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Vegetation effects on urban street microclimate and thermal comfort during overheated period under hot and dry climatic conditions

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Abstract

Urban Planning has a great impact on local microclimate which in turn affects the comfort and the space quality within a city. This directly influences the absorption and emission of incoming solar and outgoing long wave radiation, which has a significant impact on temperature variations within the street as well as the surrounding environment (Urban Heat Island).
Green areas play the most significant role in the city; they provide shade that helps to lower surface temperatures. They also help to reduce air temperatures through the process of evapotranspiration, dissipating ambient heat.
The method is experimental, in which empirical measurements are carried out in different stations in a street of the city center of Constantine (Algeria) during overheated period. Moreover series of field simulation are done using a software tool: "TownScope3.2".
The results confirm the importance of shade by the vegetation on microclimate and human comfort, and show a positive correlation between the air temperature, Tmrt, and PET in hot seasons. Vegetated urban space influences the quality of perception, the creation of urban ambience and improves pedestrian's thermal comfort. That increases the frequency of use of outdoor spaces for such climate.

Keywords: Vegetation,Vegetation; Microclimate; Thermal Comfort; Hot and Dry Climate; Urban street

1. Introduction

The urban fabric changes the energy balance through its different reflections and heat absorptions due to roughness and absence of green areas, giving rise to the Urban Heat Island phenomena.

The shade is in general the principal outside requirement during overheated period for areas with hot and dry climate. In urban environments, green spaces have proven to act as ameliorating factors of some climatic features related to heat stress, reducing their effects and providing comfortable outdoor settings for people [1]. This shade reduces solar flows considerably, by limiting the heating of surfaces which normally should be sunny, also reduces thermal radiative flows.

It is well known that the presence of vegetation modifies the microclimate (light, heat, wind, and humidity) through shade and evapotranspiration, and also influences the perception of urban spaces by the users [1,2].

On the one hand, the use of plants to improve urban heating is one strategy that has generated significant interest [3,4]. Trees and buildings existing singly or in clusters create strong spatial variability in local heat transfer fluxes that define urban microclimates within the urban canopy layer [5].

Trees planted along the streets and in the parks, around the houses or shops or in the green areas throughout the city improve citizens' quality of life and also the quality of the air and water. On the other hand, the urban green areas offer the possibility of recreation, and make districts more pleasant [6].

The use of vegetation as a strategy to moderate the urban heat island (UHI) and improve the microclimate has been discussed in many researches [7,8]. For the hot and arid climates, the best use of the vegetation should take advantage from its shading aspect to reduce the intense solar radiation in summer as the overheating is mainly due to the heat storage by the sunlit surfaces. Vegetation should be integrated within the built up areas to improve the immediate environment of each construction., because the two main effects of vegetation are the shading impact on solar radiation and the conservation of canopy temperatures close to that of air, between 20°C-35°C, wich remain below the temperatures of the surfaces of common urban materials such as asphalt, concrete blocks, etc[9,10].

Researchers like: Grimon, Oke and Cleugh (1993), found that in a hot-dry climate the temperature in a tree-vegetated suburban area in Sacramento, was 5°C to 7°C cooler than in a mineral one. One study indicates that a significant temperature difference of up to 6°C on air temperature 2m above the ground was found in the summer season between artificial urban materials and vegetated areas in Beirut [11].

Even more [12,13], confirm the importance of tree shading effect on thermal comfort and the influence of reflected and transmitted solar infrared radiation on the energy budget of humans and buildings in their surroundings.

Shading a surface from receiving direct solar radiation is the most important, the first strategy for reducing heat load in a hot and dry climate. Field studies to evaluate the thermal environment have been performed in cities with hot and dry climate; the geometry and orientation has a wide relation to solar exposure of the urban canyon during the day. This one has a considerable effect on solar shading and urban microclimate [14]. Bourbia and Awbi (2004) found that the higher H/W ratio and smaller SVF has a cooler environment and floor-shading fraction in summer increase with increasing (H/W ratio).

Under hot and dry climate at Constantine city by Bourbia and Boucheriba (2010), one study discuss the relationship between canyon geometry (size, orientation) and SVF , how it's impacts on air and ground surface temperatures within the urban street, was done in order to evaluate the impact of geometry on the urban climate. They found that the open stations are exposed to the sun all the day and height albedo of the sol participate in reflecting the solar energy to the outdoor space and participate in increasing the UHI [15].

Further to that a study by Louafi and Abdou (2013) in same city whith an open urban space with row trees an presence of masse vegetal and a mineral one for improving the effect of vegetation on using outdoor space.

Where,measurement and observation method was done. Results show that controlling the sky view factor and inclusion of vegetation can reduce temperatures in outdoor spaces [16].

In this present paper a canyon street with different SVF and with the presence or absence of row trees are investigated, microclimate and thermal comfort based on field measurements and questionnaires during the summer,and series of simulation has done, the aim is to assess whether people located under tree shade experience comfort or stress in open spaces during hot-dry season. the study tries to:

- Investigate vegetation' effects in five different spaces on thermal conditions in outdoor spaces with different ratio and SVF.
- Compare the performance of an area shaded by trees to insolated one;
- Discuss whether trees shade affect people's thermal comfort in hot-dry climate, and
- Evaluate outdoor thermal comfort based on comfort indexes "predict equivalent temperature" (PET) and mean radiant temperature (Tmrt); and
- Try to highlight the role of shade on soil temperature and cooling effects of urban planning.

2. Site Investigation

The investigation was conducted in Constantine City (Algeria), which is located at 36.17_ North and 06.37_East. The altitude is approximately 687m above sea level. This city is characterized by a semi-arid climate that is hot and dry in the summer, with an average maximum temperature of 36°C occurring at 15h00 and an average humidity of 25%. In the winter, the area is cold and humid. In addition, the intensity of solar radiation over this region is high, with clear skies and sunny periods existing during a large portion of the day.

The wind direction comes relatively from the North, with an average speed reaching 2.1 m/s at the meteorological station. All these factors contribute to the climatic harshness of the city. The investigated site is located in the city center.

The city center has a dense traditional urban fabric (up to 80%) deprived from vegetation; and a colonial fabric which was grafted on part of traditional fabric and around this initial core. The presence of the vegetation is not regular there (fig.1).

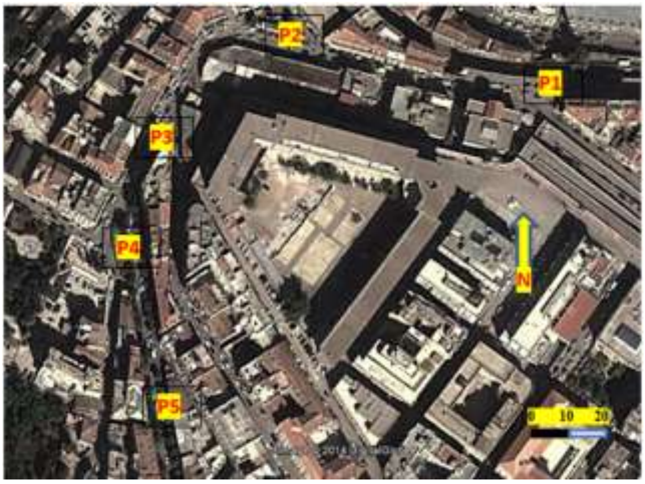


Fig.1. Stations of site measurements. *Source*: Google Earth 2014

3. Methodology

In order to evaluate the effect of vegetation cover on air and ground surface temperatures within the urban street, a series of measurements were collected from five stations that were selected based on variation of the SVF, H/W ratio and presence of trees (fig.1 and Table1).

The measurements were performed in summer during the month of July 2013, representing the hottest period. These were carried out simultaneously over a two weeks period, and one typical daily cycle has been selected to represent each of the detailed monitoring periods. Air temperature data were collected using digital instruments (Multifunction instrument (LM800), Pho-radiometer HD2302.0 with several probes) with an accuracy of ±0.2. The measurements located in the built-up environment at a height of approximately 1.5 m and were recorded every 2 hours at each station from 6:00 to 20:00 each day. Fish-eye photographs were taken at each station at both sensor heights (approximately 1.5 m above ground) with a Nikon 8 mm fish-eye lens (Picture angle of 180°). Consequently, thermal comfort was included in the study, with interviews and questionnaires to assess people's thermal sensation in different situation coverage street with trees and without trees in the day.

Series of field simulation are used by software tool, TownScope3.2. The objective is to compare the performance of an area shaded by trees to a full insolated area for two kinds of street located in this climate (dry and hot) P1 (SVF=75%, Albedo= 0.28, H/W= 1.35) and P5 (SVF=5%75%, Albedo=0.200, H/W= 1. 13)

Table 1.Characteristics of Measurement station & Fish-eye photographs.

Point of measurement		Vertical fish-eye	Horizontal fish-eye
P1 SVF= 75% Albedo= 0.28 H/W= 1.35			
P2 SVF= 1% Albedo= 0.16 H/W= 0.46			
P3 SVF= 30% Albedo= 0.29 H/W= 1.34			
P4 SVF= 10% Albedo= 0.19 H/W= 1.3			
P5 SVF= 5% Albedo= 0.20 H/W= 1.13			

4. Result and Discussion

The geometry of urban street plays a decisive role in urban heat island mitigation [15,17]. Moreover, Inclusion of vegetation can reduced and controlling the sky view factor. Shade trees reduce heat gain by directly shading buildings and also by evapotranspiration. Adding vegetation into the environment, planting trees can mitigate UHI, reduce energy use and improve air quality. This study aims to verifie and discuss how vegetation can play an important role on urban microclimate for different types of urban design.

4.1. Impact of the Vegetation on Air Temperature

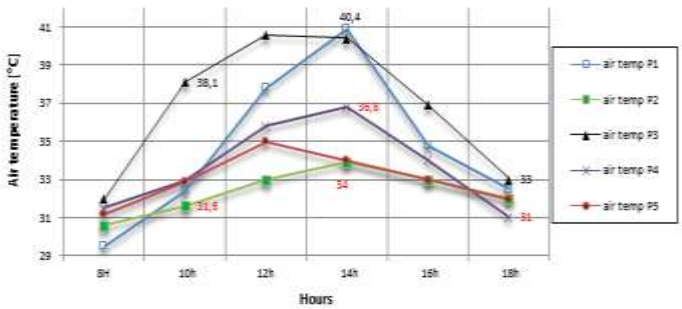


Fig.2 . Variation of air temperature in various stations period July.

Figure 2 shows the air temperature evolution during a typical summer day at the five stations of measurement. It shows that open space without trees is warmer from 10h00 to 16h00 than the vegetal areas under trees coverage, which is consistent with previous studies of the literature on this subject [1,2,12,16,18 and 19]). The air temperatures in all stations are higher than 32°C during the day, but the temperatures recorded in Station1and Station3 remain higher than that in the stations Station 2 and station 5 with a variation between -3.6°C and -6.4°C at 14:00 and variation of -3.9°C after mid-day 16:00 this result agrees with the results of many studies[11,20-22].

4.2. Impact of the Vegetation on Air Humidity

The relative humidity depends on the temperature and the quantity on water contained in the air. The values of air humidity at the beginning of the day are very high; on the other hand those of after midday are most significant [23]. The evapotranspiration of a tree can reach up to 400 liters per day, which represents a cooling effect equivalent to 5 units for 20 hours means hot and dry climate [24]

According to the graph in Figure 3, there is a negative correlation between relative humidity and air temperature. It is noted that vegetated or green stations (P2 and P5) registered higher values of air humidity than station P1. The highest value of relative humidity is recorded at 18:00 (hours) in the station P4 in the street with trees alignment and near a square, note a variation of 23%, compared to station P1 (with no trees and same space configuration).

At the time of the maximum of energy of 12:00 (hours), we observe variation between 3.5% and 10.5% in stations P1, P3 and P4. while the one cumulates solar energy, the other one records an increase in the water content, this rise is explained by the effect of the latent heat of the vaporization of the vegetation [25,26].

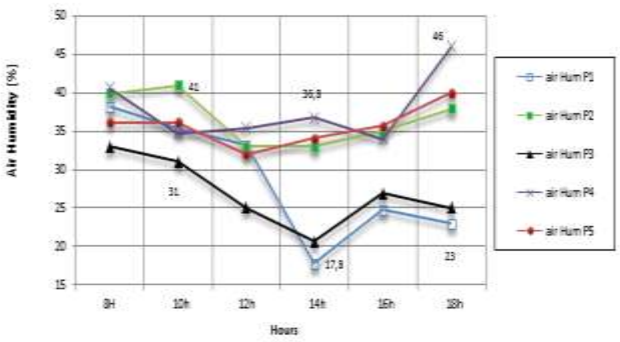


Fig.3. Variation of air humidity in various stations period July.

4.3. Impact of the Vegetation on Ground Surface Temperature

According to F Bourbia and F Boucheriba (2010)[15], an open and exposed nature of an urban street can result in an increase in the daytime air temperature within the canyon. He showed that This effect can be reduced by controlling the sky view factor and inclusion of vegetation. For that another purpose of this study was to examine the correlation between shade by trees and ground surface temperature of the streets. The same kind of analysis used for air temperature, was performed for the soil surface temperature inside the designated urban spaces. The foliage of a tree can filter 60 to 90% of solar radiation and crouching vegetation also reduces the solar radiation reflected by the ground [12,26,27]

The soil temperatures of stations P1 and P3 (highest ratio H/W, lowest SVF and mineral soil surfaces) compared to those of station P4 (tree shaded area with dense foliage coverage about 80%) mentions a difference up to 10°C, and this result is in accordance with those of [14,15], floor-shading fraction in summer increases with presence of trees.

4.4. Cooling effect of Vegetation

A comparison between the weather station (open site) and the average temperature measured at the selected site, confirm that the open site field temperatures are lower than the urban areas, with a difference ranging between 3 and 6 °C (Fig. 5).

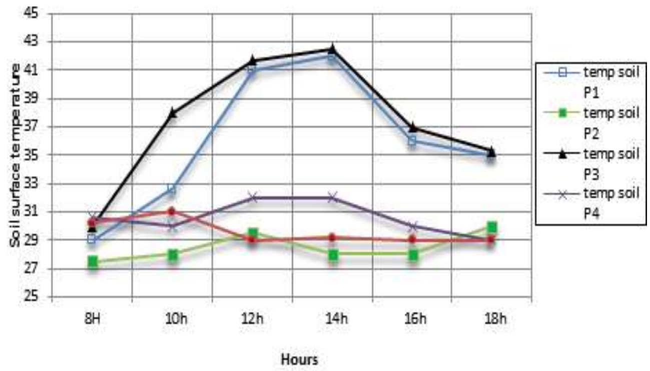


Fig. 4. Variation of soil temperature in different stations period of July

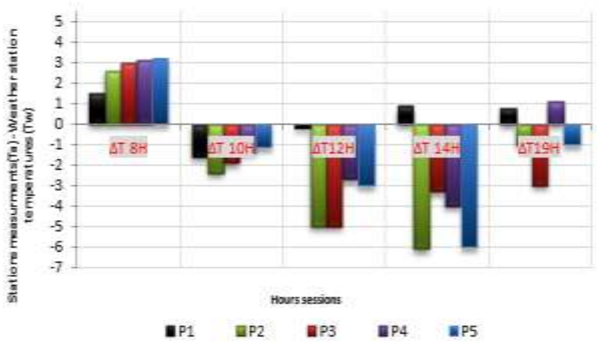


Fig.4. The range of deviation between measured staions and weather.

This difference in temperature is mainly caused by the nature of percentage of reflective surfaces and presence of vegetation. These surfaces tend to have high heat capacities, and are thus efficient at absorbing and reradiating the sun's energy later on [29].

The difference appears especially during midday session of measurements Those of the afternoon show well the moderating effect of heat in spaces covered with vegetation. The effect of permanent shade of the vegetable is translated by the absorption of the sun rays and the contribution in air humidification.

In contrary area without vegetation presents a heat amplification that is due to mineralization of surfaces, important sky view factor and long day exposure to sun rays.

Furthermore, the relationship between building height and street width is also considered to be the main contributor to the heat island effect in cities. Also, the maximum heat island intensity has been proven to correlate well with the mean sky view factor of the city center for a number of cities around the world [29].

For that vegetation in urban planning create permanent shadows on the ground and the walls, so allowing the habitability of outdoor spaces.

4.5. Thermal Comfort Analysis

The comfort parameters and indices adopted for this study are: air temperature (Ta), mean radiant temperature (Tmrt), and physiologically equivalent temperature (PET).

The mean radiant temperature is an important parameter affecting the human well-being. It expresses the radiative effect of the whole of the environment. Tmrt varies according to the importance of the solar radiations received and reflected by surfaces. Its maximum value reached 63.7°C for station P1.

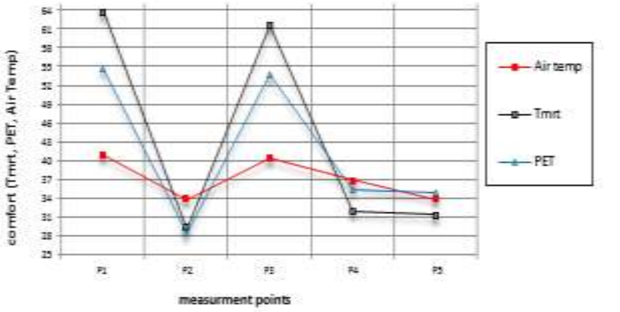


Fig.5. Relation between air temperature, PET and Tmrt in different stations.

Thermal comfort on the level of the two calculated stations is evaluated according to the index of comfort "physiologically equivalent temperature" PET. This index is between 28.5 °C and 35.3°C in the stations were there are shade of the trees (P2, P4 &P5) and about 54.6°C and 53.7°C in the mineral stations (P1 & P3). The value of PET in stations with important shade is lightly hot during all the day. Nevertheless, thermal environment in Station P1 is extremely hot and makes uncomfortable felt in the space (Fig. 6).

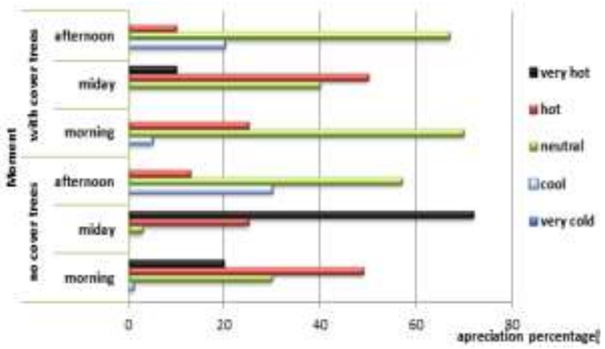


Fig.6. Perception of the urban street in different moment of the day (covre trees and no covre trees)

By questionnaire the number of people and activities outdoors are influenced by the solar radiation (Fig.7). And people from different social backgrounds in hot and dry climates have different approaches to the use of outdoor spaces. The study indicate an appreciation of neutral predominate under spaces with trees coverage witch has a positive condition in comparison to that in streets with no coverage.

The result reveals that there is a great influence of vegetation on human sensation and on PET since when rows of trees are added on the pavement, PET values are lowered due to the shading of the pedestrian pavement. Presence of vegetation optimizes the microclimatic environment for pedestrian's thermal comfort in urban spaces, under hot and dry climate.

Consequently, in urban environments that have low aspect ratios, the influence of vegetation on outdoor thermal comfort is significant. Similar results found that the direct solar radiation under a tree canopy strongly decreases [30,31].

4.6. Results of Simulation

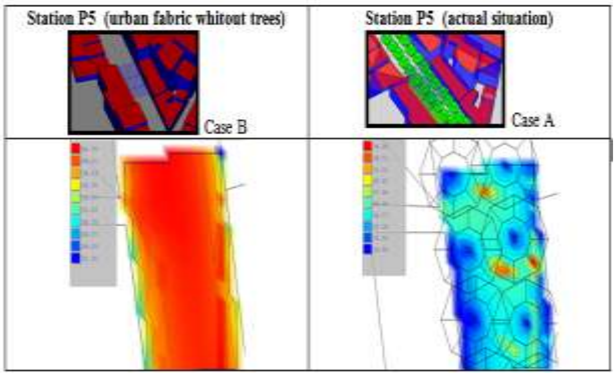
The investigation is based on a three-dimensional model TownScope 3.2 which simulates the microclimate conditions in an urban environment. It is a 3D simulation model developed for numerical modeling of urban microclimate and again the majority of atmospheric processes that affect the microclimate.

The impact of vegetation can be quantified at different levels. Indeed, the consequences of plant presence reflect the microclimatic scale in terms of: quantity of transmitting radiation, air temperature, leaf temperature and comfort.

Table 2.Result of comfort according to the average of the air temperature at 12:00

	Da (m)	**Da /W**	**Air temp** (°C)	**Air hum** (%)	***Rad*** (w/m-²)	**Tmrt** (°C)	**PET** (°C)
CaseA (with trees alignement)	10	1.33	24,84	50	130,14	16,2	20,4
CaseB (without trees)	/	0	38,16	20	911,57	**69,1**	**56,9**

Table 3. Air temperature of simulated zone [P5] (effect of presence of trees)



In the following tables (table 2 and table 3) the results of the simulation of station P5 show that the presence of trees in actual situation provides shade and minimize global radiation compared to simulated situation without trees with an mean difference of 890w. m-2. This result can improve comfort in these areas. For the P1 were in actual situation trees have an effect on the air temperature, can reduce air and soil temperature about 13.7°C.

Similarly, the global radiation in the situation (case B) is much higher than that of the actual situation (case A) at 12h: 00 (911.57 W/m2 against 130 W/m2). The vegetation keeps soil cooler and avoids direct, diffuse and reflected sunlight that may affect the cool buildings [33]. The presence of the vegetation modifies the solar radiations in outside space. According to [34] the improvements due to the effect of the vegetation in the urban outdoor space are sensitive to create sources of freshness. Also, a row of trees decreases the temperature of the surrounding air by 2°C. The simulation shows that a variation in the air temperature of 2.5°C to 3°C in open spaces according to the quantity of the shadow and the sunshine duration.

In the station P1 with no vegetation and open space (actual situation) the areas is exposed in all the day to solar intensity (fig.8). Introducing row of trees global radiation reduce sun duration about half to one hour and procure shade witch make comfort; We can note a variation in the quantity of global radiation under tree canopy in open spaces according to the quantity of the shadow. The Tmrt index is about 70.6 °C in the station P1 where there is no shade and it is about 28.8°C under crown trees, in modified landscapes of the space.

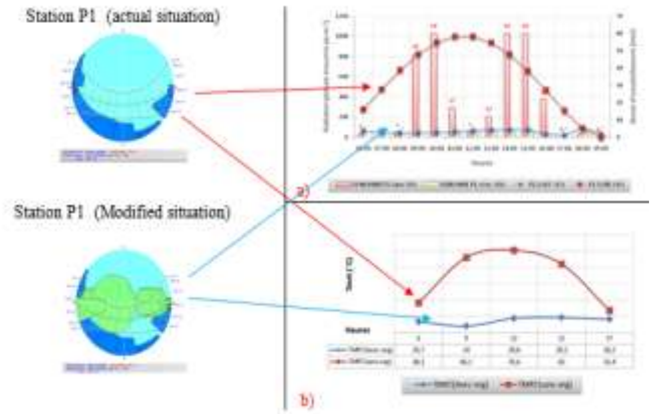


Fig.7 simulation results a) global radiation and sunshine duration in P1simulated (with and without trees) b) Tmrt values in P1 of the two situations

5. Conclusion

In urban environment vegetated spaces, acting as temperature buffer, have important climatic function such as providing shadow, windbreaks and reducing the heat island effect.

The vegetation makes esthetic improvements to an environment differently dominated by asphalt and concrete. The presence of vegetation modifies the solar radiations in outside space, the temperature and the relative humidity. It has its own cooling system imparted by the process of evapotranspiration; which transforms part of the radiation in latent heat flux. Moreover vegetation can affect the microclimate in many ways, in particular reducing air temperature, soil temperature compared to stations without trees, while getting shades.

In the present consideration, in external environment, the presence of trees has positive effects on space shading, air and soil temperatures and on the microclimatic conditions. The improvement concerns air temperatures and relative humidity as a difference of about 3 degrees and 4,4% are retained respectively.

According to the results of measurements and simulation, we can retain the following projecting points:

1) The presence of the vegetation modifies solar radiations effects in external space, air temperature, soil temperature and the air relative humidity;

2) Vegetalized space develops lower air temperatures and higher air humidity, thus offers more pleasant comfort and sensation.

3) There is a correlation between the air temperature, mean radiant temperature (Tmrt), and physiologically

equivalent temperature (PET) in hot seasons, which influences the comfort.

4) Improvement of the urban environment quality by mitigation of the urban heat island.

Very often Trees constitute an important component of the opened external space, which strongly contributes to the environmental quality. For that the valuation of the essential axes is recommended by the deciduous tree implantation for more refined environment.

In addition, the trees increase comfort sensation in external space on period of heat stress in hot and dry Mediterranean climate. where urban planning has a significant impact on the UHI in hot and dry climate and for that we recommend mitigating actions from an urban planning with vegetation cover in open spaces especially and design perspective accordingly.

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