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

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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

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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 Matzarkis 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 ( $^{\circ}\text{C}$ ), 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/km<sup>2</sup>. Madrid has Mediterranean climate, and according to Köppen-Geiger classification falls in the category of "hot dry-summer (Csa)" climate (Kotttek 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).

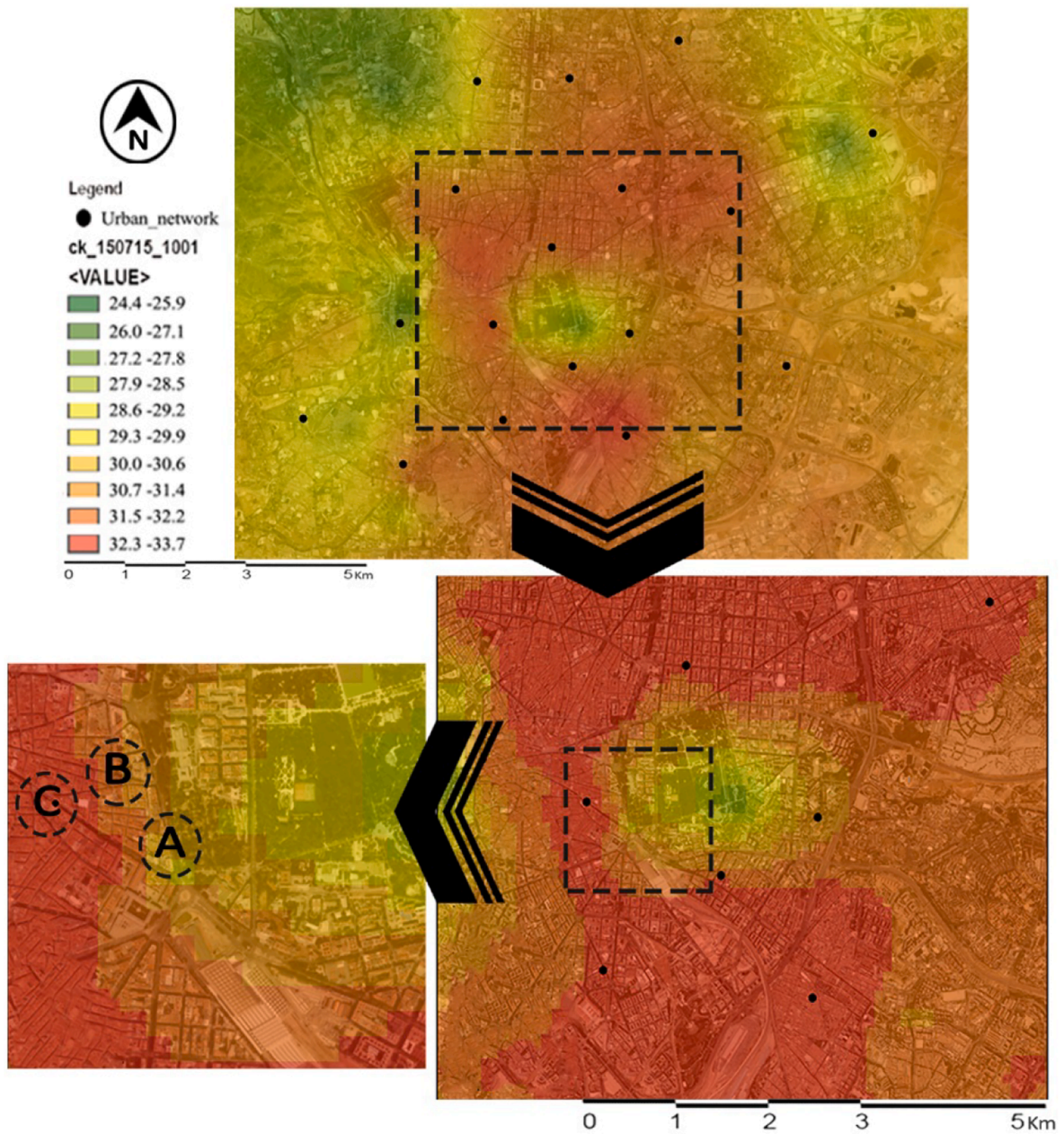


Fig. 1. Map of UHIs of Madrid on July 26, 2015 (Núñez Peiró et al., 2017) and selected area at the west side of the Retiro Park. Node A is positioned in the yellow zone, Node B is in the orange zone, and Node C is in the red zone near one of Madrid’s UHI.

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 m<sup>2</sup>, 265 m<sup>2</sup>, and 260 m<sup>2</sup>. 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  $\pm 0.2$  °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 <sup>2</sup>	Shape	SVF <sup>a</sup>	Number of trees	Mean Tree Height (m)	Mean Crown Diameter (m)	Crown Shape <sup>b</sup>
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

<sup>a</sup> Calculated by RayMan 1.2.

<sup>b</sup> 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.

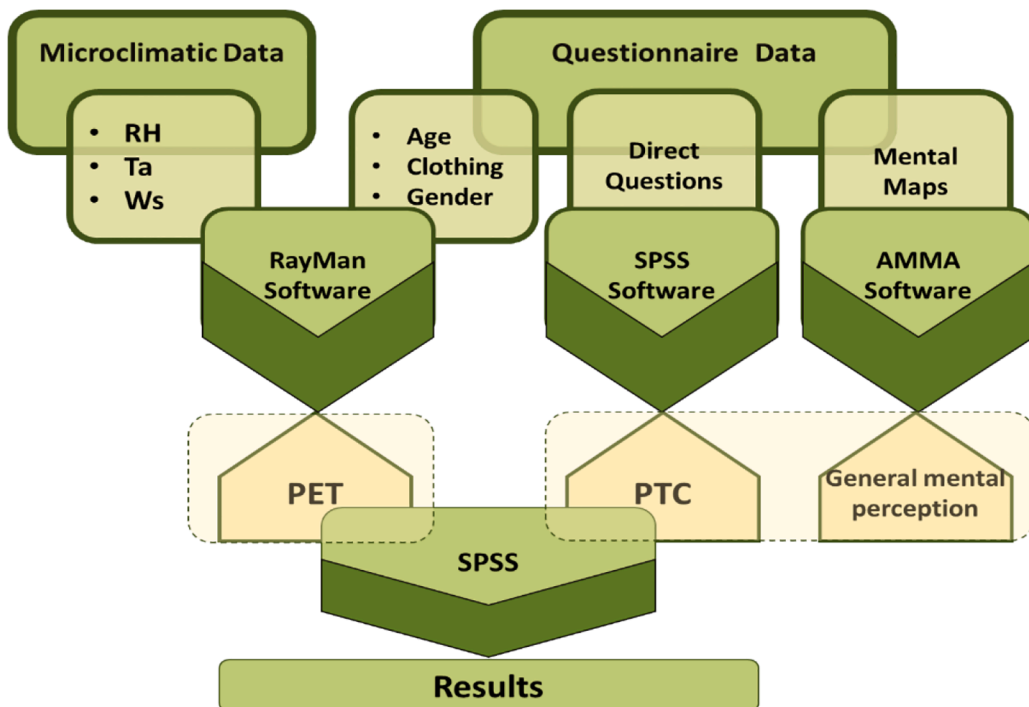


Fig. 3. Methodology structure.

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 (%)		
<b>C</b>	<b>B</b>	<b>A</b>	<b>C</b>		
2	8	0	13–21	2	<i>Age</i>
19	20	2	22–30	19	
31	30	11	31–45	31	
23	20	28	46–60	23	
25	22	36	61–85	25	
62	50	43	Men	62	<i>Gender</i>
38	50	57	Women	38	
2	0	2	Very low (1)	2	<i>Q1</i>
19	14	9	Low (2)	19	
48	42	53	Medium (3)	48	
25	36	32	High (4)	25	
6	8	4	Very high (5)	6	<i>Q2</i>
4	2	4	Very low (5)	4	
23	44	9	Low (4)	23	
33	22	40	Medium (3)	33	
25	24	38	High (2)	25	<i>Q3</i>
15	8	9	Very high (1)	15	
2	6	2	Very low (1)	2	
27	20	13	Low (2)	27	
33	38	34	Medium (3)	33	<i>Q4</i>
25	20	32	High (4)	25	
13	16	19	Very high (5)	13	
13	8	4	Very low (1)	13	
27	44	11	Low (2)	27	<i>Clothing</i>
25	36	60	Medium (3)	25	
27	10	21	High (4)	27	
8	2	4	Very high (5)	8	
15	10	11	Shirt and Normal Pants- 65 clo	15	<i>Activity</i>
23	24	21	Tshirt and normal pants_61 clo	23	
13	6	6	shirt and Shorts-45 clo	13	
31	46	38	Tshirt and Shorts (or skirt)-40 clo	31	
19	12	21	Dress-35 clo	19	
0	2	2	Suiet-90 clo	0	
50	82	66	Walking- 115 w	50	<i>AMMA results</i>
31	16	9	Standing-70 w	31	
15	0	26	Sitting- 60 w	15	
4	2	0	Jogging-220 w	4	
43.8	32	19.1	Park Mentioned (100)	43.8	
56.3	68	80.9	Park Not mentioned (0)	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 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-Cerchel 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).

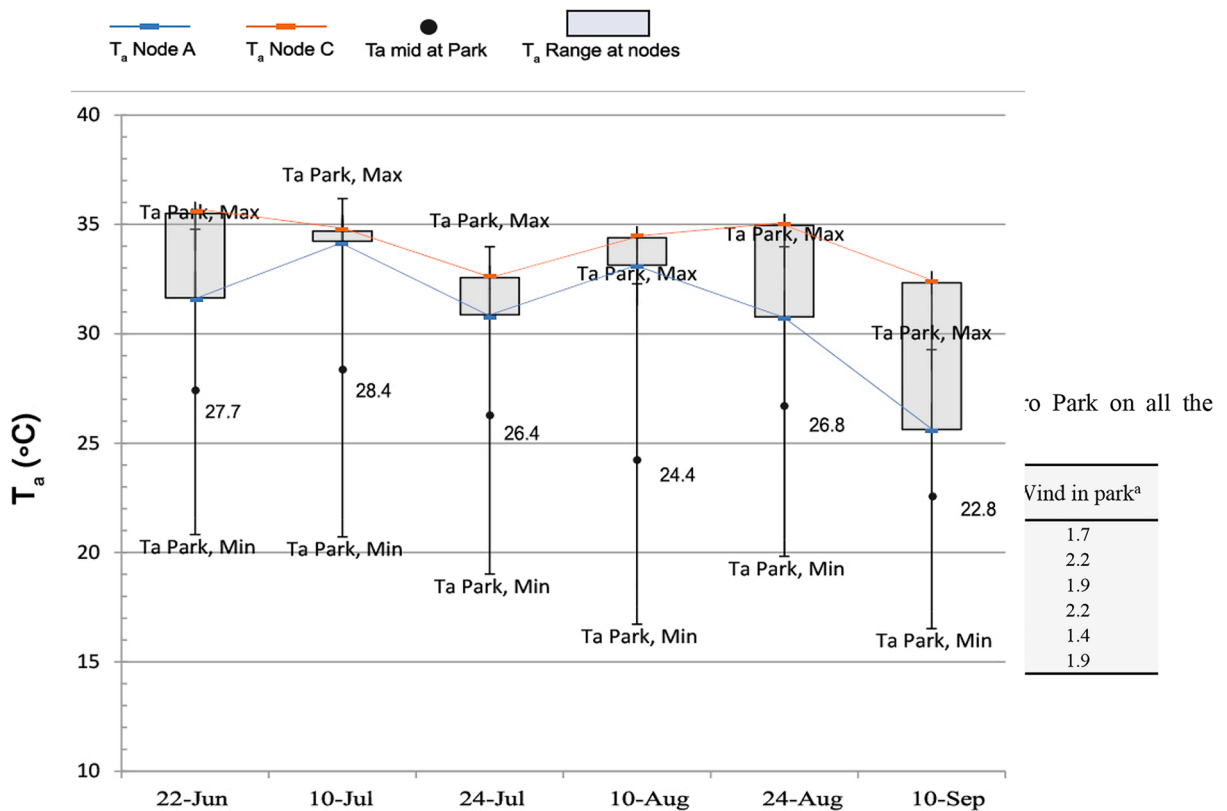
Date	Nodes	Time	Mean WS,m/s	Mean RH, %	Mean $T_a$ , °C	Mean PET, °C
22 Jun	A	13:00–13:10	2.16	20.13	31.64	37.2
	B	12:40–12:50	1.57	20.05	33.17	39.3
	C	12:15–12:25	2.5	24.96	35.5	43.1
10 July	A	13:35–13:45	1.87	20.13	34.23	41.1
	B	13:10–13:20	1.57	21.8	34.5	42.2
	C	12:45–12:55	2.25	22.34	34.69	42.0
24 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	34.38	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 4**

The 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 <sup>a</sup> $T_a$ (°C)			Time of $T_a$ in Retiro park <sup>a</sup>		HR % of park <sup>a</sup>	Wind in park <sup>a</sup>
	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*
		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

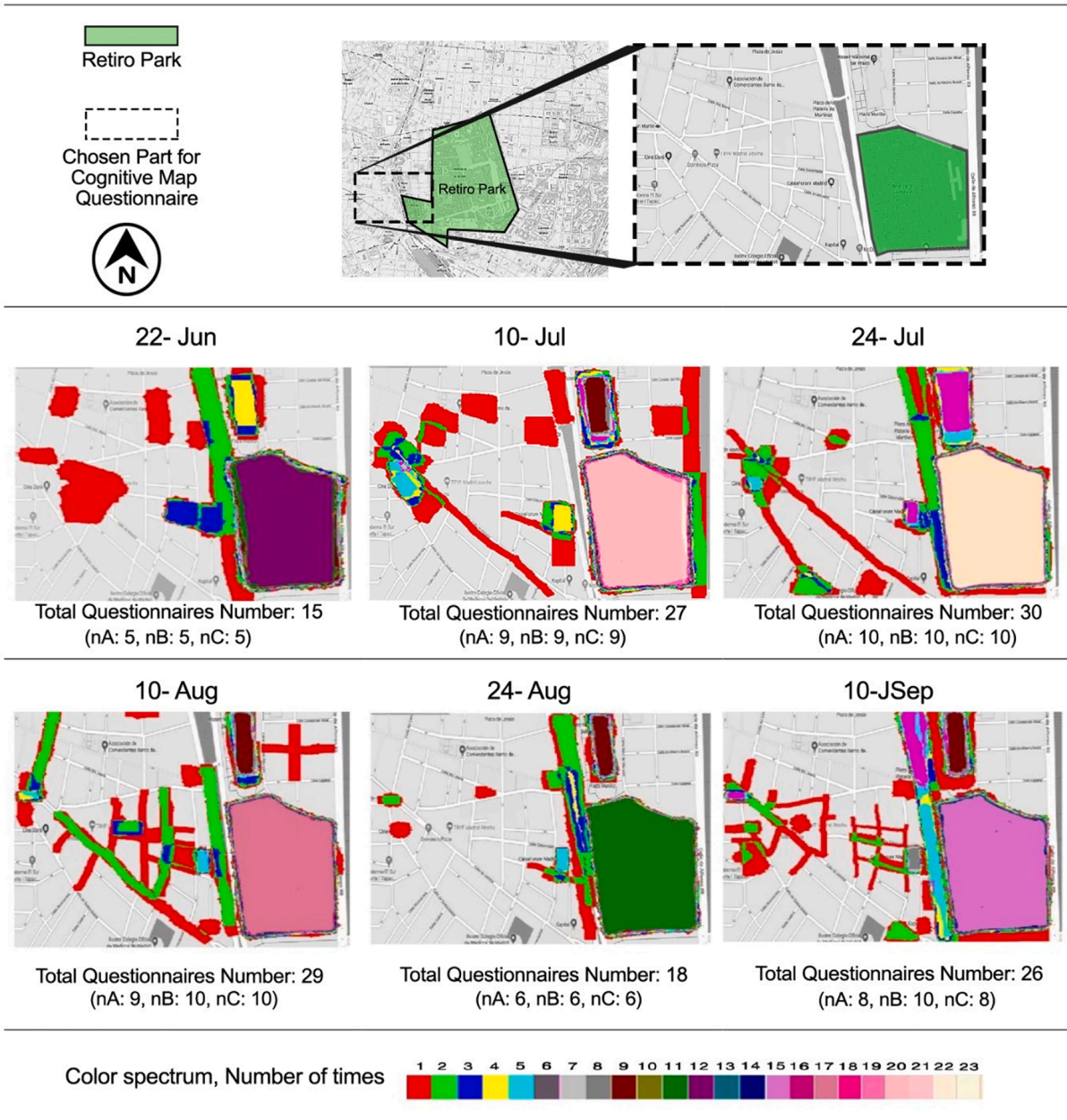


Fig. 5. Cognitive map analyses using the Aram Mental Map Analyzer (AMMA) during six summer days of 2018.

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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