20-14:30 pm	10-Aug		3	4	3	4	C1	130m		8.589	100	28.4	42	Woman
110	0.4	20	16	Man	1.73 m/s	27.27	33.73	48.8	3.8	39.7	30.7	14:20-14:30 pm	10-Aug		3	3	4	3	C1	130m		6.0733	100	0	16	Man
110	0.4	21	18	Man	1.73 m/s	27.27	33.73	48.8	3.8	39.7	30.7	14:20-14:30 pm	10-Aug		3	2	4	2	C1	130m		9.4237	100	0	18	Man
110	0.4	22	34	Woman	1.73 m/s	27.27	33.73	48.8	4	39.5	30.3	14:20-14:30 pm	10-Aug		2	2	4	3	C1	130m		5.7804	100	0	34	Woman
70	0.4	23	28	Man	1.73 m/s	27.27	33.73	48.8	3.9	39.7	32.6	14:20-14:30 pm	10-Aug		2	2	3	2	C1	130m		7.6852	100	8.1115	28	Man
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender
70	0.45	1	31	Woman	1.13 m/s	17.87	36.38	50.8	5.9	43.2	35.6	14:15-14:25 pm	24-Aug			1	5	1	C3	520m		5.6336	100	0	31	Woman
110	0.4	2	34	Woman	1.13 m/s	17.87	36.38	50.8	5.1	43.4	34.2	14:15-14:25 pm	24-Aug		2	3	3	3	C3	520m		1.1883	0	55.1015	34	Woman
110	0.61	3	53	Man	1.13 m/s	17.87	36.38	50.8	4.2	43.2	33.5	14:15-14:25 pm	24-Aug		4	4	3	4	C3	520m		6.2675	100	0.492586	53	Man
110	0.4	4	38	Man	1.13 m/s	17.87	36.38	50.8	4.6	43.6	34.6	14:15-14:25 pm	24-Aug		2	4	3	3	C3	520m		8.0867	100	0	38	Man
110	0.3	5	30	Man	1.13 m/s	17.87	36.38	50.8	4.9	43.8	35.3	14:15-14:25 pm	24-Aug		2	2	5	2	C3	520m		1.6832	0	38.6511	30	Man
110	0.4	6	22	Man	1.13 m/s	17.87	36.38	50.8	4.6	43.6	34.6	14:15-14:25 pm	24-Aug		1	2	4	2	C3	520m		2.1157	0	0	22	Man
110	0.4	7	50	Man	2.19 m/s	15.87	35.81	49	4.2	41.6	31.5	14:35-14:45 pm	24-Aug			2	3	3	C2	280		6.9734	100	0	50	Man
110	0.61	8	38	Woman	2.19 m/s	15.87	35.81	49	4.1	40.9	30.5	14:35-14:45 pm	24-Aug		4	4	3	3	C2	280		6.3591	100	0	38	Woman
70	0.4	9	19	Man	2.19 m/s	15.87	35.81	49	4.5	41.5	33.4	14:35-14:45 pm	24-Aug		2	3	4	3	C2	280		7.8311	100	0	19	Man
70	0.4	10	19	Man	2.19 m/s	15.87	35.81	49	4.5	41.5	33.4	14:35-14:45 pm	24-Aug		2	3	3	3	C2	280		8.7376	100	7.56717	19	Man
110	0.4	11	32	Woman	2.19 m/s	15.87	35.81	49	4.5	41.3	31.1	14:35-14:45 pm	24-Aug		1	3	4	3	C2	280		2.6097	0	0	32	Woman
110	0.4	12	23	Man	2.19 m/s	15.87	35.81	49	4.2	41.6	31.5	14:35-14:45 pm	24-Aug		3	3	4	3	C2	280		5.7008	100	0	23	Man
110	0.3	13	35	Woman	3.00 m/s	15.78	35.56	47.7	4.7	40.3	29.9	14:55-15:05 pm	24-Aug		4	5	4	5	C1	130m		5.8237	100	0	35	Woman
110	0.4	14	26	Man	3.00 m/s	15.78	35.56	47.7	4	40.5	30	14:55-15:05 pm	24-Aug		2	3	4	4	C1	130m		8.2639	100	0	26	Man
110	0.4	15	29	Woman	3.00 m/s	15.78	35.56	47.7	4.3	40.1	29.6	14:55-15:05 pm	24-Aug		4	5	3	4	C1	130m		6.0276	100	0	29	Woman
110	0.65	16	63	Man	3.00 m/s	15.78	35.56	47.7	3.5	39.9	29.5	14:55-15:05 pm	24-Aug		2	4	4	3	C1	130m		6.6521	100	7.43534	63	Man
58	0.3	17	45	Woman	3.00 m/s	15.78	35.56	47.7	5.9	40.4	32.7	14:55-15:05 pm	24-Aug		3	4	4	4	C1	130m		8.8733	100	0.648739	45	Woman
Act	CLO	NO	Age	Gender	Wind	HR, %	Temp, °C	T mrt	PEV	PET	SET	Time	Date		QD	QC	QB	QA	Part	Dis		CP	APL	GO	Age	Gender
110	0.61	1	40	Man	1.1 m/s	36.41	32.44	46.1	3.2	37.9	29.5	14:15-14:25 pm	10-Sep		1	2	4	4	C3	520m		6.0802	100	0	40	Man
110	0.3	2	31	Woman	1.1 m/s	36.41	32.44	46.1	3.6	37.9	29.7	14:15-14:25 pm	10-Sep		3	4	4	3	C3	520m		6.785	100	3.80172	31	Woman
58	0.61	3	32	Woman	1.1 m/s	36.41	32.44	46.1	3.7	37.7	32	14:15-14:25 pm	10-Sep		3	3	3	3	C3	520m		3.5929	0	42.861	32	Woman
110	0.61	4	61	Woman	1.1 m/s	36.41	32.44	46.1	3.4	37.8	29.2	14:15-14:25 pm	10-Sep		3	4	2	3	C3	520m		6.0371	100	0	61	Woman
110	0.3	5	16	Woman	1.1 m/s	36.41	32.44	46.1	3.6	37.9	29.7	14:15-14:25 pm	10-Sep		2	2	2	3	C3	520m		6.0416	100	0	16	Woman
110	0.65	6	48	Woman	1.1 m/s	36.41	32.44	46.1	3.3	37.8	29.2	14:15-14:25 pm	10-Sep		4	4	3	4	C3	520m		2.7009	0	0.535205	48	Woman
110	0.45	7	16	Woman	1.1 m/s	36.41	32.44	46.1	3.3	37.8	29.3	14:15-14:25 pm	10-Sep		2	1	2	3	C3	520m		5.9581	100	0	16	Woman
110	0.61	8	41	Woman	1.1 m/s	36.41	32.44	46.1	3.3	37.8	29.2	14:15-14:25 pm	10-Sep		3	3	3	4	C3	520m		5.9697	100	0	41	Woman
110	0.3	9	77	Woman	1.1 m/s	36.41	32.44	46.1	3.8	37.9	29.7	14:15-14:25 pm	10-Sep		3	4	2	4	C3	520m		5.8785	100	0	77	Woman
110	0.61	10	15	Man	1.33 m/s	28.16	31.65	43.8	2.7	35.6	27.3	14:45-14:55 pm	10-Sep		3	5	5	2	C2	280		7.1823	100	0	15	Man
110	0.61	11	17	Man	1.33 m/s	28.16	31.65	43.8	2.7	35.7	27.3	14:45-14:55 pm	10-Sep		1	3	1	5	C2	280		6.1945	100	0	17	Man
110	0.37	12	52	Woman	1.33 m/s	28.16	31.65	43.8	2.9	35.5	26.9	14:45-14:55 pm	10-Sep		4	5	3	4	C2	280		6.0458	100	0	52	Woman
110	0.3	13	15	Woman	1.33 m/s	28.16	31.65	43.8	2.9	35.5	26.8	14:45-14:55 pm	10-Sep		2	3	5	4	C2	280		6.9629	100	0	15	Woman
110	0.3	14	15	Woman	1.33 m/s	28.16	31.65	43.8	2.9	35.5	26.8	14:45-14:55 pm	10-Sep		2	3	5	4	C2	280		7.386	100	0	15	Woman
70	0.61	15	46	Man	1.33 m/s	28.16	31.65	43.8	2.8	35.6	29.2	14:45-14:55 pm	10-Sep		4	4	4	3	C2	280		9.836	100	0	46	

Questionnaires

W3-24 Aug

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W3-10 Sept

Figure 1.7 is a map of the 'Barrage' area. The map shows a large industrial complex with several buildings and a central area labeled 'Barrage'. A road runs along the top and right side of the complex. A river or canal is visible on the left side. The map is labeled with 'Barrage' and 'Barrage'.

W3-10 Sept

The drawing is a technical architectural floor plan of a building. It features a central corridor system connecting various rooms. On the left side, there are several rooms, some of which are labeled with numbers like '100' and '101'. On the right side, there is a large, irregularly shaped area that appears to be an outdoor space or a large hall, labeled '102'. The drawing includes numerous lines representing walls, doors, and structural elements. There are also some handwritten notes and labels in a non-English script, possibly indicating room names or specific architectural details. The overall layout suggests a complex building with multiple functional areas.

W3-10 Sept

[illegible]

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W3-10 Sept

4.10.1.1. Kiloban (Jarak dari stasiun: 100 m)

Properti

No	Waktu	Ke	Dari	Waktu	Waktu
1	10.00	10.00	10.00	10.00	10.00
2	10.00	10.00	10.00	10.00	10.00
3	10.00	10.00	10.00	10.00	10.00
4	10.00	10.00	10.00	10.00	10.00
5	10.00	10.00	10.00	10.00	10.00
6	10.00	10.00	10.00	10.00	10.00
7	10.00	10.00	10.00	10.00	10.00
8	10.00	10.00	10.00	10.00	10.00
9	10.00	10.00	10.00	10.00	10.00
10	10.00	10.00	10.00	10.00	10.00

5.10.1.1. Kiloban (Jarak dari stasiun: 100 m)

Properti

No	Waktu	Ke	Dari	Waktu	Waktu
1	10.00	10.00	10.00	10.00	10.00
2	10.00	10.00	10.00	10.00	10.00
3	10.00	10.00	10.00	10.00	10.00
4	10.00	10.00	10.00	10.00	10.00
5	10.00	10.00	10.00	10.00	10.00
6	10.00	10.00	10.00	10.00	10.00
7	10.00	10.00	10.00	10.00	10.00
8	10.00	10.00	10.00	10.00	10.00
9	10.00	10.00	10.00	10.00	10.00
10	10.00	10.00	10.00	10.00	10.00

W3-10 Sept

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W3-10 Sept

[illegible]

W3-10 Sept

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W2-10 Sept