Evaluation of bioclimatic design features of vernacular architecture in Cyprus. Case studies from rural settlements in different climatic regions.

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ABSTRACT: Traditional settlements are characterized by their adaptability to the local climatic conditions, available resources and topography and they incorporate a variety of bioclimatic design elements. This study is part of an extensive research program undertaken by the University of Cyprus, dealing with the implementation of bioclimatic design elements of vernacular architecture in the environmental rehabilitation of traditional buildings. The paper aims at the investigation of the passive responses of the vernacular architecture of rural settlements in Cyprus. For this purpose, three rural traditional settlements located in different climatic regions of the island have been systematically investigated. A comparative study of the building typology, the building materials and the integrated passive cooling and heating strategies inherent in the design of selected structures has been addressed through the study of 90 traditional dwellings. The study showed that traditional buildings are well suited to local topography and the prevailing climatic conditions. The environmental features inherent in their design offer thermal adaptive opportunities to the occupants while the combination of architectural typology and the use of local building materials and techniques create site-specific sustainable design practices. Research outcomes suggest environmental refurbishment practices for traditional buildings, emphasizing the preservation and enhancement of bioclimatic features in vernacular built stock.

1 INTRODUCTION

The vernacular architecture of Cyprus is mainly derived from local lifestyle, available building materials, socio-economic factors, local climate and the topography of each region. Through the examination of the environmental aspects of traditional architecture a series of passive design strategies incorporated in traditional buildings can be noted. However, since most of the traditional design concepts and construction techniques have been recently abandoned, the traditional environmental design features are systematically neglected in rehabilitation practices and contemporary construction guidelines. For that reason, there is a need for the rediscovery and understanding of best practices from the past so as to gain valuable insights through a specifically directed research process. Recent studies undertake the documentation and codification of the passive environmental design aspects present in vernacular architecture. The study of Philokyprou et al (2013) with regard to the urban traditional architecture of Cyprus showed that the compact built form, the high thermal mass of the building envelope, the semi-open and open enclosures and the appropriate arrangement of window openings, offer opportunities for thermal adaptability that address user comfort especially during the cooling period. Furthermore, the research of Kumar Singh et al (2011) underlines the adaptation of vernacular architecture with respect to building layout configuration and building materials, to the different climatic regions of North-East India.

The main objective of this paper is to discern valuable knowledge and lessons from local vernacular architecture –focusing on the environmental design parameters– with the purpose of revealing new opportunities in the rehabilitation of vernacular built stock. The study focuses on

the analysis of data registered during on-site observations of the authors of 90 traditional buildings in three rural vernacular settlements of Cyprus – located in different climatic regions. The study discusses these findings and compares the results derived from each case study settlement. The paper concludes with a qualitative assessment of the environmental performance of vernacular buildings.

2 RESEARCH METHODOLOGY

The research study examines the bioclimatic design elements of the traditional buildings using three vernacular rural settlements of Cyprus as case studies – namely Maroni, Pera Orinis and Askas villages located in three distinct climatic zones and topographies. The settlements under study have been selected as an appropriate and representative sample, with reference to traditional typologies and methods of construction, as well as because of their climatic and topographical diversity. In considering the four climatic regions of Cyprus – Coastal Regions (CZ1), Plains (CZ2), Semi-Mountainous Regions (CZ3) and Mountainous Regions (CZ4) – Maroni village is representative for climatic zone 1, Pera Orinis for both climatic zones 2 and 3, and Askas village for climatic zone 4.

The proposed research methodology is based on a survey of the environmental design aspects of 30 representative traditional buildings located within the core of each settlement. The survey consists of on-site observations, photographical documentation of solar passive features, study of topographical maps and tabulation of the gathered information for comparative analysis. The tabulation provides information regarding (a) building typology, (b) condition of the building, (c) occupancy, (d) passive heating strategies, (e) passive cooling strategies, (f) strategies for the improvement of outdoor microclimatic conditions and (g) building materials and techniques of the building envelope (Figure 1). The collected data focus on the codification of the environmental design aspects of the various traditional building layouts which include the presentation of passive heating and cooling design elements and on design principles that improve related microclimatic conditions.

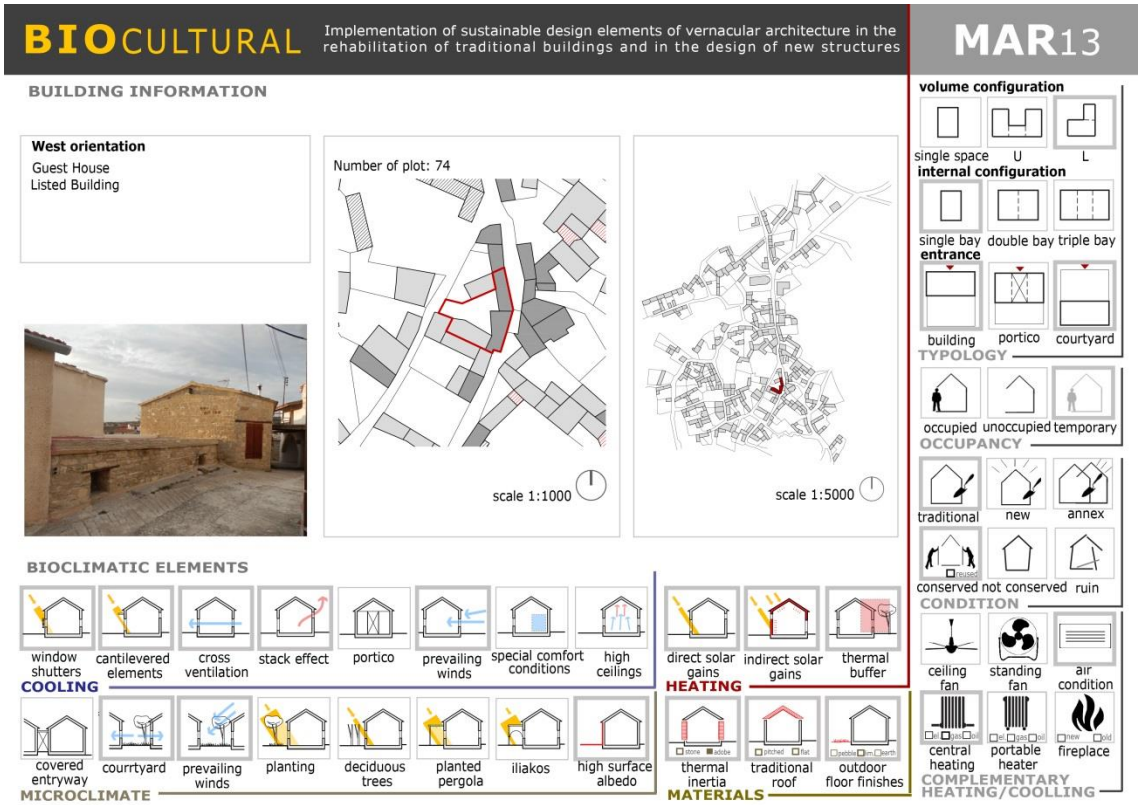

Figure 1 Representative data sheet for the registration of typological data and bioclimatic elements of traditional buildings.

The study also assesses the environmental performance of buildings in the selected case study settlements (coastal areas, plains and mountainous areas) using a detailed investigation of the variety of architectural solutions generated by the integration of traditional building elements to the specific topographic and climatic conditions of each region under study.

3 BUILT AND CLIMATIC CONTEXT OF THE CASE STUDY SETTLEMENTS

Maroni lies within the Larnaca district at a latitude of 34° 45´N and longitude of 33° 21´E, 2 km from the shore (Figure 2a and 2b), within climatic zone 1. The village is located on the southern foothills of the Troodos mountain range, 70 m above sea level. Due to its location, Maroni enjoys a southern exposure which maximizes solar penetration during the heating period (winter season). The settlement is characterized by a semi-dispersed configuration, low-rise development (single or double storey buildings), continuous building block massing and narrow streets. Relative humidity in the area is fairly high throughout the year due to its proximity to the coast and for the same reason seasonal diurnal fluctuations are limited generating mild winters and summers. Mean average temperatures during winters and summers reach 12.5°C and 25.7°C respectively. Mean summer maximum temperatures reach 33.6°C whereas mean minimum winter temperatures reach 6.1°C (Figure 3a).

(a) (b)

Figure 2 (a) Map of Cyprus indicating the three settlements under study and (b) Images indicating Maroni, Pera Orinis and Askas settlements respectively.

The prevailing winds –usually low to medium speed– blow from the northwest (land breezes) and southwest (sea breezes) during summers and from the northwest during winters (Passiardis, 1995). The relatively strong southwesterly summer sea breezes can improve user comfort. Total annual precipitation is rather low reaching 384 mm, while rainfall is rare during the summer months. The average relative humidity during summertime reaches 68% (Figure 3b).

Pera Orinis is located inland in the high plains – at an elevation of 400 m. The village lies within the Nicosia district at a latitude of 35° 2´N and a longitude of 33° 15´E. The village is located at the boundary of transition between climatic zones 2 and 3. It has a semi-compact configuration and a low-rise (single or double storey buildings) and continuous building block massing. Its semi-compact configuration increases mutual shading between buildings during the summer period. Summers in Pera Orinis are relatively harsh and winters are mild due to the location of the village further inland. Mean average winter temperatures reach 10.2°C and mean average summer temperatures reach 26.7°C. Mean maximum summer temperatures reach 35.5°C whereas mean minimum winter temperatures reach 5.7°C (Figure 3a). Annual rainfall reaches 342 mm whereas high summer aridity causes a significant drop of the average relative humidity during summertime (46%). The prevailing winds –usually low to medium– blow from the west and east during winters and from the west during summers due to the location of the settlement between the Pentadaktylos mountain range to the north and the Troodos mountain range to the south.

Askas lies at a latitude of 34° 55´N and a longitude of 33° 4´E, within climatic zone 4. The village is located in the Nicosia district upon the southeastern slope of the Askas river valley –at an elevation of 900 m – on mountainous terrain. Due to its topography, the settlement enjoys a

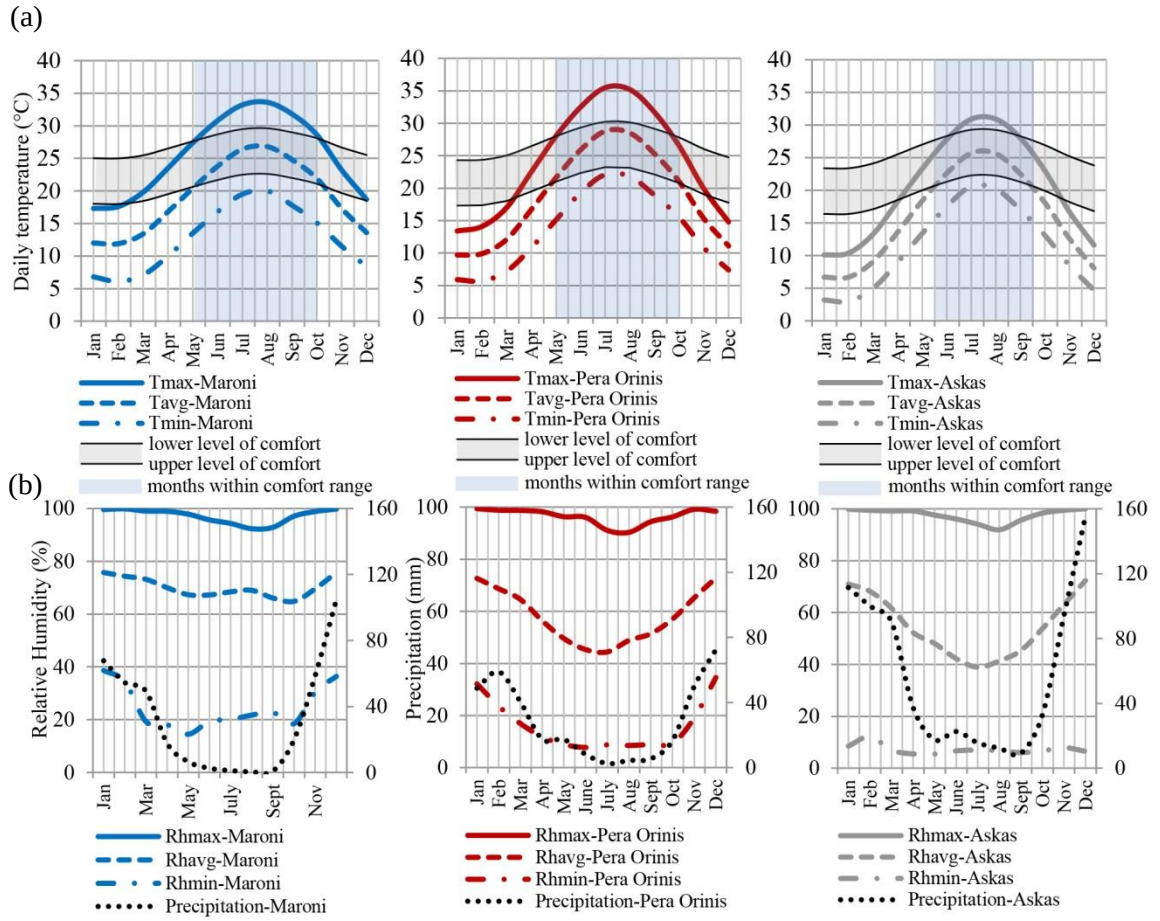

Figure 3 (a) Mean minimum, average and maximum air temperature, comfort range limits (±3.5, 80% acceptability limits) using Ashrae Standard 55 (T_n=17.8+0.31T_{avg}) and months within comfort range (b) Mean minimum, average and maximum relative humidity and average monthly precipitation at Maroni, Pera Orinis and Askas villages respectively.

southern exposure and avoids excessive western solar heat gains. The settlement has a compact, mid-rise built configuration of three or four stories and deep and narrow streets. These features reflect the prevailing topographical constraints and the lack of space as well as the noticeable extension of the building stock vertically. The planning configuration of the settlement considerably enhances desirable shading of the public and private open spaces during the cooling period (summer season). Winters in Askas are rather chilly and summers are mild due to the high altitude on which the settlement is located. Mean average temperatures reach a low of 7.2°C and a high of 24.6°C during wintertime and summertime respectively. Mean maximum temperature reaches 30.9°C while mean minimum temperature reaches 3°C. As shown in Figure 3b, total annual precipitation for the region is 699 mm, making it significantly higher than Maroni and Pera Orinis settlements, while average humidity during summers reaches 41% (Figure 3b).

4 RURAL TRADITIONAL DWELLING TYPOLOGY WITH RESPECT TO ENVIRONMENTAL DESIGN ASPECTS

Tracing the evolution of the rural traditional dwelling of Cyprus, the *monochoro* (i.e. single-space room - *macrynari*) typology has been the archetypal building layout configuration. The extension of the room –with the purpose of better accommodating the everyday activities of the occupants– resulted in the development of the *dichoro* (i.e. double-space room) typology (Sinos, 1976). The *monochoro* typology can be found in the form of *platymetopo* characterized by a shallow space with a wide building frontage or *stenometopo* characterized by a deep plan layout with a narrow building façade, i.e. narrow frontage (Papacharalambous 2001) (Figure 4a). *Dichoro* resembles to a greater degree a square space with a deep plan layout (Figure 4b).

Stenometopo and *dichoro* occur in more compact building forms compared to *platymetopo*. From the environmental perspective, the façades of *stenometopo* and *dichoro*, while being less exposed to ambient temperatures and wind conditions, incur smaller heat losses through their building envelope. However, *platymetopo* offers better potential for natural daylight and ventilation due to its elongated façade and shallow layout configuration.

In the context of rural traditional settlements, *monochoro* and *dichoro* can be found in linear shaped, L-shaped or U-shaped configurations around central courtyards. The L-shaped and U-shaped forms provide desirable mutual shading between building volumes, enhanced shading of the open enclosures and opportunities for cross-ventilation of the indoor spaces. Such configurations provide desirable conditions during the cooling period. On the contrary, linear configurations being more compact and less exposed to ambient temperatures, are more environmentally efficient during the heating period.

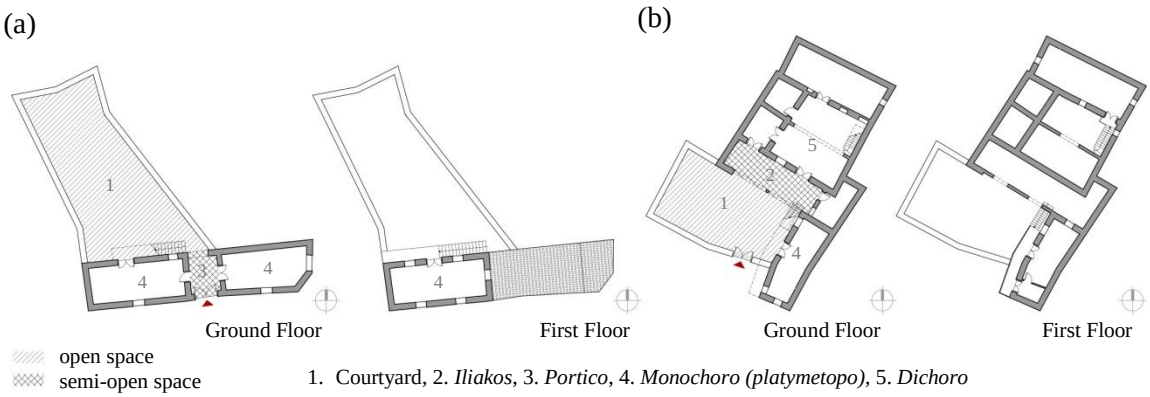

Figure 4 Typical rural dwelling typologies (a) *Monochoro* typology with *portico* in linear shaped configuration (b) *Dichoro* typology with *iliakos* in L-shaped configuration.

Semi-open transitional spaces and courtyards are also fundamental parts of the traditional dwelling typology. *Iliakos* (i.e. semi-open space), *portico* (i.e. semi-open pass-through space) and *covered entryway* constitute the most typical semi-open transitional spaces in rural traditional architecture in Cyprus (Figure 5). *Iliakos* is usually an arched space in the form of a wide corridor, attached to the main building. *Portico* and *covered entryway* are deep pass-through spaces which connect the street with an internal courtyard. The difference between *portico* and *covered entryway* is that the former provides access to both an internal courtyard and interior spaces of the dwelling while the latter only offers entrance to the internal courtyard. *Iliakos* – usually oriented due south in rural settlements– allows sunlight to enter the indoor spaces during the heating period when the solar altitude angle is low. During the cooling period when the solar altitude angle is high it prevents unwanted solar penetration to the interiors and provides a shaded semi-open space for outdoor activities (Sinos 1976). *Portico* and *covered entryway* due to their deep plan layout provide enhanced cross-ventilation through the building volumes and shading during the summer period. Internal courtyards due to their sheltered configuration mitigate weather extremes, especially if planted. Such open spaces also shield the buildings from unwanted cold winds during the heating period and ensure adequate natural ventilation, passive solar heating and daylight penetration to the building interiors.

A limited number of vernacular dwellings in rural settlements and the majority of the dwellings in urban areas follow a more compact configuration. They are mainly comprised by the *trimeres*, i.e. a plan layout which is divided into three zones (triple bay space). The *trimeres* typology consists of a central pass-through space, in the form of a semi-open or closed *portico*. From the environmental perspective, the *portico* constitutes a key feature. Due to the existence of openings at both its ends and its central configuration it offers enhanced cross-ventilation and it also facilitates natural ventilation of its adjacent spaces.

The different topographies and local climates related to the rural traditional settlements resulted in typological variations of the traditional dwellings. The coastal settlements of Cyprus, such as Maroni, are usually located on hilly landscapes or in the plains where moderately dispersed or semi-compact configurations are typical. Buildings in such regions are usually arran-

Figure 5 Open and semi-open typological features of the rural traditional dwelling (a) *iliakos*, (b) *portico*, (c) internal courtyard.

ged in linear and L-shaped configurations around courtyards and usually have elongated facades that allow enhanced natural ventilation. In settlements located in the plains, such as the case of Pera Orinis, moderately dispersed or semi-compact configurations are prevalent as well. In these regions the courtyard and semi-open *iliakos* form the central core of the dwelling and L-shaped and U-shaped building arrangements around the internal courtyard are typical. In the case of mountainous settlements, such as Askas linear shaped and compact building configurations are prevalent providing protection from excessive heat losses during the heating period. Due to the steep terrain, a vertical building layout was usually developed. For the same reason, the lowest floor of these buildings usually resulted in partially subterranean spaces. Due to topography restrictions semi-open spaces and courtyards are limited. As a result of this, intermediate floors or roof tops are characterized by open and/or semi-open spaces, which are used as verandas.

5 ENVIRONMENTAL DATA ANALYSIS

The analysis that follows is the result observations and data gathering as spelt out in the research methodology.

5.1 Building layout configuration and typology

Regarding building layout configuration, in the case of Maroni (CZ1), linear shaped and L-shaped building configurations are predominant –constituting 50% and 40% of the building stock respectively– whereas at Pera Orinis (CZ2/3) there is a more even distribution among linear (37%), L-shaped (26%) and U-shaped (37%) building configurations (Figure 6a). In the case of Askas (CZ4) the majority of buildings (90%) have a linear and compact spatial layout. The predominance of the L-shaped and U-shaped configurations at Pera Orinis offer the poten-

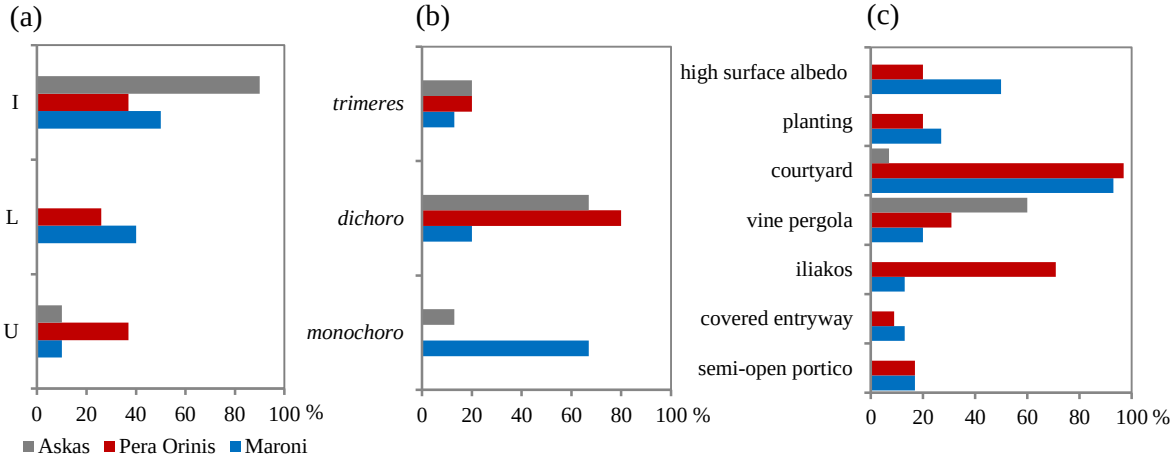

Figure 6 Summary of the research results for the settlements under study: (a) Building configuration, (b) Building typology and (c) Microclimatic conditions.

tial for mutual shading between buildings, shading of internal courtyards and enhanced wind penetration of the building interiors during the cooling period.

Regarding building typologies, the shallow *monochoro* and *platymetopo* spaces dominate in the case of Maroni village at a percentage of 67%. Such typologies offer a greater potential for enhanced natural daylight and natural ventilation. On the contrary, in the case of Pera Orinis and Askas, the compact *dichoro* space prevails constituting 80% and 67% of the building stock respectively. The *dichoro* space minimizes the building envelope heat losses during the heating period. However, the *dichoro* spaces of the dwellings at Pera Orinis, while having "deeper" plan than comparable dwellings at Askas, reduce the potential for natural daylight and ventilation. It is noted that, a small percentage of the building stock under study, is designated as the urban *trimeres* typology (Figure 6b).

5.2 Microclimatic conditions

Semi-open spaces: Research results showed that semi-open arrangements are most frequently found in the case of Pera Orinis village rather than Maroni and Askas villages. This fact is mainly related to structural, socio-economic, topographic and climatic reasons. Data analysis indicates that the different types of semi-open transitional spaces (i.e. *iliakos*, semi-open *portico*, *covered entryway* and vine pergola), which are predominant in each of the three settlements under study, have been adapted to the local climatic conditions. As shown in Figure 6c, in the case of Maroni the semi-open *portico* and *covered entryway* account for 17% and 13% of the village's buildings respectively, whereas *iliakos* occasionally appears in the building layout configuration for 13% of the building stock. In coastal regions, with high humidity such as Maroni village, the *portico* and the *covered entryway* are very effective in improving thermal comfort while they provide enhanced cross-ventilation. In the case of Pera Orinis, *iliakos* dominates with a presence of 71% in examined building stock, whereas semi-open *portico* and *covered entryway* account for 17% and 9% of buildings respectively. Semi-open structures such as *iliakos*, which offers protection from high solar intensity in the cooling period, is very important in the hot and arid regions such as Pera Orinis. In the case of Askas, deciduous vine pergolas located on elevated verandas (60%) are preferred. Vine pergolas allow solar penetration during the heating period and provide shade during the cooling period. Such configurations are sometimes found on roof tops (13%). *Iliakos* and semi-open *portico* rarely appear in the case of Askas village.

Open enclosures: As shown in Figure 6c, the internal courtyards are a main architectural characteristic and bioclimatic element in the case of Maroni (93%) and Pera Orinis (97%). In contrast, lack of space due to the mountainous topography in the case of Askas village restricted the incorporation of internal courtyards to only 7%. Planting within the courtyards is limited to 27% and 20% of the building stock in the case of Maroni and Pera Orinis settlements respectively. The water shortages on the island resulting from summer drought could explain why planting is generally limited. Thus, benefits from the cooling effect of trees via evapotranspiration and shading are not enjoyed. Furthermore, the non-shaded courtyard floors usually with massive and hard surfaces (e.g. limestone, cobblestone) lead to a daytime air and radiant temperature increase causing human discomfort during the cooling period.

5.3 Passive cooling strategies

Window shutters: Shutters are a characteristic feature of Mediterranean vernacular architecture, offering privacy, safety and protection from intense daylight and sunshine during the cooling period, as well as a reduction of heat losses during heating period. As shown in Figure 7a, shutters, i.e. timber planked or louvered shutters appear in 70% of the building stock in the case of Maroni and Askas, whereas in the case of Pera Orinis they account for 97% of the building stock. Timber planks prevail by constituting 72%, 65% and 100% of the shutters in the case of Maroni, Pera Orinis and Askas respectively. Timber shutters with adjustable louvers were registered at Maroni and Pera Orinis in 28% and 35% of the sample taken, respectively. Research results indicate that in the case of Maroni and Askas, a significant number of traditional timber shutters were removed in recent years, canceling this passive environmental controller. It is also

observed that timber shutters with adjustable louvers, which are characteristic of urban vernacular architecture, were introduced in the rural traditional settlements, especially in those situated near urban centers. Shutters with adjustable louvers offer better daylight and thermal control to the occupants compared to timber planks.

Natural ventilation: The environmental data analysis showed that the traditional dwelling of Pera Orinis combines strategies for extensive cross-ventilation and stack ventilation, whereas in the case of Maroni and Askas only cross-ventilation constitutes a predominant passive cooling strategy in buildings (Figure 7a). Specifically, cross-ventilation accounts for 67%, 74% and 70% of traditional buildings in the case of Maroni, Pera Orinis and Askas respectively. Cross-ventilation is also achieved through the closed *porticoes* which characterize the urban typology of traditional dwellings. Closed *porticoes* are most commonly found in the case of Pera Orinis (34%). Security reasons, i.e. the absence of street-facing windows at ground level and compact built forms, as well as structural constraints and topographical restrictions, limited the application of double-sided windows in indoor spaces and thus the application of a cross-ventilation strategy. Stack ventilation is achieved through small clerestories known as *arseres,* which appear in 13%, 63% and 10% of the building stock in the case of Maroni, Pera Orinis and Askas respectively.

Natural cooling: At the rear interior space of the *monochoro* or *dichoro* the *sospito*, i.e. inner house, constitutes the storage space. *Sospito* is usually a windowless room (or with small and sparse openings), with low lighting levels and significantly lower temperatures compared to the other interior spaces. Functioning as a storage room for food products, it is particularly widespread at Pera Orinis and Askas constituting 60% and 93% of the surveyed building stock respectively. In the case of Askas this storage space forms part of a partially subterranean level at the lowest floor of the building (Figure 7a).

High ceilings: Pera Orinis dwellings greatly benefit from high ceiling spaces which contribute to user comfort during the cooling period. This is attributed to the fact that the stratification of the air in the case of high-ceilinged spaces affords occupants the benefit of lower air-temperatures while the effect of high solar heat gains through the roof is minimized (Asimakopoulos, 1996). High ceiling rooms account for 27%, 80% and 7% of buildings studied in the case of Maroni, Pera Orinis and Askas respectively.

5.4 Passive heating strategies

Solar heat gains: The majority of buildings under study enjoy direct solar gains through window openings as well as indirect solar gains through the building envelope (Figure 7b). Specifically, direct solar gains account for 90%, 89% and 90% of the building sample at Maroni, Pera Orinis and Askas respectively. It can be concluded that, either the dense fabric or the semi-open spaces attached to the buildings limit the potential for direct solar gains in a limited number of buildings.

Thermal buffering: The continuous building block massing, which characterizes the settlements examined, reduces the exposed surface area of the building envelope to the outdoor environment. Such building configurations lead to a significant reduction of heat losses through the building envelope during heating period (Yannas 1994). The continuous building block massing accounts for 80%, 77% and 93% of the buildings studied in the case of Maroni, Pera Orinis and Askas respectively (Figure 7b). It can be noted that the majority of buildings under study benefit from the thermal buffering effect of adjacent buildings to a large extent especially in the case of Askas village.

5.5 Building materials

Traditional buildings in the settlements under study benefit from thick, high thermal mass, masonry walls. High mass walls have the ability to regulate indoor maximum temperatures, especially during the hot summer days (Decay & Brown 2001). In the case of Maroni the local stone, i.e. ashlar light-colored limestone, accounts for 63% of masonry, while mixed construction, i.e. limestone and adobe, is less widespread (37%). In the case of Pera Orinis, adobe masonry built on top of stone bases of 1-1.5 m in height, prevail (100%). In the case of Askas village, local stone, i.e. rubble dark-colored volcanic stone, is the most common material used

(87%) while mixed construction, i.e. volcanic stones and fired bricks, is limited (13%) (Figure 7c). Besides the materiality of the wall, the surface albedo of the wall also affects indoor comfort. Interior, light-colored, high surface albedo wall surfaces –typical in rural traditional buildings– improve visual comfort conditions while contributing to the uniform distribution of natural light. Visual comfort constitutes an essential environmental design aspect in the context of traditional buildings where daylighting problems are fairly common due to their small window to floor area ratio. In the case of Maroni, Pera Orinis and Askas the majority of buildings (77%, 100% and 84% respectively) retain their light-colored interior wall finishes.

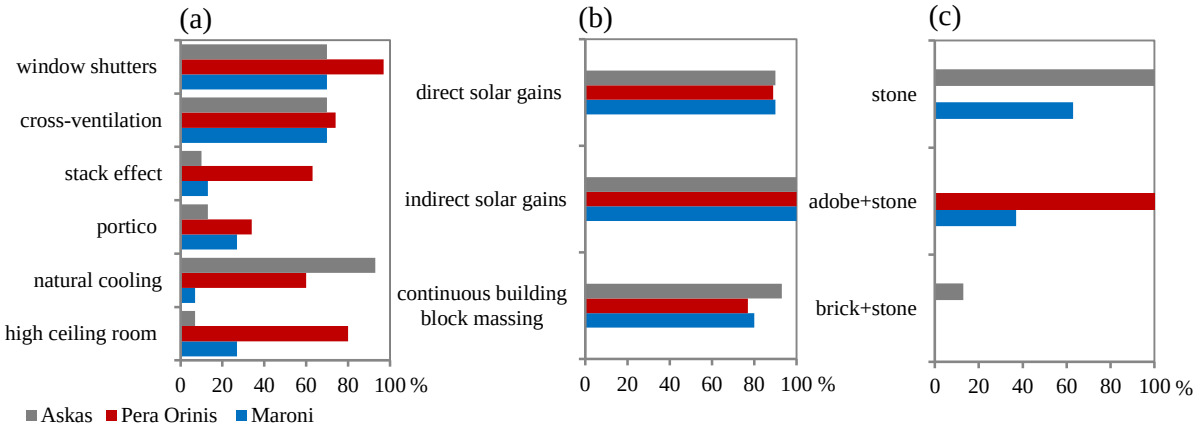

Figure 7 Summary of the research results for the settlements under study: (a) Passive cooling strategies, (b) Passive heating strategies and (c) Building materials.

6 CONCLUSION

The study showed that the traditional dwellings are well integrated to their natural environmental and local climatic conditions. Specifically, the building typology, the building materials and the inherent passive techniques for heating and cooling of traditional buildings significantly define the form and layout of building volumes. In the case of Maroni, Pera Orinis and Askas the main concern is to provide improved comfort conditions during the hot and sunny summers (cooling period) and cold winters (heating period).

The research revealed that traditional dwellings integrate a wide variety of passive cooling opportunities that offer cross-ventilation, stack effect and sun shading using overhangs, vine pergolas, window shutters, high-ceilinged rooms and high thermal mass walls, as well as through the use of spatial configurations, such as the internal courtyard, *iliakos*, *portico*, *sospito* and the partially subterranean rooms. Additionally, it was observed that traditional dwelling typologies, which are characterized by elongated plans and wide building facades, offer enhanced opportunities for natural ventilation. The research showed that passive cooling strategies are more prevalent in the case of Pera Orinis compared to the coastal Maroni and mountainous Askas. This fact might be related to the harsher summers at Pera Orinis compared to the other case study settlements and it has led to the wide adoption of passive cooling techniques to overcome high summer daytime temperatures.

The traditional buildings studied showed that direct and indirect solar gains constitute the main passive heating strategies during the heating period for the buildings in the settlements under study. Additionally, compact built forms, i.e. linear building shapes, continuous building block massing and narrow building frontages, ensure reduction of heat losses through the building envelope and contribute to thermal comfort during heating period. In general, a particular concern for protection from low winter temperatures is observed in the case of Askas village through compact building configurations. This is probably attributed to the chilly winters as well as the mountainous terrain of the settlement, which in turn have led to the noted design solutions, both at the settlement, as well as at the building scale.

The microclimatic data collected showed that the typical dwelling at Pera Orinis is dominated by the *iliakos* space and internal courtyard, the typical dwelling of Maroni village is mainly characterized by courtyards and the Askas dwelling by deciduous vine pergolas. Overall, the

village of Pera Orinis offers a wider variety of semi-open and open spaces when compared to Maroni and Askas villages. This fact is linked to the need for mitigation of extreme summer temperatures.

The analysis above showed that vernacular architecture may offer valuable lessons both for the rehabilitation of built heritage, as well as for the environmental design of contemporary buildings. Future research will focus on the quantitative assessment of the environmental performance of traditional buildings to be derived from on-site measurements of indoor thermal conditions and extensive simulation studies, in order to propose environmental solutions for the preservation and enhancement of bioclimatic features in vernacular stock and in new construction.

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