Thermal performance and comfort of vernacular earthen buildings in Egypt and Portugal

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ABSTRACT: Despite the far distance between Portugal and Egypt, it was possible to find points of similarity on the influence of Roman and Arab cultures, and on solar passive and construction techniques used in vernacular architecture. Earthen construction techniques are one of these examples, being used in both countries for thousands of years. Through an explanatory qualitative and quantitative analysis, this paper presents an overview of the effects of climate-responsive strategies on thermal performance and indoor comfort of earthen architecture from Northern Egypt and Southern Portugal. To understand the effectiveness of these strategies, measurements of hygrothermal parameters and surveys on occupants' thermal sensation were conducted in two case studies. From the results, it has been found that the case studies have shown a good thermal performance only by passive means and that the occupants expressed as being comfortable. Thus, vernacular passive strategies still can contribute to achieve indoor comfort conditions and reduce the dependency on mechanical systems.

1 INTRODUCTION

The wide area of the Mediterranean, although it is a physical border between countries, it is also a mean of connection and communication between the various countries around it. Through history, the presence of different cultures in these territories has generated a beneficial transference and mix of knowledge. In addition, this sea is a climate regulator in the region.

Despite the distance between Portugal and Egypt and their opposite position in the Mediterranean basin, it was possible to find common approaches regarding passive vernacular strategies used in both countries (Fernandes et al. 2014). They are mainly due to the influence of Mediterranean climate but also a reflection of a common Roman and Arab cultural and architectural influence.

This article is a continuation of a previous work developed by the authors (Fernandes et al. 2014), and the follow-up from a qualitative approach to a quantitative approach. In this study, the authors have chosen two representative residential earth buildings located in Egypt and Portugal. The two buildings were monitored to evaluate their thermal performance during summer peak time and how they managed to reach adequate indoor comfort for their occupants. This study tried to retrieve the main reasoning for thermal behaviour for different and common combined passive solutions used in both the case studies. This paper analyses the thermo-physical properties of earth, as main building material in the two studied case study buildings in order to understand the effectiveness of vernacular climatic responsive strategies. Results are supported by in-situ monitoring and occupancy surveys.

2 METHODOLOGY

The methodology adopted in this study is based on the analysis of case studies, applying an exploratory approach through quantitative analysis and comparative explanatory synthesis methods for thermal perfomance and comfort assessment of earthen vernacular buildings.

The main aim of this study is to compare and establish a relation between occupant's perception and expectation regarding their comfort in dwellings built with earthen materials but located in different geographies of the Mediterranean region. For this purpose, the analysis is based on data from the in-situ monitoring of both indoor thermal performance and perceived comfort conditions of earthen buildings located in the southern part of Portugal and northern part of Egypt. Taking into consideration the climate-responsive strategies adopted in these buildings, the comparative analysis is only focused on the summer season and on the effectiveness of passive cooling strategies.

In the assessment of the indoor environmental quality, the air temperature (ºC) and relative humidity

(%) were measured in compliance with ASHRAE standard 55 (2010). In this paper, the analysis of the in-situ monitoring is based on a representative summer week of each specific location. The indoor environment conditions were also evaluated by surveying the occupants. The survey allowed to assess occupants' satisfaction according to ASHRAE thermal sensation scale and was based on the "Thermal Environment Survey" and "Point in Time Survey" from ASHRAE standard 55 (2010). The surveys were carried for the rooms that occupants considered more comfortable and/or where they spend more time.

In the analysis of thermal comfort conditions, the relation between indoor comfort temperature and the outdoor temperature was evaluated considering an adaptive model of thermal comfort. The reasoning for this is that this is the adequate model for naturally conditioned buildings. This procedure is in compliance with the ASHRAE standard 55 (2010). The adaptive comfort charts were performed using the CBE Thermal Comfort Tool (Hoyt et al. 2013). The results obtained were then compared to conclude if they converged or diverged.

3 VERNACULAR ARCHITECTURE AND CLIMATE

The close relation between architectonic form and the geographical context is widely recognized as one of the main features of vernacular architecture. Among all the geographic conditions, the climate stands out as one aspect that most affects the buildings performance. Buildings, in their primary function of shelter and protection, are aimed to mitigate the effects of climate. Thus, the need to develop specific mitigation strategies has shaped vernacular buildings differently from region to region.

3.1 *Southern Portugal and Northern Egypt climate and architecture*

The inland Southern part of Portugal and Northern part of Egypt have a Mediterranean climate, subtype Csa, temperate and BWh respectively, with hot and dry summer (AEMET & IM 2011; Fathy 1986). In the Portuguese case, summer is the most demanding season in that part of the country with an average mean temperature of 22.5/25 ºC. The average maximum air temperature varies between 30 and 35 °C (AEMET & IM 2011), reaching maximum temperatures of 40°C or 45°C. In summer, the inland southern part of Portugal has more than 80 days with a maximum temperature above or equal to 25 ºC, being July and August the hottest months (AEMET & IM 2011). The annual average rainfall is below 500 mm, and July is the driest month (AEMET & IM 2011). In the case of Egypt, the warmest months are July and August, the mean maximum temperature is around 38° and the peak around 45°C. In January, the mean minimum temperature is as low as 8°C. The average relative humidity (RH) varies between 34% in May and 57% in December. The mean daily wind speed varies between 1.7 m/s in December and 2.8 m/s in June. The yearly average rainfall is as low as 2 mm (Meteotest 2014).

In both Southern Portugal and Northern Egypt, the range and combination of strategies used to deal with a harsh summer season are varied and resilient. To suit these climatic conditions, the strategies developed are in general more focused on passive cooling (Fernandes et al. 2016; Fernandes, Mateus, et al. 2015; Dabaieh & Eybye 2016; Fathy 1986), such as: i) minimising the size and number of windows and doors facing the outdoor environment, to reduce solar gains; ii) proper orientation of openings, normally facing north for summer cool breeze and south for direct sun needed for winter cold days. The window to wall ratio ranges from 1:20 to 1:25 iii) high thermal inertia building systems (rammed-earth walls, adobe, and vaulted ceilings); iv) the use of light colours for the building envelope, mainly whitewashed surfaces, to reflect the incident solar radiation (Oliveira & Galhano 1992; Koch-Nielsen 2002); iv) ventilation openings to promote overnight cooling and remove diurnal thermal loads. In some cases, these ventilation openings are similar to the Arab *mashrabiya* (Fernandes et al. 2014; Fathy 1986); v) patios (courtyards), usually containing vegetation and/or water, useful to generate a cool microclimate through evapotranspiration and water evaporation, respectively; and vi) the compact building layout, to reduce the surface area exposed to the sun and to generate shade.

The combination of all these strategies is a great asset to achieve indoor thermal comfort during summer season only by passive means, as demonstrated in recent studies (Fernandes, Pimenta, et al. 2015; Fernandes, Mateus, et al. 2015).

3.2 *Description of the case studies*

3.2.1 *Case study 1 – Southern Portugal*

The case study is in a small village from Moura's municipality, located in inland Southern Portugal. This territory has an ancient occupation with a long dominion of the Romans (3rd century BC to 5th century AD) and the Arabs (8th to 13th century AD). The building is probably from the 19th century and was renovated in 1983. It has main and rear facades facing southeast (street) and northwest (*patio*) (Fig. 1), respectively. The gross floor area is of approximate 200 m^2 divided into two storeys, although the upper storey is just a small attic area. In the ground floor, at the southeast are the living areas and the bedrooms, and in the northern part are the kitchen and the bathroom (Fig. 2).

The building envelope consists of whitewashed rammed-earth walls (average thickness of 60cm) with a pitched roof, wooden doors and wooden framed single glazed windows. Indoors, the partitions walls are in rammed-earth; several indoor spaces are vaulted; the floor is in *baldosa*—a sun-dried clay tile. Regarding the windows, it is relevant to highlight the existence of small ventilation shutters above the glazed window to promote controlled natural ventilation, which are particularly useful for overnight cooling without compromising the security level. The heat transfer coefficient (U-value) of the building envelope is presented in Table 1.

Figure 1. External view (northwest façade)

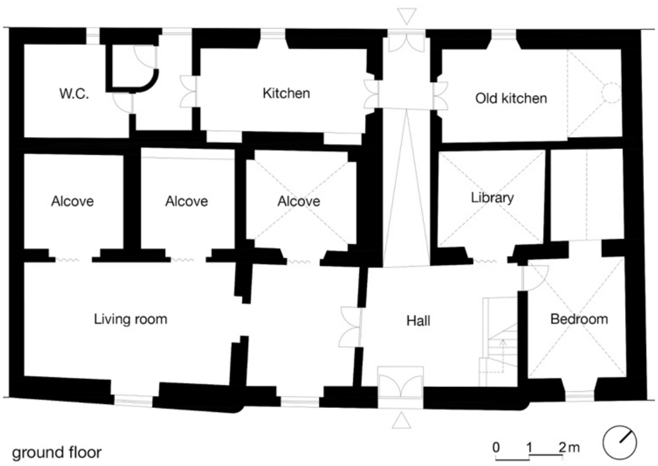

Figure 2. Case study 1 - Ground floor plan

Table 1. CS1 – Building envelope characteristics.

Envelope element	Heat transfer coefficient U-value (W/(m2.ºC))
External walls	1.30
Roof	0.49
Doors	2.15
Windows	3.40*

Sources: .(Pina dos Santos & Matias 2006; Pina dos Santos & Rodrigues 2009). Note: *Uwdn—mean day–night heat transfer coefficient, including the contribution of shading systems.

3.2.2 *Case study 2 – Northern Egypt*

The case study is located in the Western Desert of Egypt in New Valley governorate. It is a dwelling and the office of the city mayor (Fig. 3). The building is constructed from locally available traditional materials, which are primarily adobe, acacia and palm tree wood. The dwelling is built around the late 18th century. The house consists of two floors (Fig. 4). It has a main courtyard in the centre used in the morning for official purposes and the evening for family gatherings. The kitchen and meals areas for socialization are shared with the neighbouring extended family house. The two houses are connected from the roof top where the bread oven and chicken coop with grain storage are located. Small and controlled openings are located on the north façade for ventilation and the west and south façade are mostly in shade to reduce heat gain. The building is plastered with white wash lime. The characteristics of the building envelope are presented in Table 2.

Figure 3. External view (west façade)

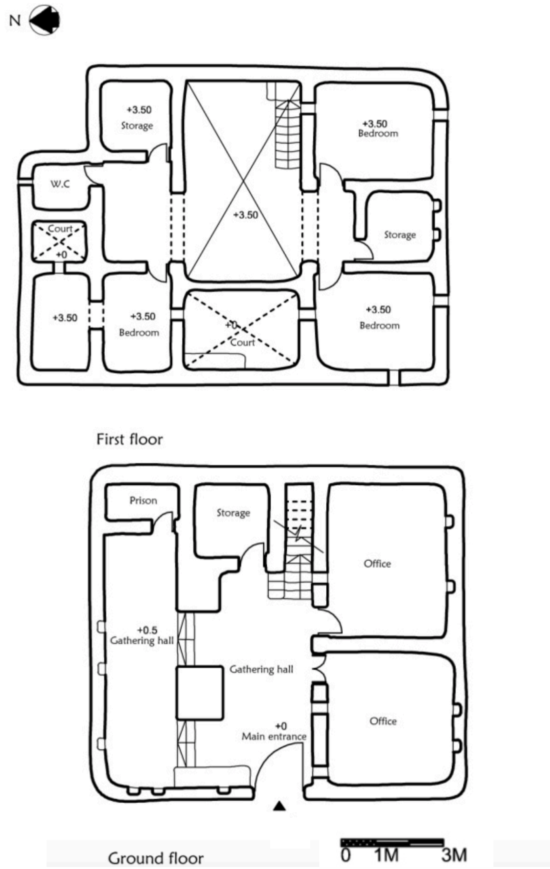

Figure 4. Case study 2 - Building plans.

Table 2. CS2 – Building envelope characteristics.

Envelope element	Heat transfer coefficient
	U-value (W/(m2.ºC))
External walls	0.47
Roof	1.30
Doors	2.40
Windows	1.30

Note: Calculations made based on material lab tests.

4 THERMAL PERFORMANCE AND COMFORT ASSESSMENTS

The vernacular buildings discussed in this study showed a variety of passive low-tech approaches in the design and construction to achieve indoor human thermal comfort. Such passive approaches have been devised to suit the local Mediterranean climatic conditions.

4.1 *Case study 1 – Southern Portugal*

The data and results presented were collected during a monitoring conducted in the summer of 2015. From the analysis of the results, it is possible to verify that during the representative week, the outdoor mean air temperature was of about 27 °C (Fig. 5). During the day, the maximum air temperature was often higher than 35 °C, reaching and exceeding 40º C on some days (Fig. 5). Although the daily outdoor temperature amplitude is high, it was found that indoor temperature remained very stable over the monitoring period, with temperature values around 26 °C (Fig. 5).

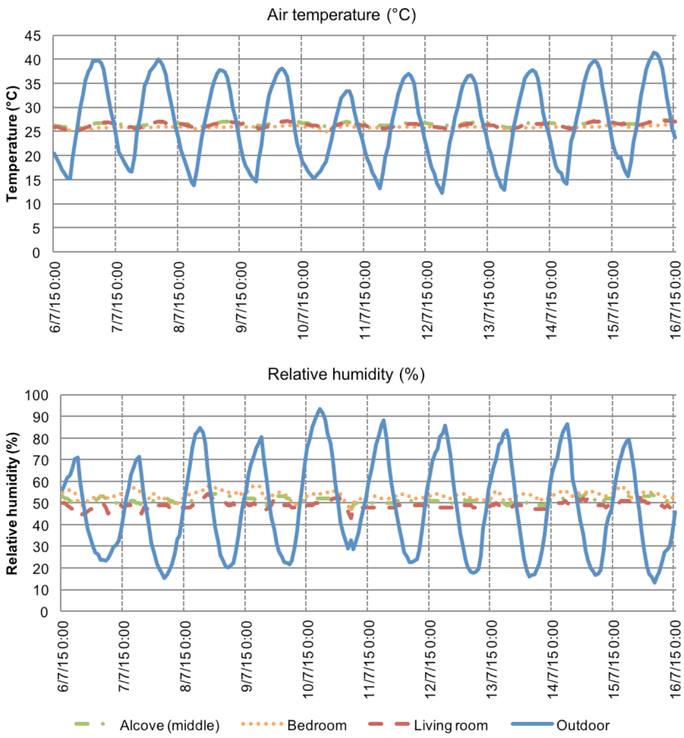

Figure 5. Case study 1 – Indoor and outdoor air temperature and relative humidity profiles.

In what relative humidity is concerned, there is a high outdoor day/night variation, with maximum values of 93% and minimum lower than 20% (Fig. 5). In comparison, indoor spaces have more stable relative humidity profiles with mean values around 50% —the most appropriate for human health and comfort (Morton 2008).

Regarding the thermal comfort assessment, in-situ assessments were conducted in the living room. The results show that the living room has thermal comfort conditions within the defined limits, with an operative temperature almost in the centre of the comfort range (Fig. 6). In the “thermal environment survey”, all the three occupants answered as being “neutral” (comfortable), confirming the objective measurements.

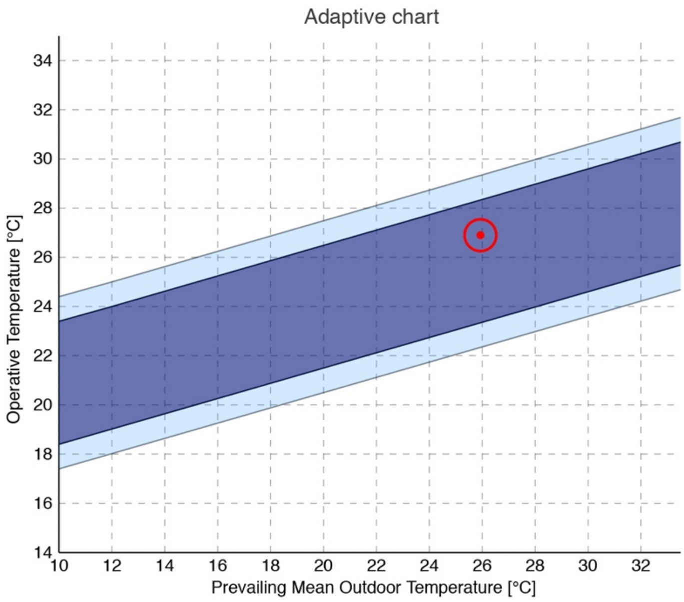

Figure 6. Case study 1 – Adaptive comfort chart. Thermal comfort temperature (operative temperature) in the living room during one representative day in summer.

4.2 *Case study 2 – Northern Egypt*

The data and results presented were collected during a monitoring conducted in the summer of 2014. Figure 7 shows the monitoring results for a bedroom and office space during July 2014. The two rooms studied behaved similarly, however, the average temperature of the office was almost 1.5°C higher than the bedroom. According to the ASHRAE, the average upper limit for thermal comfort is 30.9 °C. The bedroom average temperature during the monitoring time was 29 °C, while the office was outside the comfort range with an average of 32 °C. The average relative humidity was 40 % and 29 % for the bedroom and office space, respectively.

From the application of the thermal environment satisfaction survey, it was possible to conclude that the occupants were comfortable in the bedroom and slightly warm in the office room. Occupants’ answers confirm the objective measurements. The survey was conducted in a representative day where the in-situ measurements were carried out. In Figure 8 is possible to verify that the bedroom has good thermal comfort conditions, with an operative temperature almost in the centre of the comfort range.

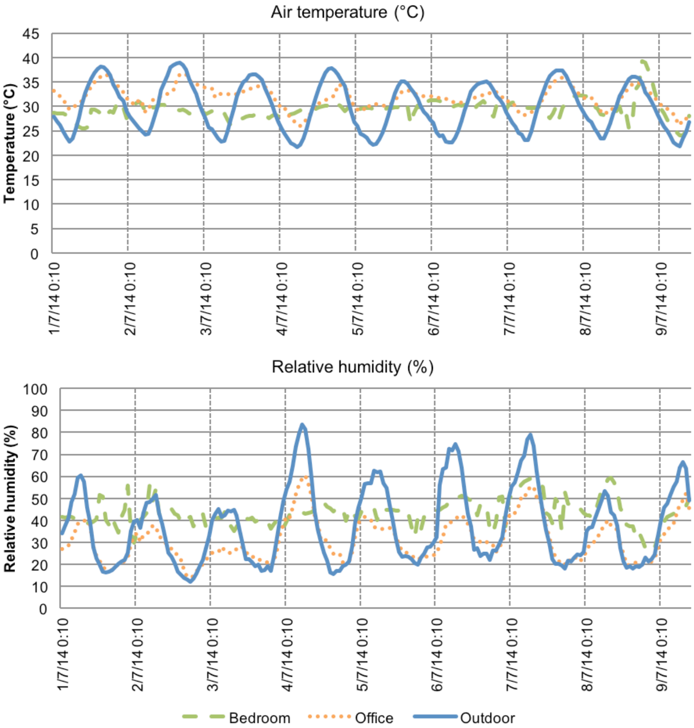

Figure 7. Case study 2 – Indoor and outdoor air temperature and relative humidity profiles.

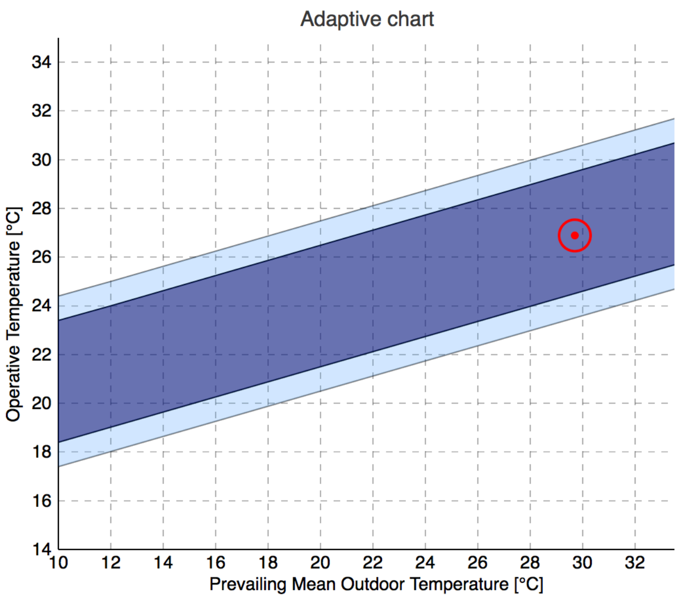

Figure 8. Case study 2 – Adaptive comfort chart. Thermal comfort temperature (operative temperature) in the bedroom during one representative day in summer.

5 DISCUSSION

Vernacular earthen buildings, as the ones used as case studies, are seen by many people as low income households. Nevertheless, these buildings can achieve good comfort conditions only by passive means and the materials used to build them have low potential environmental impact.

The stability in indoor temperature is due to the high thermal inertia of the building envelope (e.g., thick earthen walls and vaulted ceilings), which provides a high capacity to store heat and to delay the progress of the heat flux (with an average time-lag from 7 to at least 12 hours (Koch-Nielsen 2002). This feature is particularly useful to minimise the effect of high diurnal temperature and the daily thermal range. In addition, the light colours used in façades and the narrow streets reduce direct heat gains by the envelope.

Regarding relative humidity, the difference between indoor (more stable) and outdoor relative humidity values is due to the hygroscopic inertia of the building systems, namely the rammed-earth or adobe walls and the lime plaster, among others, that have the capacity to regulate air humidity (Berge 2009), i.e., absorbing humidity when moisture is excessive and releasing it when the air is too dry. This property of the materials allows a natural regulation of humidity levels, without requiring any equipment, providing a healthy and comfortable indoor environment.

In the Egyptian case study, although the heavy thermal mass walls have a major contribution to indoor thermal comfort, in the case of the office, the room was slightly outside the comfort range. That is due to higher indoor thermal loads (e.g. from the office equipment), to the heat accumulated in the walls during the day and released into indoor environment at night, and inadequate ventilation during the night time. Normally occupants tend to use the night flush effect by opening the windows for night ventilation. This allows cooling the spaces during night-time, but normally this is not done in the office room. This aspect shows that the effectiveness of some passive solutions to achieve comfort depend on occupants' behaviour. Additionally, occupants that voted as feeling slightly warm have indicated the possibility of controlling the operable windows as an aspect to enhance cross ventilation and therefore the thermal comfort.

Natural ventilation, as mentioned above, is an essential strategy to promote passive cooling through the stack effect, and also by cross ventilation through the openings (doors and windows) and courtyards. The presence of courtyards in the two projects enhances air circulation inside the building by creating a difference in air pressure between indoor and outdoor. This is an asset to foster air flow inside the building, contributing to increase users' satisfaction during hot summer days.

In the two case studies, the active behaviour of the occupants to improve their comfort conditions should be noted. It is very common in the two regions to promote passive cooling by natural ventilation of the indoor spaces during the night and early morning, and to shut windows and doors during the periods of direct solar radiation in order to avoid unwanted heat gains.

Since the two case studies use a different earth building technique it is also possible to analyse the different the different thermal behaviour between rammed-earth walls in the Portuguese building and adobe walls in the Egyptian one. For example, the time lag for the adobe walls ranges from 10 to 12 hours while in the rammed earth is higher than 10 hours (Koch-Nielsen 2002). Regarding the U-value, the adobe construction performs better than the rammed earth one. That is due to the air bubbles inside these type of adobe bricks, while rammed earth is more compressed and compact (Berge 2009). These different characteristics show that each building system suits best the specific micro-climate.

6 CONCLUSIONS

The study showed the correlation between the thermal performance of earth vernacular buildings and human comfort perception in two different case studies located in the Mediterranean climate. It shows the common passive strategies and climate responsive practice in both cases despite the location in two different contexts. The culture, human adaptation and interaction with passive solutions affects the overall building performance. The study is still considered as a pilot and should be followed by more in-depth work using a full year monitoring to test the building performance during different seasons. Nevertheless, the results obtained show the effectiveness of a set of passive cooling strategies to achieve thermal comfort conditions. The results obtained both in objective and subjective measurements reveal that the case studies had good thermal conditions and that occupant's expectations were satisfied. Thus, the passive strategies used have potential to reduce energy consumption for cooling.

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