An Analysis of the Potentialities of Portuguese Vernacular Architecture to Improve Energy Efficiency

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ABSTRACT

Vernacular architecture is characterised by a type of formal expression that has been developed in response to a number of factors – climatic, lithologic, cultural and economic – characterising the local area or region. In its various forms, a range of techniques has been employed in different regions to mitigate the effects of climate. Despite the fact that Portugal is a small country, it has a territory full of contrasts, which gave origin to many different architectural manifestations. The approaches adopted in the design and construction of vernacular buildings have the potential for further development and could be adapted in response to contemporary needs. In the future, a blend of tradition and modernity should be aimed at in order to develop a new form of aesthetics and functional construction. Portuguese vernacular architecture is associated with a fund of valuable knowledge that should be studied and aligned with the principles of sustainability. In this paper, is presented the climatic contrast between the northern and southern parts of Portugal and the relation with the purpose of different passive solar techniques used in vernacular architecture to provide comfort. The focus is on the effectiveness of passive cooling techniques (e.g. high thermal inertia, the use of light colours and patios), and the findings of a case study in which the thermal performance during the summer of a vernacular residential building located in the south of Portugal are presented. In the context of the current global drive for clean energy and sustainable buildings, much can be learned from a review of past experience in order to provide an understanding of such forms of construction, which are an intrinsic feature of specific places and have evolved over time in the face of a lack of resources.

INTRODUCTION

Nowadays, sustainability and energy efficiency are inevitable discussion topics for building industry. This industry is one of the largest raw materials and energy-consuming sectors of the economy and responsible for almost a third of all carbon emissions (Ürge-Vorsatz, Danny Harvey, Mirasgedis, & Levine, 2007). In order to address this problem various bodies have set medium and long-term targets for improving efficiency in construction, such the European Union that has outlined a path of 70% of reuse/recycling/recovery of construction and demolition waste by 2020 (European Comission, 2012) and an 80-95% reduction in CO_2 emissions by 2050 (EEA, 2012).

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In order to achieve the above-mentioned objectives, there is an urgent need to rethink the ways of building. In a era of globalization that led to the homogenization of the different ways to build, according to some authors we should reflect on past experience, since traditional buildings are an example of a more sustainable construction and so they could have an important role to play in the future of construction (Foruzanmehr & Vellinga, 2011; Oliver, 2006). Intrinsically bound up with the local conditions, vernacular architecture could contribute towards reducing waste and energy consumption through the use of passive solar design, traditional techniques and local materials, which were developed in accordance with a specific territory and climate (Fernandes, Mateus, & Bragança, 2013; Kimura, 1994; Singh, Mahapatra, & Atreya, 2011).

This paper is focused on energy efficiency (other sustainability categories are not discussed), since this issue is particularly relevant in the contribution of vernacular architecture towards sustainable building. This is because vernacular buildings gave prime importance to passive climate control for ensuring indoor conditions of comfort. Additionally, the strategies used to mitigate the effects of climate are usually low-tech and not very dependent on non-renewable energy, while they do not require special technical equipment, which makes them suitable for contemporary construction, especially passive building design. In this sense it is important to highlight that a passive houses provide the lowest contribution in terms of such equipment as far as LCA results are concerned, mainly due to the fact that there is little need for conventional ventilation and air-conditioning equipment (HVAC) (Passer, Kreiner, & Maydl, 2012).

Although “Energy” is just one of the sustainability categories, several comparative studies (Forsberg & von Malmborg, 2004; Haapio & Viitaniemi, 2008) about Building Sustainability Assessment (BSA) tools have shown that energy efficiency is a relevant aspect of the overall sustainability of a building. For example, according to the Portuguese assessment and rating system (SBTool^{PT}), the “Energy Efficiency” category has the highest weighting (32%) in the assessment of environmental performance and the third highest weighting in the assessment of the global sustainability of a building (Mateus & Bragança, 2011). Energy consumption is also a key issue in terms of the environmental life-cycle impacts of buildings, mainly during the operation stage, and is related to the provision of healthy and comfortable conditions for occupants (Passer et al., 2012)

Nevertheless, some studies have been carried on the passive strategies used in Portuguese vernacular architecture, the state of the art is that there are no results available from *in situ* measurements that can demonstrate the contribution of these different approaches to improve energy efficiency. Therefore, this paper attempts to provide a contribution in this field by presenting both: an overview of the climatic contrast between the northern and southern parts of Portugal and its influence on the type of approaches adopted by vernacular architecture; their potential contribution to passive building design; and the results of a study on the effects of passive cooling strategies on the control of indoor temperature and humidity of a building during summer.

THE CONTRIBUTION OF VERNACULAR TECHNIQUES TOWARDS ENERGY EFFICIENCY

In the past, due to the lack of advanced technological systems for the maximization of comfort, buildings were built using passive systems. While simple and clever, these were based only on the available endogenous resources and on a range of criteria such as: geographical characteristics; insolation; orientation; geometry; form; and materials, among others (Coch, 1998; Oliveira & Galhano, 1992).

The relationship between the built environment and the natural environment is well described by the Roman mythological concept of the *Genius Loci* and has primal importance on buildings’ conception and thermal performance. The significant differences between the way house-construction developed in northern Africa and northern Europe, for example, demonstrates that this was not a random process; similarly, in Portugal, there is a considerably difference between the houses from north and south.

Several quantitative studies on the thermal performance of vernacular buildings conducted in different parts of the world have shown that vernacular buildings achieved acceptable comfort standards throughout much of the year just using passive strategies, in some cases indoor temperatures remaining almost constant (Cardinale, Rospi, & Stefanizzi, 2013; Martín, Mazarrón, & Cañas, 2010; Shanthi Priya, Sundarraja, Radhakrishnan, & Vijayalakshmi, 2012; Singh, Mahapatra, & Atreya, 2010). The results support the idea that passive strategies are in many cases feasible for use in contemporary buildings and that they could contribute to reduce buildings's energy demands for HVAC.

VERNACULAR ARCHITECTURE IN NORTHERN AND SOUTHERN PORTUGAL: STRATEGIES TO SUIT THE CLIMATE

Vernacular architecture in Portugal, as in other countries all over the world, is influenced to a great extent by geographical location. Climate and other geographical features account for differences between the various types of vernacular constructions found in the different regions of this country.

Continental Portugal is located between latitudes 37º and 42ºN in the transitional region between the sub-tropical anticyclone zone and sub-polar depression zone. Beside latitude, the most important features affecting the climate of the territory are orography and the influence of the Atlantic Ocean (Santos, Forbes, & Moita, 2002). With regard to relief, the highest peaks rise to a height of 1,000m to 1,500m, except for the Estrela Mountains, whose highest point is just under 2,000m.

Even though it is a small country, Portugal is a territory of contrasts. In spite of the fact that the variation in climate factors be rather small, it is sufficient to justify significant variations in air temperature and precipitation, such as (Santos et al., 2002):

- Air temperature – in winter the average minimum temperature varies between 2ºC in the mountainous interior zone and 12ºC in the south zone of Algarve; in summer Summer: the mean maximum temperature vary between 16ºC in Serra da Estrela and 34ºC in inner central region and eastern Alentejo.
- Precipitation – in the highlands of the northwest region the mean annual accumulated precipitation is above 3000 mm, one of the wettest zones in Europe; in southern coast and in the eastern part of the territory: the average amount of rainfall is in the order of just 500 mm; southern interior has a Mediterranean climate, well known for its vulnerability to climate variability, namely to droughts and desertification.

To suit different climate conditions Portuguese vernacular architecture developed specific mitigation strategies. In a general form, as shown in Figure 1, it is possible to verify that in the northern part of the country the adopted strategies aim to increase heat gains and to reduce indoor heat losses during winter, while in the south the strategies are more focused on passive cooling during summer.

In order to respond to cold winters, reducing heat losses and taking advantage of solar radiation, vernacular builings from the north frequently used thatched roofs – due to their insulating properties – to reduce heat losses, and south-facing balconies to take advantage of solar radiation. The glazed-balconies are a feature of the architectonic identity of the Beira Alta region and, due to the advantages they bring many are still in use today. They are usually facing between south and west so that they receive the highest number of hours of sunshine and a high level of radiation during the winter, while affording the best shelter from the prevailing winds, as shown in Figure 1 (a). The use of this kind of structures is feasible in refurbishment projects with energy efficiency purposes, as demonstrated at the Residential complex in Dornbirn, Austria, where residents' heating bills have been significantly reduced (Küess, Koller, & Hammerer, 2011).

In the south of the country, in order to minimise heat gain, several techniques were developed, such as (Figure 1 (b)): reducing the size of doors and windows; the use of a high thermal inertia building systems; the use of courtyards (patios); and the use of light colours in order to reflect the excess solar radiation. The effect of these passive cooling strategies on the thermal performance of buildings is described in the case study in the following section.

The abovementioned strategies are relevant to the debate on energy efficiency in buildings because they are aimed at reducing energy consumption and increase the comfort level for occupants by passive means. Despite the advantages of the presented passive strategies, for the Portuguese context there is a lack of quantitative data on the effectiveness of these approaches on the thermal performance of vernacular buildings in different climate zones. Nevertheless, the interpretation of the results of studies conducted in other European countries points to some techniques of Portuguese vernacular architecture being effective and having the potential for use in contemporary buildings.

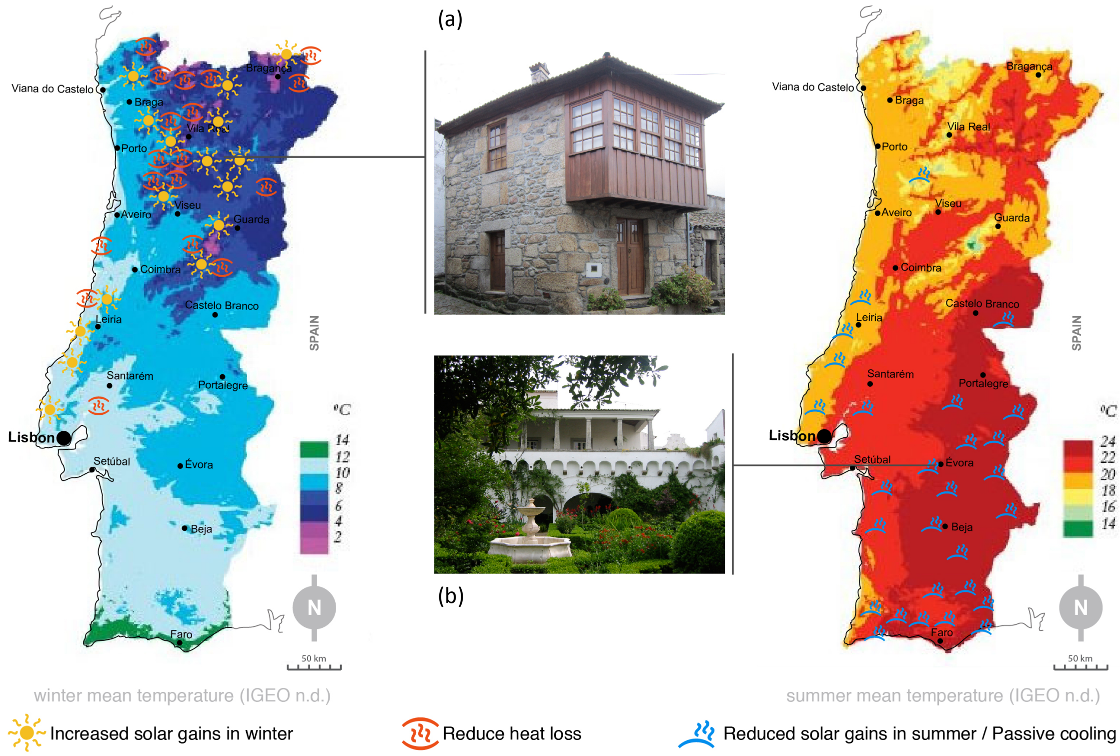

Figure 1 Winter / summer mean temperature maps (IGEO, n.d.) and vernacular strategies distribution; (a) glazed-balcony building; (b) building with a courtyad (*patio*).

PASSIVE COOLING STRATEGIES EFFECT IN THERMAL PERFORMANCE OF A CASE STUDY

Aim and description of the case study

The study presented in this paper is aimed at a quantitative analysis of the contribution of passive cooling strategies, a vernacular approach used mainly in the south of Portugal (Figure 1), in the control of indoor temperature and humidity during the summer to achieve comfort conditions.

The case-study is situated in the historic city centre of Évora, a city located in southern interior Portugal (latitude 38º34’N, longitude 7º54’W). The climate in Évora is Mediterranean temperate (Csa – according to the Köppen climate classification), with hot and dry summers and high temperatures during July and August (with maximum temperatures of 30°C to 40°C, occasionally reaching 45°C) (AEMET & IM, 2011). In July and August severe drought is normal and rainfall is rare, with an average total precipitation of 8,6 and 6,6 mm, respectively (AEMET & IM, 2011).

The monitored building has an L shape, with the façades facing the courtyard oriented to SE and SW, as shown in Figure 2a-b. The courtyard has plenty of vegetation and in which two trees offer considerable shade for the building. The building has two storeys and a total area of approximately 900m^2: the ground floor houses the kitchen, a bedroom, and various storage spaces; on the upper floor there are living rooms and other bedrooms.

The *in situ* measurements were carried out in the ground floor (Figure 2a), which have the following construction features: traditional brick vaulted ceilings, ceramic tile finished floors, lime mortar finished walls and single glazed wooden windows. The average wall thickness of the building is about 100 cm. It was not possible to rigorously determine the composition of the walls but, so taking into consideration that this kind of buildings were usually built with rammed earth or massive brick masonry, it was estimated that the heat transfer coefficient (U-value) is of about 1,00 W/m2.ºC. The floor area of the monitored spaces is approximately of: kitchen – 33m^2; bedroom - 17m^2; courtyard - 600m^2.

Methodology and equipments

The effect of passive cooling strategies in the control of the indoor temperature and humidity of the building was quantified through *in situ* experimental measurements. Two physical parameters were quantified: air temperature (ºC) and relative humidity (RH %). For this purpose, were used three equipment with an internal sensor to measure temperature and relative humidity of the air. It has a measuring range between -35 to 70ºC and an accuracy of ±0.9ºC. Readings recorded can be downloaded to a PC.

Field measurement involved the positioning of units inside and outside the house: one in the courtyard and two inside, in the ground floor: one in the room adjacent to the courtyard (the kitchen) and the other in the bedroom (Figure 2a). Data was recorded continuously over the period from 17th to 26th July 2007; data from the different sensors was recorded at 30-minute intervals. Secondary data for the study was collected at the Geophysics Centre of Évora for the same time period.

Figure 2 a) Ground floor plan showing the position of measuring instruments; b) View of the courtyard (*patio*).

Analysis of results

Indoor air temperature, both in kitchen and bedroom, varied slightly, remaining nearly constant, while in the courtyard there were great fluctuations in air temperature throughout the day (Figure 3). The high thermal inertia of the building is the most probably reason for this, but the presence of abundant vegetation in the courtyard also contributed towards reducing direct heat gain through the envelope by providing shade. In order to provide an understanding of the effectiveness of different passive cooling techniques used in the building, these results were compared with the data recorded in the city centre during the same period. This showed not only the importance of the thermal inertia for reducing variations in indoor temperature but also the role of the courtyard in substantially reducing air temperature around the building. An analysis of recorded data shows that air temperatures in the courtyard always remained lower than those recorded for the city centre, especially during peak periods of heat, with a maximum difference of around 9ºC, as shown in Figure 3. It may also be concluded that this vernacular approach also allows for a delay of approximately 90 to 150 minutes between the moment at which the temperature in the courtyard starts to rise and that at which peak temperatures are reached in the city centre. An analysis of the chart in Figure 3 shows that during daytime, in the city centre, outdoor relative humidity reaches a minimum of about 20% whereas the maximum temperature is nearly 40ºC. For the same period, in the courtyard, minimum relative humidity is nearly 30% and the maximum temperature is about 30ºC. A possible reason to explain the lower air temperature in the courtyard is that the existing vegetation does not allows that this area contributes for the local heat-island effect (Figure 2b). Additionally, both the abundance of vegetation and the presence of a water fountain contribute to the evaporative cooling of the courtyard, thus raising the relative humidity and diminishing the air temperature. Another plausible reason for this difference is that cool humid air, which is consequently dense, remains in the courtyard during the early hours of the morning, until is warmed by the sun. In this confined space, the air takes longer to gain heat than the air in the city centre, thus its temperature remains lower and its relative humidity higher than the air in the city centre during warm periods.

Indoor relative humidity shows slight fluctuations throughout the day with an average of around 50%, the most suitable level for human health and comfort (Morton, 2008). This difference between indoor and outdoor relative humidity can be explained by the use of materials that contribute to the regulation of indoor humidity. Indoor wall surfaces and ceilings are covered with lime plaster, with a thickness of about 3cm. This material regulates the quality of the indoor environment, as it is not only permeable to water vapour but also contributes towards moisture buffering (Berge, 2009), i.e. it moderates changes in relative humidity by absorbing moisture from the surrounding air and, when the air is less humid, giving off absorbed moisture.

In what concerns the assessment of the thermal comfort conditions indoors, was applied an adaptive model of thermal comfort, since this is the most adequate model for naturally conditioned areas, and used a psychrometric chart representing Évora's climate conditions and the adaptive comfort range for July. Due to high fluctuations in outdoor temperature and humidity between night and day, the thermal conditions for each indoor space were represented separately for day and nigh. Analysing the results it is possible to conclude that both kitchen and bedroom spaces have thermal conditions within the limits of the adaptive thermal comfort range for summer in the majority of the days without any mechanical cooling system, as shown in Figure 4. Only the bedroom did not reach the comfort conditions in two days. However, is very close to the comfort limit.

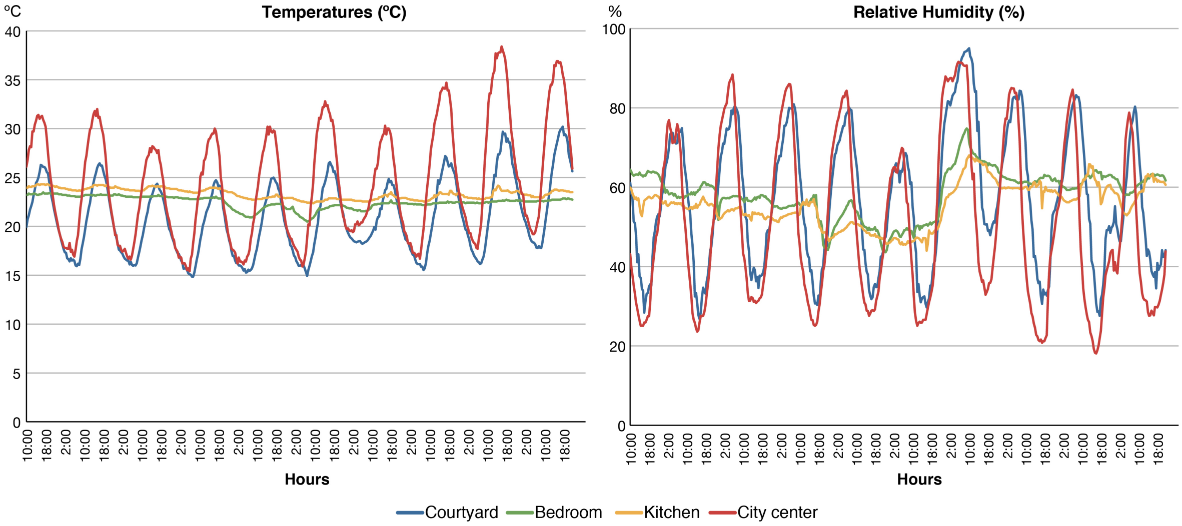

Figure 3 Indoor and outdoor temperature and relative humidity profiles.

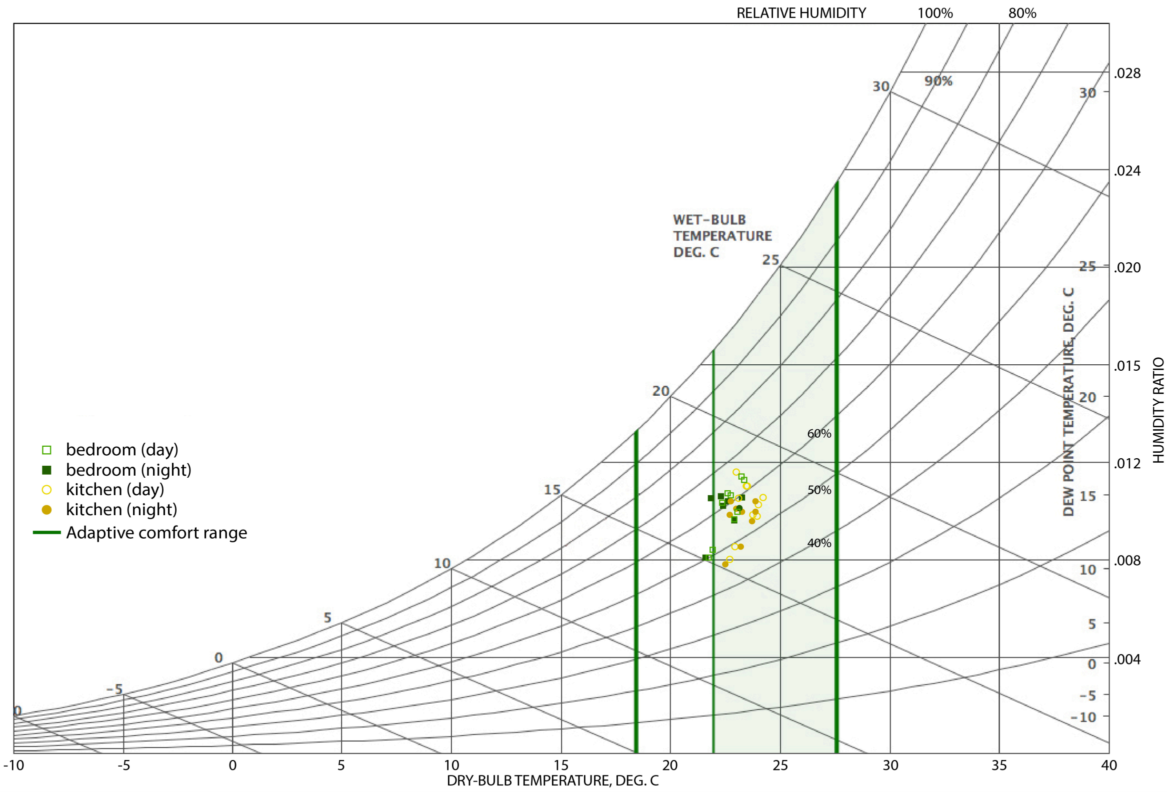

Figure 4 Psychrometric chart for Évora representing the indoor comfort conditions in the case-

study, applying the Adaptive Comfort Model in ASHRAE 55 (2010) (Chart adapted from: "Climate Consultant 5.5," 2014)

DISCUSSION AND CONCLUSIONS

Vernacular architecture is the paradigm of the interaction between architecture and climatic conditions. The techniques presented in this paper, due to their simplicity and pragmatism, have great potential for use both in the design of refurbishment projects and the construction of new buildings. For example, the passive cooling strategies employed in the south of the country, as shown in the case study in Évora, are simple to implement and can improve indoor comfort conditions in buildings during the summer season. Our findings show a difference of 7ºC and 16ºC between indoor temperatures and the peak outdoor temperatures (recorded in the courtyard and in the city centre, respectively) and the psychrometric chart showed indoor spaces within the thermal comfort limits during all the monitoring period, which means that such a vernacular approach has great potential for decreasing energy consumption by means of active cooling systems. These results are achieved by combining several passive-cooling strategies, such as: whitewashed walls; small exterior doors/windows; high thermal inertia walls; and courtyards or *patios*. In these strategies, the two last have considerable influence in indoor climate. The courtyard revealed to have a large influence on the creation of a microclimate near the building, with air temperatures remaining lower than those recorded for the city centre, with a maximum difference of around 9ºC. It is likely that these features affect the thermal performance of the building during the winter. However, taking into consideration the regional climate classification considered in the Portuguese Regulation for Energy Performance of Buildings (DL118/2013, 2013), the most difficult issue to solve in this region is the hot summer period.

With an opposite purpose, the balconies in Beira Alta provide an efficient mean of increasing solar gains and preventing heat loss, are easy to install and play an important role in minimising heating requirements. It may also be concluded that these strategies are perfectly adapted to the local area in which they were developed and there is no negative aesthetic impact on buildings.

Vernacular knowledge on passive strategies is relevant when current buildings are known to have a high level of energy consumption for providing air conditioning. It is imperative that priority is given to building design that adopts passive methods for controlling the indoor climate, limiting mechanical systems no more than a backup role, to be used only when the passive strategies are not sufficient for meeting the comfort needs of occupants. This paper assesses in holistic terms this architectural manifestation in the light of current knowledge in order to seek scientific justification for the principles of vernacular architecture and validate and promote its use in the future. However, there are limitations to this study and some aspects are only discussed qualitatively. Further studies are required to provide quantitative assessments in order to generate specific scientific information about the thermal performance of vernacular buildings in Portugal. More accurate information about the contribution of passive vernacular solar strategies would be useful for architects and engineers concerned with climate-responsive and energy efficient buildings and therefore could provide a contribution to the sustainability of buildings.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support granted by the Portuguese Foundation for Science and Technology (FCT) in the scope of the projects with the references PEst-OE/ECI/UI4047/2014 and EXPL/ECM-COM/1801/2013, that were fundamental for the development of this study.

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