

THERMAL COMFORT STUDIES ON HOUSES IN HOT ARID CLIMATES

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Abstract. The traditional houses in Ghardaia City in Algeria had been built using traditional construction materials and passive solar design (PSD) strategies for the hot desert climate. These thousand-year-old houses are still standing and conditioning the harsh desert climate while maintaining indoor thermal comfort for its occupants. Of late, two trends of modern housing and construction were observed to have evolved in Ghardaia. Firstly, were the modern houses (Mod.H) following the international style and secondly, the eco-friendly houses (Eco.H), modern houses but utilising passive solar design. The Mod.H was observed to implement some of the traditional features but using the modern construction material. Meanwhile, the Eco.H modified the characteristics of the traditional construction and materials carefully in a modern context. Analyses were conducted to investigate the thermal performances of the three house designs. The intention was to ascertain the best construction that can achieve and maintain thermal comfort according to ANSI-ASHRAE 2014, in this harsh desert climate. Based on the Trad.H model, comfort data the two more modern houses were also monitored. Data collection was carried out in July, which was one of the hottest months. The study indicated that passive solar techniques employed in the Trad.H were able to maintain the comfortable indoor environment for the occupants without any mechanical aid. The indoor temperature of the Eco.H was 3 to 9 °C higher, and the Mod.H difference was 5 to 9°C above the thermal comfort zone. The study ascertained that designs of buildings with traditional construction and material played a significant role in moderating the indoor environment when the outdoor climate of the Algerian desert was unbearable. Inadvertently, energy for cooling was saved creating a significant impact not only on the economy both at the national and global level, but on the environmental scale as well.

Keywords: Thermal comfort, Passive Design Strategies, Ghardaia, Traditional houses, Eco-friendly houses, Modern houses, hot desert climate.

1. Introduction

The issues of thermal comfort have become a global point of interest to many researchers around the world. This fact is attributed to the realisation that people are spending most of their time (more than 90%) in an indoor environment (Lee & Chang, 2000). Passive methods of achieving thermal comfort in buildings in several countries have been commonly investigated (Sharples & Malama, 1997). These passive methods are the solution to provide the comfort of the indoor environment, healthy lifestyle and energy efficiency (Hegde & Ananthakrishna, 2008). Thermal comfort is considered an essential and necessary aspect in the urban sector especially in the desert climate where the outdoor temperature reaches 50oC in the summer season and freezing point during winter. Diurnal swings of 15-20oC or more are common with minima often reaching below 15oC. Under these climatic conditions, the ability to store



energy is a vital strategy for controlling and improving the building microclimate and lowering energy demand weighing on the infrastructure. The thermal mass strategy is highly recommended to maintain thermal comfort in this regions, and this is the characteristic of the unique fortified human settlement of the Algerian desert (Chabi & Dahli, 2014).

This paper attempted to look for an explanation of the little known “Ksar” (plural is Ksour), a fortified human settlement in the desert - on its traditional design and passive solar design in Ghardaia city in the middle of Algeria. Houses are packed tightly together to protect against the extreme climate, and these designs have stood the test of time for over a thousand years (O.P.V.M Ghardaia, 2014). However, in recent years modern house designs and construction were on the increase compromising the traditional designs. In the interest of thermal comfort, the paper compares the thermal performances of these unique houses. The first was a traditional house (Trad.H) build around the 11th century. The other two houses: the modern house (Mod.H) and the ecological house (Eco.H) were more recently developed, after 2000.

2. Aim and Objectives

This research aimed to investigate the thermal performances of the two contemporary houses about the Trad.H's. The objectives were to determine whether the Eco.H or the Mod.H with contemporary designs provided better indoor thermal comfort in the context of the summer season. Another objective was whether these houses required any improvements to be taken as a good model for the future construction in Algerian desert cities.

3. Ghardaia at a Glance

Ghardaia is located in the centre of the northern part of the Algerian desert. It is situated 600 km south of the capital Algiers between 32° Northern latitude and 2°30' Eastern longitude. The climate of the Ghardaia city is a hot desert climate characterised by summers with torrid heats reaching 50°C and soft winters with the average minimum just above freezing point. Relative humidity is very low except for the winter months where 60% is common. Precipitation is low and less than 25 mm throughout the year. The thermal comfort zone (TCZ) for the hot and arid climate of Algeria as according to ASHRAE 55-2014 standards is $18^{\circ}\text{C} < T < 30^{\circ}\text{C}$.

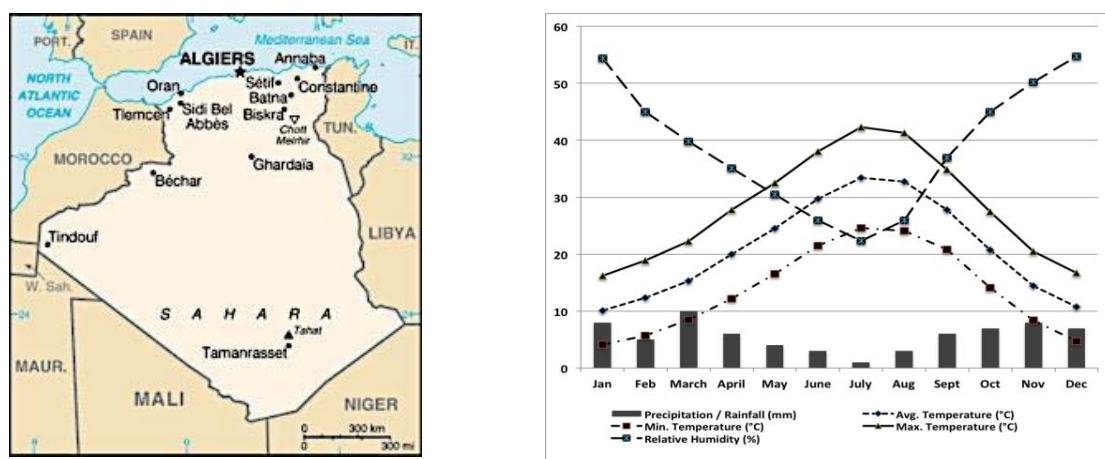


Figure 1: The location and climate of Ghardaia, Algeria
Source: Britannica.com

Due to the intense heat in the dry desert the desert cities in Algeria and also North Africa are defined by a grouped habitat called “Ksar”. The fortified morphology of the Ksar reiterated the historical need to protect itself from external threats and to cope with climatic conditions. The Ksar is an agglomeration of

very tight houses usually surrounding a mosque in the center and fortified. The number of houses in one *Ksar* may exceed 1000 houses (Bisson, 1957). Some literature relates that once the population growth exceeds the capacities of the mosque, it is necessary to build another *Ksar* and a new city around it, as shown in Figure 2.

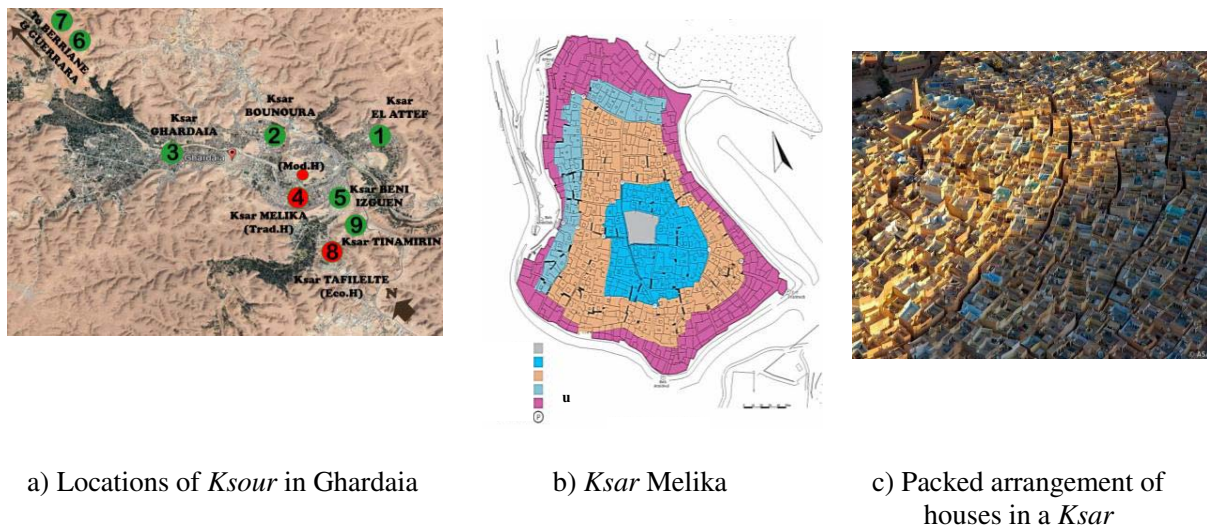


Figure 2: *Ksar/Ksour* in Ghardaia city, Algeria

4. Passive Design Strategies (Pds) and Thermal Comfort

In achieving thermal comfort in the hot desert climate, Szokolay (2014) recommended several passive design strategies. Amongst them are the use of thermal mass to condition the internal environments. Thermal mass is equivalent to thermal capacitance or heat capacity, i.e., the ability of a body to store thermal energy. When outside temperatures are fluctuating throughout the day, a large thermal mass within the insulated portion of a house can serve to moderate the daily temperature fluctuations. The traditional design of the houses in a *Ksar* uses this PDS to its fullest. Not only were the houses built with stones and clay at least 500mm thick for the envelope, as far as possible only the entrance façade is exposed, if not shaded by neighbouring buildings across narrow alleys.

5. Traditional House Construction

The traditional case-study house (Trad.H) in *Ksar Melika* was designed based on this PDS principle. The house consisted of 3 to 4 rooms grouped around an open court called *Wast-eddar* (centre of the house). It is the central space that organises the dwelling and the primary means of daylight into the house within the densely packed residential of a *Ksar* (Chabi & Dahli, 2014). By its form and position, it regulates the organisation of the whole dwelling, as well as its functioning. *Wast-eddar* is the most active space in the house and in addition to its roles, it ensures aeration and lighting throughout the home by the skylight grill called the '*Chebek*'. All other main rooms (entrance, living, dining and kitchen) are in direct relation with *Wast-eddar*. A superposition of the *Wast-eddar* has the effect of reducing the radiant heat inside the house in the summer, by covering it with cloth or canvas. As for the functional top terrace on the roof, it was reserved for women and used for sleeping at night. The terrace was a flat and heavy slab, allowing the reduction of heat transfer into the house (Ali-Toudert, et al., 2005). Other climatic integration strategies characterised by the Ghardaïan houses started with a south orientation to benefit the oblique sun rays in winter and the vertical rays in summer (Ali-Toudert, et al., 2005). Stones were the most used building material and characterised by a high thermal capacity. The stones have the advantage of capturing solar energy and accumulating it, to restore it later and easily evacuated at night by natural ventilation effect.

Of late modern houses built in Ghardaia do not follow the traditional guidelines. As a result, these houses became energy intensive to achieve and maintain thermal comfort in the harsh climate in the desert of Algeria. It had become urgent to intervene in the design and urban planning of Ghardaia because of the increasing level of demographic growth and energy usage. This paper investigated the thermal performances of the three different types of houses to provide scientific data of the bioclimatic requirements essential for the construction of these houses.

6. Methods

To understand the thermal performances of the various houses of the *Ksour* the methods undertaken in this study were the buildings measurement survey and climatic data monitoring. The building survey was pertinent for this study to get similar physical and climatic parameters for consistency of collected data and results. Three houses were selected due to their differing house types as required for this study and from different *Ksour*. The first is the Trad.H from *Ksar Melika*, the second a typical Mod.H (*not in any Ksar*) and the third a modern house but built with ecological principles (Eco.H) from *Ksar Taffilelt*. The three houses were selected, and physical measurements were taken and drawn on Archicad. The environmental parameters used for the analysis were indoor air temperature, relative humidity and the outdoor air temperature. The readings are taken during summer on various days in July 2017. Measuring instruments and devices include Onset data logger to measure relative humidity and air temperature continuously and the infra-red thermometer to measure the surface temperature.

Building descriptions

Modern house (Mod.H)

The Mod.H was constructed in 2000 and located approximately 1.5 km from the Trad.H. The layout of the buildings is different than the closely-packed Trad.H. This house is 73 sq.m. area and was constructed using 400 mm thick stone external walls in the basement level, 300 mm concrete external walls in upper floors and 100 mm thick internal walls of hollow concrete blocks. The materials used for the ceiling were the concrete compression slab of reinforced concrete beams and 200 mm thick reinforced concrete roof. The internal height of the rooms is 2.6 m. It has the most common layout in present day modern houses.

Eco-friendly house (Eco.H)

The Eco.H, also constructed in 2000, was located in *Ksar Taffilelt* with a built-up area is 96 sq. m. The construction materials used were stone, concrete and plaster. Stone exterior walls of 400 mm thick, constituted the building-supporting structure of the house as well as all the walls on the façade. The internal walls were made of hollow concrete blocks 150 mm thick. The materials used for the ceiling were the concrete compression slab of reinforced concrete beams, spaced 650 mm apart. The plaster vaults ensured the thermal and sound insulation. The void between the compression slab and the vaults was filled with a mixture of lime and sand which were also used in the exterior cladding to allow better malleability of the mortar.

7. Results and Discussion

Data loggers were located at five different locations in the houses. But this paper discussed those situated in the living, kitchen and Wast-eddar areas only. In all three houses, only the kitchen walls were proximal to the outdoors. The other walls of the houses were attached to neighbouring buildings, if at all.

Table 1 summarises the results of indoor temperature monitoring and thermal comfort analyses in the three spaces of the case study houses.

Table 1: Results of data monitoring

Living	Min °C	Max °C	Diurnal °C	Diff. with TCZ (K)	Diff. outdoor/indoor (K)
Trad.H	30.4	30.6	0.2	0.4 - 0.6	22
Mod.H	31	32.1	1.1	1 - 2	10.8
Eco.H	30.1	32.3	2.2	0.1 - 2	11.2
Kitchen					
Trad.H	30.4	30.6	0.2	0.4 - 0.6	22
Mod.H	34.9	37.2	2.3	5 - 7	16
Eco.H	31.9	35	3.1	2 - 5	18
Wast-eddar					
Trad.H	33.7	34.4	0.7	4 - 5	22
Mod.H	37.2	38.9	1.1	7 - 9	16
Eco.H	36.8	38.7	1.9	7 - 9	18
Outdoor	35	54.6	20	5-25	

Data monitoring was conducted on a sweltering summer day on 15/7/2017 where the maximum temperature was almost 55°C, and the minimum was 35°C with a diurnal range of nearly 20 K. Although all indoor temperatures monitored were above the upper limit of the thermal comfort zone (TCZ) of 30°C, all houses were able to moderate the indoor climate below the maximum outdoor temperatures.

In all three spaces monitored in the houses, the Trad.H performed the best where the difference of the level of the thermal comfort zone of only 0.4 to 0.6 K. Only in the wast-eddar the thermal condition there was 4 – 5 K above the comfort level of 30°C because the wast-eddar is the most exposed space in the house. During the period the survey it was noticed, however, that only a fan was used, ensuring energy efficiency. The fan was required to alleviate the stagnant hot air. The Mod.H fared the worst of all three spaces monitored. It was gathered that the thickness and material of the walls had the least thermal capacity between the three houses resulted in the higher temperature variations. The kitchen and the wast-eddar spaces were between 5 and 9 K above the TCZ. Five air-conditioners and eight fans were frequently used in this house. The wast-eddar in the Eco.H was the hottest space in the house with a difference of 7 to 9 K above the comfort zone. The roof construction is similar to Mod.H. Air-conditioning was required to be switched on to maintain comfort. In all three spaces monitored, the living rooms of the three houses were able to moderate the indoor temperatures closest to the upper limit of the comfort zone. This was because the living rooms do not have openings to the outside.

Relative humidity (RH) data was also monitored, and results showed that when outdoor conditions were so dry (ave. 10%) the indoors of the Trad.H, Mod.H and Eco.H were 25%, 24% and 20% respectively. Although still on the low side, the RH indoors were more comfortable. Energy consumption was also recorded, and the Eco.H used twice and the Mod.H thrice more than the Trad.H. From the results, it is apparent that the traditional house retained the temperature nearest to the comfort zone as indicated in the ASHRAE 55-2014 standards. The Eco.H can provide a better thermal comfort than the Mod.H, within the dense surrounding environment at Ghardaia city.

8. Conclusion

Results from data monitoring taken during the hot summer month of July showed that the indoor temperatures indoors of all three houses were much lower than the outdoor temperature. The Trad.H performed the best to retain the temperature nearest to the comfort range as indicated in the ASHRAE 55-2014 standards. The Trad.H still has better ability in providing the indoor thermal comfort for the more extended periods than the two modern houses in the same condition. Low thermal conductivity due to less thickness of walls and using non-local building materials like concrete in the Mod.H showed the higher temperature variations compared to Trad.H and Eco.H. The ultimate aim of providing thermally comfortable and energy efficient building is thus achieved by incorporating passive design strategies with

traditional construction materials. This plays a significant role to save energy creating a significant impact on the economy. The study ascertained that designs of buildings with traditional construction and materials played a significant role in moderating the indoor environment when the outside climate of the Algerian desert was unbearable. For a more holistic understanding of the thermal performance of Ghardaian houses, a study during the cold winter months is pertinent.

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