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Impact of Orientation on the Thermal Performances in Vernacular Buildings in Hot Arid Climate

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***Abstract*: Morocco faces enormous climatic constraints. A large part of the national territory has a hot and dry climate, hence the importance of the climate aspect in the choice of an energy saving strategy. The use of reinterpreted, decontextualized, totally or partially vernacular architectural techniques and/or forms is visible at different levels in the Maghreb countries.**

The large-scale integration of this aspect seems to be ignored by the designers. The objective of this research is to evaluate the impact of the building orientation and vernacular architecture towards the occupant comfort, in order to meet its energy and comfort needs at a lower cost on one hand, and on the other hand, to design more efficient collective buildings from a thermal and energy point of view. The proposed methodology allows examining the thermal performances of a traditional building under the climatic conditions of the city of Rissani in order to naturally control comfort summer and winter, in addition to ensure a good thermal comfort without using any heating or cooling system. Finally, the simulations carried out lead to the identification of the optimal orientation that demonstrates an effective reduction in indoor temperatures and a decrease in the large daily fluctuations in these temperatures. The research focuses on the influence of the orientation of a building's facades in relation to the solar radiation and on providing the necessary thermal comfort.

***Keywords* : Vernacular architecture; buldingorientation; Ksour; ecological building materials; energy efficiency; thermal comfort; thermal dynamic simulation.**

I. INTRODUCTION

Today, the reality of the impending exhaustion of fossil resources is reviving the need to reflect on excessive energy consumption and its economic, ecological and environmental impacts on everything in the residential building sector, which is responsible for 30% to 40% of final energy consumption.

The residential sector in Morocco reached a consumption of nearly 6.5 million Tep representing 33% of national energy consumption [1].Morocco is undergoing an acute housing crisis in terms of in terms of thermal comfort that the developers and architects have often ignored and neglected.

With its geographic and climatic richness, Morocco is a pertinent example of scientific practices to adapt its urban landscape to its natural and human environments.The question of the fragmentation of earthen architecture has been a concern for many years, it is a question that has come to maturity as a result of the various actions of restoration, studies and inventories carried out in valley regions pre-Saharan countries of Morocco [19]. Building design, architecture and urban design, considered as the art cannot ignore environmental issues. Indeed, the architect, in hisactivity, must manage three main areas that relate to the environment: space, resources and living conditions [23].

Therefore, vernacular architectures, such as ksours and traditional medina-type houses, have always faced certain environmental and climatic challenges by perfectly adapting to the different climates: humid, semi-arid, arid and desert [2].

These architectures are defined as sustainable buildings that use local thermo-regulating materials such as unfired clay, stone and wood, thick walls and large flat roofs which create required inertia and good comfort inside.The effect of urban changes on the traditional culture was not taken into account, although the latter is a rich tool for sustainable building practices [3].The south Moroccan climate generates heating needs in winter and cooling needs in summer with heating design temperatures close to freezing point and summer temperatures of 35°C. Climate moderation itself makes it possible to satisfy almost all needs in a natural way, particularly in the residential sector [7].In this context, it is important to determine the influencing factors and their impact on the energy consumption of traditional buildings for hot and arid climate.The building thermal comfort related to energy savingis impacted by various factors, including the thermophysicalproperties of the building materials, ventilation, building orientation, building space distribution and integration of modern and passive energy saving technologies[26]. As mentioned by Givoni [4] the choice of building orientation is subject to many considerations; however the position of the facade in relation to the sun and wind affects the interior atmosphere. Confronted to this problem, the occupant will resort to mechanical means resulting in excessive energy consumption.

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Passive techniques, which are directly subject to climate variations, can induce uncomfortable and uncontrolled indoor environments, while systems allow for atmosphere control that can be adjusted at any time [5]. Passive techniques are essentially based on the integration of the building to its environmental ambient and then moves on to an architecture that integrates thenew technologies related to the production, transformation and distribution of energy to produce a large part or all of its heating from the sun [6].

Many research studieshave been carried out on vernacular architecture, but especially on the human sciences or social sciences. And very little in terms of sustainability, thermal and environmental engineering.Quellec et al [23] demonstrated that in the desert, the control of solar radiation is one of the major elements of urban and architectural choices in vernacular design.It is generally accepted that the technical processes used in vernacular architectural designs generate a comfortable internal atmosphere when the thermal difference with the exterior reaches about ten degrees [24].

Kazimee et al [25] sought to demonstrate the principles of vernacular design and technologies such as the sustainable performance of common homes and settlements in a case study of Nuristan's vernacular architecture in northeastern Afghanistan. Barozzi et al [8] provided an analysis of adaptable envelopes and shading sys ems implemented in contemporary architecture, with a review of various design methods and a brief examination of case studies.

Soflaei et al. [9] studied the social and economic environmental sustainability factors of contemporary courtyard houses in Iran and China. Dayaratne et al. [10] demonstrated that orientation in courtyard buildings is the main energy efficieny factors in vernacular architecture to boost thermal indoor comfort conditions in arid regions of Sri Lanka.. The present study is dedicated to the investigation of the envelope orientation in traditional bindings displaying the effects of Vernacular architecture on the thermal behavior and the building energy performancesbased on the variation of the outdoor temperatures.

II. METHODOLOGY

The Moroccan city of Rissani is chosen for its representativeness of semi-arid conditions in the south of the country. It is characterized by a hot and dry climate unfavorable to the achievement of thermal comfort during the summer. The choice of Rissani allows measuring the perception of comfort in traditional buildings.The buildings of this city has a built environment marked by an arbitrary, dispersed and fragmented orientation, which considers the quantities of energy to be consumed, the thermal comfort inside of these traditional buildings and the use of materials adapted to climatic requirements[21]. "Fig1" represent an overview of the chosen case study which isKsar El Fid, located some 4 km northeast of theRissani City, and is both the largest and oldest of the Alawi tafilaletksours.The ksar is a collective place for the inhabitants of the community of the raid and desert regions. It is also the traditional urban form in these areas, with fortified cities.

Fig.1. Overview of the Studied Building

The stability of the ksar is linked to the presence of water resources, a condition that emphasizes palm cultivation and the presence of large gardens: oases. These act as microclimates essential for human stability. The couple (Ksar-Oasis) also represents an ecosystem that allows occupation. From a morphological point of view, the ksar also appears as a harmonious compact shape, with the colors of clay, horizontal, directly linked to the green space that is the oasis. The function of the ksar is essentially agricultural.

A. *Description of the studied building*

The research deals with typical Ksar El Fida building samples in Rissani City which characterize by a light urban typology and represents a place of memory filled with invaluable cultural messages and reflects the image of community villages built of mud and mud bricks [19]."Fig. 2", shows a vernacular residential construction, in which eight buildings of similar architectural design are employed. Buildings are surrounded by an external enclosureof 3m of high to help escape the extreme temperatures [22]. The urban caracterstics of this type of building is characterized by a high degree of compactness, both vertical and horizontal, which exposes a minimal surface area to the sun and cold winter winds. Each building covers an area of 80 m² for a volume of 240 m²"fig 2''.

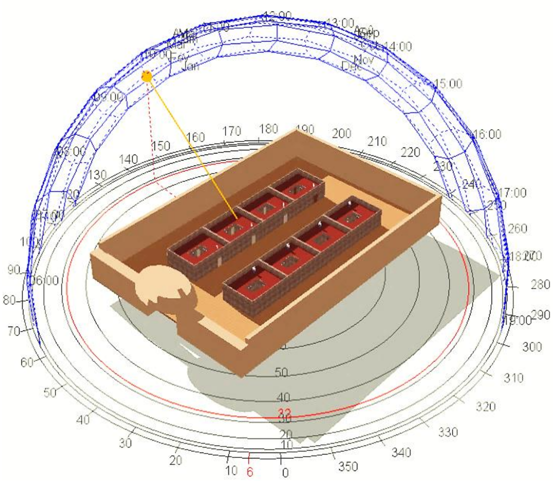

Fig.2. 3D View of the studied building

The buildings are built in the shape of a ground floor with a ceiling height of 3,03 m, the width of the windows (1,20 x 1,40) m according to the different building components..

This covers 17.46% of the façade exposed to the patio (32.34% of the floor surface) reflecting an open-air courtyard around which the various elements of the house are articled.Its design focus on providing temperature regulations and source of light and sun. The Patiorepresents fundamental space for the articulation of the different parts of the house, not only inside but also for the external terraces, accessible by masonry or wooden stairs [20]. With its trough-shaped configuration, the patio, around which the kitchen and bedrooms are built, is the ultimate protection of a private open space against extreme temperatures, dust-laden winds and sand storms [21].

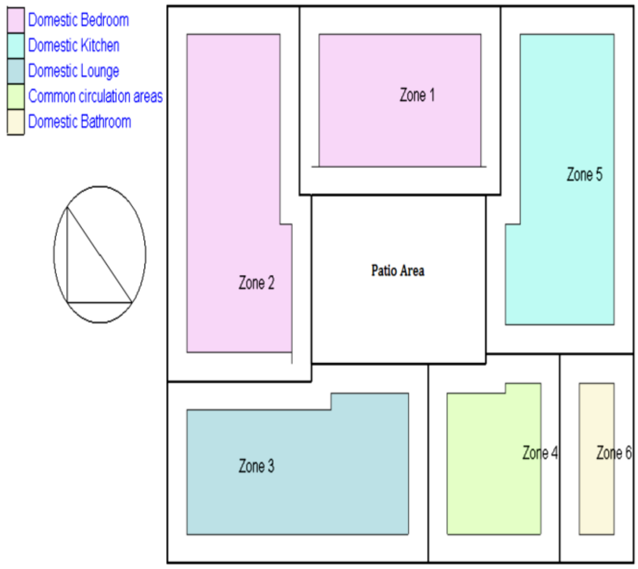

Fig.3. Spatial distribution of building

A wooden joinery typifies the windows, that its thermal properties have been identified previously in the work of Souihel et al.[32].The windows are characterized by simple glazing of 3cm in thickness. The spatial distribution of a typical building is represented in "Fig. 2".

B. Climate analysis of Rissani city

The Rissani City connected to Errachidia Province of Errachidia is situated in southeastern Morocco, 31 ° 55′53″ north latitude and 4 ° 25′35″ west longitude. It rises to 1039 m above sea level. The annual high temperatures vary from 28.5°C to 40°C.The climate of Errachidia province as presented in "Fig. 4" and "Fig.5"is a cold climate in winter and a hot and dry climate in summer. It is expressed by intense solar radiation, with very high temperatures in summer with a maximum average of 41.6°C during the month of August.The climate of this city is a favourable climate of around 18°C all year round with an average temperature range of 8°C and a low humidity level of 57.5% [11].

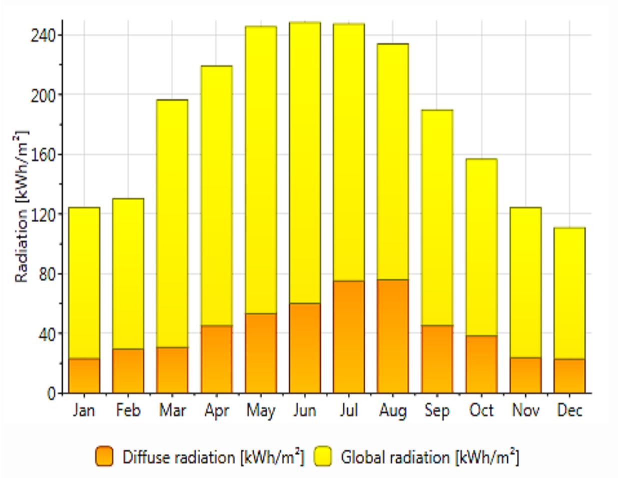

Fig.4. Global and diffuse Solar Irradiation of Errachidia Province

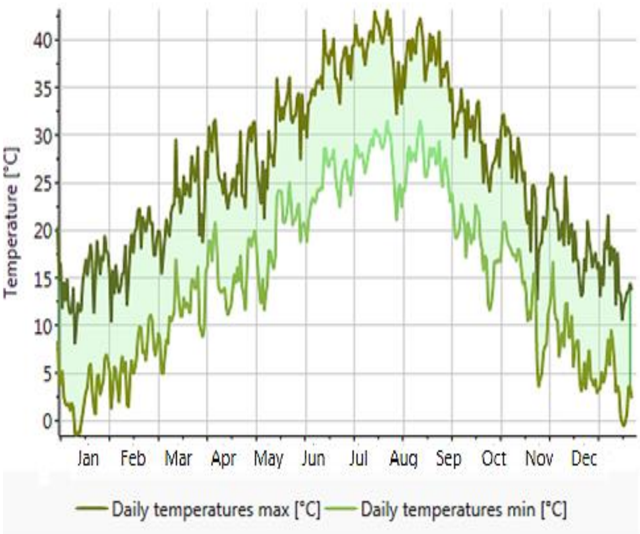

Fig.5. Outdoor daily temperature of Errachidia Province

C. Description of building envelope

The building envelope plays an important role of thermal separation between the interior and exterior environment, it acts as heat storage in the building and as a distributor of the interior and exterior air, wherefore the choice of construction materials is a major element in providing the necessary building energy efficiency. An efficient choice of construction materials significantly reduces the ambient temperatures inside building areas. Two key attributes, thermal resistance and heat capacity, depends on their thermal effects.The low floor (the slab) consists of a layer of stone with a thickness of 20 cm followed by 10 cm of compacted unfired clay [12] covered with tiles (the underlay is made of 2 cm thick lime mortar).

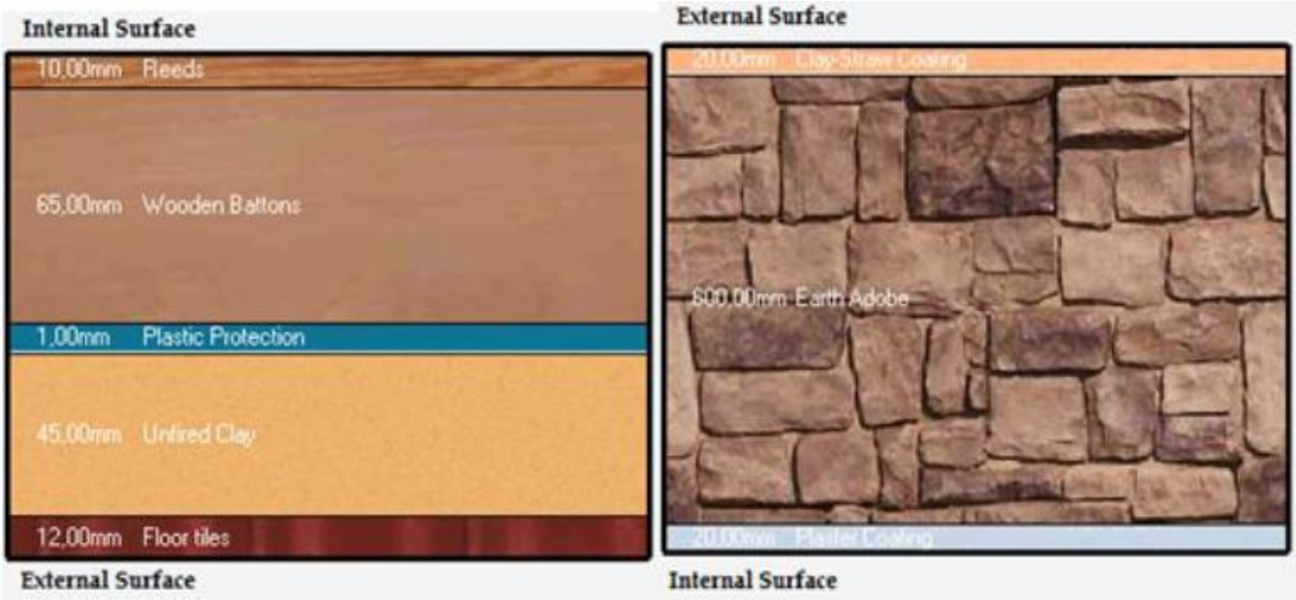

Fig.6. Description of external roof and external wall layers

Table- 1: Thermal characteristics of the building envelope

Component	Material	Thickness (cm)	Thermal Conductivity (W/m.K)	Density (Kg/m³)	Specific heat (J/Kg.K)
External wall	Gypsum Plaster	2	0,520	1196,3	772,7
	Unfired clay adobe	60	0,699	2097,2	920
	Coating clay straw	2	0,263	1544	595,6
Roof	Reeds	1	0,88	600	1256
	Wood	6,5	0,113	510	1380
	Plastic protection	0,1	0,2	1050	1500
	Unfired clay	4,5	0,58	1800	772
	Floor tiles	2	0,8	2000	800
Window	Simple Glazing	0,6	0,9	-	-
Door	Reed wood	3	0,15	650	2300

The exterior walls are in adobe of a thickness of 60 cm with an external coating composed with straw-clay and an internal plaster coating. Usedthermophysical properties include conductivity, k ($W.m^{-1}.°C^{-1}$density, p ($kg.m^{-3}$), and specific heat capacity C ($J\ kg^{-1}.°C^{-1}$), Such properties are time-dependent due to variations in material temperature and/or humidity and may depend on location or direction if the material is non-homogeneous or anisotropic.

Table 1 describes the different layers of materials that constitute each studied building's exterior roof and exterior wall. Recent experimental research studies have been conducted to determine the thermo-physical properties of the material used [13][14] [15] [16].

D. Parametrization of Thermal Dynamic Simulation:

The facade is considered as a fundamental initial element of the design. The building profits from two natural ventilation types, including horizontal ventilation created windows and vertical ventilation created by opening the building on the patio, which reflects an efficient natural ventilation system in arid areas, known for its capacity to maintain good breeze inside building and reduce heating during summer. The studied building has an opening window to ensure intensive ventilation. Common corridors and stairwells shall be ventilated by means of a natural evacuation opening of at least (0.5×vol. of the room (m^3/3600) m^2). The house corresponds to the type "patio house", i.e. courtyard house or summer-winter house, organized around a patio where the different rooms open. As shown in Figure 3, the openings are located on the interior facades of the Patio. The surface area of the façade openings is 3.88 m^2. With density occupancy of 0.14 pers/m^3, the natural ventilation rate including infiltration is about 36 m^3/h/ pers.There is no used system for heating or cooling. Based on their activity as shown in Fig.3, each building is splitted into six thermal zones. The average number of occupants per house reflecting the inhabitant occupancy equal to five persons.

Across all the different simulations, a defined energy consumption schedule is used, defined based on the typical culture and lifestyle for Moroccan residents (holidays, working hours, etc.). A simulation of thermal behaviour and thermal comfort was performed for each combination of evaluated parameters.

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The metabolic activity level is 1.5 puts from 08:00 to 23:00, and 1 puts from 23:00 to 08:00. The thermal resistance of clothing is equal to 0.5 clo (summer clothing) and a relative air velocity of 0.1 m/s.The air change rate is assumed to be 0.6 vol/h, it has been assumed that occupants open windows in the mornings and in the evenings after 6 pm.

The simulation tool used for this study is the Designbuilder System Simulation software, a simulation environment dedicated to calculating the thermal performance of multi-zone buildings and their equipment, as well as thermal systems in general [34]. Designbuilder has a modular architecture of new components and simulation problems in completely different areas using an energy simulation based on the EnergyPlusEngineering.Simulation software conducted using the Energy Plus interface (V.5.0.0.105).Designbuilder use several mathematical, multiple complex equation forms to accurately solve such a system and, since these equations represent strongly interrelated heat transfer processes, simultaneous solution techniques must be applied if the prediction of output is to be both reliable and to maintain the spatial and temporal integrity of the modeled system.

III. RESULTS AND DISCUSSION

The results and analyses of the simulated data are limited to:

- The evaluation of the indoor temperature in the study area;
- The impact of the building's orientation on the temperature of the indoor environment;
- The quantities of total solar radiation absorbed in multiple directions for the summer period;
- The quantities of total solar radiation absorbed in multiple directions for the winter period;

In order to determine the optimal orientation, an evaluation of the different orientations has been carried out by rotating the axis of orientation at an angle of 15° from the North. The heat balance of the part allows comparing the simulated results. Thus, any heat transfer between the living room and the outdoor climate must be compensated by the same amount of air conditioning and heating energy. Therefore, it is possible to obtain the necessary amount of energy for the air conditioning and heating needs of the different orientations to maintain a stable temperature within the living room and the comfort zone.

A. Impact of the Building orientation

The analysis of the results presented in Figures 5 and 6 illustrates the effect of the orientation of the exterior wall on indoor environments during the summer and winter periods, respectively. The influence of taking into account the change in orientation, which is most noticeable in the case of semi-central south-eastern, northeastern and south-western orientations, is more important. For example, while the north orientation allowed a 0.5°C drop in temperature compared to the south orientation, the difference between the wrong orientation and the best orientation in temperatures is 2°C, as shown in “Fig 7”.

On the other hand, the North and South orientations for the summer period are considered, the most favorable, contrary to the West and East orientations, which are to be avoided, given the temperature increases recorded over a 24-hour period.

“Fig. 8” shows that during the winter period, the impact of the orientation remains perceptible, especially for semi-cardinal orientations. The South-East orientation considered as the most favorable highest records in terms of temperatures. This is due to the fact that a large amount of energy is absorbed by the wall and window. Between 12:00 and 18:00 the average temperature of the stay-oriented South-West increases by about 2°C compared to the other two orientations (Northeast and Southeast) create a slight increase of about 1.05°C respectively for the Northeast orientation and 1.09°C for the Southeast orientation.

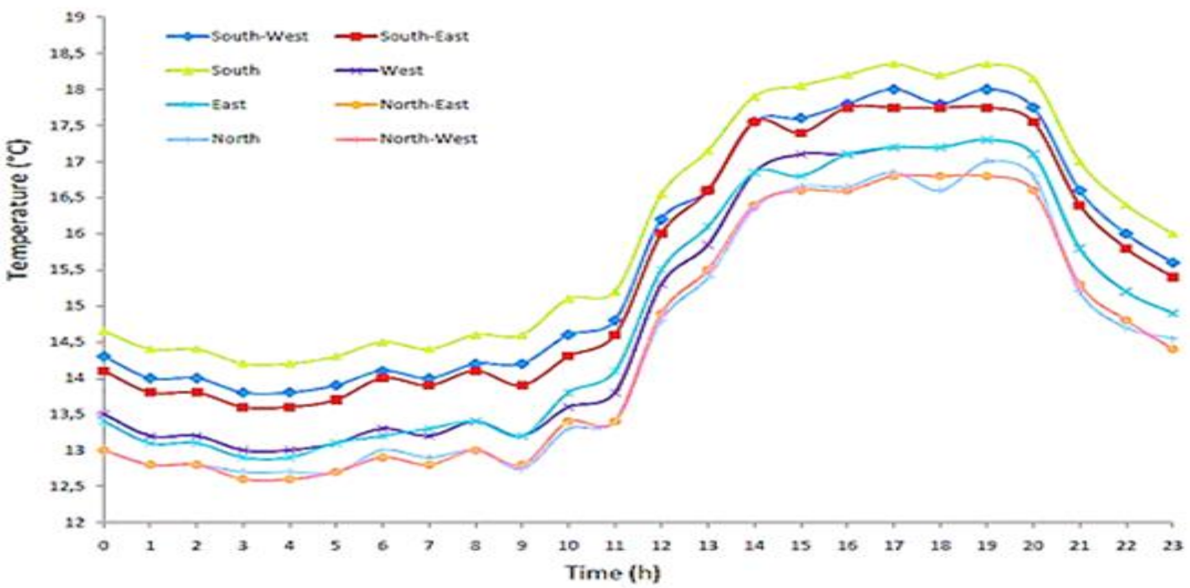

Fig.7. Comparison of modeled indoor temperatures of the different orientations during the winter period

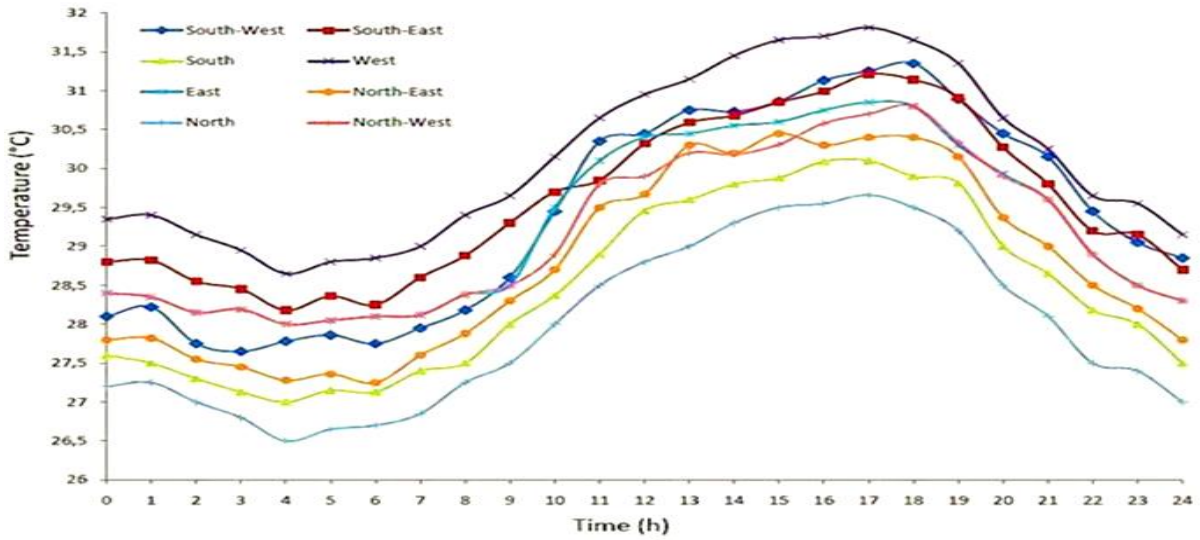

Fig.8. Comparison of modeled indoor temperatures of the different orientations during the summer period

Indeed, this strong increase in the temperature of the southwest facade is due to the fact that the effect of solar radiation in the afternoon that hits the facade at an angle closes to the vertical, the transmission of heat. The indoor atmosphere of each stay depends on the effect of orientation; these results have been verified by Syakubu et al. [17] and Borong et al. [30].

The average indoor temperature of buildings facing Northeast remains lower than the average indoor temperature of buildings facing southeast by about 2°C from 8:00 am to 12:00 pm; this is due to the effect of radiation on both orientations, the effect of the wind breeze from the Northeast and which contributes to this decrease.

However the duration of sunlight is reduced by about half compared to the Southeast orientation. For the average internal temperature of the southwest façade, it remains lower than that of the other two orientations of around 3°C during the morning period, which is explained by the total absence of solar radiation on this façade and by the effect of natural ventilation. This is in line with the results of B. GIVONI et al.[4] and Boussalh et al. [18] who confirms that the indoor temperature is largely determined by natural ventilation and the degree of efficiency of solar protection As for the South-East and South-West orientations, they are less favorable than the orientation South, with a temperaturedecrease compared of than those in the South which is automatically due to the sun's course, this permit them to be they are less exposed. However, the North, North-East and North-West orientations are avoided during this period due to the low temperatures that affect the degree of indoor comfort.

The results of the simulations, graphically represented, illustrate that it is possibleto know the influence of orientation and reflect the significant improvement in the conditions ofcomfort obtained, i.e. the decrease in temperatures during hot hours, which clearly appears on the curves of "Fig 7" and "Fig.8".Indeed the present investigation shows the role of the external enclosure on providing the necessary thermal comfort. The regulation of architectural design factors in relation to solar radiation, wind and shade contributes to the indoor thermal activity and produces a comfortable atmosphere [22]. Builders used temperature variations to obtain a good distribution of air in buildings. Because the houses were built around courtyard or central hall. When the interior courtyard is exposed to the sun, the weight of the warm air decreases and rises above the open interior courtyard, with cold air being drawn through the windows of the rooms to replace the warm air.

A.The optimal orientation

"Fig.9" shows the solar radiation absorbed by a wall for different orientations, where orientations, from 165 ° East to 195 ° West benefit from the contributions in summer after the full North. Contrary to the East and West orientation, which have the highest solar gains."Fig 10" illustrates solar radiation for moderately bright days absorbed by the wall for different orientations, where the orientations from 150° East to 195° West benefit from the most important energy inputs.

Therefore, the optimal orientation is the one that adapts more to the local climate, which permit to limit solar gains in order to reduce heating and cooling needs.The Comparison of the results for the different orientations of the corresponding facades with the range limits of the comfort zone, in particular those of the temperatures of Rissani City whose neutral temperature varies from 28°C to 34°C and relative humidity vary from 20% to 55%, shows that comfort temperatures are partially achieved. This depends on many criteria including: the orientation of the facade, the control of the sunlight, the external façade and the integration of bioclimatic devices. This coupling even reduces the energy requirements of an air-conditioned building and heating, as well as the maximum daily fluctuations recorded and ensure a good heat distribution in spaces in all seasons.

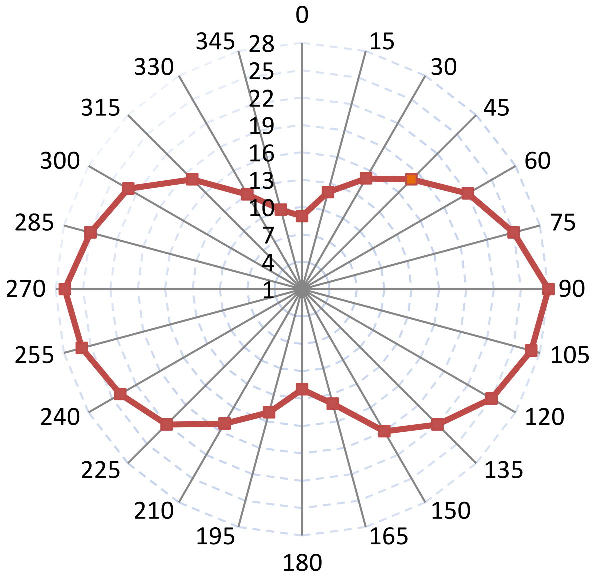

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Fig. 9. Total solar radiation absorbed in kWh/m^2 according to the orientation by the exterior wall during the summer period

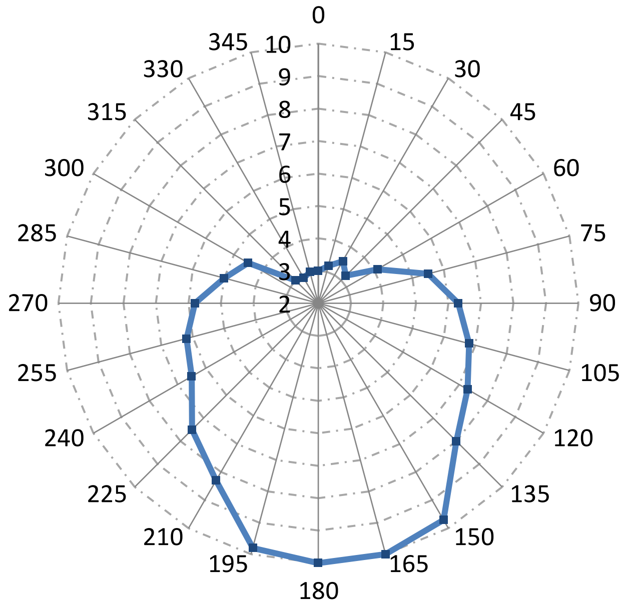

Fig. 10. Total solar radiation absorbed in kWh/m2 according to the orientation by the exterior wall during the winter period

IV. CONCLUSION

The objective of this study is to evaluate the evolution of temperature variations according to the choice of building materials, their insulation and the thermal comfort conditions of residential vernacular building located in arid hot regions.

The results of this research show that in vernacular architecture, climatic conditions can be a determining factor. Controlling the design factors of architecture in relation to solar radiation, wind and shade leads to the thermal activity of indoor spaces and provides a comfortable environment.

By their nature, thick earth walls protect against excessive external climatic conditions and contribute to a natural thermal regulation that, traditionally, ensures significant energy savings. To achieve this objective, an experimental and simulation investigation has been developed to study the thermal behaviour of a traditional building and verify the real impact of building orientation in vernacular architecture on the thermal performances. This study covered the most unfavorable period of the year, which is July, knowing that it takes three to four times more energy to cool spaces than to heat them. Finally, these results demonstrated the connection between the amounts of energy absorbed by the wall at interior temperature, which is closely dependent on orientation. According to the analysis carried out, the favorable orientation for controlling thermal comfort is the South for this type of climate. On the other hand, the north orientation should be avoided. As for the East and West orientations, the deficit is 43%.

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