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

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Research

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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 130m and 280m distance of the park was respectively 1.6°C and 0.9°C lower than the temperature at the 520m 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 130m and 280m 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.

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 (IPCC, 2019; Bulkeley, 2013). 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) (Ward et al., 2016; Oke, 1982; Taha, 2017). This effect is strong enough to cause major physical and mental health problems for citizens (Luber & McGeehin, 2008; Tan et al., 2010; Lemonsu et al., 2015; Błażejczyk et al., 2018). Urban green spaces not only beautify the urban landscape but also moderate urban climate by increasing humidity and lowering air temperature (Brown et al., 2015; Zhang et al., 2017). 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 et al., 2017; Bertram & Rehdanz, 2015; Twohig-Bennett & 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 et al., 2018; Aram, Solgi, & Holden, 2019; Shahab & Viallon, 2020). 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 et al., 2009;Buyadi et al., 2015; Lee et al., 2016; Shahab & Viallon, 2019). Urban green spaces are known to have a cooling effect on air temperature (Du et al., 2017; Fan et al., 2019). 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 (Hamada & Ohta, 2010; Yan et al., 2018; Yu et al., 2018).

Thermal comfort has received much attention because of its great impact on the quality of life of citizens (Lai et al., 2019; Chen & Ng, 2012). According to CIBSE, human thermal comfort refers to the temperature conditions that satisfy at least 80% of individuals (CIBSE, 2015). Human thermal comfort depends on several factors including climate, air temperature, humidity, sunlight, and air movements (Rupp et al., 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 & Hensen, 2007).

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 (Orosa, 2009). 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 (Nikolopoulou & Lykoudis, 2006; Lin, 2009). 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 & Ng, 2012; Jamei et al., 2016; Lai et al., 2019). Over the years, researchers have introduced various indexes for measuring outdoor thermal comfort, which include; Predicted Mean Vote (PMV) (Fanger, 1973), Standard Effective Temperature (SET*) (Gagge et al., 1986), which was later developed into OUT-SET* (Pickup & De Dear, 2000), Man-Environment heat Exchange (MENEX) (Blazejczyk & Krawczyk, 1994), Physiological Equivalent Temperature (PET) (Höppe, 1999), Comfort Formula (COMFA) (Kenny et al., 2009), and Universal Thermal Climate Index (UTCI) (Jendritzky et al., 2009) 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 (Sharmin et al., 2015; Lai et al., 2014; Ng & Cheng, 2012). 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 (Matzarakis et al., 1999; Krüger et al., 2017; Matzarakis & Amelung, 2008). 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 (Potchter et al., 2018).

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 (ASHRAE, 2010, 2015). In this definition, the term "condition of mind" refers to the fusion of mental and physiological conditions in the concept of thermal comfort (ASHRAE, 2017). 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 & Steemers, 2003; Knez & Thorsson, 2008; Lenzholzer et al., 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 et al., 2018; Klemm et al., 2015a).

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 et al., 2001). Since people's mental conditions play a key role in their cognition of the environment (Mansournia et al., 2020), these conditions can massive impacts on their thermal perception of the environment and consequently their comfort conditions (Knez et al., 2009; Aljawabra & Nikolopoulou, 2010; Shin, 2016). Indeed, the response of a human to an external stimulus depends on the "information" that the individual has in and about that particular situation (Moskaliuk et al., 2017). 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 (Kitchin, 1994; Heft, 2013; Wang & Schwering, 2015). 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 (Aram et al., 2019). In other words, these maps can help us examine the citizens' perception of places based on their role in creating thermal comfort (Klemm et al., 2015b).

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 (Aram et al., 2019; Aram et al., 2020). In one study, the northern part of the park with structured urban configuration was examined in the morning (Aram et al., 2019), while in the other study, the western part of the park, located in the historical area (organic urban configuration) was examined at noon (Aram et al., 2020). 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 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 (Kottek et al., 2006). 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 520m distance from the edge of the park (Núñez Peiró et al., 2017).

According to the UHI of Madrid (Núñez Peiró et al., 2017), there is a heat island near the Granada-Narciso Serra district located 520m away from the southern edge of the park (marked red in Figure 1)(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. For easier reference, hereafter, the Torrejón-Agustín Querol intersection (150m) is called intersection A, the Gutenberg-Valderribas-Fuenterrabía intersection (280m) as called intersection B, and the Granada-Narciso Serra intersection (520m) is called intersection C.

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 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 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' 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 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 peak temperature inside the park in the summer of 2017 had been observed, on average, between 13:28 and 15:08 CEST (AEMET, 2018), 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 ±2.5% for RH and ±0.2°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. 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. 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 (AEMET, 2018).

Survey

Throughout the study, researchers surveyed a total of 133 individuals ($N_{node\ A}$= 46, $N_{node\ B}$=43, $N_{node\ C}$=44), who were randomly chosen from among people either living or working in the area. 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 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 (Aram, Solgi, García, Mohammadzadeh, et al., 2019). 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).

Table 1

The proportional percentages questionnaire data in the three investigated intersection ($N_{node\ A}$= 46, $N_{node\ B}$=43, $N_{node\ C}$=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	13.0	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)	13.0	14.0	31.8
	Medium (3)	37.0	41.9	34.1
	High (4)	39.1	34.9	27.3
	Very high (5)	10.9	7.0	2.3
Q2	Very low (5)	8.7	18.6	18.2
	Low (4)	45.7	34.9	47.7
	Medium (3)	37.0	37.2	25.0
	High (2)	6.5	4.7	9.1
	Very high (1)	2.2	4.7	.0
Q3	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
Q4	Very low (1)	.0	.0	6.8
	Low (2)	34.8	23.3	6.8
	Medium (3)	32.6	32.6	34.1
	High (4)	19.6	27.9	34.1
	Very high (5)	6.5	9.3	13.6
AMMA results				
	Park Mentioned (100)	8.7	18.6	29.5
	Park Not mentioned (0)	91.3	81.4	70.5
Clothing				
	Shirt and Normal Pants- 0.65 clo	21.3	6.5	13.6
	Tshirt and normal pants_0.61 clo	8.5	37.0	29.5
	shirt and Shorts-0.45 clo	6.4	6.5	6.8
	Tshirt and Shorts (or skirt)-0.40 clo	31.9	30.4	31.8
	Dress-0.35 clo	23.4	13.0	13.6
	Suiet-0.90 clo	2.1	2.2	0.0
	Other clothing	6.4	4.3	4.5
Activity				
	Wlking- 115 w	80.4	73.9	77.3
	Standing-70 w	13.0	15.2	18.2
	Sitting- 60 w	6.5	17.4	4.5

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 such as One-Way Analysis of Variance (ANOVA) in order 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 (Matzarakis et al., 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 et al., 2008) (Table 1).

Results

As mentioned, the data of this study were collected on six 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 (AEMET, 2018), 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-Fuenterrab intersection at a distance of 280m from the park and the Granada-Narciso Serra intersection at a distance of 520m from the park had higher average temperatures (34.4°C and 35.3°C) (Figure 3).

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 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

Considering these temperature differences, PET and PTC were also predicted to be different. After determining the PET of each respondent (based on gender, age, clothing type, and weather conditions at the time of the survey) with the software RayMan 1.2 (Fröhlich et al., 2019), the average PET at distances of 130, 280, and 520m 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 130m and 280m distance from the park have respectively 3.9°C PET and 2.3°C PET less than those at the 520m 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 130m away from the park, to 3.07 for intersection B, which was 280m away from the park, and finally to the sub-average score of 2.88 for intersection C, which was 580m away from the park (Table 3).

Table.3

Intersection mean values for air temperature (T_a), relative humidity (RH), mean radiant temperature (Tmrt), 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* 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	0. 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

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

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-Fuenterrabía 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 (Figure 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<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 et al., 1975) (Table 4).

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			

Since the results of ANOVA showed a significant difference between the average PETs of nodes A, B, and C (P-value <0.05), Tukey's test was used to determine which of the response levels had a significant difference (Tables 5 and 6).

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*	.56029	.018	-2.8795	-.2227
	C	-3.86057*	.55699	.000	-5.1811	-2.5400
B	A	1.55111*	.56029	.018	.2227	2.8795
	C	-2.30946*	.56641	.000	-3.6523	-.9666
C	A	3.86057*	.55699	.000	2.5400	5.1811
	B	2.30946*	.56641	.000	.9666	3.6523

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

Table 6. Tukey PET analyses in the three investigated intersections (A, B and C).

Tukey HSD				
		Subset for alpha = 0.05		
Intersection	N	1	2	3
A	46	38.4326		
B	43		39.9837	
C	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. A, B and C, 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.

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).

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			

Since the results of ANOVA showed a significant difference between PTC 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 8 and 9).

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*	.10984	.034	.0165	.5373
B	A	-.08784	.11049	.707	-.3498	.1741
	B	.18909	.11170	.212	-.0757	.4539
C	A	-.27693*	.10984	.034	-.5373	-.0165
	B	-.18909	.11170	.212	-.4539	.0757

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

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

		Subset for alpha = 0.05	
Intersection	**N**	**1**	**2**
C	44	2.8807	
B	43	3.0698	3.0698
A	46		3.1576
P-value		.206	.708

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 130m 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 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 (Xu et al., 2017), extensive shading (Sun et al., 2017), and moisture generation and evaporation from leaf surfaces (Vidrih & Medved, 2013), the space within a park often has a lower ambient air temperature than the surrounding environments (Park et al., 2017; Yu et al., 2020a). The results of the present study showed that during the data collection days (June 22, July 10 & 24, August 10 & 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 520m 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 meters (Aram, Higueras García, Solgi, et al., 2019). 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 280m distance and a 1.6°C reduction in air temperature within the 130m 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 (Aram et al., 2019) and western (Aram et al., 2020) sides of Retiro Park in Madrid have shown that the park cooling effect can reduce the air temperature during the summer days at a distance further from the park (Figure 6). That is, in the northern area, the cooling effect of the park up to a distance of 665 meters can reduce the air temperature compared to the area located in UHI between 0.6 ° C and 1.3 ° C (Aram et al., 2019). This effect is also able to reduce the air temperature in the western part of the park to the range of located at 855 meters (adjacent to UHI) between 2.4 ° C and 2.8 ° C (Aram et al., 2020). 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 (Yu et al., 2020b; Yu et al., 2017). Because the prevailing wind direction was shifty during data collection, it was not considered in this study, but other 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 (Figure 5). Based on the previous research about the role of urban texture in reducing air temperatures (Taleb & Abu-Hijleh, 2013; Zhou et al., 2011; Faroughi et al., 2020) 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 to 60 meters compared to the western area and 55 to 70 meters compared to the northern area (Figure 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 (Figure 6). Being in a lower elevation area according to studies on the effect of topography on urban heat (Alcoforado & Andrade, 2006; Ketterer & Matzarakis, 2014) 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 meters), as a result, the distance of the cooling effect in the urban fabric is less that than 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 (Aram et al., 2019). 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 ° C 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 (Aram et al., 2020; Aram et al., 2019). As the buildings of all three areas had the same height system (buildings of 5 to 6 floors), and the dimensions of the streets in the places where the data was 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 (Alobaydi et al., 2016; Jamei et. al., 2017). 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 (Sun et al., 2017). 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 (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 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 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 develope 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 520m, 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 130m distance and a 0.9°C reduction in air temperature within the 280m distance of the park compared to Granada-Narciso Serra intersection (520m 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 130m distance of the park was 4% less than the PET at the 280m distance and 9.3% 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 5.4% less than the PET at the 520m 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

Declarations

Ethics approval and consent to participate

In this study the data is anonymized. Authors would like to confirmed 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 concent for the publication.

Availability of data and material

Data is available upon request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization, F.A. and E.H.G.; methodology, F.A. and E.S; software, F.A. and A.M.; validation, F.A., E.S. and E.H.G.; formal analysis, F.A. and A.M.; investigation, F.A.; data curation, A.M. and E.S.; writing—original draft preparation, F.A. and E.S; writing—review and editing, E.H.G. and A.M.; visualization, F.A. and A.M; supervision, E.H.G and E.S.

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Figures

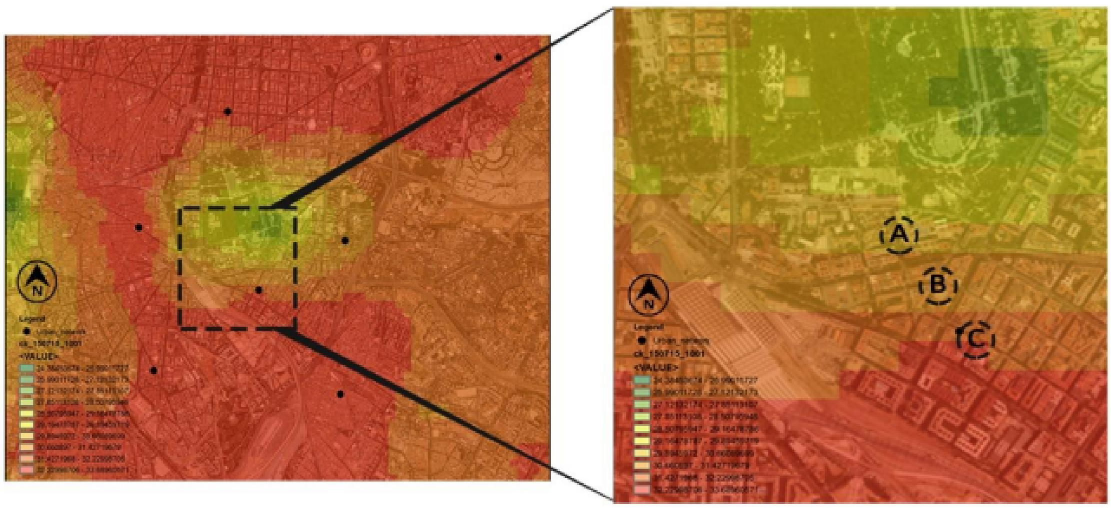

Figure 1

Madrid's UHI map (July 26, 2015) and the investigated area at the southern side of the Retiro Park (green zone). Area A is located in the yellow zone, area B in the orange zone, and area C in the red zone near one of the Madrid's UHIs

Figure 2

Street views of the three investigated intersections (A-C), and their Sky View Factor values (calculated by RayMan 1.2)

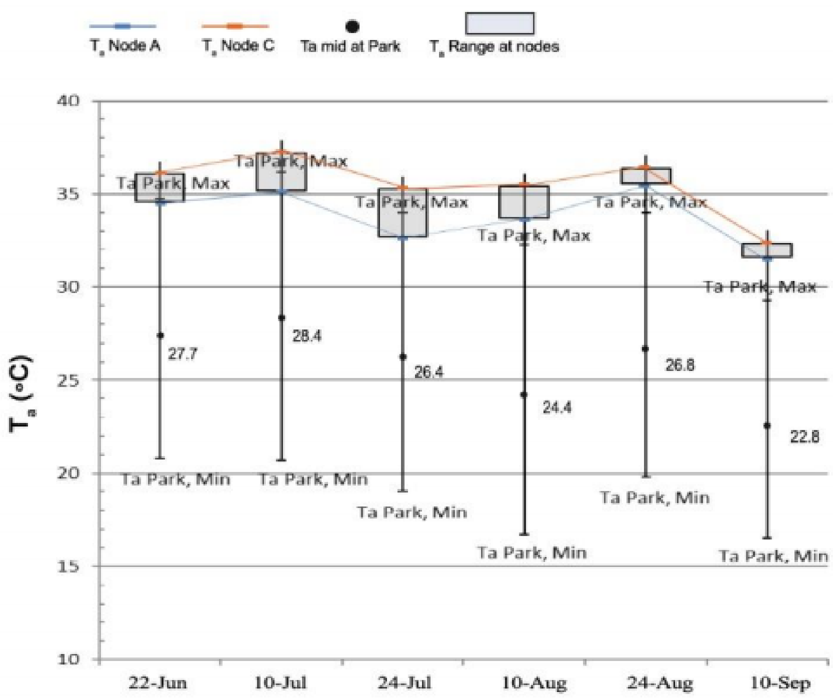

Figure 3

The diagram illustrates the temperature range of the three investigated intersections A, B & C on the southern side of the Retiro Park, and the temperature range inside of the park. Gray rectangles: temperature range at three Nodes (bottom side: Ta Node A, top Side: Ta Node C). Linear range: the temperature range of the park, bottom line: Ta Min of the park, top line: Ta Max of the park

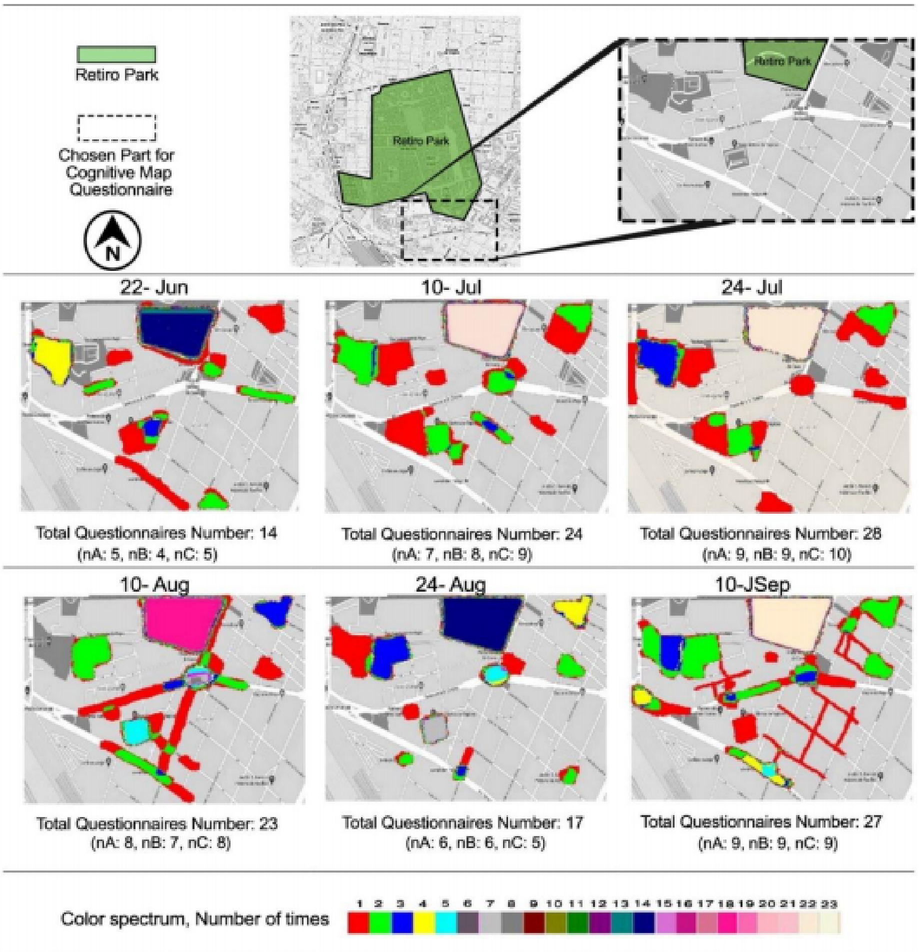

Figure 4

Cognitive map analyses using the Aram Mental Map Analyzer (AMMA) in the southern side of the Retiro Park during six summer days of 2018.