Urban morphology, outdoor thermal comfort and walkability in hot, dry cities: *Case study in Sidi Okba, Algeria*

Nassima Mouada^{1*}, Noureddine Zemmouri¹, Rim Meziani²

¹ Department of Architecture, University of Biskra

² Department of Architecture, Abu Dhabi University

* Corresponding Author, Email: nissmouada@gmail.com

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Abstract: Urban morphology should carefully consider climatic and behavioural aspects for hot arid climates. To put these insights into practice, this study aims to investigate different urban environments in the hot, dry city of Sidi Okba, (Biskra) during the summer season and defines the upper and lower limits of the thermal comfort range for the PET index. A second aim is to quantify the walkable environment and highlight the relationship between urban morphology and walking behaviour. The study was based on physical measurements combined with a questionnaire survey and a walking audit instrument. The findings from this research show that urban morphology, defined by building density, height/width (H/W) ratio and tree density, is significantly associated with the outdoor thermal conditions and potential pedestrians over short distances. The study also shows that in order to provide a comfortable climate and to increase pedestrian choice in the urban environment, the public space should include high building density, combined with deep streets with a high connection between them, and a large amount of vegetation along the lower parts of streets. This type of design has a positive effect on the walkability score of public spaces.

1. INTRODUCTION

Due to the harsh weather conditions and excessive level of urbanization in Algeria's Saharan cities, urban planning in these cities has focused more on automobile usage and less on people's physical activity. This strategy has created an automobile-dependent society. As a result, walking has gradually decreased as a mode of transport. Sidi Okba is one of the most important hot, dry cities in Algeria. With an area of 254.55 km², it is located about 20 kilometres south-east of Biskra, between 34°45' N and 5.54° E. In Sidi Okba, urban forms can typically be classified into three distinct development types, each representing a different period of time, which are traditional (A), modern (B) and extensions (C). The traditional form, which has been developing around a large group of palms with a high level of built density, was the prevailing type of urban development prior to the colonial war, and a second type of urban form flourished during the years following the war. During the period beginning in the 1980s, the government developed a new urbanization

law, reflected in the general layout of the city by a low-built density with more regular planning and wide streets. However, the city's population growth in recent years created the need for expanding to the surrounding areas, creating a new urban form with wide streets and big open areas. [Figure 1](#) indicates the location of Sidi Okba in Algeria, [Figure 2](#) presents the relative size of each urban form of the city. The history of neighbourhood development in Sidi Okba is one of different microclimates with differential support for pedestrians, especially affecting the walkability of outdoor environments. In the context of supporting sustainable design practices, one of the main ways that sustainability can be achieved is through the improvement of the microclimate design parameters and the advancement of a walkable environment. This article addresses the issue of the diversity of urban morphology present in the hot, dry city of Sidi Okba and its relationship with outdoor thermal sensation and walking behaviour within different public spaces across the three neighbourhood types being discussed.

Figure 1. Location of Sidi Okba (left). Location of Sidi Okba in Biskra (right)

Figure 2. Google Earth picture of Sidi Okba city showing the three neighbourhood types

2. LITERATURE REVIEW

Urban morphology, outdoor thermal comfort, and walkability are generally given little importance in urban planning processes. Moreover, few studies have dealt with the relationship between urban form and microclimates. In the city of Fez, ([Johansson, 2006](#)) found that urban geometry, defined by the height/width (H/W) ratio, plays an important role in the regulation of outdoor thermal conditions; he found that compact urban form typically found in old

parts of the city, characterized mainly by very deep canyons, has a cooling effect during the daytime and contributes to the achievement of outdoor thermal comfort, while the dispersed form creates an extremely uncomfortable environment. ([Mahmoud, 2011](#)) investigated the microclimate and thermal sensation of an urban park in Cairo, Egypt during the hot and cold seasons. The study was based on field measurements and a questionnaire survey. Using the physiologically equivalent temperature (PET) index, the result showed an alteration in the sensation of human comfort between different landscape zones and it was argued that most of the landscape zones in the study are thermally comfortable within a range of 22 – 30 °C PET in the hot month studied (June). Another study carried out by ([Ali-Toudert & Mayer, 2006](#)), attempted to understand the impact of the H/W ratio and street orientations on thermal comfort in the desert city of Guardia (Algeria). It demonstrates, through a simulation using Envi-met 04, that the ratio affects both incoming and outgoing solar radiation, and the result of simulation shows that a deep street canyon with orientation (north/south) is preferable for achieving thermal comfort during the summer time. In addition, vegetation is considered an important element in improving urban microclimates and outdoor thermal comfort in urban spaces. Regarding this topic, ([Bernatzky, 1977](#)) shows through field measurements in a central German city that the presence of an urban square contributes to a decrease in air temperature of 3 to 3.5°C, an increase in the relative humidity of the air of 5 to 10%, and creates fresh air in an outdoor environment. In addition to the thermal environment, walking behaviour as an issue in outdoor spaces has received increased research attention. Evaluating the relationships between urban morphology and physical activity is a difficult process mainly due to the many parameters involved in its assessment, in this context, some studies have been carried out around density, diversity and connectivity of the street network ([Ewing & Cervero, 2010](#); [Grasser et al., 2013](#)). The general conclusion is that people tend to walk more in areas with high neighbourhood densities combined with high street connectivity, as well as where there is higher mixed land use. ([Carmona et al., 2012](#)) indicates that a high building density is likely to generate more pedestrian traffic because it leads to a sense of enclosure and humanizes public space; in order to maintain an intimate and comfortable enclosure, the authors state that the H/W ratio should be equal to 2.5, ([Jacobs, 1993](#)) suggesting that the proportion of building height to street width should be at least 0.5. This study recommends proportions as high as 2.5 and as low as 0.5. In addition, tree density can moderate the scale of public space.

Previous studies provide useful insights into the behavioural aspects of pedestrians, however, they include only physical features, omitting thermal sensation and its effects on the decision to walk. Moreover, they were not conducted in hot, dry cities; there is thus a need for further studies within this challenging environment. This research, therefore, focuses on the hottest summer conditions in the hot, dry city of Sidi Okba (Algeria). The main aim is to evaluate the physical parameters of different public spaces that may influence people's subjective perception and make one space more inviting and walkable than another., this includes finding the lower and upper limits of the thermal comfort range of the PET index that is acceptable for walking. The study is focused on micrometeorological measurements combined with a questionnaire survey and audit instrument. As a result of the findings from this research and the literature reviewed in this paper, recommendations for existing actions for urban planners are proposed to help to create design proposals according to climatic requirements.

3. MATERIAL AND METHODS

3.1 Measurement location and time periods

This study was carried out in eight public spaces within the three neighbourhood types being discussed; for each neighbourhood a section was taken as a study area (see [Figure 2](#)). In the old city, the spaces selected were one street, one canyon and a passage with palm trees on either side. In the new part of the city, the chosen areas were one street, one garden and one road. The extension part of the city contained two measurement locations, one playground and one road. These spaces represent the most common types of environments for each neighbourhood in Sidi Okba, and they were particularly selected because they comprise a variety of morphology factors, including the built density, vegetation and H/W ratio (see [Table 1](#) [Figure 3](#)). The investigation was carried out during the hottest month of the year (July 2017), the fieldwork was scheduled for every 4 hours of the measured days, starting from 8:00 am to 8:00 pm.). The studied spaces are shown in [Figure 3](#). The investigation was carried out during the hottest month of the year (July 2017), the fieldwork was scheduled for every 4 hours of the measured days, starting from 8:00 am to 8:00 pm.

Table 1. Morphological characteristics of the measurement locations in three neighbourhoods

Neighborhood	Density	Location	Space	H/W	Orientation	Vegetation
Old	86.70%	1	Street 1	0.86	N-S	1 tree on 10 m
		2	Canyon	2.50	SW-NE	0 tree
		3	Passage	1.53	E-W	1 tree on 2m
Modern	63%	4	Street 2	0.66	N-S	0 tree
		5	Garden	0.10	N-S	1 tree on 4m
		6	Road 1	0.16	E-W	1 tree on 8m
Extension	17.71%	7	Play ground	0.08	NE-SW	0 tree
		8	Road 2	1.10	NE-SW	0 tree

3.2 Physical measurements

Field measurements of thermal environment parameters were taken, including air temperature, mean radiant temperature, relative humidity and wind speed; these values were obtained from a mobile measurement station, where all instruments are certified to ISO standard 7726 ([ISO, 1985](#)) and positioned at 1.10 m above the ground for measuring air temperature, air humidity, and wind speed measurement.

Figure 3. The three neighborhoods of Sidi Okba

3.3 Questionnaire survey

While field measurements were being carried out, a questionnaire survey was performed, consisting of 180 participants (59% males and 41% females), undertaken four times a day at 8:00, 12:00, 16:00, and 20:00. The majority of participants were between 20 and 60 years old. This questionnaire was conducted in eight different public spaces during the hot season (July 2017), and was validated by significantly fewer participants. The final version contains two parts. The first part covers questions about a participant's personal information (age, gender, clothing, reason for being in the space, etc.), and also deals with outdoor thermal comfort, applying a 9-point scale of thermal sensation votes (TSV) defined by ASHRAE Standard 55 ([ASHRAE, 2004](#)). The percentage of people dissatisfied (PPD) was assigned for each public space, where feeling uncomfortable is defined as a choice of "No" in response to the question, "Do you perceive the thermal environment as comfortable or not?" The second part of the questionnaire includes behavioural questions, based on a selection of questions from several studies ([Azmi, Karim, & Amin, 2012](#); [Clemente et al., 2005](#)); included in the evaluation were the participant's point of view about the walkable environment, the reason for walking, the best time to walk, and which factors mostly affect their walking speed. The questions were as follows in [Table 2](#).

Table 2. Questionnaire survey used in this study

Part 1 : Outdoor thermal comfort				
Sex:	Female	Male		
Age :	≥ 25	21-35	36-50	51-60
Live in the neighborhood	work in the neighborhood			
How do you feel the climate at this time in this space?				
-4 very cold	-3 cold	-2 cool	-1 slightly cool	0 comfortable
+1 slightly warm	+2 warm	+3 hot	+4 very hot	
How would you prefer the climate in this space?				
Air Temperature:	more	less	no change	
Air Humidity:	more	less	no change	
Wind Speed:	more	less	no change	
Sun:	more	less	no change	
Do you perceive the thermal environment as comfortable or not?			Yes	No
Part 2: Walkability				
What is the reason for walking in this space?				
Walking as a leisure activity		Walking for utility		
Which moments do you prefer more to walk in this space?				
Early morning (8 am)				
Lunch period (12 am)		Afternoon (4 pm)		Evening (8 pm)
When you walk your walking speed affected more by :				
Pedestrian density:	increase your walk speed	decrease your walk speed		
Quality of texture floor:	increase your walk speed	decrease your walk speed		
Direct solar radiation:	increase your walk speed	decrease your walk speed		

3.4 Walking audit instrument

An audit instrument was developed by selecting specific criteria from the literature. All criteria are listed in [Table 3](#). The walkability audit forms incorporate a rating for all criteria. Each criterion can be rated on a scale of 0-3, where 0 is unacceptable and 3 is acceptable; the final score of walkability was obtained by collecting all criteria scores.

Table 3. Walkability audit used to collect environmental data of the eight study spaces

Criteria	Explication	Method
Density	Totale surface of building (m ²) devised to total surface of the zone covered by the study (m ²)	0.Very low density 1.low density 2.Medium density 3.High density
Design	Street connectivity	0.one possible direction 1.Two possible directions 2.three possible direction 3.more than three possible direction
Diversity	Land-use mix	0.No land use 1.One land-use 2.Two land- use mix 3.Three or more land-use mix
Enclosure	The degree to which public spaces are visually defined by vertical elements	0.Space is not shaped by vertical elements 1. Space partially shaped 3. space is shaped by vertical elements
Human scale	The proportion of building widths and building heights : (H/W) ratio	0. H/W: Lower or higher than 0.5 2.5 3. $0.5 \leq H/W \leq 2.5$
	Vegetation and trees	0.0 tree on 100 m 1.1 or 2 trees on 100 m 2. more than 2 on 100 m 3. more than 3 trees on 100 m
Human speed	Amount of shade that influences a person's normal walking speed	0.No shade in the space at 8:00 1.Space partially shaded at 8:00 3.space shaded at 8:00

Thermal comfort	At 8:00 am, the degree of falling the mean values of PET index within the thermal comfort range of (24 °C – 32 °C)	0.MPET does not include in the thermal comfort range. 3. MPET include in the thermal comfort range
Score of Walkability:.../24		

4. RESULTS

4.1 Microclimatic variation

[Table 4](#) shows the environment data for all measurement sites. Data were obtained across three measurement days from 11 July to 13 July 2017. These days were clear and calm summer days, with a daily mean air temperature of 37.45°C and a mean wind speed of 1.15 m/s, where the relative humidity varied between 17.34% and 22.56%. The field campaigns took place between 8:00 and 20:00. Analysis of the results showed microclimatic differences between the three neighbourhoods of Sidi Okba. For air temperature (Ta), the values in the old part of Sidi Okba were considerably lower than the two other neighbourhoods, where the average air temperature varied between 33 °C and 35 °C, cooler than the extension part by 5 °C and 4.82°C respectively. This is mainly because of the combined effect of the urban density, H/W ratio and vegetation density. In fact, the high levels of these parameters in the old city of Sidi Okba was reported to have resulted in a reduction of both incoming and outgoing solar radiation, leading to a considerable reduction of temperature values.

Table 4. Measurement data: air temperature (Ta, °C), relative humidity (RH, %), wind speed (W, m/s), direct solar radiation flux (SF, W/m²)

Space	Ta (°C)	W (m/s)	RH (%)	SF(W/m ²)
Street 1	35.98	0.63	19.28	254.60
canyon	35.50	0.28	18.24	100.98
passage	33.42	0.69	23.03	80.20
Street 2	36.81	0.51	14.41	253.25
Garden	38.25	0.77	20.43	249.40
Road 1	40.75	0.63	14.24	697.66
play ground	39.96	0.98	13.07	709.79
Road 2	38.25	0.70	13.21	163.07

As stated by ([Dursun & Yavas, 2015](#)), a cooling effect is expected to be more significant in high density urban areas due to the existence of obstacles to solar radiation. Results also illustrate that locations with lower air temperature recorded a higher relative humidity, and the highest values were recorded in the old city, reaching 23.03%, which is due to shading by palm trees combined with the cooling effect of evapotranspiration processes, whereas the lowest values of relative humidity were noted in the playground. For the wind speed, the values are negatively affected by a higher H/W ratio and urban density. It is notable that all spaces with low H/W ratios (two roads and one park) recorded higher values of wind speed, varying between 0.63 m/s and 0.70 m/s. In terms of solar radiation, the ENVI-met simulation was used to examine the distribution of direct solar flux reaching public spaces over the period of measurement (8:00 am - 20:00 pm). The highest values of DF are noticed in spaces which have E-W, NE-SW, or SW-NE orientations, except for the canyon and the passage with the palm tree on either side; these two spaces

received only limited direct solar radiation, reaching 100.98 and 80.20 Watt-hours per square metre respectively, due to the high proportion of H/W combined with the shading effects of palm trees. This is followed by spaces with N-S orientations, which recorded values of DF between 249.40 (W/m^2) and 254.60 (W/m^2) (see [Table 4](#)).

4.2 Subject thermal sensation in different urban spaces

The percentage of subject votes for all spaces is presented in [Figure 4](#). The result shows that in the hottest day people's thermal sensation in Sidi Okba is between slightly warm (-1) and very hot (+4). It is clear that the highest percentage of people voted within the interval (+3, +4), whereas the lowest percentage of respondents accepted the thermal environment. According to ([Fanger, 1970](#)), the range between -1 and +1 should represent the range of acceptable conditions, but in this study in the morning 78.45 % of people who voted +2 consider the thermal environment to be comfortable (see [Table 6](#)). This result illustrates that people who live in hot, dry cities may accept higher air temperatures in summer. The analysis of PET, TSV and PPD indexes is shown in [Table 5](#). For the PET index, results revealed that the highest value of 47.15 °C was detected in the playground, whereas a minimum value of 33.43 °C was found in the passage with palm trees on either side. The results of the PPD analysis shows that the maximum dissatisfaction was found in the park, road 1, playground and road 2. However, the preferred spaces were street 1, canyon, and passage with palm trees on either side. Through these results, it can be seen that for all indices, old urban spaces are less stressful than the outdoor urban spaces in modern and extension parts, which is due to individual differences in people's thermal sensation. Additionally, sufficient shading in the old city of Sidi Okba is another reason behind the higher satisfaction of thermal conditions.

Table 5. Average values in all locations for Physiological Equivalent Temperature (PET, °C) Thermal Sensation Vote (TSV), Percentage of People Dissatisfied (PPD, %)

Public space	PET (°C)	TSV (°C)	PPD (%)
Street (1)	39.89	3.00	61.66
Canyon	33.43	2.25	58.14
Passage	34.51	2.00	35.50
Street (2)	39.04	2.75	65.09
Park	40.00	2.50	74.00
Road (1)	44.10	3.89	97.89
Play ground	47.15	3.88	98.25
Road (2)	47.09	2.89	89.40

Figure 2. Summary of subject thermal sensation votes (TSV) in different public spaces

Table 6. Percentage of people who accept the thermal condition for each thermal sensation vote.

TSV	Percentage of people who accept the thermal conditions (%)
-1	100
0	100
1	100
2	78.45
3	0
4	0

4.3 The correlation between thermal sensation vote (TSV) and thermal index (PET)

In order to identify the acceptable range of the PET index that corresponds to TSV in Sidi Okba, it was important to calculate the neutral temperatures of each space and then compare them. The neutral temperature can be calculated by regression equations in each of the eight public spaces, with the mean thermal sensation vote (MTSV= 0). [Figure 5](#) shows the variation of mean TSV as a function of the PET index. The correlations between MTSV and PET in all locations are described as follows:

- MTSV = 0.32 PET – 7.84 $R^2 = 0.87$ Canyon
- MTSV = 0.20 PET – 4.90 $R^2 = 0.76$ Street 1
- MTSV = 0.25 PET – 6.74 $R^2 = 0.72$ Passage
- MTSV = 0.16 PET – 4.61 $R^2 = 0.67$ Garden
- MTSV = 0.18 PET – 5.31 $R^2 = 0.69$ Street 2
- MTSV = 0.22 PET – 6.51 $R^2 = 0.75$ Road 1
- MTSV = 0.10 PET – 3.28 $R^2 = 0.63$ Playground
- MTSV = 0.17 PET – 4.91 $R^2 = 0.70$ Road 2

The slope of the regression line indicates the sensitivity to changes in the PET index values. The slope values in the old city of Sidi Okba varied between 0.32, 0.20 and 0.25, corresponding to variations of 3.12 °C, 5.00 °C and 3.82 °C respectively for every sensation unit, whereas in the modern part of Sidi Okba the slope values varied between 0.22, 0.16 and 0.27, corresponding to 4.54°C, 5.55°C and 5.60°C respectively. In the extension part, the slope varied between 0.17 and 0.08 corresponding to 5.77°C and 10°C. A comparison of the results indicates that people's thermal sensation in modern and extension parts of Sidi Okba is significantly less sensitive to variations of PET than those who live in the old city. The result also shows that the PET index, particularly in the old city of Sidi Okba, better correlates with TSV than the PET in other neighbourhoods, whereas R^2 varies between 0.87 and 0.72, corresponding to 87% and 72% of the variance in subjective thermal sensations, which can be explained by a PET with a linear regression line, whereas R^2 varied between 0.70 and 0.63 in the two neighbourhoods (modern and extension parts). These results are likely due to the difference in climate conditions, and differences in thermal history, clothing and physical activity.

Canyon

Street 1

Passage

Street 2

Garden

Road 1

Playground

Road 2

Figure 3. Correlation between TSV and PET in different public spaces

4.4 Neutral temperature of the PET index and thermal comfort zone

The calculation of neutral temperatures across all locations, using fitted equations where MTSV = 0, shows that in the old city, the neutral temperatures of PET were the lowest of all spaces, varying between 24.50 °C and 26.96 °C; in the modern part of Sid Okba the neutral temperatures varied between 29.50°C and 32.53°C; and in the extension part, neutral temperatures varied between 28.88°C and 31.49°C ([Table 7](#)). The reason behind the differing PET index is the varying weather conditions of each space, but also that people have adapted themselves differently due to individual differences in their thermal

sensations. Using this result, thermal comfort of the PET index can be defined under two limits, the lower and upper limits of 24°C and 32°C respectively.

Table 7. Summary of results of the correlation between PET and TSV

Public space	Neutral PET °C
Street 1	24.74
Canyon	24.74
Passage	26.96
Street 2	29.50
Garden	28.81
Road 1	32.53
Playground	31.50
Road 2	28.88

4.5 Walking behaviours in different urban spaces

4.5.1 Results of the questionnaire

4.5.1.1 Purpose of walking

In all neighbourhoods of Sidi Okba, 64.44% of participants considered walking as an action only undertaken in situations where it is necessary in the summer season, whereas 33.45% of respondents walked for leisure purposes; furthermore, as shown in [Figure 6](#), utility walking tends to be more common in the modern part of Sidi Okba (74.50%); this can be explained by the mixed land use existing in the modern part, which invites people to walk more. For leisure, the highest percentage was found in the modern part (38.18%) and in the old city (36.67%), which can be explained by the positive effect of outdoor climatic conditions encouraging people to walk for leisure in the old city. For the modern part, it is because of the presence of multiple destinations, which promotes active transport for leisure.

Figure 4. Purpose of walking in the three neighbourhoods

4.5.1.2 Preferred walking hours

The results presented in [Figure 7](#) reveal that the percentage of participants who prefer to walk at 8:00, 12:00, 16:00 and 20:00 was 54.35%, 0%, 0% and 46.22% respectively. It seems that the preferred walking hours are during the morning at 8:00 and in the evening at 20:00. One reason behind this result is the lower direct solar radiation flux at 8:00 and 20:00, as shown in [Table 8](#); at

these moments the majority of studied areas were totally shaded and less stressed than at other times.

Figure 5. Preferred walking times

Table 8. Direct SW radiation calculated for all measurement times in all studied areas

Space	Direct SW Radiation (W/m ²)			
	8:00 am	12:00 am	16:00 pm	20:00 pm
Street 1	0	1018.40	0	0
Canyon	0	1021.60	0	0
Passage	0	178.32	110.83	0
Street 2	0	997.10	0	0
Garden	426.59	099.01	298.10	178.48
Road 1	803.55	1022.10	965.65	0
Playground	820.06	1037.10	982	0
Road 3	906.99	1016.40	0	0

4.5.1.3 Walking speed

For walking speed, results showed that in the hot, dry city of Sidi Okba, the speed of pedestrians is extremely dependent on the amount of shade. 78.49% of people tend to increase their normal speed due to the heat effect of direct solar radiation, whereas for 10.19% of people, their walking speed is negatively affected by the quality of the ground. This low percentage was noted in the old city, which is characterized by a low quality of ground covering. On the other hand, for 15.32% of participants, walking speed was negatively affected by the pedestrian density. This percentage was detected in few commercial locations in the modern part of Sidi Okba, and the result is in concordance with ([Azmi, Karim, & Amin, 2012](#)) They confirm that as the density of people increases, the walking speed decreases; people do not like to walk behind or alongside unknown people, so they tend to walk to the side and slightly ahead.

4.5.2 Results of audit instrument

4.5.2.1 Built density, land-use mix, and connectivity

The built density is one of the most important parameters for measuring the aspects of urban morphology affecting travel behaviour, the high level of density can humanize the H/W ratio of public spaces ([Carmona et al., 2012](#)), but density alone does not seem to have any significant influence on travel behaviour over short distances without mixed land use. The combination of density and diversity clearly reduces car use in residential environments. As a macro level indicator, density also influences street connectivity by providing

direct and short routes to destinations and more route options ([Barros, Martínez, & Viegas, 2017](#)). [Table 10](#) shows the results of criteria scores in all public spaces. The findings demonstrate that the old city of Sidi Okba has the highest values of built density (86.70%) compared with other neighbourhoods, whereas the extension part has the lowest density of all neighbourhoods (17%). This result has significant implications for the score of street connectivity; the result shows that a low density score leads to a low score of street connectivity and low-density intersections, as is noted in the playground and Road C, whereas high street connectivity is typically found in the old city of Sidi Okba, characterized by a considerable density level. In terms of mixed land use, the result reveals that the highest diversity score was detected in the modern part of Sidi Okba, which contains commercial areas (Road 1, Street 2). These spaces have more daytime pedestrian traffic than those that are only residential (old and extension).

4.5.2.2 Enclosure

The results show that enclosures were higher in older neighbourhoods with higher built density. In fact, all spaces located in the old city of Sidi Okba (Street, Canyon) have a distinct and definite shape with unbroken building fronts of roughly equal height, whereas the large building setbacks in the majority of public spaces of modern and extension parts seem to be a source of dead space, which negatively affects human responses to the environment.

4.5.2.3 Human scale

The findings from this research reveal that the human scale was higher in the old neighbourhood (5.33/6). However, the minimum value was detected in the modern and extension part of Sidi Okba, which can be explained by the small-scale building elements with a high presence of palm trees in all old public spaces. In contrast, all public modern and extension spaces were characterized by a monumental scale due to the presence of tall civil and religious buildings and wide streets that would not intimidate pedestrians.

4.5.2.4 Human speed

Examination of the results of the questionnaire surveys indicates that in hot, dry cities, the most important factor that influences a person's normal walking speed is the amount of shade existing in public space. In addition, results illustrate that the highest percentage of people (54.46%) prefer to walk at 8:00; for this reason, the level of shading in all studied areas at this time of the day was chosen for evaluation. The results revealed that old public spaces have the highest score of human speed (3/3), due to sufficient shading provided by palm trees combined with high H/W ratios, and results show that people tend to walk at a speed that they find most comfortable. However, the average walking speed is higher in the studied areas of modern and extension parts compared to the average walking speed in the old city. These results suggest that these spaces are more exposed to solar radiation, due to the low ratio H/W combined with E-W or NE-SW orientations, which negatively affect walking speed.

4.5.2.5 Outdoor thermal comfort

The first part of this study has defined the acceptable comfort range of the PET index, which varies between 24°C and 32°C. This range can be used as the baseline in assessing the walkability score in all studied areas. [Table 9](#) shows the average values of the PET index at 8:00 in all studied spaces. Analysis of the results demonstrates that all old spaces are thermally comfortable at 8:00, which can be explained by the combined effect of low air temperature and MRT due to an increasing H/W ratio and the cooling effect of

palm trees. However, the average values of the PET index are higher in all spaces with low density and a low H/W ratio. Consequently, these spaces are more exposed to solar radiation, which has a negative effect on the score of outdoor thermal comfort.

Table 9. Average values of PET index in all public spaces at 8:00 am

Location	Public space	PET °C
Old city	Street 1	31.56
	Canyon	28.44
	Passage	30.06
Modern city	Street 2	31.34
	Garden	33.12
	Road 1	39.34
Extension part	Playground	43.56
	Road 2	33.86

4.5.2.6 Score of walkability

[Figure 8](#) highlights the clear differences in walkability scores for different urban environments. As a general observation, old spaces that are characterized by a high density had a higher walkability score varying between 21/24 and 23/24. However, other spaces with a lower range of density tend to have lower walkability scores varying between 07/24 and 19/24). The result confirms the positive association between the density of buildings and walking for transport in the summertime. In fact, high-density areas (old city of Sidi Okba) may have high street connectivity and more destinations within walking distance. In addition, building mass becomes more important in defining spaces highly proportional to the human form. In terms of human speed, analysis of the results shows that all old spaces are totally shaded during the morning at 8:00, at which time people can walk at a speed that they find most comfortable. They also appreciate and tolerate the outdoor thermal conditions, and therefore the average values of PET are included in the comfort range (24°C - 32°C). This shows the importance of the effect of shade to reduce summer heat and make outdoor spaces liveable and walkable.

Figure 6. Summary of results of scores in all public spaces

4.6 Problem to resolve in all spaces

The main aim of this study is to ensure a walkable environment in hot, dry cities. This aim can be achieved by evaluating and comparing the fundamental criteria of walkability in existing spaces. [Table 10](#) shows the result of all criteria in each public space, where the orange score represents the lower scores that should be treated and modified in order to improve the walkable environment. It is notable that there is a low score for density in all spaces located in the extension part, which is due to the large streets and big open areas. At the level of public space, the low density of buildings can affect the sense of enclosure and human scale. ([Arnold, 1993](#)) posits that where streets are very wide, additional rows of trees are needed to achieve a human scale. This solution should be applied in all spaces that have a low score of enclosure and human scale, such as the garden, playground, Road 1 and Road 2. Therefore, adding ranges of streets in the low parts of public spaces helps to produce the maximum amount of shadow and offers comfortable conditions. As a result, the score of human speed and outdoor thermal comfort will increase during the hottest period of the year. In addition, the low diversity score in the old city can be resolved by the creation of new land uses (commercial, public services, landscape area), which is essential to the development of local communities. However, the new part of the city is perfectly suited for this goal. For road connectivity, there is no problem. The majority of spaces present more travel options and easier access with two or more connections.

Table 10. Scores of all criteria in all public spaces Public space

Public space	Density	Design	Diversity	Enclosure	Human scale	Human speed	thermal comfort
Street 1	3/3	3/3	1/3	3/3	5/6	3/3	3/3
Canyon	3/3	1/3	1/3	3/3	3/6	3/3	3/3
Passage	3/3	3/3	2/3	3/3	6/6	3/3	3/3
Street 2	2/3	3/3	2/3	3/3	3/6	3/3	3/3
Park	2/3	3/3	1/3	1/3	2/6	1/3	3/3
Road 1	2/3	3/3	3/3	1/3	2/6	1/3	0/3
Play ground	1/3	3/3	1/3	1/3	0/6	1/3	0/3
Road 2	1/3	3/3	2/3	3/3	3/6	3/3	0/3

5. CONCLUSION

The first part of this paper examined the influence of urban morphology of three different neighbourhoods on microclimate and outdoor thermal comfort. The results showed that the microclimate in urban spaces varies considerably, mainly due to the variation of physical parameters such as the level of building density, H/W ratio and vegetation, and it was concluded that Sidi Okba should include more shaded spaces by increasing building density and increasing the level of vegetation. The acceptable range of PET. Analysis of the results demonstrated that all old spaces are thermally comfortable within a range of 24 °C - 32 °C. The second part of this study highlighted the significance of the association between the urban morphology of the three neighbourhoods and walking behaviour by calculating a series of urban criteria. It was revealed that the walkability score in different urban environments was found to be inadequate, and the high density combined with mixed land use would encourage people to walk more. In terms of trip purposes, utility walking tends to be more common in hot, dry cities, and it can be noted that most people in

Sidi Okba require a reason to take a recreational walk, such as catching the bus, walking for shopping, or going to meet someone; it seems that the preferred walking hours are during the morning at 8:00 and evening at 20:00, which is mainly expressed by the lesser potential for solar radiation in comparison with other times of the day. Further, an important finding that comes out of this analysis is that solar radiation was found to have a considerable influence on the thermal environment at the level of public space and consequently on the walking speed of people. It was found that the majority of respondents (74.50%) tend to increase their normal walking speed due to the heat effect of direct solar radiation. This can be noted in areas that received extensive solar radiation while the physical environment lacks sufficient shading due to the impact of orientation (E-W), low density and low H/W ratio, combined with the lack of trees in outdoor spaces. Finally, in order to introduce the walking behaviour as a main form of everyday travel over short distances in hot, dry cities, it is recommended that design guidelines be applied to support the development of all criteria, such as outdoor thermal comfort, diversity, density, connectivity, enclosure, human speed and human scale, which are more relevant to the explanation of the flow of people present in outdoor public spaces.

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REFERENCES

- Ali-Toudert, F., & Mayer, H. (2006). "Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate", *Building and Environment*, 41(2), 94–108. Retrieved from <https://www.sciencedirect.com/science/article/pii/S0360132305000120>
- Arnold, H. F. (1993). *Trees in Urban design*, Van Nostrand Reinhold,.
- ASHRAE (2004). *Thermal environmental conditions for human occupancy*, (Vol. 55) American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Azmi, D. I., Karim, H. A., & Amin, M. Z. M. (2012). "Comparing the walking behaviour between urban and rural residents", *Procedia-Social and Behavioral Sciences*, 68, 406–416.
- Barros, A. P., Martínez, L. M., & Viegas, J. M. (2017). "How urban form promotes walkability?", *Transportation Research Procedia*, 27, 133–140.
- Bernatzky, A. (1977). *Der Gartenratgeber: Planung, Bepflanzung u. Pflege von Hausgärten*, Mosaik Verlag.
- Carmona, M., Heath, T., Oc, T., & Tiesdell, S. (2012). *Public places-Urban spaces*, Routledge.
- Clemente, O., Ewing, R., Handy, S., & Brownson, R. (2005). *Measuring urban design qualities: An illustrated field manual*,. Retrieved from https://drum.lib.umd.edu/bitstream/handle/1903/21525/ewingclementehandyetal_fieldmanual_2005.pdf?sequence=1&isAllowed=y
- Dursun, D., & Yavas, M. (2015). "Climate-sensitive urban design in cold climate zone: the City of Erzurum, Turkey", *International Review for Spatial Planning and Sustainable Development*, 3(1), 17–38.
- Ewing, R., & Cervero, R. (2010). "Travel and the built environment: a meta-analysis", *Journal of the American Planning Association*, 76(3), 265–294.
- Fanger, P. O. (1970). "Thermal comfort. Analysis and applications in environmental engineering.", *Thermal Comfort. Analysis and Applications in Environmental Engineering*.
- Grasser, G., Van Dyck, D., Titze, S., & Stronegger, W. (2013). "Objectively measured walkability and active transport and weight-related outcomes in adults: a systematic review", *International Journal of Public Health*, 58(4), 615–625.

- ISO, I. S. O. (1985). *7726-Thermal Environment-Instruments and method for measuring physical quantities*, International Standards Organization, Geneva,.
- Jacobs, A. B. (1993, September). "Great streets", 23–27. Retrieved from <https://escholarship.org/uc/item/3t62h1fv>
- Johansson, E. (2006). "Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco", *Building and Environment*, 41(10), 1326–1338.
- 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(12), 2641–2656.