Assessment of the Outdoor Thermal Comfort and the Role of Urban Trees in Regulating the Urban Microclimate in the North-Eastern of Algeria; Case of Souk Ahras City

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ABSTRACT:

It is well established that urban heat island UHI has a negative impact on the health and quality of life of city dwellers, particularly during heat waves. Such as a reduction in thermal comfort, an increase in heat-related illnesses and deaths, and deterioration in air quality .Outdoor public spaces play an important role in the overall quality of life. In the north-eastern of Algeria, particularly in Souk-Ahras city, the majority of the population spends most of their time outdoors, in very hot conditions. The aim of this research is to assess the outdoor thermal comfort (OTC) in two public spaces in souk ahars city and to examine the role of urban trees in regulating the urban microclimate and optimizing OTC. A questionnaire survey on the sensation of thermal comfort was carried out simultaneously with in situ measurements of the following microclimatic parameters: air temperature T_a*, relative humidity RH and wind speed* V_a *during July 2022 in the two public spaces at a total of six measurement points; to calculate and compare the physiological equivalent temperature (the PET index), the mean radiant temperature Tmrt and the sky view factor SVF using Rayman 1.2 software. The results show that air temperature (Ta) is one of the most important factors influencing a person outdoor thermal comfort in the warmer seasons. Evapotranspiration and trees shading modify the thermal perceptions of humans outdoors by affecting the outdoor thermal environment through a lowering of air temperature and an increase in relative humidity.*

Keywords: *Heat stress; outdoor thermal comfort; physiologically equivalent temperature; trees effect; Rayman.*

INTRODUCTION:

Faced with the rapid acceleration of global climate change, cities are exposed to numerous environmental problems and challenges. (Karakounos et al., 2018). It is essential to work towards a better understanding of the complex processes at the intersection of urbanization, climate change and human health, as urban population growth is set to continue, with 67% of the world's population living in cities by 2050.(Debbage & Shepherd, 2015). With the continuing rise in global temperatures, known as global warming, the probability of extreme weather events is also increasing, making people more vulnerable.(Djalante, 2019) .

The relation between the climate and cities is a two-way process: the climate affects the way urban spaces are used; on the other hand, cities affect their climate. (Kleerekoper et al., 2012) ; it modifies the regional climate, leading to variations in precipitation, solar radiation, air temperature and wind speed ; between the city and the surrounding area (Sangiorgio et al., 2022).

The urban heat island (UHI) is one of the most intense phenomena affecting cities as a result of the increasing effects of global warming. (Gatto et al., 2021) ; in addition, the excessive rise in impermeable surfaces, the loss of urban green spaces and the release of anthropogenic heat into urban areas, are all factors contributing to the increase in heat stress in cities.(Chapman et al., 2017). It is well established that UHI has a negative impact on the health and quality of life of city dwellers, particularly during heat waves. (Marando et al., 2022) such as a reduction in thermal comfort, an increase in heat-related illnesses and deaths, and a deterioration in air quality (Liu et al., 2021).

To prevent UHI and provide comfortable outdoor spaces, more attention has recently been paid to outdoor thermal comfort. (Bandurski et al., 2020; Faragallah & Ragheb, 2022)

The general quality of life is greatly influenced by outdoor public spaces. An improvement in urban dynamism and citizen health can best describe their significance.. (Hanafi & Alkama, 2017) because they encourage outdoor activities , pedestrian traffic and considerably improve the liveability of cities, outdoor spaces are essential to sustainable cities(Gatto et al., 2020) .

However, because of the higher temperatures in outdoor spaces compared to indoor spaces on warmer days and in the absence of cooling facilities, and because of their thermal discomfort, few people are able to remain actively outdoors for a prolonged period of time. (J. Zhang et al., 2022) . Outdoor thermal comfort OTC is not only related to the increase in air temperature but also to various microclimatic parameters such as: wind speed, relative humidity and radiation.(Kumar & Sharma, 2020) .

The OTC must be taken into account in urban planning because it has a significant impact on the viability and habitability of urban public spaces, that are open to the public and offer city dwellers areas where they can engage in recreational and other activities, including streets, parks, squares and squares. (Clarence & Gamini, 2022a).

In light of the current climate change situation, specialists are more interested than ever in finding ways to enhance outdoor thermal comfort and give city dwellers a pleasant urban microclimate.

Among these key elements, are green urban infrastructures such as trees, green roofs and vertical greenery, which are considered to be a useful strategy for reducing urban heat stress and guaranteeing outdoor thermal comfort. (Balany et al., 2020; Hami et al., 2019; Lobaccaro & Acero, 2015; Simon et al., 2019; Tochaiwat et al., 2023) ; Research shows that vegetation can improve the temperature, humidity, radiation and recreational conditions of an urban area. (Yan et al., 2020) . As a natural way to cool cities, vegetation may mitigate the effects of the UHI by modifying the microclimate, providing thermal comfort, and other functions. (Clarence & Gamini, 2022b). The degree of cooling varies according to the type and amount of vegetation, the urban form and the length of time the heat is absorbed. (Nuruzzaman, 2015) ; it has beneficial microclimatic effects, including lowering air temperature, providing shade, improving air quality and lowering noise levels, as well as offering aesthetic benefits to walkers (Lai et al., 2019; Nasrollahi et al., 2020; Yilmaz et al., 2021).

Compared to other plant parts, trees are more effective at controlling the urban microclimate and reducing temperatures.(Abdi et al., 2020; Teshnehdel et al., 2020) They offer thermal comfort by blocking the sun's rays through their capacity to cool through evapotranspiration, which is made possible by their special structures and functions. (Georgescu et al., 2014).

Trees also offer shade on surfaces, which lowers the temperature and improves ventilation in the surroundings. (Hami et al., 2019). Different tree species have different cooling effects because they have different transpiration rates, leaf area indices and crown diameters..(Gupta et al., 2018). A considerable amount of incoming radiation can be blocked by shade-producing trees because their leaves reflect and transmit short-wave radiation..(Kong et al., 2017).

Using a variety of thermal comfort indices, the researchers evaluated the degree of thermal comfort in urban areas (Aminipouri et al., 2019) ,such as the physiological equivalent temperature PET; the universal thermal climate index UTCI ; the predicted mean vote PMV. (Fang et al., 2019; Khalili et al., 2022; Meili et al., 2021). The mean radiant temperature Tmrt as a variable component is used to evaluate these thermal assessment indicators (Tan et al., 2013),Tmrt is a critical measure in evaluating outdoor thermal comfort (Manavvi & Rajasekar, 2020).An essential geometric factor for assessing the urban thermal environment is also be used, the sky view factor (SVF) with a range of [0, 1], it has a controversial effect in various urban contexts. In general, its value is positively correlated with temperature in vegetated areas(J. Zhang et al., 2019) ;a lower SVF indicates a cooler climate during the day and greater ground shading.(Lyu et al., 2019) .

In Algeria, cities are also affected by the phenomenon of UHI and its negative effects on outdoor thermal comfort in outdoor public spaces. (BADACHE Halima, s. d.). A number of scientific studies have been carried out, in particular on several cities. (Gherraz et al., 2018; Talhi et al., 2020; Toufik Boutellis & Ammar Bouchair, 2022). Contrary to these cities, this phenomenon has not previously been studied in the city of Souk Ahras. A region in north-eastern Algeria with a hot Mediterranean climate and a dry summer, according to the Koppen-Geiger classification (Csa), outdoor public spaces form the main structure of the city and determine its urban morphology. The Taghaste square and the 16 April esplanade are the busiest outdoor public spaces in Souk Ahras city during the hot season.

The aim of this study is to evaluate users' thermal sensations in these public spaces, and analyze outdoor thermal comfort in order to determine how trees affect the urban microclimate and OTC. The findings of this study will be beneficial in improving the livability of the city at the stages of urban planning and landscape design for urban public areas.

However, a questionnaire survey on the sensation of thermal comfort among users of public spaces in the city of Souk Aharas was carried out. At the same time, in-situ measurements were taken of the following three microclimatic parameters: air temperature (Ta), wind speed (Va) and relative humidity (RH), to compare them, numerical modelling was then used to analyse the outdoor thermal comfort at 6 measurement points using of the Rayman 1.2 software.(Matzarakis et al., 2010). The level of thermal comfort is assessed at each point using the PET (physiological equivalent temperature) thermal index.

MATERIALS AND METHODOLOGY:

Three methods were applied in this research: field measurements and numerical modelling followed by a questionnaire survey to assess the thermal sensation of users. We employed an empirical scientific approach to evaluate the influence of urban trees on outdoor thermal comfort in Souk Ahras city (see Figure 2).

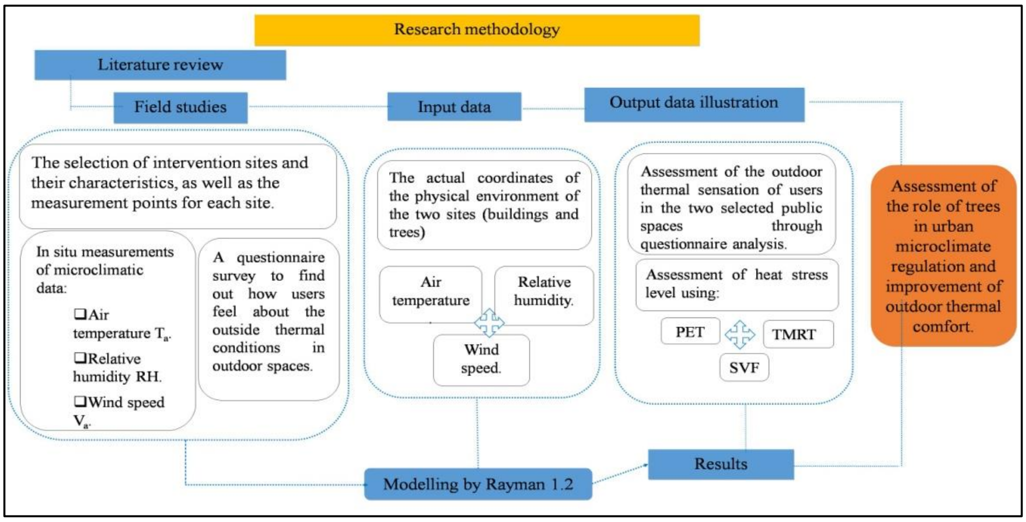

Figure 1: The conceptual framework of the research.(Source: Author 2022).

OVERVIEW OF THE STUDY AREA AND CLIMATIC CONDITIONS:

Souk-Ahras city is located in the north-eastern part of Algeria (36° 17′ 15 North, 7° 57′ 15 East) , with an altitude of 697 m above sea level , near the Tunisian frontier and 640 kilometers from Algiers (see Figure 3). The Koppen-Geiger classification (Csa) assigns the Souk Ahras region a hot, Mediterranean climate with dry summers. It is exposed to desert influences to the south as well as Mediterranean influences to the north.

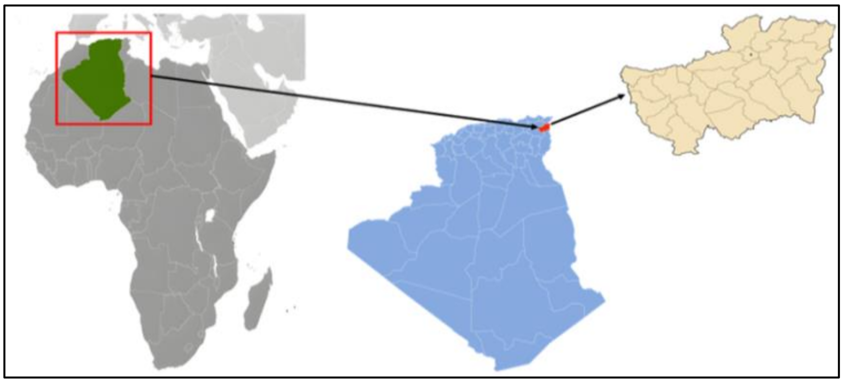

Figure 2: The situation of the town of Souk Ahras (Source: Author 2022.)

The climate is characterised by a hot, dry summer of 25 to 35°C in July and August, and a cold, wet winter of 1 to 15°C in January (see Figure 4). Average rainfall is 650 mm/year in the north, with regular rainfall in March and April, and stormy rainfall in August and September.

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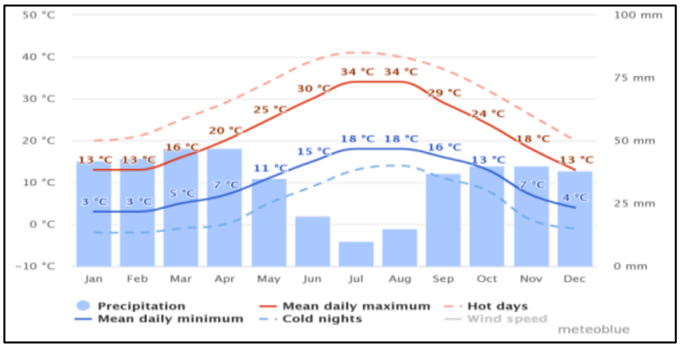

Figure 3: Minimum and maximum temperatures, as well as the average temperatures of hot and cold days, for a 30-year period (1993-2023) for the Souk Ahras region (Source: https://www.meteoblue.com/)

CHARACTERISTICS OF SELECTED SITES :

Based on these multiple criteria, intervention sites are selected:

- ✓ The positioning in the city's center.
- ✓ The user frequency.
- ✓ the Vegetation Coverage percentage.
- ✓ The current environment.

Specifically, two public spaces have been chosen (see picture 5):

- ✓ **Site 1:** The Taghaste square (36°17'5.29 "N; 7°57'22.80 "E).
- ✓ **Site 2:** The 16 April esplanade. (36°17'28.69 "N; 7°56'26.02 "E).

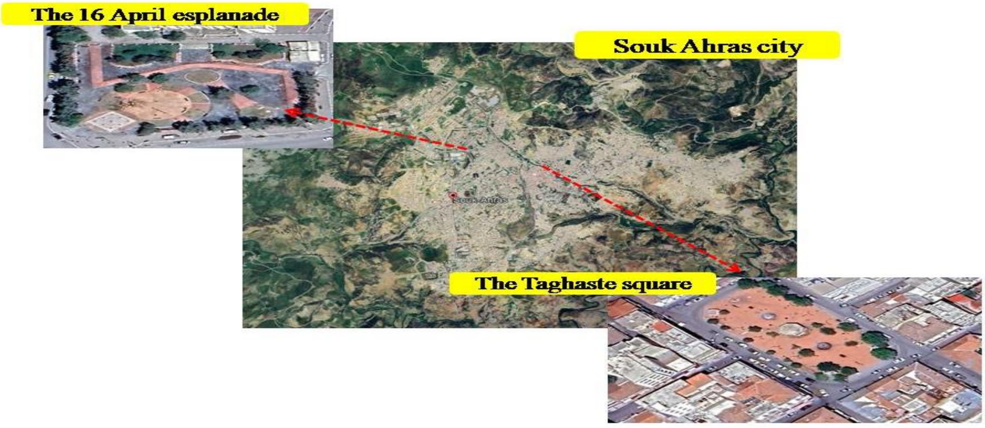

Figure 4: The location of the two selected sites (Source: Author 2022.)

Site 1: is a structured area dating back to the French colonial era, consisting mainly of structures varying in height from 6-15 meters. With its rectangular geometric shape, it has a total surface area of about 2572.75 m^2. Vegetation cover in the Taghaste square is estimated at 9.33%, with only one type of tree: deciduous trees (ash and plane trees).

Figure 5: The types of trees in the Taghaste square (Source: Author 2022.)

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Site 2: structured around an open environment. With its regular geometric shape, it has a total surface area of approximately 4054.54 m ². The vegetation cover in the 16 April esplanade is estimated at 27.05%, presented by a mixture of deciduous trees (ash trees) and coniferous trees (the Cypress trees.)

Figure 6: The types of trees in the 16 April esplanade (Source: Author 2022.)

The Taghaste Square and the 16 April Esplanade's tree characteristics and number are displayed in Table 1.

Table 1: The characteristics of the trees on the 2 selected sites (Source: Author 2022.)

Site	***Tree type:***		***Characteristics:***		
	Ash tree	Plane tree			
Site 1: The Taghaste Square			**Height**	7 m	13m
			Crown width	from 5m - 6m	6m
			Number of trees	7	9
Site 2 : the 16 April Esplanade	Cypress trees 	Ash tree 	**Height**	13m	7m
			Crown width	3m	from 5m - 6m
			Number of trees	11	18

Around 2.20 kilometers separate the two sites, this requires a 2-minute drive in a car (see picture 8).

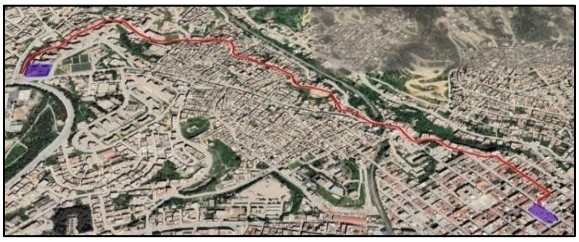

Figure 7: Distance between the two sites.(Source : Google earth.)

IN-SITU MEASUREMENTS AND DATA COLLECTION:

A field measurement campaign was carried out in July, the hottest month of the year in the city of Souk Ahras (between 6 and 9 July 2022). This period was selected to estimate the impact of the effect of trees on outdoor thermal comfort during the hottest days of the year, which is the main objective of this study.

Measurements of the urban thermal environment at the two selected sites were obtained simultaneously, including air temperature (°C), relative humidity (%), and wind speed (m/s). Measurements were taken at 1.5 meters above ground level; eight times a day (bi-hourly) from 06:00 a.m. to 20:00 p.m. to cover all thermal situations (sunrise; morning; midday; afternoon and sunset). To achieve the main objective of this study, which is the effect of trees

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on the regulation of outdoor thermal comfort, 6 measurement points (3 measurement points for each site) were selected (see Figure 9):

Site1: the Taghaste square:

- ✓ **P1 :** a free point near the centre of the square
- ✓ **P2:** a free point in the limits of the square.
- ✓ **P3:** a vegetal point under the shade of the plane trees.

Site 2 : the 16 April esplanade.

- ✓ **P4:** a free point near the centre of the esplanade.
- ✓ **P5 :** a vegetal point in the shade of ash trees
- ✓ ***P6:*** a vegetal point near the ash trees.

Figure 8: The six measurement points (Source: Author 2022.)

Measurements were taken using the following equipment:

- ✓ Handheld thermo-hygrometer HANNA (HI9565 -A02350072111).
- ✓ The hygrometer thermometer Chauvin Arnoux (C.A 846; 692670A00 - Ed.5).
- ✓ A propeller anemometer TROTEC ba16.

Figure 9: The hygrometer thermometer Chauvin Arnoux, in the centre: Handheld thermo-hygrometer HANNA, on the right: A propeller anemometer TROTEC ba16. (Source: Author 2022.)

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The following table shows the technical characteristics of each piece of equipment used in the in situ investigation, which gives a high degree of reliability to the results of the meteorological measurements obtained.

Table 2: Characteristics of measuring equipment. (Source: Author 2022.)

Equipment	Description
The hygrometer thermometer Chauvin Arnoux (C.A 846 ; 692670A00 - Ed.5)	**Measurement of maximum absolute temperature** +60°C **Measurement of maximum humidity** 100%HR **Optimum accuracy of temperature measurement** ±0,5 °C **Temperature measurement resolution** 0.1°C **Optimum humidity measurement accuracy** ±2,5 % HR **Humidity measurement resolution** 0.1%HR **Minimum operating temperature** -20°C **Maximum operating temperature** +60°C
Handheld thermo-hygrometer HANNA (HI9565 -A02350072111)	**Temperature range** -10,0 to 60,0 °C / 14,0 to 140,0 °F **Temperature resolution** 0.1°C / 0.1°F **Temperature accuracy** ±0,4 °C / ±0,8 °F **Humidity range** 0,0 to 100,0 % HR **Humidity resolution** 0,1 % HR **Humidity accuracy** ±2,5 % HR (0 to 90 % HR) ; ±3,5 % HR (90 to 100 % **Environnement** 1 à 60°C (32 to 140°F); HR max 98% without condensation
A propeller anemometer TROTEC ba16	**Air flow velocity :** ***Measuring range:*** 1.00-30, 00. /s ; 196-5.900ft/min,3.6-108.0 km/h ***Resolution :*** 0.01m/s ; 1 ft/min ; 0.1 km/h ***Precision :*** ± 33 % ± 0,2 m/s, ± 3 % ± 40 ft/min, ± 3 % ± 0,8 km/h ***Measuring range :*** 0-999.9m^3/min (CFM) ***Resolution :*** 0,1 CFM

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THERMAL COMFORT INDEXES :

The concept of thermal comfort, which is related to microclimate, is broad and affected by a number of factors, including ambient air temperature, humidity levels, solar radiation, wind speed, and the insulation of clothing. To standardize and streamline the assessment of thermal comfort, some indices that fully encompass these factors have been presented including the PET, Tmrt, PMV, SET, and UTCI.

PHYSIOLOGICAL EQUIVALENT TEMPERATURE (PET):

The PET is the air temperature at which the body's energy balance is balanced with central and surface temperatures that are comparable to those in typical indoor environments (without wind or solar radiation). (Matallah et al., 2020).

Table 3: PET value ranges (source : (Yilmaz et al., 2021))

PET	> 4.0	4.1–8.0	8.1–13.0	13.1–18.0	18.1–23.0	23.1–29.0	29.1–35.0	35.1–41.0	> 41.0
thermal sensitivity	Very cold	Cold Strong	Cool Moderate	Slightly cool	Neutral	Slightly warm	Warm	Hot Strong	Very hot
Grade of physiological stress	Extrem cold stress	cold stress	cold stress	Slightly cold stress	No thermal stress	Slightly heat stress	Moderate heat stress	heat stress	Extrem heat stress

THE SKYE VIEW FACTOR :

The sky view factor (SVF) is the proportion of a point's visible sky area to the overall sky area. It describes how covered areas, such buildings or street trees, relate to the region of viewable sky. The SVF has frequently been employed as a key metric in urban climate research and urban planning processes.(Miao et al., 2020).

MEAN RADIANT TEMPERATURE (TMRT):

Is defined as the temperature of a hypothetical uniform enceinte at which the transfer of radiant heat from a human body is equivalent to the transfer of radiant heat in the hypothetical non-uniform enceinte in reality.(Thorsson et al. 2007).

PREDICTED MEAN VOTE PMV:

This index, which takes into consideration the two personal factors and the four physical variables, forecasts the average thermal sensation vote for a large group of inhabitants based on a standard scale.(Yau & Chew, 2014). Additionally, an ASHRAE thermal feeling scale with seven points (Ikeda et al., 2021) used to illustrate the PMV model (see figure 11):

Figure 10: ASHRAE seven-point thermal sensation scale (Source: Author 2022.)

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QUESTIONNAIRE SURVEY PROTOCOLS:

To find out about the outdoor thermal sensation of users at the two chosen sites, 122 people were arbitrarily interviewed at the same time as the micro-meteorological measurements, in which they were divided into 7 sessions:

Figure 12: The different sessions (Source: Author 2022.)

Three components make up the survey (see figure 14).

- ✓ General information about the respondent, including the sex, age, function, and level of education, is provided in the first part.
- ✓ The second component includes inquiries about how selected public locations are used, such as choice, attendance, and time duration.
- ✓ The third part includes a vote on the respondents' transient thermal perception (TSV), which consists of four questions. Question 4 asks respondents to rate their thermal perception using an ASHRAE scale of nine points: 3, cold, -2, cool, 1, slightly cool, 0, neutral, 1, slightly warm, 2, warm, and 3, hot. The sensation of meteorological variables, such as air temperature, relative humidity, wind speed, and solar radiation, is found in questions no. 5 to no. 7, and the eighth question is about describing the general level of comfort in the two selected sites. Following that, question Q9 asked respondents to describe their current thermal sensitivity in order to determine the impact of their psychologically subjective characteristics on their level of thermal comfort.

The IBM SPSS Statistics 29.0 "Statistical package for the social sciences" software greatly facilitated the management and accessibility of the data collected during the field investigation

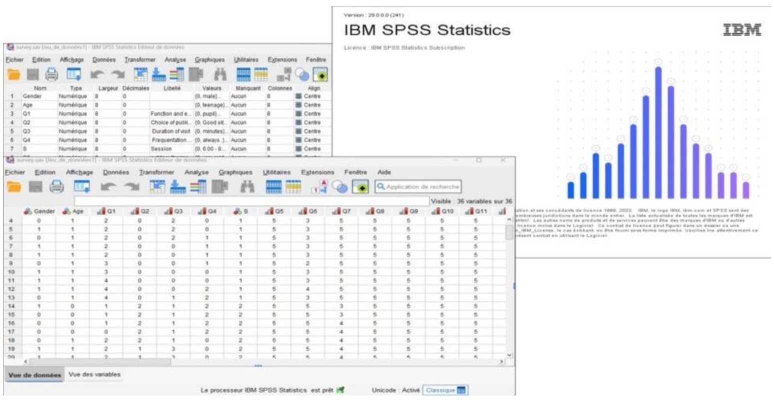

Figure 13: Data management using IBM SPSS Statistics 29.0 software (Source: Author 2022.)

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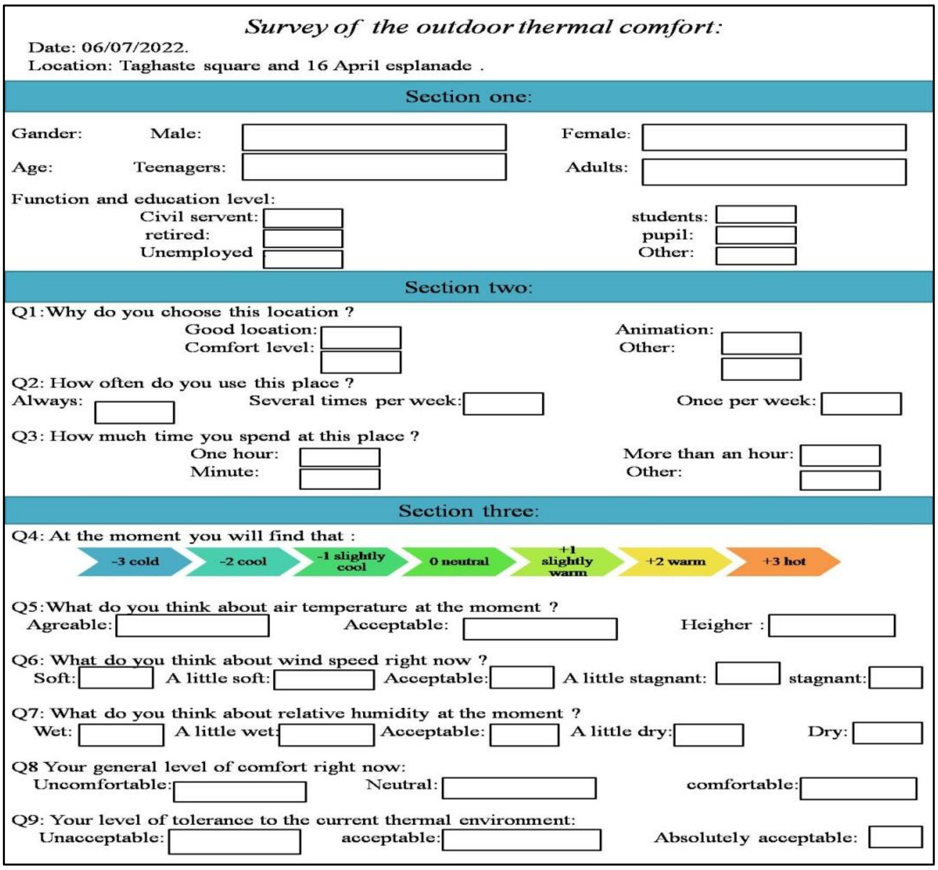
Survey of the outdoor thermal comfort:
Date: 06/07/2022.
Location: Taghaste square and 16 April esplanade .

Section one:

Gender: Male: Female:
Age: Teenagers: Adults:
Function and education level:
Civil servent: students:
retired: pupil:
Unemployed Other:

Section two:

Q1:Why do you choose this location ?
Good location: Animation:
Comfort level: Other:
Q2: How often do you use this place ?
Always: Several times per week: Once per week:
Q3: How much time you spend at this place ?
One hour: More than an hour:
Minute: Other:

Section three:

Q4: At the moment you will find that :
-3 cold | -2 cool | -1 slightly cool | 0 neutral | +1 slightly warm | +2 warm | +3 hot
Q5:What do you think about air temperature at the moment ?
Agreable: Acceptable: Heigher :
Q6: What do you think about wind speed right now ?
Soft: A little soft: Acceptable: A little stagnant: stagnant:
Q7: What do you think about relative humidity at the moment ?
Wet: A little wet: Acceptable: A little dry: Dry:
Q8 Your general level of comfort right now:
Uncomfortable: Neutral: comfortable:
Q9: Your level of tolerance to the current thermal environment:
Unacceptable: acceptable: Absolutely acceptable:

Figure 11: The survey form (Source: Author 2022.)

MODALISATION PROCESS (RAYMAN MODEL):

Rayman 1.2 is a micro-scale model developed for environmental meteorology. The programme is used to determine the thermal comfort index, which is the physiological equivalent temperature (PET), as well as the mean radiant temperature (Tmrt) and the Skye view factor (SVF) for the two selected sites, the Taghaste square and the 16 April esplanade.

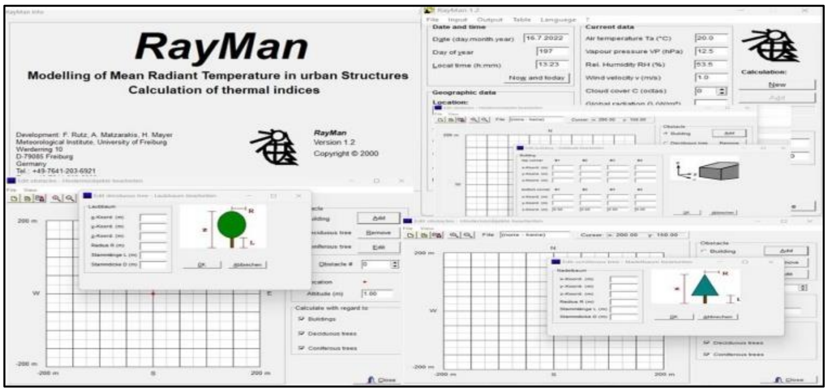

Figure 12: The Rayman 1.2 interface (Source: Author 2023.)

For a total of six measurement points, in order to compare and assess the impact of the cooling effect of urban trees on outdoor thermal comfort .All metrological data and coordinates of the physical environment (landscape and trees) of the two sites are entered into the Rayman1.2 model to determine the indices Tmrt, PET, and SVF.

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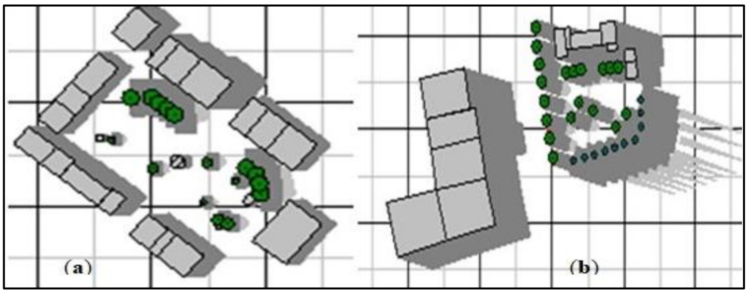

Figure 16: Illustration of the physical environment of the two intervention sites by Rayman1.2; (a) the Taghaste square and (b) the 16 April esplanade (Source: Author 2023.)

Figure 17 shows the different six measurement points for each sites selected from the Taghaste square (P1, P2 and P3) and the 16 April esplanade (P4, P5 and P6).

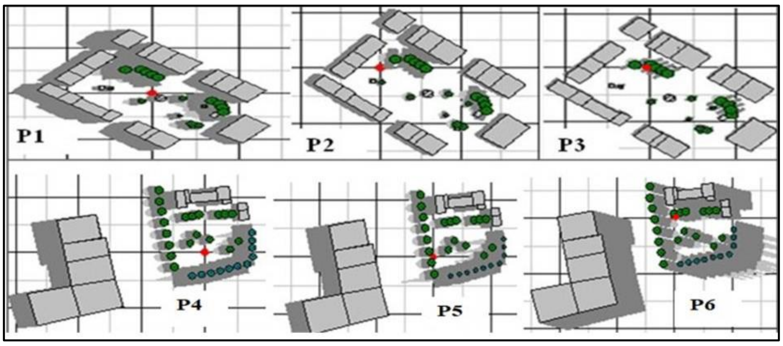

Figure 13: Rayman 1.2 modelling of the various measurement points (Source: Author 2023.)

In Rayman output data tables, the PET, Tmrt, and SVF are performed. Other geographical information is used in this study in addition to the meteorological measurements and the coordinates of the physical environment (building and tree), such as longitude 7° 57′ 15 E, latitude 36° 17′ 15 N, altitude 697m and time zone (UTC + h) 1; as well as the modelling date 6 /07/2022.

Table 4: The meteorological data from the two sites; for July 16, 2022 (Source: Author 2023.)

Météorologiques Data 6/07/2022.		date	Unit	the Taghaste square			The 16 Avril esplanade		
				P1	P2	P3	P4	P5	P6
T_a	6 :00 Am		°C	27.9	28.1	28.2	28.2	27.9	27.8
	8 :00 Am			37.4	38.1	35.5	32.6	33.4	31.0
	10 :00 Am			40.1	39.4	37.5	36.9	34.1	34.3
	12 :00 Am			40.3	41.5	39.4	40.0	38.0	40.6
	14 :00 Pm			41.0	41.5	38.5	40.8	37.4	40.6
	16 :00 Pm			38.7	39.7	36.4	37.3	35.8	39.3
	18 :00 Pm			34.2	33.9	33.3	32.8	32.3	32.4
	20 :00 Pm			33.10	32.5	31.9	29.8	31.2	31.5

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	6 :00 Am	**06-07-2022**		37.9	36.20	37.4	33.7	34.8	34.7
	8 :00 Am			22.8	24.1	24.5	28.1	33.8	29.2
	10 :00 Am			20.25	21.54	21.6	24.5	27.4	26.06
	12 :00 Am		**%**	16.2	19.5	19.4	19.5	21.1	21.2
R_H	**14 :00 Pm**			23.0	23.4	25.2	24.2	26.5	24.1
	16 :00 Pm			23.4	25.3	27.9	25.9	28.6	26.2
	18 :00 Pm			30.0	31.0	32.7	34.3	35.8	35.6
	20 :00 Pm			32.5	33.20	35.2	35.6	36.3	36.2
	6 :00 Am			1.35	0.77	0.82	1.14	0.75	0.75
	8 :00 Am			1.45	0.96	1.12	1.17	1.43	0.90
	10 :00 Am		**m/s**	0.95	0.85	0.85	1.41	1.90	1.11
V_a	**12 :00 Am**			0.93	1.12	0.75	1.02	0.77	1.08
	14 :00 Pm			0.80	1.30	1.24	1.85	1.30	0.80
	16 :00 Pm			0.83	0.75	0.75	0.85	1.2	0.86
	18 :00 Pm			0.75	1.04	0.80	0.77	1.25	0.76
	20 :00 Pm			0.95	0.90	0.85	1.30	1.02	0.83

3- RESULTS:

QUESTIONNAIRE SURVEY RESULTS:

The number of effective questionnaires in this study was 122, distributed equally between the 2 sites. The subjective survey had a gender-equal participation rate of 55.7% men and 44.3% women. It was conducted across 7 sessions, during which time the average age of those interviewed was 63.1% for adults and 36.9% for teenagers (see Table 5).

Table5: Distribution of respondents by number and means by gender, session and age (Source: Author 2023)

Criteria	choice	numbers	Average
	Male	68	55.7%
gender	Female	54	44.3%
	Session 1	4	3.3%
	Session 2	12	9.8%
	Session 3	24	19.7%
Session	Session 4	8	6.6%
	Session 5	23	18.9%
	Session 6	29	23.8%
	Session 7	22	18%
Age	Adults (aged between 20-68).	77	63.1%
	Teenagers (aged between 15-19).	45	36.9%

The average function and education level of those questioned is 34.4% for civil servent; 15.6% for retired people and students; 18.9% for pupils; 13.9% for unemployed people; and 1.6% for other responses. In terms of how often people use outdoor spaces, the majority of respondents said they use them for "their good location" (41%), "for their animation"

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(26.2%), and "comfort level" (17.2%), respectively. The remaining respondents said they use them for "others," which accounted for 15.6% of the total. 50% of users use outdoor spaces all the time, 29.5% several times per week and 20.5% only once a week.

The length of time visitors spend in the outdoor space is divided into four categories, with a majority of 47.5% choosing a visitation time of one hour (see Table 6).

Table 6: Distribution of respondents by number and means according to function and level of education; choice and use of public space and length of visit (Source: Author 2023.)

Criteria	choice	numbers	Average
Function and education level	Civil servent	42	34.4%
	students	19	15.6%
	retired	19	15.6%
	pupil	22	18.9%
	Unemployed	17	13.9%
	Other	2	1.6%
Choice of public space	Good location	50	41%
	Animation	32	26.2%
	Comfort level	21	17.2%
	Other	19	15.6%
Frequent use of public space	Always	61	50 %
	Several times per week	36	29.5%
	Once per week	25	20.5%
Visit duration	One hour	58	47.5%
	More than an hour	18	14.8%
	Minute	35	28.7%
	Other	11	9 %

As part of the vote on thermal perception (TSV); most voted in both sites is "warm =+2"with a percentage of 36.9%; followed by "slightly warm=+1" with a percentage of 32.8% and 19.7% for "neutral =0"; the remainder voted for "hot=+3"with a percentage of 10.7%. Regarding the sensation of air temperature at each site, respondents voted for "heigher" with a percentage of 44.3%; then came "acceptable" with 35.2% and "agreeable" with 20.5%. In the sensation of wind speed; the most voted is "acceptable "with a percentage of 36.1% followed by "a little bit stagnant" with 33.6% and 19.7 % for "a bit soft"; 7.4% for "soft" and 3.3% for "stagnant". On the sensation of relative humidity; the majority vote for "acceptable"33.6 % and then 24.6 % for "a little wet" and 23% for "a little dry".

In addition, the largest number of respondents voted ''unconfortable'' for describing their general level of comfort; with a percentage of 47.5 % followed by ''confortable'' 29.5% and ''neutral'' with a percentage of 23% at each site. The majority of survey participants vote for ''unacceptable''; for the description of the tolerance level of the thermal environment with a percentage of 47.5%. (See table7).

Table 7: A list of the answers to the third section's questions in the form of a summary on the two intervention sites (Source: Author 2023)

Question	variable	Option	numbers	percentage
		Cold -3	0	0%

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4	**The vote on thermal perception(TSV)**	Cool -2	0	0%
		Slightly cool -1	0	0%
		Neural 0	24	19.7%
		Slightly warm +1	40	32.8%
		Warm +2	45	36.9%
		Hot +3	13	10.7%
5	**Sensation of air temperature**	Agreable	25	20.5%
		Acceptable	43	35.2%
		Heigher	54	44.3%
6	**Sensation of wind speed**	Soft	9	7.4%
		A little soft	24	19.7%
		Acceptable	44	36.1%
		A little stagnant	41	33.6%
		stagnant	4	3.3%
7	**Sensation of relative humidity**	Wet	21	19.2%
		A little wet	30	24.6%
		Acceptable	41	33.6%
		A little dry	28	23%
		Dry	2	1.6%
8	**Description of comfort level**	Uncomfortable	58	47.5%
		Neutral	28	23%
		comfortable	36	29.5%
9	**Description of the tolerance level of the current thermal environment**	unacceptable	58	47.5%
		acceptable	34	27.8%
		Absolutely acceptable	30	24.7%

In order to determine the thermal perception of users of the two selected sites, data on the respondents' thermal sensorial votes were compiled and evaluated. The findings show that on the first and second sites; ''warm=+2''has the highest percentage of 42.6 % for the Taghaste square and 32.8 % for the 16 April esplanade. In addition ''neutral =0''is in third place among the two sites with a percentage of 14.8% for the Taghaste square and 23.0% pour the 16 April esplanade ; This means that Site 2 is more comfortable in terms of temperature than Site 1. (See figure 18).

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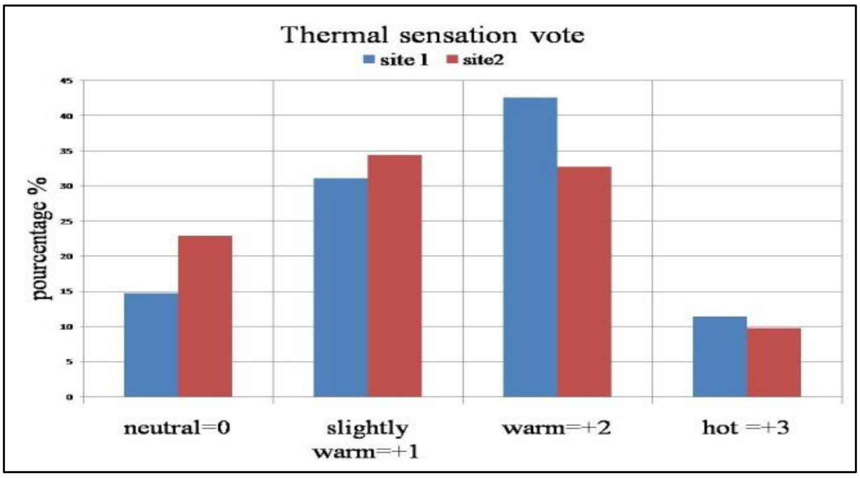

Figure 18: The vote of thermal sensation at the two sites (Source: Author 2023.)

For the sensation of air temperature in both sites; the majority vote for ''height'' with a percentage of 47.5 % for the Taghaste square and 41% for the 16 April esplanade; followed by ''acceptable'' in second position with a percentage of 32.8% for the first site and 36.1% for the second site.

However ''a little stagnant''is the most voted in the first site for the sensation of air speed, with a percentage of 41.0% ; on the contrary at the second site where ''acceptable'' is in first position with the same percentage. "Acceptebal" is the most voted in both sites for the sensation of relative humidity with a percentage of 31.1% for the first site and 36.1% for the second site. The results show that temperature is the most important factor affecting users' outdoor thermal comfort in summer.

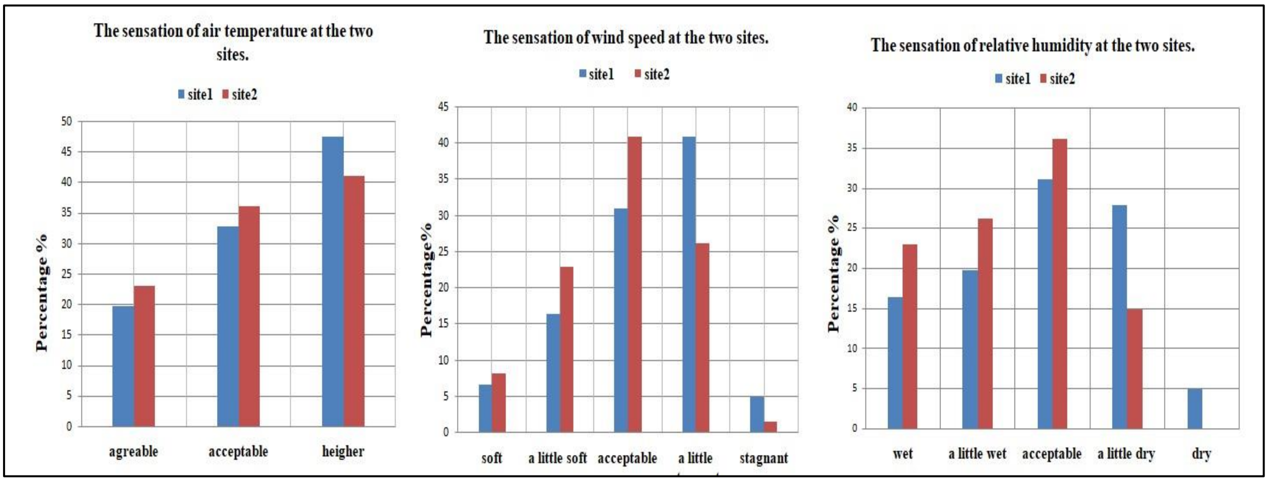

Figure 19: The sensation of air temperature, wind speed and relative humidity at the two sites (Source: Author 2023.)

Figure 20 shows the results of the description of the general level of comfort of respondents at the two sites; "unconfortable" is the most voted in both sites with a percentage of 52.5**%** for the first site and 42.6% for the second site; What demonstrates a strong correlation between thermal perception and the general comfort level of the people who use these public spaces.

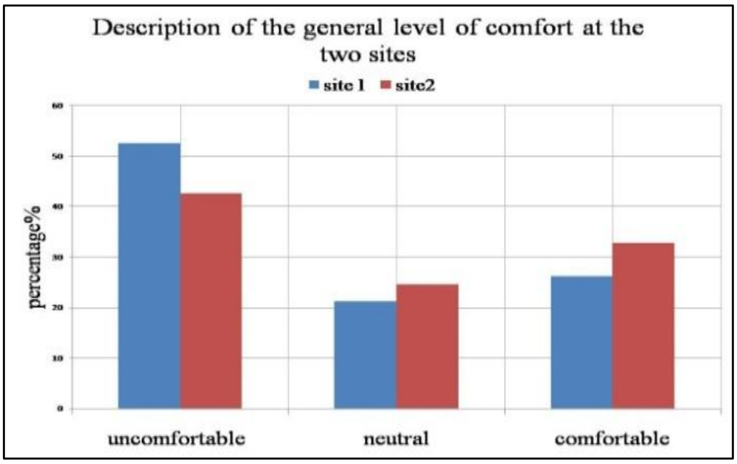

Figure 20: Description of the general level of comfort at the two sites (Source: Author 2023.)

The results of the vote on the acceptability of the thermal environment of the respondents in the two chosen sites are in line with the results of the vote on the thermal sensation and the vote on the general level of comfort. The percentage of respondents who voted in favor of the thermal environment at the two sites is shown in Figure 21; where "unacceptable" is the most voted in both sites with a percentage of 51.73% in the first site and 48.27% in the second site; followed by "acceptable" with 58.82% in the second site and 41.18% in the first site.

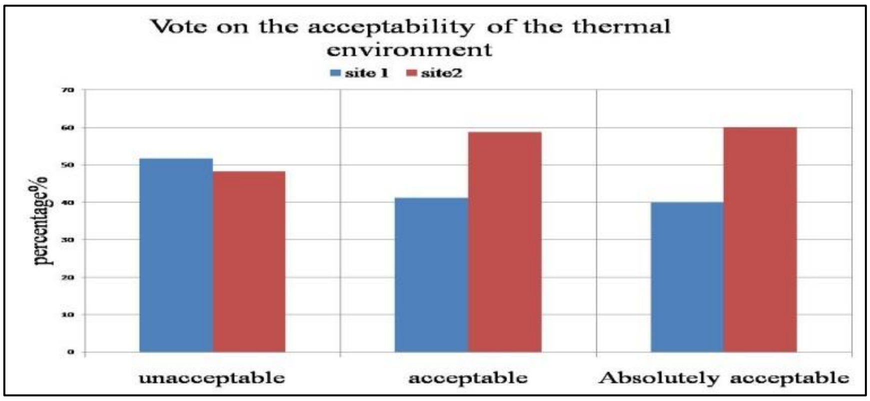

Figure 21: Vote on the acceptability of the thermal environment at the two sites (Source: Author 2023.)

An analysis of the results obtained from the questionnaire on the sensation of outdoor thermal comfort in the two selected sites shows that the second site, the Esplanade du 16 April, is the most comfortable compared with the first site, the Taghaste square; This result is strongly correlated with the percentage of vegetation present at the two intervention sites, where the 16 April esplanade had the highest percentage of vegetation cover (27.05%).

From all of the preceding results, it can be seen that the study's findings for the vote on thermal sensation seem appropriate, and Souk Ahars city is found to fit the criteria for the application of thermal sensation according to the ASHRAE seven-point scale.

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COMPARISON OF THE DIFFERENT PARAMETERS MEASURED IN THE THERMAL ENVIRONMENT:

Figure 22 shows a comparison of the air temperature, relative humidity, and wind speed at the two sites, via 6 measurement points, for 8 times between 6.00 a.m and 20.00 p.m.

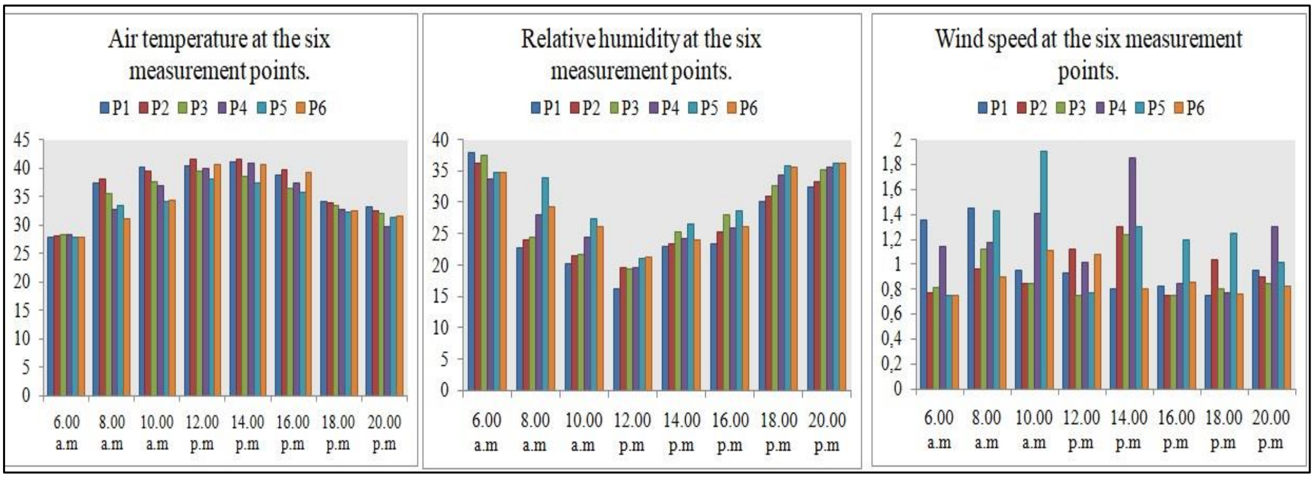

Figure 22: The metrological parameters measured at the two selected sites via the 6 points (Source: Author 2023.)

The highest air temperature value was 41.5°C recorded at 14.00 p.m. in the second point P2 of the first site, while the lowest was 27.8°C at 6.00 a.m. in the sixth point P6 of the second site.

Evaluation of the air temperature values shows that the third point P3 of the first site and the fourth P4 and fifth points P5 of the second site had the lowest air temperatures throughout the day, where $T_{a.average.P3}$=35.08°C ; $T_{a.\ average.P4}$=33.76°C and $T_{a.average.P5}$=35.08°C; this indicates that trees have a direct impact on the air decreasing temperatures on hot days. The temperature values measured throughout the day are lower at the second site than at the first site by $T_{a.average.S2}$ =32.71 °C and $T_{a.average.S1}$ =36.17°C.

For relative humidity; the lowest value obtained is 16.2% at 12.00 p.m in the first point P1 of the first site; so for the highest value with 37.9 % at 6.00a.m.

The evaluation of the relative humidity values shows that the highest averages of relative humidity throughout the day were recorded at point P3 of the first site and points P4 and P5 of the second site; where $RH_{.\ average.P3}$=27.98**%** **;** $RH_{.\ average.P4}$=28.22**%** and $RH_{.\ average.P5}$=30.53**%.** This means that trees have an impact on relative humidity. The relative humidity values measured at the two sites throughout the day showed that the second site had the highest average relative humidity, with $RH_{.\ average.S2}$= 29.30%; on the other hand $RH_{.\ average.S1}$=24.7% for the first site.

In addition, the highest recorded wind speed was 1.90 m/s at the fifth point P5 the second site, while the lowest was 0.75 m/s in the sixth P6. The highest average wind speed is marked in the fifth P5 and fourth points P4 of the second site; where $v_{a.\ average.P4}$= 1.20 m/s and $v_{a.\ average\ P5}$= 1.20 m/s. The average wind speed registered was higher in the second site than in the first, by $v_{a.\ average\ S2}$=1.092 m/s for the second site and $v_{a.\ average\ S1}$=0.95 m/s.

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These differences obtained in the values of various metrological parameters are directly related to the percentage of vegetation cover present in the two selected sites, which is higher on the second site with 27.05% compared to 9.33% on the first site.

THE EVALUATION OF THERMAL COMFORT LEVELS IN THE TWO SITES:

Figure 23 shows the horizon limits for the various six-point measurements in a polar coordinates diagram (fish-eye view) created using Rayman 1.2.

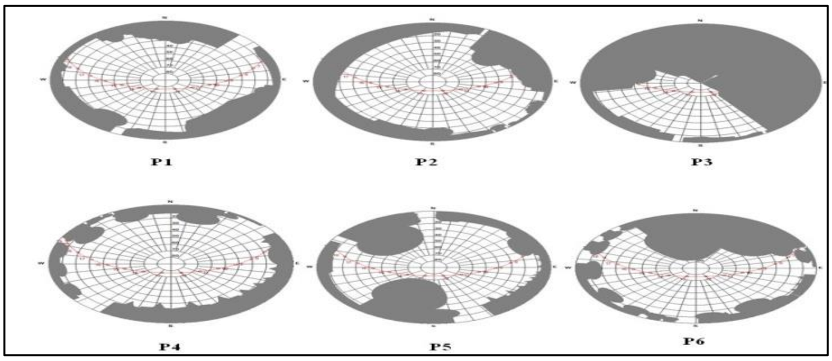

Figure 23: Polar diagram (a fish-eye image) of the 6 measurement points made by Rayman 1.2 (Source: Author 2023.)

In which the third point of the first site demonstrates the highest horizontal restriction of 69.6%; with an SVF equal to 0.304, mainly due to the presence of plane trees near the measurement points. In second place is the fifth point at the second site, near ash trees, with a horizon limitation of 41.3% and an SVF equal to 0.587 (see table 8). These results show that trees have an effect on reducing the value of SVF.

Table8: horizon limitation and SVF calculated by Rayman 1.2 (Source: Author 2023.)

Site	***Measurement point***	***Limitation of the horizon***	***SVF***
Site 1 : Taghaste square	**P1**	30.2%	0.698
	P2	32.3%	0.677
	P3	69.6%	0.304
Site 2 : 16 April esplanade	**P4**	26.4%	0.736
	P5	41.3%	0.587
	P6	41.1%	0.589

THE ASSESSMENT OF PET VALUES:

According to the PET evaluation, during the study period, four distinctive thermal comfort zones were observed: slightly warm; warm; hot strong and very hot (see table 9). The results show an increase in PET values in all 6 measurement points during the day; more precisely from 6.00 a.m to 16.00 p.m. The PET values recorded at 14:00 p.m. were extremely high, with a zone of peak temperature of 55.7 °C at the sixth point P6 in the second site for the whole period of clarity, resulting in significant thermal discomfort. The minimum PET value is 26.0°C obtained in fourth point P4 of the second site at 20.00 p.m. According to the obtained results, the thermal stress levels at the two selected sites, the Taghaste square and the 16th of April Esplanade, are quite similar at all six measurement points.

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Table 9: Assessment of outdoor thermal comfort using the PET thermal index at all 6 measurement points on both sites. (Source: Author 2023.)

Site	*Measurement point*	*6 :00 a.m*	*8 :00 a.m*	*10 : 00a. m*	*12 :00 p.m.*	*14 :00 p.m.*	*16 : 00 p.m.*	*18 :00 p.m.*	*20 :00 p.m.*
The Taghaste square	**P1**	27.3	46.9	54.8	54.6	56.2	49.9	35.4	30.2
	P2	28.1	48.7	54.0	55.6	55.3	51.1	34.8	29.5
	P3	28.2	40.9	46.1	53.9	51.6	42.4	34.2	30.1
The 16 April esplanade	**P4**	27.9	41.9	49.7	54.3	53.6	48.3	34.0	26.0
	P5	27.8	42.2	44.7	52.6	50.4	45.5	32.9	28.3
	P6	27.9	40.6	47.2	54.5	55.7	50.3	33.3	28.7

The results of the PET evaluation at the two sites indicate that the third P3 and fifth points P5 of the first site and the second site, respectively, had the lowest PET averages during the whole day ; with $PET_{average.P3}$=40.92°C and $PET_{average.P5}$= 40.55°C. This lowering of the average temperature shows that the shade provided by plane and ash trees that were present in the two sites and were close to the two measurement points, had a significant impact on the improvement of thermal comfort.

PET values were almost similar in points P1 and P2 of the first site where $PET_{average.P1}$=44.41°C; $PET_{average.P2}$=44.63°C. The PET values are lower in the second site than in the first site, with average values of PET $_{average\ .site\ 1}$=43.40°C and $PET_{average.site\ 2}$= 41.64°C .This difference between the PET averages of the two selected sites shows that the vegetation cover at the two sites is directly related to the difference recorded, since the 16 April esplanade has the highest percentage of vegetation cover (27.05%);on the other hand, the first site; the Taghaste square has a percentage of 9.33%.

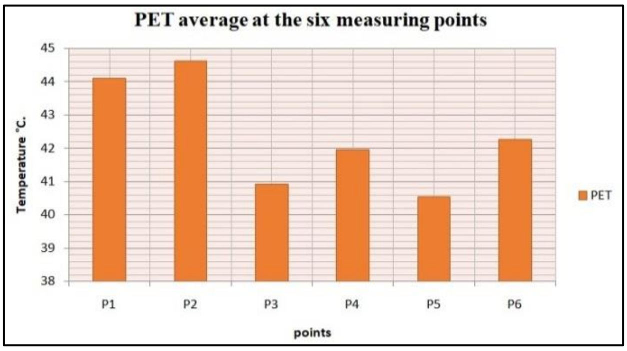

Figure 23: PET average at the six measuring points (Source: Author 2023.)

THE ASSESSMENT OF TMRT VALUES:

The results obtained (see Table 10) show that the Tmrt values are very similar to the air temperature values at 6.00a.m and 18.00a.m. The Tmrt values rise during the day,

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demonstrating the strong influence of solar time on Tmrt values; the highest value is 69.8°C recorded at the first point P1 of the first site at 14.00 p.m., followed by a value of 69.0°C p.m. at the sixth point P6 of the second site at the same time. On the other hand, the lowest Tmrt value was obtained in the fourth point P4 at 20.00 p.m. at the second site, where Tmrt =23.1°C

Table10: Tmrt values at the different measurement points at the two selected sites calculated by Rayman 1.2 (Source: Author 2023.) 51.14/42.24

Site	***Measurement point***	***6 :00 a.m***	***8 :00 a.m***	***10 : 00a.m***	***12 : 00 p.m.***	***14 : 00 p.m.***	***16 : 00 p.m.***	***18 : 00 p.m.***	***20 :00 p.m.***
The Taghaste square	**P1**	31.5	59.0	68.7	68.5	69.8	61.0	37.3	26.6
	P2	31.3	60.1	68.2	69.1	69.0	61.8	36.7	26.2
	P3	31.2	48.1	55.6	67.8	66.0	49.1	36.0	28.9
The 16 April esplanade	**P4**	31.7	55.7	65.3	68.2	67.5	59.9	36.1	23.1
	P5	31.0	55.6	61.9	67.1	65.6	57.7	35.6	25.8
	P6	31.3	54.2	63.6	68.3	69.3	61.0	35.3	26.0

Evaluation of the Tmrt values at the two selected sites shows that the third point P3 at the first site and the fifth point P5 at the second site have the lowest average Tmrt values throughout the day; where $Tmrt_{average.P3}$ =47.83°C and $Tmrt_{average.P5}$ = 50.03°C. In addition, Tmrt values were equal at points P1 and P2 at the first site, where $Tmrt_{average.P1et\ P2}$=52.8°C; and similar in points P4 and P6 of the second site, where $Tmrt_{average.P4}$=50.93°C; $Tmrt_{average.P6}$=51.12°C. The Tmrt values are lower in the second site than in the first site, with average values of $Tmrt_{average\ .site\ 1}$=51.14°C and $Tmrt_{average.site\ 2}$= 42.24°C. This difference in Tmrt averages between the two selected sites demonstrates that the higher percentage of vegetation cover in the 16 April esplanade (27.05%); is attributable to this decrease.

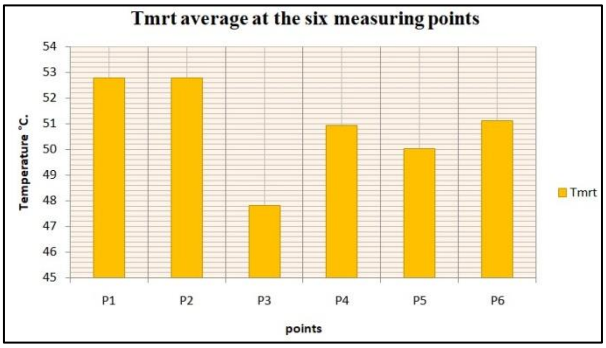

Figure 24: Tmrt averages at the six measurement points (Source: Author 2023.)

According to the results of the assessment of the calculated values of PET and Tmrt in the two sites via the different six measurement points, two thermal periods can be distinguished during the day; the first period is during sunrise and sunset (6.00 a.m and 20.00 p.m) and the second during daylight hours (8.00 a.m to 18.00 p.m). PET and Tmrt values were lower in the first period at all six measurement points; in which the maximum values of PET et Tmrt are PET_{max} =30.2°C and $Tmrt_{max}$=31.7°C . However, during the second period, the values of PET and Tmrt increased with a significant difference in the values recorded on the six measurement points in the two sites; in which the values of Tmrt are higher than the values of PET (see figure 25).

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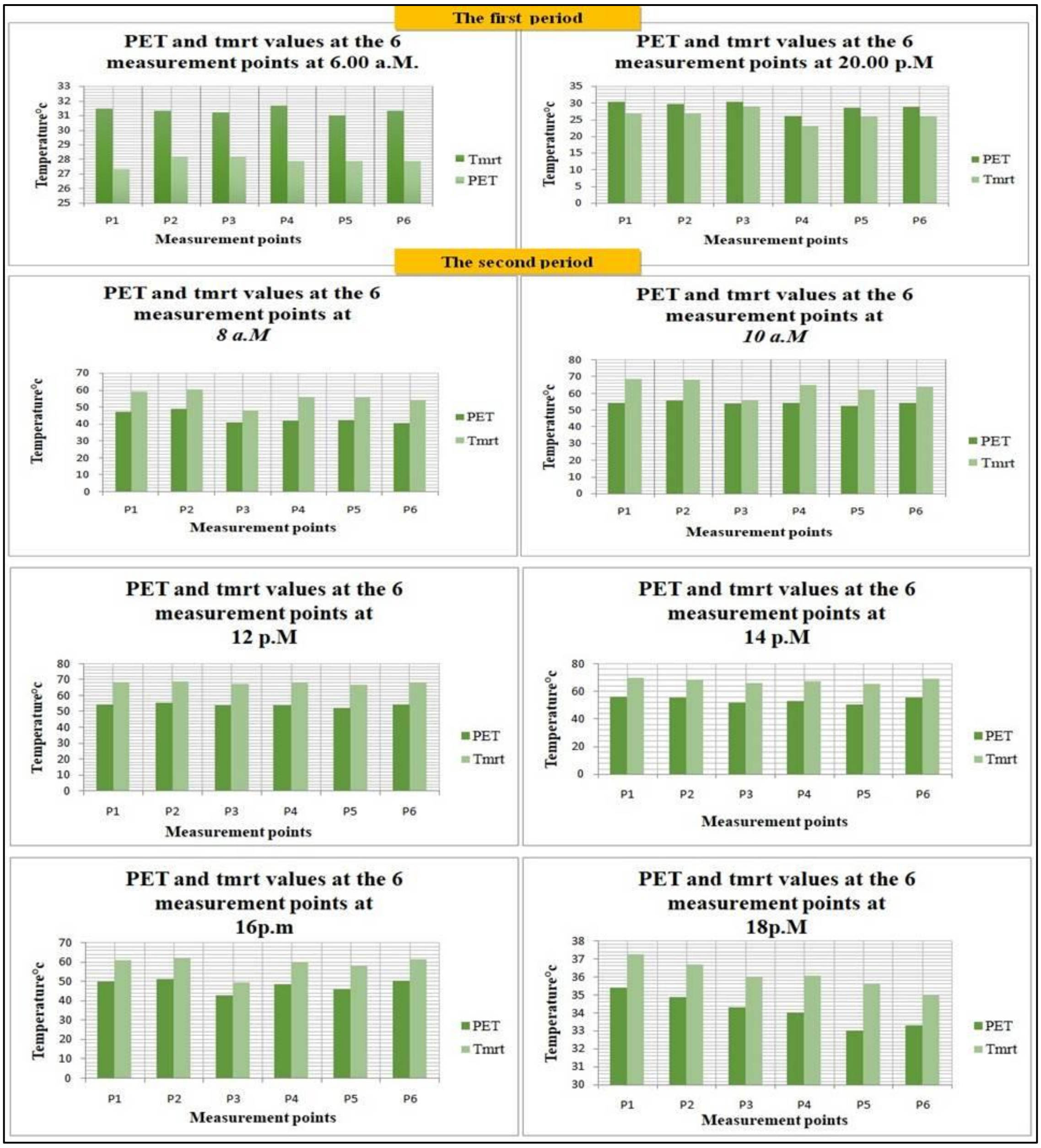

Figure 25: PET and Tmrt values at the six measurement points (Source: Author 2023.)

Figure 26 shows the PET and Tmrt values obtained from the six measurement points at the two selected sites in relation to the SVF throughout the day. We note that the minimum values of PET and Tmrt are recorded in the second thermal period (6.00 a.m and 20.00 p.m) at the vegetal points: P3 in the first site and P5 in the second site; these points have the lowest SVF values, where SVF $_{P3}$= 0.304 and SVF $_{P5}$=0.587; which shows that there is a relation between SVF and PET and Tmrt.

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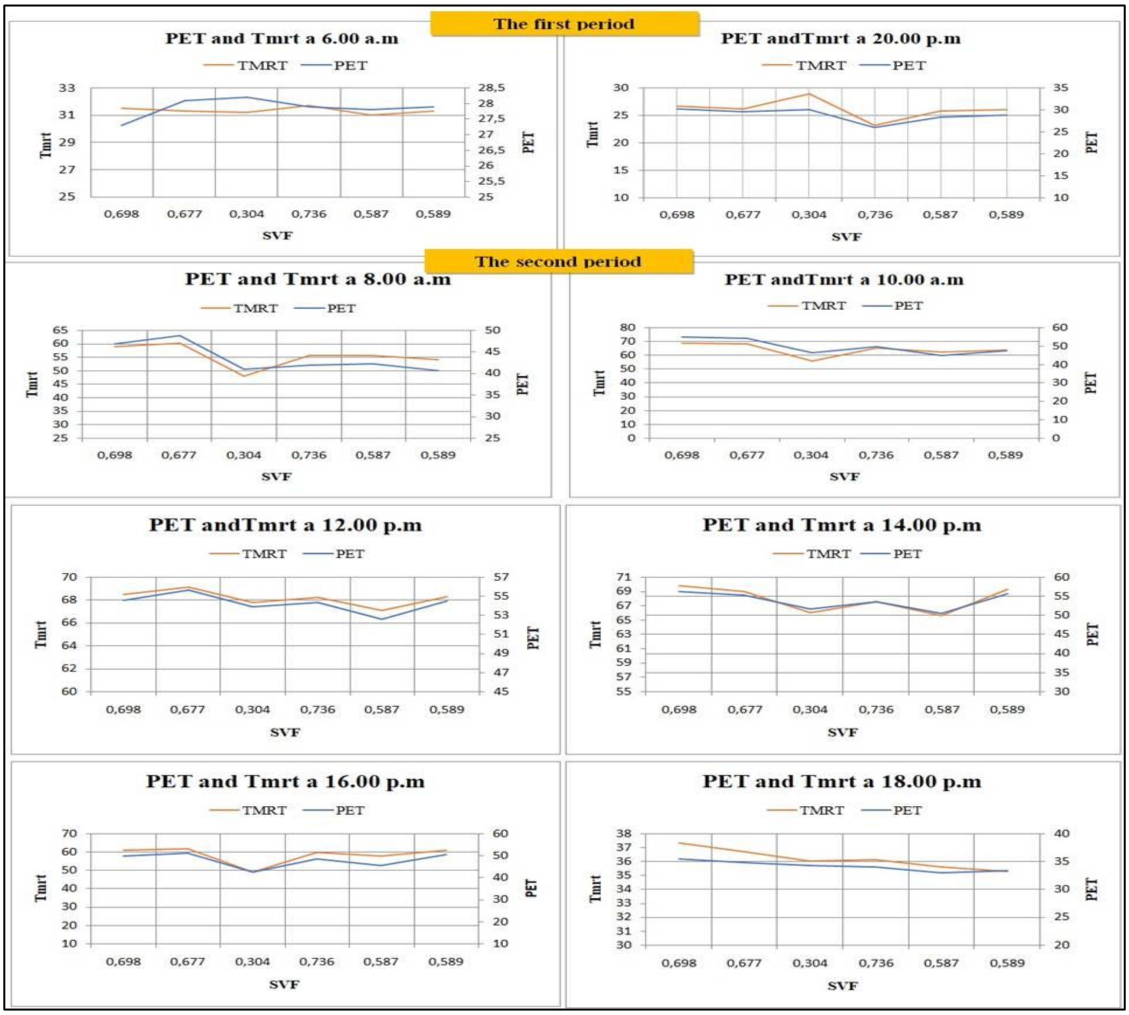

Figure 26: The variation between PET and Tmrt values in relation to SVF via the six measurement points (Source: Author 2023.)

DISCUSSION:

The main objective of this study was to assess the outdoor thermal comfort and to examine the effect of trees on the regulation of the urban microclimate. In Souk ahars city through two public spaces, the Taghaste square and the 16 April esplanade, measurements and values of thermal comfort were examined and compared at six different points in July 2022.

FACTORS INFLUENCING HUMAN OUTDOOR THERMAL COMFORT:

By comparing the results of the questionnaire survey which was carried out in two public spaces in Souk-Ahras city and the data from the meteorological parameters, measured via the six points (Table 4); and the results related to thermal comfort (section 2) ; The rating for thermal sensation is directly related to the air temperature T_a . This means that the sun's radiation is the main factor affecting people's thermal comfort outside in the summer because an increase in solar radiation directly causes an enhance in air temperature, leaving users of public spaces in a situation of thermal discomfort.

In the questions relating to the sensation of meteorological variables (Q5-Q6-Q7); Analysis of the findings showed that the following two meteorological factors: relative humidity and wind speed not significantly affecting and upsetting users of the two selected sites; contrary to the air temperature. Thus, after data analysis and comparison, it was shown that neither the relative humidity (RH) nor the wind speed (v_a) significantly affected the results of the thermal sensation vote.

In conclusion, we consider that air temperature (T_a) is one of the most important factors influencing a person's outdoor thermal comfort in the warmer seasons. The results of this study are consistent with those of (L. Zhang et al., 2020) and (Lai et al., 2014) .

THE EFFECTS OF TREES ON OUTDOOR THERMAL COMFORT:

The results of the metrological measurements show that the measurements carried out in the two sites under the plane and ash trees ; That of P3, P5, and P6 has the best atmospheric conditions, with the lowest air temperature, the highest relative humidity, and the fastest average wind speed. The differences between the mean air temperatures at the vegetation points (P3,P5,P6) and the free points(P1,P2,P4) are estimated at 1.62°C at the first site and 0.57°C at the second site; for relative humidity, the differences between the averages recorded in the vegetation points (P3,P5,P6) and the free points (P1,P2,P4) at the two selected sites are : 1.71% in the first site and 1.61% in the second, confirming the benefits of evapotranspiration and shading provided by the trees in these two outdoor spaces in summer; by modifying the capacity of the soil to receive direct solar radiation, the shade of trees has an impact on air temperature. These findings line up with those of (Li et al., 2022) ; (Speak & Salbitano, 2022) and (Fu et al., 2022). The second site, the 16 April esplanade, recorded the most favorable average climatic conditions, with lower air temperatures T_a, higher relative humidity RH and higher wind speeds V_a, compared with the first site, the Taghaste square because of its canopy; Findings align with this previous research (Kong et al., 2017; Meili et al., 2021).

In addition, according to the results shown in Table 8, the effect of tree shading has a positive impact on the values of an essential geometric measure for assessing the urban thermal environment; which is the SVF. In which the vegetal points in the two sites (P3; P5; P6) recorded the lowest SVF values (shaded area); and this means that the effect of shading has contributed to the reduction in the SVF value in these points, resulting in a situation of comfort in summer; this is consistent with the study by Lin et al.(Lin et al., 2010). The positioning of trees in a public space can also reduce the SVF sky view factor, as demonstrated by (Estacio et al., 2022). A previous scientific study proved that air temperatures are high in most outdoor spaces that have a high SVF. (Abdallah et al., 2020).

The Physiological Equivalent Temperature (PET) is an essential variable for assessing outdoor thermal comfort. The results of the analysis of the mean values of this variable in the two sites selected via the six measurement points revealed a difference in the levels of heat stress in the free points and the vegetal points; which is estimated at 3.6 °C at the first site (Taghaste square), and at 0.55 °C at the second site (16 April esplanade). This difference is largely due to the shading factor of the plane trees on the first site and the ash trees on the second site; the findings are consistent with (Ren et al., 2022).

The mean radiant temperature Tmrt is an important parameter that determines the human energy balance, especially on hot, sunny days; it has a significant impact on PET, which is in agreement with (Du et al., 2020). The free points of the two sites (P1; P2; P4) are the most

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influenced by the increase in direct solar radiation, hence the mean values of Tmrt in these points are 52.8°C in the first site (P1; P2) and 50.93°C in the second site (P4), which causes a warming effect in these outdoor spaces. A relation found between SVF and the other two thermal variables (PET and Tmrt) which is in agreement with (Shata et al., 2021); in which the lowest PET Tmrt values are recorded in points with a lower SVF (shaded area); this is in agreement with (Kim et al., 2022; Wang & Akbari, 2014) .

The percentage of vegetation cover at the second site has an impact on the decrease of PET and Tmrt values compared with the first site result of a larger shadow density; this is consistent with (Aboelata & Sodoudi, 2019).

CONCLUSION:

In Souk Ahras city, an empirical study was conducted in two public spaces and compared at six different times during the hottest month of the year, July 2022; a questionnaire survey on the sensation of thermal comfort was carried out, simultaneously with in situ measurements of the following microclimatic parameters: air temperature T_a, relative humidity RH and wind speed V_a, for the entire day. Using the Rayman 1.2 model, modelling and calculation were based on three main parameters: the sky view factor SVF, mean radiant temperature Tmrt and physiological equivalent temperature PET index. The conclusions of the analysis of the questionnaire survey and the modelling can be summarised as follows:

- Air temperature (Ta) is one of the most important factors influencing a person's outdoor thermal comfort in the warmer seasons.
- The results of the general thermal comfort level vote; the thermal acceptability vote (TAV) and the thermal sensation vote (TSV) are closely related.
- Evapotranspiration and the shading of trees modify the thermal perceptions of humans outdoors by affecting the outdoor thermal environment through lowering air temperature and increasing relative humidity.
- The shading of trees contributes to the reduction in the value of SVF, PET and Tmrt.
- The percentage of vegetation cover has a positive effect on reducing Ta, PET and Tmrt values.
- A significant relationship between SVF, PET and Tmrt.
- Urban and municipal planners must ensure that public places offer shade and prepare the outdoors for people in situations of acute heat stress.

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