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MICROCLIMATIC REGULATION OF PALM TREES IN SEMI-ARID ENVIRONMENT DURING HEAT STRESS

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ABSTRACT

Vegetation affects the urban microclimate in different ways, including shading, aspersing the humidity and controlling the wind velocity. In urban areas, microclimatic regulation depends on a number of features such as type and ratio of vegetation. This paper investigates the microclimatic regulation of palm trees in semi-arid environment during heat stress. El Nakhlette Street located in Guelma, Algeria has been selected to conduct the investigation, we measured air temperature, relative humidity and wind velocity during the hottest period of 2019.The study simulates four scenarios of El Nakhlette space in hot season with different ratio and type of vegetation using Envi-met model. The index PMV has been used to measure the heat stress levels. The findings show that palm trees as an evergreen type have the lesser microclimatic regulation and it is not the most suitable type to semi-arid environment.

Keywords: palm trees; microclimatic regulation; heat stress; PMV index; semi-arid environment.

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1. INTRODUCTION

Facing the problem of climate change and its impact on built environment, cities must reinforce connection within its different systems to consider policies and adaptation strategies to climate change [1]. Some researchers have described climate change as a challenge for cites [2,3], while Malcolm Eames see that the real challenge is to anticipate sustainable solutions for better livable future [4]. Both views agreed that the urban environment is constantly deteriorating due to the extreme climatic conditions including the heat weaves and (UHI) urban heat island [5]. As a result, several sciences like architecture, town planing, urban design, and climatic engineering have been gathered to fight this intruder phenomena, declared the architect Victor olgyay *"To meet the problem of climate control in an orderly and systematic way requires a pooling of effort by several sciences ……review the climatic conditions and this depends on the science of meteorology"* [6]. At the city scale greening, surface materials and water bodies have the key role on improving climatic and microclimatic conditions [7]. Historically Japan is one early adopter of climate planning techniques that embedded microclimate awareness, moreover Japanese were the first to highlight the microclimatic regulation function induced by trees, for example pine hedges are used as windbreaks and sunshades [8].

The effect of vegetation on urban microclimate has been the subject of numerous researches, at the large scale mainly focused on addressing strategies of thermal environment optimization [9,10], at local scale investigating vegetation role on cooling down air temperature in particular and improving atmospheric conditions [11]. In their almost total, vegetation has showed a great interest to city specialists, hence it should be fully considered in designing outdoor spaces [12].In order to explore how trees affect microclimate in summer time, Yafei Wang carried out field measurements among sites with different environmental characteristics under different weather conditions. It was been demonstrated through simulations that trees significantly altered the surrounding summer microclimate [13].

In recent years, a significant scientific progress has been made, not simply in improving urban microclimate, but rather to evaluate qualitatively and quantitatively the outdoor thermal comfort [14,15]. Many indexes have been developed to assess thermal sensation in outdoor spaces, amongst them (PMV) Predicted Mean Vote and (UTCI) Universal Thermal Climate

Index incorporated with the software Envi-met, considered one of the best indexes [16].

It was already demonstrated during cold stress that microclimatic parameters are significantly affected by vegetation type and ration important to control wind speed and moderating microclimate in outdoor spaces in Guelma city [17]. Our purpose is to investigate the effect of microclimatic regulation of palm trees during heat stress. Once again, ratio and type of vegetation are the two aspects examined in the present investigation through an atmospheric simulation of four different scenarios.

2. MATERIALS AND METHODS

2.1. Study site

The study was conducted in Guelma, a city located in northeastern Algeria, about 65 kilometers from the Mediterranean coast (36° 27' 43 N; 7° 25' 33 E; 840 ft. Elevation). With semi-arid climate (classified as Csa by the Köppen-Geiger system). It has a distinct hot season (May-October) and cold season (November-April). The highest mean air temperature 34.5°C occurs in August, while the lowest occurs 4°C in January.

El Nakhlette our case study is one of the most frequented outdoor spaces in hot season situated in downtown Guelma figure.1. It is about a linear amenity space that hosts modest activities and services, it is mainly composed of low-rise buildings and it covers a total surface area of about 2060 m². Palms are the only type of vegetation in this outdoor space.

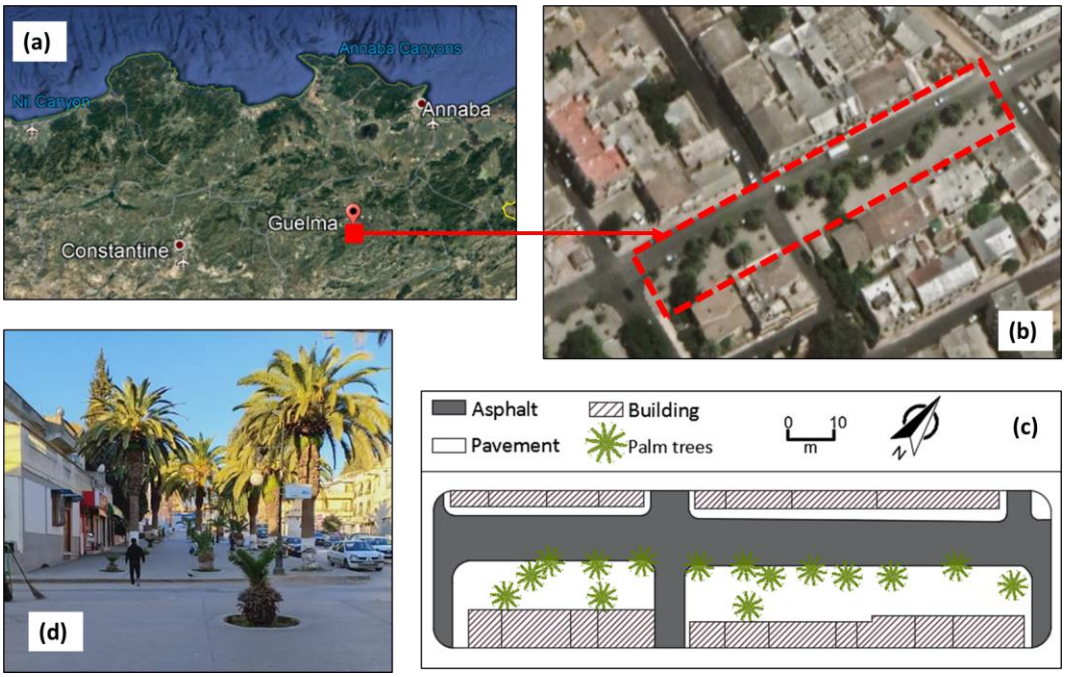


Fig. 1. (a) Location of Guelma city, (b) study Area (source: https://www.google.com/earth/), (c) Plan view of El Nakhlette space, (d) Picture of the study area.

2.2. Field measurements

Before collecting the microclimatic data, the hottest period of the year was calculated based on the data weather 2017 and 2018. July 24th, 2019 was the selected day to conduct the measurement companion, we obtained an hourly record from 09:00 to 21:00 of the three microclimatic parameters; air temperature (Ta), relative humidity (RH), and wind Velocity (Wv); "Testo 480 - AG 501 1ST, 0563 4800" is the device used in measurements is a multifunction instrument equipped with intelligent digital probes calibrated independently used as thermo-hygrometer and as anemometer, a Full description of Testo instruments is available in the online manual [18] .

2.3. PMV and heat stress levels

PMV was originated in 1970 by Fanger, is one of the most important indices in measuring physiological temperatures, which is used to predict the population perception of a group exposed to the same microclimatic conditions [19,20]. This index includes seven-point scale categorization from -3 to +3, with 0 as a neutral thermal sensation and four positive values indicating the Physiological stress in hot season as shown in table 1. the index is used to

assess the heat stress in both indoor and outdoor thermal environment [20,21]. PMV is icoropretaed with urban design simulation models and supported by numerical softwares, such as Ray-man and Envi-Met being used in our study.

Table 1. PMV scale and categorization for the hot season

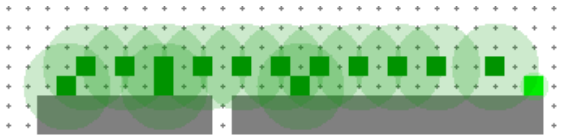
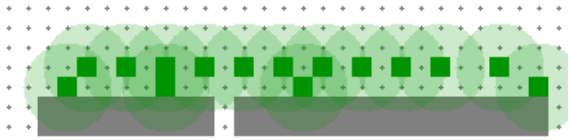
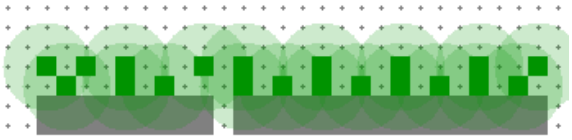
PMV scale	**0**	**+ 0.5**	**+ 1.5**	**+ 2.5**	**+ 3**
perception	comfortable	Slightly warm	Warm	hot	Very hot
Physiological stress	No thermal stress	Slight heat stress	Moderate heat stress	Strong heat stress	Extrem heat stress

2.4. Atmospheric simulation

As the main idea of this paper is to study the microclimatic regulation of palm trees in semi-arid climate, the simulation of different scenarios in hot season is crucial, including the existing cover vegetation. Four (04) scenarios with different ratio and type of vegetation (two species of urban evergreen trees) have been simulated in the present study using a licensed version of Envi-met V4.4.4 (version winter19/20). The atmospheric model of Envi-met allowed us to acquire a set of microclimatic parameters of El Nakhlette space in summertime. Based on the obtained simulation data, the PMV index was calculated using the post-processing tool Biomet. Table 2 shows the detailed framework of the simulation process.

Table 2. Detailed framework of the simulation process of the four scenarios

Specification of the simulation process by Envi-met model	
Location	Guelma (Long:7°25’33’’ Lat 36°27’43’’)
Climate	Semi-arid
Simulation date	24.07.2019
Simulation start time	09:00:00 am
Model dimensions	x-Grids: 35 / y-Grids: 10 / z-Grids: 10
Grid cell	dx= 2 / dy= 2dz= 2
Grid north (north 0, east 90)	335
PMV index Calculation	Biomet process
Results visualization	Leonardo
First Scenario: current outdoor space	**Second Scenario:** 0% vegetation

 Current outdoor space including the existing vegetation cover (100% palm trees).	 Current outdoor space with removing the existing vegetation cover.
Third Scenario: 100 conifer trees	**Fourth Scenario:** mixed cover
 Changing the existing vegetation cover (100% evergreen trees –Conifer trees).	 Changing the existing vegetation cover (40% palm trees and 60 % evergreen trees).

3. RESULTS

3.1. Envi-met model validation

In order to validate the Envi-met model, simulated values of air temperature and relative humidity were correlated to recorded values (July 24th, 2019) for the current area. Wherase, the R^2 is the reconcile factor, the results are presented in figure 2. Simulated values of both parameters are strongly agreed with recorded values in the hottest period time of the day, from 10:00-15:00. R^2 = 0.97 and R^2 = 0.95 these higher values indecate the evidence of the simulation model, respectively for air temperature and relative humidity. At this point, it could be wrapped up that the simulation model by Envi-met is suitable for the present study.

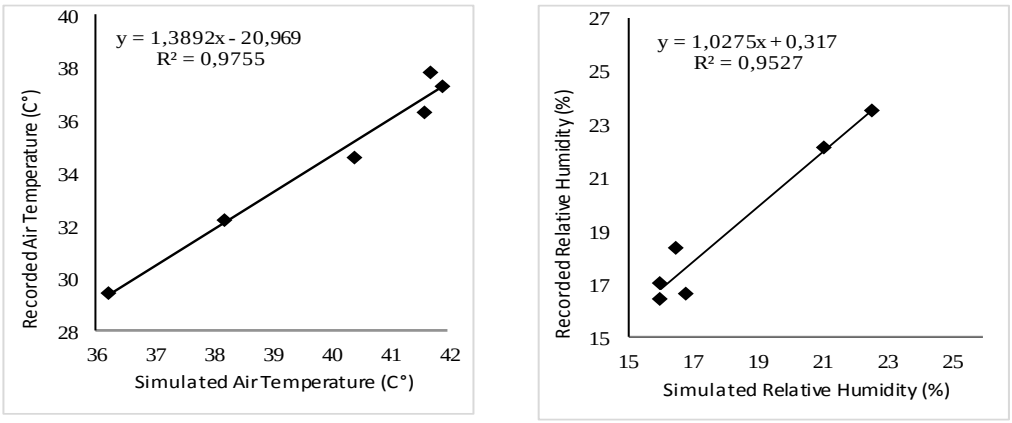


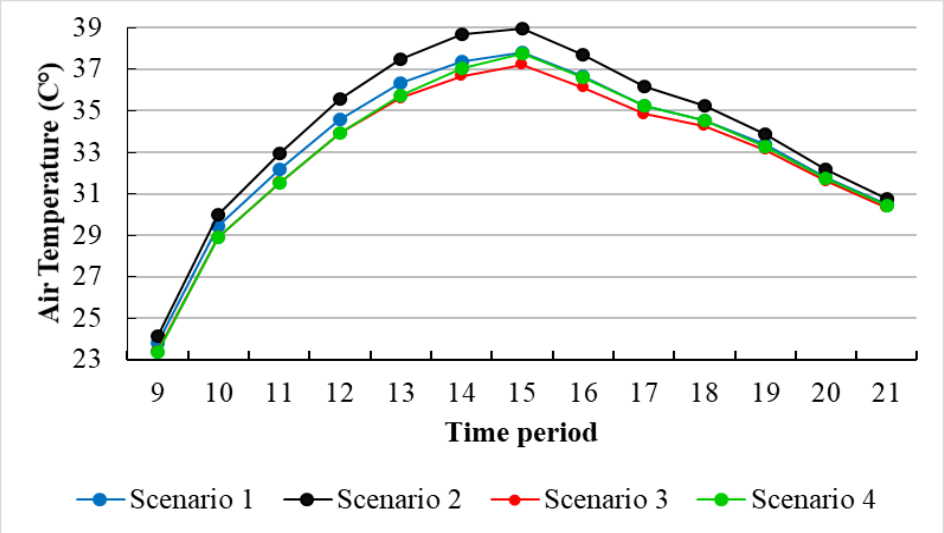
Fig. 2. Simulated and recorded values of Air temperature and Relative humidity for the current outdoor space in period time (10:00-15:00)

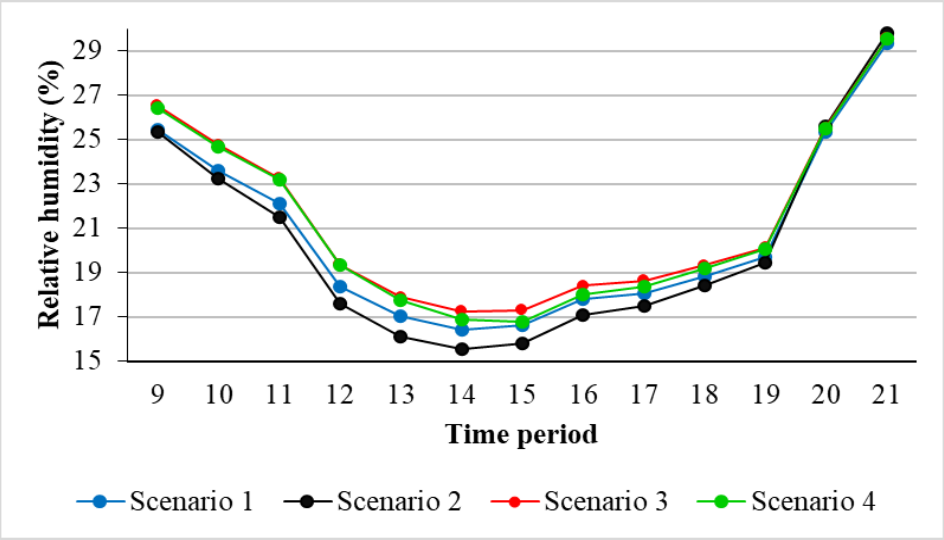
3.2. Comparison of microclimatic parameters in different scenarios

Figure 3 shows the results of simulated parameters, air temperature (Tp), relative humidity (RH) and wind velocity (WV) in different scenarios in period time from 09:00 to 21:00.

For all the scenarios, the general trend of air temperature was ascending from 09:00 to 15:00 and descending from 15:00 to 21:00. The highest temperature (34.1°C) was observed in scenario 2 where vegetation cover was completely removed (0% vegetation), while the lowest temperature (32.9° C) was observed in scenario 3 of 100% evergreen trees. It has been observed too that air temperature was low (33°C) in scenario 4 with mixed vegetation cover (40% palm trees and 60% evergreen trees).

Inversely relative humidity was higher respectively in scenario 3 (100% evergreen trees), scenario 4 (40% palm trees and 60% evergreen trees), scenario 1 (100% palm trees) and scenario 2 (0% vegetation). 1.1 m/s was the highest wind velocity observed in scenario 2 of 0% vegetation, the second-high value 0.9 m/s was found in scenario 1 of 100% palm trees, then 0.8m/s was observed in scenario 4 with mixed vegetation cover, finally 0.6 m/s in scenario 3 with 100% evergreen trees.





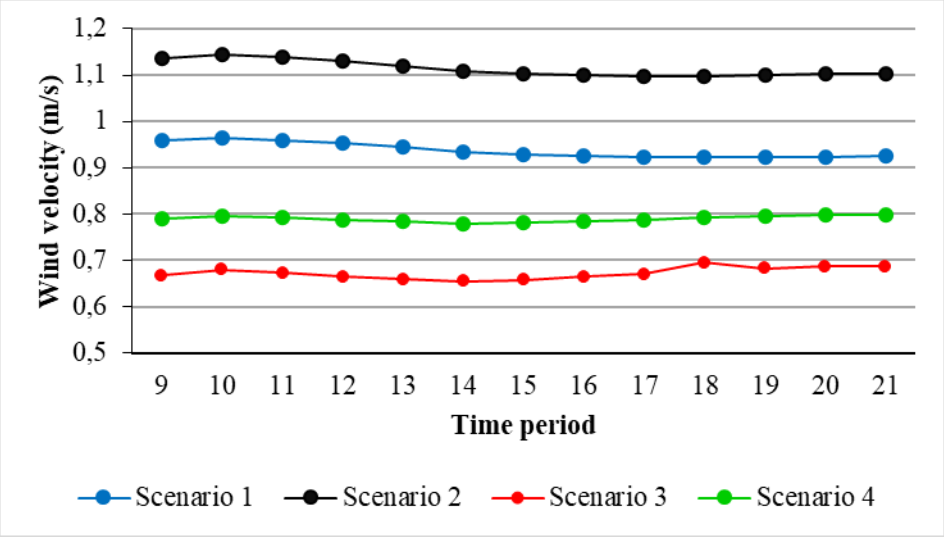


Fig.3. Comparison of the three parameters; Air temperature (Tp), Relative humidity (RH) and wind velocity (WV) in the various simulated scenarios in period time (09:00-21:00)

3.3. Comparison of PMV index in different scenarios

For the selected day (July 24th, 2019) and during the period time from 09:00 to 21:00 we obtained PMV index for the different simulated scenarios, results are presented in figure 4. Firstly, the PMV index for the mentioned period time was ranging in between 0.5 and 3 considered within the following categories and conditions slight heat stress (0.5 > PMV > 1.25), moderate heat stress (1.25 > PMV > 2), strong heat stress (2 > PMV > 2.25) and extreme heat stress (2.25 < PMV). Two significant periods for PMV variations, the first is the hotesst one from 09:00 to 15:00 where values were higher respectively in scenarios 2 without vegetation, scenario 1 with 100% palm trees, scenario 4 with mixed cover 40% palm trees and

60% evergreen trees and scenario 3 with 100% evergreen trees. The second period time from 15:00 to 21:00 values of PMV are nearly matched. The highest PMV (3) was obtained in scenario 2 coresspending to exterm heat stress, the folowing values 3 and 2.25 were obtained respectively in scenario 1 and scenario 4 within the extreme heat stress range. while the lowest obtained PMV was in scenario 3 coresspending to strong heat stress.

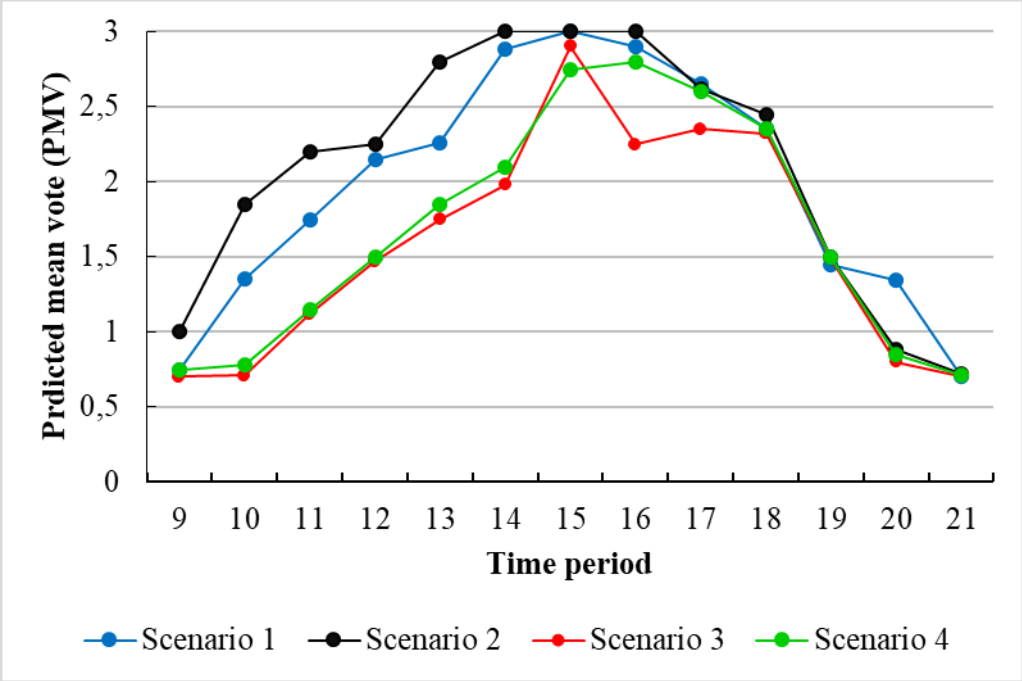


Fig.4. Comparison of PMV index (Predicted Mean Vote) in the different simulated scenarios for the period time (09:00-21:00)

4. DISCUSSION

In Algeria, palm trees are native much more in hot and arid environment and it is the main type of vegetation growth in cities situated in the south of the country. Previous studies have showed that palm trees are the most suitable type for such environment, thus it can reduce air temperature from 5°to 10°C and it is recommended to maximize its area in new urban extensions [22].

The main purpose of this research is to investigate the same function (microclimatic regulation) of palm trees in semi-arid environment during heat stress. El Nakhlette outdoor space in Guelma was chosen to conduct the investigation and to answer the flowing points. Can palm trees improve the microclimatic conditions during heat stress? Do palm trees have

the same regulatory effect of other evergreen trees? Are palm trees suitable too to semi-arid environment?

In order to estimate the function of regulation of palm trees, the study has involved three parameters; air temperature (Tp), relative humidity (RH) and wind velocity (WV). Nemours review and researches have discussed the capacity of vegetation to reduce temperature [23–25], few of have tackled the features and characteristics of vegetation that modify locally the microclimatic parameters [26]. The most important characteristics are species and type of vegetation, this gives an overall comprehension of trees used in each of the simulated scenarios. Simulating the outdoor space with removing vegetation (scenario 2), indicates that the palm trees in El Nakhlette space affects positively the microclimatic conditions. Air temperature was significantly lower (- 0.8°C) while relative humidity (+0.4%) and wind velocity (+0.2m/s) were higher. Palms are distinguished by their large compound, evergreen leaves, arranged at the top of an unbranched stem [27], regarding these features the effect of cooling down the outdoor temperature in El Nakhlette space can be interpreted by the largest shaded area that provides one palm tree (50 m²). Considering the classification of palm trees within the evergreen type, scenario 3 has simulated the current space with replacing palm trees with other evergreen trees (Conifer trees) this type has shown the best microclimatic conditions during heat stress. As a result, the temperature was lower (-1.2°C) while relative humidity (+1.1%) was higher. The type of conifers used in the simulation has a cylindrical configuration with dense and evergreen leaves. At the example of palm trees lowest temperature was interpreted by shading effect, the higher value of humidity could be interpreted by the effect of evapotranspiration induced by conifers biomass, in other words the transfer between trees leaves have aspersed water vapour in the atmosphere. Which leads too cooler conditions in El Nakhlette space during heat stress. In scenario 4 the idea was to maintain the high representativeness of the place due to the palms or El Nakhlette, so we kept palm trees at the border of the space as a landscaping natural element and we replaced them by conifer trees inside. This mixture was ranked second in term of microclimatic regulation with low temperature (-1.1°C) and high relative humidity and mean wind velocity, using palm and conifer trees have contributed to maximize shaded area in scenario 4. Therefore. microclimatic parameters were relatively cool.

Trees as important naturel regulatory of microclimatic conditions in heat stress could improve the thermal sensation. In order to exanimate the heat stress levels in El Nakhlette space PMV index was calculated on a seven-point thermal sensation scale, in the simulated scenarios 1,2 and 4 the PMV index was higher where heat stress was extreme in particular for scenario 2 in period time from 13:00 to 17:00, while heat stress in scenario 3 was strong in period time 17:00-18:00. In transitive relationship trees in various simulated scenarios affected the PMV index through Shading and humidification. Therefore, these effects can affect thermal sensation individually or in combined way. Palm trees have affected the PMV individually through shading effect. Conifer trees due to its features have affected the PMV index through both effects shading and humidification, however when the tow effects were combined, the wind velocity increased, thus the heat stress was slight and moderate from 9:00 to 21:00. Utilize palm and conifer trees affected PMV index through shading effect where shaded area was maximum, compared to the use of Conifers (100%) the effect of humidification was less. The combination of tow effects has shown a relative high wind velocity.

5. CONCLUSION

This paper aimed to investigate the microclimatic regulation of palm trees in semi-arid environment. From our findings it can be seen that evergreen trees affect positively the microclimatic conditions in heat stress, wherase palm trees have reduced (-0.8° to -1.1° C).

At the answer of the addressed questions in discussion section, palm trees affect the microclimatic conditions through shading effect during heat stress and it can improve microclimatic conditions by cooling down the outdoor temperatures (-0.8°C). Compared to conifers, the role of palm trees in outdoor spaces during heat stress can be assimilated to a huge parasol or umbrella. As an evergreen type palm trees have a less effect on microclimatic regulation, so that palm trees are not the most suitable type to semi-arid environment.

Holding on the ratio of the used trees, palm trees could be used as landscaping natural element in semi-arid environment, its role is more significant during heat stress in term of microclimatic regulation unless it’s used with other evergreen type like conifers (-1.2°C).

The findings of our study have answered its purpose, additionally the results of this study can help designers for designing future outdoor spaces in semi-arid environment and it can help

users to find a comfy outdoor locus during heat stress.

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