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The effect of urban geometry on outdoor thermal comfort. Application of the UTCI index in hot and arid climates.

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Abstract. The object of our study is to evaluate the effect of urban geometry on microclimate and outdoor thermal comfort. In this context, "the RayMan pro 2.1" software was adopted to define UTCI index applying in hot and arid climates, exactly, in the urban fabric of the Ksar of The Red Village, El Kantara in Biskra city, Algeria, to define the most efficient urban geometry in term of summer thermal comfort by studying the real impacts of the urban form on the solar control and microclimatic conditions. studying the correlation between the geometry of the street estimated by the ratio H/L, the sky view factor (SVF), its orientation and the evolution of the physical variables (Ta, MRT, Ws) and the values of UTCI index.
Significant relationships were found between UTCI index, urban geometry and heat stress in outdoor environments. The results of this research have shown the effect of urban design strategies on modifying the microclimatic conditions in hot summer for outdoor spaces in hot-arid climate.

Keywords. urban morphology; urban microclimate; outdoor thermal comfort; hot and arid climate; UTCI index.

1. Introduction

According to ASHRAE standard [1], thermal comfort is defined as "That condition of mind which expresses satisfaction with the thermal environment".
For several decades, the influence of environmental parameters on the comfort conditions at the urban scale has motivated a great deal of research. Urban climatology specialists have sought to evaluate the thermal comfort in outdoor spaces, which has acquired its acclaim and becomes of similar importance to interior comfort, widely discussed, where effects of urban configuration on urban thermal climate have also been recently explored through series of investigations in many climatic conditions [2], [3], [4,7].
The level of well-being sensation of the users of outdoors is one of the factors influencing outdoor activities in streets, plazas, playgrounds, urban parks, etc. The amount and intensity of such activities is affected mainly by the level of the discomfort experienced by the users of such spaces when they are exposed to the climatic conditions in these outdoor spaces [8].
Beyond the effect of microclimate on human activity, especially pedestrian, in the spaces between buildings, the spaces outside a building can often influence the perceptions use of a

building on the inside, the relationship between the inside and outside living spaces of houses may affect the way the occupants use the spaces and perceive the environment, also, a strong inverse correlation was founded between energy consumption and the use and satisfaction with outdoor spaces [9].

Thermal comfort is a complex and global notion because of the multiplicity of parameters that interact and influence its evaluation, taking into account both objective and subjective factors [10] and translated by psychological factors such as: past experiences, perceived control, time of exposure, environmental stimulation, expectations and naturalness [11].

Thermal comfort is worldwide assessed using different indices based on thermal energy balance of the human body in an urban space and was developed in order to quantify this notion.

Every climatic region has its own characteristics and meanings of an index. It has to be adjusted to the local situation and cannot be used globally.

In general, Scudo, 2002 classified thermal indices in the following four groups [12]:

- Empirical thermal indexes correlating only a few environmental factors and usually developed for specific climatic conditions, such as the wind chill Index and discomfort index.
Psycho-sociological-climatic indexes, correlating subjective perception (e.g., actual sensation vote, satisfaction indexes) of microclimatic variables and comfort index [10].
- Energy balance equation indexes based on a two-node model of the human body and on the assessment of all relevant thermal climatic parameters, coupling the heat balance equation with a simplified model to evaluate Mean Radiant Temperature [13].
- Energy balance equation based on a one-node model of the human body: perceived temperature (PT) model based on Fanger's equation (1972) plus an outdoor radiant evaluation model: PVM index and COMfort FormulA-COMFA+ with a simplified radiant evaluation model.

Urban geometry and thermal properties of urban surfaces have been found to be the two main parameters influencing urban climate. The ratio between the height of buildings (H) and the distance between them (W) influences the amount of both incoming and outgoing radiation and also affects wind speeds [14]. This paper aimed mainly to investigate the influence of urban geometry on microclimate and thermal comfort at outdoor spaces level in a hot and arid climate. This is done by the application of UTCI thermal index in different locations chosen in a compact urban fabric. The UTCI is defined as the air temperature (Ta) of the reference condition causing the same model response as the actual condition. Thus, UTCI is the air temperature which would produce under reference conditions the same thermal strain as in the actual thermal environment. [15].

2. Case study

The Dachra El Hamra (the red village) is a traditional fabric of the pre-colonial era. It is the first nucleus of El Kantara which, through its opening on the desert and by its richness in date palms (more than 50000), constitutes the portal of the transition between two regions whose climatic aspects are quite different: the north and the south of Algeria Figure (1). It is an oasis located in the wilaya of Biskra to 50 km to the north of the city and in the Southwest of the Aures to 80 km of Batna [16].

The Red Village is a compact entity characterized by a densely populated urban fabric with narrow, unpaved streets and a dominant type of building constructed in the Saharan architectural style. The streets, the narrow streets, the blind alleys (Darb), the covered passages (Skifa), the plots (Rahba or Batha) constitute the elements of the structure designed according to the style of the old towns (Ksour) and the introverted model of the Arab-Islamic medina [17] where streets are narrow, irregular and generally covered to reduce direct exposure to sun. This region is characterized mainly by the aridity of her climate, high summer daytime temperatures, large diurnal temperature range, and high solar radiation.

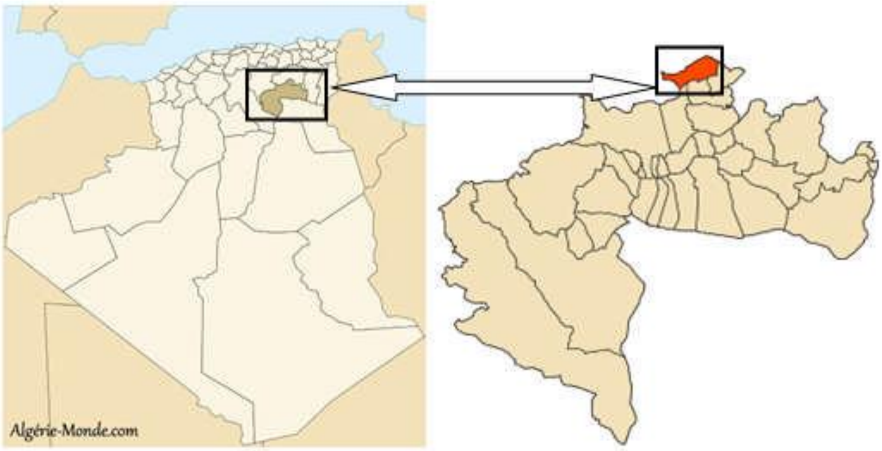


Figure 1. localization of el Kantara in Algeria and in the wilaya of Biskra

3. Methods

3.1. Conduct of the investigation. The In order to determine the mean radiant temperature required for the calculation of UTCI, the index adopted for the evaluation of thermal comfort in the study site, it is inevitable to examine the four main climatic parameters previously cited, of the instrument: "TESTO data logger 480" whereby the air temperature, relative humidity, wind speed and the temperature of a globe thermometer.

The investigations of this study are limited to the summer period of a meteorological data series (2006–2015), because climatic heat stress in the urban open spaces mainly occurs during this season. Conversely, thermal cold stress only occurs in winter for a few days between 27 July and 04 August is where the thermal stress reaches its maximum values. During this period, 29 and 30 July were chosen for the elaboration of the investigation and considering the days with the typical summer conditions.

In order to estimate the UTCI thermal index, used to quantify the level of thermal comfort, the mean radiant temperature was calculated by the method B described by THORSSON [18] must first be calculated, based on the pre-measured climatic variables and the overall temperature, according to the following formula:

MRT= [(GT+237)4+2,5×108×Ws0, 6× (GT-Ta)] (1/4)-273 (1)

3.2. Conduct of Location and representation of measurement point.

The selection of measurement points is the result of a typo morphological analysis of the urban fabric of the case study, in order to identify the different typologies existing in the external space.

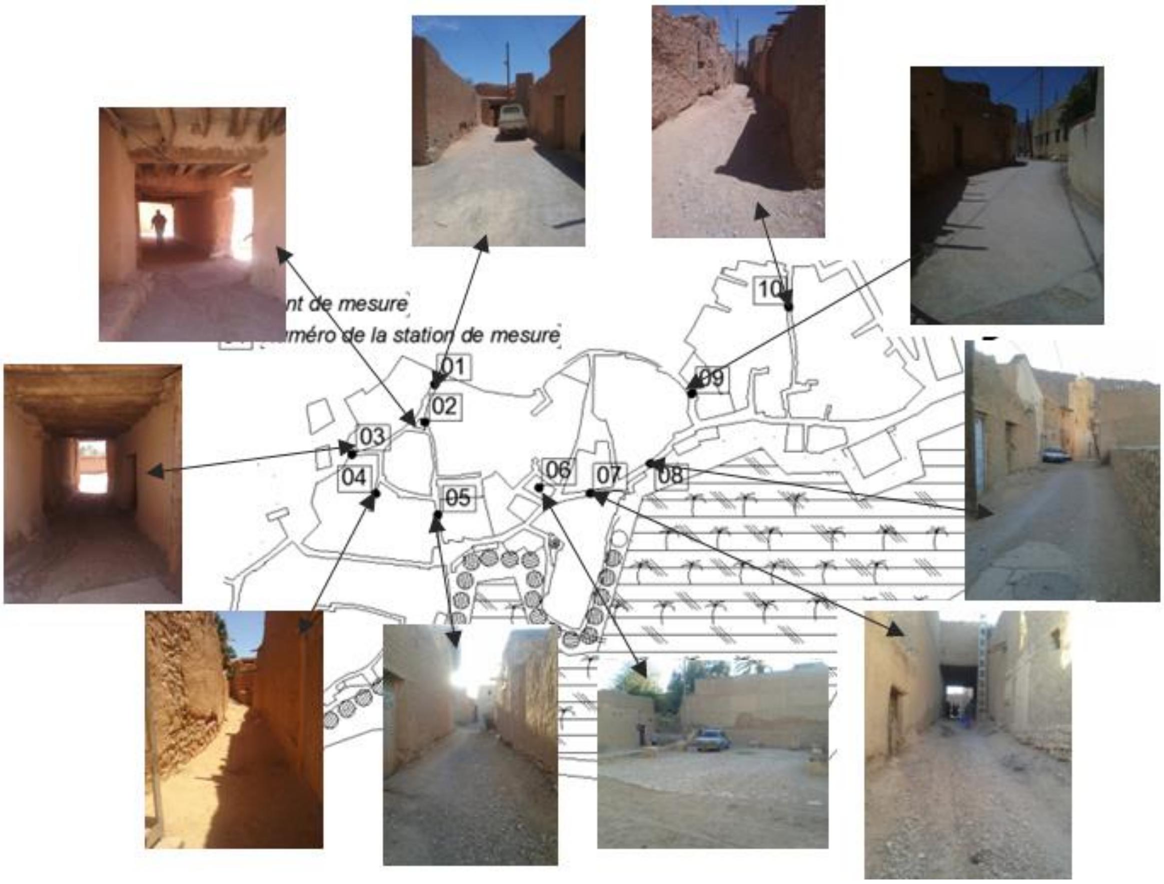
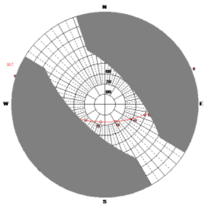
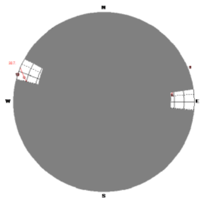
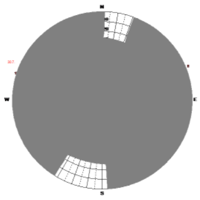
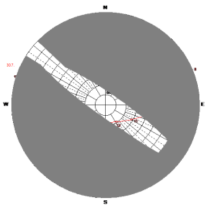
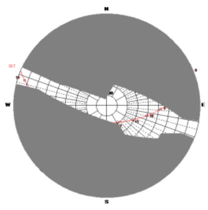
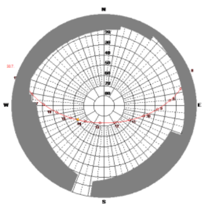
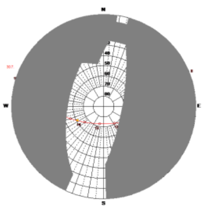
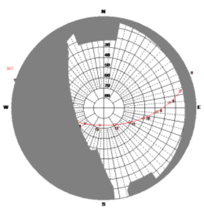
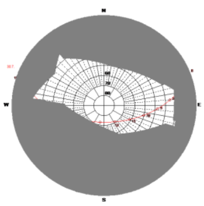
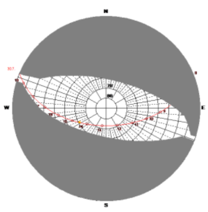


Figure 2. Localization of measured point

Each measuring point describes distinct geometric features reflecting spatial diversity in order to characterize their effect on the thermal comfort and fluctuation of the thermal environment. Measurement points were chosen in order to represent differences in urban geometry (H/L ratio and SVF) and street orientation. According to the typo morphological analysis of the urban fabric, the following types of exterior space were identified: streets, alleys, covered streets (Skifa), impasses, streets delimited on one side and cleared on the other , streets of building on one side and an oasis on the other (Balconies), small square of (Rahba or Batha).

The different points chosen (10 measurement points) along a trajectory presented in Figure (2) representative of the urban fabric studied are presented in Table (1).

Table 1. Representation of geometrical characteristics of measured points.

Station	**1**	**2**	**3**	**4**	**5**
Solar diagram					
SVF	0.277	0.006	0.016	0.104	0.151
Station	**6**	**7**	**8**	**9**	**10**
Solar diagram					
SVF	0.610	0.224	0.421	0.249	0.249

4. Results

4.1. Impact of urban geometry on mean radiant temperature.

The mean radiant temperature reaches its maximum value in point six (06) where the lowest H / L ratio was recorded with a considerable difference with the temperature of the air measured under the effect of the sunshine. As well as recording low values in points with a high H / L ratio or in the covered passages where the graph begins to decrease, this difference relates to exposure to solar radiation, according to which points Exhibits a small gap are the least exposed (Figure 03).

4.2. Impact of urban geometry on mean radiant temperature.

Thermal comfort level is related to the thermal sensation; the different values of the UTCI index are categorized in terms of thermal stress in table. I. The obtained results of this index were classified using this table in the Table (2).

The evaluation of the values of the UTCI thermal index presented in the graph (Fig. 04), we note the relationship between this index and the values of MRT, the increase of MRT of which leads to an increase in UTCI index values. It is also remarkable that the values of MRT and UTCI index vary simultaneously with the variation in the values of the SVF (presented in Table (2)) the increase of which leads to an increase in the values of this index, the maximum value at point 06 with the highest SVF. In addition, the minimum values for UTCI index were recorded under the covered passages thanks to the shadow generated by the latter at the street level. The considerable difference between the SVF of the two points 07 and 08 did not result in a large difference between the values of the UTCI index recorded there, thanks to the solar orientation of the point 08 which presents the highest SVF. The solar orientation also has a considerable effect when comparing the two points 09 and 10 which have the same SVF and an apparent deviation from the values of the UTCI index, finding that the point 10 oriented North- West.

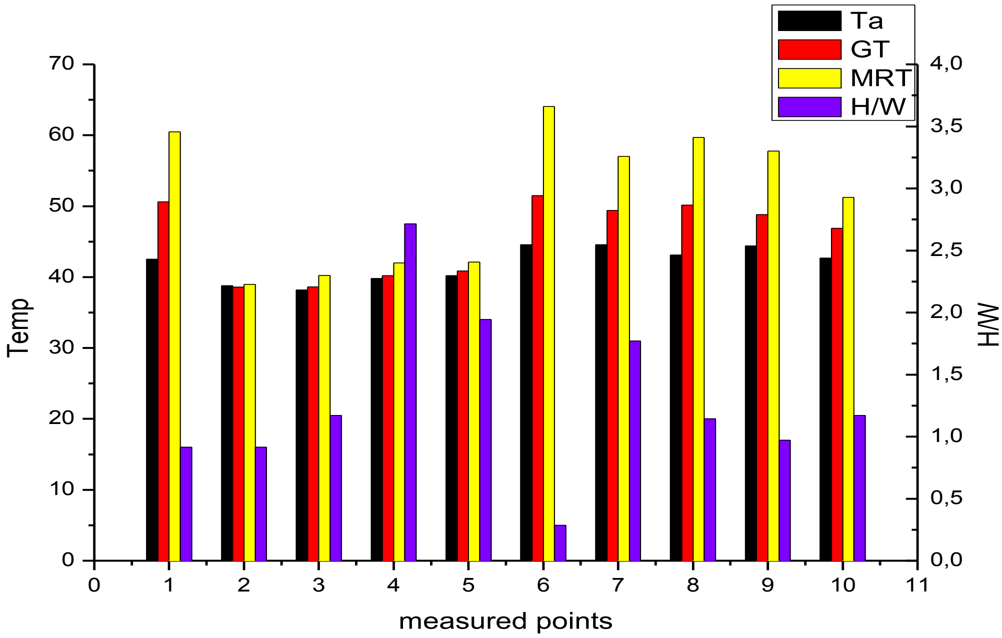


Figure 3. Mean radiant temperature measured in different points at 29-30/07/2016.

Table 2. Obtained results of UTCI thermal index categorized in terms of thermal stress.

Measured points	UTCI values (°C)	Thermal stress category	
01	47,9	4	Extreme heat stress
02	39,9	3	Very strong heat stress
03	38,9	3	Very strong heat stress
04	41,2	3	Very strong heat stress
05	41,7	3	Very strong heat stress
06	50,6	4	Extreme heat stress
07	48,8	4	Extreme heat stress
08	48,2	4	Extreme heat stress
09	48,9	4	Extreme heat stress
10	45,7	3	Very strong heat stress

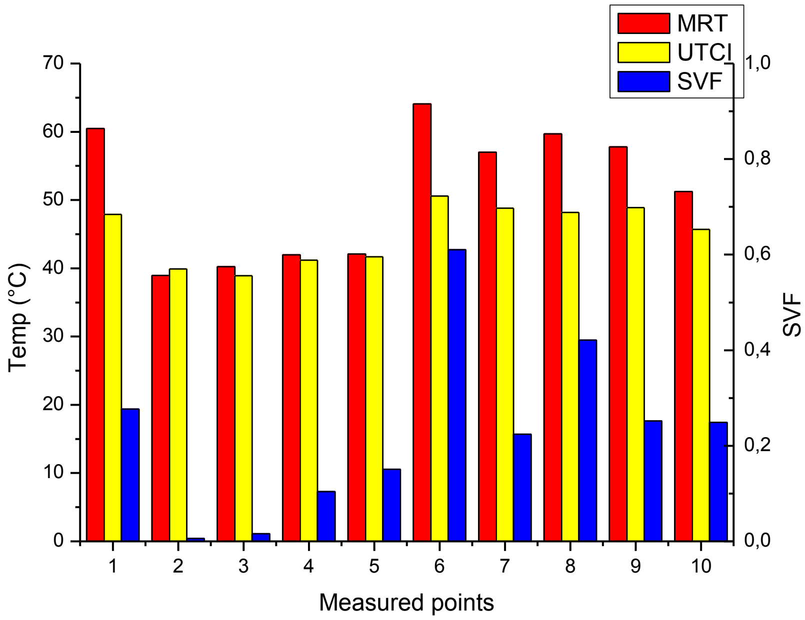


Figure 4. UTCI values measured in different points at 29-30/07/2016

5. Conclusions

The results acquired in this study shows that the thermal comfort parameters (MRT and UTCI) at different points can be significantly affected by the urban configuration.

The study of the above graphs in relation to the geometrical characteristics of the points studied, represented in Table II, and enabled us to reach a number of recommendations relating to urban design in hot regions. The analysis of the results of the investigation allowed us to demonstrate the considerable effect of SVF, the ratio H/W and the solar orientation on the thermal fluctuations in the street by affecting mainly the wind conditions that contribute to moderate air temperature, sun and shade in streets. Optimal decrease of Tmrt and UTCI thermal index values could particularly be obtained on the north-south reoriented streets and with increased buildings heights. In this study, narrow and covered streets, at the orientations north-south, north west - south east, provide better shading by buildings, desirable at this region in summer, for pedestrians on sidewalks than wide streets, to ensure human thermal balance and guaranteed an optimal level of thermal comfort, and the protection from the solar exposure is the more important objective related to the streets.

The opening to the sun is defined by a controlled SVF and an optimal H /W ratio combined with a controlled solar orientation, favouring the North-South, North-West-South-East orientation which offers acceptable conditions in terms of comfort Compared with other solar orientations. Although the level of thermal comfort is a quantifiable and measurable element, its evaluation also requires consideration of the psychological aspect required for the control of perceived thermal sensation, using observation techniques, questionnaire and Surveys.

6. Nomenclature

Ta: air temperature

GT : global température
Ws: Wind speed
RH: Relative humidity.
MRT: mean radiant temperature.
SVF: Sky view factor.
UTCI: Universal Thermal Climate Index.

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