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Effect of vegetation on outdoor thermal comfort in hot arid regions, a lesson of sustainability from the traditional Ksar of Ain Madhi, Algeria

K. Dohsi[1], D. Djaghrouri[2], M. Benabbas[3]

[1 2 3]University of Biskra- Lacomofa Laboratory - Biskra, Algeria

khadidja.dohssi@univ-biskra.dz, djamila.djaghrouri@univ-biskra.dz, m.benabbas@univ-biskra.dz

Abstract. Regarding the important effects of thermal comfort on residents, especially in hot regions, our study aimed to investigate and determine the influence of vegetation on the external thermal comfort conditions in the Algerian Sahara. In our work, we examine the determining factors of thermal comfort at three points in the Ksar of Ain Madhi by coupling in-situ measurement and simulation with the Rayman 1.2 software. The measured parameters are air temperature (Ta), relative humidity (HR). The simulated parameters are global actual radiation (Gact), direct actual radiation (Sact), surface temperature (Ts), mean radiant temperature (MRT), predicted mean vote (PMV) and physiological equivalent temperature (PET), this work is such a lesson of sustainability that we should take into account for future urban development especially in hot arid regions.

Keywords. Outdoor thermal comfort, Vegetation, Ksar of Ain Madhi, hot and arid regions, Rayman

1. Introduction

Outdoor spaces are important to sustainable cities because they accommodate pedestrian traffic and outdoor activities, and contribute greatly to urban livability and vitality. In the global context of climate change, outdoor spaces that provide a pleasurable thermal comfort experience for pedestrians effectively improve the quality of urban living spaces [1]. The question of the city sustainability was involved in the process of sustainable development, which is considered as guarantees of a harmonious urban development for future generations [2]. Urban Heat Island effects create great concern for the outdoor thermal comfort. Urban morphology (defined by the geometry of built-environment, natural or man-made features, their configuration, street layout, land surface and human activities) along with meteorological and climate conditions also determines human thermal comfort [3].

For better comfort to the users, we must integrate the microclimate concept in each design operation or intervention on the city and take into account the greening process. Through these interventions, can make some improvement on the thermic ambiances by contribution to moderating the microclimate [4]. Comfortable micrometeorological conditions increase the time that the people spend outdoors and thus help save energy via reducing the use of air

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conditioning [5]. MRT is the most important parameter governing human energy balance, especially on hot sunny days, MRT also has a strong influence on thermophysiological comfort indexes such as physiological equivalent temperature (PET) or predicted mean vote (PMV) [6].

In Saharan cities with arid climate, the population concern is to avoid the sun's rays and seek the shade and freshness therfore in these conditions people always leave the public spaces (urban outdoor spaces). Especially the very open ones, of which they are assailed all day by a hot and burning sun, towards built-up areas while using air conditioning [7].

The traditional residential building in the Algerian Sahara (the Ksour) implements in its design in both the exterior and the interior ingenious ideas and simple accents. This gives perfection to their images. The hot and dry climate that characterizes the region has forced the residents to pay particular attention to thermal comfort and ventilation of the exterior and interior when designing the Ksour. These principles not only affect the design of the building, but also the design of the surrounding area; the latter includes the integration into the topography of the area, the orientation, the urban geometry and the nature of the area (water, vegetation, etc. ...).

The role of vegetation (urban vegetal) is not limited to the beautification of public spaces and makes them pleasant; but its role touches all dimensions of the environment: social, ecological and psychological [7]. Trees, as a form of vegetation, foster microclimatic control and thermal comfort [8]. Vegetation shading is one of the important factors that significantly affects thermal comfort [9].

The estimation of micro-climatic conditions in outdoor urban spaces requires a thorough knowledge of many parameters related to the urban environment, such as air temperature, relative humidity, air speed, rainfall, and above all; solar radiation and ventilation [10].

In our research, we will examine one of the essential components of the site, namely the vegetation, which makes up more than half of the surface of the Ksour. In order to demonstrate the influence of vegetation on nmicroclimate parameters and outdoor thermal comfort conditions (air temperature, relative humidity, surface temperature, mean radiante temperature, solar radiation, PMV, PET) in the oudoor space in the Ksar, We shoose three locations in our case study, this ksar is located in the Ain Madhi city in Algeria.

2. Presentation of the case study

The commune is located in the southwest of the wilaya of Laghouat, 66 km west of Laghouat in the south of the country. The modern locality is located in a plain below the Jebel Amour (Saharan Atlas) [11].

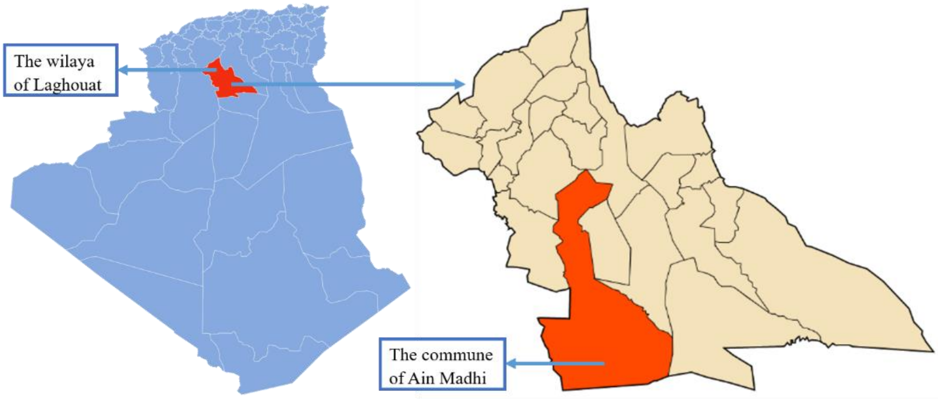

Fig. 1. Maps showing the location of the commune of Ain Madhi.

Technium Social Sciences Journal
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The ksar of Aïn Madhi with a surface area of 2.5 ha was built during the 12th century, like many that were built in the desert. The ksar of Ain Madhi is surrounded by a wall with 3 doors of which Bab el kebir (the main door) and bab seghir (the door of the canal) are original. The third door, Bab charqui (i.e. eastern door) was added later. The compound (the enclosure) contains living quarters, the mosque, several zaouiya and accommodations for the guards, responsible for the defense of the Zaouiya. The construction were built with large stone and mortar forming narrow small alleys. Zaouiya have kitchens, rooms for spiritual retreat and learning, pantries [12]. The gardens of Aïn Madhi have a total area of 40 ha and are intended for the self-development of the local population, crops and various types of fruits and vegetables in this region are produced, the irrigation turn between owners is carried out according to the concept of time [13].

To determine the various outdoor thermic ambiances in this environment, our study was carried out at three main representative locations in the Ksar. The first point was on the northeastern border of the ksar gardens, the second on the west border of the ksar with a high proportion of green spaces, and the third point in the middle of the ksar far from the gardens.

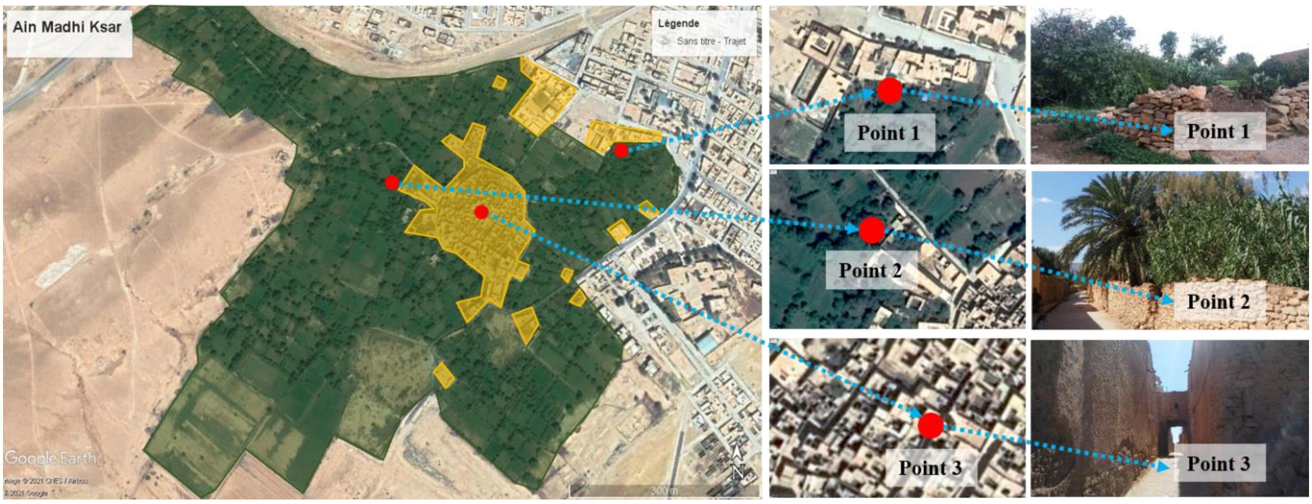
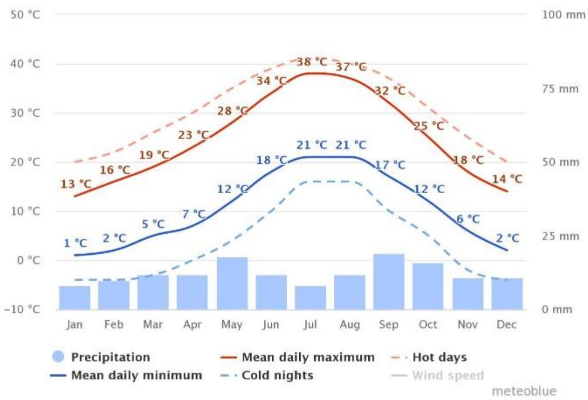
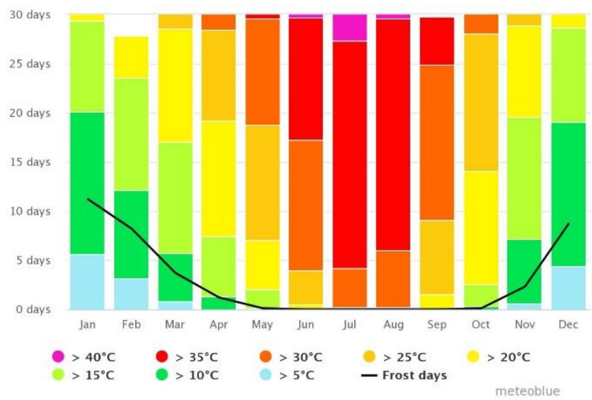


Fig.2. Satellite view of the Ksar of Ain Madhi and the location of the three points.

2.1 The climatic characteristics of Ain Madhi city. According to the classification of Köppen [14], the region of Ain Madhi has a dry desert climate (BWk) with the following climatic data (figures 3, 4 and 5).





Technium Social Sciences Journal
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Fig. 3. The temperature and precipitation data of Ain Madhi city (Meteoblue, 1990-2020).

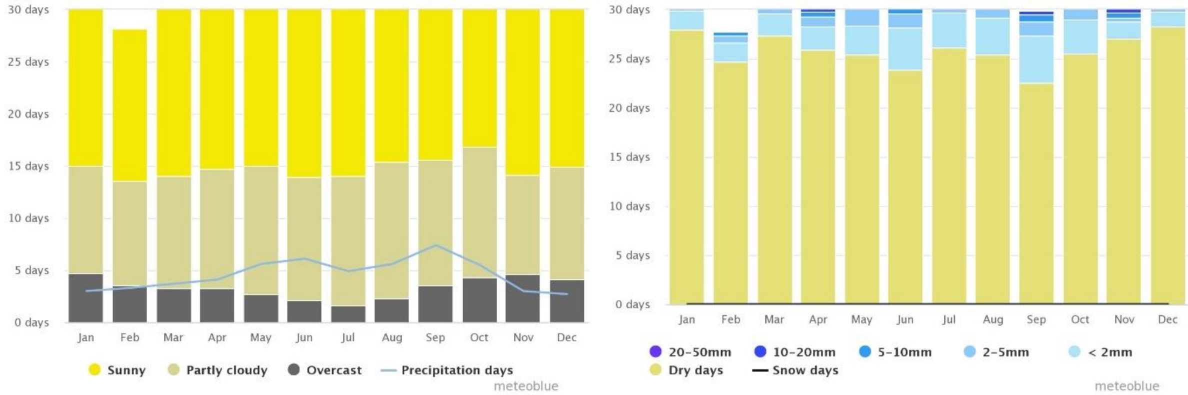

Fig. 4. Cloudy Sunny days and precipitation data of Ain Madhi city (Meteoblue, 1990-2020).

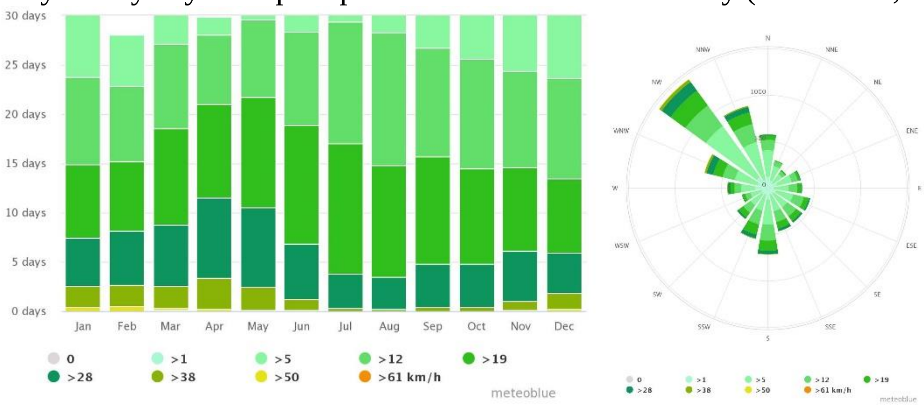

Fig. 5. Wind speed and wind rose of Ain Madhi city (Meteoblue, 1990-2020).

3. Methodology

Our research was based on the coupling of on-site measurements and simulations to compare the results and precisely identify the core of our study, accordingly with (figure 6).

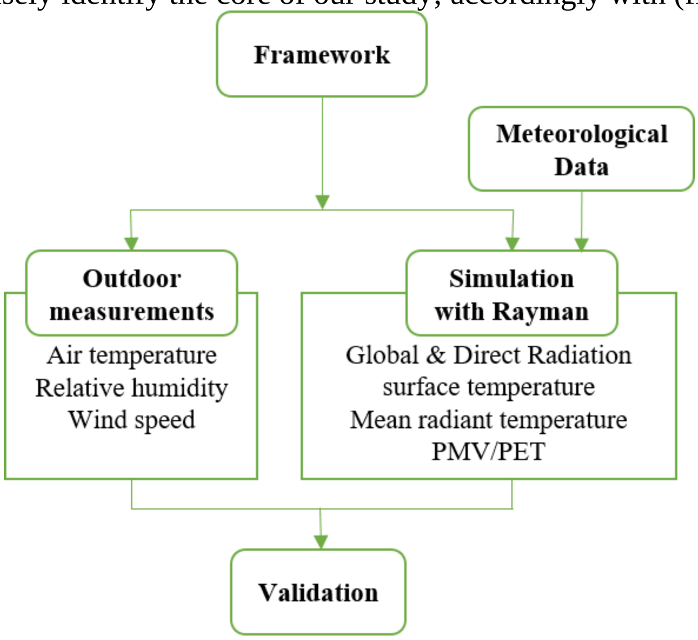

Fig. 6. Research Framework.

Technium Social Sciences Journal
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3.1. Investigation & on-site measurements. The climate data were collected in the tree locations with the Testo 480 handheld device.

Fig. 7. handheld device Testo 480.

The measurements were taken from 8:00 a.m. to 8:00 p.m., on a summer day (July 30, 2019), this day was selected after reviewing the hottest and clearest day of the year.

3.2. *Simulation.* In this study, the simulation was carried out with the RayMan 1.2 software. The RayMan model was used to calculate the thermal comfort conditions in relation to the six indices Gact, Sact, Ts, Tmrt, PMV and PET. RayMan is a diagnostic micro-scale radiation model developed at the Chair for Meteorology and Climatology of the Albert-Ludwigs-University Freiburg [15, 16]. It is designed to calculate radiation fluxes in simple and complex environments [15, 16]. This allows the calculation of Tmrt, which is an important input parameter for the calculation of thermal biometeorological indices [17].

We enter the data of the location (data and time, geographic data, Current meteorological data and the personal data) (figure 8).

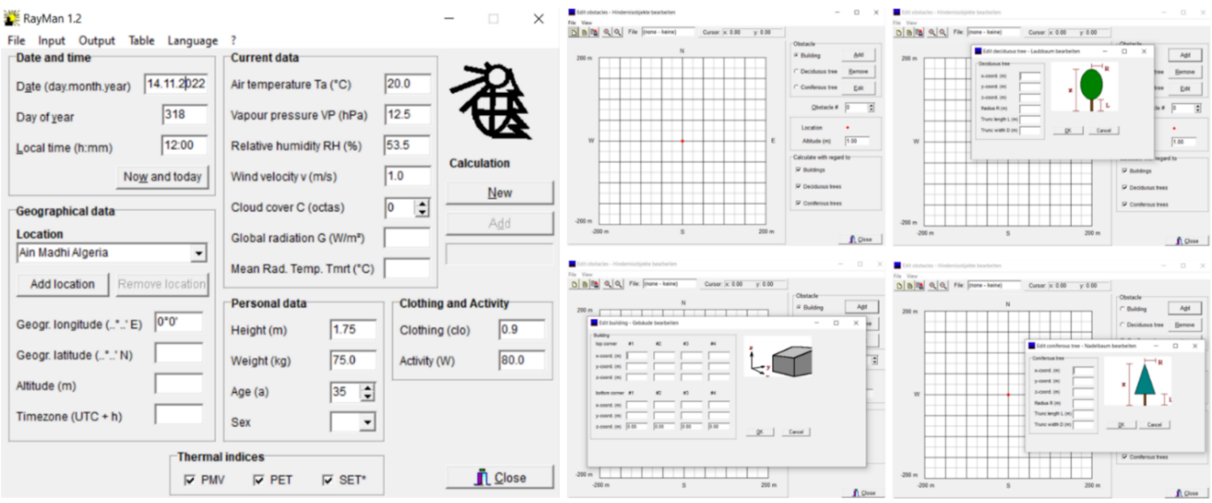
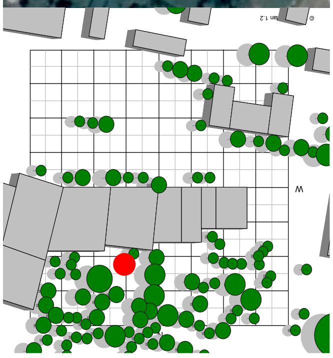
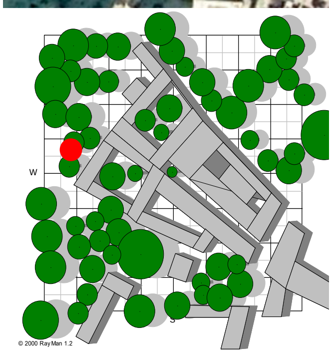
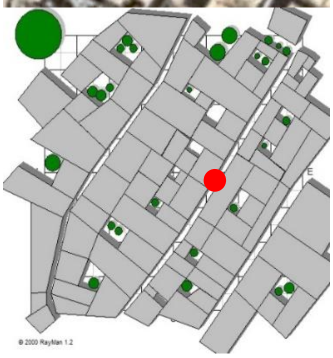


Fig. 8. RayMan 1.2. Interface.

Table 1. Geographic data of the case study.

	Date	Latitude	Longitude	Altitude
Point 1	30.07.2019	33°47’45.88”N	2°18’14.80”E	983
Point 2	30.07.2019	33°47’41.98”N	2°17’58.62”E	985
Point 3	30.07.2019	33°47’38.36”N	2°18’05.84”E	988

Table 2. The three points to simulate modeled with Rayman 1.2.

	Point 1	Point 2	Point 3
Points location			
Points location modeled by Rayman			

4. Results & Discussion

4.1.On site measurement results. The results of these measurements are summarized in the following figures.

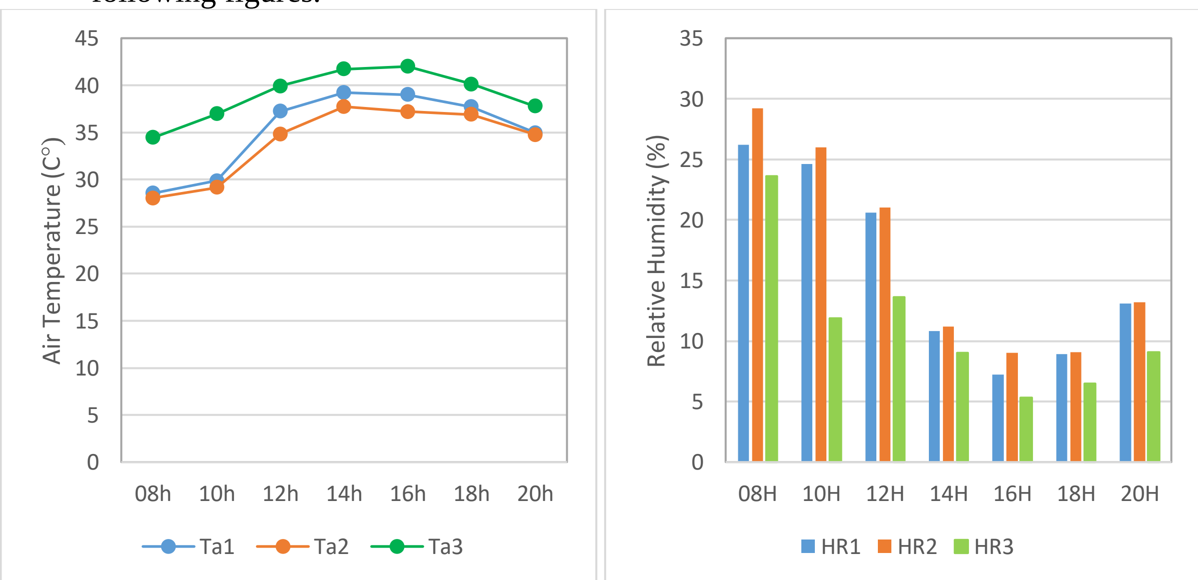


Fig. 9. Air temperature (left), Relative humidity (right).

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The above figure 9 illustrate the fact that when comparing the measured results at the three locations where the climatic conditions were recorded, we find that the air temperature of the third point (where there is a lack of vegetation) is higher than the temperatures of the other two points (the two greened locations). The difference between the 2nd and the 3rd point reaches up to 7.8 ° C at 10:00 a.m., while the difference between the 1st and 2nd point does not exceed 1 C°. By analyzing the figure, we see that the relative humidity at points 1 and 2 (the overgrown locations) is higher than the relative humidity at the 3rd point. The difference between the 2nd and 3rd location is up to 14.1% at 10:00 a.m. A comparison of the results shows that vegetation plays an important role in lowering air temperature and increasing relative humidity by the evapotranspiration effect that humidify the air in order to obtain a satisfaction.

4.2. Simulation results and discussion. After the results of the in-situ measurements, to investigate the role of vegetation on the different thermal comfort conditions in the three selected locations, the three cases modelled with the software RayMan 1.2, taking into account the geographical and climatic conditions of the city.

Table 3. Recapitulation of the findings by Rayman 1.2.

Time	Location	Gact(w/m²)	Sact(w/m²)	Ts(C°)	Ta(C°)	Tmrt(C°)	PMV	PET(C°)
	Point 1	195	122	34.3	34.4	43.8	2.9	36.4
08:00	Point 2	77	0	33	34.4	40.8	2.8	35.6
	Point 3	121	0	35.5	34.4	45.7	3	37
	Point 1	334	234	40.9	37	50.3	3.7	41.6
10:00	Point 2	325	234	40.9	37	49.9	3.7	41.5
	Point 3	740	624	46.6	37	60.8	4.2	45.2
	Point 1	385	278	46.3	39.9	54.1	4.6	46.6
12:00	Point 2	375	278	46.2	39.9	53.4	4.5	46.3
	Point 3	657	556	51.4	39.9	59.2	4.8	48.5
	Point 1	334	234	46.8	41.7	55.2	4.7	46.7
14:00	Point 2	325	234	46.8	41.7	54.7	4.6	46.6
	Point 3	128	0	52.2	41.7	58.2	4.9	48.1
	Point 1	195	122	43.8	42	50.8	4.9	48.1
16:00	Point 2	77	0	42.5	42	48	4.8	47.3
	Point 3	97	0	48.8	42	55.2	5	49.9
	Point 1	22	0	40	40.1	40.2	4.1	43.2
18:00	Point 2	20	0	40	40.1	40	4.1	43.2
	Point 3	25	0	45.1	40.1	47.1	4.2	43.3
	Point 1	0	0	37.5	37.7	35.6	3.7	39.4
20:00	Point 2	0	0	37.5	37.7	35.1	3.7	39.4
	Point 3	0	0	39.6	37.7	40.1	3.7	39.4

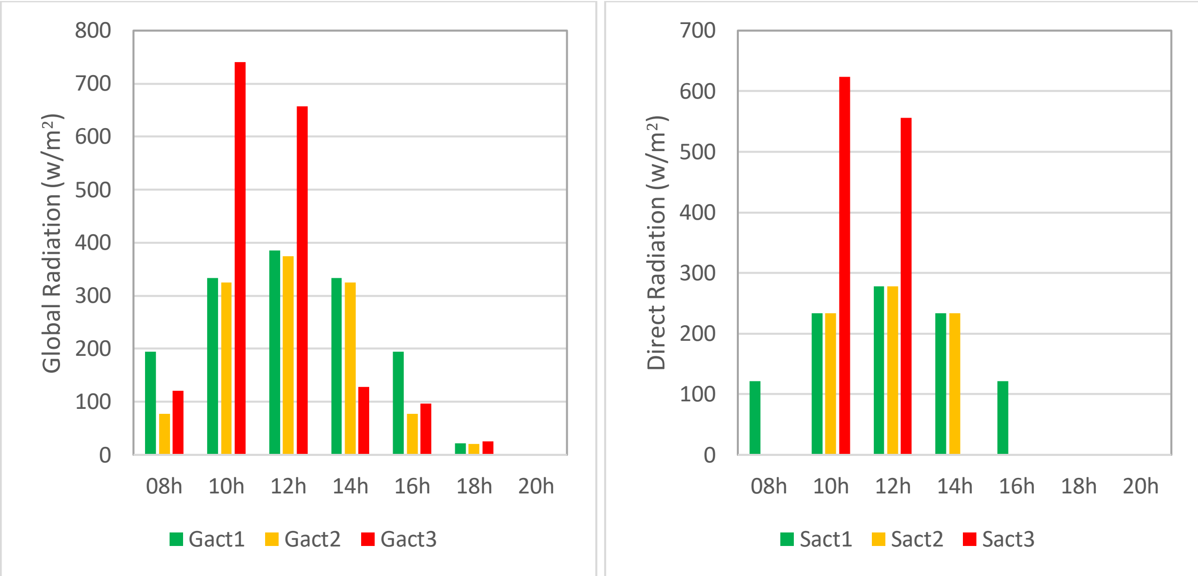

Fig. 10. Global actual radiation (left), Direct actual radiation (right).

By observing the figure 10, we see that the actual global radiation in the no greened location (point 3) the value exceeds (740w/m²) at 10:00 a.m. and (657w/m²) at 12:00 p.m., while the values of points 1 and 2 are very close and do not exceed (385w/m²) in its maximum value at 12:00 p.m. The same is observed for the Sact where the values in the points 1 and 2 at 10:00 do not exceed (234w/m²) while in the point 3 it exceeds (624w/m²) in the same period. This is caused by the effect of the existing greenery in the 1st and 2nd point which acts as an interceptor, absorbing the solar rays and creating shaded areas. Looking at figure, on left, we notice that the value of Gact in the 3rd point decreases in a remarkable way compared to the 1st and 2nd points, and for the values of Sact in the 3rd point from 14:00 is equal to 0 (figure B). This is due to the compactness that characterizes the Ksourian urban form.

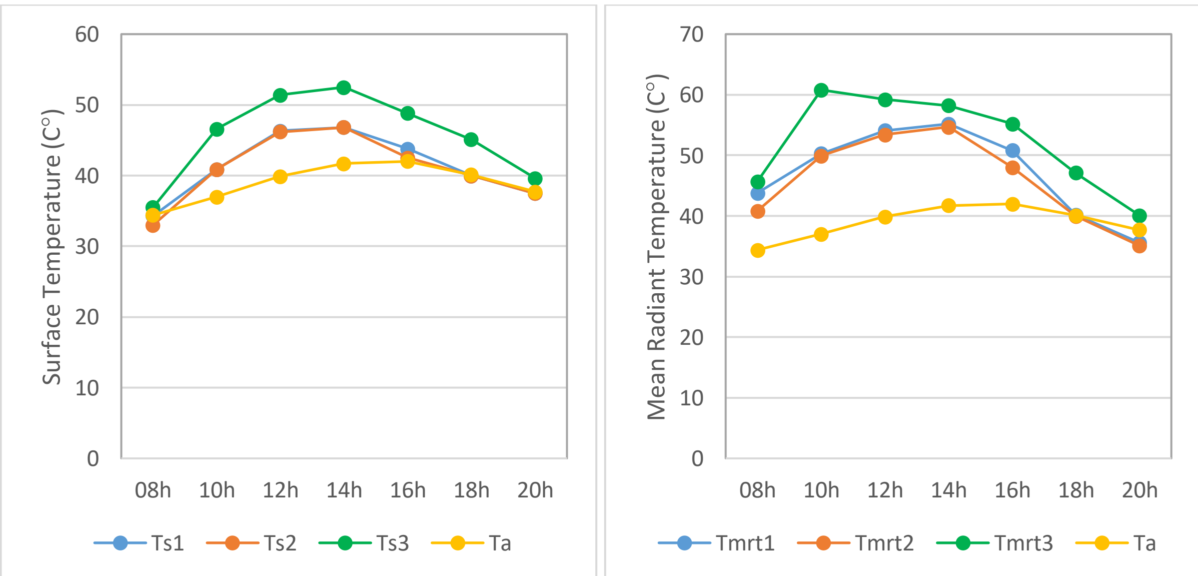

Fig. 11. Surface temperature (left), Mean radiant temperature (right).

From figure 11 on the left. It can be seen that the surface temperature in the bare area exceeds 52°C, while in the two greened areas it does not exceed 46 ° C, where the difference arrives until 6°C. According figure 11 on the right. The average radiant temperature in the planted areas (1st and 2nd point) reaches up to 55 ° C; while in the non-greened area (3rd point); it exceeds 60°C, with a difference reaching 10°C at 10:00 a.m. The above figures illustrate the fact that, the surface temperature and the mean radiant temperature depend on the sun's rays and the shade created by the trees and surrounding vegetation.

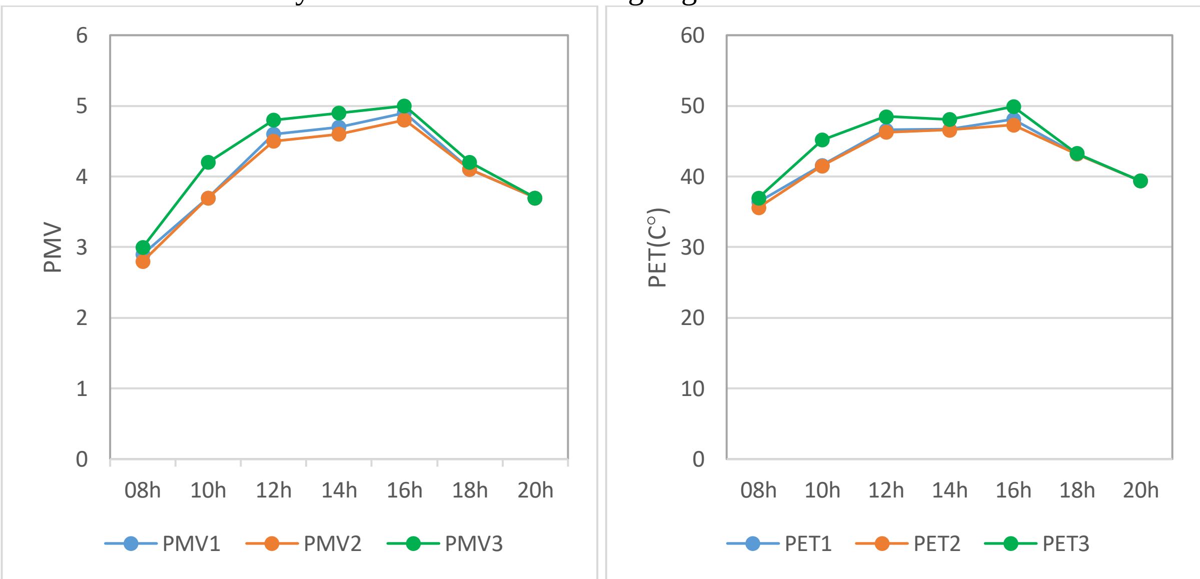

Fig. 12. PMV (left). PET (right).

As can be seen in the figure, the PMV at 8 o'clock in the morning we measured 2.9 in 1st place, 2.8 in 2nd place and 3 in 3rd place. At 10 o'clock, we measured 3.7 at the 1st and 2nd location and 4.2 at the 3rd location. In the afternoon, we observe a negligible difference from 06:00 p.m. We observed that the PMV at the third location from 08:00 a.m. to 04:00 pm is higher than the PMV at the first and second locations.

The figure shows that the simulated PET is 41°C at the 1st and 2nd location at 10 a.m. and 45°C at the 3rd point, where the difference between the covered points (1 and 2) and the uncovered point (3) riches 4°C.

5. Conclusion

The aim of this research is to evaluate the effect of vegetation on local microclimate and outdoor thermal condition in the old Ksour of Saharan Atlas.

In situ measurements results have shown that the air temperature decreases remarkably in vegetated outdoor spaces in contrast to non-vegetated ones. In addition to the temperature, the relative humidity results affirm that the more vegetation is present, the more relative humidity increases in the exterior.

Simulation results obtained by Rayman software, showed the impact of the plant element on several parameters of the microclimate and outdoor thermal comfort. Solar radiation can be influenced by several parameters. The presence of vegetation plays an essential role in reducing solar radiation by absorbing it. The surface temperature and the average radiant temperature are dependent on the presence of the green elements; the shade created by the vegetation has a great effect on the cooling of the ambient air. The PMV and PET are the

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important indices of the thermal comfort, when we see the results, we observe that the vegetation reduces theses indices, and this minimize the dissatisfaction of the users and thus allowing more sustainability for this kind of environment.

For that, it is the vegetal element (palm grove, gardens) that was always among the main elements that defined the Ksar in the Algerian Sahara.

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