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Vegetation Impact on Thermal Comfort in Courtyard Houses Using Passive System Techniques. Case of Semi-Arid Areas

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Abstarct

This research aims to study the presence of green spaces and their important roles in improving the quality of the thermal environment. The use of green space in courtyard houses influence on specific physical climatic properties. The influence of green spaces in the regulation of microclimate and assessment of the indoor thermal comfort in courtyard houses was studied. Two types of houses has been selected as a case study.The spaces that determine the internal organization of housing are: courtyard, bedrooms, kitchen and garden.Since comfort describes the state of the body and the state of mind of an individual, the assessment of thermal conditions (air temperature, shading and sunlight) affect thermal exchanges and increase evaporation and relative humidity). This was done according to the statistical calculation index average. The purpose is to assess thermal comfort conditions using PMV and PPD indicators, its adaptation ability according to ISO 7730 standards obtained through a questionnaire for users of the two types of houses selected. The method used for this study is inductive experimental based on an on-site measurement campaign on the hot days of July 2021. The measurements carried out provide the following results: density and percentage of shade by type of plant have a decisive influence on the conditions of thermal comfort and each plant has its thermal constant. These indicators create good thermal environment in the courtyard houses situated in semi-arid areas.

Key words: thermal comfort; individual behavior; vegetation; architectural strategies; courtyard habitat.

INTRODUCTION

In hot arid regions, introverted architecture is a passive and beneficial strategy to reduce energy consumption and provide comfort to space users. The introduction of green spaces in courtyard houses (Sala et al.2021) demonstrated in several previous studies, improves the thermal qualities of the indoor environment, in particular indoor spaces adjacent to courtyard containing vegetation (Sodoudi et al. 2018; Zhao 2018). In order to protect the entire enclosure from overheating and improves the thermal environment of the interior spaces regardless of the position of the courtyard in the dwelling.Green spaces can create a cooling effect that extends to the immediate surroundings of indoor spaces. This study analyzes the thermal performance of green spaces in the courtyard houses in a semi arid area. The use of composite walls made up of deferent materials and the green facade act essentially as a passive system through three mechanisms: the shade produced by the vegetation, the insulation provided by the vegetation (Thuring and Dunnett 2014) and the substrate, evaporative cooling by evapo-transpiration seems effective to reinforce the weakness of the courtyard houses (Forouzandeh2014) in order to protect all the facades overlooking the courtyard against overheating and improves the thermal environment of interior spaces through the use of green spaces which are linked to the contextual environment and the quality of design of the buildings and their organization. Among all the advantages, there is an improvement in thermal conditions. Green spaces can also provide ideal locations for social interaction. There is a strong relationship between microclimatic conditions (Leo Samuel et al. 2017) and the ways in which spaces are used. Studies also show that most users tend to perceive the importance of green spaces in improving the thermal environment (KontoleonandEumorfopoulou, 2010), especially by providing shade during warmer periods. Those indicators Influence the thermal environment by providing shade (Hoelscher et al. 2016), intercepting radiation. Reduce the surface temperature, followed by convective heat transfer (Jumabekova et al. 2021) in homes located in warmer regions. Consciously or unconsciously, people tend to be adapted to local conditions by changing their behavior towards the use of green spaces inside their houses. They often show preferences for spaces containing vegetation. The facade is considered as a dynamic interface between the internal and the external environment (Coma et al. 2014) whose role is to control the heat transfer between the interior and the exterior to ensure the well-being of the users (Malys et al. 2014; Ottelé et al. 2011). This control is important not only to ensure the quality of indoor environments (Cantin et al. 2005; Mokhtari 2008) but also to minimize the amount of energy required to operate constructions (Buccolieri et al. 2018). The thermal process of a construction is complex and depends on the constraints to which it is subjected, in particular to outside temperatures (Herath et al. 2018). The judicious choice of green spaces and building design models contributed to the reduction of indoor air temperatures (Connelly and Hodgson 2013).

The aim of this research is to evaluate the actual and potential environmental aspects associated with the construction, the influence of green spaces in the regulation of microclimate and assessment of the indoor thermal comfort of buildings. In addition, the quantifiable positive aspects of the vertical surfaces of vegetated interior walls (due to a reduction in energy savings) have begun to be determined. This has made it possible to evaluate their sustainability in relation to the achievable environmental benefits. Sustainability can be defined as a general property of a material or product that indicates the extent to which existing requirements are met in a specific application. These requirements that have influences on the well-being and health of the living beings that occupy the building.

METHODOLOGY

Presentation of Case Study Area

The context of the study is that of the city Ghoufi located in the Aures in a pre-Saharian area of the white valley 90 km south of the wilaya of Banta (Algeria). It rises 700 meters above sea level. This city is characterized by a hot and arid Saharian climate; the temperature is very different between day and night of both seasons (Figure 1).

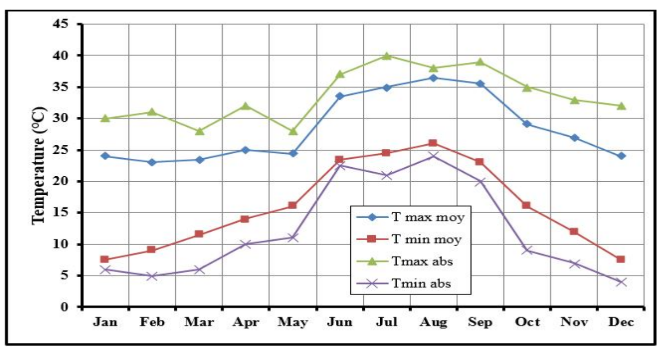

Figure 1. Monthly temperatures in the city of Ghoufi (Batna-Algeria) for one year (2021)

As shown in Figure 1, it was noted that there is large thermal amplitude between the maximum and minimum temperatures for each month. In addition, the hot period was characterized by very high temperatures that influence the thermal behaviour of the courtyard constructions and the comfort of the users.

Courtyard Building Samples

The two buildings selected for the experiments both had courtyards with vegetation. The first building type 2 with two floors and the second building type 1 with one floor. The main specifications are presented in (Figure 2).

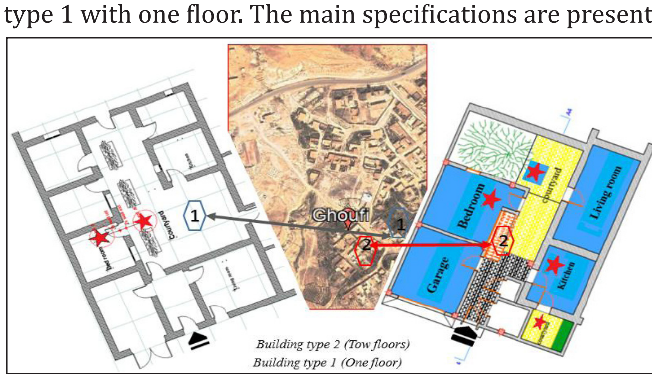

Figure 2. organization plan and location of the buildings selected for the experiments.(Source:Author,2022)

In order to ensure thermal comfort inside buildings containing green spaces, it is necessary to take into account the laws of heat transfer such as conductivity and convection. This statement has been made by similar studies(Marty 2012; Lenzholzer et al. 2018; Shooshtarian et al. 2018).

Conductivity

Conductivity is an exchange of energy without displacement of the material. Therefore, it was related to solids and solid fluids (Marty 2018). In the simplest case of a solid-thickness wall with two distinct surfaces (S) with a heterogeneous temperature difference (T_1-T_2), the heat flow depends on the material thermal conductivity of the material (λ) ($W\ m^{-1}\ K^{-1}$). (e) is wall thickness, R_{th} ($R_{th} = e/S\lambda$) is the thermal resistance of conduction as shown in the equation Eq.(1)(Marty 2018).

$$\phi_{1-2} = \lambda S\,(T_1 - T_2)/\,e = (T_1 - T_2)/R_{th} \quad (1)$$

Convection

Convection that is due to the displacement of molecules that induces a macroscopic displacement of thermal energy: it occurs in fluids (liquids or gases) and at the interface between a solid and a fluid. As these molecules move, they transfer their thermal energy to another part of the system. There are two types of convection. Natural (or free) convection is due to the difference in density between the particles composing the fluid. The forced convection is due to the setting in motion fluid by an external action as an effect of a fan. The movement accelerates the heat transfer(Eq (2)).

$$\phi_{1-2} = \lambda S\,(T_1 - T_2) = (T_1 - T_2)/\,R_{th} \quad (2)$$

In the simplest case of a solid wall of surface (S) and of homogeneous temperature (T_1) in contact with a fluid at the temperature (T_2) at a great distance from the wall, the heat flow depends on the thermal convection coefficient of the material.

The thermal transfer formulated by Newton's cooling law indicates that it is proportional to the temperature difference between the studied body and its surrounding environment.

Monitoring Devices

The in-situ measurements were made using the instruments provided by the Laboratory of Conception and Modelling of Forms and Architectural and Urbans Ambiences (LACOMOFA) of the Department of Architecture, university of Biskra. These devices are a "Testo 480","Testo 875" thermometer and an "infrared thermometer" (Figure3).

The Testo 875is a thermal imager that enables us to determine and display the temperature distribution of surfaces without contact. The Testo 480is a device for measuring climate-relevant parameters (temperature, relative humidity, etc.). The infrared thermometer is a thermometer that allows us to deduce the temperature from part of the thermal radiation emitted by the object (the surface of the wall) being measured.

Figure 3. Measurement devices used for the monitoring of temperature and relative humidity

RESULTS ANALYSIS

Measurements at 2 pm were made under ordinary conditions during the summer period (July 2021). The measured temperatures are the average indoor ambient temperature (T.A.in), the average surface temperature of the internal walls (T. w. in), the average surface temperature of the external walls (T. w. out) and the average ambient temperature outside (T. A. out). For spaces (courtyard, kitchen, bedroom, living room) that are related to the green areas and Thermo-physical characteristics of materials .

As shown in Figure 4. It can be seen for the two types of construction that the average ambient temperature outside (T.A.out) for the month of July at 2 pm (highest air temperature of the day). In addition, the internal surface temperature values of the facade that opens onto the courtyard vary from one space to another according to its position in relation to the plant spaces and the thickness of the walls.

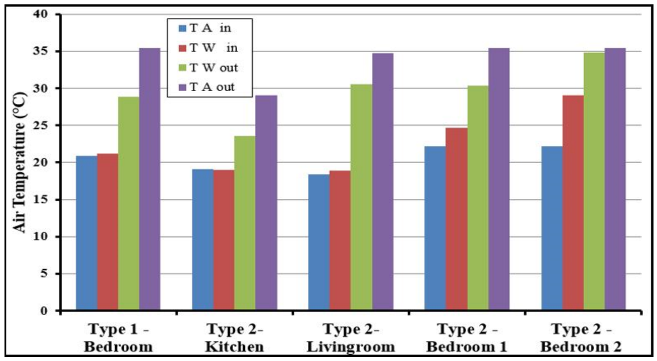

Figure 4. The average surface temperature of the interior spaces of the two types of construction

Effect of Vegetation on Indoor Living Space

It was found that the areas of the courtyard planted with vegetation were cooler, whether in the sun or in the shade. The same result was noticed by Francis and Lorimer (2011)andSusca et al (2011).The thermal characteristics of the vegetation seem appropriate for the hot zones that havean important impact offering a protection by their own shadow on the external surfaces. The recorded temperature difference recorded is 5 ° C to 10 ° C at 2 pm compared to the outdoor temperature which significantly influences the thermal behavior of the external surfaces and ensure user comfort, it is clear that the sample of spaces that have thick walls and are protected by vegetation keeps an adequate the thermal environment inside the building during the hot summer days. To make the results of this research more precise, it was used the thermal camera for the study areas.

Results of measurement are regrouped in Figure5 to Figure 9. The difference in temperature on the surface of the interior wall of the part exposed to the solar radiation can be clearly seen. And the part protected by the vegetation on the histogram of the bedroom of the type 2 and by the comparison of the result obtained by the measurement instruments on types of constructions, it can be deduced that the effect of cooling near green areas during the period of high temperatures depends on the density and type of vegetation cover. Resulting in a reduction of the temperature between 5 ° C to 10 °C.

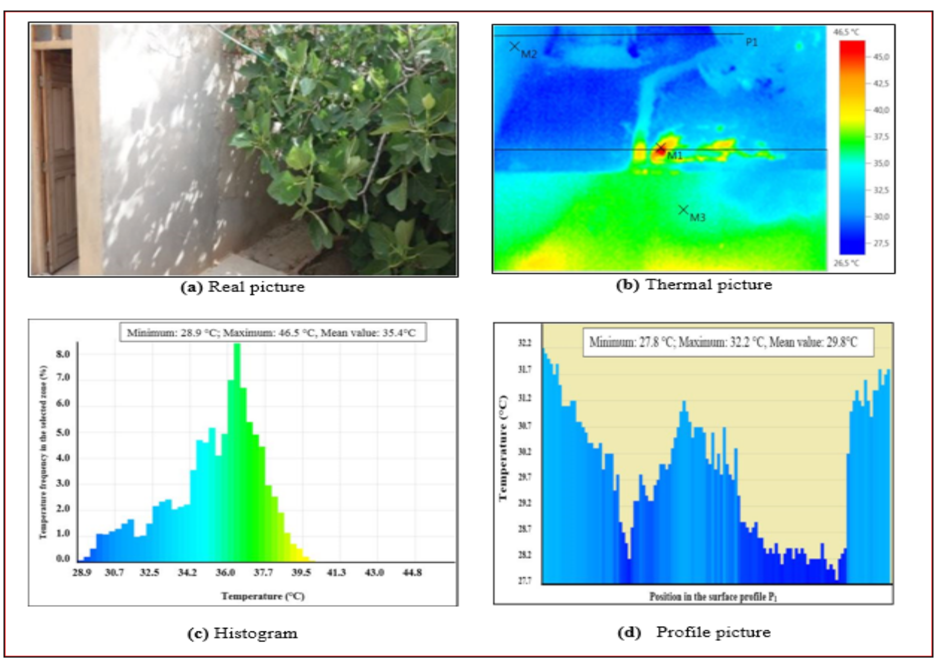

Figure. 5 Treatments of different space (Type 2 courtyard) ((T. A.out)=34.5°C; (T. A. in)=27.5°C protected by vegetation (ΔT = 7°C))

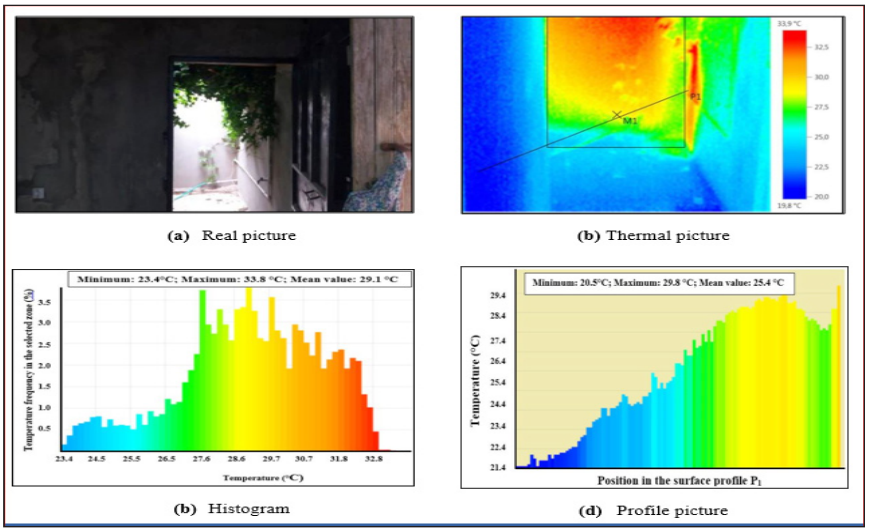

Figure 6. Treatments of different space (Type2 kitchen) (T.w.out) from the courtyard = 34.5°C ; (T.w.out) from the kitchen =25°C protected by vegetation (ΔT = 9.5°C) ; (T. w. in) =19.8°C, (ΔT = 5.2°C)

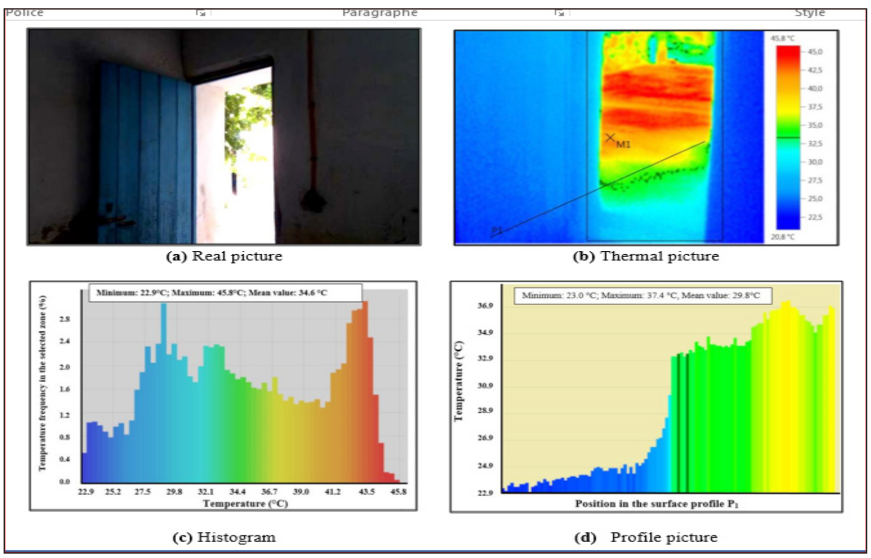

Figure 7. Treatments of different space (Type 1Bedroom) (T.w.out) = 27.5°C protected by vegetation (ΔT = 7°C); (T. w. in) = 22°C, (ΔT = 5.5°C))

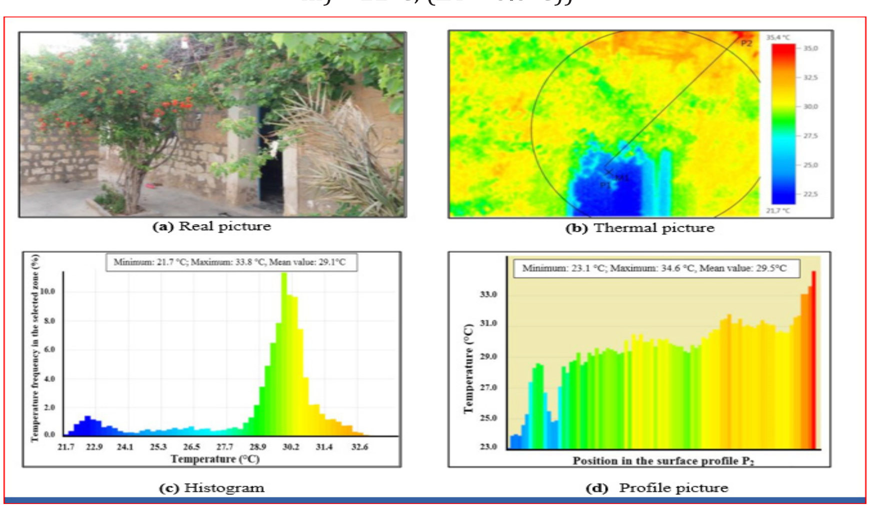

Figure 8. Treatments of different space (Type1 Courtyard) (T.A.out) = 34.5°C (T. w. out)from the bedroom = 27.5°C protected by vegetation(ΔT = 7°C)

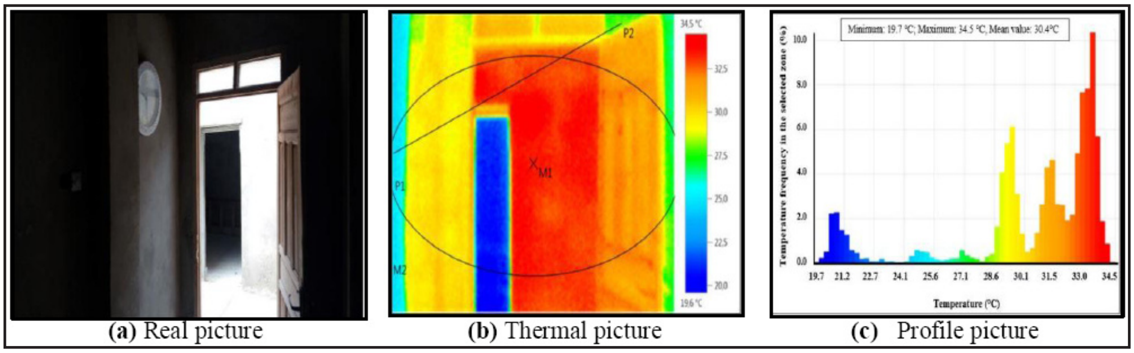

Figure 9. Treatments of different space(Type2 Bedroom) (T.w.out) =34.5°C, (T. w. in) =30°C not protected by vegetation (ΔT =4.5°C); (T. w. in)= 25°C protected by vegetation (ΔT = 9.5°C))

Building Material Effect on Indoor Living Space

According to the examples studied, it is noted that the measurements confirmed the importance of controlling the thermal properties of local building materials (stone and gypsum) for the exterior and interior walls of buildings. Such as the thickness of the wall and the thermal quality of the materials that reduce the interior temperature and create acceptable conditions for the occupants especially at the external surfaces. From where we found the temperature difference between the outside of the wall and inside using the thermal camera close to 5 °C.

Comfort Assessment

The comfort conditions monitoring and user needs providing objective information on the vegetation efficiency in the building's design which are essential in the permanent mobilization of users. The collected information of possible discomforts makes it possible to identify unnecessary parameters during the building design and improve users comfort.A questionnaire was carried out to assess the indoor spaces of the dwellings, especially those adjacent to the green spaces, in particular the interior courtyard and the bedrooms. A study of the sensation of their feelings concerning thermal comfort according to ISO 7730(Alfano et al. 1996), was carried out during a day in July (summer period), and results were compared with the results measured in the field survey. The idea of thermal comfort is a still subjective, to some extent, so, we relied in this study on the feeling of the total number of household members, estimated at (15 people), in addition to the thermal, data derived from the field.

It is known that the balance of thermal comfort depends on the crucial information related to the environment, and the behavior of the individual. The balance is represented by six points:

1.Ambient temperature,

2. Surface or wall temperature,

3. Relative air humidity,

4.Air speed "influence the exchange of heat by convection. In our study, the speed of air is stable, and does not exceed0.2 m / s.

5. "Metabolism" is the production of internal heat in the human body. This maintains about 36.7 °C,

6. "Clothing" represents thermal resistance heat exchange between the surface of the skin and the environment, difficult to determine because of the diversity of clothing. ")

For this purpose, an administered questionnaire was used. The formulation of questions and judgment scale is evaluative (Parsons 1993).

A questionnaire constitutes an important element as a complementary study to the in-situ studies. Distribute to the participating subjects (the habitants of the two buildings studied) at the same time of the measurements to allow them to assess the personal thermal state as well as the quality of the building's interior environment on predefined scales. The questionnaire was recognized on the basis of the measured indicators. The main objective of the questionnaire is to establish an analysis plan based on 5 scales representing thermal comfort degrees.

- Evaluative scale(5-level scale)(Figure10).

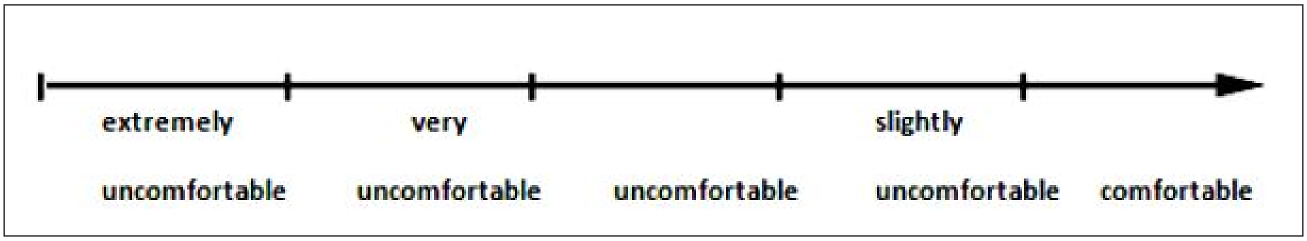

Figure 10. Evaluative scale

The questionnaire data was represented in Figure 5 and Figure 6, shown the thermal comfort zone which is determined for the majority of individuals,that being80% of the totality of subjects.After the collections of all the studied data, the result was as follows:

- The interior courtyard containing vegetation was used from 8:00 p.m. to 11:00 p.m. and from 7:00 a.m. to 11:00 a.m.

- Courtyard was considered a gathering space for users and a circulation space especially times when thermal comfort is unavailable in indoor spaces. It was noted that that the temperature varies between 28 °C -30 °C and the relative humidity varies between 23 .00% to 40.30% at night, while in the morning the temperature varies between 28.40 °C to 32.90°C and the relative humidity varies between 20, 90% to 33.6%

- For rooms, whose walls are adjacent to the green space, used from 8 p.m. to 7 a.m. and from 2 p.m. to 5 p.m, when thermal comfort is available from 11 p.m. to 7 a.m., it was noted that the temperature inside the rooms varies between 28, 70 °Cand 30.80 °C and relative humidity from 24.00% to 34.60% at night, while in the evening the temperature varies between 28 ° C to 31.00 °C and relative humidity from 19.70% to 18.00%.

- Times from 11 a.m. to 5 p.m., users 80% of users feel a thermal discomfort in the interior courtyard due to the sun's rays and the high temperature.

- Times from 8 p.m. to 11 p.m., 80% of users feel a thermal discomfort in the rooms (Figure 11 and Figure12).

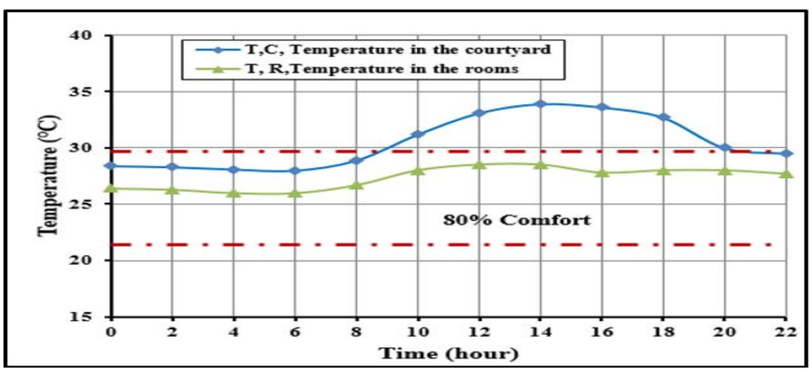

Figure 11. Diurnal temperature variation of indoor air of T.C. and TR. And the comfort limits

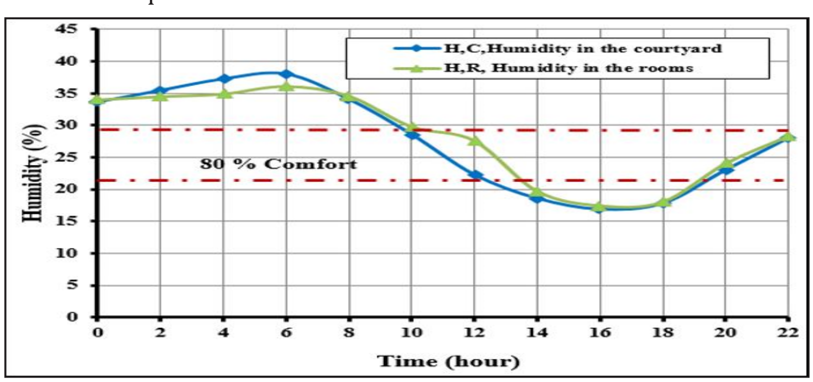

Figure 12. Diurnal relative humidity variation of indoor air of H.C.and H.R. and the comfort limits

This information is essential to best define the building technical systems that will ensure maximum comfort during all seasons.

Trees and climbing plants (Oliveira et al. 2011; Müller et al. 2014) are always used in the warm climate inside the building yard, because they are characterized by thick leaves, green color and cover the walls of buildings during the summer and spring seasons. These leaves fall in autumn and winter, leaving contact with solar radiation with the facades surrounding the building.

According to Rui et al (2019), the effect of cooling trees and plants climbs is important, especially in both habitat types. During the hottest period, the cooling effect of the plants increases, reducing the average surface temperature of adjacent walls. The effect of cooling near green areas during the high temperature period depends on the density and type of vegetation cover, leading to a reduction in temperature from 5 °C to 10 °C at the most warm time of 2 pm. Equations (3) and (4) can be deduced with a recommendation to better control the heat transfer for buildings:

ΔT = Average outside temperature - Average outside temperature of walls shading by vegetation (5 °C to 10 °C). (3)

Example of calculation of heat transfer by conductivity

$$\phi_{1-2} = \lambda S\,(T_1 - T_2)/e = (T_1 - T_2)/\,R_{th} \qquad (1)$$

T_1 will be replaced by:

$$T_1 = (T.a.out. - \Delta T) \qquad (4)$$

Where T.a.out. is average outside temperature.

It can be noted that the temperature used is reduced according to the variation of the vegetation density, which requires having an inventory of the species of plants by the calculation of the constant ΔT of each species to be used in the laws of heat transfer for buildings.

CONCLUSION

This article presents the main results obtained after a study based on an empirical survey (measurements made in situ in existing courtyard dwellings). The objective of the study is to evaluate the impact of vegetation on the thermal comfort of courtyard dwellings in a hot and arid climate. The measurements confirmed the importance of controlling the thermal properties of local building materials (stone and gypsum) in the exterior and interior walls of the building reduces the indoor temperature and creates acceptable conditions for the occupants, in particular at the level of the facade and its impact on the thermal behavior of the facade and the building. The use of green spaces near and on façades in hot arid areas resumes in the decrease of the surface temperature of the walls and the decrease of the ambient temperature, creating comfortable thermal environments for user's space area. Green spaces have a positive impact on the decrease of the ambient temperature in the interior spaces of courtyard dwellings; the thermal environment would be considerably improved. In addition, it is suggested to have an inventory of plant species by calculating the constant ΔT of each species for future use in the field of heat transfer for the buildings thermal comfort.

The results of this research demonstrate that these constructions can be considered as a guide for the design of modern architecture in hot and arid climates. These techniques will help reduce energy consumption and build environmentally friendly buildings.

This research gives new horizons for future investigations of new form of vegetation techniques as alternative materials of the walls and roofs design. These materials will be chosen according to it thermal quality, impact on indoor air quality and energy consumption.

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