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Influence of Urban Morphology on Outdoor Thermal Comfort in Summer: A Study in Tunis, Tunisia

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Abstract: Classified as a subtropical Mediterranean climate city, the city of Tunis, Tunisia, knows a hot and dry summer seasons over a long period of the year. This study focuses on the influence of urban geometry on the summer outdoor thermal comfort by comparing the morphological characteristics of the streets, especially the ratio Height-to-Width H/W and the Sky View Factor SVF. A numerical simulation of the urban microclimate has enabled us to obtain the climate parameters required for the evaluation of outdoor thermal comfort through the Universal Thermal climate Index UTCI. The results showed that the fight against overheating summer seasons of a subtropical Mediterranean climate, deep and narrow streets were best for outdoor thermal comfort.

Key words: outdoor thermal comfort, urban morphology, universal thermal climate index, urban planning, environmental sustainability

1. Introduction

Climate change is one of the most alarming topics of the moment. Among the most important indicators of global warming we are experiencing is the effect of the urban heat island, which is the temperature difference between a city and its surroundings. As a result, the interest in the urban microclimate has increased because it causes not only an increase of the energy consumption of buildings dedicated to air conditioning, but it also affects the quality of outdoor spaces.

Indeed, these air conditioning systems produce anthropogenic energy, which is in turn responsible for global warming of the outdoor air. Then a vicious cycle sets in, and it is essential to stop. As designers, we must participate by better urban planning that tends to decrease the effect of the urban heat island.

Our urban planning influences considerably the microclimatic variations at the urban scale: slowdown of the winds by the height of the buildings or storage of solar radiation by the urban construction materials [1, 2]. In this study, we are interested in the effect of outdoor thermal comfort urban morphology, and more specifically the impact of the geometry of urban canyon streets.

2. Background on Outdoor Thermal Comfort

The growing interest towards the alarming situation of global warming has emerged various studies concerning sustainable development and especially as regards energy efficiency.

Thus, several studies have examined the internal thermal comfort and showing various regulations aimed at designers. It was only later that researchers were interested in the outdoor thermal comfort. It is a little-known field of designers and has a particular difficulty: the multiplicity of factors to be considered and the interactions between them.

In order to carry out an analysis of outdoor thermal comfort, should be considered the physical,

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physiological and psychological aspects. It is essential to consider the interrelationships between the thermal conditions of the environment, the physiological responses of users and perceptions of thermal sensations [3].

With regard to the physical approach of the comfort, the human being is considered as a heat engine. To study it, we have to take into account interactions with the environment in terms of heat exchange. The physiological approach, meanwhile, is interested in the mechanisms of self-regulation such as sweating or shivering. Finally, the psychological approach attempts to explore the relationships between these physical quantities and the physiological and sensory outcomes among users.

These different approaches require multidisciplinary, each discipline attempting to assess the external thermal comfort from the specific angle of his specialty. However, they all agree to say that the thermal comfort of a person mainly depends on its environment first and then his body. Many factors affect the flow of heat from the body; they can be classified into three categories [4]. First, there are the climatic factors such as the temperature of the air, the radiation, the relative humidity, or even the wind speed. Then, there are the personal factors that are defined by the metabolism or the level of clothing. Finally, there are the factors contributors such as acclimation, socio-cultural influence, age or sex.

Among these factors, those who are more taken into account are climatic factors since they are the more concrete and quantifiable aspect. Climate parameters involved are mainly the air temperature (Ta), the mean radiant temperature (Tmrt), the wind speed (Va) and the relative humidity (RH). From these parameters, the researchers were able to normalize thermal comfort by developing thermal comfort indices. Among these, we can cite the Predicted Mean Vote (PMV), the physiological equivalent temperature (PET) or the Universal Thermal Climate Index (UTCI).

In addition, researchers have tried to understand the influential factors on climatic parameters. There are those who are not controllable in the urban design (human activities) and those that are (morphological factors) [5]. By studying these controllable factors in urban design, they managed to highlight the close relationship between the urban morphology and its direct impact on the microclimatic variations [6, 7]. It is in the continuity of the research that we are interested in the impact of the urban morphology on outdoor thermal comfort, specifically in the summer in Tunis, Tunisia.

3. The City of Tunis, the Study Areas

Tunis, the capital of Tunisia (36.48°N, 10.10°E) is classified as having a subtropical Mediterranean climate. This kind of climate is characterized by two large highly contrasted seasons: a cool, mild winter and a hot, dry summer. In a country where the sun reigns, it is difficult to manage overheating during summer periods, and thermal comfort is affected, both inside and out. Indeed, during the summer, average temperatures are around 29°C with maximum of up to 38°C on some days and sunshine duration of about 11 hours daily.

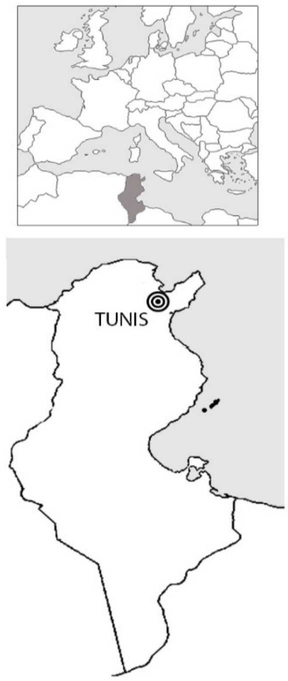

Fig. 1 Localization of Tunis.

The city of Tunis has features at the urban level: it has what is called the “Medina” of Tunis, which is the oldest of the urban fabrics. This oldest city is a dense neighborhood with narrow, deep, sinuous streets, and a system of residential patios assembled in clusters. The new districts are, generally built in subdivisions governed by urban rules with a standardization of widths of streets, withdrawals or occupation on the ground.

For this study, we choose to compare the two of the urban fabrics. Deep and narrow streets characterize the oldest city. For the new fabrics, we have wide streets with an opening to the fairly clear sky.

4. Methodology

4.1 Study Plot Selection

For each type of urban fabric, we have chosen a representative plot. Then, we began by analyzing the morphological differences observed, namely the ratio H/W which is the ratio between the smallest width of the street and the average height of the buildings. Then, we calculated the corresponding Sky View Factor. The SVF is the solid angle under which the sky is seen from an urban space. We calculate the SVF using the photographic method based on fish-eye photographs directed to the sky.

For each fabric, we delimited a plot by trying to be as representative as possible. For the Medina of Tunis, we opted for a parcel in the center of the Medina, the residential type. The occupation of the soil is almost with a built-up density of 0.71, where the only empty spaces are the streets and patios. The buildings vary in height and are on average equivalent to two levels. With regard to the new area, we opted for a residential parcel, with isolated and collective dwellings. The density of buildings is of about 0.19, where the occupation on the ground is very low; favoring the spaces, they are public (streets) or private (gardens). The heights of constructions of isolated dwellings are on average equal to two levels, collective dwellings are of five levels.

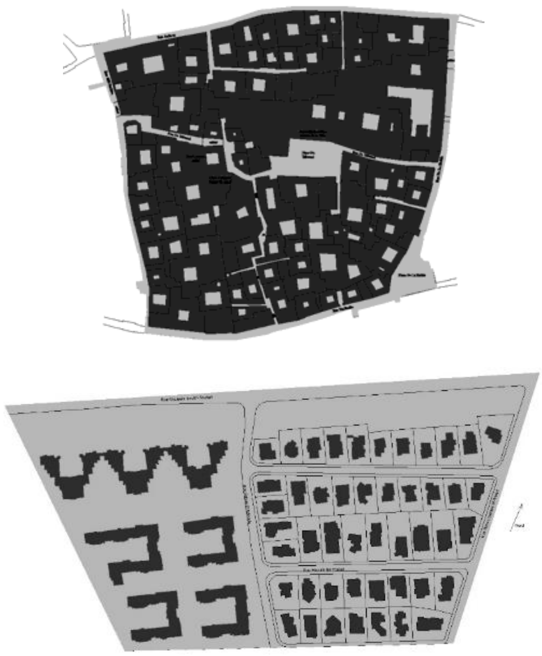

Fig. 2 Site map for the studied areas (the old city and the new one).

4.2 Numerical Simulation of the Urban Microclimate

To obtain climate data needed for the assessment of the outdoor thermal comfort, we resorted to the numerical simulation because of the lack of availability of measurement devices. We conducted a campaign of short-term measures and then, we simulated the daily variations of the same date of the measures in order to validate the simulation results.

The numerical simulation was performed on the ENVI-met model (V4) that simulates the microclimate interactions surfaces, plants and air of the urban environment [8]. To this end, we conducted a simulation of a typical day in the summer, entering the climatic data collected from the National Institute of Meteorology.

Table 1 Configuration of the simulation.

Configuration data for the simulation of the two fabrics	
Simulation date	26 August 2014
Simulation time	24h00
Beginning of the simulation	06h00
Air temperature	299.15°K (26°C)
Relative humidity	61%
wind speed at 10 m to the ground	3.1 m/s
Wind direction	N-NE

We have modeled the compared plots on ENVI-met according to the reality. To do this, we have introduced the location of the buildings and their characteristics (length, width, height, type of materials used). We also specified the nature of the soil, the emplacement and type of vegetation.

After running the simulation, we have extracted the needed data, namely air temperature, and mean radiant temperature, wind speed and relative humidity.

4.3 Outdoor Thermal Comfort Analysis

In order to assess the outdoor thermal comfort, we opted for the Universal Thermal Climate Index. From microclimate data obtained from the numerical simulation, we were able to calculate the UTCI from the simplified regression function [9].

5. Results

5.1 Comparison of Microclimate Parameters

We calculated the average daily different microclimate parameters: air temperature Ta, mean radiant temperature Tmrt, wind speed Va and the relative humidity HR in order to compare them.

It appears that the old city has lower temperatures than the new one. The two curves follow the same look with a difference about 4.5°C. The old city has an average temperature of 20.53°C with a minimum of 17.70°C at 6.am, and a maximum of 23.87°C at 2 p.m. The new city meanwhile has a daily average of 25.01°C with a minimum of 21.69°C also at 6 a.m., and a maximum of 28.93°C to 2 p.m..

Table 2 Characteristics of the plots to simulate.

Fabric	Old city	New city
Location	36.48° N 10.10° E	36.51°N 10.9°E
Size of fabric (m)	210 × 198	477 × 246
Simplified maximum height of buildings (m)	15	24
Size area (cells)	70 × 66 × 15	159 × 82 × 20
Resolution (m)	3 × 3 × 3	3 × 3× 3
Rotation of the model from the North	65°	-24°

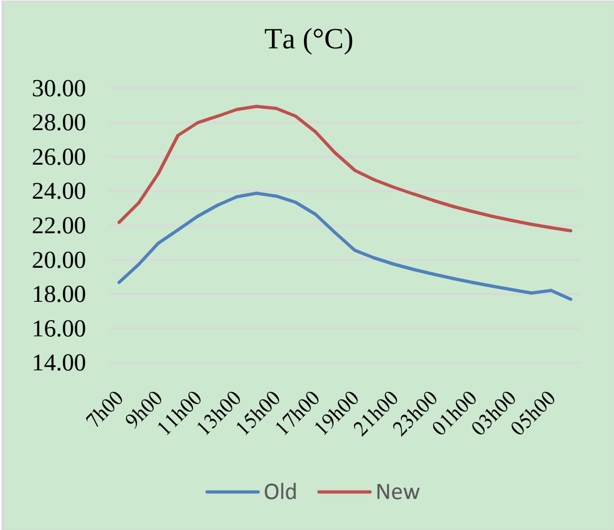

Fig. 3 Air temperature daily variation.

In terms of mean radiant temperature, the appearance of the two curves remain substantially the same with an average deviation of 3.8°C. We should note that the recent city has an UTCI that increases approximately 1 hour before the old city and it goes down about half an hour after the old one.

With regard to wind speed, it is almost constant for the old city with an average of 0.9 m/s. While it is descending for the new city, with an average of 1.7 m/s.

Finally, relative humidity presents a difference of about 6.5% between the two cities the recent one being better.

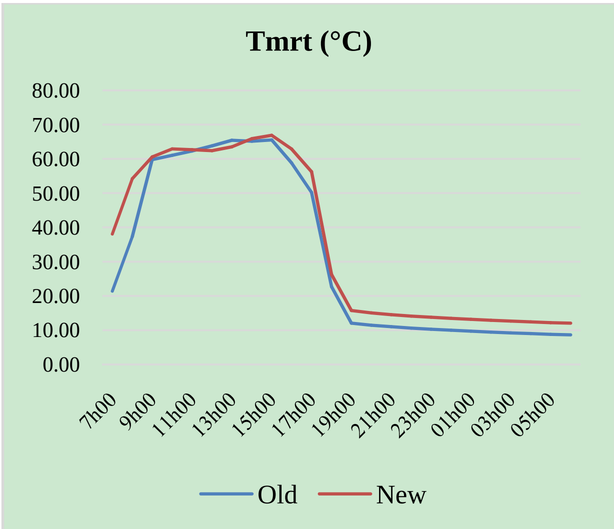

Fig. 4 Mean radiant temperature daily variation.

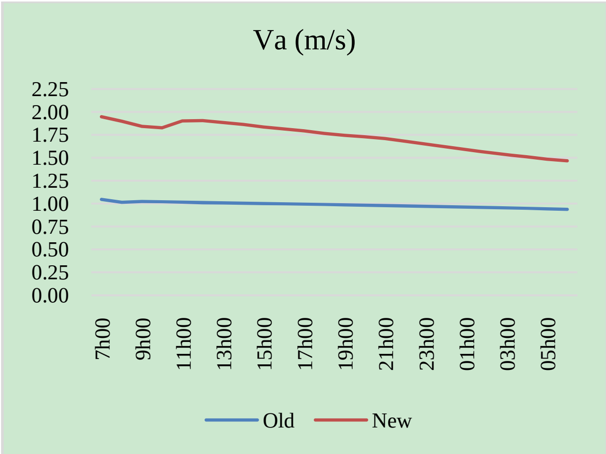

Fig. 5 Wind speed daily variation.

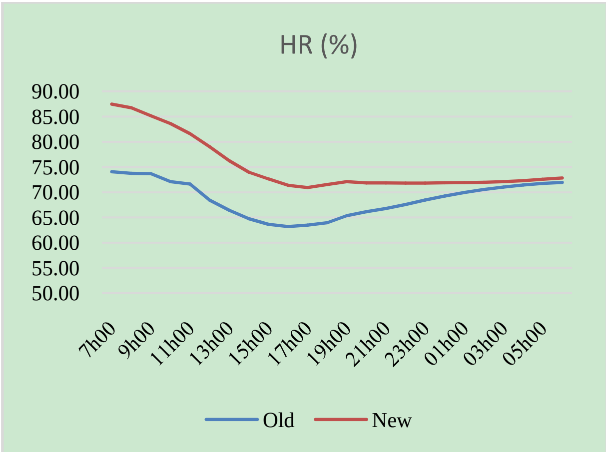

Fig. 6 Relative humidity daily variation.

5.2 Outdoor Thermal Comfort Assessment

In order to assess the outdoor thermal comfort, we calculated the Universal Thermal Climate Index. We started by calculating for each reference point the corresponding UTCI then we averaged the value of each city.

The result shows that the old fabric is more comfortable with an average of UTCI equal to 23.50°C, against 26.58°C for the new one. The two curves follow the same appearance, that is to say, the value of UTCI climbs gradually as we advance in the day and down in the late afternoon. The difference between the two fabrics is on two levels: first, an average difference of about 3°C between them. Then, the recent city comes into discomfort zone earlier in the day and remains in this longer than the old city. It begins to

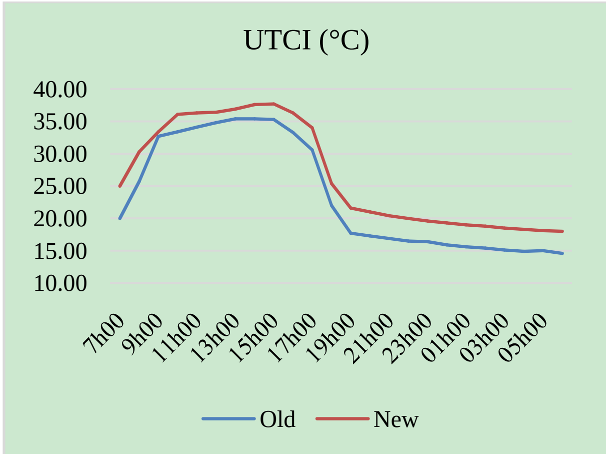

Fig. 7 UTCI daily variation.

return to comfort zone about an hour before the recent fabric. We recall that the old fabric has a ratio H/W through 3.51 against 0.48 for the recent.

We sought to explore different levels of comfort within the same fabric based on morphological indicators considered. To this end, we highlighted here two points of each fabric: the one with the highest ratio H/W and the lowest one.

In the following graph (Fig. 8), we present the daily variations of UTCI in the selected points in order to compare the outdoor thermal comfort level.

Table 3 Geometric characteristics of the selected points.

Neighborhood	Location	H/W	SVF	Orientation
Old city	O_A	3.40	0.09	N-S
	O_B	1.65	0.14	W-E
New city	N_A	0.56	0.60	NW-SE
	N_B	0.42	0.45	SW-NE

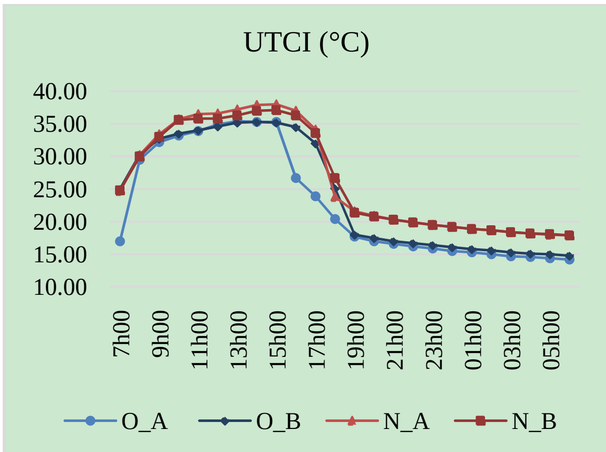

Fig. 8 UTCI daily variations for the selected points.

The results show that the curve indicating a higher level of outdoor thermal comfort (UTCI = 22.7°C) is that which corresponds to the highest ratio H / W (point O_A) and the one with the worst comfort (UTCI = 26.53°C) is the one corresponding to the lowest ratio H/W (point N_A).

6. Discussion

6.1 Impact of Urban Morphology on the Microclimate and Outdoor Thermal Comfort

The results clearly demonstrated the impact of urban morphology on microclimate parameters. Indeed, the old city that is compact and deep tissue have air and mean radiant temperatures lower than the newest city that is more open; as confirmed by similar studies [10, 11].

Gradually as the ratio H/W decreases, the temperatures tend to increase substantially. Inversely, the more the SVF is small, more comfort is better, and this, due to the strong correlation existing between the H/W ratio and the SVF.

We can explain this influence by the fact that the more the street is narrow and deep, the more public spaces are protected from direct sunlight. As a result, the air temperature and mean radiant temperature are greatly reduced and this contributes to a better outdoor thermal comfort [12]. Similarly, the higher the SVF is smaller, overheating is avoided.

6.2 The Need to Find A Seasonal Compromise

We have conducted this study during the summer season, which is the largest season in Tunisia. Indeed, periods of cold temperatures are small and in a country where the sun is an integral part of everyday life, the greatest concern is to protect the pedestrians. However, it remains necessary to understand the concept of outdoor thermal comfort in winter where expectations in terms of sun and thermal comfort are quite contradictory in relation to the summer season. Future research is planned to investigate winter outdoor thermal comfort and try to find a compromise to get the best thermal comfort in both seasons.

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