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Pocket parks for human-centered urban climate change resilience: Microclimate field tests and multi-domain comfort analysis through portable sensing techniques and citizens' science

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ABSTRACT

Dense urban areas are subject to dynamic and urgent challenges, exacerbated by anthropogenic forcing. Urban Heat Island and heatwaves pose a threat to citizens' comfort, due to extreme microclimate conditions. In this panorama, urban parks represent effective strategies towards more livable and comfortable urban areas. In particular, small pocket parks could aid in the mitigation of such challenges in every neighborhood. Indeed, they are in close proximity to citizens, allowing large population groups to benefit from the advantage of living green areas. Therefore, this paper assesses for the first time microclimate conditions and personal multi-domain perception imputable to pocket parks, by means of human-centered experimental analyses, coupling objective and subjective assessment. Wearable monitoring-systems are employed for the assessment of granular-microclimate variables mapping, and questionnaire-surveys are collected in the pocket parks and their surroundings, for comparison purposes. Results show that, while microclimate mitigation is not extremely significant as expected (−0.5 °C air temperature, +5–10% relative humidity inside the park), perceived comfort in pocket parks is higher than on the streets, shifting from "neutral" on the close by streets to "good/very good" in the park. Therefore, a better design for microclimate mitigation of pocket parks is needed, especially taking into account the potential air stagnation, while acknowledging their fundamental societal role.

1. Introduction

In the last decade, Urban Heat Island (UHI) arose as one of the best documented environmental climate-change related phenomenon, which is due to synergistic anthropogenic actions [1–3]. UHI consists of a local temperature increase affecting urban areas with respect to their rural surrounding [2]. In detail, UHI depends on several factors including urban morphology and density, as well as the urban land consumption with impervious construction materials, i.e. asphalt and concrete, which have different thermal properties with respect to the green areas and consequentially modify the urban energy budget [4,6]. Indeed, impervious urban materials lead to increased absorption of solar radiation and heat storage by construction materials in the built environment. Other causes of UHI are high anthropogenic heat accumulation and reduced evapotranspiration, especially in those packed urban layout dealt as urban canyons singularities [5]. The reduction of green areas and water bodies in cities limits evapotranspiration, leading to higher air and surface temperatures [7] and relatively higher building energy consumption for cooling [8]. As foreseen by the Department of Economic and Social Affairs, urbanization is an ongoing process and according to this estimation, 60% of world population is predicted to live in cities by 2030 [9]. This implies an increasing trend of anthropogenic heat accumulation [5] due to vehicles, emissions from HVAC systems in buildings, industry and other uses. On its turn, increased air temperature produces a significant impact on the energy consumption of buildings in terms of peak electricity demand and building cooling loads, as documented by Santamouris et al. [10], which found significantly increased building cooling load and even higher peak in electricity demand for cooling due to UHI phenomenon.

The result of the combination of soaring urban population, urban land consumption and UHIs is a threat to the livability of

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cities, which impends both environmental impact and human health. UHI affects both air (air UHI) and surface (surface UHI) temperatures. Air UHIs intensity can reach 5 °C and often exceeds 8 °C, especially during the nighttime, while surface UHI is especially high during the day [11,12]. This increase in urban air and surface temperature implies a reduction of the ventilation contribution, that may result in an increase of the ozone and nitrogen oxides concentration [13], which consequentially compromises human health and comfort perception during the hot season [14]. In addition, studies have shown a synergy between UHIs and heatwaves that produce potential heat stress for citizens, tourists and pedestrians in general [15–17]. UHI exacerbates heatwaves, increasing the risk of heat-related illness, mortality and whole health vulnerability for citizens. This effect is even more relevant considering that future projections oversee more intense, frequent and longer heatwaves due to climate modifications [18].

In this panorama, the analysis and implementation of effective mitigation strategies in urban areas is of paramount importance. In the last decade, several contributions have been produced by the scientific community about effective strategies. Among them, the most documented one consist of (i) replacing dark materials with high albedo light colored materials, increasing the albedo of the cities [19–21]; (ii) introducing water bodies and water elements [22–24]; (iii) increasing urban greenery, i.e. vegetated urban areas and green surfaces [25]; and (iv) increasing thermal energy storage capability [26,27]. In particular, advanced cool surfaces have been assessed, proposed and implemented as passive cooling strategies both to decrease building energy demands and mitigate urban microclimate [28–30]. Several studies demonstrated how cool and green roofs are indeed able to reduce surface and air temperature peaks in urban environment during the hot season [31].

Castaldo et al. analyzed the air UHI magnitude of 5 °C in an historical hilly town in central Italy and highlighted a reduction of about 3 °C related to urban greenery [32]. The potential of such mitigation strategy is confirmed by AboElata that investigated the effect of greenery and vegetation on UHI in Cairo [33]. Rosenfeld assessed a heat reduction equal to 4 K in outdoor air temperature as a result of the presence of trees. At the same time, water-based systems seem to be very promising in reducing UHI and local overheating [34–38]. By coupling the above-mentioned solutions, even better results can be obtained, as shown by Ballout Amor and colleagues, which examined the effectiveness of integrating vegetation, water ponds and fountains in improving urban microclimate and human well-being in a semi-arid climate context (Setif, Algeria), with air temperature reductions up to 6 °C [39].

Parallel to studying the possible mitigation strategies, also their application in urban areas is crucial. Indeed, cities are characterized by a high level of heterogeneity and complex morphology, leading to different microclimate conditions within the same urban context and even neighborhood [40–42]. Thus, the analysis of local intra-urban microclimate can play a key role in identifying suitable and effective mitigation strategies that aim at improving human well-being [39]. Indeed, outdoor human perception and well-being affect citizen habits, outdoor activities and tourist flow [39]. Therefore, to preserve the resilience and environmental sustainability of cities, mitigation strategies that focus on human-centered wellbeing solutions, should be taken into account. In this view, the application of small urban parks, which are the focus of this contribution, could aid towards an increased and more spread presence of greenery, water bodies and high albedo materials, and serve as an effective human-centered urban and suburban mitigation strategy. In detail, pocket parks are peculiar urban components that can be inserted even in dense urban areas as spot oasis of coolness and greenery in the urban texture [43]. Pocket parks are characterized by small dimensions and are usually located in residual spaces in dense urban areas, meant to represent high-quality social contexts [44]. While there is not a univocal definition of their specific architectural features [44,45], in this work we refer to pocket parks as small "vest-pocket-dimension" parks in dense urban areas. The name derives from the shape and dimension of vests' pockets: small and closed on three out of four sides [44]. While they are now diffused in many regions and countries, the most famous examples and typological epitomes of pocket parks are located in New York City. Here, the famous Paley Park and Greenacre Park have been built first after the II World War in Europe [44] and later diffused in the USA and worldwide with mainly a social and community-aggregation function. This article, for the very first time, investigates their potential for enhancing outdoor comfort and counteracting UHI. Previous studies confirmed the relevance of park materials and configuration, with respect to occupants' comfort and UHI mitigation due to vegetation, shading, dimension and position in the urban texture [46–48].

In order to investigate intra-urban granular microclimate with a *human-centered* perspective, portable monitoring stations are increasingly employed in recent studies [41,49]. Examples of the employment of portable monitoring stations are being carried out in Tempe (AZ, USA), where carts equipped with microclimate sensors are employed to gather heat data across neighborhoods or to assess shade types [50,51]; or in Ohio (USA), where small and low-cost sensors were mounted on bikes to measure UHI [52]. In New South Wales (Australia), researchers employed wearable wrist-band devices to obtain integrated data on human heat exposure with the Coolbit Project [53,54]. The aim to consider more human-centered data is also evidenced in Singapore, where mobile and fixed sensors at the district-scale level were used together with online and on-site survey campaigns to investigate the willingness to pay for heat mitigation strategies [55]. Indeed, in addition to the need of considering intra-granular microclimate in urban areas, recent research demonstrated the importance of considering human-centered data [41,49]. The existence of a gap between objective and subjective multi-domain (thermal, visual, acoustic, air quality) comfort assessment is motivated by psychological and subjective aspects, which could be triggered by specific environments, e.g., by pocket parks presence. To assess this gap, microclimate monitoring campaign and personal questionnaire surveys were paired in recently published studies [56]. In fact, not only physical, but also physiological and psychological dimensions contribute to shape comfort sensation [57]. Additionally, the whole comfort sensation is obtained by the simultaneous consideration of different domains of comfort, i.e., thermal, visual, acoustics, air quality [56]. While each singular dimension is clearly studied, the whole combination of multi-domain perception through a multi-dimensional approach (i.e., physical, psychological and physiological) is not yet widely investigated in the outdoors, while the pocket park context may represent a key resource, since it is expected to produce non-negligible societal benefits as well as microclimate mitigation actions. In this panorama, no comprehensive study has been conducted until now, to the best of authors' knowledge, on the whole comfort experience in pocket parks, considering both (i) intra-urban, granular, objective microclimate measurements and (ii) subjective assessment. Indeed, intra-urban studies are responding to an emerging field of investigation, while we add to this emerging field also the multi-domain subjective assessment of citizens' perception [56,58], towards the codification of pocket parks for overall urban overheating mitigation.

Therefore, this article is organized as follows: the research questions are presented in Section 1.1. Then, the coupled objective/subjective experimental methodology and the employed tools are described in Section 2. The experimental campaign sites, which are two relevant and significant case studies, are identified and then results are presented. Finally, conclusions are drawn.

1.1. Research questions

As mentioned, in this work, we aim at investigating for the first time the role of small urban parks (namely pocket parks) in reducing thermal stress from UHI during the hot season and improving pedestrians' comfort and safety, by means of experimental in-field monitoring of intra-urban, granular microclimate and multi-domain questionnaire surveys to pedestrians.

While considering granular microclimate conditions and subjective assessment, different aspects related to comfort sensation in urban areas and to the role of small urban parks and their architectural features are considered, and several key original research questions are answered.

The first objective is to verify whether and how pocket parks are able to mitigate urban microclimate during the hot season. Thus, the related research question #1 is:

- RQ1: which is the role of pocket parks in mitigating intra-urban microclimate during the hot season?

Then, after assessing the role of pocket parks with respect to microclimate variables, we focus on the subjective perception of pedestrians, leading to research question #2:

- RQ2: How are pocket parks perceived by pedestrians with respect to thermal, visual, acoustic, air quality, [5] and whole comfort sensation, compared to the surrounding urban environment?

Finally, after assessing microclimate variables (objective measurements) and pedestrians' perception (subjective assessment), the two are compared, leading to research question #3:

- RQ3: Are the measured microclimate variables and subjective pedestrians' perception consistent or is there a significant gap between them?

2. Methods

The implemented methodology combines microclimate-monitoring campaigns by means of an innovative portable weather station with longitudinal survey campaigns, simultaneously submitted to citizens in two pocket parks in summer conditions. Thus, the methodology allows assessing physical-objective and subjective parameters, which contribute to delineating comfort perception of pedestrian in the outdoors. Moreover, it also allows highlighting differences in both microclimate and human perception between the urban environment and the specific environment of the pocket parks. The planned monitoring campaign and the designed monitoring system are described in greater detail in the following subsection.

2.1. Microclimate monitoring campaign

The experimental monitoring campaigns are carried out through an innovative portable weather station specifically designed to detect the pedestrian-, human-centered perspective within the urban environment, especially along pathways that are not accessible by car, e.g. pocket parks. The station is carried around during walking-based monitoring; and the measurements are performed dynamically, at persons' height within pocket parks and their surroundings. This system is able to monitor the main environmental parameters, i.e. air temperature, relative humidity, wind speed and direction, solar radiation, and is equipped with a GPS antenna. The setup consists of a classic walker-rollator and an all-in-one weather station, connected to an 1.8 m-high iron pole of, which records data with a frequency equal to 1 Hz. Table 1 reports technical specifications of the sensors embedded in the compact weather station, with respect to accuracy and resolution.

Moreover, the gathered data can be instantaneously read and post-processed through a tailored graphical interface, by connecting the weather station via cable to a portable computer. Fig. 1 shows the described innovative monitoring system and the tailored graphical interface to manage the collected environmental parameters.

The described monitoring station was used to perform the experimental monitoring campaigns in the two selected pocket parks and their surrounding urban environment during summer 2019, during a classic heat-stressing time. Each pathway was carefully planned in order to include pocket parks and their close-by streets, so as to detect the hypothesized difference in terms of microclimate conditions between urban densified and spot green areas. Moreover, each experimental path was designed to be covered in<30 min, to avoid time dependencies of the mentioned physical findings, and the measures were taken walking at a slow and constant pace. In doing so, we selected two experimental pathways, corresponding to two pocket parks and their surrounding streets. The same selected pathways were covered three times per day, i.e. at 9 a.m., 1p.m., 7p.m., to assess the dynamic daily variation of the above-described collected key environmental parameters, at overheating and overcooling peak time, and also to pose questionnaire surveys to the users of the mentioned pocket parks in those hours. Additionally, the experiment was carried out during two different-weather days, allowing for daily comparison. Thus, the analysis took into account the existing correlation between environmental parameters and urban configuration [59,60] and were conducted during (i) a sunny day with clear sky conditions and (ii) a cloudy day, in order to compare different weather conditions and environmental dynamic variation during summer. Table 2 reports the experimental campaign details in terms of monitored area, selected days, weather conditions and time of each monitoring campaign.

These monitored data are then elaborated to evaluate the apparent temperature (*At*) and the physiological equivalent temperature (PET), as useful additional indicators to be employed for

Table 1
Technical specifications of the sensors embedded in the compact weather station.

Monitored parameter	Technical specifications
Air temperature [°C]	Range −40 °C to + 70 °C, Accuracy ± 0.3 °C- 20 °C, Resolution 0.1 °C
Relative humidity [%]	Range 0–100%, Accuracy ± 2% @20 °C (10% to 90%), Resolution 1%
Wind Speed [m/s]	Range 0.01 to 60 m/s, Accuracy ± 3% 0.01 m/s to 40 m/s ± 5% above 40 and up to 60 m/s, Resolution 0.01 m/s
Wind Direction [°C]	Range 0–359°, Accuracy ± 3° 0.01 m/s to 40 m/s ± 5° above 40 and up to 60 m/s, Resolution 1°
Barometric Pressure [hPa]	Range 300 to 1100 hPa, Accuracy ± 0.5 hPa@ 25 °C, Resolution 0.1 hPa
Solar radiation [W/m^2]	Spectral range 300 to 3000 nm, Intensity Range 0 to 1600 W/m^2, Resolution 1 W/m^2
GPS	Horizontal accuracy: <2.5 m, Accuracy: longitude and latitude report to 6 decimal places

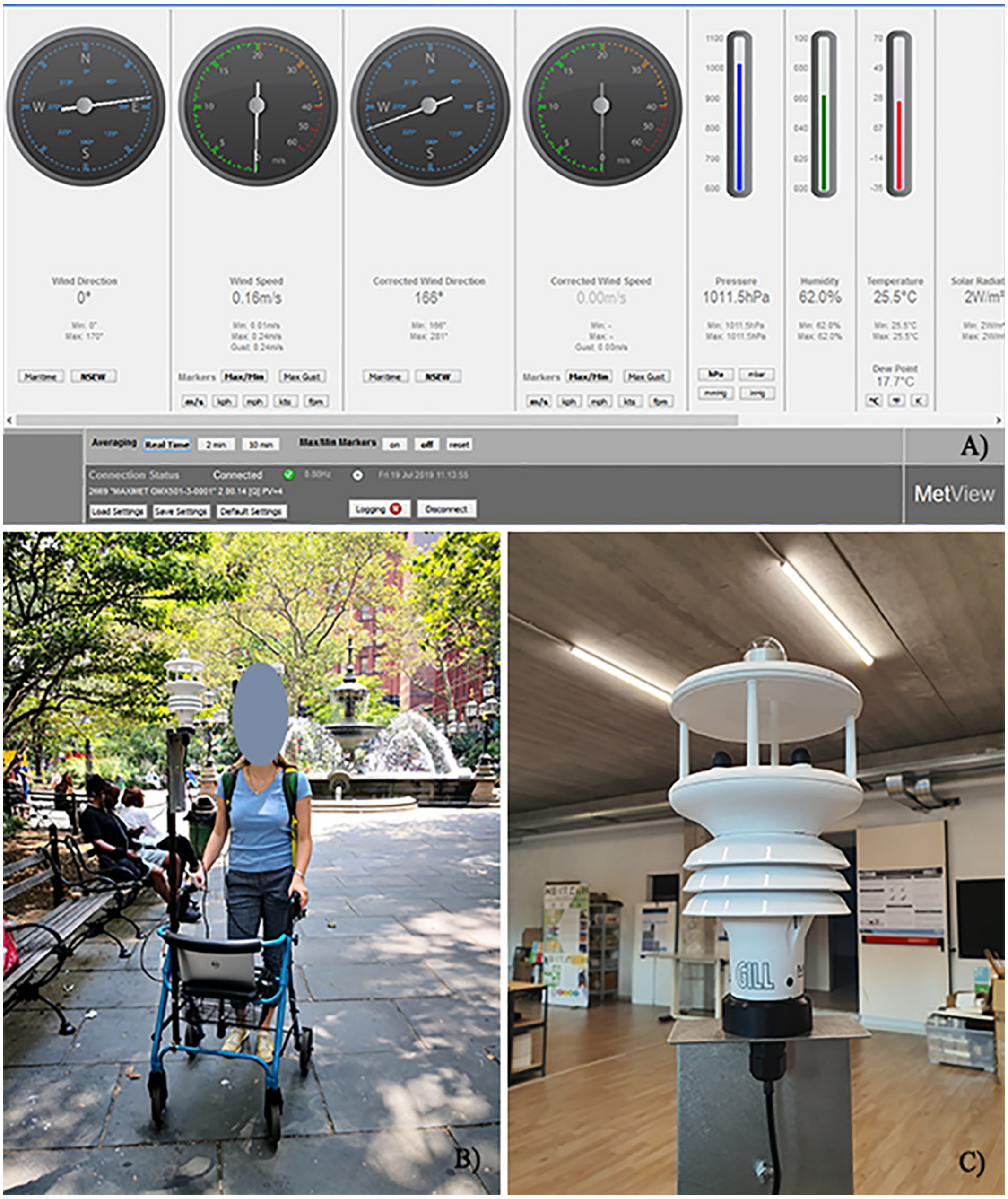


Fig. 1. A) Graphical interface B) innovative monitoring system C) detail of the compact weather station.

Table 2
Details of the monitoring campaign in terms of area, day and time.

Area	Day	Weather condition	Time
Greenacre Park	July 26th 2019	Cloudy	9 a.m.
	August 1st 2019	Sunny	1 p.m.
			7 p.m.
Paley Park	July 26th 2019	Cloudy	9 a.m.
	August 1st 2019	Sunny	1 p.m.
			7 p.m.

comparing objective and subjective comfort sensation. The apparent temperature is defined as "the temperature at the reference humidity level producing the same amount of discomfort as that experienced under the current ambient temperature, humidity, and solar radiation" or "heat index" [61]. *At* takes into account dry bulb temperature, wind speed and relative humidity [62,63]. The formula to calculate this index is reported below (Eq. (1)) and it is applicable to hot weather conditions [63]:

$$At = T + 0.33 \cdot vp - 0.7 \cdot v - 4.0 \tag{1}$$

where T is the dry bulb temperature, v the wind speed and vp the water vapor pressure (Eq. (2)).

$$vp = \frac{RH}{100} \cdot 6.105 \cdot \exp(17.27 \cdot \frac{T}{237.7 + T}) \tag{2}$$

The Physiologically Equivalent Temperature (PET) is a rational index that takes into account all the basic thermoregulatory processes of the human body. In greater detail, PET is based on the thermo-physiological heat balance model called "Munich energy balance model for individuals" [64], defined by the energy balance equation of human body (Eq. (3)):

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \quad (3)$$

where M is the metabolic rate, W the physical work output, R the net radiation of the body, C the convective heat flow, ED the latent heat flow to evaporate water into water vapor diffusing through the skin, E_{Re} the sum of heat flows for heating and humidifying the inspired air, E_{Sw} the heat flow due to evaporation of sweat, and S the storage heat flow for heating or cooling the body mass.

2.2. Survey campaign

To assess the subjective perception of comfort inside the pocket parks, a questionnaire survey campaign was conducted on site, in parallel to the microclimate monitoring campaign. The questionnaire survey possesses determined characteristics, so as to fit the scope of the investigation: it is multi-faceted so as to comprehend information on thermal, acoustic, visual and whole comfort sensations; and at the same time it is synthetic enough so as to attract more respondents as possible.

While ISO 10551 [65] defines the standard questionnaire for subjective thermal sensation, there is not a standard for other subjective comfort sensations. Based on previous research, which "translated" the standard survey on thermal comfort to assess subjective visual and acoustic comfort [56,66], also in this case, for comparison purposes, we adopt the question indicated for thermal perception also for other comfort sensations. The questions allow a response based on a 5-point Likert scale (−2 to + 2), where "0" indicates neutral comfort sensation, "−2" very bad, "−1" bad, " +1" good and "+2" very good comfort sensation, and is repeated for (i) whole comfort sensation; (ii) visual comfort; (iii) acoustic comfort; (iv) air quality; and finally, once the respondent is thermally acclimated to the surrounding space (v) thermal comfort (Fig. 2).

The question regarding overall comfort sensation is the first one, so that interviewees are not influenced in declaring their whole comfort sensation by previously focusing on their individual sensations with respect to visual, acoustic, air quality and thermal sensation.

In addition to questions assessing respondents' subjective comfort sensation, the survey comprises other questions asking for personal characteristics of the interviewees, which are useful in better framing other variables possibly influencing comfort. The questions are (i) how long have they been staying in the park, (ii) whether they are usual users of the space, (iii) the reason to visit the park, (iv) age, (v) gender. These questions are reported at the end if the questionnaire in order not to distract interviewees from the primary scope of the survey, i.e., assessing comfort sensation.

Participation to the survey during the 2019 campaign was voluntary and anonymous. Users of the pocket parks and close-by streets were approached by researchers conducting the survey campaign, informed about the general scope of the research and were then free to decide to participate or not. The interviewees were either standing or sitting in the pocket park, or standing or sitting on close-by streets. The questionnaire survey required 1–2 min to be completed.

The survey campaign was conducted at the exact same time of the monitoring campaign, in order to have the same conditions for both the objective and subjective assessments, for better consistency purpose. Therefore, as for the microclimate monitoring campaign, the survey campaign was conducted three times each day, during the morning, midday and evening, in all the case studies. A total of 178 surveys were collected during the campaign. The sample size fully satisfies the rule of thumbs of 10 observations for each considered variable in each regression model [67,68].

Data from the surveys are gathered and analyzed by means of statistical analysis (regression analysis and t-tests, with a confidence interval equal to 95%), to assess the significance of different variables on subjective comfort. While each comfort sensation is a dependent variable (i.e., the one that is influenced by the independent variables), positon, hour, age, gender, time spent in the park, being (or not) usual users of the park are all considered as independent variables.

2.3. Experimental campaign sites

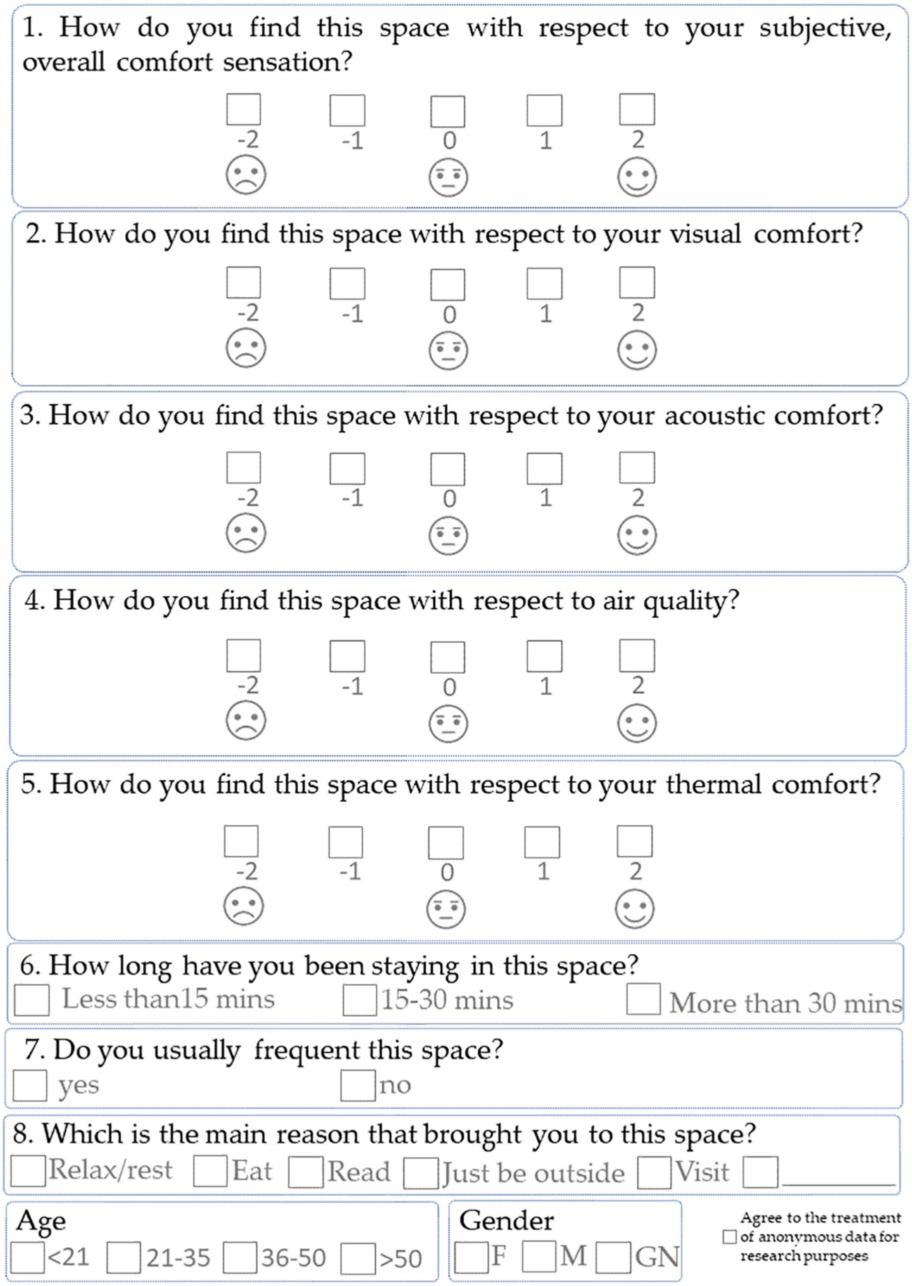
The described methodology is applied to two selected case studies in New York City NYC, USA (latitude 40° 43′ 50.1960″ N and longitude 73° 56′ 6.8712″ W). The climate of the city, according to Köppen Geiger Classification [69], is a Cfa, Humid Subtropical Climate. This climate is characterized by high summer temperature and distributed precipitation throughout the year, with air temperature average of 24.6 °C in summer, 12.2 °C in winter and average range of precipitation of 1140.5 mm.

NYC is indeed selected because it represents the perfect example of urban experimentations and UHI presence, with pocket parks being here diffused since the 60 s' in their first examples in USA. As above-described, pocket parks are usually built, even temporarily, in unused spaces between buildings, in densely built areas [70] and are highly populated by citizens working and living in the surroundings, as well as by tourists or locals looking for a pause from the chaotic city life. Among the first and most famous pocket parks, Paley Park (PP) [71] and Greenacre Park (GP) [72,73] have become eponymous examples of the pocket park typology. The shape, materials and position with respect to the street and surroundings allow PP and GP to act as pocket parks since they are characterized by all the most relevant pocket parks elements: (i) greenery, (ii) water bodies/fountains, (iii) furniture, (iv) shade and (v) separation from the street [43]. Therefore, the two abovementioned parks and their immediate surroundings (i.e. the block where they are located) constitute the case study and experimental location of this work. In this section, we detail the design characteristics of the case studies, in order to frame the microclimate and comfort analysis. Fig. 3 shows the experimental sites and the pathways covered during the monitoring campaign. Each pathway includes one of the two pocket park and its surrounding urban context.

Both the parks are located in Midtown Manhattan (Fig. 5). PP is on the 53rd Street (PP_St_S), close to the 5th Avenue (PP_Ave_W). GP is on the 51st Street (GP_St_S), close to the 3rd Avenue (GP_Ave_W) and they are 11 min apart walking-distance. The acronyms allow defining the investigated streets: the first two letters identify the site (PP or GP parks or blocks); the second term identifies the orientation of the streets, whether it is a North-South Avenue (Ave), or a West-East Street (St). Finally, the third term indicates the position of the street/avenue with respect to the block (N for north, S for south, E for east and W for west).

Paley Park (PP) opened a few years before GP, in 1967. It has rectangular shape, the front on the street is open while the two lateral sides are closed by brick walls covered by ivy, and the opposite façade to the entrance is a 20-foot high "water-wall", entirely covered by a continuously falling water layer. The granite paving is shaded by honey locust trees, planted on a regular grid, while seasonal plantings are added in dedicated containers. Movable seating and other fixed seating options on the sides provide basic furniture to the park, together with small tables. The park is slightly elevated with a few steps separating it from the sidewalk.

Greenacre Park (GP) was completed in 1971. It is 60 feet by 120 feet wide. Similarly to PP, it is closed on three sides and open on the street front only. Also in this case, there are a few stairs so the park is on a slightly higher level than the sidewalk, allowing the park to be better isolated from the street. As in PP, there are (i) greenery, (iii) water elements, (iv) basic furniture (seats and



1. How do you find this space with respect to your subjective, overall comfort sensation?

☐ -2 ☐ -1 ☐ 0 ☐ 1 ☐ 2

☹ 😐 ☺

2. How do you find this space with respect to your visual comfort?

☐ -2 ☐ -1 ☐ 0 ☐ 1 ☐ 2

☹ 😐 ☺

3. How do you find this space with respect to your acoustic comfort?

☐ -2 ☐ -1 ☐ 0 ☐ 1 ☐ 2

☹ 😐 ☺

4. How do you find this space with respect to air quality?

☐ -2 ☐ -1 ☐ 0 ☐ 1 ☐ 2

☹ 😐 ☺

5. How do you find this space with respect to your thermal comfort?

☐ -2 ☐ -1 ☐ 0 ☐ 1 ☐ 2

☹ 😐 ☺

6. How long have you been staying in this space?

☐ Less than15 mins ☐ 15-30 mins ☐ More than 30 mins

7. Do you usually frequent this space?

☐ yes ☐ no

8. Which is the main reason that brought you to this space?

☐ Relax/rest ☐ Eat ☐ Read ☐ Just be outside ☐ Visit ☐ ________

Age

☐ <21 ☐ 21-35 ☐ 36-50 ☐ >50

Gender

☐ F ☐ M ☐ GN

☐ Agree to the treatment of anonymous data for research purposes

Fig. 2. The questionnaire survey that was completed by participants to the experimental campaign during summer 2019.

tables) and a canopy of honey locust trees that provide shading from the sun and cover the view of surrounding buildings. Also in GP, the opposite front with respect to the entrance wall is a water cascade, which flows in a runnel ending in a fountain at the entrance of the park. GP is characterized by granite paving and a high variety of greenery (evergreens, rhododendron, azaleas, seasonal flowers, ivy on the brick walls).

In both of the pocket parks (Fig. 4), the trees' canopies and the greenery are meant to provide acoustic insulation from the noise of the traffic on the nearby streets, while the water walls in both the parks are conceived to produce a grey noise that potentially mitigates traffic noise. Visually, the higher level with respect to the sidewalk and the presence of trees allow the park to be disconnected from the sidewalk.

The presence of greenery, trees and water has been deemed as able to significantly influence the microclimate [35,74]; in this case, due to the small dimension of the park, the effectiveness of microclimate mitigation is one of the research questions.

3. Results and discussion

3.1. Microclimate assessment

In this section, the results of the monitoring campaigns are reported. In detail, Figs. 6 and 7 present the main environmental parameters collected at 9 a.m. (morning), 1p.m. (midday-lunchtime) and 7p.m. (evening) along **Greenacre Park** area on August 1st and July 26th, i.e., a sunny and a cloudy day respectively. Starting from the bottom to the top, each graph within Figs. 6 and 7 spatially maps air temperature deviation with respect

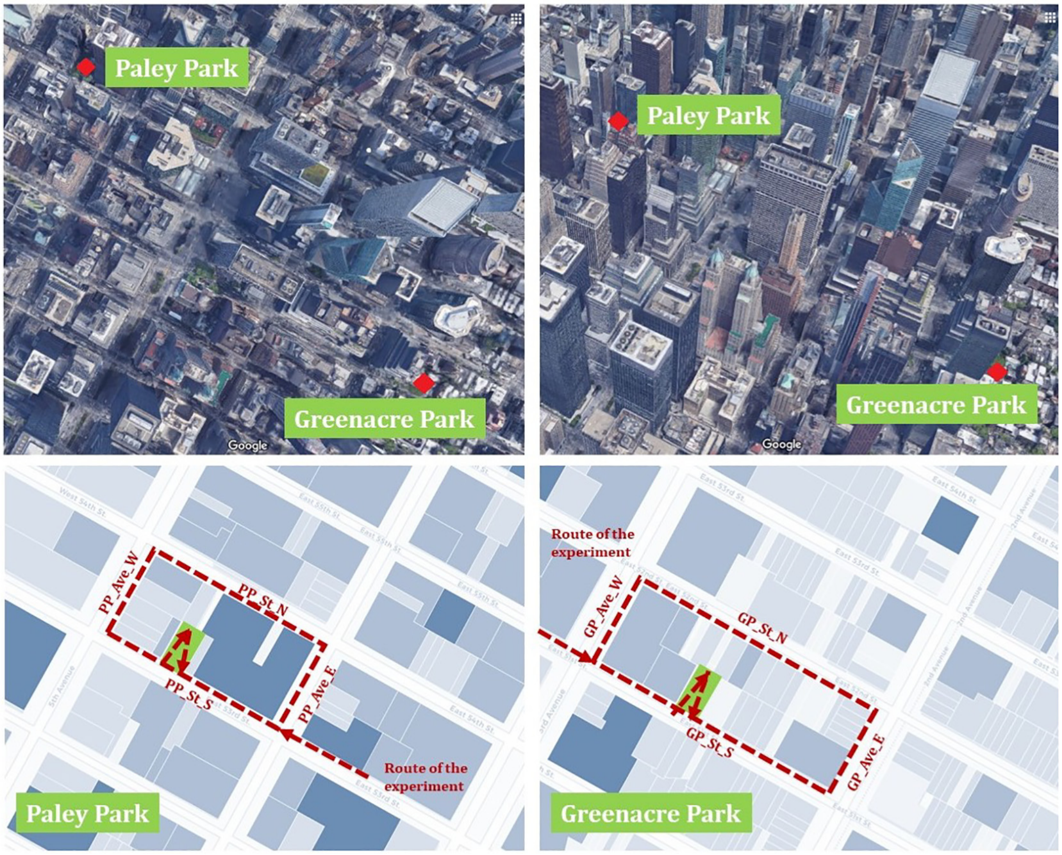


Fig. 3. Paley Park and Greenacre Park, Midtown Manhattan; on the left, plan view; on the right 3d view (Google Maps).

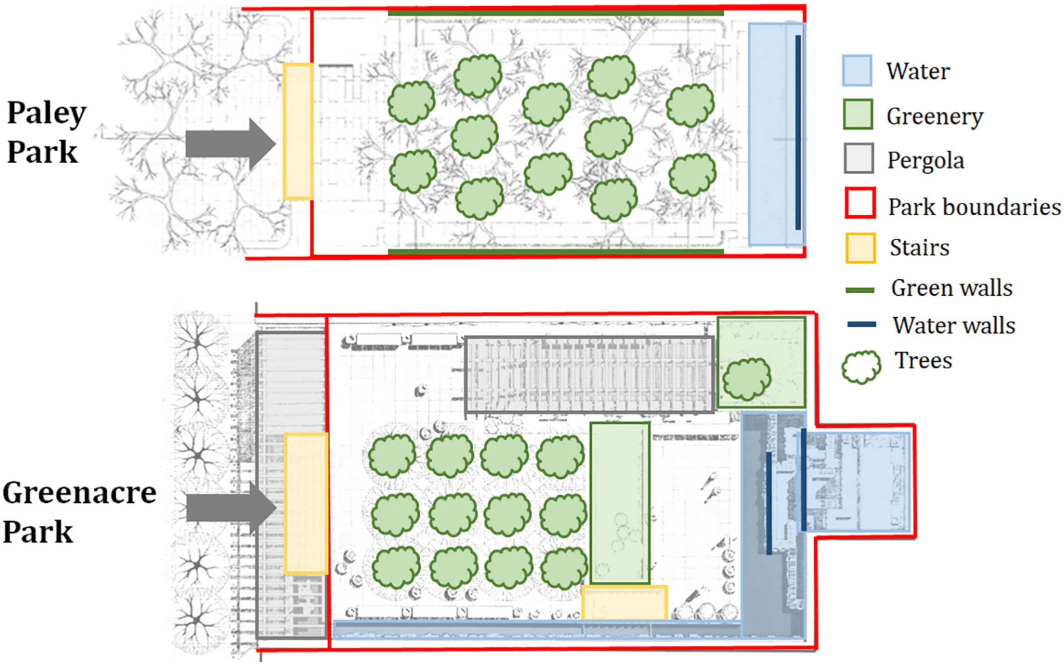


Fig. 4. Geometry, components and configuration of the pocket parks.

to the average [°C], relative humidity deviation with respect to the average [%], wind speed [m/s] and solar radiation [W/m^2].

In greater detail, Fig. 6 shows a variation of the air temperature, i.e. 0.5 °C, along the pathway. A maximum and minimum peak of 27.1 °C and 27.9 °C, 30.6 °C and 31.3 °C, 30.0 °C and 30.4 °C can be detected respectively at 9 a.m., 1p.m. and 7p.m. While at 9 a. m. and 7p.m. air temperature presents lower values inside the park than in the dense urban surroundings, i.e. −0.3 ÷ 0.2 °C with

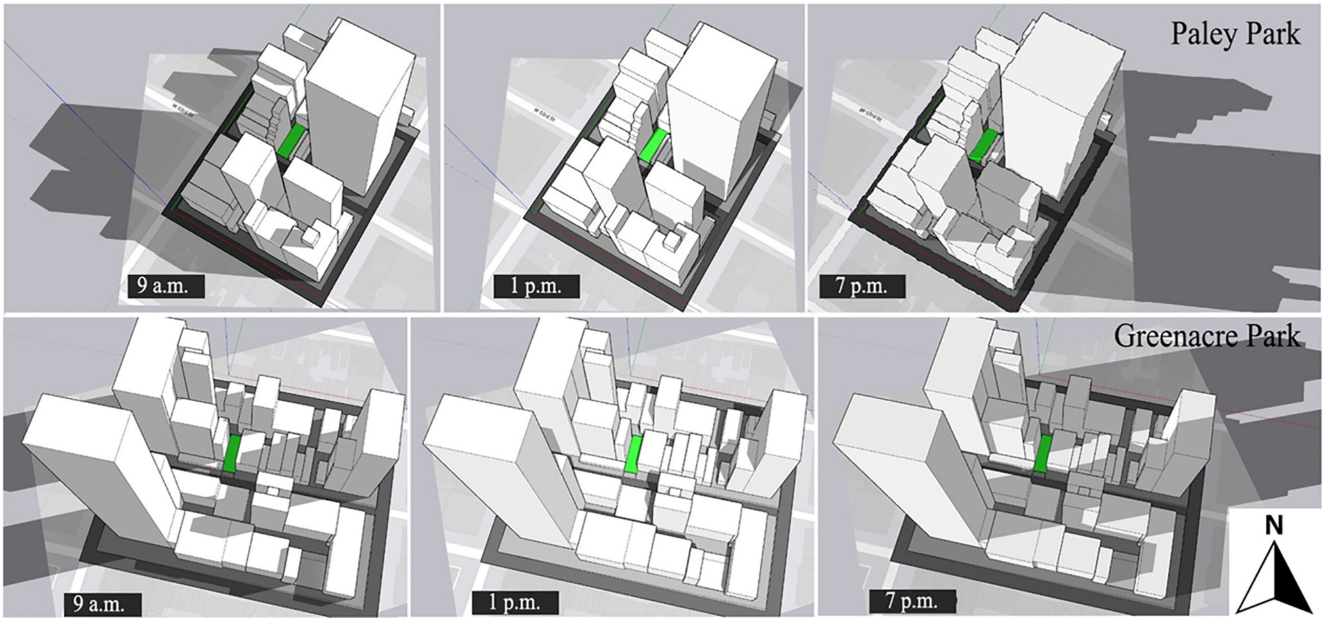


Fig. 5. Position of the pocket parks with respect to the investigated blocks and shading during the day, at 9 a.m., 1p.m. and 7p.m..

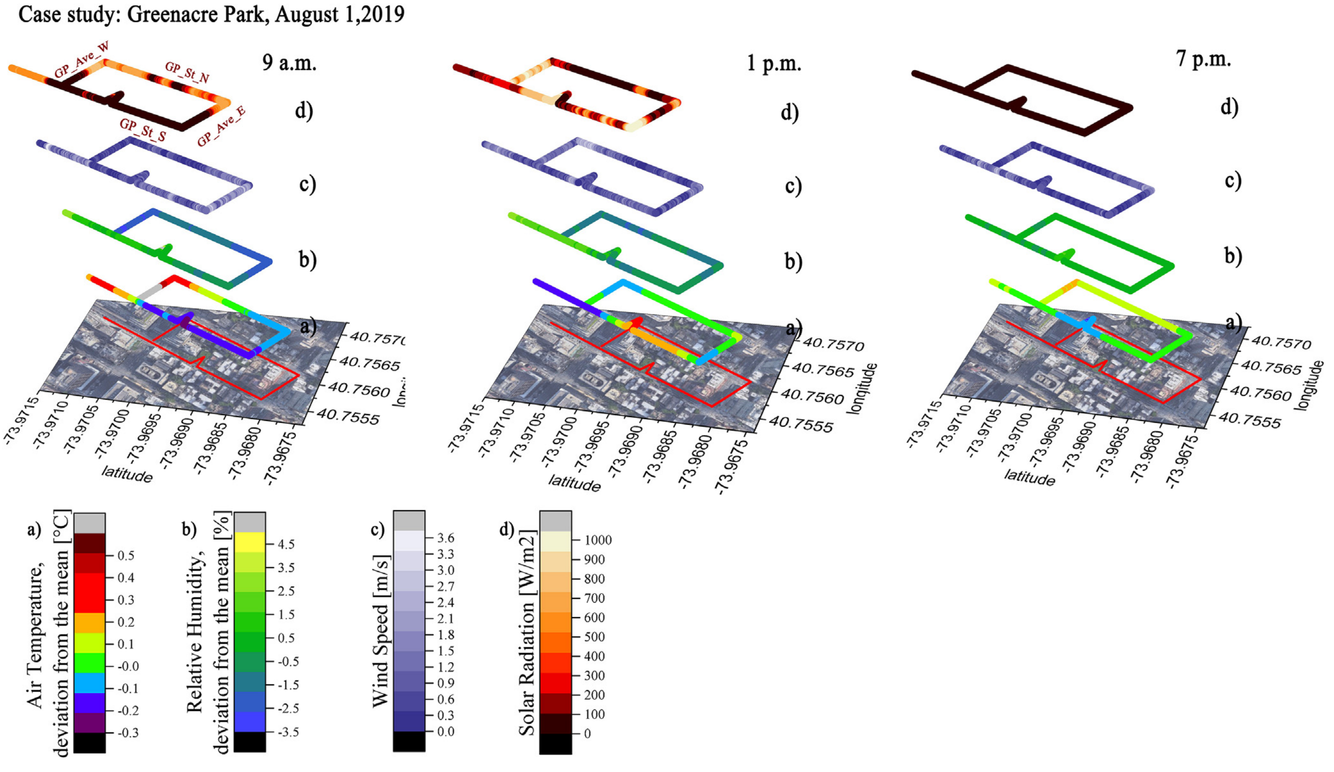


Fig. 6. Results of the monitored campaign along PP and surroundings during the sunny day.

respect to the average, at 1p.m. air temperature peaks inside the pocket park. This trend underlines the mitigation effect related to the combination of urban greenery and water bodies, which alters the urban energy budget leading to evaporative cooling and urban shading, also fostered. This positive gap is also related to the low radiative and convective contribution detected at both early morning and evening time inside the park, i.e. by about 50 W/m^2 and 0.4 m/s. At the same time, the mitigation actions are not enough to produce sensitive passive cooling when the contribution of building shading is not given (Fig. 5), i.e., at 1p.m. Moreover, shading by vegetation acts as solar interceptor and keeps the air cooler. In fact, at 9 a.m. the maximum value of solar radiation, i.e. 790 W/m^2, is observed at the corner between Northern Street (GP_St_N) and the Western Avenue (GP_Ave_W), according to the air temperature trend. Instead, at lunchtime, high values of air temperature are collected inside the park, with a deviation of + 0.3 °C with respect to the average. Such increase may be related to the shortwave absorption by urban surfaces/materials and re-radiation of

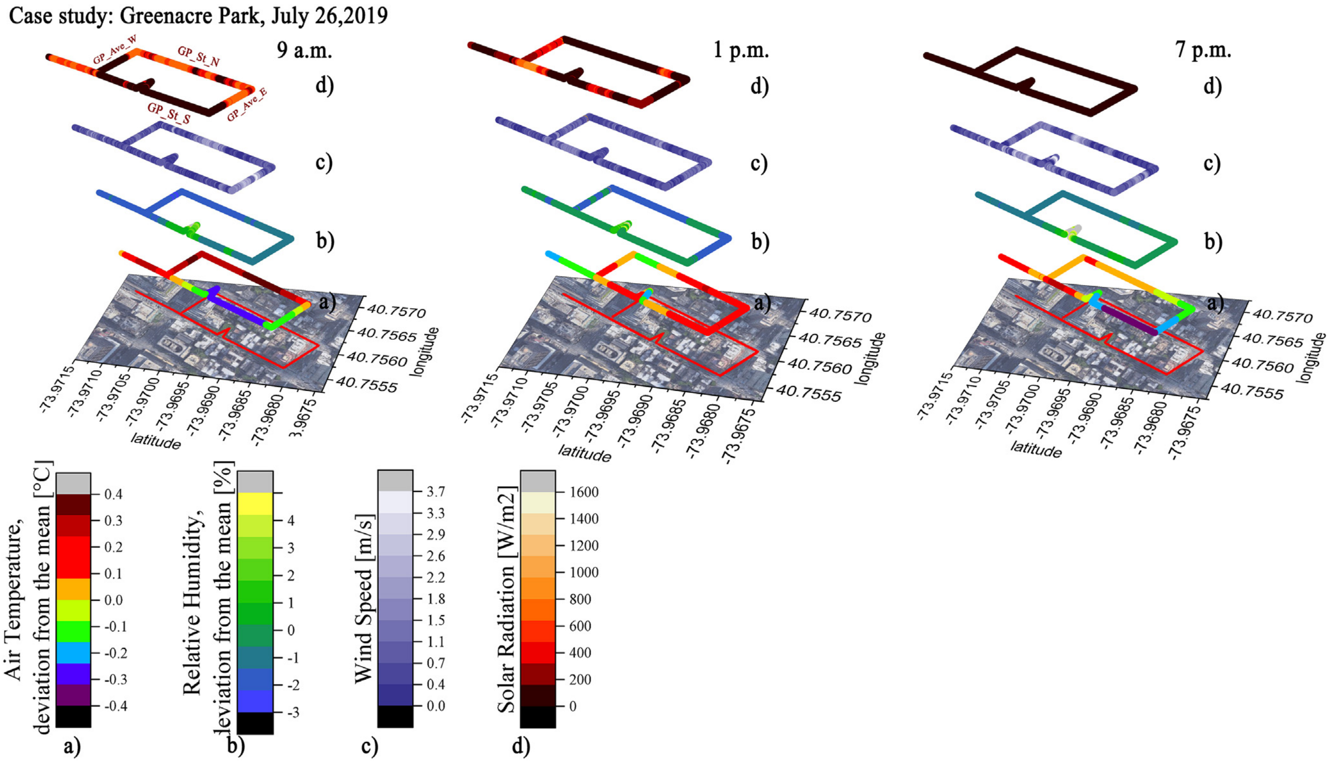


Fig. 7. Results of the monitored campaign along GP and surroundings during the cloudy day.

heat to the canopy layer atmosphere, which leads to increased air temperature. On the other hand, relative humidity results show, during the entire monitoring time session, generally higher values inside the park, i.e. a deviation of + 0.5% with respect to the mean value. This behavior could be due to the blue space, i.e. a large waterfall based on the lower level of Greenacre Park, which leads to rising relative humidity values. However, the difference in relative humidity is much higher during the cloudy day (Fig. 7), with values of + 5%, compared to the slight + 0.5% observed during the sunny day. In greater detail for the cloudy day, at 9 a.m., air temperature shows a drop of 0.3 °C in air temperature and low solar radiation values, i.e. 200 W/m^2, within Greenacre Park, which can be related to the orientation and the shading effect of vegetation. At midday, the mitigation effect of the park slightly decreases with respect to the morning, since air temperature trend shows a slight decrease by −0.2 °C with respect to the surrounding built environment. However, the mitigation potential is explicit at midday compared to the sunny day. In fact, at that time air temperature peaks at the corner between GP_Ave_E and GP_St_N and decreases along the pathway. On the other hand, solar radiation has a heterogeneous trend along the pathway, which varies from 0 to 950 W/m^2, characterized by values close to zero under the scaffolders located along GP_St_N. On the contrary, at 7 p.m. a deviation of + 0.2 °C and + 0.3 °C can be respectively detected along GP_Ave_W and at the beginning of GP_St_S, while a reduction of 0.2 °C can be underlined inside Greenacre Park. Accordingly, relative humidity increases by 5% within the park thanks to the dual presence of greenery and water.

More in general, during the entire monitoring period, solar radiation assumes low values along the Southern Streets, i.e. GP_St_S, compared to the other Streets and Avenues around the block where the park is. This trend can be imputed to the urban canyon geometry, since GP_St_S has an aspect ratio of 2.1, which limits the access of direct solar radiation, increases shading and leads to cooler pedestrian environment, as confirmed by the air temperature spatial mapping. Convection has a limited role in the microclimate mitigation, since wind speed is quite homogenous during all the monitoring time. Wind speed affects air temperature behavior especially during the cloudy day inside the park, and assumes its maximum value, i.e. 3.7 m/s, at 9 a.m. along the Eastern Avenue, while 0.4 m/s inside GP, and at 7p.m. along the Southern Street, where GP is located, with a singular point of 3.7 m/s also inside the park.

The results of the monitoring campaigns carried out along **Paley Park** area on August 1st and July 26th are shown in Figs. 8 and 9. In detail, Fig. 8 (sunny day) shows that during daytime Paley Park is characterized by generally lower temperature than the urban surrounding, i.e. −0.2 °C at midday, i.e. −0.1 °C during the evening. Streets and Avenues around Paly Park, i.e. PP_St_N, PP_St_S, PP_Ave_E, PP_Ave_W, are warmer at evening time than at lunchtime. This warming-up process may be imputed to the heat stored by urban surfaces during daytime and released during nighttime, which appears to be counteracted by PP evapotranspiration strategy. Indeed, streets surrounding the block where the park is located are characterized by asphalt and impervious materials and have two or three carriageways. However, at both 9 a.m. and 1p.m., the highest values of air temperature are collected along PP_St_S and low convective contribution can be observed, i.e. an average of 0.5 m/s. On the contrary, with respect to the results illustrated for GP area collected during the same day (Fig. 6), relative humidity is quite heterogeneous along the path. While at 9 a.m. and 1p.m. increased humidity values are gathered at the manholes from which steam of the district heating plant comes out, at 7p.m. relative humidity peaks inside the park and goes up by + 7.5% with respect to the surroundings. This effect may be due to the waterfall in the park, which alters the urban energy budget through evapotranspiration process. On the other hand, solar radiation spatial maps emphasize the urban geometry role in microclimate assessment. Indeed, at 1p.m., peaks of 1000 W/m^2 are collected along the PP_St_N and at the corner between the

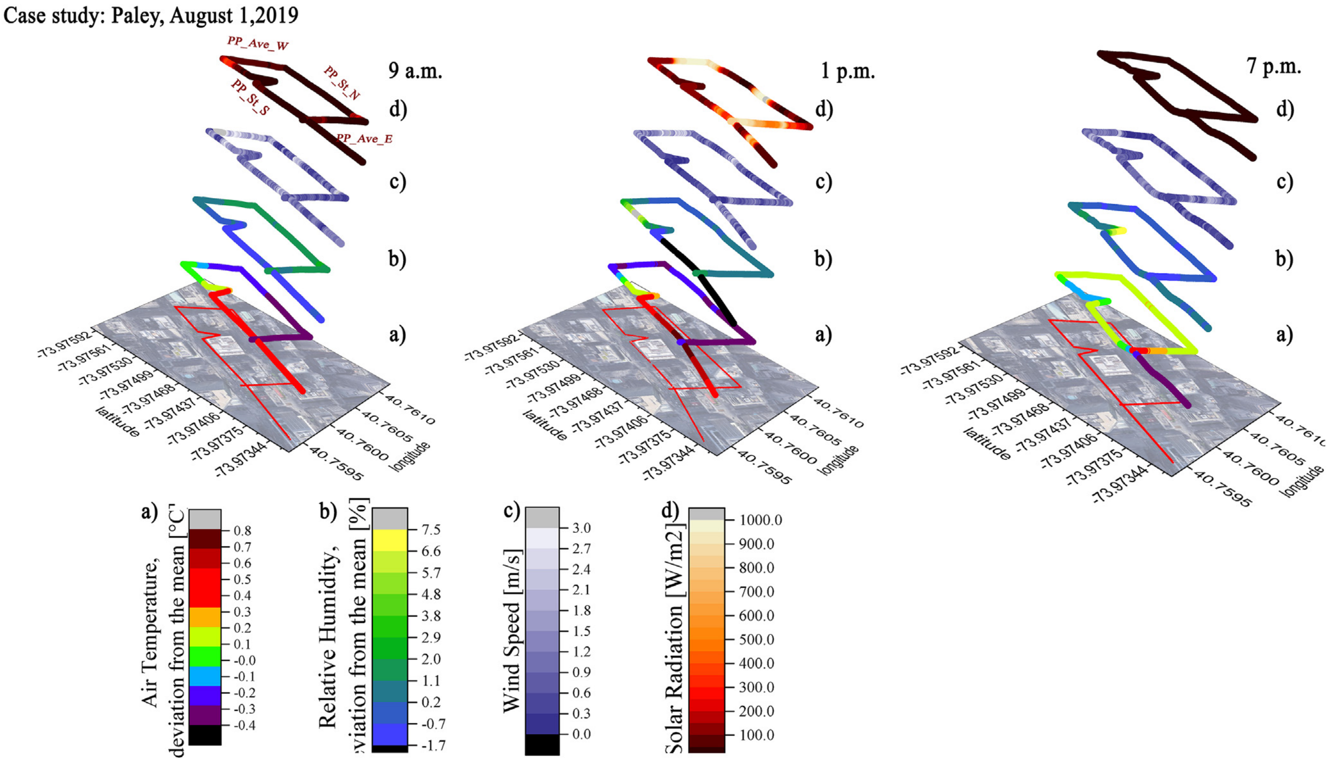


Fig. 8. Results of the monitored campaign along PP and surroundings during the sunny day.

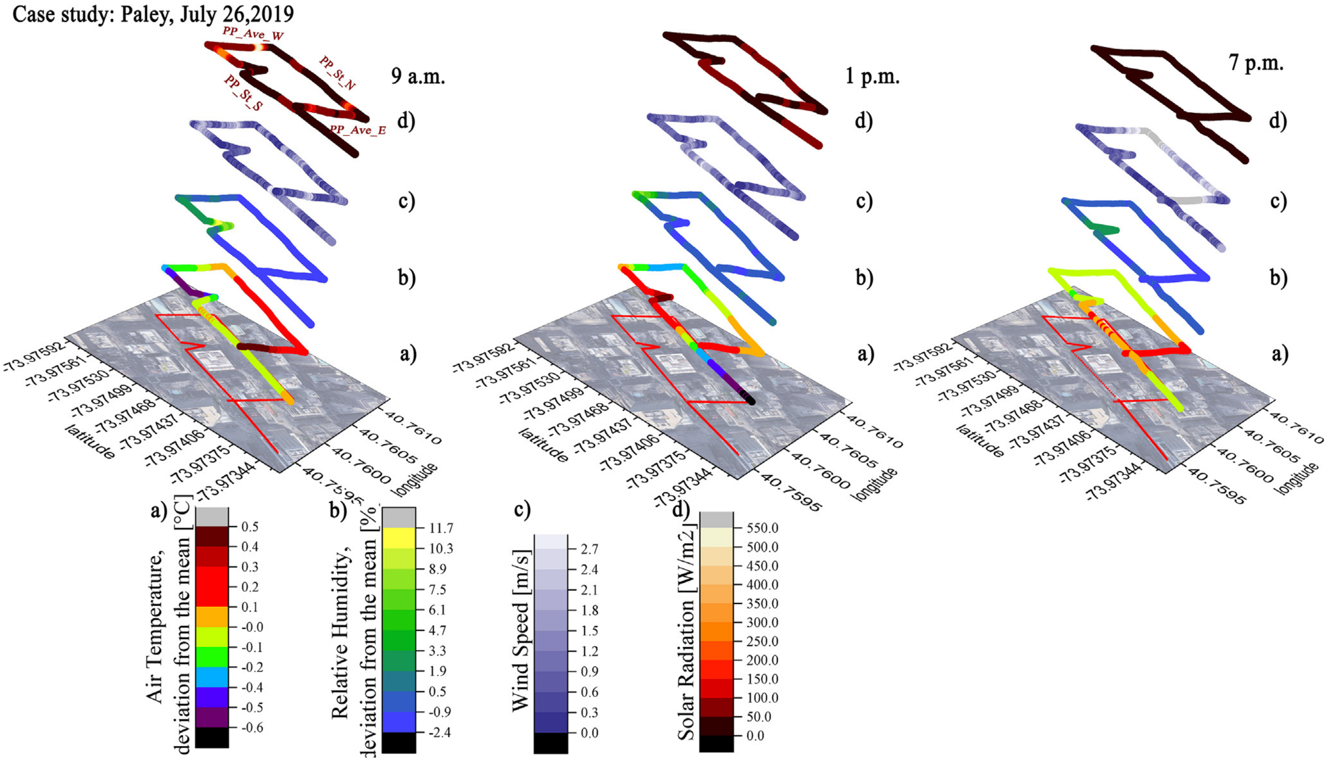


Fig. 9. Results of the monitored campaign along PP and surroundings during the cloudy day.

same street and the PP_Ave_W. Indeed, the Northern Street is characterized by low local aspect ratio, which implies less shading in every orientation and more access of direct solar radiation during daytime. More in general, during each monitoring session, solar radiation decreases inside the park thanks to greenery and trees that provide natural shading for pedestrians, improving the thermal environment of the park. Moreover, as expected, also wind speed has a relation with urban geometry, since it assumes higher values along the avenues than on the streets, i.e. 3 m/s vs 1.5 m/s with peaks along the PP_Ave_W that is characterized by an aspect ratio of 0.4.

On July 26th (cloudy day, Fig. 9) the maximum differences in microclimate variables along the pathway are as follows: – 0.6 °C air temperature during the morning in the park, up to 0.5 °C on the street, +11.7% relative humidity during the morning in the park, 550 W/m^2 solar radiation during the morning on PP_Ave_W. As also underlined in Fig. 8 for the sunny day, the mitigation effect of the park in terms of air temperature decrease is mostly visible at morning and evening time. On the contrary, at lunchtime, i.e. 1p.m., air temperature reaches its maximum values inside the park, 30.5 °C. Since these outcomes are similar to the results of the monitoring campaign conducted during the sunny day along the same area, it can be assessed that urban geometry and orientation heavily affect the microclimate of this area, as key anthropogenic drivers for urban microclimate.

3.1.1. Statistical analysis of the microclimate variables

The results of the microclimate analysis are further investigated by means of statistical analyses. In greater detail, regression analyses and t-tests, both with a confidence interval equal to 95%, are performed.

The aim of the **regression analysis** is to identify information about the significance of the difference between the measurements. Such differences are investigated with respect to independent variables, e.g., position of the monitoring system on the planned experimental path and the time (hour) of the day when the experiment is conducted. With respect to position, which is the main variable we are interested in, as we aim at disclosing intra-urban microclimate differences due to the presence of pocket parks, we consider geographical clusters with increasing dimensions.

The choice to manually select the cluster to investigate is given by the regular urban geometrical grid of NYC, with avenues and streets that are orthogonal to each other and with the same orientation. Therefore, we first take into account (i) each single street as a cluster (PP_St_S, PP_St_N, GP_St_S, GP_St_N streets and PP_Ave_W, PP_Ave_E, GP_Ave_W, GP_Ave_E avenues) and each single pocket park as a cluster (Paley Park (PP) and Greenacre Park (GP)). Then, we enlarged the clusters considering the streets as a cluster (PP_St_S, PP_St_N, GP_St_S, GP_St_N streets), the avenues as a distinct cluster (PP_Ave_W, PP_Ave_E, GP_Ave_W, GP_Ave_E avenues), and the pocket parks as another cluster. We considered the data gathered during each day (the cloudy day and the sunny day) as a further distinction, as well as all the data together for both the days in total. The results of the analyses are reported graphically in Fig. 10.

With respect to comparisons for inside/outside the park, the statistical analyses confirm that the microclimate inside and outside the park is weakly different (in general cooler, damper and darker in the parks compared to streets and avenues), even if such a difference is statistically significant.

When comparing microclimate variables during the different times of investigation (morning, midday and evening), there are significant differences in the intra-urban microclimate, as the morning hours are significantly cooler and damper than midday. Air temperature is significantly higher during midday and evening hours, with different trends for the cloudy and the sunny day. Indeed, during the cloudy day, evening is the warmest time, while during the sunny day, midday is the warmest, due to higher solar radiation hitting the parks, streets and avenues, which are especially exposed to the sun at midday.

In addition to the regression analyses, a ***t*-test** to compare the means of the different microclimate measurements is also conducted (confidence interval is 95%) (Table 3). The results of the t-tests confirm those of the regression analyses, demonstrating that while differences are not massive between the parks and surrounding urban environment, they are still statistically significant. Additionally, the *t*-test verifies that air temperature is higher on the avenues than on the streets, due to higher solar access, and the lowest Ta is in the parks. Solar radiation is significantly higher on the streets and avenues than in the parks, and avenues have significant higher values than streets, as a possible motivation for solar overheating. With respect to wind speed (Ws), it is significantly lower in the parks than on the streets and avenues. Again, Ws is higher in the avenues than in the streets. This may compromise the potential benefits of microclimate mitigation strategies within the pocket parks, which overlook the streets and not the avenues, given the minor wind speed again due to anthropogenic actions induced by the built environment.

3.2. Survey results and comparison with monitoring results

Results from the survey do not mirror the results of the microclimate analysis, highlighting the gap between objective and subjective sensation. Indeed, while in the microclimate analysis the difference between microclimate conditions inside the park and on the streets is not massive, the subjective assessment demonstrates that the perception of users is quite improved in the park and on the immediate streets surrounding the block.

The regression analysis (confidence interval equal to 95%) is conducted not only for the whole comfort sensation but also for each individual comfort sensation, namely visual, acoustic, air-quality and thermal comfort. The dependent variables are the comfort sensations, while the independent variables comprise position, age, gender, being usual users of the park and time spent in the park.

Firstly, we consider all the data, both for the parks and the surrounding streets (Fig. 11).

About perceived **whole comfort**, the statistical analysis shows that all the considered variables have a significant impact on it. "Position" determines comfort sensation inside or outside the park: whole comfort is significantly higher inside the park than on the surrounding streets. Moreover, the younger the participant, the better the whole comfort sensation, which is slightly better for males than for females. It is interesting to highlight the role of frequency of use of the park, as whole comfort is higher for those who are typical users of the considered park. Moreover, time spent in the park is a significant variable, as the higher the time spent in the park, the higher the comfort sensation.

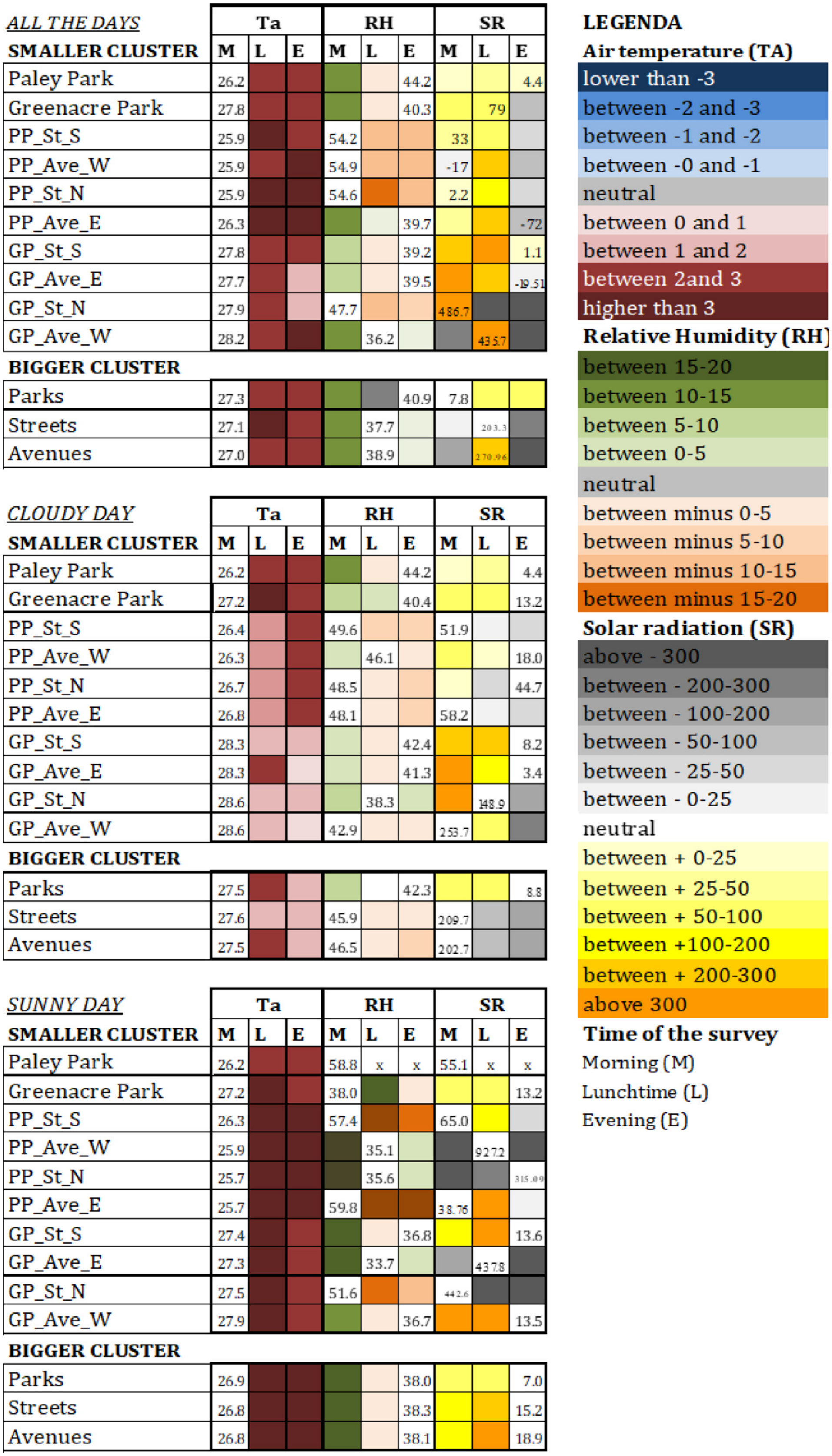
Considering the single domain aspects of comfort, such trends are confirmed.

Visual comfort is significantly higher inside the park than on the street. Being usual-users of the park and time spent in the park positively impact visual comfort, as for whole comfort sensation, even if with relatively lower coefficients.

With respect to **acoustic comfort,** this is significantly higher in the park, and it grows with the time spent in the park. Age and being usual users are not significant with respect to acoustic comfort, while female participants assign lower values of acoustic comfort compared to male participants.

With respect to **air quality**, the related comfort sensation inside the park is higher than on the street. It improves when spending more time inside the park, and it is higher for younger and male participants.

Perceived **thermal comfort** is significantly higher in the park and for those who spent more time in the park. Being usual users does not influence thermal comfort, while again the younger the interviewees the higher the thermal comfort, and male interviewees declare higher thermal comfort sensation.



ALL THE DAYS

	Ta			RH			SR		
SMALLER CLUSTER	**M**	**L**	**E**	**M**	**L**	**E**	**M**	**L**	**E**
Paley Park	26.2					44.2			4.4
Greenacre Park	27.8					40.3		79	
PP_St_S	25.9			54.2			33		
PP_Ave_W	25.9			54.9			-17		
PP_St_N	25.9			54.6			2.2		
PP_Ave_E	26.3					39.7			-72
GP_St_S	27.8					39.2			1.1
GP_Ave_E	27.7					39.5			-19.51
GP_St_N	27.9			47.7			486.7		
GP_Ave_W	28.2				36.2			435.7	
BIGGER CLUSTER									
Parks	27.3					40.9	7.8		
Streets	27.1				37.7			203.3	
Avenues	27.0				38.9			270.96	

CLOUDY DAY

	Ta			RH			SR		
SMALLER CLUSTER	**M**	**L**	**E**	**M**	**L**	**E**	**M**	**L**	**E**
Paley Park	26.2					44.2			4.4
Greenacre Park	27.2					40.4			13.2
PP_St_S	26.4			49.6			51.9		
PP_Ave_W	26.3				46.1				18.0
PP_St_N	26.7			48.5					44.7
PP_Ave_E	26.8			48.1			58.2		
GP_St_S	28.3					42.4			8.2
GP_Ave_E	28.3					41.3			3.4
GP_St_N	28.6				38.3			148.9	
GP_Ave_W	28.6			42.9			253.7		
BIGGER CLUSTER									
Parks	27.5					42.3			8.8
Streets	27.6			45.9			209.7		
Avenues	27.5			46.5			202.7		

SUNNY DAY

	Ta			RH			SR		
SMALLER CLUSTER	**M**	**L**	**E**	**M**	**L**	**E**	**M**	**L**	**E**
Paley Park	26.2			58.8	x	x	55.1	x	x
Greenacre Park	27.2			38.0					13.2
PP_St_S	26.3			57.4			65.0		
PP_Ave_W	25.9				35.1			927.2	
PP_St_N	25.7				35.6				315.09
PP_Ave_E	25.7			59.8			38.76		
GP_St_S	27.4					36.8			13.6
GP_Ave_E	27.3				33.7			437.8	
GP_St_N	27.5			51.6			442.6		
GP_Ave_W	27.9					36.7			13.5
BIGGER CLUSTER									
Parks	26.9					38.0			7.0
Streets	26.8					38.3			15.2
Avenues	26.8					38.1			18.9

LEGENDA

Air temperature (TA)
- lower than -3
- between -2 and -3
- between -1 and -2
- between -0 and -1
- neutral
- between 0 and 1
- between 1 and 2
- between 2and 3
- higher than 3

Relative Humidity (RH)
- between 15-20
- between 10-15
- between 5-10
- between 0-5
- neutral
- between minus 0-5
- between minus 5-10
- between minus 10-15
- between minus 15-20

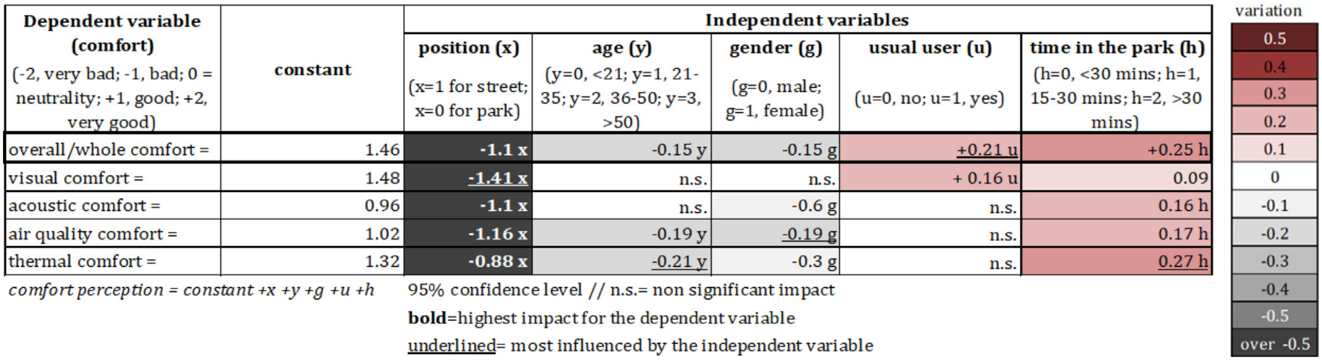
Solar radiation (SR)
- above - 300
- between - 200-300
- between - 100-200
- between - 50-100
- between - 25-50
- between - 0-25
- neutral
- between + 0-25
- between + 25-50
- between + 50-100
- between +100-200
- between + 200-300
- above 300

Time of the survey
- Morning (M)
- Lunchtime (L)
- Evening (E)

Fig. 10. Results of the regression analyses with respect to monitored microclimate variables. Each column (Ta, RH and SR) should be read separately, and the written number in the cell is the constant.

Table 3
Results of the *t*-test analyses (** 95% significance; * 90% significance). Reported are the means for all the considered variables.

#	Comparison	Ta	RH	SR	Ws
1	parks	28.56	47.00	57.88	0.80
	streets	28.98	42.00	138.02	1.00
	significance	**	**	**	**
2	parks	28.56	47.00	57.88	0.80
	avenues	28.80	43.00	187.00	1.20
	significance	**	**	**	**
3	streets	28.98	42.00	138.02	1.00
	avenues	28.80	43.00	187.00	1.20
	significance	**	*	**	**
4	parks	28.56	47.00	57.88	0.80
	streets/avenues	28.93	42.89	151.10	1.03
	significance	**	**	**	**



Dependent variable (comfort) (-2, very bad; -1, bad; 0 = neutrality; +1, good; +2, very good)	**constant**	**Independent variables**				
		position (x) (x=1 for street; x=0 for park)	**age (y)** (y=0, <21; y=1, 21-35; y=2, 36-50; y=3, >50)	**gender (g)** (g=0, male; g=1, female)	**usual user (u)** (u=0, no; u=1, yes)	**time in the park (h)** (h=0, <30 mins; h=1, 15-30 mins; h=2, >30 mins)
overall/whole comfort =	1.46	**-1.1 x**	-0.15 y	-0.15 g	<u>+0.21 u</u>	+0.25 h
visual comfort =	1.48	<u>**-1.41 x**</u>	n.s.	n.s.	+ 0.16 u	0.09
acoustic comfort =	0.96	**-1.1 x**	n.s.	-0.6 g	n.s.	0.16 h
air quality comfort =	1.02	**-1.16 x**	-0.19 y	<u>-0.19 g</u>	n.s.	0.17 h
thermal comfort =	1.32	**-0.88 x**	<u>-0.21 y</u>	-0.3 g	n.s.	<u>0.27 h</u>

comfort perception = constant +x +y +g +u +h

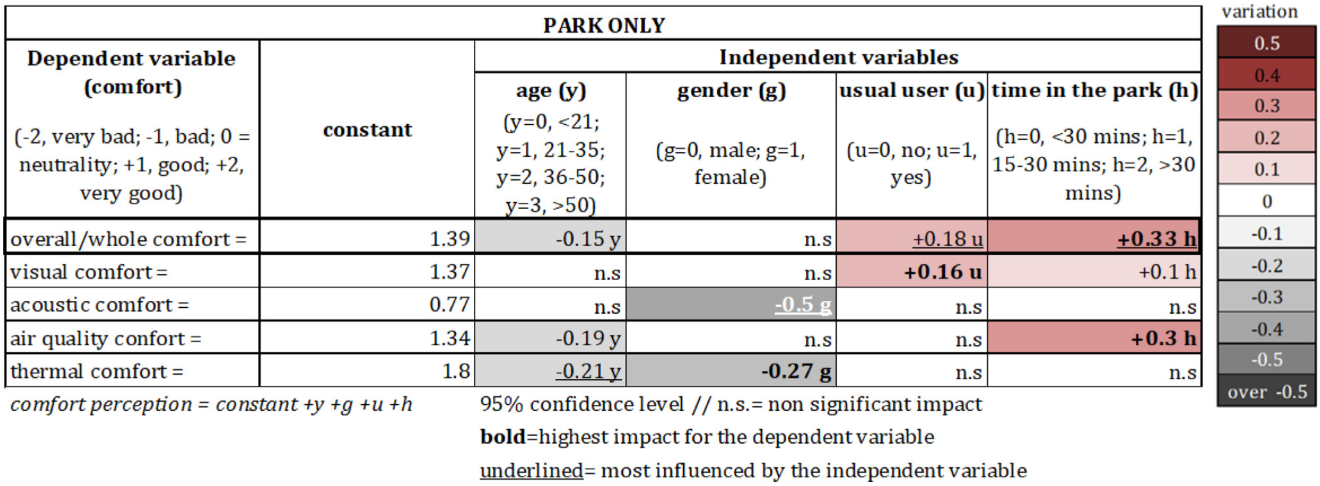
95% confidence level // n.s.= non significant impact

bold=highest impact for the dependent variable

<u>underlined</u>= most influenced by the independent variable

variation
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
over -0.5

Fig. 11. Results of the regression analysis for comfort sensations (dependent variables that are separately considered), as influenced by the independent variables (i) position, (ii) age, (iii) gender, (iv) being usual users of the park and (v) amount of time spent in the park, for data gathered inside the park and on the surrounding streets.



PARK ONLY					
Dependent variable (comfort) (-2, very bad; -1, bad; 0 = neutrality; +1, good; +2, very good)	**constant**	**Independent variables**			
		age (y) (y=0, <21; y=1, 21-35; y=2, 36-50; y=3, >50)	**gender (g)** (g=0, male; g=1, female)	**usual user (u)** (u=0, no; u=1, yes)	**time in the park (h)** (h=0, <30 mins; h=1, 15-30 mins; h=2, >30 mins)
overall/whole comfort =	1.39	-0.15 y	n.s	<u>+0.18 u</u>	<u>**+0.33 h**</u>
visual comfort =	1.37	n.s	n.s	**+0.16 u**	+0.1 h
acoustic comfort =	0.77	n.s	<u>-0.5 g</u>	n.s	n.s
air quality confort =	1.34	-0.19 y	n.s	n.s	**+0.3 h**
thermal comfort =	1.8	<u>-0.21 y</u>	**-0.27 g**	n.s	n.s

comfort perception = constant +y +g +u +h

95% confidence level // n.s.= non significant impact

bold=highest impact for the dependent variable

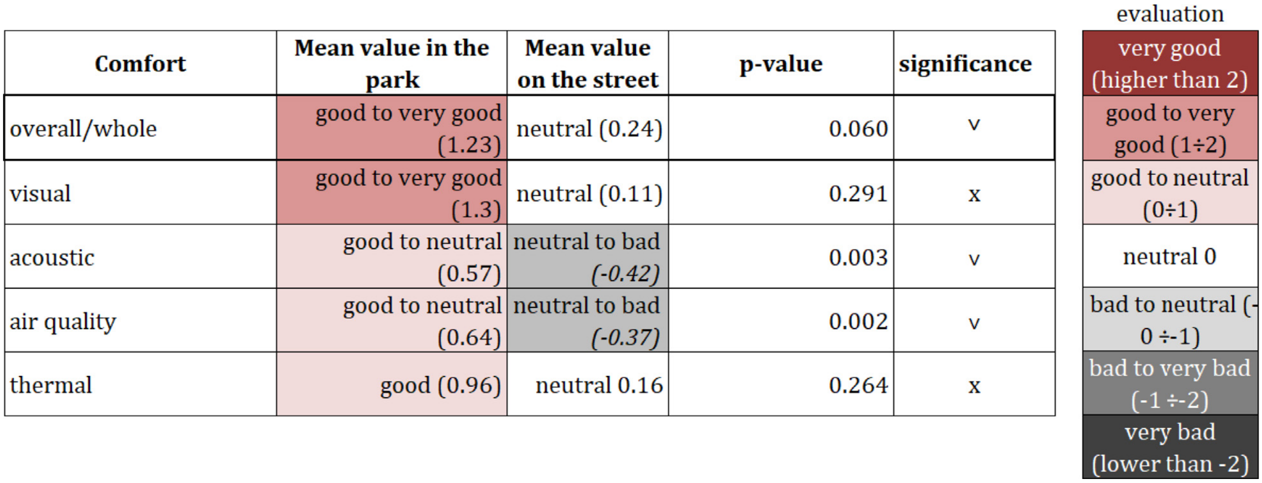
<u>underlined</u>= most influenced by the independent variable

variation
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
over -0.5

Fig. 12. Results of the regression analysis for comfort sensations (dependent variables that are separately considered), as influenced by the independent variables (i) age, (ii) gender, (iii) being usual users of the park and (iv) amount of time spent in the park, for data gathered inside the park.

A second set of statistical analysis is performed on the data gathered inside the park only, to better dissect comfort sensation with specific reference to the pocket parks (Fig. 12). The significance of being usual users of the park is confirmed also here with respect to the whole comfort and visual comfort. Citizens that often live the park confirm a significantly higher whole comfort sensation and visual comfort in the park with respect to non-usual users. This finding aid in demonstrating that the benefit of the park, especially for usual users, is not (or, at least, not only) related to microclimate or objective physical behavior of the park, but more to subjective features. Time spent in the park is again a significant variable. It influences whole, visual and air quality-related comfort: the more time spent in the park, the higher the perceived comfort.

In addition to the regression analyses, *t*-test analysis is conducted to compare the mean of the declared comfort inside and outside the park (Fig. 13). Whole comfort, acoustic comfort and air-quality comfort perception present significantly different average values as declared inside and outside the park. Declared perception about whole comfort inside the park is “good to very



Comfort	Mean value in the park	Mean value on the street	p-value	significance
overall/whole	good to very good (1.23)	neutral (0.24)	0.060	v
visual	good to very good (1.3)	neutral (0.11)	0.291	x
acoustic	good to neutral (0.57)	neutral to bad *(-0.42)*	0.003	v
air quality	good to neutral (0.64)	neutral to bad *(-0.37)*	0.002	v
thermal	good (0.96)	neutral 0.16	0.264	x

evaluation
very good (higher than 2)
good to very good (1÷2)
good to neutral (0÷1)
neutral 0
bad to neutral (-0 ÷-1)
bad to very bad (-1 ÷-2)
very bad (lower than -2)

Fig. 13. Results of the *t*-test, comparing the mean of the results of the questionnaire inside and outside the parks (v, significant; x, non-significant).

good", while on the street the same is "neutral". Acoustic and air quality-related comfort goes from "good to neutral" inside the park to "neutral to bad" on the street. Visual comfort and thermal comfort mean values do not result in significantly different means, while still going from "good to very good" (visual comfort) and "good" (thermal comfort) inside the park to "neutral" on the street.

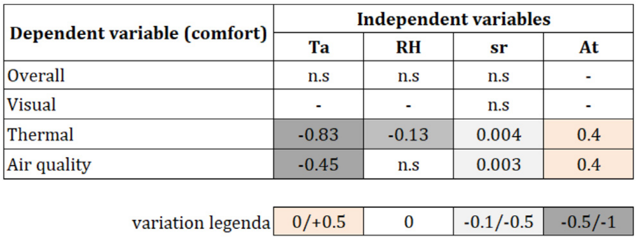
A low significant difference is detected in terms of visual comfort while comparing responses collected inside and outside the parks. In order to provide a preliminary explanation for this observation, which could be further explored in future studies, we hypothesize that this may be imputable to lower flagship visual effect or to the fact that even people outside the park may have looked at the park from the street.

The finding of the subjective survey related to thermal comfort, showing that thermal comfort is not significantly different inside and outside the park, is consistent with the findings of the objective assessment (microclimate monitoring). Such a result highlights that the difference in comfort perception inside and outside the park is mainly due to an holistic subjective perception and human-centered drivers. Indeed, subjective comfort perception is evident mainly in the whole comfort assessment rather than in the specific perceptions. As a matter of fact, when interviewees declare their thermal, visual, acoustic and air quality comfort perception they are forced to dissect their physical comfort perception, realizing that, while their whole comfort is better in the park compared to the street, their thermal comfort, for example, is not.

For acoustic comfort, the results confirm the difference between outside and inside the park, where inside the park acoustic comfort is much better. The significance of the difference with respect to acoustic perception inside and outside the park could be explained by hypothesizing that the presence of gray noises (those produced by the water-walls) and the acoustic insulation provided by trees and greenery, which separate the park from the city noise and contribute in shaping detached, oasis-like environment, were effective in improving acoustic comfort.

3.2.1. Comparison between subjective perception and physical objective microclimate monitoring results

Finally, microclimate measurements are statistically compared to the subjective whole, visual and thermal sensation, thus directly coupling objective and subjective assessment in the same analysis. Indeed, the comfort vote extracted from the subjective assessment (the survey) and the microclimate data gathered by means of the dynamic monitoring (objective measurements) are analyzed by means of statistical regression analysis. The latter (overall, visual and thermal comfort declared votes) are the dependent variables of the regressions, the former are the independent variables, jointly considered, influencing the dependent ones. The independent microclimate variables air temperature (Ta), relative humidity (RH), solar radiation (SR) and apparent temperature (At) are considered. Apparent temperature is computed specifically to serve as a comprehensive indicator, including the effect of different microclimate variables. Results are displayed in Fig. 14. It is worth noting that in this comparison the above-mentioned dependent variables included in Fig. 14 are related to the subjective comfort perception deduced from the questionnaire surveys, and not to the measurements performed with the microclimate monitoring station. Therefore, the table is useful in evidencing the gap between the perceived comfort and the physical microclimate variables. Indeed, the measured microclimate variables proved to have no significant impact in influencing overall and visual comfort, while thermal comfort and perceived air quality are impacted by Ta, RH, SR and At (thermal comfort) and Ta, SR and At (air quality perception). Therefore, it is evident also from these last findings, that while specific comfort sensations are influenced by microclimate conditions of the pocket parks, whole comfort is not significantly impacted by them. With respect to the overall, whole comfort sensation, a subjective perception of the architectural space is preponderant, due to the specific design feature of urban pocket parks. Also visual comfort results not to be affected by microclimate variables, such as SR, that could cause glare. In this case, we hypothesize that the visual effect of greenery, water and disconnection from the traffic and chaos of the city influences the subjective visual perception, due to "pleasantness to the eye", more than SR hitting the park.



Dependent variable (comfort)	Independent variables			
	Ta	RH	sr	At
Overall	n.s	n.s	n.s	-
Visual	-	-	n.s	-
Thermal	-0.83	-0.13	0.004	0.4
Air quality	-0.45	n.s	0.003	0.4

variation legenda	0/+0.5	0	-0.1/-0.5	-0.5/-1

Fig. 14. Statistical regression analyses with coupled subjective and objective assessment of comfort and microclimate variables.

In order to further investigate the mismatch between measured comfort and subjective perception, the collected environmental parameters (i.e., air temperature, relative humidity, solar radiation and wind speed) are collapsed into the Physiological Equivalent Temperature (PET) indicator. The PET index is here computed by means of the Rayman model [75–77] by taking into account the thermo-physiological data of a standard 35-years-old man, 1.75 high, weighing 75 kg, who was walking (2.5 met) and wearing 0.5 clo. According to the existing literature PET neutral sensation is adapted to different climate and the most suitable range [64,78]. Even if the *At* already allowed to consider thermal comfort (heat index), PET provides a more comprehensive index for comparing thermal comfort subjective, declared perception by the interviewees and physiological objective comfort.

August 1st is the selected day to conduct this kind of analysis since it was the hottest one between the two analyzed days, and therefore more representative of overheating risk.

In detail Fig. 15 shows the PET spatial results around Greenacre Park respectively at 9 a.m. (morning), 1p.m. (midday) and 7p.m (evening), while Fig. 16 shows the PET results obtained along Paley Park pathway during the same day, i.e., August 1st, respectively at 9 a.m., 1 p.m. and 7 p.m.

Both the parks show at 9 a.m. and 7 p.m. value of PET around 20–25 °C, which means comfortable to slightly-warm conditions both in the park and generally along the streets around the park. This trend is confirmed by the subjective perception whose mean is equal to 0.6, standing for "good to neutral" perception.

At 1 p.m. in both GP and PP, PET varies from comfortable-slightly warm to slightly warm-warm thermal perception, corresponding to no thermal stress up to slight-to-moderate thermal stress. These results are partially in accordance, but with the same trend, with the outcomes of subjective perception, which is equal to 0.8 and 0.6, i.e. "good to neutral", for GP and PP respectively. At the same time the subjective perception along the streets around the park is "neutral", while the PET mean value is around 37 °C, which underlines warm-hot thermal perception, i.e., moderate-to-strong heat stress.

It can be further observed that the worst PET and lower differences between the PET in the surrounding streets and in the pocket parks is at midday, the warmest hour and the hour where less shading is available in the parks (Fig. 5). The presence of trees, in addition to providing evapotranspiration, is crucial also with respect to shading in the mitigation of heat stress and improvement of thermal comfort. The specific role of shading in pocket parks could thus be further deepened in future studies.

4. Critical discussion and conclusions

In this work, we aim at investigating the potential of pocket parks, i.e., small parks spread among neighborhoods, as further strategies for local climate mitigation, through a novel human-centered investigation. In so doing, we couple objective and subjective assessment, by means of dynamic microclimate monitoring via novel portable technology and questionnaire survey to pedes-

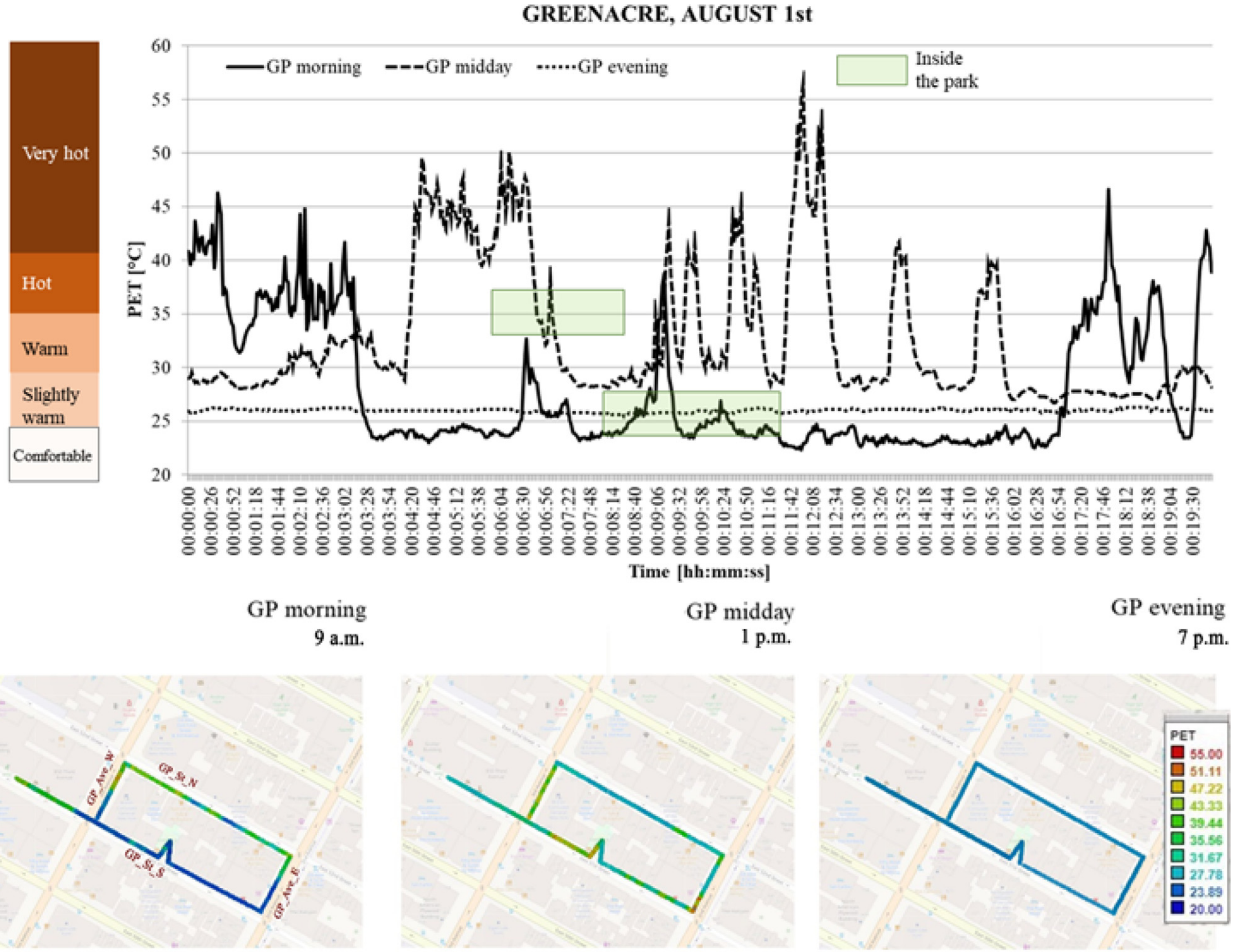


Fig. 15. PET spatial distribution along Greenacre Park in August 1st at 9 a.m., 1p.m., 7p.m.

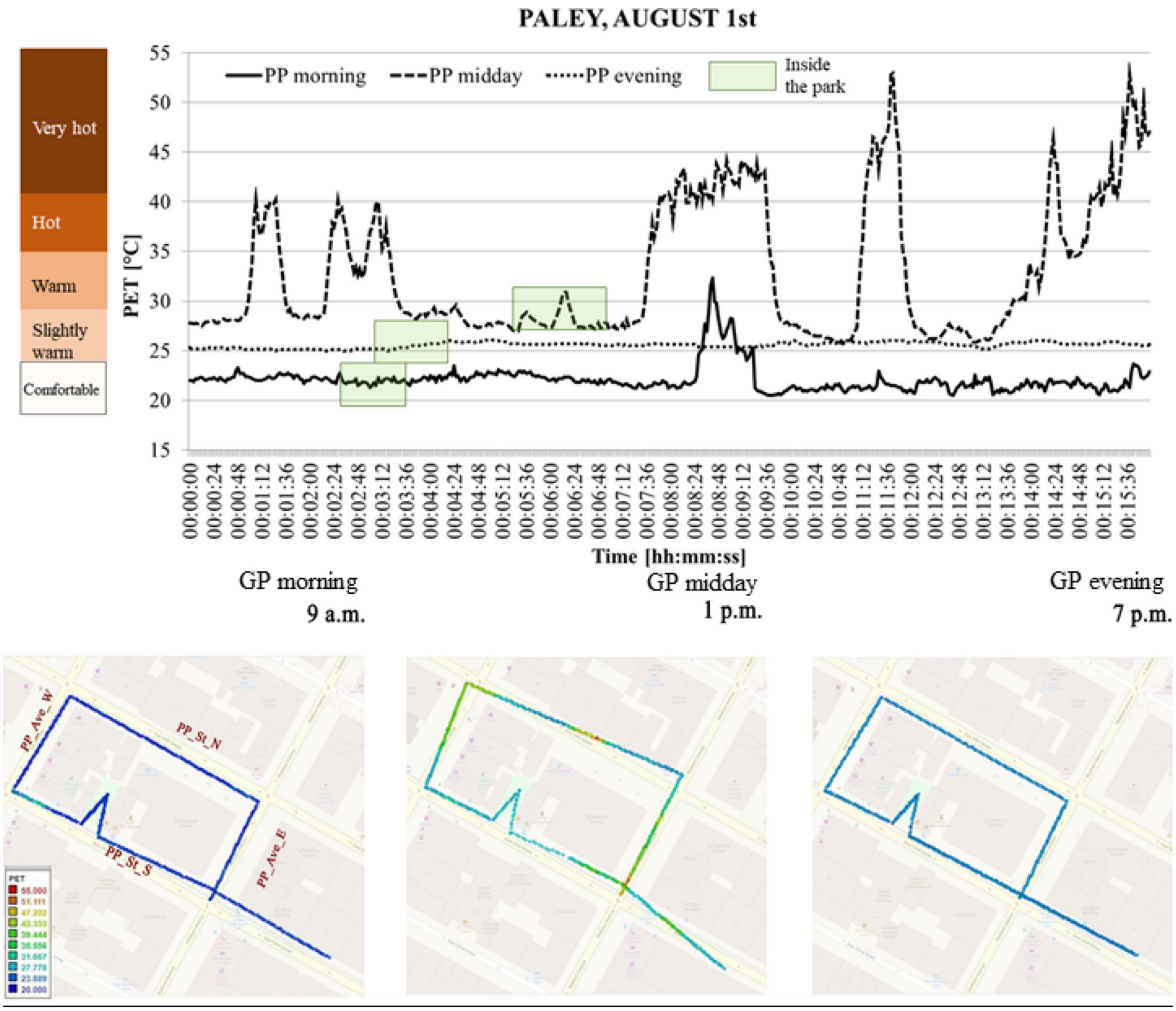


Fig. 16. PET spatial distribution along Paley Park in August 1st at 9 a.m., 1p.m., 7p.m

trians in the parks. The findings allow replying to the three posited research questions:

- RQ1: Which is the role of pocket parks in mitigating intra-urban microclimate during the hot season?
  Pocket parks, as they are currently designed and adopted allow a minor, but still statistically significant, mitigation of air temperature and solar radiation with respect to their surrounding urban environment. The difference in T_a between parks and streets/avenues is up to 1 °C, consistent in both the experimental campaign days and during the morning, midday and evening times. RH is instead higher in the parks, due to the presence of water bodies and greenery and weak recirculation capability of such packed geometries. Solar radiation is significantly lower in the parks, due to shading from surrounding buildings and the small trees, given the small dimension of the parks, and the presence of trees' canopies, and this also helps a lot the measured cooling at pedestrian's level.

- RQ2: How are pocket parks perceived by pedestrians with respect to thermal, visual and whole comfort sensation, compared to surrounding urban environment?
  Pocket Parks are perceived as significantly more comfortable and pleasant than surrounding built environment: the average vote for the whole comfort in the pocket park was "good to very good", while a few steps from the park, on the street, the same vote was "neutral". The same can be said for thermal and visual comfort. The acoustic and air quality perception, the comfort vote went from "good to neutral" or "very good" in the park to "neutral to bad" outside the park.
- RQ3: Are the measured microclimate variables and subjective pedestrians' perception consistent or is there a significant gap between them?
  Measured/objective and subjective perception did not coincide, the latter being way higher than the former one in terms of mitigation. The highlighted gap confirms the role of pocket parks in mitigating heat stress during the hot season, but also to provide other significant restorative experience to users, which is not limited to the measured microclimate variables. The statistical analyses conducted on coupled subjective/objective assessment showed that microclimate variables were significantly influencing thermal comfort, but they were not effectively correlated to whole and visual comfort.

As a general remark and synthesis of the above-mentioned responses to the research questions, pocket parks demonstrated a limited, but still significant, role in the actual physical mitigation of granular, intra-urban microclimate which is potentially underexploited due to limited local ventilation contribution. On the other hand, the subjective perception of citizens using the park evidences a significantly improved overall comfort inside the pocket parks with respect to the surrounding local urban environment. Thus, the presence of a significant gap between the physical-objective and the subjective comfort is demonstrated. By further investigating this phenomenon, it is evident that while microclimate physical variables are able to affect thermal comfort subjective perception, they are not sufficient to describe the overall, holistic comfort perception inside the park.

Concluding, pocket parks demonstrate to have a significant role that could be exploited even further in dense urban areas for mitigating heat stress and provide overall restorative experiences for pedestrians, local citizens and tourists, even if they are not able to massively improve physical microclimate. These benefits of pocket parks pair the already mentioned one related to the possible diffusion of these parks in each neighborhood. By implementing diffuse pocket parks in cities, more and more easily accessible green space could be provided to citizens, towards a more just and safe urban outdoor public space. The pocket park strategy could be particularly effective also in providing local green space in urban areas where large urban parks are not present, especially in pandemic and post-pandemic panorama, when it is advised to citizens to stay close to home, not exceeding neighborhoods limits. Thus, while larger urban parks are more effective in mitigating urban microclimate, they are less spread and diffused in urban neighborhoods and thus they are able to reach less citizens. On the contrary, the pocket park model, i.e., the spread insertion of pocket parks in every neighborhood, while less effective in mitigating hyper-local microclimate, is able to reach and provide a restorative perceived experience for a much wider number of citizens, allowing to go towards the objective of a more just and equitable city. Moreover, given the small dimension, pocket parks require less attention and expenses with respect to maintenance and construction, further favoring their diffusion.

On the other side, more attention should be paid to the ventilation capability and the possibility to prevent possible stagnation volumes inside pocket parks, which may compromise their performance. Given the above findings and considerations, pocket parks could be employed to complement the less-spread presence of larger urban parks, and their effectiveness towards microclimate mitigation could be improved starting from the results of this study. Moreover, the more diffused the pocket park model is in the urban area, the more effective its mitigation potential could become: future studies could investigate the effect of spread small pocket parks in improving urban microclimate, while in this work we considered the effect of each pocket park with respect to intra-urban, granular microclimate.

Therefore, the relevance of this study is both for researchers aiming at advancing studies in intra-urban microclimate and urban stress mitigation by means of architectural passive strategies, but also to policymakers and urban administrations, interested in implementing effective green areas in cities; and to professionals in urban and architectural studies, towards a conscious design of small urban areas.

Future studies could apply and investigate the "pocket park model" to other climate contexts, while the concept of pocket parks could be enlarged to include and investigate other low-cost solutions for simpler and easier implementation in disadvantaged locations and countries in developing countries/urban areas.

CRediT authorship contribution statement

Federica Rosso: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Investigation, Visualization. **Benedetta Pioppi:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Anna Laura Pisello:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

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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Appendix A

Here in the Appendix, the descriptive statistics and frequencies for the questionnaire survey are reported.

Table A1
Frequencies for the independent variables, describing the sample.

Frequencies		%
Total Questionnaire	#178	
Park	Greenacre	51.69
	Paley	48.31
Usual user of the park	No	76.7
	Yes	23.3
Reason to visit	Relax	87.5
	Eat	11.93
	Work meeting	0.57
Time in the park	<15 min	42.94
	>15–30 min	41.24
	>30 min	15.82
Age	<21	3.37
	21–35	83.71
	35–50	6.18
	>50	6.74
Gender	Male	43.82
	Female	56.18
	Gender neutral	0
Hour	Morning (9 am)	20.79
	Midday (1 pm)	43.26
	Evening (7 pm)	35.96
Date	Cloudy day	57.3
	Sunny day	42.7

Table A2
Descriptive statistics for the questionnaire survey data.

Variable		Obs	Mean	Std. Dev.	Min	Max
Subjective Perception	Overall comfort	178	1.23	0.84	−1.00	2.00
	Visual comfort	176	1.30	0.84	−1.00	2.00
	Acoustic comfort	176	0.57	1.07	−2.00	2.00
	Air Quality perception	176	0.64	1.03	−2.00	2.00
	Thermal comfort	175	0.92	1.01	−2.00	2.00
Personal information	Time in the park	177	0.73	0.72	0.00	2.00
	Usual user of the park	176	0.23	0.42	0.00	1.00
	Reason to visit	176	0.13	0.35	0.00	2.00
	Age	178	1.16	0.58	0.00	3.00
	Gender	178	0.56	0.50	0.00	1.00
Location and time	Park (GP or PP)	178	1.48	0.50	1.00	2.00
	Position (park or street)	178	0.21	0.41	0.00	1.00
	Hour (9 am, 1 pm, 7 pm)	178	1.15	0.74	0.00	2.00
	Day (sunny or cloudy)	178	1.28	1.49	0.00	3.00
Subjecitve perception votes legenda						
−2	−1	0	1	2		
very bad	bad	neutral	good	very good		
Personal information legenda						
Time in the park		*Usual user of the park*			*Reason to visit*	
0	<15 min	0	no		0	relax
1	>15–30 min	1	yes		1	eat
2	>30 min				2	work meeting
Age		*Gender*				
0	<21	0	Male			
1	21–35	1	Female			
2	35–50	2	Gender Neutral			
3	>50					
Location and time legenda						
Park (GP or PP)		*Position (park or street)*				
0	Greenacre Park (GP)	0	Park			
1	Paley Park (PP)	1	Street			
Hour (9 am, 1 pm, 7 pm)		*Day (sunny or cloudy)*				
0	9 am, morning	0	26 July, cloudy			
1	1 pm, midday	3	1 August, sunny			
2	7 pm, evening					

References

[1] A.J. Arnfield, Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island, Int. J. Climatol. 23 (1) (2003) 1–26, https://doi.org/10.1002/joc.859.

[2] T.R. Oke, The energetic basis of the urban heat island, Q. J. R. Meteorol. Soc. 108 (455) (1982) 1–24, https://doi.org/10.1002/qj.49710845502.

[3] M. Santamouris, Recent progress on urban overheating and heat island research. integrated assessment of the energy, environmental, vulnerability and health impact synergies with the global climate change, Energy Build. 207 (2020) 109482, https://doi.org/10.1016/j.enbuild.2019.109482.

[4] SUE Grimmond, Urbanization and global environmental change: Local effects of urban warming, Geogr. J. 173 (1) (2007) 83–88, https://doi.org/10.1111/j.1475-4959.2007.232_3.x.

[5] Emanuele BEmanuele, Federico Rossi, Valentina Coccia, Anna Laura Pisello, Andrea Nicolini, Beatrice Castellani, Franco Cotana, Mirko Filipponi, Elena Morini, Mat Santamouris, An energy-balanced analytic model for urban heat canyons: comparison with experimental data, Adv. Build. Energy Res. 7 (2) (2013) 222–234, https://doi.org/10.1080/17512549.2013.865561.

[6] N.B. Grimm, S.H. Faeth, N.E. Golubiewski, C.L. Redman, J. Wu, X. Bai, J.M. Briggs, Global Change and the ecology of cities, Science 319 (5864) (2008) 756–760.

[7] G. Lobaccaro, J.A. Acero, Comparative analysis of green actions to improve outdoor thermal comfort inside typical urban street canyons, Urban Clim. 14 (2015) 251–267, https://doi.org/10.1016/j.uclim.2015.10.002.

[8] V.L. Castaldo, A.L. Pisello, C. Piselli, C. Fabiani, F. Cotana, M. Santamouris, How outdoor microclimate mitigation affects building thermal-energy performance: a new design-stage method for energy saving in residential near-zero energy settlements in Italy, Renew. Energy. 127 (2018) 920–935, https://doi.org/10.1016/J.RENENE.2018.04.090.

[9] P.D. United Nations, Department of Economic and Social Affairs, The world's cities in 2016–Data booklet, in: 2016.

[10] M. Santamouris, N. Papanikolaou, I. Livada, I. Koronakis, C. Georgakis, A. Argiriou, D.N. Assimakopoulos, On the impact of urban climate on the energy consuption of building, Sol. Energy 70 (2001) 201–216, https://doi.org/10.1016/S0038-092X(00)00095-5.

[11] M. Santamouris, On the energy impact of urban heat island and global warming on buildings, Energy Build. 82 (2014) 100–113, https://doi.org/10.1016/j.enbuild.2014.07.022.

[12] M. Santamouris, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, Sol. Energy 103 (2014) 682–703, https://doi.org/10.1016/j.solener.2012.07.003.

[13] C. Sarrat, A. Lemonsu, V. Masson, D. Guedalia, Impact of urban heat island on regional atmospheric pollution, Atmos. Environ. 40 (10) (2006) 1743–1758, https://doi.org/10.1016/j.atmosenv.2005.11.037.

[14] C. Heaviside, S. Vardoulakis, X.-M. Cai, Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK, Environ. Heal. A Glob. Access Sci. Source. 15 (S1) (2016), https://doi.org/10.1186/s12940-016-0100-9.

[15] D. Founda, M. Santamouris, Synergies between Urban Heat Island and Heat Waves in Athens (Greece), during an extremely hot summer (2012), Sci Rep 7 (1) (2017), https://doi.org/10.1038/s41598-017-11407-6.

[16] S. Falasca, V. Ciancio, F. Salata, I. Golasi, F. Rosso, G. Curci, High albedo materials to counteract heat waves in cities: An assessment of meteorology, buildings energy needs and pedestrian thermal comfort, Build. Environ. 163 (2019) 106242, https://doi.org/10.1016/j.buildenv.2019.106242.

[17] B.-J. He, J. Wang, H. Liu, G. Ulpiani, Localized synergies between heat waves and urban heat islands: implications on human thermal comfort and urban heat management, Environ. Res. 193 (2021) 110584, https://doi.org/10.1016/j.envres.2020.110584.

[18] H.L. Macintyre, C. Heaviside, J. Taylor, R. Picetti, P. Symonds, X.M. Cai, S. Vardoulakis, Assessing urban population vulnerability and environmental risks across an urban area during heatwaves – Implications for health protection, Sci. Total Environ. 610–611 (2018) 678–690, https://doi.org/10.1016/j.scitotenv.2017.08.062.

[19] F. Rosso, A. Pisello, V. Castaldo, M. Ferrero, F. Cotana, On innovative cool-colored materials for building envelopes: balancing the architectural appearance and the thermal-energy performance in historical districts, Sustainability 9 (12) (2017) 2319, https://doi.org/10.3390/su9122319.

[20] F. Rosso, A.L. Pisello, V.L. Castaldo, C. Fabiani, F. Cotana, M. Ferrero, W. Jin, New cool concrete for building envelopes and urban paving: Optics-energy and thermal assessment in dynamic conditions, Energy Build. 151 (2017) 381–392, https://doi.org/10.1016/j.enbuild.2017.06.051.

[21] M. Santamouris, G.Y. Yun, Recent development and research priorities on cool and super cool materials to mitigate urban heat island, Renew. Energy 161 (2020) 792–807, https://doi.org/10.1016/j.renene.2020.07.109.

[22] G. Schuch, S. Serrao-Neumann, E. Morgan, D. Low Choy, Water in the city: green open spaces, land use planning and flood management – An Australian case study, Land Use Policy 63 (2017) 539–550, https://doi.org/10.1016/j.landusepol.2017.01.042.

[23] C. Inard, D. Groleau, M. Musy, M. Musy, Energy balance study of water ponds and its influence on building energy consumption, Build. Serv. Eng. Res. Technol. 25 (2004) 171–182, https://doi.org/10.1191/0143624404bt106oa.

[24] E. Di Giuseppe, G. Ulpiani, C. Cancellieri, C. Di Perna, M. D'Orazio, M. Zinzi, Numerical modelling and experimental validation of the microclimatic impacts of water mist cooling in urban areas, Energy Build. 231 (2021) 110638, https://doi.org/10.1016/j.enbuild.2020.110638.

[25] M. Chàfer, A.L. Pisello, C. Piselli, L.F. Cabeza, Greenery system for cooling down outdoor spaces: Results of an experimental study, Sustainability 12 (15) (2020) 5888.

[26] A. Gutierrez, L. Miró, A. Gil, J. Rodríguez-Aseguinolaza, C. Barreneche, N. Calvet, X. Py, A. Inés Fernández, M. Grágeda, S. Ushak, L.F. Cabeza, Advances in the valorization of waste and by-product materials as thermal energy storage (TES) materials, Renew. Sustain. Energy Rev. 59 (2016) 763–783, https://doi.org/10.1016/J.RSER.2015.12.071.

[27] L.F. Cabeza, A. Castell, C. Barreneche, A. de Gracia, A.I. Fernández, Materials used as PCM in thermal energy storage in buildings: a review, Renew. Sustain. Energy Rev. 15 (3) (2011) 1675–1695, https://doi.org/10.1016/j.rser.2010.11.018.

[28] F. Rosso, A. Pisello, F. Cotana, M. Ferrero, Integrated thermal-energy analysis of innovative translucent white marble for building envelope application, Sustainability 6 (2014) 5439–5462, https://doi.org/10.3390/su6085439.

[29] H. Khan, M. Asif, M. Mohammed, Case study of a nearly zero energy building in italian climatic conditions, Infrastructures 2 (2017) 19, https://doi.org/10.3390/infrastructures2040019.

[30] H. Gilbert, B.H. Mandel, R. Levinson, Keeping california cool: recent cool community developments, Energy Build. 114 (2016) 20–26, https://doi.org/10.1016/j.enbuild.2015.06.023.

[31] C. O'Malley, P. Piroozfar, E.R.P. Farr, F. Pomponi, Urban heat island (UHI) mitigating strategies: a case-based comparative analysis, Sustain. Cities Soc. 19 (2015) 222–235, https://doi.org/10.1016/j.scs.2015.05.009.

[32] V.L. Castaldo, A.L. Pisello, I. Pigliautile, C. Piselli, F. Cotana, Microclimate and air quality investigation in historic hilly urban areas: Experimental and numerical investigation in central Italy, Sustain. Cities Soc. 33 (2017) 27–44, https://doi.org/10.1016/j.scs.2017.05.017.

[33] A.A.A. AboElata, Study the vegetation as urban strategy to mitigate urban heat island in Mega City Cairo, Proc. Environ. Sci. 37 (2017) 386–395, https://doi.org/10.1016/j.proenv.2017.03.004.

[34] N. Theeuwes, A. Solcerova, G.-J. Steeneveld, Modeling the influence of open water surfaces on summertime temperatures and thermal comfort in the city, J. Geophys. Res. (2013).

[35] T.A.L. Martins, L. Adolphe, M. Bonhomme, F. Bonneaud, S. Faraut, S. Ginestet, C. Michel, W. Guyard, Impact of urban cool island measures on outdoor climate and pedestrian comfort: Simulations for a new district of Toulouse, France, Sustain. Cities Soc. 26 (2016) 9–26, https://doi.org/10.1016/j.scs.2016.05.003.

[36] D. Kolokotsa, M. Santamouris, S.C. Zerefos, Green and cool roofs' urban heat island mitigation potential in European climates for office buildings under free floating conditions, Sol. Energy 95 (2013) 118–130, https://doi.org/10.1016/j.solener.2013.06.001.

[37] D. Kolokotsa, M. Santamouris, Review of the indoor environmental quality and energy consumption studies for low income households in Europe, Sci. Total Environ. 536 (2015) 316–330, https://doi.org/10.1016/j.scitotenv.2015.07.073.

[38] E. Di Giuseppe, M. Iannaccone, M. Telloni, M. D'Orazio, C. Di Perna, Probabilistic life cycle costing of existing buildings retrofit interventions towards nZE target: Methodology and application example, Energy Build. 144 (2017) 416–432, https://doi.org/10.1016/j.enbuild.2017.03.055.

[39] B. Amor, D. Lacheheb, Y. Bouchahm, Improvement of thermal comfort conditions in an urban space (case study: the square of independence, Sétif, Algeria), Eur. J. Sustain. Dev. 2239–5938 (4) (2015) 407–416. https://doi.org/10.14207/ejsd.2015.v4n2p407.

[40] L. Chen, B. Yu, F. Yang, H. Mayer, Intra-urban differences of mean radiant temperature in different urban settings in Shanghai and implications for heat stress under heat waves: a GIS-based approach, Energy Build. 130 (2016) 829–842, https://doi.org/10.1016/j.enbuild.2016.09.014.

[41] I. Pigliautile, A.L. Pisello, Environmental data clustering analysis through wearable sensing techniques: new bottom-up process aimed to identify intra-urban granular morphologies from pedestrian transects, Build. Environ. 171 (2020) 106641, https://doi.org/10.1016/j.buildenv.2019.106641.

[42] A. Chokhachian, K. Perini, S. Giulini, T. Auer, Urban performance and density: generative study on interdependencies of urban form and environmental measures, Sustain. Cities Soc. 53 (2020) 101952, https://doi.org/10.1016/j.scs.2019.101952.

[43] F. Rosso, F. Cappa, R. Spitzmiller, M. Ferrero, Pocket parks towards more sustainable cities. Architectural, environmental, managerial and legal considerations towards an integrated framework: a case study in the Mediterranean region, Environ. Challenges (2021) 100402, https://doi.org/10.1016/j.envc.2021.100402.

[44] P. Faraci, Vest Pocket Parks, 1967.

[45] W.H. Whyte, The social life of small urban spaces, 2001.

[46] S. Sodoudi, H. Zhang, X. Chi, F. Müller, H. Li, The influence of spatial configuration of green areas on microclimate and thermal comfort, Urban For. Urban Green. 34 (2018) 85–96, https://doi.org/10.1016/j.ufug.2018.06.002.

[47] H. Yan, F. Wu, L. Dong, Influence of a large urban park on the local urban thermal environment, Sci. Total Environ. 622–623 (2018) 882–891, https://doi.org/10.1016/j.scitotenv.2017.11.327.

[48] Y. Xing, P. Brimblecombe, Role of vegetation in deposition and dispersion of air pollution in urban parks, Atmos. Environ. 201 (2019) 73–83, https://doi.org/10.1016/j.atmosenv.2018.12.027.

[49] A. Chokhachian, K. Ka-Lun Lau, K. Perini, T. Auer, Sensing transient outdoor comfort: a georeferenced method to monitor and map microclimate, J. Build. Eng. 20 (2018) 94–104, https://doi.org/10.1016/j.jobe.2018.07.003.

[50] A. Middel, The SHaDE Lab, (n.d.). https://shadelab.asu.edu/ (accessed December 16, 2021).

[51] A. Middel, S. Alkhaled, F.A. Schneider, B. Hagen, P. Coseo, 50 Grades of Shade, Bull. Am. Meteorol. Soc. (2021) 1–35, https://doi.org/10.1175/bams-d-20-0193.1.

[52] M. Reed, Mapping our urban heat island, by bike, (2016). https://www.yaybikes.com/blog/2016/6/10/cxjtazf3vit2dnxeqpao7qdfvihq8y (accessed December 16, 2021).

[53] N. Nazarian, Project Coolbit, (n.d.). http://www.projectcoolbit.com/ (accessed December 16, 2021).

[54] N. Nazarian, S. Liu, M. Kohler, J.K.W. Lee, C. Miller, W.T.L. Chow, S.B. Alhadad, A. Martilli, M. Quintana, L. Sunden, L.K. Norford, Project Coolbit: can your watch predict heat stress and thermal comfort sensation?, Environ Res. Lett. 16 (3) (2021) 034031, https://doi.org/10.1088/1748-9326/abd130.

[55] N. Borzino, S. Chng, M.O. Mughal, R. Schubert, Willingness to pay for urban heat island mitigation: a case study of Singapore, Climate 8 (2020) 1–26, https://doi.org/10.3390/CLI8070082.

[56] V.L. Castaldo, I. Pigliautile, F. Rosso, F. Cotana, F. De Giorgio, A. Laura, How subjective and non-physical parameters affect occupants ' environmental comfort perception, Energy Build. 178 (2018) 107–129, https://doi.org/10.1016/j.enbuild.2018.08.020.

[57] M. Nikolopoulou, N. Baker, K. Steemers, Thermal comfort in outdoor urban spaces: understanding the Human parameter, Sol. Energy 70 (3) (2001) 227–235, https://doi.org/10.1016/S0038-092X(00)00093-1.

[58] B. Pioppi, I. Pigliautile, C. Piselli, A.L. Pisello, Cultural heritage microclimate change: human-centric approach to experimentally investigate intra-urban overheating and numerically assess foreseen future scenarios impact, Sci. Total Environ. 703 (2020) 134448, https://doi.org/10.1016/j.scitotenv.2019.134448.

[59] M. Vuckovic, K. Kiesel, A. Mahdavi, The extent and implications of the microclimatic conditions in the urban environment: a Vienna case study, Sustainability 9 (2) (2017) 177, https://doi.org/10.3390/su9020177.

[60] L.W.A. van Hove, C.M.J. Jacobs, B.G. Heusinkveld, J.A. Elbers, B.L. Van Driel, A.A. M. Holtslag, Temporal and spatial variability of urban heat island and thermal comfort within the Rotterdam agglomeration, Build. Environ. 83 (2015) 91–103, https://doi.org/10.1016/j.buildenv.2014.08.029.

[61] R.G. Steadman, A universal scale of apparent temperature, J. Clim. Appl. Meteorol. (1984), https://doi.org/10.1175/1520-0450(1984)023<1674:AUSOAT>2.0.CO;2.

[62] B. Pioppi, I. Pigliautile, A.L. Pisello, Human-centric microclimate analysis of Urban Heat Island: wearable sensing and data-driven techniques for identifying mitigation strategies in New York City, Urban Clim. 34 (2020) 100716, https://doi.org/10.1016/j.uclim.2020.100716.

[63] Australian Government Bureau of Meteorology, Thermal Comfort Observations WBGT and Apparent Temperature for New South Wales and the ACT, (n.d.). http://www.bom.gov.au/products/IDN65179.shtml.

[64] P. Höppe, The physiological equivalent temperature – A universal index for the biometeorological assessment of the thermal environment, Int. J. Biometeorol. 43 (2) (1999) 71–75.

[65] International Organization for Standardization, ISO 10551:1995 - Ergonomics of the Thermal Environment - Assessment of the Influence of the Thermal Environment Using Subjective Judgement Scales, (1995).

[66] F. Rosso, A.L. Pisello, F. Cotana, M. Ferrero, On the thermal and visual pedestrians' perception about cool natural stones for urban paving: A field survey in summer conditions, Build. Environ. 107 (2016) 198–214, https://doi.org/10.1016/j.buildenv.2016.07.028.

[67] P.C. Austin, E.W. Steyerberg, The number of subjects per variable required in linear regression analyses, J. Clin. Epidemiol. 68 (6) (2015) 627–636, https://doi.org/10.1016/j.jclinepi.2014.12.014.

[68] F. Cappa, R. Oriani, E. Peruffo, I. McCarthy, Big data for creating and capturing value in the digitalized environment: unpacking the effects of volume, variety, and veracity on firm performance*, J. Prod. Innov. Manag. 38 (1) (2021) 49–67, https://doi.org/10.1111/jpim.12545.

[69] M.C. Peel, B.L. Finlayson, T.A. McMahon, Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci. 11 (5) (2007) 1633–1644, https://doi.org/10.5194/hess-11-1633-2007.

[70] W.N. Seymour, Small Urban Spaces: The Philosophy, Design, Sociology, and Politics of Vest-Pocket Parks and Other Small Urban Open Spaces, New York University Press, 1969.

[71] Project for Public Spaces, Paley Park, (n.d.). https://www.pps.org/places/paley-park (accessed September 3, 2020).

[72] Project for Public Spaces, Greenacre Park, (n.d.). https://www.pps.org/places/greenacre-park (accessed September 3, 2020).

[73] Greenacre Foundation, Greenacre Park, (n.d.). https://greenacrepark.org/about/ (accessed September 3, 2020).

[74] F. Xue, Z. Gou, S.S.Y. Lau, Green open space in high-dense Asian cities: Site configurations, microclimates and users' perceptions, Sustain. Cities Soc. 34 (2017) 114–125, https://doi.org/10.1016/j.scs.2017.06.014.

[75] A. Matzarakis, F. Rutz, H. Mayer, Modelling the thermal bioclimate in urban areas with the RayMan model, in: PLEA 2006 - 23rd Int. Conf. Passiv. Low Energy Archit. Conf. Proc., 2006.

[76] A. Matzarakis, F. Rutz, H. Mayer, Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model, Int. J. Biometeorol. 54 (2) (2010) 131–139, https://doi.org/10.1007/s00484-009-0261-0.

[77] A. Matzarakis, F. Rutz, H. Mayer, Modelling radiation fluxes in simple and complex environments - Application of the RayMan model, Int. J. Biometeorol. 51 (4) (2007) 323–334, https://doi.org/10.1007/s00484-006-0061-8.

[78] A. Matzarakis, H. Mayer, M.G. Iziomon, Applications of a universal thermal index: physiological equivalent temperature, Int. J. Biometeorol. 43 (2) (1999) 76–84, https://doi.org/10.1007/s004840050119.