*Research Paper*

# Outdoor thermal comfort levels in the historical city fabric Casbah of Algiers

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## Abstract

*Thermal comfort in cities is an influential factor for citizens' wellbeing and life quality. Urban microclimate studies have gained popularity following increasing urbanization trends and global climate change in recent years. Urban fabric and morphology in traditional cities represent a unique pattern both spatially and climatically. However, few studies have investigated traditional cities' urban thermal comfort conditions. Therefore, this study aimed to assess the thermal comfort in different subspaces of Algiers Casbah's historic urban fabric, which falls in the hot Mediterranean climate (Csa). This research evaluated the human thermal sensation by applying the physiological equivalent temperature (PET) index. The methodology used was a mixed approach, including field measurements, calculations, and a survey questionnaire. The results indicate the presence of a high-stress level during the measurement periods, and notable differences between the subspaces in January (ΔPETMax.Jan = 3.7 °C) and August (ΔPETMax.Aug = 2.2 °C). The highest discomfort was recorded in spaces with collapsed buildings, especially during the hot hours of the day. The findings also highlight a strong impact of the sky view factor on the the physiological equivalent temperature (PET). The study discusses recommendations and ways to improve the design of outdoor spaces and relieve heat stress in the streets of traditional cities. Finally, this work helps urban managers and heritage conservators in urban rehabilitation policies concerning outdoor microclimate improvement.*

## Keywords

*Urban; Heritage; Morphology; PET; Mean radiant temperature; Rayman Model.*

## 1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) (Georgescu et al., 2014; Wang et al., 2019), urbanization and global climate change are two significant factors affecting cities' climate. Indeed, today's world is experiencing a considerable acceleration in terms of 'urbanization, more than 50% of the world's population lives in an urban area, and this proportion is expected to increase. By 2050, 70% of the population will live in towns and cities ("Urbanization and health," 2010). Through different mechanisms, these climatic changes affect human health, tourism, and outdoor activities (Hein et al., 2009; McMichael and Lindgren, 2011). Several studies investigated the impacts of urbanization on the urban climate and human thermal comfort (Emmanuel, 2005; Mahmoud and Gan, 2018; Morris et al., 2017). Therefore, ensuring wellbeing and comfort in the city is an essential indicator in Sustainable Development Goal 11 ("United Nations Development Program. (2015). Sustainable Development Goals. [online]. United Nations. Retrieved from https://www.undp.org/content/undp/en/home/sustainable-development-goals.html," n.d.). Sustainable cities and human settlements, established by the United Nations General Assembly in 2015.

Air temperature and solar radiation are the main factors affecting thermal comfort in urban climates (Jin et al., 2020). Nikolopoulou studies (Nikolopoulou, 2004) revealed that temperature, wind speed, and sunshine are the most critical parameters of outdoor comfort and influence thermal sensation. More recent research defines outdoor pedestrian thermal comfort by both meteorological (air temperature, relative humidity, wind speed, and mean radiant temperature) and personal factors (clothing type and activity level) (Jamei et al., 2016). Urban geometry, which is defined by the aspect ratio, sky view factor, street orientation, and neighborhood configuration, greatly impacts outdoor thermal comfort (Krüger et al., 2011; Sharmin et al., 2017).

Several studies have been carried out on modern urban typologies (Bourbia and Boucheriba, 2010; Givoni, 1998; Johansson, 2006; Johansson and Emmanuel, 2006; Ratti et al., 2005; Thorsson et al., 2011). Givoni investigated the urban design effects on the Urban Climate and the impact of green areas. Similarly, Ratti studied solar radiation and the height-to-width ratio (H/W) incident. Findings show that large courtyards are environmentally adequate in cold climates. Taleghani (Taleghani et al., 2015) evaluated the outdoor thermal comfort within five different urban forms using physiological equivalent temperature (PET) based on real models as well as simulation (Rayman, ENVI-met). In life quality studies, Kruger (Krüger et al., 2011) studied the impact of urban geometry on outdoor thermal comfort and air quality through the sky view factor, PET. Jamei (Jamei et al., 2016) explored the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. Findings showed that the main pedestrian level green infrastructures are urban geometry, street trees, and city parks.

On the other side, few studies addressed the issue of outdoor thermal comfort in traditional urban morphologies. This latter is characterized by the narrow and shallow street corridors, resulting in closer public interactions and closed private spaces (Dhingra and Chattopadhyay, 2016). The urban morphology of these cities consists of an assemblage of houses' courtyards (patios) linked by a hierarchical street network (Ben Salem et al., 2021). The form was almost completely homogeneous, organized by a system of open spaces and circulations present at all scales (Kiet, 2011). The main characteristics of traditional urban fabric are introversion, use of local materials, and the low H/W ratio (Berkani, 2013). Historic centers have mostly undergone reconfigurations at the city limits, thus making this part of the traditional fabric "Hybrid" (Alsayyad, 1995).

Some studies have been carried out on the impact of urban morphology of the traditional urban fabrics, Ali-Toudert (Ali-Toudert et al., 2005; Ali-Toudert, F and Mayer H, 2006) first investigated in an old desert city of Gherdaia, Algeria. The relation of outdoor thermal comfort in a hot and dry concerning urban geometry. At the same time, they studied the development of comfortable street-scale microclimates through design, aspect ratio (H/W) and solar orientation. These studies demonstrated that Building materials associated with deep streets play a decisive role in mitigating heat stress in the daytime. Also, that the high and heavy walls of traditional constructions provide more shading and more heat storage, leading to lower surface temperatures.

Other studies (Cortesão and Alves, 2010; Rosso et al., 2018) investigate attenuation and mitigation strategies in historical urban canyons. In this sense, the bioclimatic aspect, and the impact of innovative materials on outdoor thermal comfort have been studied in Porto, Portugal, and Rome, Italy.

Despite the presence of studies that dealt with the morphological and bioclimatic specificities of traditional urban fabrics and the outdoor thermal comfort, their number remains reduced compared to studies in contemporary cities. Nevertheless, few studies (Achour-Younsi and Kharrat, 2016; Ali-Toudert, F and Mayer H, 2006; Castaldo et al., 2017) have quantified outdoor thermal comfort in traditional urban morphologies, specifically in the Mediterranean climate, following an empirical approach using PET.

Therefore, this study is motivated by limited knowledge regarding microclimate characterization in historical urban fabrics. This paper investigated outdoor urban comfort through a validated empirical mixed approach. More specifically, the study investigates the outdoor therm comfort conditions in the subspaces of a complex urban morphology in a Mediterranean climate. The results of this research are significant because they are part of an incremental effort to bridge the knowledge gap regarding the influence of traditional urban morphology on thermal comfort. This work could serve as a basis to aid urban designers and urban managers to obtain answers for future environmental strategies to be adopted to renovate and rehabilitate their cities' fabrics.

Evaluating the existing outdoor thermal comfort is imperative for the characterization of this morphological typology. This study aimed to quantify the microclimate in different subspaces of the Casbah of Algiers. More specifically, the following questions are answered:

- What are the thermal comfort levels in the historical urban fabric?
- How far do the sub-spaces of historical urban fabrics affect the subjective and objective effect of Microclimatic thermal comfort?
- To what extent does the sky view factor affect the outdoor thermal comfort within the Casbah of Algiers?

In this context, we developed our study to characterize the traditional urban space and create the characterization of the study area is the first step in urban rehabilitation. This approach can be generalized to other cities with similar traditional urban morphology.

The second benefit of this work is to improve the occupants' quality of life. Indeed, the characterization of the outdoor thermal comfort and the thermal stress range will allow identifying the hotspots in traditional cities. Consequently, different urban managerial strategies can improve human interaction and revive public spaces. Achieving thermal comfort in outdoor spaces will encourage leisure activities. Also, local citizens will benefit from outdoor activities and overall improved quality of life in the traditional built environment.

This research makes it possible to highlight the thermal comfort in a specific urban morphology. Indeed, a literature review revealed a scarcity of existing knowledge regarding traditional cities. It is necessary to evaluate the current state of the streets by following an empirical approach to propose targeted solutions. This study can serve as an input for urban planning decision-making and guide urban designers and managers of heritage fabrics.

## 2. Materials and Methods

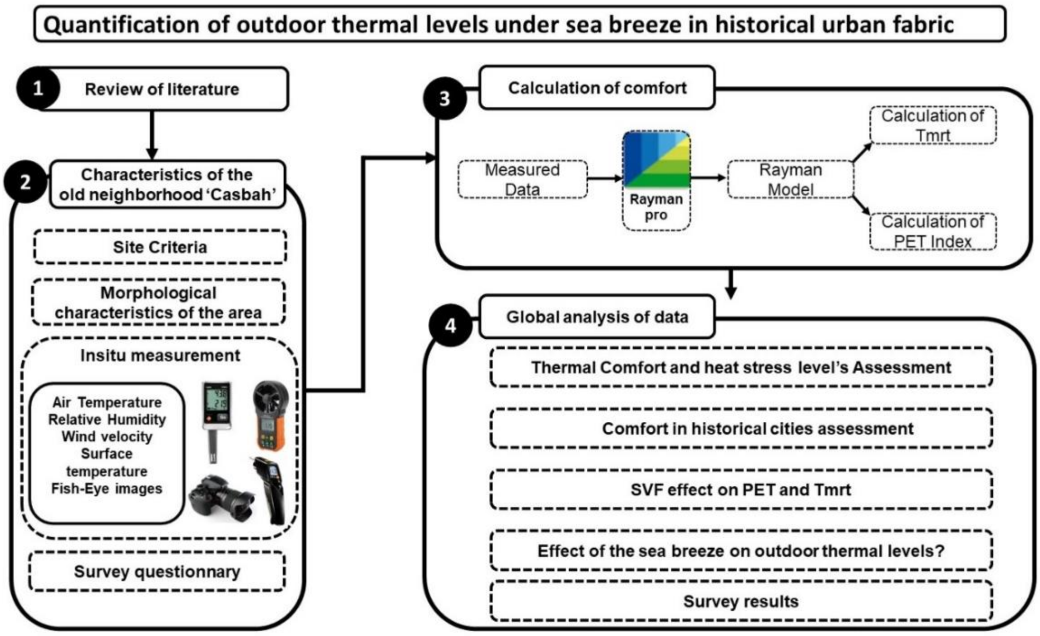


**Figure 1: Study conceptual framework.**

### 2.2. Characteristics of the old neighborhood "Casbah of Algiers"

#### 2.2.1. Site Criteria

The study has been attended in the Casbah of Algiers situated in the north of Algeria (36° 47′ 00″ N, 3° 03′ 37″ E) at elevation 107m (Figure 2). The Casbah is the historic center of Algiers' city and a historic neighborhood listed as a world heritage site by UNESCO (United Nations Educational, Scientific and Cultural Organization) since 1992. Thus, representing a typo morphology of traditional Islamic architecture construction. Building materials are generally with local materials (Terracotta, lime) (Abdessemed-Foufa, A., 2011). The urban space is subdivided into several subspaces, which is one of the characteristics of the traditional urban space (Figure 2). For this study, the PPSMVSS (Permanent plan for the safeguarding and enhancement of safeguarded sectors) for the Casbah was consulted and several google maps/satellite images. Our study focuses on the residential area of the Upper Casbah.

From the climatic classification found in the literature (Semahi et al., 2020), Algeria has five climate zones according to the Koppen classification (Beck et al., 2018) and seven climatic zones according to the heating and cooling degree-days classification approach (Ghedamsi et al., 2016). The average high temperature registered is 35°C on hot days, temperatures can soar to 42°C, and the lowest is 6°C with temperatures on cold nights reaching until 0°. For the climatic classification, according to Köppen-Geiger, Algiers is of the Mediterranean climate type (Csa, hot summer).

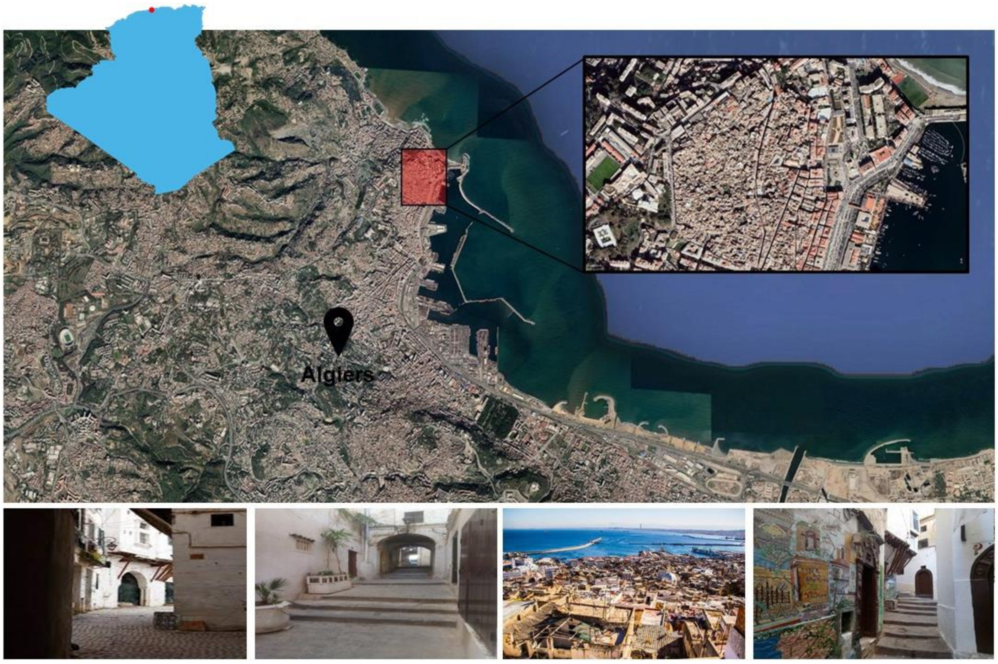


**Figure 2: Location of the historic urban fabric studied in the territory of Algiers.**

### 2.2.2. Morphological characteristics of the conducted stations

Several measurement points are taken to assess outdoor thermal comfort and determine the impact of the sky view factor on comfort. The 14 most representative and significant subspaces (Figure 3) depend on the streets' type, width, length, and orientation. The urban morphological details are explained in Table 1 and are summarized in Figure 3. The methodology followed for the in-situ measurements is explained in the following steps.

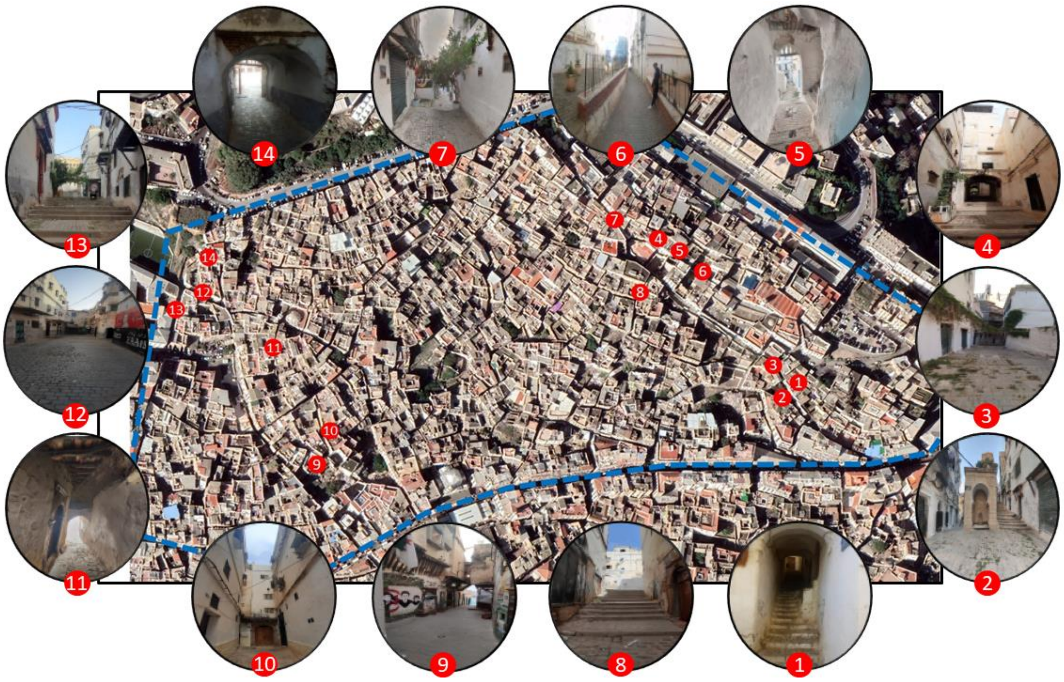

**Figure 3: Map of the selected points in the Upper Casbah**

**Table 1: Morphological characteristics of sites and measurement points**

| Site | Measurement point | SVF | Street direction | Width | Height | Covered area |
|---|---|---|---|---|---|---|
| Casbah of Algiers | 1 | 0.01 | N-S | 1.30 | 3.15 | Y |
| | 2 | 0.24 | E-W | 5.50 | 13.20 | N |
| | 3 | 0.18 | E-W | 2.80 | 11.30 | N |
| | 4 | 0.00 | N-S | 2.17 | 3.30 | Y |
| | 5 | 0.01 | N-S | 2.10 | 2.90 | Y |
| | 6 | 0.56 | N-S | 18.6 | 8.10 | N |
| | 7 | 0.24 | E-W | 3.95 | 8.20 | N |
| | 8 | 0.10 | N-S | 0.90 | 12.50 | N |
| | 9 | 0.05 | N-S | 1.80 | 8.60 | N |
| | 10 | 0.07 | N-S | 1.97 | 9.00 | N |
| | 11 | 0.00 | E-W | 1.80 | 2.20 | Y |
| | 12 | 0.29 | N-S | 4.90 | 8.95 | N |
| | 13 | 0.25 | E-W | 4.55 | 8.60 | N |
| | 14 | 0.01 | N-S | 1.95 | 2.50 | Y |

### 2.2.3. Morphological characteristics of the conducted stations

The collected data concerned in-situ measurement and field survey. The in-situ measurements protocol was designed to measure microclimate variables which are: Air temperature (Ta), Relative humidity (RH), Wind velocity (Va), and Surface temperature (TS); this last one is necessary to calculate the Tmrt. The measurements were taken using the Testo 175H1, a reliable and validated instrument for data acquisition (Table 2). All the instruments used were newly acquired, mainly for the study.

Sensors were kept at 1.40 m height from the ground to avoid the effect of surface contact (Ali-Toudert and Mayer, 2007) Testo 830 Infrared Thermometer for surface temperature measurements (ground and walls). Table 2 lists the name, the range, and the accuracy of the instruments used in the monitoring study. Meteorological measurements were conducted for a period of 7 days twice a year, once in winter (26th January to 1st February) and the other in summer (5th to 11th of August). Measurements have taken place every two hours, from 6 am to 8 pm. The Fish-eye images took the degree of the opening to sky. Processing of the photos and the calculation of the SVF will be done by Rayman software.

**Table 2: Instruments used for the study fields**

| Fish-Eye Images Parameters | | | | | |
|---|---|---|---|---|---|
| | Camera | Focal length | Resolution | Dimensions | Colors representation |
| (a) | Canon EOS 1100 D | 32mm | 230000 pixels | 4272 x 2848 | sRGB |
| **Meteorological Data Parameters** | | | | | |
| | Variable | Device | Unit | Accuracy | Range |
| (b) | Air temperature (Ta) | Testo 175H1 | °C | ± 0.4 °C | -20 to +55 °C |
| (b) | Relative Humidity (RH) | Testo 175H1 | °C | ± 2% | 0 to 100 %RH* |
| (c) | Wind Velocity (Va) | PEAKMETER PM6252A | m/s | ± 0,1m/s | 0.2 to 30.0 m/s |
| (d) | Surface temperature (Ts) | Testo 830-T2 | °C | ±1.5 °C | -30 to +400 °C |


### 2.2.4. Survey questionnaire

A survey was carried out for the inhabitants and visitors of the Casbah to determine the subjective feeling of comfort. our questionnaire was carried out during the January period on a sample of 60 people. 44 men and 16 women, 40 residents and 20 tourists visiting the casbah. It has been adapted according to various research conducted on outdoor thermal comfort. The field survey has been done in the same periods as the meteorological measurements. The questionnaire includes questions on metabolism and meteorological parameters that influence daily comfort with 5-point scale importance and evaluation of the parameters that influence daily comfort in the different spaces with an ASHRAE 7-point scale Pleasantness scale and a ranking of outdoor spaces from the most comfortable to least comfortable. The survey is accessible in the dataset (Arrar et al., 2022b).

## 2.3. Calculation of comfort

### 2.3.1. Measured data

The shared dataset (Arrar et al., 2022a) gathers meteorological data measured during the reference weeks. Table 4 is an example of the measured data summarized in the latter. Fish-eye images used in the data inputs to calculate the sky view factor, taken by the Canon EOS 1100D cameras, are summarized in Figure 4 according to the order of the measurement points.

**Table 3: Example of Measured meteorological data input**

| | | | | Summer | Day: 7 | 12 P.M |
|---|---|---|---|---|---|---|
| Unit | °C | % | m/s | °C | °C | °C |
| Points | Ta | HR | Ws | TGround | TWall 1 | TWall 2 |
| 1 | 18.5 | 71.6 | 1.4 | 18.1 | 18.0 | 17.9 |
| 2 | 20.0 | 66.7 | 0.3 | 18.0 | 18.2 | 18.1 |
| 3 | 19.1 | 69.2 | 1.1 | 18.6 | 18.5 | 18.2 |
| 4 | 19.0 | 69.1 | 0.1 | 18.3 | 18.3 | 18.2 |
| 5 | 18.1 | 72.0 | 1.1 | 18.1 | 18.0 | 17.7 |
| 6 | 19.1 | 69.5 | 0.2 | 21.5 | 20.4 | 19.9 |
| 7 | 19.1 | 70.0 | 0.1 | 18.1 | 17.9 | 17.6 |
| 8 | 19.8 | 67.2 | 1.4 | 19.0 | 18.6 | 18.5 |
| 9 | 18.6 | 70.9 | 1.5 | 18.1 | 18.0 | 18.0 |
| 10 | 19.4 | 68.8 | 0.0 | 18.1 | 18.2 | 18.0 |
| 11 | 18.7 | 70.0 | 0.7 | 18.0 | 18.0 | 17.9 |
| 12 | 19.0 | 68.8 | 0.7 | 17.9 | 18.7 | 18.5 |
| 13 | 18.9 | 68.8 | 1.2 | 19.2 | 18.9 | 18.7 |
| 14 | 19 | 69.1 | 2.0 | 18.6 | 18.5 | 18.6 |

**Figure 4: Fisheye in different measurement points**

### 2.3.2. Calculation of PET Index

The most critical factors of PET are the mean radiant temperature Tmrt (◦C) (Chen and Matzarakis, 2014), wind speed (m/s), and air temperature (◦C) (Matzarakis, 2018). Relative humidity RH (%) only shows a very weak impact on PET (Fröhlich and Matzarakis, 2016). The thermal impact of the actual environment in PET is assessed through a human energy balance equation (2). Based on MEMI model "Munich Energy Balance Model for Individuals" (Höppe, 1999).

$$M + W + R + C + E_{SK} + E_{RE} + E_{SW} + S = 0 \quad (2)$$

All meteorological parameters and SVF were inserted as Input data in the Rayman model to calculate Physiologically Equivalent Temperature (PET). Geographical data: (36° 47′ 00″ N, 3° 03′ 37″ E) and elevation 107m were also used in the study. PET results were classified into nine classes of thermal perception (Very cold, Cold, Cool, slightly cool, Comfortable, slightly warm, Warm, Hot, and Very hot).

## 3. Results

### 3.1. Thermal comfort and heat stress level's assessment:

The assessment of PET shows that during the studied period there are seven different thermal comfort zones (Table 5 - 6): Cool, slightly cool, neutral, slightly warm, warm, hot, and extremely hot. Based on the PET ranges for the Mediterranean climate (Potchter et al., 2018) (Table 7). Table 5 shows almost a similarity in evolution for all measuring points. For January, PET temperatures are stable from 6.00 am to 8.00 am, and from 6.00 pm to 8.00 pm. PET values increase during the daytime from 8.00 a.m. to 12.00 p.m. After midday, from 1.00 pm to 6.00 pm, the PET temperatures decrease with values in the neutral zone of thermal comfort, with nevertheless, some values of slightly warm (26 °C – 28 °C) and warm values (> 28 °C), Creating slight and moderate heat stress (points 2,3,6,7 and 10) at 12:00 pm.

Assessment of PET shows an extremly low temperature in point 8 (14.9 °C) and 12 (14.5 °C) at 8.00 pm and point 6 (14.8 °C) from (6.00 am to 8.00 am) and (6.00 pm to 8.00 pm) creating a period of discomfort called moderate cold stress. Measurement point 6 is most of the time in areas of thermal stress and the most affected by temperature variations.

**Table 4: Outdoor thermal comfort level stress via PET index in the 14 study cases in January 2021.**

| District | Measurement point | PET 6:00 am | PET 8:00 am | PET 10:00 am | PET 12:00 pm | PET 2:00 pm | PET 4:00 pm | PET 6:00 pm | PET 8:00 pm |
|---|---|---|---|---|---|---|---|---|---|
| Casbah of Algiers | 1 | 18 | 17.4 | 21.3 | 25.5 | 24.5 | 22 | 17.6 | 15.9 |
| | 2 | 17.1 | 17.7 | 22 | 29.5 | 26.7 | 22.1 | 17 | 16.2 |
| | 3 | 17.3 | 16.5 | 22.7 | 28.7 | 25.1 | 21.8 | 16.9 | 17 |
| | 4 | 17.4 | 18.6 | 22.8 | 27.7 | 26 | 23.1 | 19 | 17.4 |
| | 5 | 17.6 | 16.1 | 19.4 | 25 | 23.8 | 21.5 | 17 | 16.4 |
| | 6 | 14.8 | 14.8 | 22.8 | 29 | 23.6 | 18.7 | 14.8 | 14.7 |
| | 7 | 16.5 | 16.6 | 21.9 | 26.9 | 28.2 | 22.3 | 16.5 | 16.6 |
| | 8 | 16.8 | 16.9 | 21.5 | 25.5 | 23.3 | 20.9 | 17.7 | 14.9 |
| | 9 | 18.5 | 18.5 | 22.7 | 26.5 | 24.9 | 22.7 | 18 | 18.4 |
| | 10 | 18.8 | 18.7 | 24.4 | 28.8 | 28.4 | 24.1 | 18.5 | 18.9 |
| | 11 | 18.9 | 18.4 | 23.4 | 27.3 | 27.1 | 23.5 | 18.4 | 18.3 |
| | 12 | 16.4 | 15.3 | 19.8 | 24.9 | 23.4 | 21.2 | 15.5 | 14.5 |
| | 13 | 17.7 | 15.9 | 21.7 | 26.1 | 22.8 | 20 | 16.8 | 15.1 |
| | 14 | 17 | 15.6 | 20.6 | 25.2 | 22.3 | 20.3 | 17.1 | 15.4 |
| | 12 – 15 | 15 – 19 | | 19 – 26 | | 26 – 28 | | 28 – 34 | |
| Thermal comfort | Cool | Slightly Cool | | Neutral | | Slightly warm | | Warm | |
| Stress level | Moderate cold stress | Slight cold stress | | No thermal stress | | Slight heat stress | | Moderate heat stress | |

Table 6 shows two phases in the variations of PET in August's values, and an overall similarity, from 6:00 am to 12:00 am an increase in values at all points, and from 02:00 pm to 08:00 pm a decrease in PET. An apparent period of discomfort (> 28 °C) throughout the day (From 8:00 am to 8:00 pm), with only the measurement point 6 at 6:00 am (24.8 °C) being in the neutral thermal comfort zone.

Results demonstrate an extreme heat stress level (> 36 °C) from 10:00 am to 4:00 pm in all points studied. Peak zone over 40 °C at the midday hours (12:00 pm to 02:00 pm) except for the measurement points (5,9 and 13). It should be noted that the extreme temperatures are in measurement point 6 with the lowest temperature (24.8 °C at 6:00 am) and the peak temperature (42.7 °C at 12:00 pm).

**Table 5: Outdoor thermal comfort level stress via PET index in the 14 study cases in August 2021.**

| District | Measurement point | PET 6:00 am | PET 8:00 am | PET 10:00 am | PET 12:00 pm | PET 2:00 pm | PET 4:00 pm | PET 6:00 pm | PET 8:00 pm |
|---|---|---|---|---|---|---|---|---|---|
| Casbah of Algiers | 1 | 27.2 | 32.8 | 38 | 41.1 | 41.2 | 37.9 | 32.7 | 29.1 |
| | 2 | 26.5 | 33.2 | 39.2 | 42.1 | 41.7 | 39.1 | 33.3 | 28.3 |
| | 3 | 27.1 | 33.1 | 38.8 | 42.3 | 40.4 | 38.3 | 33.1 | 28.4 |
| | 4 | 26.8 | 31.9 | 37.1 | 40.7 | 39.9 | 37.1 | 32.5 | 28.5 |
| | 5 | 26 | 32 | 37.7 | 39 | 39.5 | 37.3 | 32.5 | 28.6 |
| | 6 | 24.8 | 35.8 | 42.1 | 42.7 | 38.2 | 41.2 | 33.7 | 26.3 |
| | 7 | 26.2 | 32.9 | 37.8 | 41.4 | 40.8 | 37.4 | 33.1 | 27.8 |
| | 8 | 26.9 | 33 | 37.5 | 42.3 | 40.9 | 37.3 | 32.4 | 28.3 |
| | 9 | 27.1 | 31.6 | 36.6 | 39.8 | 38.4 | 36.7 | 32.7 | 28.7 |
| | 10 | 27.8 | 32.8 | 38.7 | 42.2 | 41 | 38.3 | 32.9 | 28.8 |
| | 11 | 27.9 | 32.8 | 39.2 | 41.8 | 41.2 | 38 | 32.8 | 28.9 |
| | 12 | 26.6 | 34.9 | 40.6 | 41.5 | 40.6 | 41.3 | 34.9 | 28.2 |
| | 13 | 26.1 | 32.1 | 37.2 | 39.5 | 39.9 | 36.2 | 32 | 28.1 |
| | 14 | 27.4 | 32.1 | 37 | 40.2 | 40.4 | 38.1 | 32.7 | 28.4 |

| | 19 - 26 | 26 - 28 | 28 - 34 | 34 - 40 | > 40 |
|---|---|---|---|---|---|
| Thermal comfort | Neutral | Slightly warm | Warm | Hot | Extremely hot |
| Stress level | No thermal stress | Slight heat stress | Moderate heat stress | Strong heat stress | Extreme heat stress |

**Table 6: PET range for Middle/Western Europe and the adjusted PET for the Mediterranean climate**

| Thermal sensitivity | Grade of physiological Stress | Mid/West Europe (Matzarakis,1999) (52) Cfb | Csa Mediterranean (Potchter et al., 2018) (51) Csa |
|---|---|---|---|
| Very Cold | Extreme cold stress | < 4 | < 8 |
| Cold | Strong cold stress | 4 – 8 | 8 – 12 |
| Cool | Moderate cold stress | 8 – 13 | 12 – 15 |
| Slightly Cool | Slight cold stress | 13 – 18 | 15 – 19 |
| Neutral | No thermal stress | 18 – 23 | 19 – 26 |
| Slightly warm | Slight heat stress | 23 – 29 | 26 – 28 |
| Warm | Moderate heat stress | 29 – 35 | 28 – 34 |
| Hot | Strong heat stress | 35 – 41 | 34 – 40 |
| Extremely hot | Extreme heat stress | > 41 | > 40 |

## 3.2. Comfort in historical cities assessment:

### 3.2.1. Subjective comfort:

According to our observation and based on 60 respondents. Air temperature and humidity have the most significant impact on daily comfort. Figure 5 shows user's preference for subspaces. As stated by the results of the votes, the sub-spaces are distributed in 3 categories: The most comfortable (ranking 1 to 2), moderately comfortable (ranking 3 to 6) and the least comfortable (7 to 9).

Spaces that emerge to be the most comfortable are the points (5, 7, and 9) with more than 15 votes for each ranking 1/9 or 2/9. On the other hand, measurement points (6 and 10) are the most uncomfortable for users with the lowest rank (over 25 voices for each at the last position).

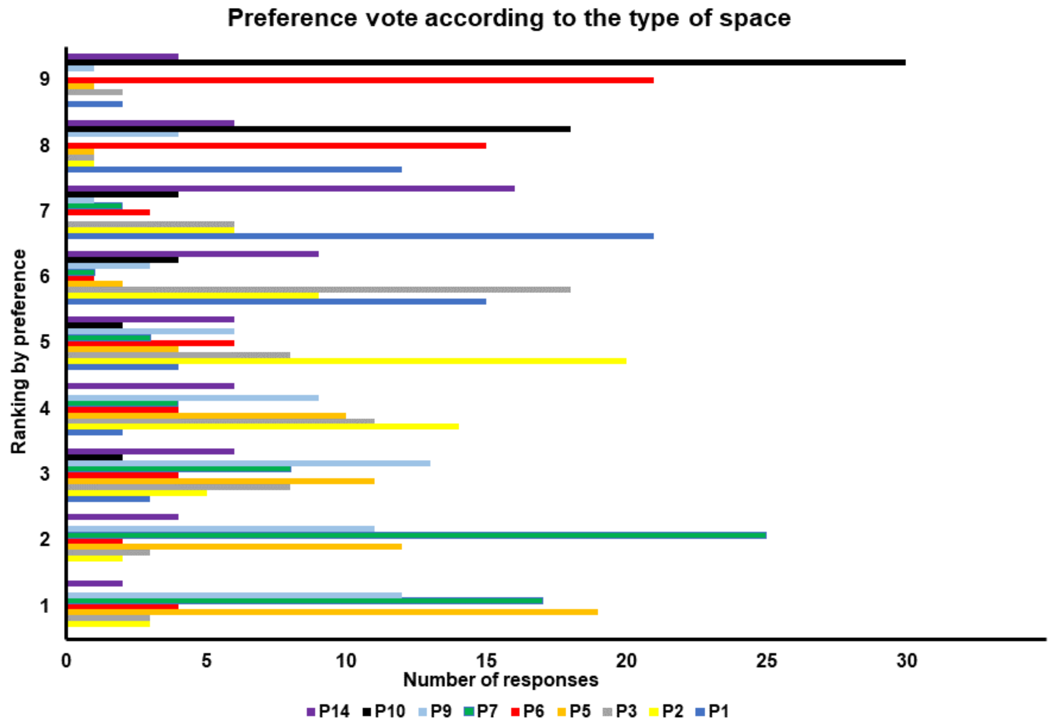


Figure 5: Users' feeling of comfort vote according to the type of space in Casbah of Algiers

## 4. Discussion

The present study was conducted to assess the outdoor thermal comfort in the historic fabric Casbah of Algiers and the impact of the urban subspaces on microclimate in Mediterranean climatic conditions. The study focuses on investigating the thermal comfort parameters and values in 14 measurement points during January and August.

### 4.1. Major findings and recommendations

Our study dealt with the existing microclimatic variations in the sub-spaces of the Casbah of Algiers. Firstly, covered passages and streets with low SVF present the best performances of thermal comfort over all the measurement periods. Indeed, in the two subspaces, solar radiation control plays a decisive role in mitigating and protecting from heat perception in hot seasons. Indeed, the high level of shade and the punctual winds make it possible to reduce the temperature up to 2°C than the other sub-spaces. During cold periods, covered passages store heat by the destratification of the air, allowing these subspaces to have warmer temperatures. In fact, a difference which reached ΔPETMax.Jan = 3.7 °C was recorded between covered passages and other subspaces. These findings align with the work of Ali-Toudert (Ali-Toudert, F and Mayer H, 2006), Andreou(Andreou and Axarli, 2012), and Elnabawy (Elnabawi et al., 2013) on the influence of urban morphology of traditional cities in creating urban microclimates.

Secondly, measurement points 6 and 12 present the most uncomfortable points during January and August (PETJan.P6 = 19.1°C, PETJan.P12 = 18.8°C) (PETAug.P6 = 35.6°C, PETAug.P12 = 36.1°C). Indeed, for point 6 these significant variations are justified by the size of the square. The wide opening to the sky in this space results from the collapse of houses, which induces strong solar radiation during the day and increases the place's temperature considerably. The rehabilitation of collapsed houses in this space is strongly recommended to avoid these high-temperature variations and thus find a comfortable microclimate in this area. For point 12, the north-south orientation benefits from the sun all day long. In addition, the high sky view factor of the street and its multiple intersections increase the sunshine of the street canyon throughout the day. A suspended vegetation cover is recommended in this type of streets to increase its shade and thus reduce perceived temperature.

Thirdly, we refer to the insignificant effect of the sea breeze despite the proximity between the Casbah of Algiers and the sea. Indeed, the wind values recorded during the two measurement campaigns remain relatively low, which induces the concentration of a high rate of humidity in the measured streets. Nevertheless, for the PET values of measurement points 12 and 13. Although the streets are adjacent, with similar height and width ratio (H/WP12 = 1.82, H/WP13 = 1.89), ΔPET between them is: 2.2°C. The latter is linked to the orientation (P12: North-South, P13: East-West), to the average wind velocity (VAvg.P12 = 0.20 m/s; VAvg.P13 = 0.48 m/s). But also, to the presence of suspended vegetation in the entrances of the street P13. We recommend conducting a more in-depth study of the impact of traditional urban morphology on wind flows.

Finally, the results of our survey campaign are consistent with the outdoor thermal comfort calculations. According to the survey, measurement points 6 and 10 are the most uncomfortable subspaces, as indicated in the PET comfort results (PETAUG.P6 = 42.7°C; PETAUG.P10 = 42.2°C). The survey questionnaire was able to bring out the subjective feelings of residents and visitors.

### 4.2. Implication on practice and future work

Planners should consider mitigation strategies for cases of extreme heat stress to improve the comfort of the inhabitants in traditional urban cities. But also, to visitors to the Casbah of Algiers, a UNESCO World Heritage Site, and therefore a very attractive region for tourists (Nasrollahi et al., 2017) and economic activities.

One of the strategies that can be developed is the introduction of vegetation (Fahmy et al., 2020) in the streets to reduce exposure to the sun (Lin et al., 2010) and thus the stress level. This research may have significant implications for advising decision-making in urban planning in Algeria and similar Mediterranean environmental contexts. They can be applied in improving the existing urban fabric, contributing to more liveability and vitality in outdoor areas.

## 5. Conclusions

The present study evaluates the microclimatic comfort conditions in the historical urban fabrics in the Mediterranean environment. To this end, an empirical investigation was performed in 14 subspaces. In the present study, the research scale was limited to the most significant subspaces in the historical city to evaluate the thermal comfort conditions within their microclimates. The measured data (Air temperature, relative humidity, wind velocity, surface temperature, and fish-eye images.) were taken between 26th January – 1st February and 5th – 11th August, several times in the day (From 6 am to 8 pm, every 2 hours).

The outdoor comfort index "Physiologically Equivalent Temperature (PET)", was evaluated through the RayMan tool in the 14 reference points where the modelling and calculation were made to identify the heat stress level. In January, it emerged that PETJan is in the "no thermal stress" zone 38.4% of the daytime. The cold stress percentage is 49.1% and was recorded mainly at sunrise and sunset, while a 12.5% rate of heat stress is present at midday. In August, heat stress is almost permanent. In fact, 52.67% of the time PETAug is in strong or extreme heat stress, while the rest of the daytime the heat stress is slight. The impact of the SVF has been demonstrated in the various sub-spaces of the Casbah. With the most significant temperature variations occurred in vacant spaces following collapses. Additionally, the 'Sea breeze effect' on the outdoor thermal comfort was insignificant (during the study period). Future studies should investigate to expand our knowledge on heat stress and sea breeze with both in situ and station measurements for various climatic parameters during all months and seasons of the year in historic cities.

## References

Abdessemed-Foufa, A., 2011. Le manuel de réhabilitation comme outil de conservation dans le cadre du plan permanent de sauvegarde de la Casbah d'Alger.RehabiMed, Alger.

Achour-Younsi, S., Kharrat, F., 2016. Outdoor Thermal Comfort: Impact of the Geometry of an Urban Street Canyon in a Mediterranean Subtropical Climate – Case Study Tunis, Tunisia. Procedia - Social and Behavioral Sciences 216, 689–700. https://doi.org/10.1016/j.sbspro.2015.12.062

Ali-Toudert, F., Djenane, M., Bensalem, R., Mayer, H., 2005. Outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria. Clim. Res. 28, 243–256. https://doi.org/10.3354/cr028243

Ali-Toudert, F., Mayer, H., 2007. Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. Solar Energy 81, 742–754. https://doi.org/10.1016/j.solener.2006.10.007

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. Build. Environ. 94–108.

Alsayyad, N., 1995. From vernacularism to globalism: the temporal reality of traditional settlements. Traditional Dwellings and Settlements Review 13–24.

Andreou, E., Axarli, K., 2012. Investigation of urban canyon microclimate in traditional and contemporary environment. Experimental investigation and parametric analysis. Renewable Energy 43, 354–363. https://doi.org/10.1016/j.renene.2011.11.038

Arrar, F.H., Attia, S., Kaoula, D., 2022a. Measured Comfort Data - Casbah. https://doi.org/10.7910/DVN/R0AYI7

Arrar, F.H., Kaoula, D., Attia, S., 2022b. Thermal comfort sentation survey - in the Casbah of Algiers. https://doi.org/10.7910/DVN/JGBSLY

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5, 180214. https://doi.org/10.1038/sdata.2018.214

Ben Salem, S., Lahmar, C., Simon, M., Szilágyi, K., 2021. Green System Development in the Medinas of Tunis and Marrakesh—Green Heritage and Urban Livability. Earth 2, 809–825. https://doi.org/10.3390/earth2040048

Berkani, Y., 2013. Urban morphology and pedestrian movement of traditional marketplace in casbah algiers. Teknologi Malaysia.

Bourbia, F., Boucheriba, F., 2010. Impact of street design on urban microclimate for semi arid climate (Constantine). Renewable Energy 35, 343–347. https://doi.org/10.1016/j.renene.2009.07.017

Castaldo, V.L., Pisello, A.L., Pigliautile, I., Piselli, C., Cotana, F., 2017. Microclimate and air quality investigation in historic hilly urban areas: Experimental and numerical investigation in central Italy. Sustainable Cities and Society 33, 27–44. https://doi.org/10.1016/j.scs.2017.05.017

Chen, Y.-C., Matzarakis, A., 2014. Modification of physiologically equivalent temperature. Journal of Heat Island Institute Internationa 26–32.

Cortesão, J., Alves, B., 2010. Alternative (bioclimatic) urban design for compact urban fabrics. CITTA 3rd Annual Conference on Planning Research Bringing City Form Back Into Planning.

Dhingra, M., Chattopadhyay, S., 2016. Advancing smartness of traditional settlements-case analysis of Indian and Arab old cities. International Journal of Sustainable Built Environment 5, 549–563. https://doi.org/10.1016/j.ijsbe.2016.08.004

Elnabawi, M.H., Neveen, H., Dudek, steven, 2013. Use and evaluation of the envi-met model for two different urban forms in cairo, egypt: measurements and model simulations.

Emmanuel, R., 2005. Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka. Building and Environment 40, 1591–1601. https://doi.org/10.1016/j.buildenv.2004.12.004

Fahmy, M., Mahdy, M., Mahmoud, S., Abdelalim, M., Ezzeldin, S., Attia, S., 2020. Influence of urban canopy green coverage and future climate change scenarios on energy consumption of new sub-urban residential developments using coupled simulation techniques: A case study in Alexandria, Egypt. Energy Reports 6, 638–645. https://doi.org/10.1016/j.egyr.2019.09.042

Fröhlich, D., Matzarakis, A., 2016. A quantitative sensitivity analysis on the behaviour of common thermal indices under hot and windy conditions in Doha, Qatar. Theor Appl Climatol 124, 179–187. https://doi.org/10.1007/s00704-015-1410-5

Georgescu, M., Morefield, P.E., Bierwagen, B.G., Weaver, C.P., 2014. Urban adaptation can roll back warming of emerging megapolitan regions. Proceedings of the National Academy of Sciences 111, 2909–2914. https://doi.org/10.1073/pnas.1322280111

Ghedamsi, R., Settou, N., Gouareh, A., Khamouli, A., Saifi, N., Recioui, B., Dokkar, B., 2016. Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach. Energy and Buildings 121, 309–317. https://doi.org/10.1016/j.enbuild.2015.12.030

Givoni, B., 1998. Climate considerations in building and urban design.

Hein, L., Metzger, M.J., Moreno, A., 2009. Potential impacts of climate change on tourism; a case study for Spain. Current Opinion in Environmental Sustainability 1, 170–178. https://doi.org/10.1016/j.cosust.2009.10.011

Höppe, P.R., 1999. The physiological equivalent temperature – a universal index for the biometeo-rological assessment of the thermal environment 71–75.

Jamei, E., Rajagopalan, P., Seyedmahmoudian, M., Jamei, Y., 2016. Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. Renewable and Sustainable Energy Reviews 54, 1002–1017. https://doi.org/10.1016/j.rser.2015.10.104

Jin, H., Liu, S., Kang, J., 2020. Gender differences in thermal comfort on pedestrian streets in cold and transitional seasons in severe cold regions in China. Building and Environment 168, 106488. https://doi.org/10.1016/j.buildenv.2019.106488

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, 1326–1338. https://doi.org/10.1016/j.buildenv.2005.05.022

Johansson, E., Emmanuel, R., 2006. The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka. Int J Biometeorol 51, 119–133. https://doi.org/10.1007/s00484-006-0047-6

Kiet, A., 2011. Arab Culture and Urban Form. Focus 8. https://doi.org/10.15368/focus.2011v8n1.4

Krüger, E.L., Minella, F.O., Rasia, F., 2011. Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. Building and Environment 46, 621–634. https://doi.org/10.1016/j.buildenv.2010.09.006

Lin, T.-P., Matzarakis, A., Hwang, R.-L., 2010. Shading effect on long-term outdoor thermal comfort. Building and Environment 45, 213–221. https://doi.org/10.1016/j.buildenv.2009.06.002

Mahmoud, S.H., Gan, T.Y., 2018. Long-term impact of rapid urbanization on urban climate and human thermal comfort in hot-arid environment. Building and Environment 142, 83–100. https://doi.org/10.1016/j.buildenv.2018.06.007

Matzarakis, A., 2018. RayMan Pro - A tool for Applied Climatology : Modelling of Mean Radiant Temperature and Thermal Indices.

McMichael, A.J., Lindgren, E., 2011. Climate change: present and future risks to health, and necessary responses: Review: Climate change and health. Journal of Internal Medicine 270, 401–413. https://doi.org/10.1111/j.1365-2796.2011.02415.x

Morris, K.I., Chan, A., Morris, K.J.K., Ooi, M.C.G., Oozeer, M.Y., Abakr, Y.A., Nadzir, M.S.M., Mohammed, I.Y., Al-Qrimli, H.F., 2017. Impact of urbanization level on the interactions of urban area, the urban climate, and human thermal comfort. Applied Geography 79, 50–72. https://doi.org/10.1016/j.apgeog.2016.12.007

Nasrollahi, N., Hatami, Z., Taleghani, M., 2017. Development of outdoor thermal comfort model for tourists in urban historical areas; A case study in Isfahan. Building and Environment 125, 356–372. https://doi.org/10.1016/j.buildenv.2017.09.006

Nikolopoulou, m, 2004. Outdoor Comfort, in: Environmental Diversity in Architecture. Spon Press, pp. 101–120.

Potchter, O., Cohen, P., Lin, T.-P., Matzarakis, A., 2018. Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. Science of The Total Environment 631–632, 390–406. https://doi.org/10.1016/j.scitotenv.2018.02.276

Ratti, C., Baker, N., Steemers, K., 2005. Energy consumption and urban texture. Energy and Buildings 37, 762–776. https://doi.org/10.1016/j.enbuild.2004.10.010

Rosso, F., Golasi, I., Castaldo, V.L., Piselli, C., Pisello, A.L., Salata, F., Ferrero, M., Cotana, F., de Lieto Vollaro, A., 2018. On the impact of innovative materials on outdoor thermal comfort of pedestrians in historical urban canyons. Renewable Energy 118, 825–839. https://doi.org/10.1016/j.renene.2017.11.074

Semahi, S., Benbouras, M.A., Mahar, W.A., Zemmouri, N., Attia, S., 2020. Development of Spatial Distribution Maps for Energy Demand and Thermal Comfort Estimation in Algeria. Sustainability 12, 6066. https://doi.org/10.3390/su12156066

Sharmin, T., Steemers, K., Matzarakis, A., 2017. Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment. Sustainable Cities and Society 34, 293–308. https://doi.org/10.1016/j.scs.2017.07.006

Taleghani, M., Kleerekoper, L., Tenpierik, M., van den Dobbelsteen, A., 2015. Outdoor thermal comfort within five different urban forms in the Netherlands. Building and Environment 83, 65–78. https://doi.org/10.1016/j.buildenv.2014.03.014

Thorsson, S., Lindberg, F., Björklund, J., Holmer, B., Rayner, D., 2011. Potential changes in outdoor thermal comfort conditions in Gothenburg, Sweden due to climate change: the influence of urban geometry. Int. J. Climatol. 31, 324–335. https://doi.org/10.1002/joc.2231

United Nations Development Program. (2015). Sustainable Development Goals. [online]. United Nations. Retrieved from https://www.undp.org/content/undp/en/home/sustainable-development-goals.html, n.d.

Urbanization and health, 2010. . Bull. World Health Organ. 88, 245–246. https://doi.org/10.2471/BLT.10.010410

Wang, Y., Chan, A., Lau, G.N., Li, Q., Yang, Y., Yim, S.H.L., 2019. Effects of urbanization and global climate change on regional climate in the Pearl River Delta and thermal comfort implications. Int J Climatol 39, 2984–2997. https://doi.org/10.1002/joc.5996