AKADÉMIAI KIADÓ

Thermal analysis of the vernacular architecture in the Ziban, Algeria

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ABSTRACT

Modern buildings in Algeria consume a huge amount of energy and deliver modest thermal comfort, due to their design which does not address the local climate conditions. In contrast, it is commonly recognized that vernacular architecture is climate-responsive and environmentally friendly architecture.

This study aims to assess the thermal performance of vernacular architecture in the hot and dry climate of the Ziban region, Biskra. It was achieved by describing the main passive strategies in this architecture, later performing field hygrothermal measurements on two different houses in this region. The results revealed that the thermal effectiveness of these vernacular houses depends on the interaction of all their vernacular passive strategies from architectural to urban scale.

KEYWORDS

vernacular, thermal, performance, hot dry climate, Biskra, Ziban, measurement

1. INTRODUCTION

The global growth in energy consumption has been identified as the primary challenge of the 21st century. The building sector is one of the largest energy consumers, it accounts for more than 35% of the world's electricity use and nearly 28% of energy-related CO_2 emissions [1]. In Algeria, it has been reported that 35% of the overall energy consumption was attributed to buildings; this value has increased awfully between 2018 and 2019 by 2.9% [2]. This is due to shortcomings in design practices that do not comply with the updated energy standards and often neglect the local climate conditions [3].

Hot and dry climate presents the major part in Algeria, it is characterized by excess solar gains and extreme outside temperature in summer. Moreover, the hot season presents the longest period of the year, this led to a huge growing demand on electricity for cooling to maintain indoor comfort [4, 5]. Passive building design techniques, as a key to overcoming this challenge, can play an important role in maintaining thermal efficiency and lowering energy usage in this region's buildings [6–8].

Vernacular architecture that employs efficient passive design strategies can be described as genuine climate-responsive and environmentally-friendly architecture; it is widely acknowledged that this architecture adapts well to local climate conditions and provides thermal and energy performance for buildings [9, 10].

The Ziban region around Biskra city exhibits a type of vernacular architecture in Algeria known as Ksour [11, 12], which incorporates several climate-based architectural strategies that can provide an excellent opportunity to overcome the tough climate conditions [13]. Due to the lack of a deep investigation of passive design strategies in this region, this study takes the initiative to evaluate their effect on the thermal performance of buildings, by performing on-site hygrothermal field measurement in two separate vernacular buildings.

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2. AN OVERVIEW OF THE STUDY'S CONTEXT: THE ZIBAN REGION

The Ziban Region of the province of Biskra is located in south-eastern Algeria, north of the lower Sahara [14]. Depending on the Köppen-Geiger climate classification this region is characterized by a hot desert climate [15], Fig. 1a. This region holds a particular vernacular architecture known as Ksour; an original architectural model of fortified villages proper to the Maghreb (Northern Africa). They are made of attached built-up houses that form a compact urban environment with narrow irregular and shaded streets; all enclosed by an outer wall Fig. 1b.

3. MATERIALS AND METHODS

In order to evaluate the thermal performance of the Ziban region's vernacular architecture, the study was managed into two main phases. The first step was about producing an on-site observation to extract the most relevant passive design strategies used in this architecture. The second step involved quantifying their thermal effectiveness through in-situ hygrothermal measurements. For this purpose, two typical vernacular houses with diverse configurations, typologies, and space layouts were selected, then evaluated by measuring air temperature and relative humidity over three days in August 2018.

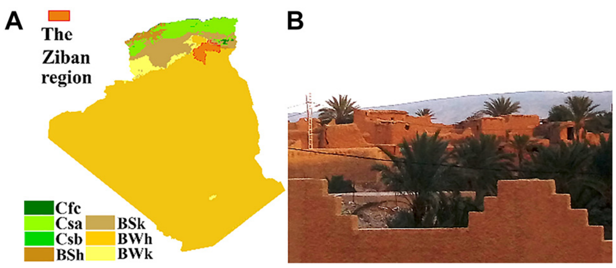


Fig. 1. a) Climate classification and b) architecture of the Ziban region (province of Biskra), (*Source*: Author)

3.1. Case studies presentation

The first case study is a large individual house located in the Mcid neighborhood, Fig. 2, The building is surrounded by an altered urban fabric between vernacular and contemporary, Fig. 2a, the main vernacular architectural components in this house are; a thick load-bearing wall built of local material (earth brick), a space layout represented by an internal covered courtyard surrounded by rooms with windows facing it (Ouest-eddar), high level positioned windows (Clerestory) Fig. 2b and a "Raouzna" as a horizontal window in the middle of the courtyard.

Figure 3 shows the ground and first-floor layouts of the Mcid home, as well as the places where hygrothermal measurements were taken.

The second case study is a small individual house located inside the Farfar neighborhood in Tolga – Biskra. It is featured with the same architectural elements as the previous house including a central internal courtyard, load-bearing earth brick wall, high level positioned windows, and Raouzna. However, there are some distinctions between the two buildings. The first difference is that the Mcidhouse is located in an urban environment undergoing transformations; as a result, the construction of an adjacent contemporary building has definitively obstructed some of

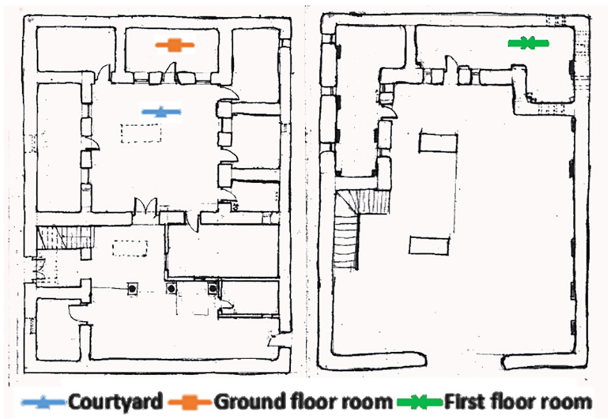


Fig. 3. Plans of the Mcid house and location of the measurement points, ground floor plan (on the left); terrace (1st floor) plan (on the right) (*Source*: Authors' plot)

a) b)

Fig. 2. Architectural features of the Mcid house, a) view of a construction in progress next to the Mcid house (right, bottom); b) a closed window at the top of the wall (*Source*: Author)

its openings Fig. 2b. In contrast to that, the Farfar house is located in an authentic vernacular urban fabric of the Farfar's ksar, Fig. 4, which keeps all high position windows open. The second difference is that the Farfar house is located in an unoccupied ksar, therefore its doors are permanently open, as opposed to the MCID house, which always has closed doors.

Figure 5 illustrates the Farfar home layouts, as well as the spots where hygrothermal measurements were taken.

3.2. Fieldwork process

For the Hygrothermal measurements campaign, a "Testo 480" was used to assess the thermal performance of the two houses Figs 3 and 5. Furthermore, environmental parameters were collected in the center of each area at 1.5 m above floor level. Table 1 displays the accuracy of the probs used along with the Testo "480".

Given the 35-km distance between the two measurement sites, the fieldwork was completed on different days throughout the hottest period of the year. In this regard, for the first case study – Mcid house, – the measurements were taken across three days from August 22 to 24, 2018 between 8 a.m. and 4 p.m. house with a time step of 2 h, whilst for the second case study – Farfar house – they were carried out from August 10 to 12 between 9 a.m. and 5 p.m. over an interval of 1 h. However, only the recorded data from 14 August, 2018 for Farfar house and 24 August, 2018 for Mcid house were considered for interpretation due to their clearness. The difference in the measurement period between the two houses leads to putting the houses in two different experimental groups. However, comparing the thermal variations of each house according to their outside temperature led to a readable analysis and interpretation, which is discussed in the next section.

Fig. 4. Actual state illustration of the urban and architectural aspects of the house in the Farfar district (*Source*: Author)

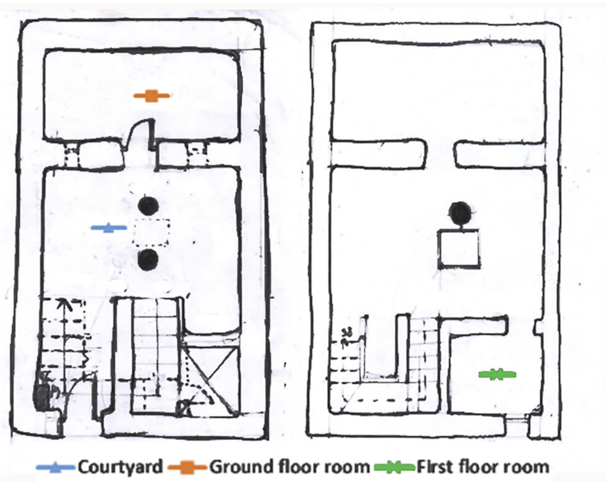


Fig. 5. Architectural plans of Farfar house and location of the measurement points, ground floor plan (left); terrace (1st floor) plan (right), (*Source*: Author)

Table 1. Parameters considered for measurements and the thermo-hygrometer sensor accuracy

Parameter	Instrument	Accuracy
Relative Humidity (%)	Humidity and temperature probe Ø 12 mm, highly accurate humidity measurement with 1% accuracy*	– ±(1.0 %RH + 0.7% of mv) (0–90% RH)
Temperature (°C)		– ±0.2 °C (+15 to +30 °C) – ±0.5 °C (Remaining Range)

4. RESULTS AND DISCUSSION

4.1. Vernacular climate-based design strategies in the Ziban region

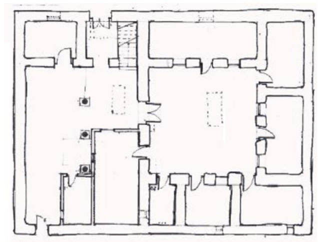
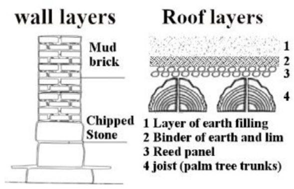
By referring to relevant literature on climate-based architectural components and specific design elements adapted to hot and dry climate conditions [16, 17]. A qualitative investigation via one-site observation was conducted to extract the most relevant passive design strategies employed in the Ziban region. Table 2 summarizes the identified passive cooling strategies based on the following components:

1. usage of the site and natural environment;
2. urban scale planning, settlement pattern, and the built volume as protection against solar radiation;
3. high thermal mass;
4. usage of natural ventilation and daylighting;
5. spatial layout and interior organization;
6. openings.

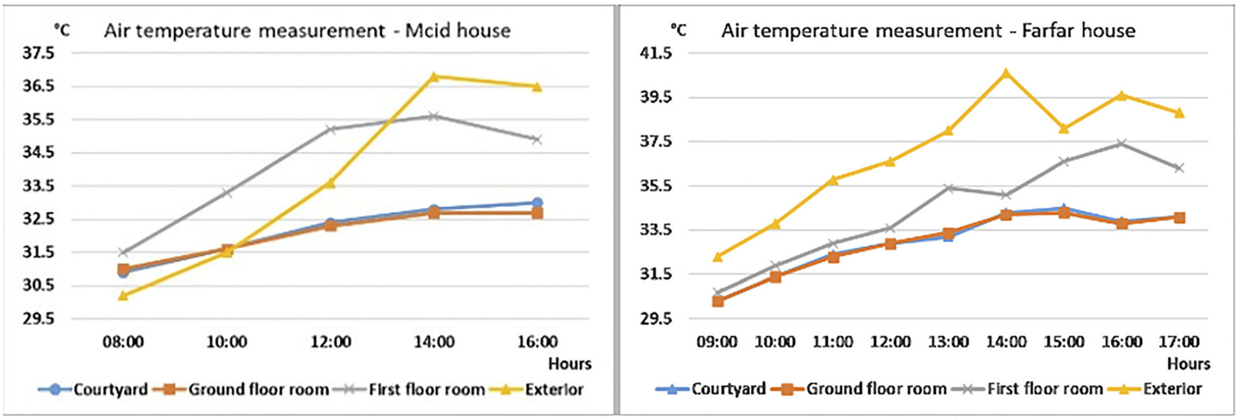
4.2. Air temperature

The data collected in the first case study of the traditional house located in the Mcid neighborhood as shown in Fig. 6a, reveal that early morning between 8 a.m. and 10 a.m., air temperatures recorded inside the two spaces of the ground floor level are higher than those monitored outside. This is probably due to an insufficient dissipation of the delayed radiant heat retained in the building mass over the previous day. Indeed, the obstruction of the openings on the top of

Table 2. The main climate-based design strategies used in the Ziban region (*Source*: Authors')

Component	Observation	Vernacular design strategies implemented	Illustration (Source: Author)
Site and natural environment	The site generates a microclimate 'oasis effect' due to the presence of vegetation and water	Lowering the thermal stress by humidification Providing protection against hot winds and sandstorms	
Urban morphology Settlement pattern	- Buildings connected together - Compactness at the scale of the built environment	- Mutual protection against solar irradiation - Urban-scale shading induces heat stress mitigating	
Building scale: built volume, shape, and envelope	- Compactness at the building scale (low surface area to volume ratio) - Dwellings are of simple and mostly cubic forms	- Reducing solar irradiation exposure - Minimizing direct solar gains and creating favorable indoor conditions	
Spatial layout/ interior organization	- Introverted plan - Central courtyard	- This specific configuration is effective in reducing solar irradiation exposure - Providing sun protection, daylighting, and ventilation	
Construction materials and techniques	Load-bearing walls built with earth and roof made from local materials (clay, palm trees wood, etc.)	- Height Thermal mass provides heat resistance and ensures a consistent time lag (> 8 hours); - Thermal heat is evacuated to the outside during the night when Text<Tint; the building's mass gets cooler	
Openings	- Small size windows located at the top of the wall - Raouzna: window in the middle of the courtyard roof	- Providing daylight and ventilation; reducing heat and solar irradiation penetration - Allows hot air evacuation through the stack effect; providing ventilation and daylight	 

the wall resulted in a lack of cross-ventilation that ensures the building mass is cooled during the night. Inversely, from 10 a.m. until the end of the measurement at 4 p.m. the results show a substantial decrease in indoor temperatures compared to outdoor temperatures. This is due to the thermal properties of the heavy adobe-bearing walls that slow down the heat transfer. Even in the first-floor room, the thermal mass of the wall and the massive roof kept the



a) b)

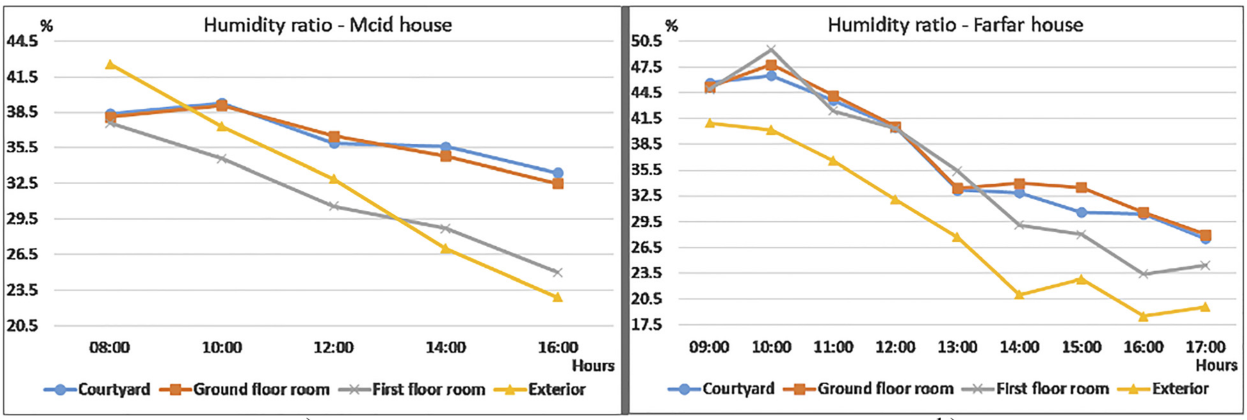
Fig. 6. Outdoor and indoor air temperatures profiles of the two measured buildings, a) First house (Mcid district); b) Second house (Farfar district)

temperature partially stable during the hottest hours of the daytime. However, in the second cases study of the Farfar house, the results show that the indoor air temperature was lower than the outside throughout the day. This clearly demonstrates that combining vernacular passive design strategies in conjunction with traditional urban fabric is more efficient than using simple passive design elements, as in the MCID house.

4.3. Relative humidity

Figure 7a illustrates the fluctuations in relative humidity rates for the first Mcid house case study. The gathered data indicates that the interior relative humidity ratios were lower than the outside values in the early morning from 8 a.m. to 10 a.m., which is due to the same reason mentioned earlier; insufficient overnight cross-ventilation owing to the occlusion of the openings on the top of the wall. As a result, the heat generated inside the house can no longer be removed, causing an increase in air temperature. Because air temperature is inversely related to relative humidity, this rise will result in a decrease in relative humidity. Therefore from 10 a.m. onward to the evening, the phenomenon is reversed and the relative humidity becomes higher inside than outside. Also, the relation between humidity and temperature leads to the same hygrothermal behavior in the first-floor room.

Meanwhile, in the Farfar house, the results show that the rate of the relative humidity is higher inside than outside, all over the day. This is due to the operation of all vernacular strategies at all scales, from architectural to urban. The surrounding urban vernacular fabric allows the ventilation through high position windows, the oasis delivers additional humidity through the phenomena of evaporation and evapotranspiration, and finally, the neighboring walls of the whole urban fabric provide an additional hygroscopic effect that maintains more humidity while also lowering the air temperature in buildings.



a) b)

Fig. 7. Outdoor and indoor relative humidity rates profiles of the two measured buildings, a) First house (Mcid district); b) Second house (Farfar district)

5. CONCLUSION

Through on-site observation and field thermal measurement, this study investigated the thermal performance of vernacular passive strategies in the Ziban region. The results revealed that the vernacular architecture of this region provides valuable lessons in terms of passive design strategies. Moreover, it was observed that sustaining a high level of thermal performance in this architecture is dependent on the combination of the whole strategies from architectural to urban scale, in order to enhance the effectiveness of vernacular passive design strategies.

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