Strategy to Improve Outdoor Thermal Comfort in Open Public Space of a Desert City, Ouargla, Algeria

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Abstract: The control of outdoor thermal comfort became a question of extreme importance in hot desert cities, knowing that people of these cities seek to shelter solar rays by all means especially during the hot season. The aim of this research is to study and analyze the effect of urban vegetation and shade on the microclimate and thermal comfort within an open public space in a hot desert city (the city of Ouargla in Algeria). As an element that minimizes and intercepts the sun's rays, it generates solar energy shade and absorbs the fluxes of radiation, modifies the temperature, the relative humidity and minimizes the wind velocity and modifies its directions. For this, we have used Ray Man which is simulation software to calculate the indices of thermal comfort. The work consists in calculating these indices before and after the insertion of two types of vegetation within our case study (the martyr’s plaza in the traditional neighborhood of the city of Ouargla). The results obtained show the main role of vegetation by the improvement of thermal comfort.

1. Introduction
Any urban project must take into account climatic factors; in fact the climatic conditions of an urban agglomeration have an impact on the lifestyle of its inhabitants, in particular the use of outdoor spaces, which are considered as supports of urban life.
Public spaces are fundamental elements of the urban environment and the architectural and aesthetic aspect of the built environment of cities. These spaces contribute to develop the social relations. These are spaces that offer a certain comfort to the inhabitants who often feel assaulted in urban environments [1].
Outdoor thermal comfort is a complex function of atmospheric conditions and physical, physiological, psychological, and behavioral factors [2]. According to S Reiter user comfort in the outdoor space have several positive effects such as improving the quality of living in an outside environment, valorization the image of the city, increasing the rate of the outdoor spaces use for meetings, relaxation and leisure, the reduction of energy consumption related to the use of inside spaces [3].
The microclimate of these spaces is influenced by several parameters such as geometry of space, vegetation, water and the thermal properties of surfaces. It is possible to improve the comfort conditions of an outdoor space taking into account the urban design. Vegetation as an element of urban design that influences the thermal comfort of outdoor spaces has three main characteristics that influence the climate: shading, humidification, and windbreak.
By its shade, the vegetation planted in urban environment modifies the physical environments (light, heat, structure, wind, sound, humidity). It influences the perception and appropriation of urban spaces by users [4]. In terms of protection against nuisances, the interests of vegetation are several: reduction of atmospheric pollution and improvement of air quality by fixing certain dust, reduction of the effect of run off by rain interception, protection against erosion due to wind and water [5].
Therefore the climatic advantages of urban vegetation are assessed either by their effects on meteorological factors or by their energy savings induced in buildings. It has been suggested that several small areas with adequate intervals are more efficient in cooling than a large green space [6]. The density of foliage determines a more or less large permeability to the light, and radiation of wavelength. This density varies significantly depending on the species considered, the configuration of its development (pruning, size …) and the season. Taking into account these different settings, we can consider that the urban trees can be three types of Screen: an opaque screen (coniferous), a screen semi-transparent (deciduous trees) and a transparent screen (some fruit trees or species of PINE) [7].

Several studies have investigated the impact of parks and green spaces on urban micro-climate and found that temperature reduction in a treed urban environment can reach up to 4°C. However, many studies suggested that urban green spaces can be warmer than the surrounding built-up area and can exacerbate unpleasant micro-climatic conditions [8]. Measurements indicate that the surface temperature of the walls is oriented west and concrete protected from direct solar radiation by trees, are weaker in average of more than 13 °C, Figure 1(a) [9]. A Chatzidimitriou revealed the importance of shading paved surfaces. Shaded surfaces have surface temperatures 21% lower than the air temperature, and are 40% cooler than the same surfaces exposed to the sun's rays [10][11], Figure 1(b).

Bernatzky's study in Frankfurt (Germany) has shown that an urban square lowers the air temperature by 3 to 3.5 °C and increases the relative humidity by 5 to 10%. It purifies polluted air and turns it into fresh air in the city center [12]. The study of S. Louafi on the esplanade of the University of Constantine, which is characterized by a large expanse of concrete totally devoid of vegetation and another vegetated space intended for the creation of students, the study shows that the outdoor space can be affected by the presence of vegetation that plays an important role in its environmental quality. In the Saharan cities, it is noticed that people seek to avoid the sun's rays, especially during the hot season. The main object of our study is the verification of outdoor thermal comfort to find the good type of vegetation and the pertinent strategy to introduce it into an open public space in a hot desert city.

2. Assessment of Outdoor Thermal Comfort

The thermal comfort could be defined as a feeling of well-being vis-à-vis a thermal environment [13]. The assessment of outdoor comfort does not only allow improving the Thermal Conditions of these spaces but also the protection of people who use those [14].

2.1. Thermal Indices of Outdoor Comfort

Several indices integrating thermal environmental factors and heat balance of the human body are applied for accessing thermal comfort, these indices are PMV (predict mean vote), SET (standard affective temperature), PET (physiologically equivalent temperature) and PPD (Predictable Percentage of dissatisfied) [15].

2.1.1. PMV. Today, one of the best-known thermal indices is the Fanger comfort equation, which allows the calculation of the Predicted Mean Vote (PMV). The equation connects the classical
parameters which are the temperature of the air, the average radiant temperature, the hygrometry, the speed of the air, the metabolism and the thermal resistance of the clothing. In addition, two physiological parameters are added, the average temperature of the skin and the evacuation of the heat by sweating. Fanger arrived at the average assessment for the thermal environment by the PMV which varies on a scale of 7 degrees between -3 and +3, but Michael Bruse, in its work performed during the updating of its simulation program, has adopted nine scales of own comfort to the outdoor spaces, where the theoretical area of comfort outside is between -3 and +3, Figure 2 (a) [16].

2.1.2. PPD. It is the percentage of unsatisfied people in relation to this situation. The PPD is a formula derived from statistical analyzes. The people are considered as dissatisfied if they vote ± 2 or ± 3 on the scale of 7 points of ASHRAE[17], Figure 2 (b).

![Figure 2(a). Classification of values of the PMV according to nine scales of comfort [16].](image)

![Figure 2(b). Correspondence between the PMV and the PPD[17].](image)

2.1.3. PET. The PET index is defined as the temperature of the air which, in a typical local indoor, without wind and solar radiation, the energy balance of the human body is balanced with the same internal temperatures and skin than those obtained in the conditions to assess, according to T. Lin, PET is defined as the air temperature at which, in a typical indoor setting (air temperature = mean radiant temperature, relative humidity=50 %, wind speed= 0.1 m/s)[15].

2.1.4. SET. The standard temperature effective is defined as the temperature of a reference isotherm environment whose surface temperatures and air temperature are equivalent, where the relative humidity is 50% and the speed of the air is (0.12 m/s). The reference environment is defined by a Metabolism (M)=1.2 met and the resistance of clothing (R clo)=0.9clo [12]. Table 1 show the correspondence between SET sensation and physiological state [13].

**Table 1. Correspondence between SET sensation and physiological state[13].**

| SET (°C) | sensation | Physiological state of a sedentary individual |
|---------|-----------|--------------------------------------------|
| >37,5   | Very hot, uncomfortable | Failure of regulation |
| 34,5-37,5 | Hot, very unacceptable | Abundant sweat |
| 30,0-34,5 | Hot, uncomfortable, unacceptable | Sweat |
| 25,6-30,0 | Slightly warm, slightly unacceptable | Low sweat, vasodilatation |
| 22,2-25,6 | Comfortable and acceptable | Neutrality |
| 17,5-22,2 | Slightly cool, slightly unacceptable | vasoconstriction |
| 14,5-17,5 | Cool, unacceptable | Slow body cooling |
| 10,0-14,5 | Cold, very unacceptable | Thrill |

3. Area of the Study

Our Area of study is situated in the city of Ouargla which is located at 128m altitude, 190 km East of Ghaidaia, 388 km South of Biskra, 160 km South-West of Touggourt, it extends between 28° and 32° north latitude and meridians 4° and 8° east, Figure 3.
The climate of Ouargla is characterized by a quasi-permanent marked aridity which is expressed by a high temperature, a serious low precipitation and evaporation, (a large hot summer contrasting with a cold winter) Figure 4, 5 and 6.

4. Methodology

Our case of study is the martyrs plaza, which occupies the south western part of the traditional quarter playing a very important role of identification and orientation, it constitutes a particular space, especially by the inclusion of different types of daily, weekly and occasional activities, this plaza is poor in vegetation except the existence of some palms that offer shade in some times of the day. This plaza was selected for according to its historical past. The plaza is very crowded during almost the whole year, Figure 7 (a), (b) and (c).

In order to evaluate the effect of vegetation on outdoor thermal comfort into this plaza, a series of measurements were collected; the measurements were performed in summer during the very hot season in the month of July 2016. The simulation will be done by the software RayMan Pro; the software can analyze complex urban structures and other environments (building and tree). It requires only basic meteorological data (air temperature, air humidity, type of sky and wind speed) for the calculation of radiation fluxes, soil temperature and common thermal indices (PMV, PET, SET, and SVF). It is taken into consideration the geographical coordinates of the site studied [18] [19].
The first step is to simulate the current state of the plaza in other words to calculate the global radiation, soil temperature, PMV, PET, SET, and SVF and the shadow during the day. The second step is to propose a type of vegetation useful for our case; the choice is based on the maturity of the tree, its height, the size of crown, the density of foliage and its adaptability to the plaza (soil temperature and humidity). Note that the large crown size of the tree ensures more shade, especially at noon when the sun is at the azimuth state [20].

5. Results and Discussion

5.1. Before the Intervention

Figure 8 (a) show an aerial view of the plaza, and Figure 8 (b) shows the plaza with the software RayMan pro.

![Figure 8. (a) and (b): the area of study](image)

The SVF of the plaza varies between 0.637 and 0.677 which is so high; this is why people in this plaza always feel uncomfortable. In some other words it is due to the high rate of solar radiation (see Figure 9 a, b and c). The plaza is exposed to sunlight almost all day except in the evening by blessing the shade provided by the houses (see Figure 10 a, b and c).

![Figure 9. (a) (b)and (c): sky view factor in different point of the plaza before intervention](image)

![Figure 10. (a) shadow at 8.00 AM (b) shadow at 12.00 PM (c) shadow at 17.00 PM before intervention](image)
5.2. After the Intervention

Figure 11 (a) shows the optimum proposal of design of the vegetation, which it gave the best results compared to current situations of the plaza. The conception of the vegetation was based on two essential parameters: first, do not plant the entire surface of the plaza except the parts of sitting most used by the inhabitants of this plaza to protect them from solar radiation. The second to use two types of vegetation; Acacia Raddiana; a deciduous tree, very used in Algerian Sahara that resists the aridity of our area, (Figure 11 b). The second type is coniferous tree (Ficus Retusa) very used too in Algeria (Figure 11 c). It is of category tree of tropical origin of the persistent type of dense port shape erected, rapid growth. In addition it has been in the city of Ouargla for a long time and it resists its climate [18]. These two types were chosen in order to protect inhabitants in summer from solar radiation and allow the penetration of solar rays through the deciduous trees in winter.

![Figure 11. (a) a true mask with solar rays (b) acacia raddiana tree (c) Ficus Retusa tree](image)

Figure 11 (a) and (b) show the variance after the insertion of vegetation, the area of study has shade almost all day long. This increase of the shadow will facilitate the unfolding of some activities like the weekly trade, and the grouping before or after the prayer.

![Figure 12. (a) shadow at noon (b) shadow at 17.00 pm (c) SVF after the insertion of vegetation](image)

Figure 12 (a) and (b) show the variance after the insertion of vegetation, the area of study has shade almost all day long. This increase of the shadow will facilitate the unfolding of some activities like the weekly trade, and the grouping before or after the prayer.

It is noticed that the SVF is decreased after the insertion of the vegetation (SVF=0.117) which will mitigate the penetration of radiation, especially in the hottest times of the day (Figure 12c).

Concerning Tmrt, in the first situation without vegetation, we measure 42.9°C at 8.00am and it reaches 52.9°C at noon but it decreases at 18.00 pm until 45.8°C. in the second situation with the vegetation we measure 35.7 ° C at 8.00 am, it reaches 43.5 ° C at noon and decreases to 36.5 at 18.00 pm, Figure 13 (a).

Figure 13(b) shows the global radiation before and after the insertion of the vegetation, for the first situation we measure 526w/m² at 8.00 am, 789 w/m² at 2.00 pm and 649w/m² at 18.00 pm, for the second situation we measure 322w/m² at 8.00 am, 587 w/m² at 2.00 pm and 439 w/m² at 18.00 pm.

For the PMV obtained in the second situation, we observe a significant reduction compared to those obtained in the first situation, the maximum PMV is 4.8 at 2.00 pm, Figure 14 (a).

For the PET, the results obtained for the second situation, we observe a significant attenuation compared to the results obtained in the first situations, the maximum PET is at 2.00pm with 47.1 °C very hot, the minimum PET is at 8.00am we measure 35°C hot layer, Figure 14 (b).
For the standard temperature effective (SET), the results obtained for the second situation, we observe a significant attenuation compared to the results obtained in the first situations, the maximum SET at 2.00pm is 41.2°C but in the first situation is 46.2°C, Figure 15.

6. Conclusion
Vegetation can affect the microclimate in many ways; it reduces air temperature, while providing shade. Vegetation brings aesthetic improvements to an environment otherwise dominated by asphalt and concrete. The main object of this research is to improve the impact of vegetation on outdoor thermal comfort, the two types of trees introduced into the area of study has given good results and wide variations in climatic parameters and indices. The Sky view factor (SVF) was changed from 0.677 in the situation without vegetation to 0.117 after the insertion of vegetation. For the global radiation we passed from 789w/m² in the first situation as maximum level to 587w/m² after the insertion of vegetation. For the PMV we passed from 7.9 to 4.8 as maximum level in the second situation, the mean radiant temperature was changed from 52.9°C to 42.9°C as maximum temperature in the second situation. So vegetation is often an important component of the open outdoor space, which contributes greatly to the quality of its development. Generally trees provide significant improvements in thermal comfort mainly at noon and in the early afternoon as they provide shading, and attenuate solar radiation. In addition, trees increase the environmental quality of outdoor space and the thermal and visual comfort felt in a semi-arid Mediterranean climate.
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