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Individual Housing Thermal Comfort Evaluation in Hot and Arid Climate Area: A Comparative Study between Modern and Traditional Houses in Ouargla City

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Abstract

The design of residential buildings in general, and of individual houses in Algeria in particular, often has a negative impact on the energy consumption and the thermal needs of their habitants. Therefore, the realization of these modern and uncomfortable dwellings requires the attention and application of passive strategies to address thermal deficiencies and excessive energy consumption.

Native building materials used in the construction of traditional homes have proven to be an effective technique for energy conservation without compromising the comfort of the occupants. The most common building material for traditional houses in southeastern Algeria is stone. Several studies have shown the thermal, physical qualities of this material through the use of passive strategies.

This paper aims to evaluate the thermal comfort in the most popular house typologies in Ouargla city in the southern part of Algeria. This research presents a comparison study between the vernacular architecture represented by the heritage houses (ksar of ouargla) and the typical contemporary house, in terms of thermal performance. For this purpose, a research method based on a questionnaire and on-site measurements is applied to determine the thermal characteristics of each of the studied types.

The results show the dissatisfaction of the inhabitants regarding the comfort and the excessive energy consumption of the modern houses made of cement. In summer, the traditional stone house is by far the most effective means to cope with the heat problem, and it is shown that passive strategies are the best solution to create more comfortable and energy efficient houses.

Key words: houses, thermal comfort, energy, hot and arid climate, passive strategies, city of Ouargla.

INTRODUCTION

Algeria has recorded in recent years an increase in energy consumption, and this may influence the national economy in the future. Among the causes of this excess energy consumption, we find, in the first place, the problem of the deterioration of the habitat sector by the high consumption of energy (heating, cooling).This leads to an energy overload and can manifest as recurrent power outages. These types of problems are due to ignoring the energy sector and comfort during the design of a building.

Over the past 20 years, there has been an increased expansion of modern architecture, as part of the overall development of other sectors. This has been associated with a lack of awareness, among the country's various architects, to the use of modern building materials and systems without taking into account environmental and spatial considerations, climate, and its compatibility with the environment that surrounds them.

However, this is in contrast to vernacular architecture. According to empirical observations, vernacular architecture is the source of essential knowledge for sustainable architectural design principles [1].

In such traditional productions, It has been found that there is a direct correlation between thermal comfort and energy consumption in buildings [2]. This link is due to the effect of the climate and the environment on the habitat areas [3,4]. To this end, it is necessary to optimize and improve the exploitation of these climatic factors in order to achieve a better outcome in terms of energy conservation. Solar optimization on buildings is the subject of several researches and

reviews that show the effectiveness of using passive strategies and solar energy for comfort improvement in winter as well as in summer [5,6]. It can also be considered as a reliable and sustainable source of energy.

Understanding vernacular architecture should not be taken as a study of old traditions but as a contribution to new methods, solutions, and achievements for the future built environment [7,8].

In this perspective and among the works carried out, we cite

The study of the Ksar of Ouargla carried out by Sebti et al , are studied the architecture of the ksar of Ouargla with measurements and field observations, in order to understand the bioclimatic concept of adaptation, and to evaluate the thermal characteristics of urban microclimatic parameters such as (air velocity, relative humidity, and air temperature). It has been found that passive design solutions allow buildings to adapt more appropriately to their local climate and better take advantage of natural energy resources, such as sunlight, ventilation, materials and shading, to create a favorable indoor environment [9].

Khoukhi and Fezzioui, Assess the thermal comfort of modern houses; compared to the existing traditional housing using the TRNSYS software. According to the simulation results, the typical modern house appears unsuitable for the desert climate. Indeed, apart from the use of electric air-conditioning during the summer season, no solution can be suggested that can ensure thermal comfort in the ksar of Kendasa in southern Algeria [10].

according to chelghoum et al, Local building materials are more efficient in the arid climate because of their conductivity and thermal diffusivity. They exploited new and traditional building materials used in construction in Tamanrasset for the experimental study. The results proved the high thermal quality of traditional materials [11].

Oueld henia in her doctoral thesis on the optimization of building materials through the evaluation of thermal comfort by the simulation software TRNSYS. It operated three types of houses (modern -traditional-prototype) located in the city of Bou-saada. The goal was to highlight the strengths and weaknesses of each house. She confirmed that the modern house seems inappropriate to the desert climate and for the two other houses (prototype and traditional), in summer the traditional house remains by far the most effective to overcome the problem of heat; this proves that the inertia plays a great role in summer. On the other hand, in winter, the prototype is tighter to the cold; this is related to the insulation of the walls [12].

In summary, the objective of this research attempts to assess the applicability of the principles of vernacular architecture in contemporary buildings as a construction technique. The study compares vernacular Ouargli architecture with contemporary architecture, in order to improve interior thermal conditions by evaluating different microclimatic parameters, such as (air velocity, relative humidity, air temperature), in the seasons hot and cold separately from the year 2019, as well as to make a subjective comparative analysis of the thermal environment between the occupants of two typologies of houses; the traditional and the modern.

Presentation of the Case Study

The city of Ouargla is located at an altitude of 128 meters, 190 km east of Ghardaïa, 160 km southwest of Touggourt, 388 km south of Biskra. It is populated by 210,175 inhabitants [13]. Figure 1.

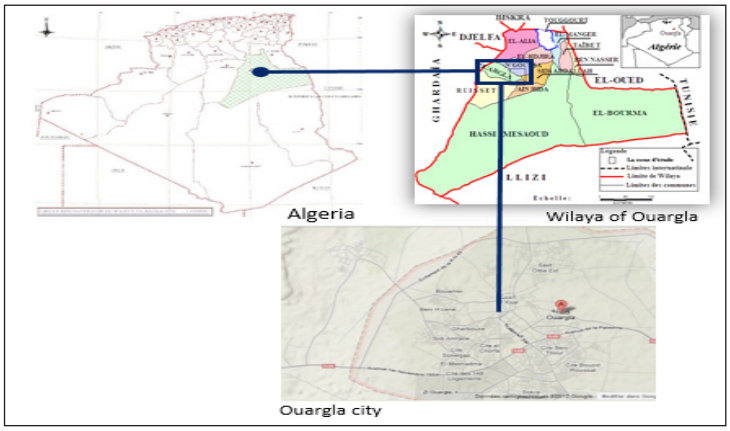


Figure 1. Location map shows the administrative boundaries of the wilaya of Ouargla. Source: PDAU Ouargla 2020 and Google image 2020.

Ouargla has a hot desert climate (Köppen BWh classification). Ouargla is the first city in the Sahara desert to have a tramway .The region where the wilaya of Ouargla is located is characterized by an arid climate presented by two main seasons very hot in summer with a maximum average temperature of 42.8 °C in July and a minimum average temperature of 4.4 °C in January.

The humidity measurement limits throughout the year vary between 24-62%. The wind blows frequently in this region in winter are the winds from the West, while in spring it is the Northeast and West winds that dominate, in summer they blow from the Northeast and Southwest. The average annual speed Vmoy = 3.70 m/s. the sun is present almost in every day of the year with a clear sky, this factor is considered as economic advantage especially for renewable energy (solar energy). The wilaya of Ouargla is characterized by a Saharan climate, with very low rainfall, high temperatures, high evaporation and a weak biological life of the ecosystem.

Description of Models of Study

Several studies show the impact of housing typologies on indoor thermal conditions and energy efficiency [10,12]. And for these measures to be more meaningful, we seek a type of habitat through a typological analysis of the urban fabrics of the city of Ouargla. According to the fabric and the study, two types of habitat have been marked: traditional habitat and modern habitat . Figure 3. The reference houses chosen in this study represent a large part of the residential dwellings of the arid region, in particular of the city of Ouargla. Figure 2.

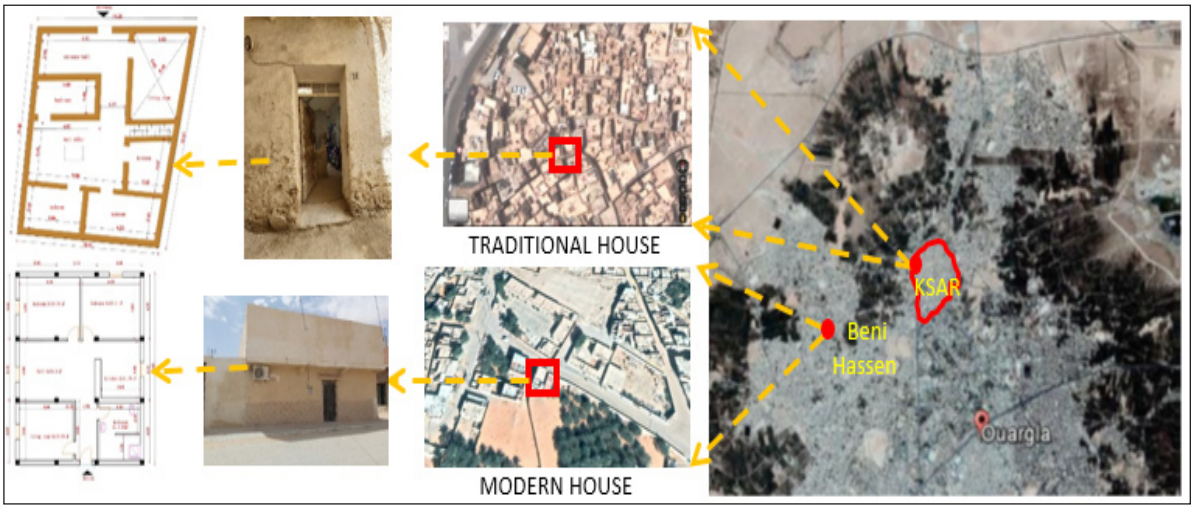


Figure 2. Location of the study models. Source: author

a. Old type **b**. New type

Figure 3. New and Old type of buildings in Ouargla. Source: Author.

The Typology of Traditional House

Location and Area

The traditional residence chosen for the study is located in the district of Bani Ibrahim, north-west of Ksar Ouargla, on an area of 131.36 m2. It is on the ground floor, which contains a hall, a living room, a kitchen, a bathroom and an accessible terrace. Table 1.

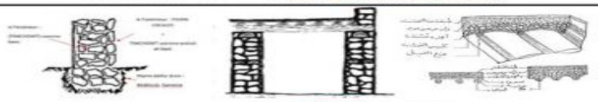
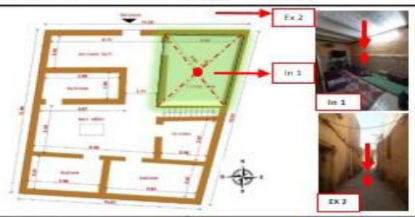
Case study	Traditional house	
situation		
Presents sketches of the construction techniques (a) foundation, (c) floor, (b) load-bearing wall, of the traditional Ksar house and the materials that compose it.		
The location of the measurement points		
Elements description of case study	Orientation Floor Height Total Floors Built Area Window–Wall (W–W) Ratio Exterior Walls Adjacent wall Exterior roof Grand floor Finish Color Glazing Shading	East–west 2.70 m 1 131.36 m2 2.83% 0.02 m Temchemt, 0.5 m Stone , 0.02 m Temchemt. U-value: 0.461 W/m2_K 0.02 m Temchemt, 0.5 m Stone, 0.02 m Temchemt. U-value: 0.461 W/m2_K 0.020 m Temchemt, 0.120 m compacted soil, 0.240 m pierre, 0.020 m Temchemt U value:0.742 W/m2_K 0.020 m Tiling, 0.050 m Cement coating, 0.200 m Concret, 0.005 m compacted soil. U value:2.925 W/m2_K Beige Simple glazed-U value:5.74 W/m2_K None

Table 1. Ground plan according to (POS Ksar Ouargla and image from Google Earth 2020), plan of the apartment with the representation of the studied areas, construction technique of the modern house, source, author 2019.

Construction Materials and Techniques

The load-bearing walls made of stone and temchemt carry the ceiling made up of different materials: an upper layer of timchemt used as an exterior coating; a layer of compacted earth followed by a thick layer of local stones mixed with timchemt as a binder;

Another layer of timchemt as exterior plaster; and finally the trunks of palm trees used as transverse load-bearing beams, and all these materials are the best known in the world for their thermal properties, wide availability and low cost [14].

The traditional house of the ksar of Ouargla is characterized by an introverted architectural organization around a main and important central core, which is wast-eddar [15].

The natural lighting system of the traditional houses of the Ksar is achieved thanks to the presence of openings at the level of the upper floors above WAST-EDDAR. The latter constitutes the source of all the architectural spaces that make up the traditional house. This opening also allows the inhabitants of the traditional house to have ventilation, which helps to balance the humidity in the rooms. "KSAR" houses while also ensuring the preservation of materials [16]. Figure4.

During the day, building materials reduce the magnitude of thermal radiation inside the window, which can soften the atmosphere inside. The reverse process takes place during the night when the radiation thermal flows outward to cool the inside in the early hours of the day. Local building materials have a high thermal insulation coefficient. This is an indication of its effectiveness against the prevailing climatic conditions [16,17].Figure 5.

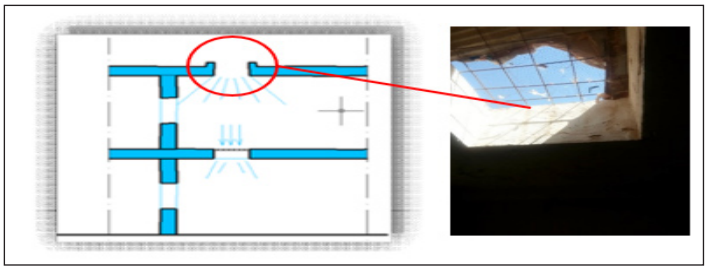


Figure 4. View on the zenithal lighting overlooking Wast-Eddar.of the traditional house of the old KSAR. Source: Author and PPSMVSS.

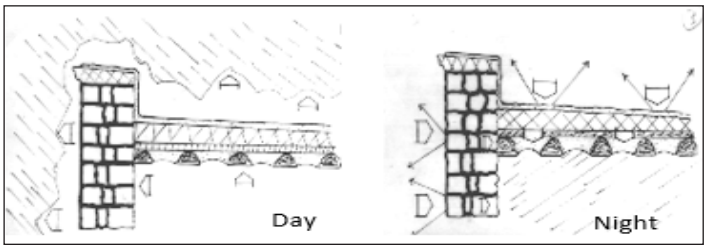


Figure 5. Schematic sketch illustrating the behavior of the building materials that make up the floor and the wall of the traditional Ksar house during the day and night. Source : PPSMVSS

The Typology of Modern Houses

Location and Area

The modern house chosen as a case study is located in the city of Ouargla in the district of Beni Hassen. A prototype house was developed based on the survey. The model is a single-family detached house. The house mainly has a living room for guests and a kitchen on the ground floor, as well as private areas. The house also has a typical Ouarglian house layout of architectural elements (doors and windows), as seen in the Table 2.This type of house represents 50% of the Ouargla housing stock.

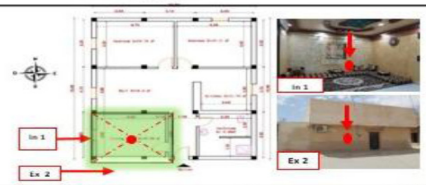
Case study	Modern house	
Situation		
Presents sketches of the construction techniques (a) foundation, (b) load-bearing wall, (c) floor, of the modern house and the materials that compose it.		
The location of the measurement points		
Elements description of case study	Orientation Floor Height Total Floors Built Area Window–Wall (W–W) Ratio Exterior Walls Adjacent wall Exterior roof Grand floor Finish Color Glazing Shading	East–west 3 m 1 430 m² 6.35% 0.01 m Cement coating , 0.1 m Hollow brick, 0.05 m Air gap, 0.15 m Hollow brick, 0.020 m Plaster coating. U-value: 0.765 W/m2.K 0.02 m Cement coating, 0.15 m Hollow brick,0.02 m Plaster coating. U-value: 1.661 W/m2.K 0.020 m Plaster coating, 0.16 m Concrete slab,0.040 m concrete, 0.100 m per 03 screed. U value:1.459 W/m2.K 0.020 m Tiling, 0.050 m Mortar, 0.200 m Concrete, 0.005 m compacted soil. U value:2.925 W/m2.K Beige-yellow Simple glazed-U value:5.74 W/m2_K None

Table 2. Ground plan according to (POS Beni Hassen Ouargla and image of Google Earthe 2020), plan of the apartment with the representation of the studied areas, photos of main facade, living room, construction technique of the modern house, source, author 2019

Construction Materials and Techniques

Construction materials and techniques: The materials used in the current construction such as concrete, cinder block and glass, are characterized by poor thermo physical properties with respect to the intense solar radiation that characterizes the region [18].The wall and the roofs with weak thermal inertia not having important insulating characteristics constitute a surface of absorption to the solar radiation [11].

Comparison of Typologies: Comparison of Traditional Vs. Contemporary Analysis

The analysis of the typologies of the traditional and contemporary house shows a variety of characteristics of which a synthesis of comparison enables us to evaluate the various advantages and disadvantages. Such a comparison participates in channeling the study towards its stated objectives. The following [Table 3] offers the different characteristics of each typology [19].

Table 3. Presents a comparison of the elements that contribute positively to the different passive design strategies for residential buildings in the two typologies (kolokotroni, 1985) re-adapted by the author 2019.

Appearance/ Criteria of houses	Traditional House	Modern House
Building shape and massing	-Curved and vaulted roofs -Flat roof -Compact form with courtyard,vault,dome -Shortages of services	-Planning is not compact -No-courtyard -Zonning problems -Flat roofs
Site and implantation groupement	Groupement compacte	-Individual houses -Collective dwellings -Semi collective dwellings
Position/ spaciale occupation patterns/ spatial planning	-Daily nomadism -Zenithal opening	Unchanged in the residential building
Envelope (architectural design)	-Ability to accumulate heat -Buffer spaces -small opening -Massive materials (thermal mass) -Local material (toub,temchemet,palm) -No balcony	-Window to wall ration <50% -No insulation -Small balconies(external solar shading) -Modern material (reinforced concrete)
Thermal performance	-Satisfactory during both summer and winter and at all times	-unsatisfactory during the times of overheating and under heating
Non-thermal comfort problems	-Necessity of annual maintenance -Shortages of services -Shortages in natural - lighting and ventilation -Inaccessibility in case of emergency	-Weathering problems -No adequate building regulations -High influence of the building contractors -Acoustic problems
Demand	Decreasing because of being not suitable for contemporary urban life	Increasing because of social and economic changes and contemporary life

METHODOLOGY

The investigation was based on two methods: one objective and the other subjective [20]. The first results in a companion of in situ measurements of the physical parameters in the most widespread typologies of houses in Ouargla. On the other hand, we pushed this research by a qualitative approach by using a questionnaire in order to evaluate the thermal environment felt by the occupants. Figure 6.

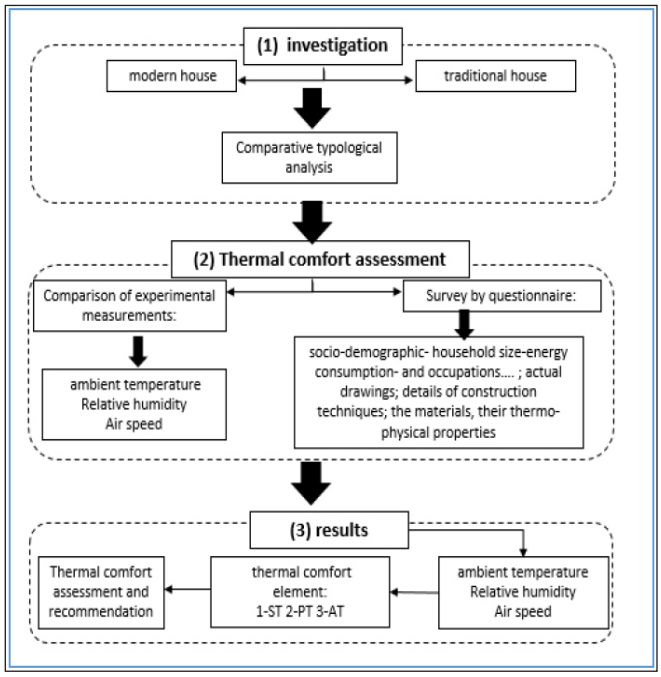


Figure 6. Graphical of the proposed methodology. Source : Author.

Quantitative Research

Comparison of Experimental Measurements

Two measurement campaigns for data acquisition were carried out during the summer period and the winter period, the purpose of which was to measure the microclimatic parameters.

1-Environmental temperature 2- Humidity 3-Air Velocity. Inside and outside the houses studied, using a testo 480 multifunction thermometer – AG 501 1ST, 0563 4800 . Figure 7.

Figure 7. Equipment used in the measurement campaigns Testo 480 Source: Author, 2020.

The measurements were carried out during the year 2019. The measurement campaigns in the summer period were from July 28 to July 30. And for The dates of the measurement campaigns in the winter period, they were from the first to the third of January. The measurement schedule lasts from 7 in the morning until 8 in the evening. The measurements are taken in the middle of the living room, and outside the houses. The relative humidity and temperature probe at a height of 1.20 m, The air speed probe at a height of 1.70 m [20].

(The location of the measurement points is shown in Tables 1 and 2).

Qualitative Study

Survey by Questionnaire

A survey questionnaire was completed to collect input data from the occupants of the house, and a semi-structured interview was conducted with the head of the household to obtain more details on the various inputs needed to improve occupant adaptation and thermal satisfaction. The survey was conducted at the same time as the on-site measurements were taken for the two types of houses chosen. The questionnaire is divided into 2 parts, as Table 4 and Table 5 shows.

Table 4. Elements of the questionnaire of the occupants and their thermal comfort ,Source author, 2020.

The 1st part: included information related to the occupants and the characteristics of the houses studied
personal characteristics of the occupants of the houses: socio-demographic; the size of the household; building materials; energy consumption; and occupations; actual drawings; details of construction techniques; the materials, their thermo-physical properties
Part 2: included information related to thermal comfort in summer and winter
Clothing, activity, type of food, and adaptive behavior. Thermal comfort and occupant behavior. Thermal sensation (TS): very cold–cold–slightly cold–neutral–slightly hot–hot–very hot Thermal sensation (TS): very uncomfortable-uncomfortable-slightly uncomfortable- slightly comfortable -comfortable-very comfortable Thermal Acceptability (TA): Unacceptable-Acceptable. Thermal preference (TP): much warmer- a little warmer- no change- a little colder- much colder.

Table 5. Occupant questionnaire and comfort indicators ,Source author, 2020

Type of house	Modern house	Traditional house
Clothing level (clo)	1.5	1.5
Metabolic rate (met)	1.2	1.2
Number of subjects	7	6
Number of houses	01	01
Survey time	January (winter), July (summer) the months of 2019	
Respondent age		
< 25 years	04	03
36-45 years	01	
> 45 years	02	03
Respondent gender		
male	03	03
female	04	03

RESULTS AND DISCUSSION

Experimental Measurements

Air Temperature

According to Table 6, We find that the temperatures measured outside and inside were very hot during the summer and cold during the winter for the modern house compared to the traditional house, for an average temperature difference of 1.08°C to 12.03°C. The maximum value of room temperature is recorded in the modern house; for this typology is visibly unsuited to the hot and arid climate.

In conclusion, it appears that the highest indoor temperatures are recorded in the modern house typology with low thermal resistance materials such as hollow and solid blocks. On the other hand, the traditional house typology gives results that are more interesting from the point of view of thermal comfort in the summer period. Note that the measured ambient temperatures also depend on other factors such as orientation and external climatic fluctuations.

Table 6. The exterior and interior environmental measures and the perceptions of thermal comfort were recorded in the two typologies of houses in Ouargla, Algeria, Source author, 2020

Period	Winter (January 1, 2,3.2019)						Summer (July 28, 29,30.2019)					
Typology	Modern house			Traditional house			Modern house			Traditional house		
variable	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
T(c°) out	10.15	14.00	6.22	11.58	13.22	10.0	37.23	42.7	28.1	26.85	32.14	21.2
H (%) out	53.01	73.00	36.00	38.90	53	26.7	31.41	40.00	26.20	36.23	39.10	34.20
T(c°) ins	14.22	20.50	7.00	20.60	22.15	19.85	28.72	32.00	23.00	19.69	20.20	19.08
H (%) ins	65.62	83.34	51.00	40.44	41.80	33.90	26.07	41.50	20.20	32.6	35.60	30.2
V air out (m/s)	3.61	6.12	0.00	1.63	2.80	0.40	4.11	7.78	0.00	1.19	2.70	0.15

Relative Humidity

Based on the measurements, we can conclude that the outdoor relative humidity is lower than the indoor relative humidity: outside, it ranges between 73% and 26.7%, while indoors, it ranges between 83.34% and 33.90% in the winter and between 41.50% and 20.20% in the summer. These results can be explained by the metabolism of human vapors and domestic activities as well as the lack of ventilation in the house.

Air Speed

The air speed is an essential climatic factor to be analyze because natural ventilation contributes positively to cooling [21]. According to the reading of the results in the measurement table 6, On the other hand, we note that the value of the air speed inside the living rooms of the houses studied is zero during the day studied, due to the absence of a draft. The speed of the air measured outside in the different typologies tested, does not exceed 7.78 m/s**.**

Survey by Questionnaire

In Figure 8, we notice that there is a difference in thermal satisfaction between modern housing and traditional housing for the summer and winter periods where:

- During summer most users of modern homes find it very hot and uncomfortable, however most users of traditional homes find it soft and comfortable.
- During winter most modern home users find it cold and uncomfortable, however most traditional home users find it soft or slightly warm and comfortable.

The difference in the thermal sensation between the two types of housing is explained by several factors, namely: the urban fabric, building materials, and the living room exposure.

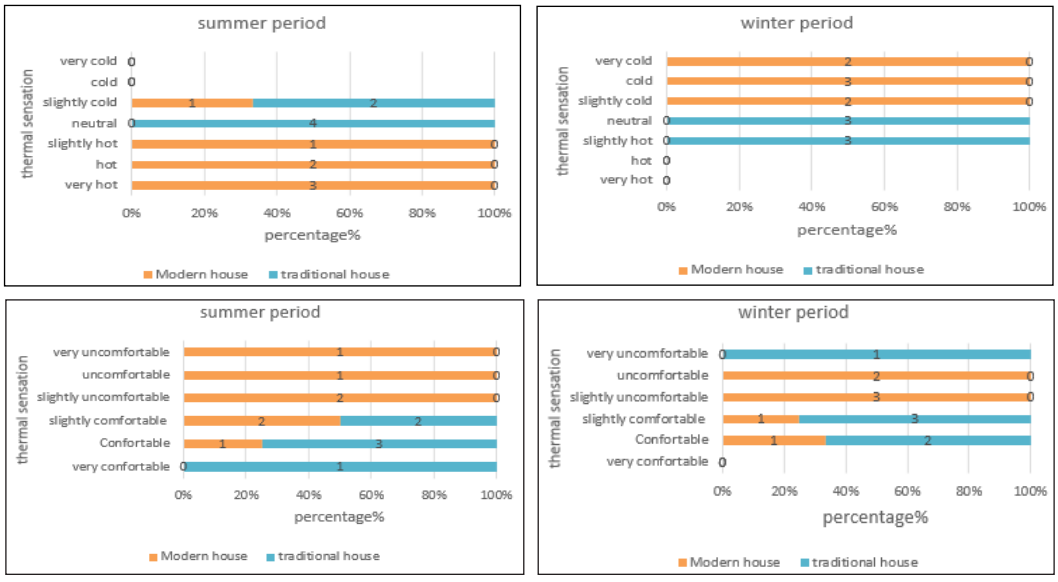


Figure 8. Breakdown of thermal sensation votes Source: Author.

In Figure 9, it can be seen that for the summer and winter periods, users of traditional houses generally prefer no change in the thermal environment, compared to users of modern houses, who prefer it to be colder during summer and warmer in winter, and in the traditional house they find the atmosphere acceptable. On the other hand, in modern houses, users find it unacceptable.

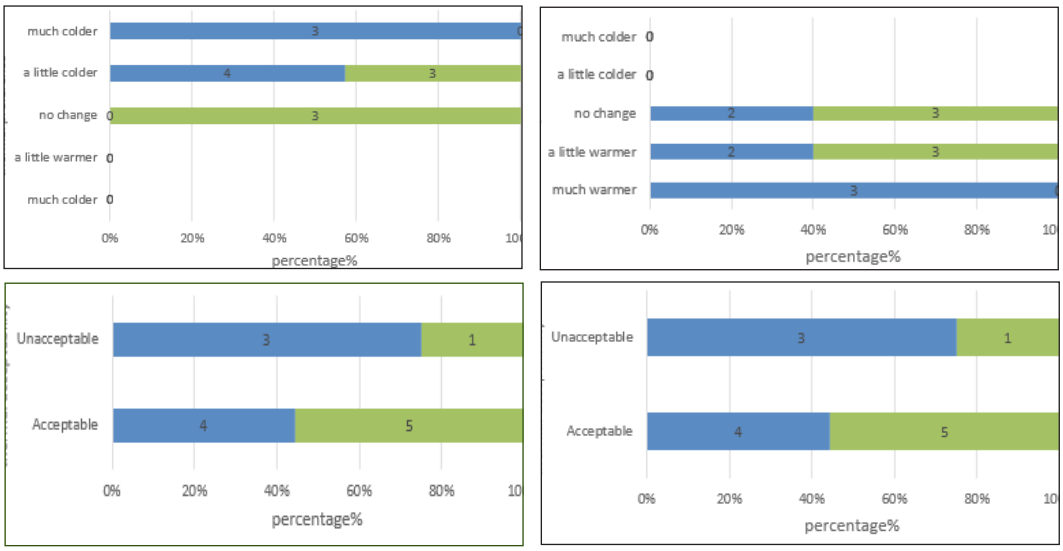


Figure 9. Distribution of thermal preference and thermal acceptability votes Source: Author.

CONCLUSION AND RECOMMENDATION

The purpose of this study is to assess the climatic adaptation level of both traditional and modern habitats. In previous studies, it was found that modern typical housings were inappropriate for arid and hot desert areas,, and in the summer, traditional houses remain the most efficient at the heat problem for both types of building materials tested (rocks with Temchemt and concrete block). Traditional architecture designed by ancient architects has as a primary purpose to provide solution for the human comfort and the harnessing of natural energies in simple and optimal ways.

The developed methodology has shown that the modern house suffers from overheating. Since they do not adhere to the basic principles of sustainable design in terms of choice of materials and number of design elements, whereas older housing units turned out to be much better than the modern ones. Their layout is characterized by a high level of compactness, with the rooms opening onto a central courtyard. This layout makes use of natural ventilation through the courtyard and the minimization of exposed exterior surfaces, which contributes to the passive cooling strategy.

The other important feature of traditional housing is the building envelope. The use of a nearly blind facade, except for a few small openings, reduces heat gain and guarantees privacy. The use of locally sourced materials is another feature of the envelope. In the case of the « ksar » of ouargla, the materials used are wood (from palm trees), natural fibers and straw, combined with earth for the construction of roofs. Both temchemt and stone are used for walls, floors and foundations. These materials provide thermal mass, essential to the passive cooling strategy.

This study confirms that future researchers will go further to develop and apply strategies in their interventions for designing and carrying out projects in general and those of housing in particular in order to ensure maximum comfort throughout the year to the occupants and at the same time minimize energy consumption.

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Conflicts of Interest: The authors declare no conflict of interest.

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