Thermal perception in outdoor urban spaces under the Mediterranean climate of Annaba, Algeria.

Kahina Labdaoui, Said Mazouz, Sigrid Reiter, Jacques Teller

https://doi.org/10.1016/j.uclim.2021.100970

Abstract

Many studies were investigated to grade outdoor thermal comfort and related thermal sensation during the past years. This study aims to explore thermal comfort conditions and thermal sensation in the hot Mediterranean climate (Csa), which annually includes 1100-1700 cooling degree days and 1200-1800 heating degree days (CDD=1100-1700, HDD=1200-1800). This research tested the human thermal sensation by applying the Physiological Equivalent Temperature (PET) index. A field survey of 1230 interviewees was conducted in Annaba, Algeria, in four outdoor environments having the same morphology and different green cover. The scientific method involved combining two software. Envi-met was used to calibrate microclimatic data (air temperature, wind velocity, relative humidity and mean radiant temperature); in comparison, RayMan used to calculate PET. The results showed the neutral sensation range for this Mediterranean climate varies between 20 °C and 26°C. The highest scores of neutral thermal sensation were recorded in spaces with vegetation cover, which involves the trees cooling effect in enhancing thermal comfort, especially during the hot hours of the day. The air temperature divergence reached 4°C and 3°C for T_{mrt} at noon, considered the day's hottest hour. The findings also highlight the existence of a thermal adaptation in outdoor spaces having a green cover.

Keywords

Cooling degree days (CDD), Heating degree days (HDD), Hot-summer Mediterranean climate (Csa), Outdoor environment, Physiologically Equivalent Temperature (PET), Thermal Sensation Vote (TSV).

1. Introduction

The world has urbanized with an advanced frequency during the past century. As a result, over 50% of the universal population lives in urban areas (Wu, 2014, 2008). Thus, the urban development and increasing population have generated a growing interest among researchers. To overcome the conflicting impacts of urbanization on microclimatic conditions (Emmanuel, 2005). The "Urban heat island" is one of the most pronounced climatic effects of urbanization. Indeed, the urban thermal balance assigns higher air and surface temperatures in cities than rural environments (Faziera et al., 2020; Jamei et al., 2016; Santamouris, 2007).

The outdoor environment contributes to the liveliness of cities by giving citizens physical, environmental, economic and social services (Lai et al., 2019; Woolley, 2003). Because of these benefits, urban design and planning studies focused on making urban open spaces attractive. In addition, exploring outdoor thermal comfort is fundamental to design liveable outdoor spaces for inhabitants, enhancing human health and outdoors activities (Andreou, 2013) as well as improving outdoor thermal comfort (Watanabe et al., 2014).

The outdoor thermal comfort is correlated to the usage of outdoor spaces (Eliasson et al., 2007; Lin et al., 2012; Nikolopoulou and Lykoudis, 2007; Thorsson et al., 2004). According to Labdaoui et al. (2021), several studies seek to characterize thermal comfort conditions in an attempt to define the concept of thermal sensation in the outdoor environments (Cohen et al., 2013; Elnabawi et al., 2016; Hwang et al., 2011; Kántor et al., 2012; Knez and Thorsson, 2006; Lai et al., 2014; Tseliou et al., 2010). Thermal comfort is related to the neutral sensation (Elnabawi et al., 2016) and satisfaction concerning the thermal environment (ASHRAE Standard, 2004; Potchter et al., 2018).

Among diverse factors that affect urban public spaces quality, the outdoor microclimate conditions directly influence inhabitants' thermal comfort (Lai et al., 2014;

Watanabe et al., 2014). According to Pantavou et al. (2014), thermal indices simulate human thermal perception. Many studies focused on the influence of microclimatic variables on human thermal sensation in outdoor environments. Pantavou et al. (2013) explored thermal comfort in the city of Tel-Aviv and identified the comfort range according to the user's thermal perception. Nikolopoulou and Lykoudis (2006) analyzed thermal comfort in outdoor urban spaces across European cities and proved a strong correlation between microclimate and comfort conditions. Their findings also affirmed the importance of air temperature and solar radiation for the outdoor thermal sensation (Liu et al., 2016).

Numerous studies explored outdoor thermal comfort using the Physiological Equivalent Temperature (PET) among different climate zone. Lin and Matzarakis (2008) examined a new method by modifying the PET index scale to a hot and humid climate. Cohen et al. (2013) defined the PET neutral range in Tel Aviv's city based on in situ measurements and questionnaire surveys. To date, many studies investigated this method for adjusting various indices scales to different climate zones (Cohen et al., 2013; Elnabawi et al., 2016; Hirashima et al., 2016; Pantavou et al., 2016).

According to Potchter et al. (2018), few Mediterranean cities have been further researched; Athens (Nikolopoulou and Lykoudis, 2006; Tseliou et al., 2017, 2010), explored a large number of questionnaires (<2313), TelAviv (Cohen et al., 2013; Schnell et al., 2012) the number of interviews fluctuated between 1457 and 1731, Rome (Salata et al., 2016) included 941 questionnaires. However, in a study carried out in Lisbon by Oliveira and Andrade (2007) and Nouri and Costa (2017), the number of in-situ interviews had not exceeded 91 and 30, respectively. Moreover, a limited number of studies based on calibrated models explored the green coverage effect on thermal comfort and perception Csa climate's outdoor environments.

Nikolopoulou and Steemers (2003) emphasized the role of physical parameters in the assessment's variation of subjective comfort. That highlights the possibility of involving the psychological process in evaluating the outdoor thermal environment (Hirashima et al., 2016). Therefore, thermal comfort variables must be calibrated to have precise boundaries for each culture and climate zone. In addition, the psychological process (e.g. cultural characteristics) noticeably affects thermal comfort evaluation even in the same thermal environment (Aljawabra and Nikolopoulou, 2010; Knez and Thorsson, 2006).

The influence of green coverage on thermal comfort is entirely explored through meteorological variables and human-biometeorological indices (Klemm et al., 2015a). Indeed, various scales of improvement have been proved by using vegetation (Klemm et al., 2015b; Lai et al., 2019; Lee et al., 2016). The green infrastructure can efficiently decrease heat and enhance outdoor thermal comfort (Bowler et al., 2010). Moreover, people appraised green urban spaces as the most thermally comfortable spaces (Klemm et al., 2015a).

Base on the above studies, few studies explored thermal comfort using PET based on in situ measurements and questionnaire surveys within the Mediterranean climate. This study aims to (1) Evaluate the PET comfort ranges in the city of Annaba, Algeria, based on in-situ measurements and a questionnaire survey (1230). (2) Assess PET using microclimatic measure with the combination of Envi-met and RayMan software. (3) Analyze the influence of vegetation cover on the thermal comfort range in outdoor spaces, and (4) Compare Annaba's PET comfort range with the previous PET neutral scale in the Mediterranean area.

This research's novelty involves the combination of three significant keys related to the PET assessment. That required five research techniques; microclimatic data file measurements, simulation, questionnaire survey and observation, besides the impact of green cover on PET and people's thermal perception. Thus this study will fill the gap area by presenting a new comfort range value to the Mediterranean climate. Moreover, thermal adaptation is analyzed through people perceptions and behaviour.

2. Literature review

The literature review section includes three (3) main concepts; urban comfort, thermal comfort, urban sociology and green cover effects. Fig 1 presents the literature review process to understand the interaction of these concepts and how to define the thermal comfort range based on current methods. Besides the effect of green cover on comfort range and people thermal perception.

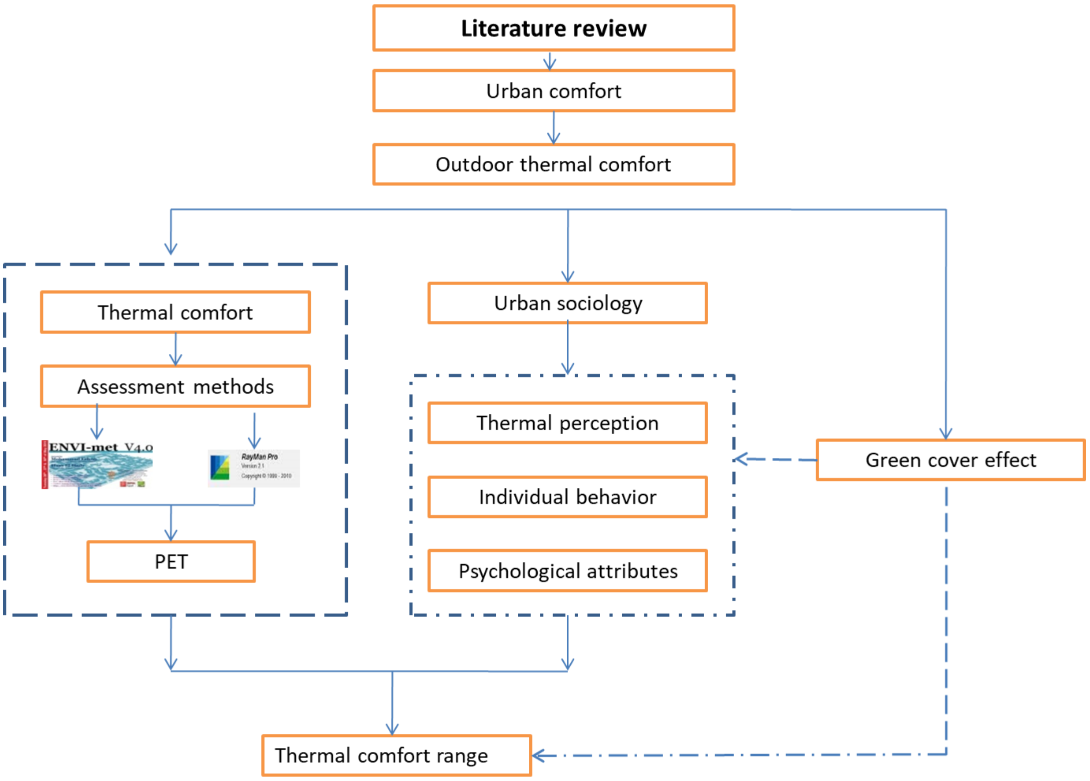


Fig. 1. Detailed outline of the literature review process.

During the last years, the urban ecology achieved the transdisciplinary regarding goals (sustainability-oriented), methods (including natural and social sciences), and participants (researchers, professional, decision-maker). Thus, the urban ecology is moving toward urban sustainability, one of its main theoretical and practice goals (Wu, 2014). To date, researchers have paid particular attention to thermal comfort in urban environments and its effect on inhabitants (Givoni, B et al., 2003; Knez and Thorsson, 2006; Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006; Potchter et al., 2018; Spagnolo and de Dear, 2003). Numerous studies have attempted to define thermal comfort conditions to determine the concept of thermal sensation in outdoor urban spaces (Cohen et al., 2013; Elnabawi et al., 2016; Hwang et al., 2011; Kántor et al., 2012; Knez and Thorsson, 2006; Lai et al., 2014; Tseliou et al., 2010).

The thermal sensation is described as a state of mind that indicates the person's estimation of its thermal environment (Nikolopoulou and Lykoudis, 2006; Pantavou et al., 2013; van Hoof, 2008). ASHRAE scale includes 7-point scales: (cold/cool/slightly cool/neutral/ slightly warm/warm/hot), the most used and more appropriate scale to evaluate the thermal sensation (Pantavou et al., 2013). Many thermal comfort indices had been explored, such as the physiological equivalent temperature (PET) (Cohen et al., 2013; Lin et al., 2013; Potchter et al., 2018), the outdoor standard effective temperature (OUT_SET*) (Thorsson et al., 2007), and the universal thermal climate index (UTCI) (Nikolopoulou and Lykoudis, 2006). However, PET and UTCI are mainly employed and verified in hot and cold climates (Johansson et al., 2014).

Lin and Matzarakis (2008) explored thermal comfort in a public square in Taiwan; the findings showed that Taiwan's thermal neutral range was higher than Western and central Europe. An investigation of thermal comfort in a park in northern China, using microclimatic monitoring and field survey, showed the local neutral temperature range is lower than the neutral temperature ranges in Europe and Taiwan (Lai et al., 2014). Mahmoud (2011) analyzed comfort level changes among different landscape zones in Cairo's urban park and found that neutral temperature is higher in Cairo than in Europe and Taiwan.

The studies mentioned above provided a critical understanding of thermal comfort's perception and thermal comfort range in outdoor environments. Hirashima et al. (2016) highlighted the difference in people's thermal comfort range in the Mediterranean and subtropical climates (Pantavou et al., 2013), markedly higher than those acquired in Central and Western Europe (Hirashima et al., 2016).

The Physiologically Equivalent Temperature Index (PET) was introduced in Western and Middle Europe (Cohen et al., 2013; Elnabawi et al., 2016; Matzarakis and Mayer, 1996). It was tested and validated in several climates zones (Gulyás et al., 2006; Johansson et al., 2014; Matzarakis et al., 1999; Thorsson et al., 2007) and investigated in different outdoors environments (Ali-Toudert and Mayer, 2007; Andrade et al., 2011; Charalampopoulos et al., 2013; Knez and Thorsson, 2006; Lai et al., 2014; Lin et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 2007; Thorsson et al., 2007).

Many studies have applied and approved outdoor thermal comfort prediction in several climatic zones using RayMan program (Cohen et al., 2013; Gulyás et al., 2006; Hwang et al., 2011; Lin et al., 2013; Matzarakis et al., 2007). This software was developed at the University of Freiburg, Germany, and is regarded as one of the most successful radiations and bio-climate models (Cohen et al., 2013; Elnabawi et al., 2016). In addition, many studies adopted RayMan to calculate PET depending on in-situ measurements (Cohen et al., 2013; Nouri and Costa, 2017; Salata et al., 2016). Other studies used Envi-met to explore thermal comfort in urban environments based on in-situ measurements and simulated models (Acero and Herranz-Pascual, 2015; Krüger et al., 2011; Lobaccaro and Acero, 2015; Ng et al., 2012; Wu and Chen, 2017). For example, Taleghani and Berardi (2018) used Envi-met simulations to predict pavement's highest effect having different albedo in the urban square in Toronto. Lee et al. (2016) explored the urban green coverage in reducing human heat stress.

According to Klemm et al. (2015b), individual, behavioural and psychological attributes influence the scale of perceived thermal comfort (Chen and Ng, 2012; Knez et al., 2009; Lenzholzer, 2012). The individual characteristics include gender and age, while the behavioural is related to metabolic rate and thermal comfort scale (Nikolopoulou et al., 2001; Thorsson et al., 2004). However, the psychological characteristics involve the thermal expectations (Lenzholzer and Koh, 2010; Nikolopoulou and Steemers, 2003; Thorsson et al., 2004). Naturalness (e.g., green infrastructure) and the esthetic of the environment (colour, material) are considered other essential psychological characteristics, which can impact the perceived thermal comfort (Lenzholzer and Koh, 2010; Nikolopoulou and Steemers, 2003). The vegetated environments have a positive influence on people's visual preferences. Indeed shaded and the sunny (light) area beside layer plants allowed people's interplay experience (Kaplan and Kaplan, 1989) and improved perceived thermal comfort (Klemm et al., 2015b).

Urban trees have a crucial impact on climate adaptation by shading and evapotranspiration (Zölch et al., 2016), minimizing air and surface temperature and cause localized cooling (Armson et al., 2012; Kong et al., 2014). Indeed the shaded area is the highest preference for people in green urban spaces that can provide relatively cooler environments and encourage the frequency of visiting parks in the hot weather (Lin et al., 2013). Furthermore, according to Klemm et al. (2015b), thermal comfort is correlated to the human perception of the thermal environment, which is essential to understand the impact of green coverage on thermal comfort sensation.

Based on the literature review, assessing thermal comfort in the Mediterranean climate can add a new value to the current research. Indeed, the correlation of three quantitative approaches using contemporary methods ensure PET accuracy. Besides, the estimation of people's thermal perception and vegetative impact. This original interactivity can enhance citizen health and improve urban comfort through outdoor thermal comfort.

3. Method and materials

This study involved a literature review besides four research methods: in-situ measurement of microclimatic data, numerical calibration of thermal environments with different vegetation arrangements, questionnaire field survey, and observations. A transversal field survey was carried out in Annaba, Algeria, where over 1230 questionnaires were recorded during two summer days, with simultaneous air temperature, relative humidity, and wind velocity. The responders expressed their thermal perception by ASHRAE 7 points scale (cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2), hot (+3). Many observation series were undertaken simultaneously with the questionnaire survey.

The field measurements were then used to calibrate microclimatic simulation using Envi-met. This step allowed having the four microclimatic data (air temperature, wind velocity, relative humidity and mean radiant temperature) estimated essential to calculate PET using Rayman software. Fig 2 shows the conceptual framework of this research.

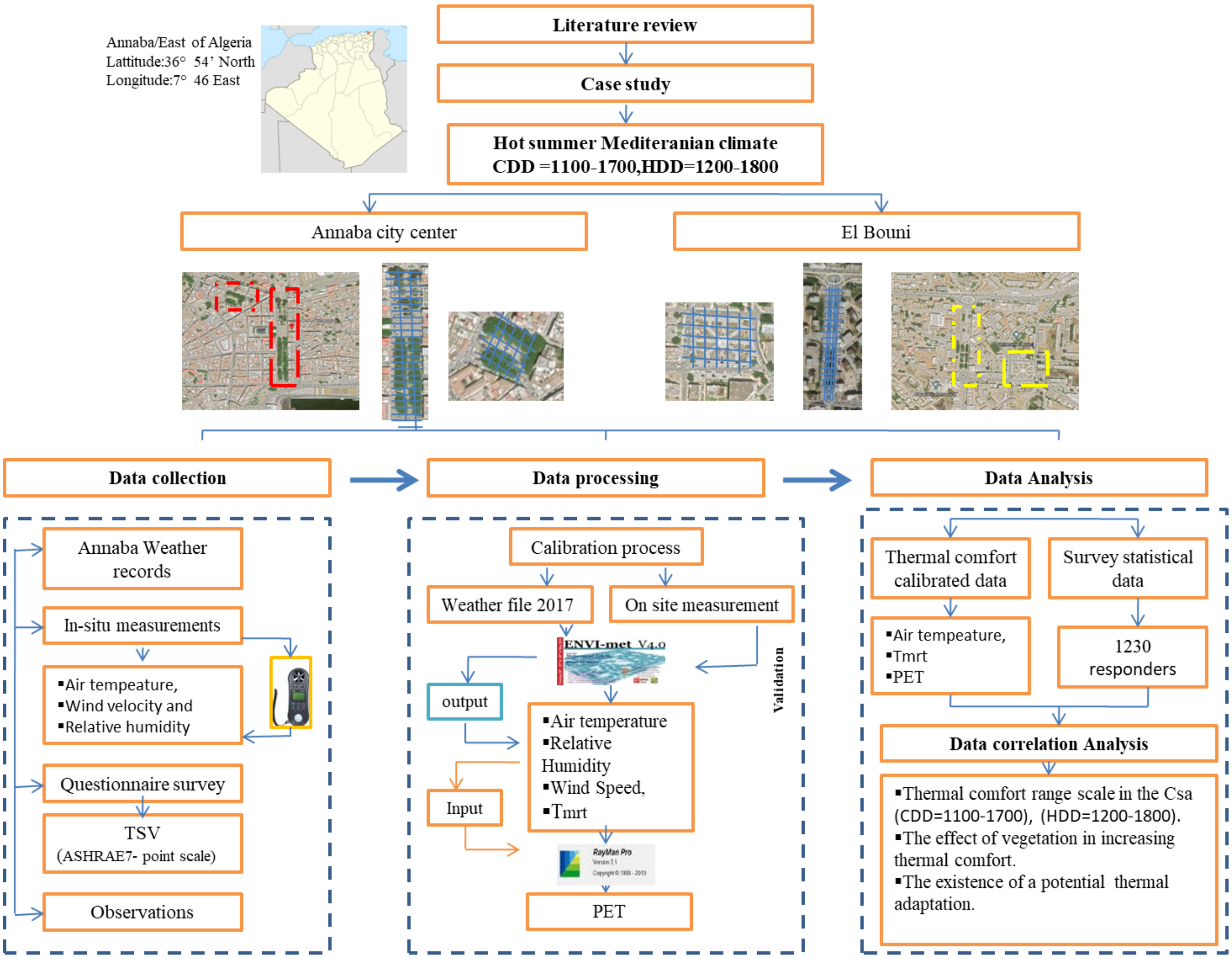


Fig. 2. Conceptual framework of the study.

In this section, we describe the foremost step briefly.

This study conducted an inclusive review considering the importance of enhancing the urban thermal environment and thermal comfort. Our research investigation detected several related research articles summarising the Urban Heat Island (UHI) studies by Mirzaei and Haghighat (2010), Mirzaei (2015) and thermal comfort strategies (Lai et al., 2019). A review of the green cover effect on thermal comfort Klemm et al. (2015a), Lee et al. (2016), Wu and Chen (2017), Morakinyo et al. (2017), and the importance of urban green spaces for health and well-being (Kaplan and Kaplan, 1989; Klemm et al., 2015a).Thermal comfort simulation and assessment Zölch et al. (2016), Pantavou et al. (2014), Taleghani and Berardi (2018), Lee et al. (2016). Analysis of cool pavement Santamouris (2013), Taleghani and Berardi (2018). The review of the influences of urban geometry and greening by Jamei et al. (2016) and the analysis of the relation between thermal range and users thermal perception by Liu et al. (2016), Potchter et al. (2018), Cohen et al. (2013), Elnabawi et al. (2016).

In addition to people distribution and behavior in the outdoor urban spaces; Cambridge, the UK (Nikolopoulou et al., 2001); Gothenburg, Sweden, Huawei, Taiwan (Eliasson et al., 2007; Thorsson et al., 2004); Taichung, Taiwan (Lin, 2009); Chiayi, Taiwan (Lin et al., 2013); Cairo, Egypt (Mahmoud, 2011); Hague, Eindhoven and Groningen, Netherland (Lenzholzer and Koh, 2010); Athens, Greece (Nikolopoulou and Lykoudis, 2007), Tel Aviv, Israel (Cohen et al., 2013) as well as thermal adaptation (Lin et al., 2013).

The literature review also concerned the most applied thermal comfort indices and Thermal Sensation Vote (TSV) in various climates, especially Csa. This part of the research showed the lack of using simulations combined with questionnaire surveys in the Mediterranean area (Table1).

Table.1 List of studies that engage microclimatic measurements, PET index and subjective thermal perception within a questionnaire.

Index	City	Country	Climate zone	Key reference	Thermal comfort process		Survey field
					Simulation	Calculation	
PET	Tel Aviv	Israel	Csa	Givoni, B et al. (2003)	-	Rayman	220
PET	TelAviv	Israel	Csa	Cohen et al. (2013)	-	Rayman	1731
PET	Lisbon,	Portugal	Csa	Oliveira and Andrade (2007)	-	Rayman	91
PET	Athens	Greece	Csa+(Cfa+Cfb)	Tseliou et al. (2010)	-	Rayman	9189
PET	Lisbon,	Portugal	Csa	Andrade et al. (2011)	-	Rayman	91
PET	Tel Aviv,	Israel	Csa	Schnell et al. (2012)	-	Rayman	1457
PET	Athens	Greece	Csa	Pantavou et al. (2013)	-	Rayman	1706
PET	Athens,	Greece	Csa	Pantavou et al. (2014)	-	Rayman	1706
PET	Crete,	Greece	Csa	Tsitoura et al. (2014)	-	Rayman	200
PET	Tel Aviv	Israel	Csa	Saaroni et al. (2015)	-	Rayman	300
PET **MOCI**	Rome,	Italy	Csa	Salata et al. (2016)	-	Rayman	941
PET	Lisbon	Portugal	Csa	Nouri and Costa (2017)	-	Rayman	30
PET	Rome,	Italy	Csa	Golasi et al. (2018)	-	Rayman	941

The collected data concerned in-situ measurements, field surveys and observation. The in-situ measurements protocol was designed to measure microclimate variables (air temperature, wind velocity and relative humidity) in the selected area. The climatic conditions were almost stable, with clear skies, hot temperatures, moderate wind speed and solar radiation reaching its peak. The questionnaire survey and observation were carried on simultaneously, just after the in situ measurements.

The calibration process was applied to simulate the microclimatic variable (air temperature, wind velocity, relative humidity and Mean radiant temperature), used as input data on the Rayman model to calculate PET. The simulation was achieved in two summer days (26th-28th August 2017) using Envi-met, which allowed generating microclimatic data on the entire surface of urban spaces compared to measurements at some specific points. To calculate PET, we used RayMan software, based on personal (height, weight, age, sex, clothing, and activity) and microclimatic calibrated data(air temperature, wind speed, relative humidity, and mean radiant temperature). RayMan model calculates the radiation for elementary and composite environments based on distinct climatic parameters(e.g. air temperature, air humidity, wind and air velocity, albedo of surrounding surfaces elevation and location, degree of cloud cover, time of day and year) (Elnabawi et al., 2016).

The different phases of the method are detailed in the following section.

3.1Study area

This study had been attended in Annaba city, Algeria, positioned between (Lattitude 36° 54' North, Longitude: 7° 46' East, Sea level: +5m), characterized by the Hot Mediterranean Climate (Csa) according to Köppen (2020) classification. Four outdoor urban spaces were explored, characterized by regular morphology. The two urban Courts and two urban Squares have similar morphologies, with distinct green coverage (Table 2).

Court 1 and Square 1 are located in the colonial center characterized by compact mid-rise, with dense mid-rise buildings (14m and 17m) and regular urban patterns. Despite the dense green cover in the selected outdoor environments, the streets have no trees. The land cover is paved. These two green spaces are well maintained because they are in the tourist area. Court 2 and Square 2 are based in the suburban area (El Bouni), characterized by a low open urban density. The average height of buildings is between (9m-14m). Considering the land cover is unfurnished, only a few footpaths are paved without trees. Court 2 is maintained by the respective authorities as a principal meeting urban space by the local citizen.

Court 1 (Le Cour de la revolution) is an urban court (13,800 m^2). It has a dense vegetation coverage (wide range of trees types including size Couronne shrubs and lawn). This urban space is characterized by four-lined Ficus Microcarpa, which provides and ensures shade for 81% of the ground area.

Square 1 (Alexis Lambert) is an urban open square (3,500 m^2) located nearby Court 1, with dense plant cover of Ficus Microcarpa, ensuring continuous shading of over 83% of the total area.

Court 2 (le Cour Bouzaaroura), with a medium-size (4,600 m^2). This urban component is in El Bouni (suburban area). The green cover shades 43% of the surface area.

Square 2, medium-size (3,500 m^2), is an urban open square next to Court 2 without green coverage. Fig 2 shows the map of Annaba city centre and El Bouni with the explored area's location.

Every urban space was divided into a grid (4 m*4 m). The measurement points have been identified based on this grid (10 measurement points for each Court and five (5) measurement points for every square.

Table 2 Geometric description of the selected outdoor spaces

Outdoor spaces	**Morphology**	**Area**(m^2)	**Length**	**Width**
Court 1	Regular	13711.7 -13,800	405-406	33-34
Court 2	Regular	4618 -4,600	224	20-21
Square 1	Regular	3474.29 -3,500	65-66	53-53.5
Square 2	Regular	3503.9 -3,500	62.5-66	53-56

2 Data collection

This study was conducted on the 26th-28th August 2017, where the questionnaire survey and observation were simultaneous and immediately after the in-situ measurement.

2.1 Insitu measurements

An experimental data collection has been carried out by measuring air temperature, wind velocity and relative humidity using LM 8000 (Thermo-Anemometer, Hygrometer, Thermometer & Illuminometer) at the height of 1.10m. Many measurement points had been selected in the grid for the four urban spaces. Measurements have taken place from 8 am to 8 pm (every two hours).

2.2.2 Questionnaire survey and observation

This study randomly administered a questionnaire survey of passers-by and seating people in each public space on the 26th (weekend day) and 28th (weekday) of August, during seven (7) periods directly after in-situ measurements were undertaken: 8 am to 8:30 am, 10 am to10:30 am, 12 pm to 12:30 pm, 4 pm to 4:30 pm, 6 pm to 6:30 pm, 8 pm to 8:30 pm. A total of 1230 people agreed to answer the question during the suggested time (See appendix C). The first section of the questionnaire concerned the demographic information (e.g., age and gender) and occupation level data. The second part asked people to rate their current thermal comfort sensation. The thermal comfort was ranked on the seven-point Thermal Sensation Vote (TSV) scale (-3 for "cold"; -2 for "cool"; -1 for "slightly cool"; 0 for "neutral"; +1 for "slightly warm"; +2 for "warm"; +3 for "hot"), (ASHRAE Standard, 2004; Cohen et al., 2013; Kántor et al., 2012; Lin and Matzarakis, 2008; Matzarakis and Mayer, 1996; Potchter et al., 2018). In addition, the observation technique constitutes a supports field technique. The majority of observations took 20, allowing the analysis of people's behaviour regarding activities and consumed time in shaded and sunny areas (See appendix A and B).

2.3 Data processing

2.3.1 Numerical simulation and calibration of the thermal environment

We combined the use of two software, Envi-met, to calibrate microclimatic data and get the T_{mrt} variable that had not been measured. ENVI-met was selected to simulate the thermal environmental variation. It has a large spatial (0.5–10 m) and temporal resolution (10 s). It is also proper for microclimate studies in outdoor environments. Envimet is three-dimensional and non-hydrostatic predictive, analytical software with computational fluid dynamics. It simulates surface –plant-air interactions considering shortwave radiation fluxes and longwave radiation besides latent heat fluxes (Ghaffarianhoseini et al., 2015; Johansson et al., 2016; Taleghani et al., 2014; Wu and Chen, 2017). It also includes new 3D vegetation elements to define distinct shapes of plants and spatial organization of trees. Building elements are considered for heat inertia of the wall and roof (Acero and Herranz-Pascual, 2015; Huttner, 2012; Yang et al., 2013).

ENVI-met (v4.0) compromises a forcing function, more accurate and realistic simulation findings could be accomplished (Lee et al., 2016). We used the full forcing command for 24 hours for the four urban spaces. This study validated the Envi-Met model based on comparing the measured and simulated air temperature (Elnabawi et al., 2013; Taleghani and Berardi, 2018), showing a good correlation between set data.

2.3.2 Thermal comfort calculation

This study applied the PET index for calculating thermal comfort in an attempt to define the boundaries of neutral thermal sensation in outdoor environments. The PET was computed using the RayMan model (Matzarakis et al., 2007, 2010). The calibrated microclimatic data (air temperature, wind speed, relative humidity, and mean radiant temperature) against selected points in the four urban spaces. We set PET for its various benefits in outdoor environments. It can generate accurate thermal environments predictions (Gulyás et al. 2006; Matzarakis et al. 2007). RayMan model calculated PET based on calibrated data (air temperature, wind velocity, relative humidity and T_{mrt}) from 8 am to 8 pm.

4. Results

This section first examined calibrated results and PET in the four urban areas since they are crucial factors in identifying the impact of green cover. Second, these findings are analyzed to find correlations between PET, thermal perception and green coverage and recognize the PET comfort range. Finally, the observation results determine the influence of green cover on people's behaviour.

4.1 Calibrated data and thermal comfort index

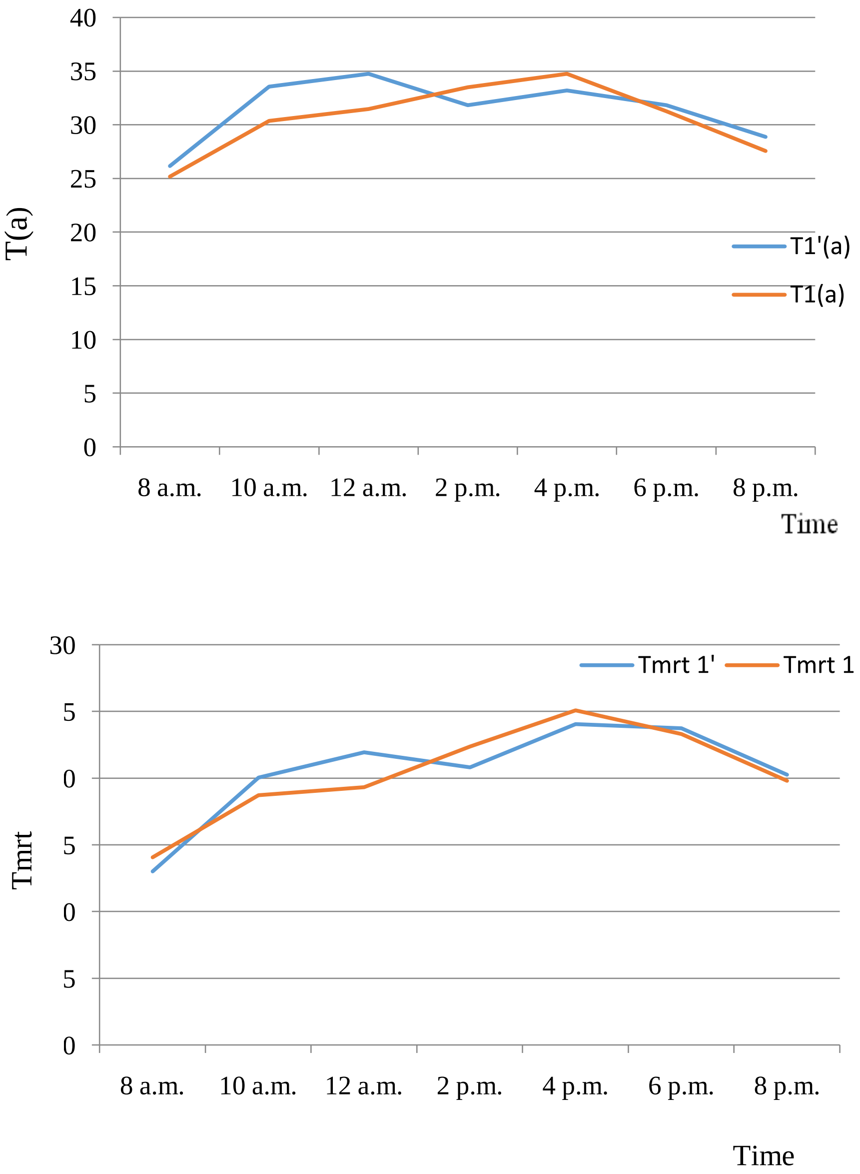
Most of the microclimatic parameters affect outdoor sensation. We presented T (a) and T_{mrt} for their strongest correlation to outdoor thermal perceptions. Table 3 shows the range average of calibrated data: air temperature and Mean radiant temperature (T (a), T_{mrt}) with the four outdoor spaces' related average hours.

Table 3 Calibrated microclimatic variable and corresponding time average in the selected area.

Urban spaces	Calibrated data		Time (%)
Court 1	**T(a)**	24 °C-26°C	15%
		27°C -28°C	15%
		30°C -35°C	70%
	T_{mrt}	14°C	15%
		18°C -20°C	43%
		21°C -25°C	42%
Court 2	**T(a)**	24 °C-26°C	15%
		28°C -29°C	14%
		32°C -35°C	71%
	T_{mrt}	13°C	15%
		19°C -20°C	28%
		22°C -25°C	57%
Square 1	**T(a)**	24 °C-26°C	15%
		27°C	15%
		30°C -35°C	70%
	T_{mrt}	14°C	15%
		18°C -20°C	43%
		21°C -25°C	42%
Square 2	**T(a)**	24 °C-26°C	15%
		29°C	15%
		32°C -35°C	70%
	T_{mrt}	13°C	15%
		20°C -21°C	28%
		22°C -25°C	57%

The results showed that the T (a) values in Court 2 are higher than Court 1(Fig 3), the range of hot temperatures (30°C-35°C) in Court 1 against 32°C -35°C in Court 2, which is related to 70% of hours of the day. The results also highlighted a significant difference in air temperature (3.9°C) at the Courts level during the hottest hours of the day (noon) (Fig 4). The T (a) divergence is more noticeable at the level of the Squares. The results showed that Square 1 is characterized by 27 °C during 15% of the day, against 29°C in 15 % of the time. The minimal average hot temperature is 30°C in Square 1 against 32°C in Square 2 for 70% of the day's hours, revealing divergence of 2 °C (Table 3). Square2 recorded a higher temperature than Square1, especially at noon where the air temperature difference reached (3.27°C) (Fig 3).

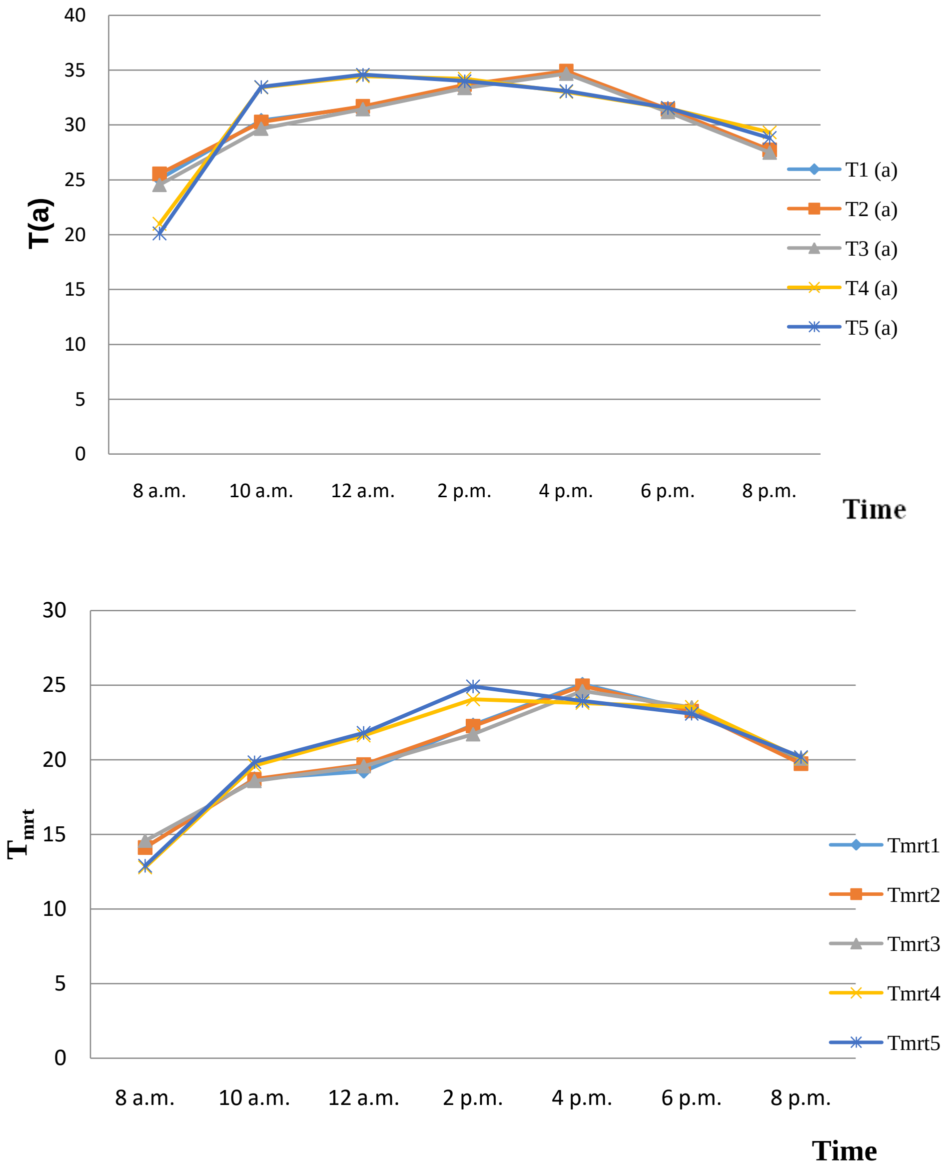
Regarding T_{mrt}, the minimal value of T_{mrt} is close to 14°C in the three selected areas (Court1, Court2, Square1) except for square 2, which the calibrated result showed a value of 13°C. Table 2 shows a significant difference in T_{mrt} ranges in the selected area. Court 1 recorded a range of 18°C -20°C and for 21°C -25°C for 43% and 42 % of the time, respectively. Compared Court 2, which registered 19°C -20°C and 22°C -25°C for 28% for 57% for the average hours of the day in. The results show more noticeable differences in T_{mrt} at the Squares level (Fig 3). Square 1 recorded less temperature (18°C-20°C), for more time(43%) In comparison to Square 2 (20°C-21°C) 28% of day's hours (Table 2). So T_{mrt} in Court 2 and Square 2 are higher than Court 1 and Square 1 for almost the hours of the day (10 am, noon, 6 pm and 8 pm). A significant difference in T_{mrt} values (3°C) was recorded at noon between Courts besides squares (Fig 4).



T1' (a), T_{mrt} 1' are calibrated microclimatic data and thermal comfort index on Square 2.

T1 (a), T_{mrt} 1, are calibrated microclimatic data and thermal comfort index on Square 1

Fig. 3. Comparison ofcalibrated variables in the selected squares



T(a)1, T(a)2, T(a)3, T_{mrt} 1,T_{mrt} 2, T_{mrt} 3, calibrated data in Court 1

T(a)4, T(a)5, T_{mrt} 4, T_{mrt} 5, calibrated data in Court 2

Fig. 4. Comparison of calibrated variables in the selected Courts

The results also showed an apparent variance in PET values (Table 4). Court 1 recorded 43% of the time against 28% of the time for the same PET range (20°C -26°C), which is similar for the two squares in terms of PET range and average time. For the 27°C - 29°C range of PET, the average time is 42%, 43%, 43%, and 57% for Court 1, Court 2, Square 1, and Square 2, respectively. However, for PET 30°C -31°C average, Court1 had

15% of the day's hours against 29% for Court 2 (Table 4), which means that Court 1 and Square 1recorded the lower values of PET during many hours of the day.

These results helped us identify crucial hours where the three variables reached their minimum scores at 8 am in contrast with the hottest hours, including noon, 2 pm and 4 pm.

Table 4 PET values and corresponding time average in the selected area.

Urban spaces	PET	Time (%)
Court 1	20°C -26°C	43%
	27°C -29°C	42%
	30°C -31°C	15%
Court 2	20°C -26°C	28%
	27°C -29°C	43%
	30°C -31°C	29%
Square 1	20°C -26°C	43%
	27°C -29°C	43%
	30°C -31°C	14%
Square 2	20°C -26°C	28%
	27°C -29°C	57%
	30°C -31°C	15%

The findings revealed a strong correlation between PET and T (a) as well as between PET and T_{mrt} in the selected areas, but with an even higher correlation between PET and T (a). The following equations present the relation between T (a) and PET besides T_{mrt} and PET in the studied outdoors (Fig 5) and (Fig6).

$T (a) = 0.847\ PET+8.233$ where $R^2=0.921$.

$T_{mrt} =0.889\ PET -3.291$ where $R^2=0.852$.

The results showed a strong and positive correlation between T (a) and PET as well as T_{mrt} and PET, where R^2 =0.921 and 0.852, respectively.

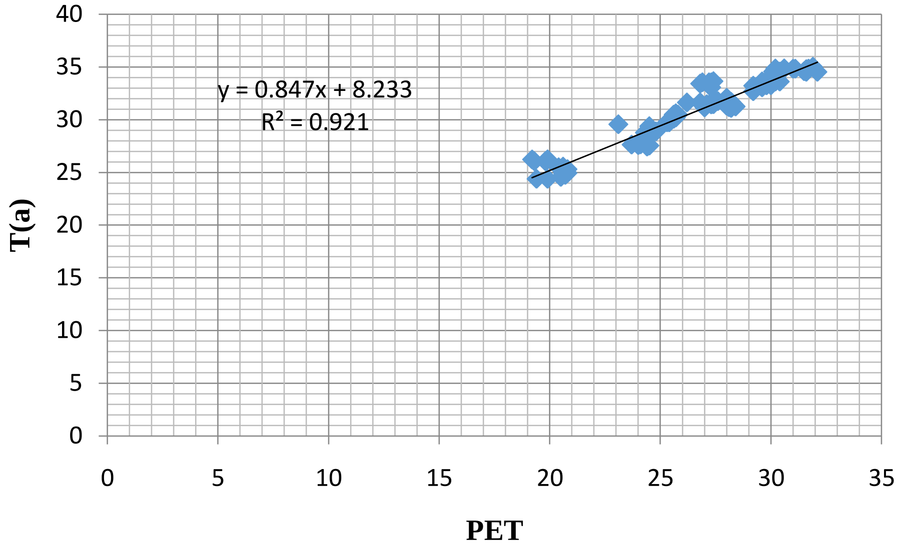


Fig. 5. Correlation between PET and T (a) in summer 2017

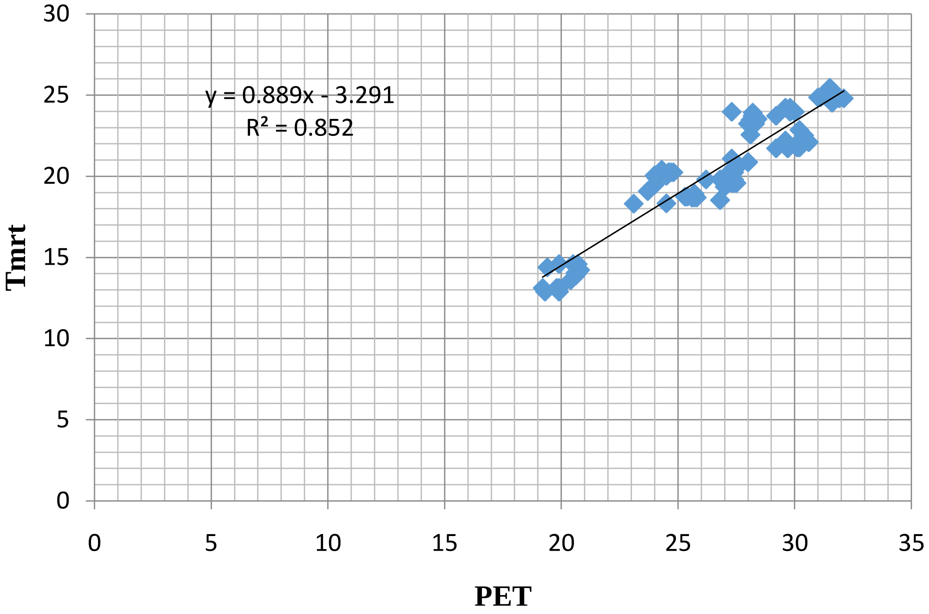


Fig. 6. Correlation between PET and T_{mrt} in summer 2017

4.2 The relative contribution of different microclimate parameters to outdoor thermal sensation

We analyzed the survey results collected in each outdoor space from 8 am to 8 pm, to define thermal sensation according to ASHRAE scale during the two summer days, in an attempt to evaluate the summer comfort range in the Mediterranean climate zone (HDD =1200-1800 and CDD =1100-1700). Furthermore, comparing the subjective values of TSV to the objective PET values allowed the examination of the homogenous groups to grade the PET scale in the Mediterranean climate.

The findings highlighted that over 300 people rating a neutral thermal sensation(Fig 7), with a PET value ranging from 19.62 °C to 25.86 °C in the four public spaces. At the same time, 180 responders noted a slightly warm thermal sensation corresponding to PET 27.08°C-27.88°C values. The warm perception was recorded for 152 persons. However, few responders (36) estimated a hot thermal sensation related to the 30.25°C-32°C rating of PET (Table 5).

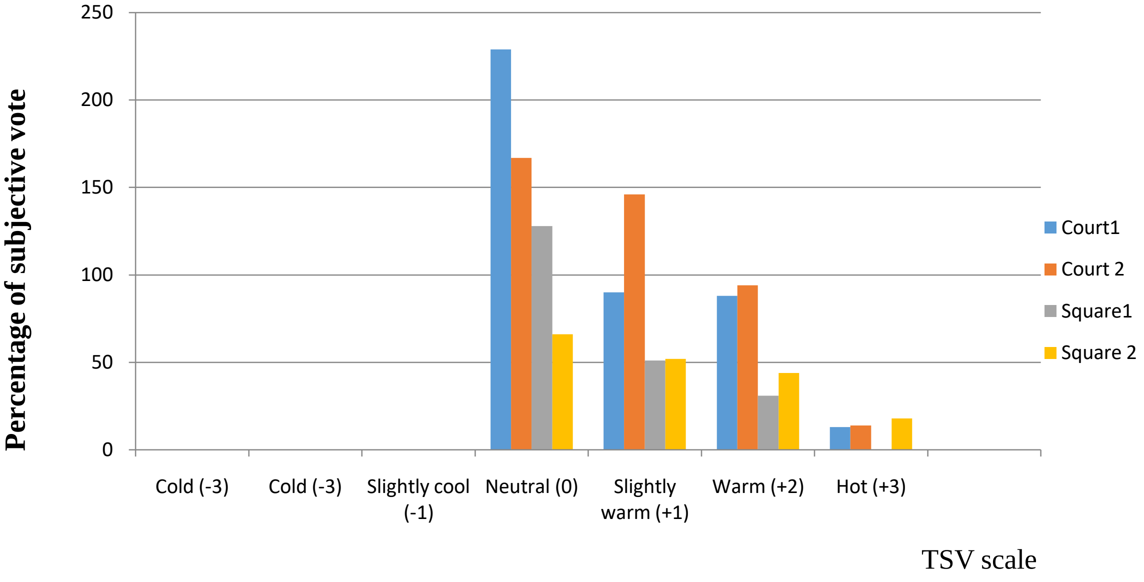


Fig. 7. The percentage distribution of subjective thermal sensation vote (TSV) in summer at the four selected outdoor public places

Table 5 Scale of Thermal Sensation Vote(TSV) and mean PET range for the Mediterranean climate of Annaba.

TSV scale	TSV	Mean PET (°C)	Number of response
0	Neutral	19.62-25.86	393
+1	Slightly warm	27.08-27.88	180
+2	Warm	28.92-29.78	152
+3	Hot	30.25-32	20
+4	Extremely hot	-	-

The results also presented significant differences in thermal sensation vote in the selected area. For example, the neutral thermal sensations had been recorded in three hours of the day (8 am, 10 am, and 8 pm) at Court 1 and Square 1 in comparison with Court 2 and Square 2 that had only benefited for 2 hours (8 am and 8 pm) (Fig 8). The hot thermal perception had been significantly recorded in Square 2, and Court 2, especially in part without trees at 12 am, 2 pm and 4 pm (Fig 8). In contrast, Court 1 and Square 1 recorded warm thermal sensation as their primary highest perception, which had mainly been reported at 2 pm and 4 pm. However, the hot thermal sensation had been registered for very few answers in Court 1 (in part without trees).

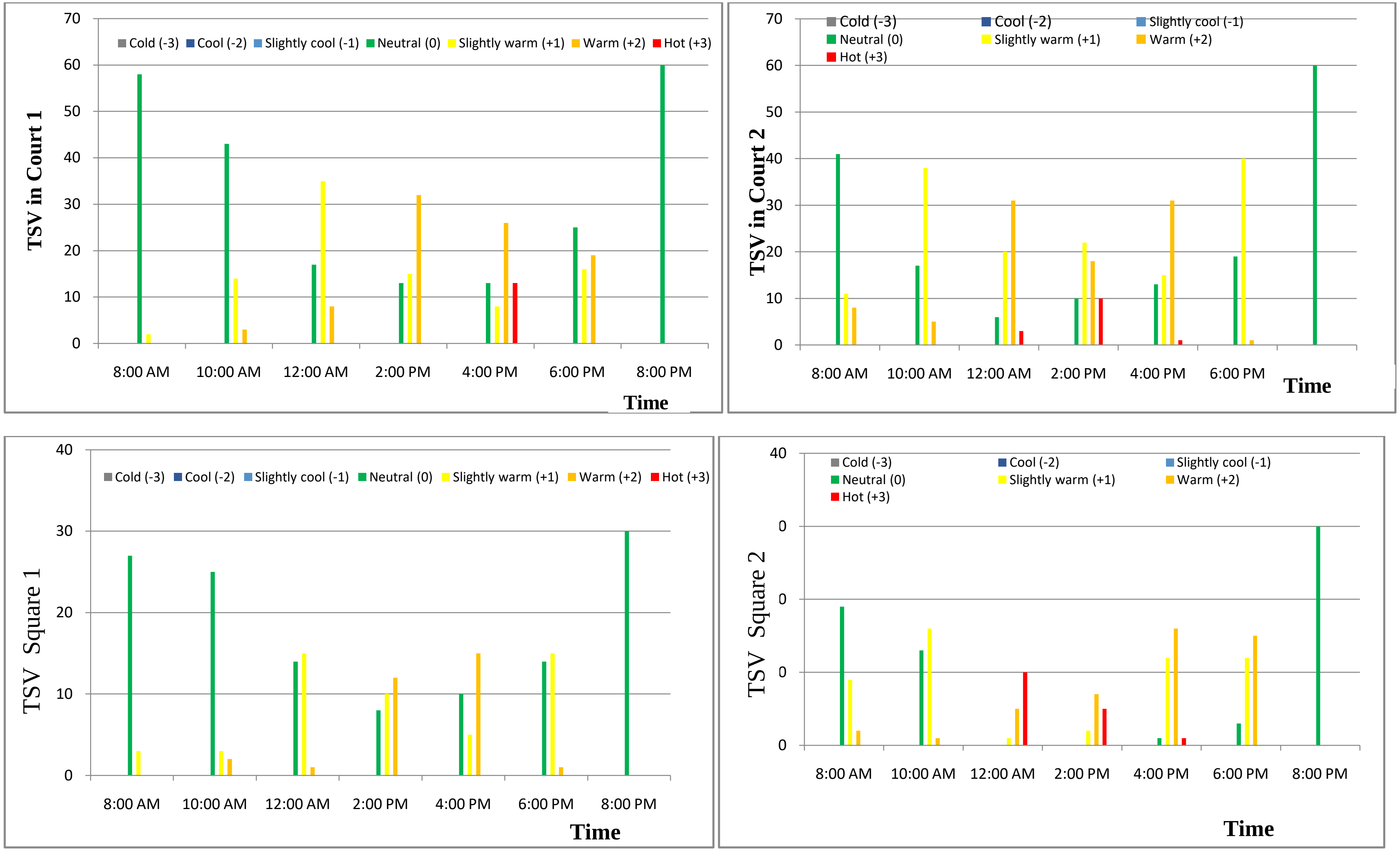


Fig. 8. Evolution of TSV during the hours of the day in the selected areas

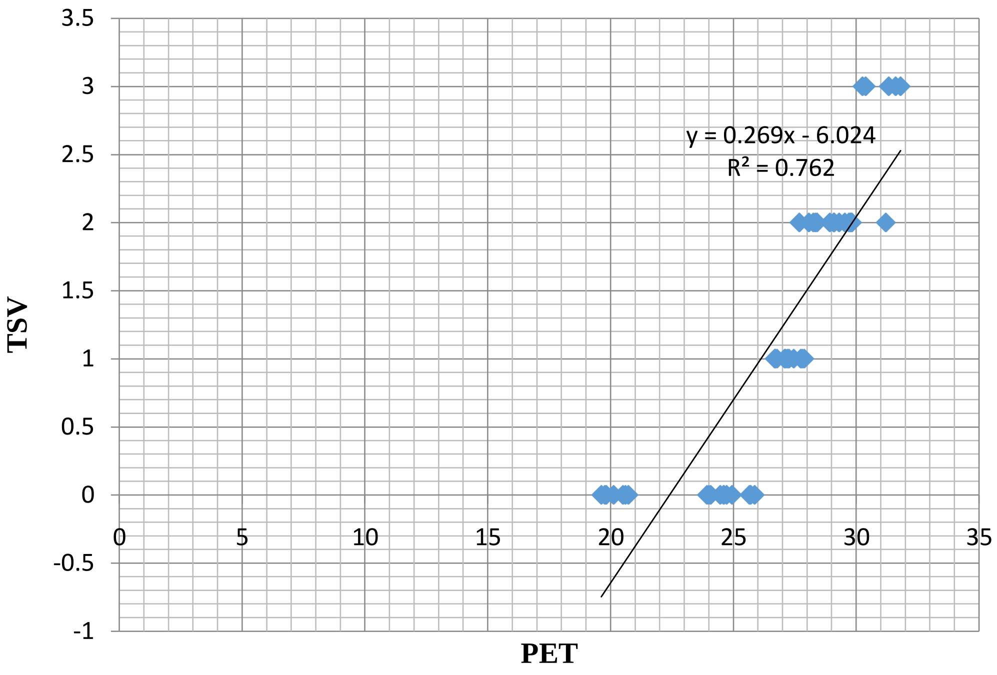
The mean thermal sensation votes (TSV) were evaluated as a PET function, consistent with weather recorded data. Fig 9 (a) highlighted a correlation between the TSV scale and the corresponding PET in the selected area. The present equation can identify the correlation.

$TSV=0.269\ PET\ -6.024$ where $R^2=0.762$

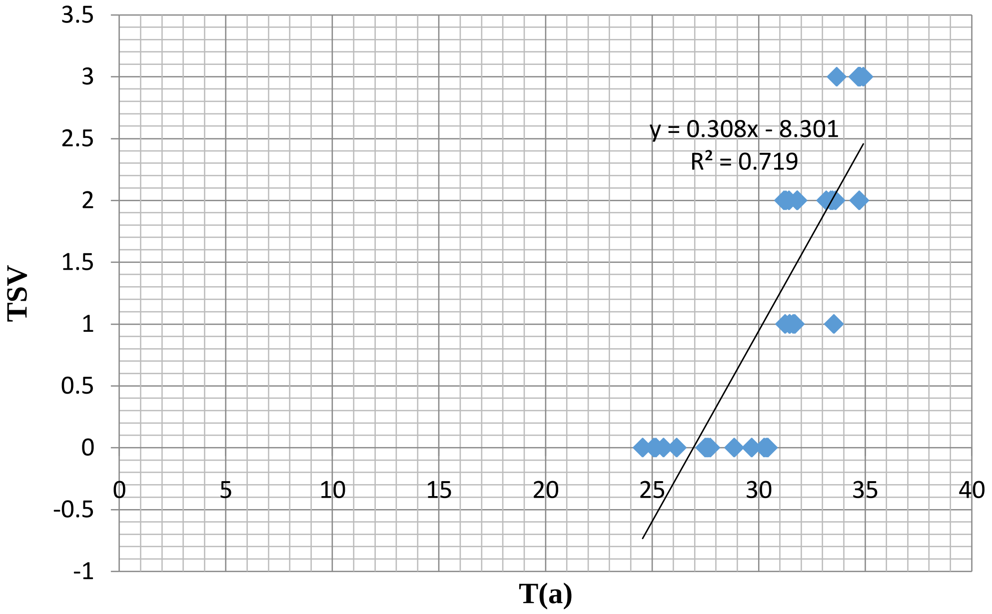
The mean thermal sensation vote (TSV) was also estimated as a function of T(a). Fig 9 (b) shows the correlation between the TSV scale and the related T(a) in the four public spaces. The following equation defines the existing correlation.

$TSV=0.308\ T\ (a) – 8.301$ where $R^2=0.719$

The results show a strong and positive correlation regarding TSV and PET ($R^2=0.762$), as well as TSV and T(a) (R^2 =0.71). However' we estimated that TSV and PET's relevance is more potent than TSV and T (a).



a.Correlation between TSV and PET in the urban spaces (summer 2017)



b. Correlation between TSV and T(a) in the urban spaces (summer 2017)

Fig.9. Correlation existing between TSV and PET, TSV and T (a) in the selected area.

4.3 Thermal comfort range in the city of Annaba

According to our finding based on 1230 responders relating to thermal sensation scale (TSV) and PET assessment based on calibrated microclimatic data, the thermal comfort range in Annaba city corresponds to 20°C≤PET≤ 26°C, defined as a neutral thermal sensation within Csa climate. Table 6 compares the TSV scale between two cities, Annaba, Algeria and Tel Aviv, Israel. Despite the differences in HDD and CDD between the two cities, the range of neutral thermal sensation is the same (26°C) except warm thermal sensation with the distinction of +4 °C. However, the minimal value of hot thermal sensation is 32°C concerning 40°C in Tel Aviv.

Table 6 Thermal sensation and PET range for Annaba and Tel Aviv

Summer season			
TSV scale	TSV	CsaMediterranian HDD= 1200-1600[b] CDD=1100-1500[b] PET Annaba	Csa Subtropical HDD= 641.2[b] CDD=2758.4[b] PET Tel Aviv[a]
0	Neutral	20°C -26°C	26°C
+1	Slightly warm	27°C-28°C	28°C
+2	Warm	29°C-30°C	34°C
+3	Hot	+32°C	40°C
+4	Extremely hot	-	-

[a] Cohen et al., 2013; Potchter et al., 2018

[b] HDD and CDD average for five years (2015-2019)

4.4 Green coverage and thermal sensation

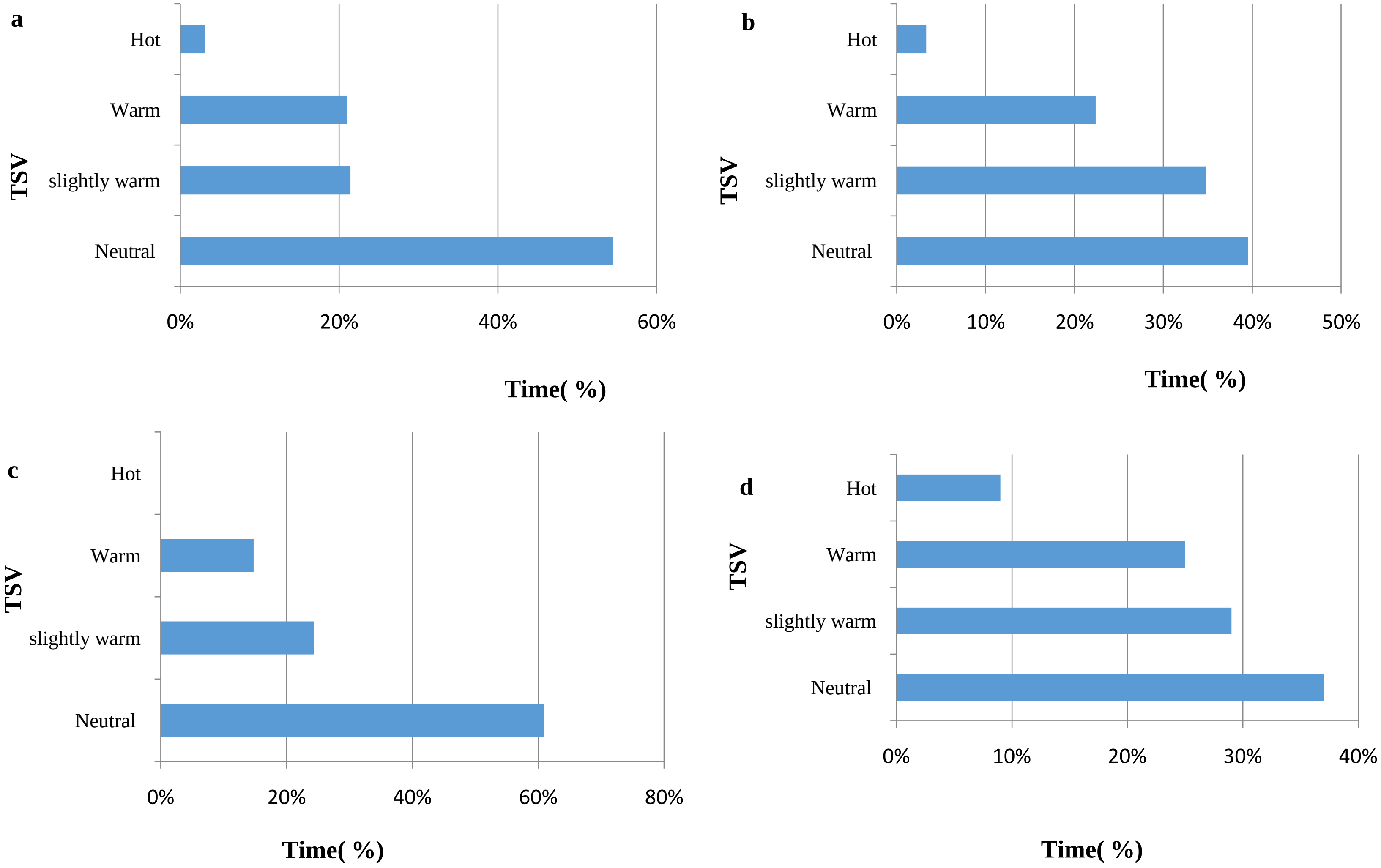
To understand the effect of vegetation on thermal comfort perception**,** a comparison of hour's average of thermal comfort in the four outdoor spaces is necessary**.** Table 7 shows the green coverage percentage of each urban area; Court 1 and Square 1 have a very dense vegetation cover (81% and 84%) against Court 2 (43%) and Square 2 with no green cover.

Table 7 Green cover average in the four outdoor environments

Outdoor spaces	**Area**	**Green average area**	**Green Coverage** (%)
Court 1	13711.7 m^2	11145.66 m^2	81%
Court2	4618 m^2	1995.82 m^2	43%
Square 1	3474.29 m^2	2923.55 m^2	84%
Square 2	3503.9 m^2	-	0%

People perceived Square1 and Court 1 as the most thermally comfortable spaces, 61% of hours of the day are identified as neutral thermal sensation in square 1, besides 55 % of the time in Court 1 in, while Court 2 had 40% of the hours of the day are expressed as thermally comfortable. Square 2 had the lowest percentage (37%) (Fig 10). Court 2 had the highest score with a slightly warm thermal sensation (35%) of the time of the day, followed by Square2 (29%) of the hours of the day, while Court 1recorded the lowest percentage (21%). Court1 and Square 1 recorded the lowest scores (21% and 15%) of hours of the day regarding warm thermal sensation, respectively (Fig 10).

The Hot thermal sensation was recorded in a few hours (hottest hour of the day) in Court1, Saquare1 and Court 2; we noticed many people under shade and trees who identified a Neutral thermal sensation during the hottest hours of the days (Fig 8). However, in Square 2, very few people were counted (less than 14) at noon and 2 pm while walking and expressed one thermal sensation (Hot) because of the absence of trees or shade.



a Court 1, **b** Court 2, **c** Square 1, **d** square2

Fig. 10. TSV scale expressed into hours

4.5 Impact of green cover on people behaviour

4.5.1 Green area and space occupancy by seated people

The analysis of the observation in the selected area highlighted the space's occupancy by seated people and the pedestrian flow. Table 8 showed the variance in occupancy between shaded and sunny environments. Moreover, this variety is also noticed in the same space depending on the hours of the day. For example, Court 1 has received the highest occupancy scores (80% -100%) at noon, 4 pm and 6 pm, compared to Court 2 at 6 pm and 8 pm, while Square 1 gets the highest occupancy at 6 pm. Despite a dense green cover in Square 1, we noticed a low space occupancy by seated people at noon and 2 pm. In addition, Court 2 has the same score (20%-39%) at noon. However, Court 1 has an average occupancy (40%-59%) at 2 pm and 8 pm (Table 8).

Considering Square 2, which has no trees, the space occupancy reached the highest score (80% -100%) at 8 pm, when there is no more sun. However, the most observed behaviour reflected a very low occupancy (1%-19%) at 8 am, 10 am, no people at noon and 2 pm. The average occupancy (40%-59%) was noticed at 6 pm.

4.5.2. Green spaces and pedestrian flow rates

The walking activity was observed in the four selected areas. However, the pedestrian flow rates fluctuated depending on the hours of the day besides shaded trees and sunny environments. The most walkable urban spaces were Court 1 and Court 2. Indeed, the height score of 55 ped/min/m at Court 1 highlights the E category, reflecting a high pedestrian flow and congested space (See appendix B). However, the overall flow rates were 44.85, 48.1 and 45, referring to an average pedestrian flow or, in another term, a crowded space (See appendix B).

The highest pedestrian flow in Court 2 was 40 (D category), besides 17.5 and 19.9 scores reflecting very low pedestrian flow rates or unimpeded space (B category). However, the lowest scores at Court 2 were 4.5 and 7.5 ped/min/m (A category) at noon and 2 pm, which emphasized the inexistence of pedestrians (open spaces). Considering Square 1, we observed the absence of pedestrians in the shaded tree area (Table 8).

4.5.3.Sunny area and pedestrian flow

The pedestrian flow has been characterized by low scores in the four urban spaces. However, the scores were increasing from 6 pm to 8 pm. The observation at Court 1 highlighted a high pedestrian flow, equivalent to 50 ped/min/m at 8 pm (E category). The in situ observation emphasized the same score of 50 in Court 2 (E category). However, the pedestrian flow in Court 1 was higher than Court 2 in most of the hours of the day. Indeed, the dominant pedestrian flow in Court 1 reflected an average pedestrian flow rate of 42.5, 39.85, 48 (D category) at 10 am, 4 pm, and 8 pm, besides 17.8 and 16.5 rates at noon and 2 pm reflecting very low pedestrian flow (B category). At the same time, Court 2 showed a very tiny presence of people with 10-5 flow rates (A category).

In Square 1, the pedestrian flow reached its highest rates (31.8 and 35) at 8 am and 6 pm, reflecting an average pedestrian flow. However, the lowest rate was observed at 2 pm with 10 ped/min/m (A category). In comparison, Square 2 has lower rates. Indeed, the highest pedestrian rate was 27.5 at 8 pm, while the dominant pedestrian flow rates were 6.25, 12.5, 9.4, 4.13 at 8 am,10 am, noon, 2 pm, 4 pm (A category) (Table 7and Appendices B).

Table 8 People's behaviour data using observation technique in the selected outdoor environments

			Shaded trees area		Sunny area (without trees)	
Selected urban environments	Hours	Observation time	Space occupancy by seated people (%)	Pedestrian flow density (ped/min/m)	Space occupancy by seated people (%)	Pedestrian flow density (ped/min/m)
Court 1	8 am-8:30 am	20 min	40-59	23.9	0	24
	10 am-10:30 am	20 min	60-79	44.85	0	42.5
	12pm -12:30 pm	20 min	80-100	30.1	0	17.8
	2 pm-2:30 pm	20 min	40-59	26	0	16.5
	4 pm-4:30 pm	20 min	80-100	48.1	0	39.85
	6 pm-6:30 pm	20 min	80-100	55	0	50
	8 pm-8:30 pm	20 min	40-59	45	0	48
Court 2	8 am-8:30 am	20 min	20-39	9	0	16.4
	10 am-10:30 am	20 min	60-79	17.5	0	24.5
	12pm -12:30pm	20 min	20-39	7.5	0	10
	2 pm-2:30 pm	20 min	20-39	4.5	0	5
	4 pm-4:30 pm	20 min	60-79	19.9	1-19	27.6
	6 pm-6:30 pm	20 min	80-100	2	20-39	39.75
	8 pm-8:30 pm	20 min	80-100	40	60-79	50

Square 1	8 am-8:30 am	20 min	40-59	0	0	15
	10 am-10:30 am	20 min	60-79	0	0	31.8
	12pm -12:30pm	20 min	20-39	0	0	17.4
	2 pm-2:30 pm	20 min	40-59	0	0	10
	4 pm-4:30 pm	20 min	60-79	0	0	27.5
	6 pm-6:30 pm	20 min	80-100	0	0	35
	8 pm-8:30 pm	20 min	40-59	0	0	18
Square 2	8 am-8:30 am	20 min	/	/	1-19	6.25
	10 am-10:30 am	20 min	/	/	1-19	12.5
	12pm -12:30pm	20 min	/	/	0	9
	2 pm-2:30 pm	20 min	/	/	0	4.4
	4 pm-4:30 pm	20 min	/	/	20-39	13
	6 pm-6:30 pm	20 min	/	/	40-59	15
	8 pm-8:30 pm	20 min	/	/	80-100	27.5

5. Discussion

This research explored thermal comfort conditions in the city of Annaba to adjust the boundaries of thermal comfort and the range of the human thermal sensation in the summer for HDD =1200-1800 and CDD=1100-1700 zone. Accordingly, this study examined four outdoor environments (two Courts and two Squares) considered one of the most used urban spaces in Annaba.

This research used the up to date version V4 of the Envi-met model for human-biometeorological model performance in simulating T(a) and T_{mrt}. Many studies validated Envi-met results (Acero and Herranz-Pascual, 2015; Chen and Ng, 2013; Jänicke et al., 2015; Ng and Cheng, 2012; Nikolopoulou and Lykoudis, 2006) and proved the accuracy of the simulated micrometeorological model in a complex urban setting (Lee et al., 2016). This study also used RayMan software in the PET calculation and validation process, based on calibrated data. The generated results' analysis highlighted a strong correlation between the mean thermal sensation vote and PET in the four public spaces during the summertime. This study investigated 24 hours of simulation and selected one of the most symbolic urban spaces in the simulation area with variance in green coverage. The authors compare the results with other previous studies, based on microclimatic variables, PET, TSV and thermal comfort.

5.1 Impact of green coverage on microclimatic variables and PET

This study demonstrated that trees had an important influence on thermal perception (Fig 6, Fig 7 and 8). People in outdoor environments with denser green cover expressed a higher thermal comfort and identified most often the temperature as neutral. Outdoor spaces having trees were estimated as thermally comfortable (Fig 7) for many hours of the day, 61% and 55 % against 37% outdoor without green coverage (Fig 10).

The spatial models of T (a), T_{mrt} and PET are widely affected by the number and dimension of trees and grasslands coverage (Lee et al., 2016). The variation of T_{mrt} and PET (Table 2,3) within the investigated urban spaces illustrates the difference in outdoors with trees shade and sun patterns. The difference in air temperature reached 4°C and 3°C in term of T_{mrt} at noon. The highest values of T(a) and T_{mrt} generate the lowest thermal comfort conditions (Klemm et al., 2015a). According to Zölch et al. (2016), trees can minimize thermal discomfort during hot days. Trees contribute to reducing PET by shade and evapotranspiration (Bowler et al., 2010).

Many studies had explored the advantages of the human-bio-metrological effects of trees through simulation in different climate zone (Ali-Toudert and Mayer, 2007; Lee et al., 2013; Müller et al., 2014; Ng and Cheng, 2012; Taleghani et al., 2015). In the same optic, Lee et al. (2016) defined shading by trees canopies as a relevant indicator based on a human – biometeorological perspective (Lee et al., 2013), especially in urban open spaces, where trees with fully developed crowns help in reducing the local human heat stress.

The results also highlighted people's adjustments to their thermal perceptions during the hours of the day. The neutral thermal sensation was mainly identified at 8 am, 10 am and 8 pm in outdoor places with trees. However, only at two specific hours (8 am and 8 pm) for public spaces without trees, where the hot thermal sensation was mostly expressed at noon, 2 pm and 4 pm. These results confirm trees and grassland participation in the local cooling (Lee et al., 2016).

5.2 Thermal comfort and thermal perception

Many studies investigated thermal comfort range in the Csa using PET index, through different cities such as Tel Aviv, Rome and Athens based on in situ measurements based on a few numbers of measurement points (Cohen et al., 2013; Pantavou et al., 2013; Salata et al., 2016). These studies explored the same urban components. For example (Salata et al., 2016) investigated three kinds of outdoor environments in Rome; parks, squares characterized by green spaces with trees, a fountain and an urban canyon. Pantavou et al. (2013) explored thermal comfort in the central square of Athen, which is considered as the main meeting point for tourists and citizens. It is surrounded by buildings and also characterized by a green cover and a fountain. In addition, (Cohen et al., 2013) explored thermal comfort in the city center of TelAviv within parks, an urban square, an urban canyon, having an interchangeable distance from the sea. Thus, all these outdoor spaces have regular morphology, with different green covers, which is relatively similar to the presented area in Annaba.

This study involved in-situ measurements for a large area based on agreed (4m*4m) for over 10 points in Court 1 and Court 2, besides five (5) measuring points in each square, which help us analyze the impact of green cover on thermal comfort and thermal perception over a large surface. Calculating PET based on calibrated data generates PET accuracy. Adding HDD and CDD criterion provides an added value concerning the previous study within Csa climate.

Despite the variance in HDD and CDD data considering Annaba (HDD=1200-1800, CDD=1100-1700) and the other Mediterranean cities such as Tel Aviv (HDD=641 CDD=2758), Rome (HDD=2393, CDD= 1562) and Athens with HDD=1468; CDD=1819.The acceptable comfort range found in this research for Annaba is 20°C-26°C according to ASHRAE Standard (2004), which is similar to results found by Cohen et al. (2013) and Potchter et al. (2018) for Tel

Aviv (19°C-26°C). The neutral thermal sensation is identified between 21.1°C-29.2°C in Rome, Italy. Salata et al. (2016), Nikolopoulou and Lykoudis (2007) identified 28.5° C as a neutral air temperature in Athens, Greece, during the summer (Shashua-Bar et al., 2012). Finally, Tsitoura et al. (2014) identified the thermal range of 20°C -25°C in Crete, Greece.

Accordingly, in Annaba, Tel Aviv, Rome and Crete, the minimum thermal comfort values are close (±1°C), while the maximal values are only similar for Annaba and TelAviv. Which can confirm the acclimatization phenomenon, related to the geographical location and the season of the year and not surpassing 1°C, 2°C, around the thermal comfort zone for the vast majority of people (Olgyay, Victor, 1998). However, the difference is significant, considering the maximum thermal comfort range in Annaba and Rome (±3°C).

5.3 Interactivity of green cover, thermal perception and people behaviour

This study showed a good correlation between the occupancy of space by the pedestrian and shaded area (Table 8). Indeed, Court1 and Square 1 have a dense green cover, ensuring shade during most hours of the day. Thus, people can sit and enjoy the positive aspects of climate (Lorraine Fitzsimons, 2013; Mehta, 2008; van der Ploeg et al., 2010) and enhance people's comfort (Gehl et al., 2006; van der Ploeg et al., 2010)**.** Furthermore, the microclimate conditions impact outdoor activities. Gehl (1987) showed shady or sunny conditions remarkably influence people's preference to stay further or leave (Chen and Ng, 2012).

The finding also highlighted a good correlation between neutral sensation and pedestrian flow rates. Indeed, the highest walkability scores are recorded when the people's thermal perception is neutral (Labdaoui et al., 2021). Moreover, the geometry and the spatial design of the outdoor environment can enhance the walking activity. For example, Court 1 and Court 2 include four lines of trees, which helps to enjoy the walking experience. Indeed, landscape and trees, besides an attractive environment, can significantly influence the perceived thermal sensation (Lenzholzer and Koh, 2010; Lin et al., 2013; Nikolopoulou and Steemers, 2003) and improve the walking experience (Aghaabbasi et al., 2018; Labdaoui et al., 2021). In comparison, Square 1 and Square 2 are missing this characteristic, making them a transitional space.

Despite the uncomfortable range of PET, the occupancy of space by seated people recorded important scores at noon and 4 pm in Court 1, and 60%-79% at 4 pm in Court 2, while in Square 2, the scores reached 40%-59% at 2 pm and 60%-79% at 4 pm (Table 8). These results illustrated the thermal adaptation of people in outdoor spaces. The high air temperature and $T_{mrt,}$ generate the lowest thermal comfort condition. However, people expressed a comfortable thermal sensation in the shaded tree area (Fig 6, Fig 9, and Table 5).

There is also a significant variation in perception between different individuals. Thus, almost all people were sitting in the shaded area, but a tiny minority was walking during the hot hours of the day (12 am, 2 pm, and 4 pm). Indeed, 21% of seating people in Court 1, Court 2, and Square1 reported a feeling of comfort at 2 pm for 29°C-30°C PET average and 26% at 4 pm for 30°C-32°C PET average, which means that people can also tolerate higher temperatures in summer. Accordingly, people can adapt their thermal perception according to mind forecasts concerning physical activity alteration (Elnabawi et al., 2016).

5. Conclusion

This innovative study specified the outdoor thermal comfort range in Annaba (HDD =1200-1800 and CDD=1100-1700), Algeria. It proved that the thermal comfort range might vary between areas with the same climatic classification (Csa). Indeed, PET comfort range compared to various locations, characterized by the same climate (Csa), relative regular morphologies and green cover, and different CDD and HDD data. This study explored four outdoor environments during two summer days, based on combining five successful techniques: in situ measurements, interviews, observation, simulations and calculation (Envimet and RayMan), which allowed analyzing the correlation between thermal comfort range, green cover effect and people behaviour. Moreover, this study proved the thermal adaptation phenomenon by using objective estimation of observation in the Mediterranean area.

These findings provide additional value to the current studies within the Csa climate. By considering the correlation between thermal comfort, perceived thermal sensation and green cover. Indeed, the dense green infrastructure in cities has a crucial role in improving thermal comfort by reducing air temperature (4°C) and T_{mrt} (3°C) during the hottest hour of the day in summer. Moreover, shaded trees may be considered as the first hypothesis of the thermal adaptation phenomenon. These findings can help architects and urban planners to design more liveable and sustainable urban spaces in Csa. In addition, the local authorities could include sustainable green projects, such as rainwater collectors, to ensure the irrigation and maintenance of green infrastructure. Thus, improving outdoor thermal comfort could be a practical and sustainable strategy to reduce Urban Heat Island in compact urban morphologies.

This study has some limitations related to accurate quantification of the trees cooling effect and the incidence of trees crown type on PET and TSV. However, having different calibrated scenarios of the spatial organization of trees using Envi-met constitute interesting future research. Furthermore, considering the thermal adaptation, using current quantitative approaches (e.g. walking speed, sitting time) allows better comprehensive analysis and knowledge of this phenomenon. In addition, using the CORINE land Cover method involves having an extensive scope of data, which allowed getting current contextual data. Finally, conducting studies that relate principal concepts such as urban ecology, urban comfort and heat island is an excellent sustainable approach for further investigation. Moreover, elaborating an in situ behavioural map within a comparative approach (weekdays and weekends) is an interesting sociological perspective for future research.

Acknowledgements

I wish to thank all of those who have supported my research for their helpful comments during its accomplishment. In particular, I would like to acknowledge the Local Environment Management and Analysis (LEMA) group at the University of Liege. The funding for this project was made possible through a research grant obtained from the Ministry of Higher Education and Scientific Research Algeria under the Programme National Exceptional (PNE).

References

Acero, J.A., Herranz-Pascual, K., 2015. A comparison of thermal comfort conditions in four urban spaces by means of measurements and modelling techniques. Building and Environment 93, 245–257. https://doi.org/10.1016/j.buildenv.2015.06.028

Aghaabbasi, M., Moeinaddini, M., Zaly Shah, M., Asadi-Shekari, Z., Arjomand Kermani, M., 2018. Evaluating the capability of walkability audit tools for assessing sidewalks. Sustainable Cities and Society 37, 475–484. https://doi.org/10.1016/j.scs.2017.12.001

Ali-Toudert, F., Mayer, H., 2007. Thermal comfort in an east–west oriented street canyon in Freiburg (Germany) under hot summer conditions. Theor. Appl. Climatol. 87, 223–237. https://doi.org/10.1007/s00704-005-0194-4

Aljawabra, F., Nikolopoulou, M., 2010. Influence of hot arid climate on the use of outdoor urban spaces and thermal comfort: Do cultural and social backgrounds matter? Intelligent Buildings International 2, 198–217.

Andrade, H., Alcoforado, M.-J., Oliveira, S., 2011. Perception of temperature and wind by users of public outdoor spaces: relationships with weather parameters and personal characteristics. Int J Biometeorol 55, 665–680. https://doi.org/10.1007/s00484-010-0379-0

Andreou, E., 2013. Thermal comfort in outdoor spaces and urban canyon microclimate. Renewable Energy 55, 182–188. https://doi.org/10.1016/j.renene.2012.12.040

Armson, D., Stringer, P., Ennos, R., 2012. The effect of tree shade and grass on surface and globe temperatures in an urban area. Urban Forestry & Urban Greening 11, 245–255. https://doi.org/10.1016/j.ufug.2012.05.002

ASHRAE Standard, 2004. American Society of Heating, Refrigerating and Air-Conditioning Engineers 55.

Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S., 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning 97, 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

Charalampopoulos, I., Tsiros, I., Chronopoulou-Sereli, A., Matzarakis, A., 2013. Analysis of thermal bioclimate in various urban configurations in Athens, Greece. Urban Ecosyst 16, 217–233. https://doi.org/10.1007/s11252-012-0252-5

Chen, L., Ng, E., 2013. Simulation of the effect of downtown greenery on thermal comfort in subtropical climate using PET index: a case study in Hong Kong. Architectural Science Review 56, 297–305. https://doi.org/10.1080/00038628.2012.684871

Chen, L., Ng, E., 2012. Outdoor thermal comfort and outdoor activities: A review of research in the past decade. Cities 29, 118–125. https://doi.org/10.1016/j.cities.2011.08.006

Cohen, P., Potchter, O., Matzarakis, A., 2013. Human thermal perception of Coastal Mediterranean outdoor urban environments. Applied Geography 37, 1–10. https://doi.org/10.1016/j.apgeog.2012.11.001

Eliasson, I., Knez, I., Westerberg, U., Thorsson, S., Lindberg, F., 2007. Climate and behaviour in a Nordic city. Landscape and Urban Planning 82, 72–84. https://doi.org/10.1016/j.landurbplan.2007.01.020

Elnabawi, M.H., Hamza, N., Dudek, S., 2016. Thermal perception of outdoor urban spaces in the hot arid region of Cairo, Egypt. Sustainable Cities and Society 22, 136–145. https://doi.org/10.1016/j.scs.2016.02.005

Elnabawi, M.H., Hamza, N., Dudek, S., 2013. Use and evaluation of the ENVI-met model for two different urban forms in Cairo, Egypt: measurements and model simulations. Presented at the 13th Conference of International Building Performance Simulation Association, Chambéry, France.

Emmanuel, M.R., 2005. An urban approach to climate-sensitive design: strategies for the tropics. Taylor & Francis.

Faziera, Y.N., Elizabeth, E.A., Danggat, C., Tarmiji, M., 2020. Coronavirus (COVID-19): Density risk mapping using Population and Housing Census of Malaysia 2010. GEOGRAFI 8, 21–47.

Gehl, J., 1987. Life between buildings. New York: Van Nostrand Reinhold.

Gehl, J., Kaefer, L.J., Reigstad, S., 2006. Close encounters with buildings. Urban Des Int 11, 29–47. https://doi.org/10.1057/palgrave.udi.9000162

Ghaffarianhoseini, Amirhosein, Berardi, U., Ghaffarianhoseini, Ali, 2015. Thermal performance characteristics of unshaded courtyards in hot and humid climates. Building and Environment 87, 154–168. https://doi.org/10.1016/j.buildenv.2015.02.001

Givoni, B, Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y, Feller, N, 2003. Outdoor comfort research issues. Energy and Buildings 1, 77–86.

Golasi, I., Salata, F., de Lieto Vollaro, E., Coppi, M., 2018. Complying with the demand of standardization in outdoor thermal comfort: a first approach to the Global Outdoor Comfort Index (GOCI). Building and Environment 130, 104–119. https://doi.org/10.1016/j.buildenv.2017.12.021

Gulyás, Á., Unger, J., Matzarakis, A., 2006. Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. Building and Environment 41, 1713–1722. https://doi.org/10.1016/j.buildenv.2005.07.001

Hirashima, S.Q. da S., Assis, E.S. de, Nikolopoulou, M., 2016. Daytime thermal comfort in urban spaces: A field study in Brazil. Building and Environment 107, 245–253. https://doi.org/10.1016/j.buildenv.2016.08.006

Huttner, S., 2012. Further development and application of the 3D microclimate simulation ENVI-met.

Hwang, R.-L., Lin, T.-P., Matzarakis, A., 2011. Seasonal effects of urban street shading on long-term outdoor thermal comfort. Building and Environment 46, 863–870. https://doi.org/10.1016/j.buildenv.2010.10.017

Itami, R.M., Avenue, D., n.d. Estimating Capacities for Pedestrian Walkways and Viewing Platforms 23.

Jamei, E., Rajagopalan, P., Seyedmahmoudian, M., Jamei, Y., 2016. Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. Renewable and Sustainable Energy Reviews 54, 1002–1017. https://doi.org/10.1016/j.rser.2015.10.104

Jänicke, B., Meier, F., Hoelscher, M.-T., Scherer, D., 2015. Evaluating the Effects of Façade Greening on Human Bioclimate in a Complex Urban Environment [WWW Document]. Advances in Meteorology. https://doi.org/10.1155/2015/747259

Johansson, E., Thorsson, S., Emmanuel, R., Krüger, E., 2014. Instruments and methods in outdoor thermal comfort studies – The need for standardization. Urban Climate 10, 346–366. https://doi.org/10.1016/j.uclim.2013.12.002

Johansson, L., Onomura, S., Lindberg, F., Seaquist, J., 2016. Towards the modelling of pedestrian wind speed using high-resolution digital surface models and statistical methods. Theor Appl Climatol 124, 189–203. https://doi.org/10.1007/s00704-015-1405-2

Kántor, N., Égerházi, L., Unger, J., 2012. Subjective estimation of thermal environment in recreational urban spaces—Part 1: investigations in Szeged, Hungary. Int J Biometeorol 56, 1075–1088. https://doi.org/10.1007/s00484-012-0523-0

Kaplan, R., Kaplan, S., 1989. The experience of nature: A psychological perspective. CUP Archive.

Klemm, W., Heusinkveld, B.G., Lenzholzer, S., Jacobs, M.H., Van Hove, B., 2015a. Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Building and Environment 83, 120–128. https://doi.org/10.1016/j.buildenv.2014.05.013

Klemm, W., Heusinkveld, B.G., Lenzholzer, S., van Hove, B., 2015b. Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning 138, 87–98. https://doi.org/10.1016/j.landurbplan.2015.02.009

Knez, I., Thorsson, S., 2006. Influences of culture and environmental attitude on thermal, emotional and perceptual evaluations of a public square. Int J Biometeorol 50, 258–268. https://doi.org/10.1007/s00484-006-0024-0

Knez, I., Thorsson, S., Eliasson, I., Lindberg, F., 2009. Psychological mechanisms in outdoor place and weather assessment: towards a conceptual model. Int J Biometeorol 53, 101–111. https://doi.org/10.1007/s00484-008-0194-z

Kong, F., Yin, H., Wang, C., Cavan, G., James, P., 2014. A satellite image-based analysis of factors contributing to the green-space cool island intensity on a city scale. Urban Forestry & Urban Greening 13, 846–853. https://doi.org/10.1016/j.ufug.2014.09.009

Krüger, E.L., Minella, F.O., Rasia, F., 2011. Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. Building and Environment 46, 621–634. https://doi.org/10.1016/j.buildenv.2010.09.006

Labdaoui, K., Mazouz, S., Acidi, A., Cools, M., Moeinaddini, M., Teller, J., 2021. Utilizing thermal comfort and walking facilities to propose a comfort walkability index (CWI) at the neighbourhood level. Building and Environment 193, 107627. https://doi.org/10.1016/j.buildenv.2021.107627

Lai, D., Guo, D., Hou, Y., Lin, C., Chen, Q., 2014. Studies of outdoor thermal comfort in northern China. Building and Environment 77, 110–118. https://doi.org/10.1016/j.buildenv.2014.03.026

Lai, D., Liu, W., Gan, T., Liu, K., Chen, Q., 2019. A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. Science of The Total Environment 661, 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062

Lee, H., Holst, J., Mayer, H., 2013. Modification of Human-Biometeorologically Significant Radiant Flux Densities by Shading as Local Method to Mitigate Heat Stress in Summer within Urban Street Canyons. Advances in Meteorology 2013, 1–13. https://doi.org/10.1155/2013/312572

Lee, H., Mayer, H., Chen, L., 2016. Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany. Landscape and Urban Planning 148, 37–50. https://doi.org/10.1016/j.landurbplan.2015.12.004

Lenzholzer, S., 2012. Research and design for thermal comfort in Dutch urban squares. Resources, Conservation and Recycling, Climate Proofing Cities 64, 39–48. https://doi.org/10.1016/j.resconrec.2011.06.015

Lenzholzer, S., Koh, J., 2010. Immersed in microclimatic space: Microclimate experience and perception of spatial configurations in Dutch squares. Landscape and Urban Planning 95, 1–15. https://doi.org/10.1016/j.landurbplan.2009.10.013

Lin, T.-P., 2009. Thermal perception, adaptation and attendance in a public square in hot and humid regions. Building and Environment 44, 2017–2026. https://doi.org/10.1016/j.buildenv.2009.02.004

Lin, T.-P., Matzarakis, A., 2008. Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. Int J Biometeorol 52, 281–290. https://doi.org/10.1007/s00484-007-0122-7

Lin, T.-P., Tsai, K.-T., Hwang, R.-L., Matzarakis, A., 2012. Quantification of the effect of thermal indices and sky view factor on park attendance. Landscape and Urban Planning 107, 137–146. https://doi.org/10.1016/j.landurbplan.2012.05.011

Lin, T.-P., Tsai, K.-T., Liao, C.-C., Huang, Y.-C., 2013. Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types. Building and Environment 59, 599–611. https://doi.org/10.1016/j.buildenv.2012.10.005

Liu, W., Zhang, Y., Deng, Q., 2016. The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate. Energy and Buildings 128, 190–197. https://doi.org/10.1016/j.enbuild.2016.06.086

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

Lorraine Fitzsimons, D.B.Me., 2013. A multidisciplinary examination of walkability: Its concept, assessment and applicability. Dublin City University.

Mahmoud, A.H.A., 2011. Analysis of the microclimatic and human comfort conditions in an urban park in hot and arid regions. Building and Environment 46, 2641–2656. https://doi.org/10.1016/j.buildenv.2011.06.025

Matzarakis, A., Mayer, H., 1996. Another Kind of Environmental Stress: Thermal Stress. WHO Collaborating Centre for Air Quality Management and Air Pollution Control. NEWSLETTERS 18, 7–10.

Matzarakis, A., Mayer, H., Iziomon, M.G., 1999. Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84. https://doi.org/10.1007/s004840050119

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

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

Mehta, V., 2008. Walkable streets: pedestrian behavior, perceptions and attitudes. Journal of Urbanism: International Research on Placemaking and Urban Sustainability 1, 217–245. https://doi.org/10.1080/17549170802529480

Mirzaei, P.A., 2015. Recent challenges in modeling of urban heat island. Sustainable Cities and Society 19, 200–206. https://doi.org/10.1016/j.scs.2015.04.001

Mirzaei, P.A., Haghighat, F., 2010. Approaches to study Urban Heat Island – Abilities and limitations. Building and Environment 45, 2192–2201. https://doi.org/10.1016/j.buildenv.2010.04.001

Morakinyo, T.E., Kong, L., Lau, K.K.-L., Yuan, C., Ng, E., 2017. A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort. Building and Environment 115, 1–17. https://doi.org/10.1016/j.buildenv.2017.01.005

Müller, N., Kuttler, W., Barlag, A.-B., 2014. Counteracting urban climate change: adaptation measures and their effect on thermal comfort. Theor Appl Climatol 115, 243–257. https://doi.org/10.1007/s00704-013-0890-4

Ng, E., Chen, L., Wang, Y., Yuan, C., 2012. A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. Building and Environment 47, 256–271. https://doi.org/10.1016/j.buildenv.2011.07.014

Ng, E., Cheng, V., 2012. Urban human thermal comfort in hot and humid Hong Kong. Energy and Buildings, Cool Roofs, Cool Pavements, Cool Cities, and Cool World 55, 51–65. https://doi.org/10.1016/j.enbuild.2011.09.025

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

Nikolopoulou, M., Lykoudis, S., 2007. Use of outdoor spaces and microclimate in a Mediterranean urban area. Building and Environment 42, 3691–3707. https://doi.org/10.1016/j.buildenv.2006.09.008

Nikolopoulou, M., Lykoudis, S., 2006. Thermal comfort in outdoor urban spaces: Analysis across different European countries. Building and Environment 41, 1455–1470. https://doi.org/10.1016/j.buildenv.2005.05.031

Nikolopoulou, M., Steemers, K., 2003. Thermal comfort and psychological adaptation as a guide for designing urban spaces. Energy and Buildings, Special issue on urban research 35, 95–101. https://doi.org/10.1016/S0378-7788(02)00084-1

Nouri, A.S., Costa, J.P., 2017. Addressing thermophysiological thresholds and psychological aspects during hot and dry mediterranean summers through public space design: The case of Rossio. Building and Environment 118, 67–90. https://doi.org/10.1016/j.buildenv.2017.03.027

Olgyay, Victor, 1998. Design With Climate Princeton.

Oliveira, S., Andrade, H., 2007. An initial assessment of the bioclimatic comfort in an outdoor public space in Lisbon. Int J Biometeorol 52, 69–84. https://doi.org/10.1007/s00484-007-0100-0

Pantavou, K., Santamouris, M., Asimakopoulos, D., Theoharatos, G., 2014. Empirical calibration of thermal indices in an urban outdoor Mediterranean environment. Building and Environment 80, 283–292. https://doi.org/10.1016/j.buildenv.2014.06.001

Pantavou, K., Theoharatos, G., Santamouris, M., Asimakopoulos, D., 2013. Outdoor thermal sensation of pedestrians in a Mediterranean climate and a comparison with UTCI. Building and Environment 66, 82–95. https://doi.org/10.1016/j.buildenv.2013.02.014

Pantavou, K.G., Lykoudis, S.P., Nikolopoulos, G.K., 2016. Milder form of heat-related symptoms and thermal sensation: a study in a Mediterranean climate. Int J Biometeorol 60, 917–929. https://doi.org/10.1007/s00484-015-1085-8

Potchter, O., Cohen, P., Lin, T.-P., Matzarakis, A., 2018. Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. Science of The Total Environment 631–632, 390–406. https://doi.org/10.1016/j.scitotenv.2018.02.276

Saaroni, H., Pearlmutter, D., Hatuka, T., 2015. Human-biometeorological conditions and thermal perception in a Mediterranean coastal park. Int J Biometeorol 59, 1347–1362. https://doi.org/10.1007/s00484-014-0944-z

Salata, F., Golasi, I., de Lieto Vollaro, R., de Lieto Vollaro, A., 2016. Outdoor thermal comfort in the Mediterranean area. A transversal study in Rome, Italy. Building and Environment 96, 46–61. https://doi.org/10.1016/j.buildenv.2015.11.023

Santamouris, M., 2013. Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. Renewable and Sustainable Energy Reviews 26, 224–240. https://doi.org/10.1016/j.rser.2013.05.047

Santamouris, M., 2007. Heat Island Research in Europe: The State of the Art. Advances in Building Energy Research 1, 123–150. https://doi.org/10.1080/17512549.2007.9687272

Schnell, I., Potchter, O., Yaakov, Y., Epstein, Y., Brener, S., Hermesh, H., 2012. Urban daily life routines and human exposure to environmental discomfort. Environmental Monitoring and Assessment 184, 4575–4590. https://doi.org/10.1007/s10661-011-2286-1

Shashua-Bar, L., Tsiros, I.X., Hoffman, M., 2012. Passive cooling design options to ameliorate thermal comfort in urban streets of a Mediterranean climate (Athens) under hot summer conditions. Building and Environment 57, 110–119. https://doi.org/10.1016/j.buildenv.2012.04.019

Spagnolo, J., de Dear, R., 2003. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. Building and Environment 38, 721–738. https://doi.org/10.1016/S0360-1323(02)00209-3

Taleghani, M., Berardi, U., 2018. The effect of pavement characteristics on pedestrians' thermal comfort in Toronto. Urban Climate 24, 449–459. https://doi.org/10.1016/j.uclim.2017.05.007

Taleghani, M., Kleerekoper, L., Tenpierik, M., van den Dobbelsteen, A., 2015. Outdoor thermal comfort within five different urban forms in the Netherlands. Building and Environment 83, 65–78. https://doi.org/10.1016/j.buildenv.2014.03.014

Taleghani, M., Sailor, D.J., Tenpierik, M., van den Dobbelsteen, A., 2014. Thermal assessment of heat mitigation strategies: The case of Portland State University, Oregon, USA. Building and Environment 73, 138–150. https://doi.org/10.1016/j.buildenv.2013.12.006

Thorsson, S., Honjo, T., Lindberg, F., Eliasson, I., Lim, E.-M., 2007. Thermal Comfort and Outdoor Activity in Japanese Urban Public Places. Environment and Behavior 39, 660–684. https://doi.org/10.1177/0013916506294937

Thorsson, S., Lindqvist, M., Lindqvist, S., 2004. Thermal bioclimatic conditions and patterns of behaviour in an urban park in G�teborg, Sweden. International Journal of Biometeorology 48, 149–156. https://doi.org/10.1007/s00484-003-0189-8

Tseliou, A., Tsiros, I.X., Lykoudis, S., Nikolopoulou, M., 2010. An evaluation of three biometeorological indices for human thermal comfort in urban outdoor areas under real climatic conditions. Building and Environment 45, 1346–1352. https://doi.org/10.1016/j.buildenv.2009.11.009

Tseliou, A., Tsiros, I.X., Nikolopoulou, M., 2017. Seasonal differences in thermal sensation in the outdoor urban environment of Mediterranean climates – the example of Athens, Greece. International Journal of Biometeorology 61, 1191–1208. https://doi.org/10.1007/s00484-016-1298-5

Tsitoura, M., Tsoutsos, T., Daras, T., 2014. Evaluation of comfort conditions in urban open spaces. Application in the island of Crete. Energy Conversion and Management 86, 250–258. https://doi.org/10.1016/j.enconman.2014.04.059

van der Ploeg, H.P., Tudor-Locke, C., Marshall, A.L., Craig, C., Hagströmer, M., Sjöström, M., Bauman, A., 2010. Reliability and validity of the international physical activity questionnaire for assessing walking. Res Q Exerc Sport 81, 97–101. https://doi.org/10.1080/02701367.2010.10599632

van Hoof, J., 2008. Forty years of Fanger's model of thermal comfort: comfort for all? Indoor Air 18, 182–201. https://doi.org/10.1111/j.1600-0668.2007.00516.x

Watanabe, S., Nagano, K., Ishii, J., Horikoshi, T., 2014. Evaluation of outdoor thermal comfort in sunlight, building shade, and pergola shade during summer in a humid subtropical region. Building and Environment 82, 556–565. https://doi.org/10.1016/j.buildenv.2014.10.002

Woolley, H., 2003. Urban open spaces. Taylor & Francis.

Wu, J., 2014. Urban ecology and sustainability: The state-of-the-science and future directions. Landscape and Urban Planning 125, 209–221. https://doi.org/10.1016/j.landurbplan.2014.01.018

Wu, J. (Jingle), 2008. Making the Case for Landscape Ecology An Effective Approach to Urban Sustainability. Landscape Jrnl. 27, 41–50. https://doi.org/10.3368/lj.27.1.41

Wu, Z., Chen, L., 2017. Optimizing the spatial arrangement of trees in residential neighborhoods for better cooling effects: Integrating modeling with in-situ measurements. Landscape and Urban Planning 167, 463–472. https://doi.org/10.1016/j.landurbplan.2017.07.015

Yang, X., Zhao, L., Bruse, M., Meng, Q., 2013. Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces. Building and Environment 60, 93–104. https://doi.org/10.1016/j.buildenv.2012.11.008

Zölch, T., Maderspacher, J., Wamsler, C., Pauleit, S., 2016. Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale. Urban Forestry & Urban Greening 20, 305–316. https://doi.org/10.1016/j.ufug.2016.09.011

Appendices

Appendix A *The space occupancy interpretation according to model scores.*

Model score (%)	***Space occupancy (seating people/m^2)***
0%	*No people*
1%-19%	*Very low space occupation*
20%-39%	*Low space occupancy*
40%-59%	*Average space occupancy*
60%-79%	*High space occupancy rate*
80%-100%	*The highest occupancy of the space*

Appendix B *Pedestrian flow density interpretation in the walkway (Itami and Avenue, n.d.)*

Level of service	***Interpretation***	***Space (m²/ped)***	***Flow Rate (ped/min/m)***	***Average speed (m/s)***
A	*no pedestrian (Open space)*	*≥ 5.6*	*≤ 14*	*≥ 1.3*
B	*Very low pedestrian density (Unimpeded space)*	*3.7-5.6*	*14.21*	*1.27-1.30*
C	*Low pedestrian density (Constrained space)*	*2.2-3.7*	*21-33*	*1.22-1.27*
D	*Average pedestrian density (Crowded space)*	*1.4-2.2*	*33-49*	*1.14-1.22*
E	*High pedestrian density (Congested space)*	*0.75-1.4*	*49-60*	*0.75-1.14*
F	*The maximum pedestrian density in a space*	*≤ 0.75*	*var*	*≤ 0.75*

Appendix C

Outdoor thermal comfort questionnaire

a. Date.../../…, time……, location

b. Gender: Male /Female, age

c. What is your job?

Intellectual and executive profession		Retired	
Independent and intermediate		Unemployed	
Students			

1. What are the main reasons that encourage you to come to this urban space?

….…………………………………………………………………………………………………

2. Could you please describe your current thermal sensation?

Comfortable	Slightly warm	Warm	Hot	Very hot

3. Among the following climatic condition, what is limiting your staying in this place?

Hot temperature	Winds	Sunlight