

EDITED BY
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URBAN HERITAGE AND SUSTAINABILITY
IN THE AGE OF GLOBALISATION





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7. The Medina of Tunis, a Heritage Model for Urban Sustainability: Urban Morphology and Outdoor Thermal Comfort

Safa Achour

Introduction

Humans have always sought to protect themselves from environmental factors, such as bad weather and intense sunlight, giving rise to the concept of the 'living space'. From simple inhabited caves and huts to modern dwellings, living spaces remain a main human priority. We continuously seek to improve these spaces over time in order to maximise comfort. Among various concerns, thermal comfort is paramount, with a substantial impact on the well-being of users. Early humans were skilled in acclimatisation and designing structures according to their immediate environment. A prime example is the traditional architecture of the medina of Tunis, designed with respect to the specific parameter of thermal comfort. In addition to being well-adapted for ventilation and natural cooling, the construction materials and spatial configurations of patio houses are tailored to the climate of Tunis.¹

1 Azeddine Belakehal, 'Ambiances patrimoniales : problèmes et méthodes', in *Ambiances in action / Ambiances en acte(s)—International Congress on Ambiances* (Montréal: International Congress on Ambiances, 2012), pp. 505–10, <https://shs.hal.science/halshs-00745537/document>

However, recent decades have witnessed evolving lifestyle patterns and urban transformations of considerable magnitude. The socio-economic changes induced by globalisation have led to an upheaval in urban spatial organisation, posing new challenges to development.² This chapter aims to evaluate outdoor thermal comfort conditions and their close relationship with urban morphology. This is done through the analysis of the medina of Tunis in comparison with more contemporary fabrics which are governed by urban planning regulations. The objective is to highlight the thermal qualities of the old fabric in terms of external thermal comfort, and consequently to draw lessons for improving the urban design of future cities.

Urban Changes and the Quality of Outdoor Spaces

In Tunis, new spatial configurations have adapted to modern needs such as vehicular traffic, as the narrow, winding streets of the medina were insufficient. Additionally, new forms of housing have emerged, including apartment buildings and standalone homes. Innovative construction techniques have enabled architects to create interior spaces that meet thermal comfort requirements, giving users greater control. Thus, heating systems provide a comfortable thermal atmosphere during the winter, while air conditioning systems allow for interior insulation during periods of intense heat.

However, these climate-adaptive solutions are not without consequences for the environment. Firstly, they lead to high levels of energy consumption, which is concerning in an era where the depletion of non-renewable energy sources is increasingly palpable. It should be noted that the building sector is among the world's largest energy consumers. In Tunisia, it is responsible for twenty-seven percent of national energy consumption.³ Secondly, thermal control systems release anthropogenic energy that directly influences external air temperatures, altering outdoor thermal comfort and necessitating further regulation of interior conditions. This sets in motion a dangerous cycle of energy consumption.

2 Albert Lévy, 'Urban Forms and Significations: Revisiting Urban Morphology', *Spaces and Societies*, 122.3 (2005), 25–48 (p. 26), <https://doi.org/10.3917/esp.122.0025>

3 Mounir Bahri, *La nouvelle réglementation thermique en Tunisie et le programme de soutien* (Tunis: Consultation Nationale sur les technologies et le financement de la maîtrise de l'énergie dans le bâtiment, 2008).

Urban Heat Island Effect

Urbanisation leads to an ‘artificial’ climate⁴ that has given rise to the phenomenon known as the Urban Heat Island Effect. This refers to ‘the temperature difference observed between urban areas and the surrounding rural areas’.⁵ These variations in the microclimate are attributable to several factors such as changes in natural land cover (deforestation, urban sprawl, etc.), reduced wind speed due to building construction, and the heat absorption capacity of building materials like glass, asphalt and concrete.⁶

As urbanisation expands to meet socio-economic demands, it constitutes a significant risk factor in the context of global warming. Thus, in the twenty-first century, there is no longer any viable approach to urban planning that does not take sustainability into account. Drawing insights from the proven success of the old city fabric of Tunis over centuries, this study proposes valuable lessons for sustainable urban systems.

While traditional architecture is widely acknowledged for the quality of its interior spaces, its urban planning elements continue to merit analysis. This research seeks to demonstrate the sustainability of traditional urban planning and investigates the impact of urban morphology on outdoor thermal comfort.

Outdoor Thermal Comfort

Outdoor thermal comfort is an area of increasing interest. Following the noticeable surge in studies of indoor thermal comfort, scientists are increasingly coming to understand the significance of external thermal factors. This growing interest is well-founded, given the complexity of the concept, its multitude of factors and their diverse interactions.

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- 4 Pierre Carrega, ‘Topoclimatologie et habitat’ (PhD thesis, Université Sophia Antipolis, Nice, 1994).
 - 5 Mélissa Guiguère, *Mesures de lutte aux îlots de chaleur urbains* (Quebec: Institut National de Santé Publique, 2009), <https://www.inspq.qc.ca/publications/988>
 - 6 Neil Debbage and Shepherd J. Marshall, ‘The Urban Heat Island Effect and City Contiguity’, *Computers, Environment and Urban Systems*, 54 (2015), 181–94, <https://doi.org/10.1016/j.compenvurbsys.2015.08.002>

The effective study of outdoor thermal comfort must consider its various physical, physiological and psychological aspects.⁷ The physical approach regards human beings as thermal machines, focusing on their interactions in terms of heat exchange with the environment. The physiological approach focuses on self-regulatory mechanisms like sweating and shivering, while the psychological approach attempts to assess the thermal sensations of users.

Outdoor thermal comfort thus emerges as a complex system of interactions between people and their environments, encompassing heat flow and sensory preferences. Research has classified the factors that affect this system into three main categories:⁸ climatic factors (air temperature, mean radiant temperature, relative humidity and air speed); personal factors (metabolism and clothing); and contributing factors (acclimatisation, age, gender, etc.). Several studies have contributed to the 'standardisation' of comfort assessments, resulting in the development of thermal comfort indices for outdoor environments, including the Predicted Mean Vote (PMV), the Physiological Equivalent Temperature (PET), and the Universal Thermal Climate Index (UTCI).

Moreover, additional research has focused on factors influencing comfort which can be controlled through urban design.⁹ With the relationship between urban morphology and outdoor thermal comfort established, scientists have sought to determine the most influential morphological factors.¹⁰

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- 7 Ken Parsons, *Human Thermal Environments*, 2nd ed. (London: Taylor and Francis, 2003).
 - 8 Andris Auciliems and Steven V. Szokolay, *Thermal Comfort: PLEA (Passive and Low Energy Architecture) Notes*, PLEA Note 3 (Brisbane: PLEA and Aepartment of Architecture, the University of Queensland, 1997).
 - 9 Ahmed Memon Rizwan, Leung Y. C. Dennis, Chunho Liu, 'A Review on the Generation, Determination and Mitigation of Urban Heat Island', *Journal of Environmental Sciences*, 20.1 (2008), 120–28, [https://doi.org/10.1016/S1001-0742\(08\)60019-4](https://doi.org/10.1016/S1001-0742(08)60019-4)
 - 10 Luc Adolphe, 'Modelling the Link between Built Environment and Urban Climate: Towards Simplified Indicators of the City Environment', in *Proceedings of IBPSA (International Building Performance Simulation Association)* (Rio de Janeiro: Actes IBPSA, 2001), pp. 679–84. Karima Ait-Ameur, 'Characterization of the Microclimate in Urban Public Spaces through the Validation of a « Morpho-climatic » Indicator System', in *Proceedings of PLEA 2002—The 19th Conference on Passive and Low Energy Architecture* (Toulouse: PLEA, 2002), pp. 305–11.

Research Framework

This study complements the author's previous comparative research on summer thermal comfort in the outdoor spaces of Tunis' main historical and contemporary fabrics.¹¹ In addition to demonstrating the outdoor thermal comfort of the Tunis medina during the summer, the research highlighted the most influential morphological indicators of exterior thermal comfort. The present chapter incorporates subsequent research pertaining to the winter season, assessing outdoor thermal comfort during both summer and winter. The analysis encompasses two distinct scales. The district scale evaluates the morphological indicators of built density (Ds) and urban roughness (Rm). This factor (Rm) refers to the urban fabric's slowing effect on the average wind speed.¹² The street scale focuses on the height-to-width ratio (H/W) and the Sky View Factor (SVF).¹³

These two scales are significant for several reasons. At the urban scale, the ongoing expansion of urban sprawl is leading to the emergence of energy-intensive megacities. The street scale serves as the interface between the architectural and urban scales, representing the common surface between buildings and their external environment.¹⁴ Given that streets are heavily used public spaces, the comfort of their design is of considerable importance. As streets are a major factor influencing not only the outdoor microclimate but also the interior atmosphere, their design impacts the thermal sensations of users and the energy consumption of buildings.

11 Safa Achour-Younsi, 'Evaluation des conditions de confort thermique d'été en espaces extérieurs à Tunis: Des tissus historiques aux nouveaux quartiers' (PhD thesis, National School of Architecture and Urbanism in Tunis, 2015).

12 Ait-Ameur, 'Characterization of the Microclimate'.

13 Yupeng Wang and Hashem Akbari, 'Effect of Sky View Factor on Outdoor Temperature and Comfort in Montreal', *Environmental Engineering Science*, 31.6 (2014), 272–87, <https://doi.org/10.1089/ees.2013.0430>

14 Faiza Ali-Toudert and Helmut Mayer, '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 (2006), 94–108, <https://doi.org/10.1016/j.buildenv.2005.01.013>

Area of Study

Climate

Tunisia, the smallest of the Maghreb states, is located in North Africa (36.48 ° N, 10.10 ° E). Its capital, Tunis, situated in the northern part of the country at the base of the Gulf of Tunis, extends over a coastal plain and the surrounding hills. The climate is classified as subtropical Mediterranean, characterised by an alternation of two highly contrasting seasons, namely a hot, dry summer and a cool, rainy winter. The average annual temperature in Tunis is approximately 20 °C, reaching an average of 28.8 °C in August and 12.9 °C in February. However, winter temperatures can drop to 7.6 °C, while summer temperatures can rise to 35.5 °C. Humidity levels are quite high, averaging sixty-six percent with a maximum value of up to ninety-five percent in winter and a minimum value of up to twenty-seven percent in summer. The winds in Tunis are predominantly north and northeast with an average speed of 3.7 m/s, which can reach 14.5 m/s in winter.

Urban Morphology of the City of Tunis

The historic heart and birthplace of Tunis is its medina, which is recognised as a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site. The urban planning of the medina is renowned for the patio house, a basic architectural unit used by all social groups. Whether a common dwelling, bourgeois house, large residence or palace, all units are constructed around a patio, with dimensions varying based on the category. These architectural units are then clustered together¹⁵ back-to-back to form the fabric of the medina. The arrangement of the medina is based upon an introverted urban layout, leaving little room for outdoor public spaces. The narrow, winding streets have very small openings, catering to the needs of households and providing privacy. Public space is not designed by the delineation of subdivisions, avenues and streets, but rather emerges from the residual gaps between housing constructions.

The city later expanded into surrounding areas with the development of the European city adjoining the medina. It presents a stark contrast

15 Jalel Abdelkefi, *La Médina de Tunis : espace historique* (Paris: Editions CNRS, 1989).

with the medina itself, with its regular grid layout and distinct building typologies, previously unknown in the medina's landscape. Later, new neighbourhoods emerged on the outskirts of the city, governed by town planning regulations and standardised specifications. This development has transformed Tunis into an agglomeration with significant urban sprawl and population density.

In order to demonstrate the superior outdoor thermal comfort conditions of the traditional urban fabric, this study draws a comparison with a district of the 'new city' governed by the existing urban planning regulations. In selecting a plot within the medina to optimally represent the traditional heritage fabric, we focused on the central medina, excluding its suburbs and the souks district. At the urban scale, we ultimately chose the Place du Tribunal district, a small plot which offers a microcosm of the diverse morphologies found within the medina's fabric. At the street scale, six reference points representing different street prospects were chosen in order to detect variations.

Within the regulated fabric, we similarly selected a district representative of the most prevalent residential units, with a variety of standalone and collective housing, as well as identified six reference points (see Figure 7.1).

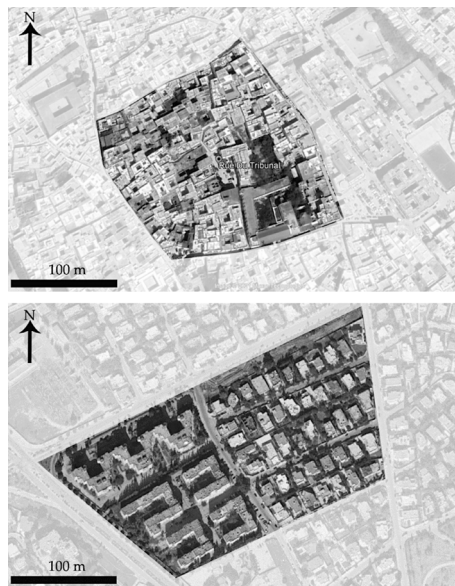


Fig. 7.1 Site map for the old city (top) and the new one (bottom). Author's illustration, based on Google Earth (2021), CC BY-NC-ND.

Methodology

A three-step investigative methodology was devised in order to demonstrate the high level of outdoor thermal comfort inherent in the town planning of the medina. This approach aims to illustrate the impact of urban morphology on the microclimatic conditions of outdoor space, which in turn influences the level of outdoor thermal comfort. The comparison between the old town and the new city confirms the efficiency of the medina's town planning and reveals the correlations between urban morphology and outdoor thermal comfort.

Urban Morphology Analysis

For the typo-morphological analysis of the medina of Tunis, influential morphological indicators identified in previous research were utilised.

At the neighbourhood scale, built density (D_s) is calculated as the total built-up area over the total plot area using the formula $D_s = \frac{A_p}{A_s}$ where A_p is the building floor area, and A_s is the total surface.

Next, urban roughness (R_m) is measured as the average height of the urban canopy, determined by the product of the building height by the area, divided by the total of built-up and non-built areas. This factor is calculated using the formula $R_m = \frac{\sum H_i A_i}{\sum A_i + \sum A_j}$ where A_i is the floor occupancy of buildings, H_i is the building height, A_j is the unbuilt area and i is the number of buildings.

At the street scale, two highly dependent indicators are studied. First is the H/W ratio, which represents the ratio of average building height to the shortest distance between streets.

Next is the Sky View Factor (SVF), defined as the solid angle at which the sky is viewed from space. The assessment of this indicator requires an equidistant image, produced using a fisheye lens photograph. An SVF of 1 means that there is no obstacle to the view of the sky, such as from isolated terrain. In this case, we can estimate that the temperatures recorded on this same site will be practically equal to those given by the meteorological stations. On the other hand, an SVF of 0 indicates a completely obstructed space. In this case, temperatures will be strongly influenced by the immediate urban environment.

Urban Microclimate Analysis

Microclimatic conditions in outdoor spaces are analysed through four key parameters impacting outdoor thermal comfort: air temperature, mean radiant temperature, relative humidity and wind speed. A measurement campaign was conducted, followed by numerical simulations using the Envi-met model (version 4.0) by Michael Bruse¹⁶ from the Institute of Geography at the University of Bochum in Germany. This software has been tested and applied in a variety of research related to urban climatology and thus to the evaluation of external thermal comfort.¹⁷

Table 7.1 Configuration of the simulations and characteristics of the fabrics.

Characteristics of the simulated plots		
	Old City	New City
Tissue location	36.48° N/10.10° E	36.51° N/10.9° E
Fabric size (m)	210 x 198	477 x 246
Plot size (cells)	70 x 66 x 15	159 x 82 x 20
Rotation of the model with respect to the North	65°	-24°
Maximum building height (m)	15	24
Climatic parameters for simulation configuration		
	Winter season	Summer season
Date of the simulation	10/02/2020	20/08/2020
Duration of the simulation	24h00	24h00
Simulation beginning	06h00	06h00
Air temperature	283.15°K (10° C)	299.15°K (26° C)
Relative humidity	67%	61%
Wind speed at 10m on the ground	12.91 m/s	3.1 m/s
Wind direction	N-NE	N-NE

16 Michael Bruse, 'Simulating Microscale Climate Interactions in Complex Terrain with a High-resolution Numerical Model: A Case Study for the Sydney CBD (Model Description)', in *Proceedings of International Conference on Urban Climatology and International Congress of Biometeorology* (Sydney: n.p., 1999), <https://www.envi-met.net/documents/papers/CBDSimu1999.PDF>

17 Ferdinando Salata, Iacopo Golasi, Roberto De Lieto Vollaro and Andrea de Lieto Vollaro, 'Urban Microclimate and Outdoor Thermal Comfort. A Proper Procedure to Fit ENVI-met Simulation Outputs to Experimental Data', *Sustainable Cities and Society*, 26 (2016), 318-43, <https://doi.org/10.1016/j.scs.2016.07.005>

To achieve this, both fabrics were modelled to reflect reality, considering building locations and characteristics (height, materials, vegetation, soil type, etc.) as outlined in Table 7.1. Simulation results were compared with measured values to validate the accuracy of the simulations.

Outdoor Thermal Comfort Analysis

In order to assess the complex concept of outdoor thermal comfort, we employed several tools. First, for the physical dimension of comfort, our evaluation is grounded in the Universal Thermal Climate Index (UTCI) scale. The latest in thermal comfort indices, it was developed for evaluating outdoor thermal comfort in various fields such as bioclimatic mapping, urban planning and climate impact research.¹⁸ Utilizing a simplified regression function,¹⁹ we calculate this index and generate comfort zone diagrams, along with daily averages in summer and winter.

Subsequently, to evaluate comfort from a physio-psychological perspective, an in-situ survey was administered to the users of the space during both the summer and winter seasons. The survey involved forty-five people in each season, questioning them about their perceived thermal sensations and preferences using the following model:

- Scale of perceptual judgments:
 - Temperature (perceived as very cold/cold/slightly cold/neutral/slightly hot/hot/very hot).
 - Wind (estimated as too much/neutral/not enough).
 - Humidity (found to be damp/neutral/dry).
- Scale of evaluative judgments:
 - Thermal ambiance (judged as unacceptable/acceptable/good).

18 Gerd Jendritzky, Richard de Dear and George Havenith, 'UTCI—Why Another Thermal Index?', *International Journal of biometrology*, 56.3 (2011), 421–28, <https://doi.org/10.1007/s00484-011-0513-7>

19 Peter Bröde, Dusan Fiala, Krzysztof Błażejczyk, Ingvar Holmér, Gerd Jendritzky, Bernhard Kampmann, Birger Tinz and George Havenith, 'Deriving the Operational Procedure for the Universal Thermal Climate Index (utci)', *International Journal of Biometrology*, 56.3 (2012), 481–94, <https://doi.org/10.1007/s00484-011-0454-1>

- Scale of thermal preference:
 - Sun preference (desired more/neutral/less).

Results



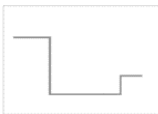





Morphological characterisation of the studied fabrics

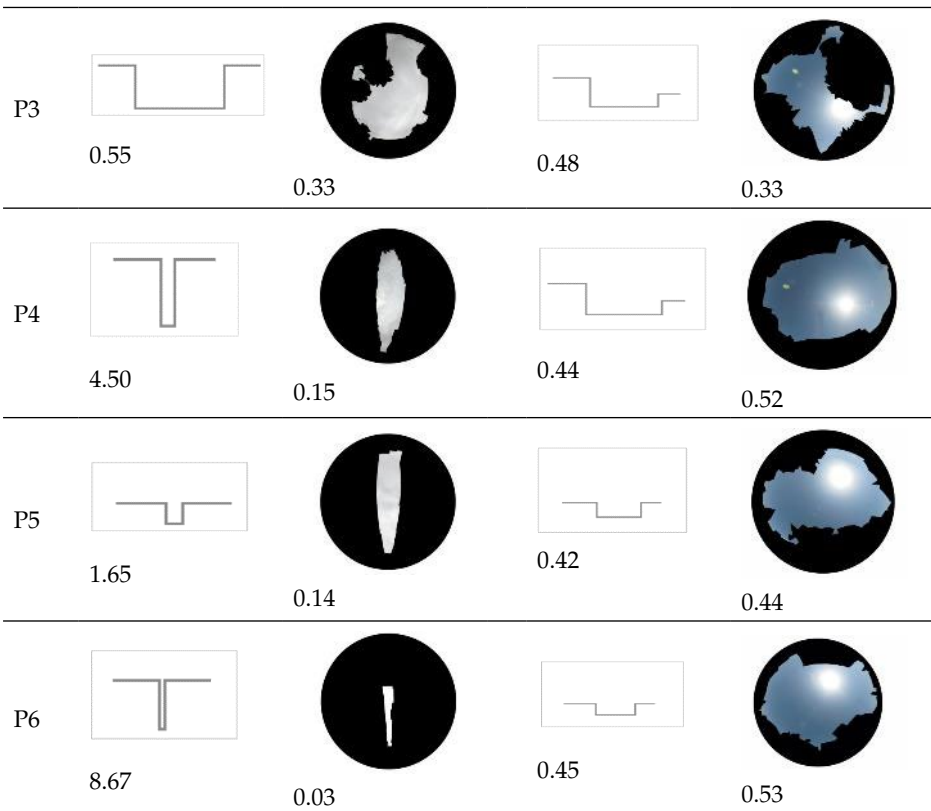
Beginning with the neighbourhood scale, the indicators D_s and R_m (see Table 7.2) reveal significant differences between the old town and new district. The fabric of the old town is very dense, roughly four times denser than that of the new district. Likewise, the roughness of the old fabric is considerably higher, nearly three times that of the new fabric.

Table 7.2 Built density and urban roughness of the two fabrics.

	Built density	Urban roughness
Old city	$D_s = 0.71$	$R_m = 6.87 \text{ m}$
New city	$D_s = 0.17$	$R_m = 2.48 \text{ m}$

Table 7.3 H/W ratio and SVF of references points.

	Old City H/W	SVF	New City H/W	SVF
P1	 3.40	 0.09	 0.56	 0.59
P2	 2.29	 0.21	 0.57	 0.53



At the street scale, the results of the H/W ratios and the SVF presented in Table 7.3 indicate that the old town fabric mainly consists of canyon-type streets, with fairly high H/W ratio values, averaging at 3.51 and reaching up to 8.67. The new town has an average H/W ratio of 0.48, representing a fabric with more open dihedral spaces. Thus, it is evident that the two fabrics are vastly different from a morphological perspective, although it should be noted that one reference point in the old fabric has an H/W ratio close to that of the new fabric, with a value of 0.55.

Microclimate Analysis

Daily variations of the microclimatic parameters (air temperature, mean radiant temperature, relative humidity and wind speed) were calculated in the selected urban fabrics at the various reference points previously set. This was followed by the calculation of tissue means to compare the two fabrics.

According to the observed results (Figure 7.2), the wind speed of the old fabric appears fairly constant in both summer and winter. Notably, the difference in wind speed between the old and new fabrics is approximately 2.46 m/s in winter and 0.75 m/s in summer. As for air temperature, the curves of both fabrics are similar in both seasons, although there is an average difference of 2.31 °C in winter, doubling in summer to reach 4.48 °C.

Regarding relative humidity, the difference between the old and the new city is around 6.33% in summer and 17.23% in winter. Finally, concerning mean radiant temperature, the disparity between the two fabrics can reach up to 16 °C in summer.

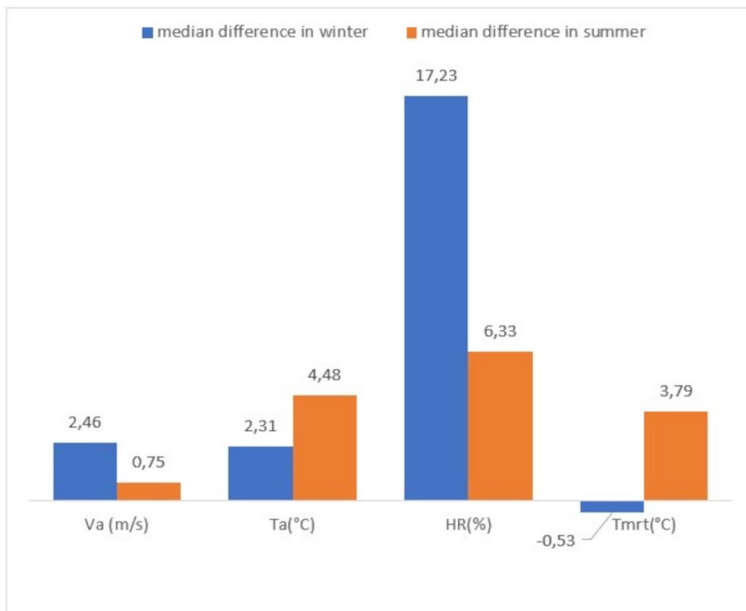


Fig. 7.2 Median differences between old and new cities. Author's graph, CC BY-NC-ND.

Assessment of Outdoor Thermal Comfort

Physical Aspect

The physical aspect of comfort is evaluated based on the UTCI thermal comfort index. UTCI values were calculated for both seasons on full days, followed by the daily average for each season. Figure 7.3 illustrates that the daily average in winter situates the old fabric in the ‘slight cold stress’ zone and very close to the ‘no thermal stress’ zone, while the new fabric falls within the ‘moderate cold stress’ zone. In summer, the old fabric is positioned in the ‘no thermal stress’ zone while the new fabric is in the ‘moderate heat stress’ zone.

Table 7.4 UTC ranges and related stress categories.

UTCI (°C) range	Stress category	UTCI (°C) range	Stress category
above +46	extreme heat stress	+9 to 0	slight cold stress
+38 to +46	very strong heat stress	0 to -13	moderate cold stress
+32 to +38	strong heat stress	-13 to -27	strong cold stress
+26 to +32	moderate heat stress	-27 to -40	very strong cold stress
+9 to +26	no thermal stress	below -40	extreme cold stress

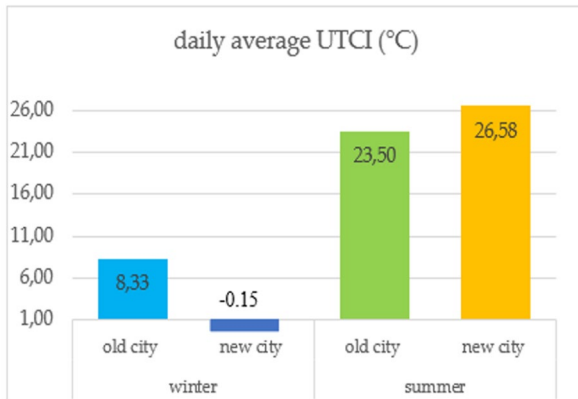


Fig. 7.3 Daily average of UTCI and Stress categories. Author’s graph, CC BY-NC-ND.

Analysing the comfort zones diagram (Figure 7.4) reveals that in winter, the old fabric has 37.5% of comfort zones compared to 25% for the new fabric. Moreover, the new fabric has 66% of its areas in moderate cold stress, while the old fabric has none. For the summer season, the fabric of the old city offers 62.5% of comfort zones with 33% of strong heat stress zones, in contrast to 58% of comfort zones for the new fabric and 37.5% of strong heat zones.

In both summer and winter, the fabric of the old city performs better with regard to outdoor thermal comfort. Indeed, according to the UTCI rating scale, the old fabric is within the thermal comfort zone in summer and is very close to it in winter. On the other hand, the fabric of the new neighbourhoods is in moderate cold stress in winter and moderate heat stress in summer.

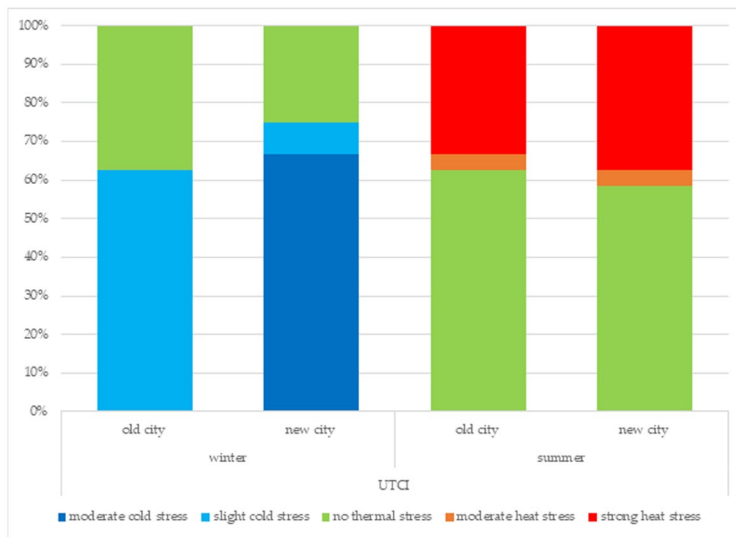


Fig. 7.4 Comfort zones percentages. Author's graph, CC BY-NC-ND.

Physio-psychological Aspect

Following the summer and winter surveys, encompassing a total of ninety participants, the data was coded and the results analysed in order to identify user opinions and perceptions regarding thermal sensation. On the perceptual judgments scale, the survey responses

indicate that the old fabric satisfies a greater number of people in terms of temperature and humidity. Conversely, the modern fabric provides more satisfaction concerning wind. On the evaluative judgments scale, the old fabric exhibits overwhelming satisfaction compared to the new fabric. Finally, on the thermal preference scale, the old fabric registers thirty-five percent satisfaction whereas the new fabric registers only five percent. In addition, the dissatisfaction rate is around forty-six percent for the new city in contrast to only five percent for old fabric. It is evident from this research that the notion of thermal comfort must be evaluated in its entirety and cannot be assessed based on individual factors. Nonetheless, the survey results support the findings of the physical aspect analysis, showing that the old fabric is more comfortable than the new fabric.

Discussion and Conclusion

This analysis demonstrates the superior outdoor thermal comfort of the medina fabric as compared to that of the new town. The results of the physical aspect, based on the UTCI index, align with the survey responses relating to the physio-psychological aspect, reinforcing this conclusion.

The study revealed that, for a subtropical Mediterranean climate like that of Tunisia, a high H/W ratio may contribute to creating acceptable thermal comfort conditions in both the summer and winter seasons. The results show that a higher H/W ratio correlates with increased comfort. In summer, the new fabric heats up more than the old fabric, and in the winter, the new fabric cools much more than the old one. For the old fabric, with an average H/W ratio of 3.51, the average UTCI in the winter season is 8.36 °C, a value very close to the neutral comfort zone (9 °C), and the UTCI average in summer is 23.43 °C, which falls within the comfort zone. Meanwhile, the modern fabric, with an average H/W ratio of 0.49 and average UTCI in winter of 2.15 °C, falls within the slightly cold zone, while the summer average of 26.61 °C indicates the moderate stress zone.

This difference is primarily due to the shading effect of the old fabric's urban morphology, reducing surface sun exposure and ambient

temperatures. Moreover, this configuration diminishes solar radiation's penetration into public space preventing radiative trapping.

Notably, the factors of built density and urban roughness play a significant role in the evaluation of outdoor thermal comfort, with considerable disparities apparent between the old and new fabrics. The old fabric is four times denser than the modern one and its urban roughness is 2.77 times greater. Nevertheless, two reference points within the two fabrics were found to possess similar H/W ratios but different UTCI values (see Table 7.5). This demonstrates that urban morphology cannot be considered at the street scale alone but must also be evaluated at the neighbourhood scale.

Table 7.5 Difference between same H/W ratio in the two fabrics.

		Old city	New city
Neighbourhood scale	Ds	0,71	0,17
	Rm (m)	6,87	2,48
Street scale	Reference point	P3	P1
	H/W	0,55	0,56
	SVF	0,33	0,59
Winter	UTCI min (°C)	-0,50	-3,80
	UTCI max (°C)	20,30	14,90
	UTCI mean (°C)	6,88	1,45
Summer	UTCI min (°C)	12,60	18,00
	UTCI max (°C)	34,20	39,00
	UTCI mean (°C)	22,39	27,11

The ancient fabric of the medina proves to be an exemplary model of outdoor thermal comfort. Its urban organisation, both at the neighbourhood and street scales, presents several advantages for sustainable urban planning given the relative comfort of its microclimate. Apart from its well-known sustainable characteristics, it offers additional advantages that warrant further study for recommendations in sustainable urban planning. Given the correlation between urban fabric density and a positive thermal environment, it is advisable to take measures to avoid the urban sprawl being witnessed in many modern cities as it contributes to the urban heat island effect, along with the deforestation and soil waterproofing

that follows. Additionally, at the street scale, adapting street prospects to modern needs by widening streets while maintaining the same H/W ratio can mitigate radiative trapping phenomena, addressing the main causes of street-scale air heating.

Bibliography

- Abdelkefi, Jalel, *La Médina de Tunis : espace historique* (Paris: Editions CNRS, 1989).
- Achour-Younsi, Safa, 'Evaluation des conditions de confort thermique d'été en espaces extérieurs à Tunis : Des tissus historiques aux nouveaux quartiers' (PhD thesis, National School of Architecture and Urbanism in Tunis, 2015).
- Adolphe, Luc, 'Modelling the Link between Built Environment and Urban Climate: Towards Simplified Indicators of the City Environment', in *Proceedings of IBPSA (International Building Performance Simulation Association)* (Rio de Janeiro: Actes IBPSA, 2001), pp. 679–84.
- Ait-Ameur, Karima, 'Characterization of the Microclimate in Urban Public Spaces through the Validation of a « Morpho-climatic » Indicator System', in *Proceedings of PLEA 2002—The 19th Conference on Passive and Low Energy Architecture* (Toulouse: PLEA, 2002), pp. 305–11.
- Ali-Toudert, Faiza and Mayer, Helmut, '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 (2006), 94–108, <https://doi.org/10.1016/j.buildenv.2005.01.013>
- Auciliems, Andris and Szokolay, Steven V., *Thermal Comfort: PLEA (Passive and Low Energy Architecture) Notes*, PLEA Note 3 (Brisbane: PLEA and Department of Architecture, the University of Queensland, 1997).
- Bahri, Mounir, *La nouvelle réglementation thermique en Tunisie et le programme de soutien* (Tunis: Consultation Nationale sur les technologies et le financement de la maîtrise de l'énergie dans le bâtiment, 2008).
- Belakehal, Azeddine, 'Ambiances patrimoniales : problèmes et méthodes', in *Ambiances in action/Ambiances en acte(s)—International Congress on Ambiances* (Montréal: International Congress on Ambiances, 2012), pp. 505–10, <https://shs.hal.science/halshs-00745537/document>
- Bröde, Peter, Fiala, Dusan, Błażejczyk, Krzysztof, Holmér, Ingvar, Jendritzky, Gerd, Kampmann, Bernhard, Tinz, Birger and Havenith, George, 'Deriving the Operational Procedure for the Universal Thermal Climate Index (utci)', *International Journal of Biometrology*, 56.3 (2012), 481–94, <https://doi.org/10.1007/s00484-011-0454-1>

- Bruse, Michael, 'Simulating Microscale Climate Interactions in Complex Terrain with a High-resolution Numerical Model: A Case Study for the Sydney CBD (Model Description)', in *Proceedings of International Conference on Urban Climatology and International Congress of Biometeorology* (Sydney: n.p., 1999), <https://www.envi-met.net/documents/papers/CBDSimu1999.PDF>
- Carrega, Pierre, 'Topoclimatologie et habitat' (PhD thesis, Université Sophia Antipolis, Nice, 1994).
- Debbage, Neil and Shepherd, J. Marshall, 'The Urban Heat Island Effect and City Contiguity', *Computers, Environment and Urban Systems*, 54 (2015), 181–94, <https://doi.org/10.1016/j.compenvurbsys.2015.08.002>
- Giguère, Mélissa, *Mesures de lutte aux îlots de chaleur urbains* (Quebec: Institut National de Santé Publique, 2009), <https://www.inspq.qc.ca/publications/988>
- Jendritzky, Gerd, De Dear, Richard and Havenith, George, 'UTCI—Why Another Thermal Index?', *International Journal of biometeorology*, 56.3 (2011), 421–28, <https://doi.org/10.1007/s00484-011-0513-7>
- Lévy, Albert, 'Urban Forms and Significations: Revisiting Urban Morphology', *Spaces and Societies*, 122.3 (2005), 25–48, <https://doi.org/10.3917/esp.122.0025>
- Parsons, Ken, *Human Thermal Environment*, 2nd ed. (London: Taylor and Francis, 2003).
- Rizwan, Ahmed, Memon, Dennis, Leung Y. C. and Liu, Chunho, 'A Review on the Generation, Determination and Mitigation of Urban Heat Island', *Journal of Environmental Sciences*, 20.1 (2008), 120–28, [https://doi.org/10.1016/S1001-0742\(08\)60019-4](https://doi.org/10.1016/S1001-0742(08)60019-4)
- Salata, Ferdinando, Golasi, Iacopo, De Lieto Vollaro, Roberto and De Lieto Vollaro, Andrea, 'Urban Microclimate and Outdoor Thermal Comfort. A Proper Procedure to Fit ENVI-met Simulation Outputs to Experimental Data', *Sustainable Cities and Society*, 26 (2016), 318–43, <https://doi.org/10.1016/j.scs.2016.07.005>
- Wang, Yupeng and Akbari, Hashem, 'Effect of Sky View Factor on Outdoor Temperature and Comfort in Montreal', *Environmental Engineering Science*, 31.6 (2014), 272–87, <https://doi.org/10.1089/ees.2013.0430>

