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A PET-Based Evaluation of Urban Thermal Comfort and Pedestrian Activity in Hot Arid Cities

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Abstract

Thermal comfort significantly affects human activity in outdoor urban spaces, especially in hot arid cities. This study examines the relationship between microclimatic conditions and pedestrian movement along two streets with different orientations, Northeast-Southwest and East-West, in Biskra city, Algeria, during spring and summer. The methodological approach combined unobtrusive pedestrian observations using the gate-count method with thermal comfort assessment based on the Physiological Equivalent Temperature (PET) index using RayMan Pro software. Results show that pedestrian presence is not determined solely by micrometeorological conditions. In spring, a strong positive correlation was identified between PET and pedestrian attendance on the East-West Street, while the Northeast-Southwest Street showed no significant correlation. During summer, both streets exhibited negative correlations, with a notable decline in pedestrian numbers during the extreme heat period. These findings provide valuable insights for designing more thermally comfortable outdoor environments, encouraging public space use, and improving urban vitality.

Keywords: Thermal comfort; Urban Design; Pedestrian; Outdoor spaces; sustainability.

1. Introduction

Urban outdoor spaces promote social interaction, physical activity, and everyday mobility. However, the quality and usability of these spaces are strongly influenced by local microclimatic conditions, particularly in cities with hot and arid climates. Therefore, thermal comfort has become an important research topic in urban climatology and urban design. It is generally defined as the state of mind that expresses satisfaction with the surrounding thermal environment (ASHRAE Standard 55; ISO 7730). This psychological state results from complex interactions between environmental parameters such as air temperature, radiant temperature, humidity, and air velocity, and personal factors such as metabolic rate and clothing insulation (Li and Liu 2020; Zhao et al. 2024). Unlike indoor environments, where conditions can be mechanically controlled (Su et al. 2023; Arsad et al. 2023; Sakhri 2025), outdoor thermal comfort depends on understanding how urban form and microclimate interact to influence human experience (Xiong et al. 2022; Aghamolaei et al 2023; Shoghi et al 2025). Studies have demonstrated that thermal conditions in urban spaces influence pedestrian movement patterns, duration of stay, and the overall vitality of public spaces (Jamei et al. 2017; Vasilikou et al 2020; Adly and Galal 2021; Amen, 2021; Sakhri et al. 2022; Liu et al.2023; Li et al. 2025; Aziz Amen & Ali, 2025;). Thermal comfort is also affected by urban morphology, including street orientation, building height-to-width ratio, and sky view factor (Nasrollahi et al. 2021; Abd Elraouf et al. 2022; Wang et al. 2023; Zhan et al. 2024; Pouri et al. 2025; Lai et al. 2025). These factors significantly affect solar radiation exposure, airflow patterns, and shading conditions within streets. Street orientation, in particular, has been identified as a critical factor in determining solar exposure and heat accumulation in urban streets. For instance, east–west-oriented streets often experience longer periods of direct solar radiation during the day, leading to higher thermal stress levels than streets oriented north–south or northeast–southwest. As a result, the orientation of urban streets plays an important role in shaping the thermal conditions experienced by pedestrians and influences people's willingness to use outdoor spaces (Elnabawi and Hamza, 2020). The evaluation of thermal comfort in outdoor urban environments relies on various thermal indices, including the Universal Thermal Climate Index (UTCI) (Jendritzky et al. 2012), the Predicted Mean Vote (PMV), and the Physiological Equivalent Temperature (PET). However, PET has been widely adopted due to its ability to integrate multiple meteorological parameters, such as air temperature, wind speed, humidity, and mean radiant temperature, into a single indicator of human thermal perception. PET is expressed in degrees Celsius, making it easier for planners and designers to interpret and apply in urban design strategies. Matzarakis et al. 2007 established reference ranges for PET that correlate with thermal perception and physiological stress levels: values between 18–23°C indicate no thermal stress, while values exceeding 41°C represent extreme heat stress

requiring physiological adaptation. These thresholds provide a valuable framework for interpreting thermal conditions in relation to human well-being and behaviour.
Despite accumulated knowledge on thermal comfort assessment, street geometry effects, and pedestrian behaviour, studies focusing on hot arid cities, particularly in the North African context, remain limited. Most existing research has been conducted in temperate or humid climates in European and East Asian contexts. Cities in hot arid regions of North Africa often experience extreme summer temperatures that significantly affect outdoor activity patterns and urban livability. To address this research gap, this paper investigated the effect of thermal comfort on pedestrian attendance in Biskra, a hot arid city in Algeria. Compared with other published studies in this field, this paper used gate-count methods to evaluate pedestrian attendance in real time and combined them with the PET thermal comfort index. The study aims to: i) evaluate outdoor thermal comfort conditions using the Physiological Equivalent Temperature (PET) index; ii) analyse pedestrian attendance patterns through systematic field observations; and iii) examine the influence of street orientation and seasonal variation on the relationship between thermal comfort and pedestrian activity. By integrating thermal comfort assessment with behavioural observation, this paper contributes to a better understanding of how urban design can enhance the usability and thermal performance of outdoor spaces in hot arid cities.

2. Materials and Methods

This research paper involved two types of data collection. In the first stage, an in situ investigation using the gate count method was conducted to collect data on naturally occurring pedestrian activity along selected streets over two seasons. This approach enabled the collection of empirical data on pedestrian movement patterns under varying environmental conditions. The second stage involved assessing thermal comfort using Rayman Pro software, which facilitated analysis of the microclimatic factors influencing pedestrian behaviour (Figure 1). The details of each step are described in Sections 2.1and 2.2. The results are presented in Section 3.

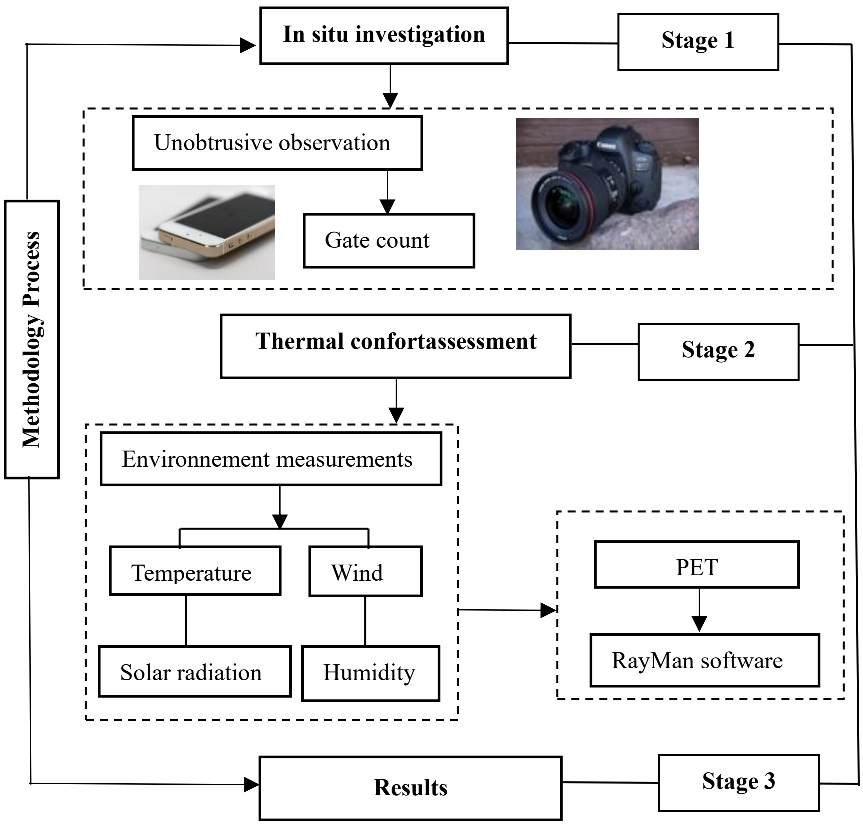
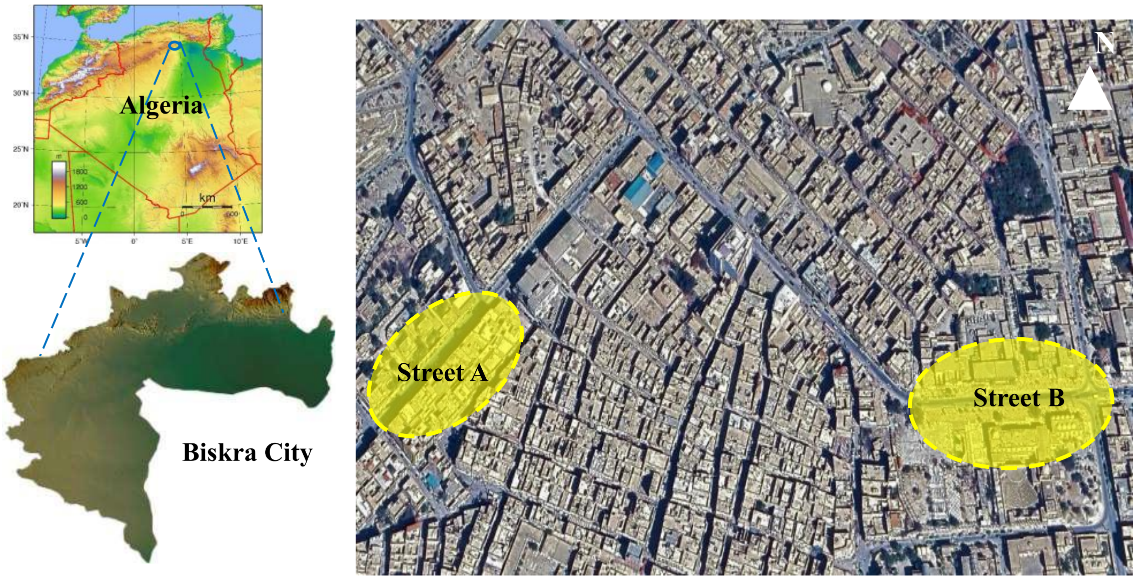


Figure 1. Methodology process (Developed by the Authors).

2.1. Study Area

The study was carried out in Biskra City, Algeria (latitude = 34.8° N, longitude = 5.733° E, altitude = 86 m). Biskra City is an oasis city located at the edge of the Saharan Atlas in southeastern Algeria. It is characterised by a hot, arid climate with an average summer temperature of 40.2 °C (Koppen–Geiger classification). Two case studies in the city centre are selected as the main sites of study (Figure 2). The street of Zaatcha (street A) is one of the city's first historic streets, located in the northeast-southwest of the city centre. The street is a very lively commercial street dominated by grocery shops, clothing stores, and barbecue kiosks, with multi-story buildings where shops occupy the ground floor, while the first to third floors house apartments, medical clinics, offices, and storage. The street of El-Amir Abed Lkader (street B) is the largest street in Biskra city, located in the East-west in the city centre. The street is a very lively administrative street that includes a cultural centre, a police station, and a bank. Both streets are characterised by: (1) density and mixed land use, (2) street connectivity, (3) street geometry with different ratios (H/W), (4) Aesthetic qualities and historic space. For urban morphology characterized, the Height-to-Width (H/W) ratio is calculated for both streets. Street A (NE-SW) has an average H/W ratio of approximately 0.61, with sections featuring continuous arcades, resulting in a lower sky view factor.

In contrast, Street B (E-W) is wider, with an H/W ratio of about 0.1 and, consequently, a higher sky view factor, leading to greater exposure to solar radiation.



Biskra city centre

Figure 2. Location of case studies in Biskra city centre, Street A (NE-SW) and Street B (E-W). (Developed by the Authors).

2.2. In situ Observation

Unobtrusive observation was applied using the gate count method to collect data about the number of pedestrians in the street. Camera video and panoramic pictures, i.e., 360° pictures, were used to carry out the observation. The camera's location was determined based on the space configuration, the length of the street, the presence of physical elements, the density of pedestrians in that area, and the absence of any viewing obstacles; in addition, the beginning and end of each pedestrian route were taken into account. Accordantly, we drew imaginary lines in the street; when people crossed the line in two directions, we counted them as walking people, if not we ignored them from the study (Figure 3). For street (A), the urban geometry contained arcades. Consequently, we counted pedestrians who walked under the arcade and along the two sidewalks. In street B, we counted the pedestrians on both sidewalks. The difficulty with this method resided in the difficulty to get permission to set up our camera in a strategic location, i.e., in the street (B) the camera set at third floor in the cutler Centre that allows as to register video and then count the number of pedestrians easily, in addition avoid the irritation factors such as trees and other people who get in the way of seeing. The observations were conducted at five time periods throughout the day: 8-10 a.m., 10-12 a.m., 12-2 p.m., 2-4 p.m., and 4-6 p.m. which represent the principal phases of daily urban activity, including both peak and off-peak pedestrian periods, while capturing variations in microclimatic conditions throughout the day. This temporal distribution enabled the examination of how changes in outdoor thermal comfort influence pedestrian behaviour. Each case study was observed for 5 to 7 minutes during both weekends and weekdays in March (spring) and August (summer). For micrometeorological conditions, measurements were taken at the airport station during the daytime, from 08:00 a.m. to 6 p.m. local solar time. Outdoor thermal comfort was evaluated using the Physiologically Equivalent Temperature (PET) index, as introduced in Section 1. PET values were calculated using RayMan Pro software (Matzarakis et al., 2007–2010), which integrates key meteorological variables, including air temperature (Ta), relative humidity (RH), wind speed (v), and global radiation (Gr), to quantify the thermal conditions experienced by pedestrians.

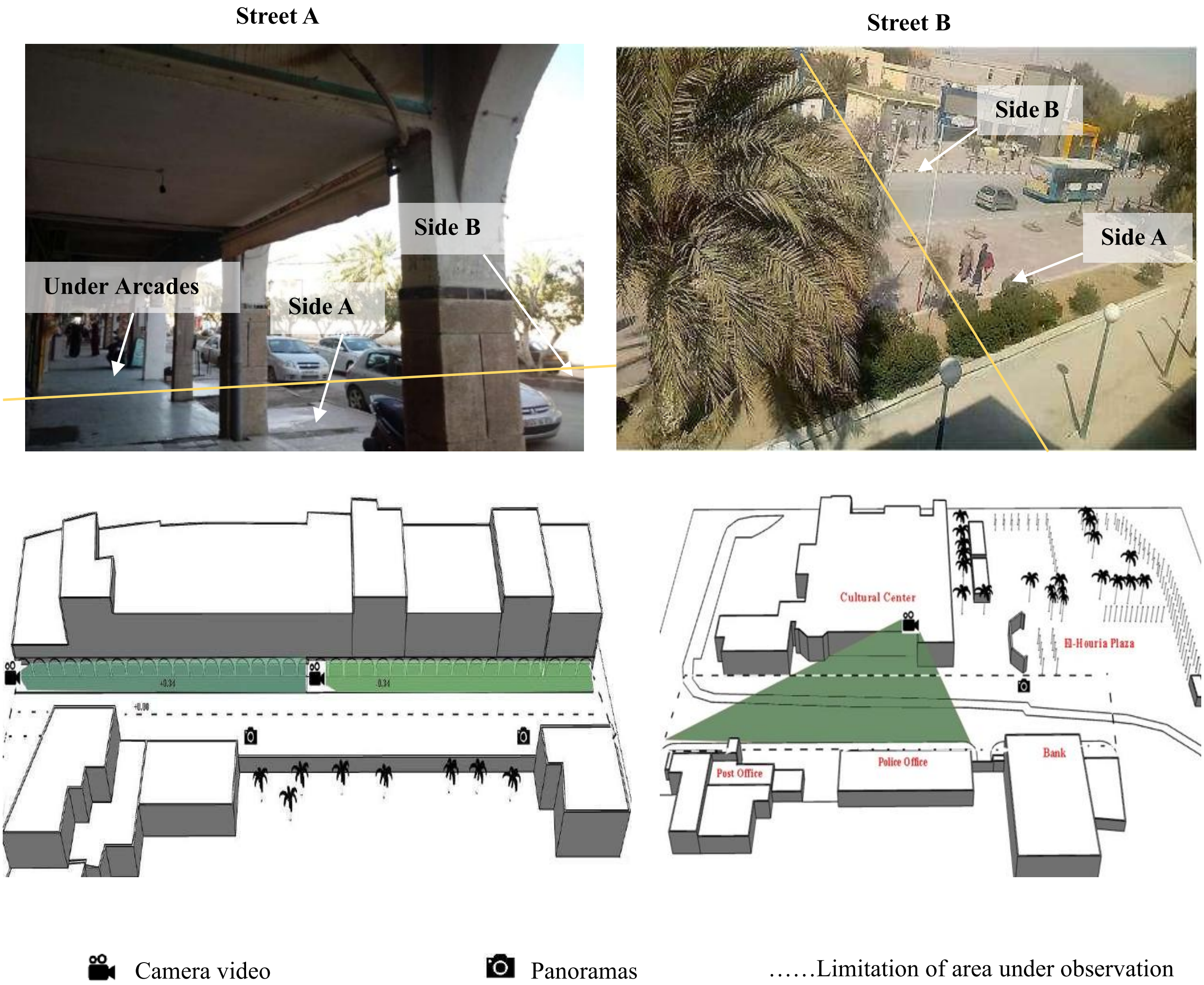


Figure 3. Three dimensions of streets describe the position of cameras and the imaginary line with yellow color in Street A t and Street B.

3. Results

3.1. Gates Counting

Table 1 presents the results of counting pedestrians on each sidewalk of the street. In the northeast-southwest street (Street A), in Spring, the results show that the number of people moving under the arcade is higher than on the other two sides, A and B, across the three periods of the day: morning, afternoon, and midday. In the morning and the afternoon, the number of people moving on side A and under the arcade is higher than on side B: more than 368 users in the morning and more than 290 in the afternoon, while on side B, 28 users in the morning and 73 in the afternoon. The street has its maximum attendance (use) during these two periods; however, during the midday period, the number of people starts to decrease. In Summer, when the day is too long and the sun is so harsh, the results show that the distribution of people in Street A changed approximately during all periods of the day. In the morning, the number of people moving on side A increased from 14 to 38, while movement under the arcade decreased from 58 to 45 until 12 a.m. At the same time, the number of people on side B decreased from 6 to 4 users until midday, when people moved under the arcade only (16 users). After midday, Side B reached its maximum occupancy, exceeding Side A's and the Arcade's.

The east-west street, in spring the movement of people in the side A was increasing in the morning from 51 users to 102 users and in the afternoon from 57 users to 119 users, as the same, the movement of people in the side B was decreasing in the morning from 106 users to 95 users and increasing in the afternoon from 61 users to 89 users, however at midday period, both sides A and B are known a decreasing of people's movement. During the hot period (summer), daytime movement in the street was lower, and the continuity of dynamic activity (people walking) decreased exactly at midday. In the morning, the number of people on side A increased from 14 to 32, and in the afternoon from 16 to 48. At the same time, the number of people on side B was around 48 in the morning and decreased to 32 in the afternoon. However, during the midday period, both sides A and B showed a decrease in the number of people. As a result, in the spring, side A has its maximum use compared with side B, while in the summer, side B has its maximum use compared with side A.

Table 1: Pedestrian Number during the experimental days and seasons.

		Pedestrian Number -Spring				
		Morning		Midday	Afternoon	
		8-10a.m.	10-12a.m.	12-2 p.m.	2-4 p.m.	4-6 p.m.
NE-SE street	Under arcade	103	149	120	109	138
	Side A	67	49	35	19	24
	Side B	6	12	0	18	55
E-W street	Side A	51	102	62	57	119
	Side B	106	95	40	61	89
		Pedestrian Number-Summer				
NE-SE street	Under arcade	58	45	14	16	36
	Side A	14	38	0	0	8
	Side B	6	4	0	0	48
E-W street	Side A	14	18	3	9	51
	Side B	24	38	18	15	29

3.2. Thermal Comfort Assessment

The environmental measurements were taken during the daytime, from 8 a.m. to 6 p.m. local time at the airport station, according to the observation days, and thermal comfort was quantified using PET calculated with Rayman Pro software. Table 2 presents the results of the PET assessment and the total number of pedestrians on both streets, comparing the two. For the NE-SW street (street A), people's space use increases during both seasons in the morning from 8 a.m. to 12 a.m., and in the afternoon from 4 p.m. to 6 p.m., while at midday from 12 a.m. to 4 p.m., it is lower than in the morning and afternoon periods. In the E-W street (case B), observation results show a disruption in the continuity of walking activities, especially during midday. In both periods, the number of pedestrians increases in the morning and afternoon but decreases around midday. Regarding occupancy density, both streets have higher occupancy in spring than in summer. When considering the total number of pedestrians over the two days and two seasons, the results confirm that the NE-SW orientation is more favourable in both seasons, with 681 pedestrians in spring and 341 in summer, compared to the E-W street, which has 782 pedestrians in spring and 219 in summer. These findings align with previous studies (Barakat et al., 2017).

Table 2. Physiological Equivalent Temperature (PET) and pedestrian frequency.

	Spring			**Summer**		
	Pedestrian Numbers		PET	Pedestrian Numbers		PET
Time	NE-SE street	E-W street	(°C)	NE-SE street	E-W street	(°C)
8-10a.m.	183	157	22	78	38	40.2
10-12a.m.	210	197	22.3	87	56	45.6
12-2 p.m.	161	102	27.3	14	21	48.2
2-4 p.m.	146	118	22.7	16	24	48.7
4-6 p.m.	217	208	16.8	92	80	45.1
Total	681	782	/	341	219	/

3.2. Thermal Comfort and People's Attendance

An attempt is made to correlate the number of pedestrians within streets with thermal comfort. A linear regression analysis is used to correlate the number of pedestrians with the PET value. In spring (Figure 4), a significant correlation (R^2 = 0.67, $p < 0.005$) was found between pedestrian numbers and thermal comfort in street B. The average air temperature was 18°C, and PET <0, which indicates that thermal environment conditions likely encourage more people to engage in outdoor activities. However, street A shows no significant correlation (R^2 = 0,51 $p > 0.005$) between pedestrian numbers and thermal comfort. This lack of correlation may point to other factors influencing pedestrian movement in this orientation, such as the street design, land use, or social interactions. As a result, the strong correlation in the E-W street during spring suggests that under moderate thermal conditions, pedestrian behaviour is highly responsive to microclimatic variations. As PET rises towards midday, attendance drops. The lack of a significant correlation in the NE-SW street is remarkable. This indicates that its design likely has the shading from arcades and taller buildings effectively decoupling pedestrian flow from thermal swings. The commercial vibrancy and historic character of street A may create a destination effect, where the purpose of the trip (e.g., shopping, socialising) overrides minor thermal discomfort.

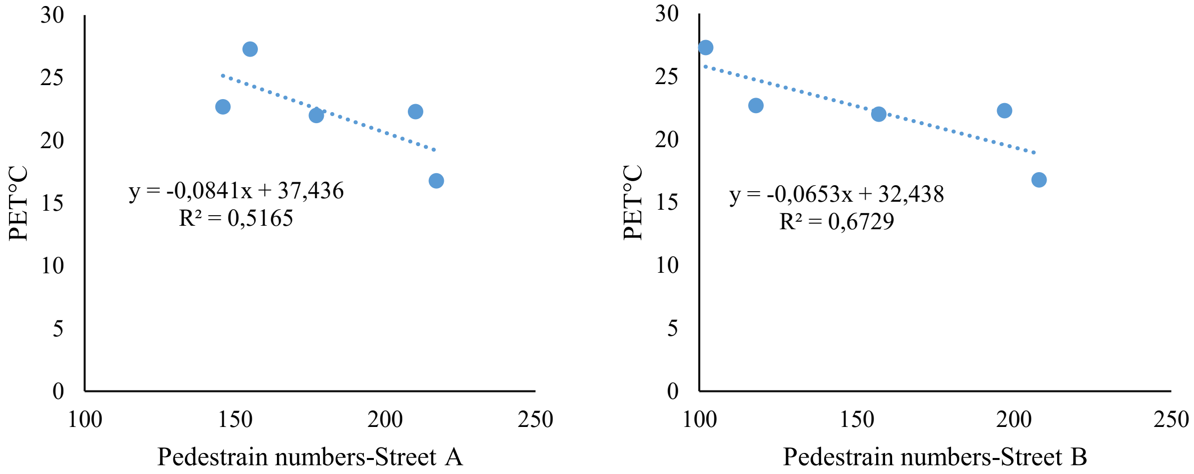


Figure 4. Pedestrian numbers as a function of PET in Spring.

In summer, both streets exhibit lower negative correlations (E-W: R^2 = 0.1; NE-SW: R^2 = 0.49) between pedestrian numbers and thermal comfort (Figure 5). The negative correlation implies that as temperatures rise, pedestrian activity tends to decrease, particularly on the E-W street. This could be attributed to heat-related discomfort, leading individuals to avoid outdoor environments during peak temperatures. The negative correlations in summer confirm the expected avoidance behaviour during extreme heat. The substantial difference in the R^2 values between the two street orientations during summer indicates that the NE-SW street may retain some pedestrian activity due to potential factors such as shading from buildings, arcades, or trees, which might mitigate heat effects. In contrast, the E-W street, likely more exposed to direct sunlight, appears less conducive to pedestrian activity as thermal comfort declines.

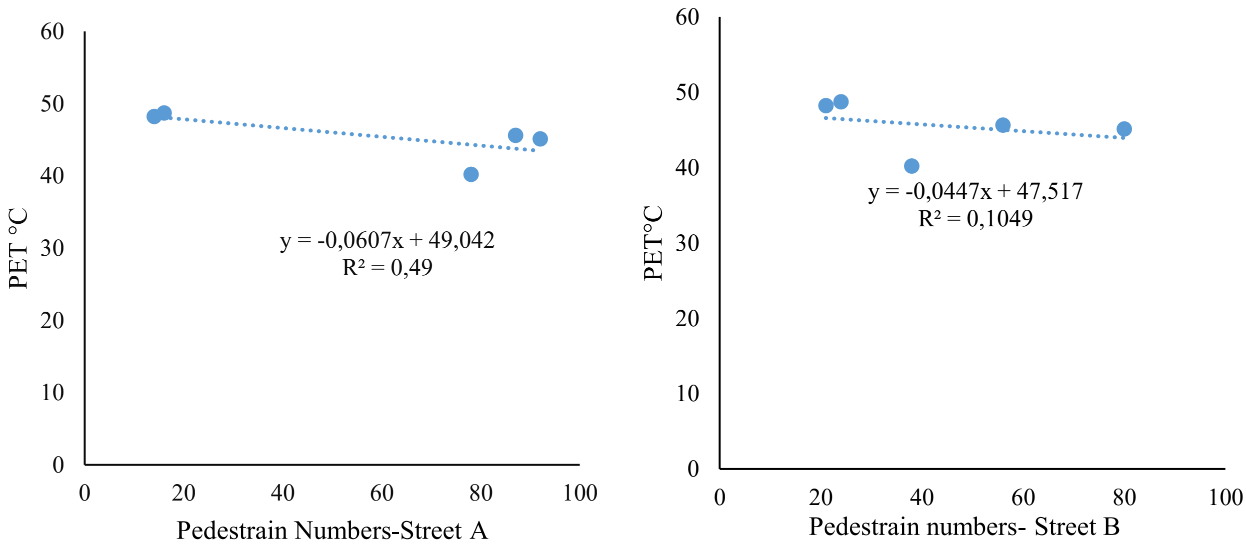


Figure 5. Pedestrian numbers as a function of PET in summer.

4. Discussion

4.1. PET-Pedestrian Correlation across Seasons

The Physiological Equivalent Temperature (PET) values recorded in Biskra ranged from 16.8 °C (spring afternoon) to 48.7 °C (summer midday). According to Matzarakis et al. 2007, PET between 18–23 °C indicates "no thermal stress," while values above 41 °C represent "extreme heat stress." Our findings show that pedestrian behaviour shifts sharply across these thresholds. In spring, when PET remained below 28 °C, pedestrian numbers on the E-W street correlated positively with rising PET ($R^2 = 0.67$, $p < 0.005$); people walked more as temperatures warmed from cool to comfortable. However, on the NE-SW street, no significant PET-pedestrian correlation appeared ($R^2 = 0.51$, $p > 0.005$), despite similar PET ranges. This indicates that PET alone does not drive behaviour; other attributes, such as street aesthetics, safety, and social vibrancy, may be more significant in attracting pedestrians.

In summer, PET exceeded 40 °C for most of the day, reaching 48.7 °C at 2–4 p.m. Under extreme heat stress, both streets showed negative correlations (E-W: $R^2 = 0.1$; NE-SW: $R^2 = 0.49$), confirming that once PET passes ~41 °C, pedestrians universally reduce outdoor activity.

4.2. PET Mitigation through Urban Morphology

The contrasting results between the two streets can be largely explained by their morphological characteristics. Street A (NE-SW): H/W ratio ≈ 0.61, continuous arcades, multi-story buildings. These features reduce the sky view factor, limit direct solar exposure during peak hours, and create a series of semi-shaded micro-spaces. Even when PET exceeds 45 °C, pedestrians continue to use the arcade (Table 1, summer: 36 users at 4-6 p.m.), whereas the unshaded sidewalks (Sides A and B) become almost deserted. Street B (E-W): H/W ratio ≈ 0.1, minimal overhanging shade. This geometry maximises solar radiation absorption and ground heat storage, leading to rapid daytime overheating. Consequently, pedestrian activity lower during midday (12-2 p.m.) in summer (only 3 and 18 users on Side A and B, respectively) and shifts entirely to morning and late afternoon hours. These findings support the recommendations of Abd Elraouf et al. 2022; Abdallah et al. 2022; Mahmoud et al. 2023; Gomaa et al. 2024 that manipulating the H/W ratio and providing artificial or natural shading are among the most effective strategies for improving outdoor thermal comfort. In hot arid cities, arcades (as seen in Street A) are a traditional and highly effective passive design solution that should be revived and maintained.

5. Conclusions

The study sheds light on the relationship between pedestrian attendance and thermal comfort on streets in Biskra city, despite their location in the heart of the city centre, with diverse land use and a variety of services. Both streets showed lower occupancy, especially during the summer. This may be attributed to the quality of the physical environment, including direct sun exposure, street geometry, and the height-to-width ratio (H/W), which directly affects the outdoor thermal environment. The findings confirm that the density of street occupancy reflects the vitality of the city. The segregation of pedestrian traffic, especially during peak periods and in the summer, negatively impacts the quality of the space. The streets become deserted and unusable during these periods. The results further indicate that thermal conditions can significantly influence the attractiveness and functionality of urban streets, regardless of their strategic location within the city centre. Although both streets benefit from commercial activities and a continuous flow of potential users, pedestrian attendance was strongly associated with variations in thermal comfort throughout the day and across seasons. This demonstrates that urban vitality depends not only on land-use diversity and accessibility but also on the environmental quality experienced by users. The comparative analysis revealed that urban form characteristics, particularly street orientation, shading availability, and geometric proportions, play a crucial role in moderating outdoor thermal conditions and supporting pedestrian activity. These findings reinforce the importance of integrating microclimatic considerations into the planning and design process from the earliest stages of urban development. In hot-arid cities such as Biskra, improving thermal comfort should be regarded as a prerequisite for enhancing the usability, inclusiveness, and sustainability of public spaces. By establishing a clear relationship between thermal comfort and pedestrian attendance, this study contributes to a better understanding of how climate-sensitive urban design can support more active and resilient urban environments.

To enhance the quality of urban spaces and encourage their use at any time or in any climate, urban design strategies must be reconsidered. The main recommendations are as follows:

- **Prioritise shading in E-W oriented streets:** Because these streets experience prolonged solar exposure, fixed shading devices (pergolas, tensile structures) or deciduous trees should be installed along sidewalks. Our data show that even a modest reduction in PET (from >48 °C to ~40 °C) could enable pedestrian activity during morning and late afternoon hours.
- **Optimise the H/W ratio:** Where possible, new developments should aim for H/W ratios between 0.5 and 1.0 on east-west axes, or incorporate colonnades and arcades, as seen in Street A.
- **Integrate green infrastructure:** Trees, green walls, and small water features can provide evaporative cooling.
- **Design for temporal adaptability:** Encourage mixed-use and vibrant street frontages (shops, cafes) that attract pedestrians during thermally moderate morning and evening hours, and provide shaded rest areas for midday periods. This “thermal-aware programming” can extend the usable time of public spaces.

These findings provide actionable insights for urban planners and designers seeking to improve outdoor thermal comfort and pedestrian vitality in hot, arid cities like Biskra.

5.1. Limitations of the Study

While this study focused on two street orientations and two seasons, future research should examine a wider range of urban morphologies and include surveys of subjective thermal perception. Further studies could also investigate the role of evaporative cooling and water features in enhancing pedestrian comfort during extreme summer conditions.

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Conflicts of Interest

The authors report no conflicts of interest

Data Availability Statement
The data that support the findings of this study are available on request from the corresponding author, upon reasonable request.

Institutional Review Board Statement
This study involved unobtrusive observation of pedestrians in public spaces. No interaction with individuals occurred, and no personal or identifiable information was collected. Therefore, ethical approval and informed consent were not required. The research was conducted in accordance with accepted ethical standards, including the Declaration of Helsinki.

CRediT Author Statement
Conceptualization; H.S; Methodology; H.S; Writing – original draft; H.S; Writing H.S and R.R– review & editing; H.S and R.R

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