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Environmental Features of Vernacular Architecture: The Case of Cyprus

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The sustainability of vernacular dwellings is closely connected with the fulfilment of the daily needs of the inhabitants, as well as the incorporation of multiple environmental features into their design. These environmental features ensure a climate responsive approach and improve the thermal performance of the dwellings. The vernacular architecture of Cyprus follows the main principles of vernacular architecture in the eastern Mediterranean region as a whole, and thus it is considered as a typical case study, suitable for in-depth investigation. The research findings presented here are an overview of systematic research carried out over the last ten years at the University of Cyprus, mainly through two multidisciplinary research programmes. Specifically, various environmental aspects were thoroughly investigated, starting from the selection and investigation of rural and urban settlements in different climatic areas (urban scale), moving to the building scale and to the selection of a representative number of vernacular dwellings for qualitative, as well as quantitative investigation. Following this, the research focuses on the different spaces within the dwellings (such as courtyards, semi-open spaces and subterranean areas), as well as on various passive strategies (such as ventilation and lighting), ending with the investigation of the thermal behaviour of the traditional building materials used for the erection of the aforementioned dwellings. The research reveals the necessity for a qualitative and quantitative assessment of vernacular architecture through a multicriteria process, and indicates a methodology that can be implemented in other similar cases especially around the Mediterranean area.

Introduction-Theoretical Framework

This paper aims to present a systematic, methodological approach towards the investigation of vernacular architecture, with emphasis on its bioclimatic features. It will also briefly touch upon the environmental perspective of the conservation of vernacular dwellings, considering the vernacular architecture of Cyprus as a typical case study.

Vernacular architecture has been growing over time with continuities, changes, transformations and adaptations to the different socio-economic conditions of each period.[1] According to Paul Oliver, vernacular architecture is the architecture of the people. This type of architecture is also closely related to the environmental context and available resources, as it is built using local materials and following traditional techniques. All of its forms are closely connected with

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1. M. Philokyprou, "Continuities and Discontinuities in the Vernacular Architecture," *Athens Journal of Architecture* 1, no. 2 (2015): 111-120.

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the satisfaction of the daily needs of the inhabitants, accommodating the values and ways of life of the different cultures that produce them.

Throughout the ages, vernacular dwellings have been reused, adapting to changing conditions and thus providing a direct link with the previous era. The sustainable identity of these dwellings comes from the incorporation of many environmental features into their design, as well as the use of local materials and resources, and the simple ways the inhabitants' needs are met. The environmental features ensure a climate responsive approach, improving the thermal conditions inside the dwellings. The vernacular architecture of Cyprus incorporates the same principles of Eastern Mediterranean vernacular architecture, thus may be considered a typical case study of vernacular architecture, suitable for the investigation described in this paper.

It is worth noting that the preservation and rehabilitation of vernacular dwellings contributes to local economies in a very positive way, generating local demands, preserving building crafts, and safeguarding the cultural identity of traditional settlements. Thus, the adaptive reuse of vernacular dwellings is an extremely sustainable method of development, as it covers all aspects of sustainability.

In Cyprus, vernacular architecture and its environmental features were not studied and documented in a systematic way until recently. Meanwhile, many vernacular buildings are being conserved and restored without taking the preservation and enhancement of their environmental elements into consideration, instead giving more emphasis to their aesthetic values and appearance. For this reason, there has been particular need for the documentation of vernacular architecture and its environmental features.

Literature Review

Different methodologies were diachronically implemented so as to investigate the environmental features and thermal performance of vernacular structures in different climatic areas.[2] A large number of qualitative studies were carried out evaluating various architectural parameters and bioclimatic characteristics,[3] sometimes focusing on socio-cultural issues,[4] as well as on geographical diversity.[5] Many studies involve the preparation of charts – either bioclimatic,[6] or psychrometric.[7] In addition, many quantitative[8] studies include

2. T. Cardinale, D. Colapietro, N. Cardinale, and F. Fatiguso, "Evaluation of the efficacy of traditional recovery interventions in historical buildings. A new selection methodology," *Energy Proc* 40 (2013): 515-524; X. Casanovas, *RehabiMed method traditional Mediterranean architecture* (Barcelona: Collegi d'Aparelladors i Arquitectes Tecnics de Barcelona), 2007.

3. A. M. Vissilia, "Evaluation of a sustainable Greek vernacular settlement and its landscape: architectural typology and building physics," *Build Environ* 44 (2009): 1095-1106.

4. A. Ghaffarianhoseini, U. Berardi, N. D. Dahlan, and A. Ghaffarianhoseini, "What can we learn from Malay vernacular houses?" *Sustainable Cities Soc* 13(2014): 157-170.

5. S. Bodach, W. Lang, and J. Hamhaber, "Climate responsive building design strategies of vernacular architecture in Nepal," *Energy Build* 81 (2014): 227-242.

6. V. Olgyay (Ed.), *Design with the climate: bioclimatic approach and architectural regionalism* (New Jersey: Princeton University Press, 1963).

field measurements[9] in order to investigate the thermal performance of vernacular dwellings. Among other researchers, Foruzanmehr and Velinga[10] highlighted the significance of adopting a holistic approach that engages the different variables of vernacular dwellings, thus allowing the drawing of solid conclusions about their long-term viability and sustainability.

More specifically, regarding the area of Mediterranean, the environmental characteristics and strategies of vernacular dwellings have recently been studied in a qualitative and quantitative way.[11] Some research studies deal with the urban scale of vernacular settlements, such as the compact, often continuous building system of dwellings attached to each other. Meanwhile, other studies focus on the building scale[12] of vernacular dwellings, and more specifically on their architectural layout,[13] as well as on special bioclimatic aspects and features.[14] These features include orientation, shading using movable external shutters and other devices for protection against solar radiation, the size and arrangement of

7. B. Givoni (Ed.), *Man, climate and architecture* (Amsterdam/London/New York: Elsevier Publishing Co. Ltd, 1969); M. Milne, and B. Givoni, "Architectural design based on climate," in *Energy Conservation Through Building Design* (ed.) D. Watson (New York: McGraw- Hill, 1979), 96-113.

8. A. S. Dili, M. A. Naseer, and T. Zacharia Varghese, "Passive control methods for a comfortable indoor environment: comparative investigation of traditional and modern architecture of Kerala in summer," *Energy Build* 43 (2011): 653-664.

9. V. Shastry, M. Mani, and R. Tenorio, "Impacts of modern transitions on thermal comfort in vernacular dwellings in warm-humid climate of Sugganahalli (India)," *Indoor Built Environ* 23 (2014): 543-564; M. N. A. Saïd, W. C. Brown, C. J. Shirtliffe, and A. H. P. Maurenbrecher, "Monitoring of the building envelope of a heritage house: a case study," *Energy Build* 30 (1999): 211-219.

10. A. Foruzanmehr, and M. Velinga, "Vernacular architecture: questions of comfort and practicability," *Build. Res. Inf.* 39, no. 3 (2011): 274-285.

11. M. Vellinga, "Vernacular architecture and sustainability: Two or three lessons," in *International Conference on Vernacular Heritage, Sustainability and Earthen Architecture* (Valencia: Taylor & Francis, 2014), 3-8.

12. N. Cardinale, G. Rospi, and P. Stefanizzi, "Energy and microclimatic performance of Mediterranean vernacular buildings: the Sassi district of Matera and the Trulli district of Alberobello," *Building Environment* 59 (2013): 590-598.

13. A. Ghaffarianhoseini, U. Berardi, and A. Ghaffarianhoseini, "Thermal performance characteristics of unshaded courtyards in hot and humid climates," *Building and Environment* 87 (2015): 154-168; M. A. Kristianto, N. A. Utama, and A. M. Fathoni, "Analyzing indoor environment of Minahasa traditional house using CFD," *Proc Environ Sci* 20 (2014): 172-179; A. Almhafdy, N. Ibrahim, S. S. Ahmad, and Y. Yahya, "Thermal performance analysis of courtyards in a hot humid climate using computational fluid dynamics CFD Method," *Proc Social Behav Sci* 170 (2015): 474-483; X. Du, R. Bokel, and A. van den Dobbelsteen, "Building microclimate and summer thermal comfort in free-running buildings with diverse spaces: a Chinese vernacular house case," *Build Environ* 82 (2014): 215-227.

14. A. Oikonomou, and F. Bougiatioti, "Architectural structure and environmental performance of the traditional buildings in Florina, NW Greece," *Build Environ* 46, no. 3 (2011): 669-689; S. Saljoughinejad, and S. R. Sharifabad, "Classification of climatic strategies, used in Iranian vernacular residences based on spatial constituent elements," *Building and Environment* 92 (2015): 475-493; M. S. Sozen, and G. Z. Gedik, "Evaluation of traditional architecture in terms of building physics: old Diyarbakir houses," *Build. Environ.* 42, no. 4 (2007): 1810-1816; Vissilia, "Evaluation of a sustainable Greek vernacular settlement and its landscape: architectural typology and building physics," 2009, 1095-1106.

openings, vegetation and other elements (water etc) in the yards and the use of light-coloured surfaces for external walls.[15]

Open spaces in the form of courtyards surrounded by walls and rooms are very often incorporated in vernacular dwellings in the Mediterranean area, and have been investigated by a large number of researchers.[16] These studies have shown the environmental values of private open spaces in the form of courtyards, and their contribution to the surrounding spaces, as well as to the overall performance of vernacular dwellings.[17]

A large number of studies investigate the environmental role of semi-open spaces (open areas with a roof, closely connected with the courtyards) that constitute a characteristic and very important bioclimatic element of vernacular dwellings in the Eastern Mediterranean.[18] These elements respond to the mild climatic conditions of their locations, while at the same time reflecting the society and way of life,[19] as they offer a more suitable space for social activities compared to closed or fully-open spaces.[20]

Two architectural elements that researchers have investigated in detail – and which are also connected to the environmental character of vernacular dwellings – are the *portico* (semi-open space in the middle of a house in the form of a wide corridor) and the *sachnisi* (a light structural projection on the main façade of vernacular dwellings with a large number of windows). The environmental values

15. I. Canas, and S. Martin, "Recovery of Spanish vernacular construction as a model of bioclimatic architecture," *Build Environ* 39 (2004): 1477-1495; M. Kolokotroni, and A. N. Young, "Guidelines for bioclimatic housing design in Greece," *Build Environ* 25, no. 4 (1990): 297-307; K. Van Den Wymelenberg, "Patterns of occupant interaction with window blinds: a literature review," *Energy Build* 51 (2012): 165-176.

16. E. Andreou, and K. Axarli, "Investigation of urban canyon microclimate in traditional and contemporary environment. Experimental investigation and parametric analysis," *Renew. Energy* 43 (2012): 354-363; Sozen, and Gedik, "Evaluation of traditional architecture in terms of building physics: old Diyarbakir houses," 2007, 1810-1816; A. Rapoport, "Vernacular design as a model system in vernacular architecture," in *Vernacular* A*rchitecture in the Twenty-First Century: Theory, Education and Practice* (eds.) L. Asquith, and M. Vellinga (England: Taylor and Francis, 2006), 179-198; M. Salman, "Sustainability in vernacular architecture: rethinking what identity is," in *Urban and Architectural Heritage Conservation within Sustainability* (IntechOpenn, 2018); S. Yannas, and W. Weber (Eds.), *Lesson from Vernacular Architecture* (London: Routledge, 2014); Ghaffarianhoseini, Berardi, and Ghaffarianhoseini, "Thermal performance characteristics of unshaded courtyards in hot and humid climates," 2015, 154-168.

17. N. Das, *Courtyards Houses of Kolkata: Bioclimatic, Typological and Socio-Cultural Study* (s.l.:Kansas State University, Department of Architecture, College of Architecture, Planning and Design, 2006); A. Petruccioli, "The courtyard house: typological variations over space and time," in *Courtyard Housing: Past, Present and Future* (eds.), E. Brian, M. Sibley, M. Hakmi, and P. Land (Taylor and Francis, 2005); A. Rapoport, "The nature of courtyard house: a conceptual analysis," *Traditional Dwellings and Settlements Review* 18, no. 2 (2007): 57-72; J. Reynolds, *Courtyards: Aesthetic, Social and Thermal Delight* (New York: John Wiley, 2002).

18. M. Achenza, G. Chiri, and I. Giovagnorio, *The Microclimatic Design of Southern Sardinian Loggias in Italy* (London: Taylor and Francis, 2014); M. Sinou, *Design and Thermal Diversity of Semi-enclosed Spaces.* (Cambridgeshire: Melrose Books, 2007).

19. B. Rudofsky, *Architecture without Architects: a Short Introduction to Non-pedigreed Architecture* (New York: Museum of Modern Art, 1964).

20. A. Foruzanmehr, "People's perception of the loggia: a vernacular passive cooling system in Iranian architecture," *Sustainable Cities and Society* 19 (2015): 61-67.

of *porticos* have been documented extensively by Vellinga et al.[21] and Oikonomou and Bougiatioti.[22] The same authors also give an overview of the environmental values of these timber projections in northern Greece, showing their contribution to ventilation and daylighting, thus underlining their suitability for many household activities. The combined effect of these two spaces – *portico* and *sachnisi* – on the enhancement of ventilation is also mentioned by the same two researchers. The arrangement of the openings in these two areas helps towards the achievement of cross ventilation.

Many studies focus on the investigation of the ventilation strategies to achieve thermal comfort in vernacular dwellings in the Mediterranean region. Field research revealed the positive contribution of these strategies.[23] According to Santamouris and Wouters,[24] night ventilation is very effective, especially in areas with high daily air temperature fluctuations and low night temperatures. The decrease in interior temperatures due to the application of night ventilation is also discussed by Blondeau, Spérandio, and Allard.[25] Many researchers refer to the necessity for external daily air temperature fluctuations in order to achieve a satisfactory cooling effect in the interior of the vernacular dwellings during night.[26] Many factors regarding the architectural layout of a dwelling can reinforce ventilation by increasing air velocity, such as the arrangement of small openings high up on the walls just below roof level, due to the stack effect.[27]

Researchers[28] have also investigated the thermal behaviour at different periods of the year, in various spaces within the vernacular houses. They have also explored human interaction regarding window opening operations, showing how occupant behaviour was adapted for optimal thermal comfort. According to the aforementioned studies, during the winter season, living spaces were situated on the ground floor of the dwelling. This floor was characterised by increased thermal mass due to the thickness of the walls and the limited number of

21. M. Vellinga, P. Oliver, and A. Bridge, *Atlas of Vernacular Architecture of the World* (London: Routledge, 2007).

22. Oikonomou, and Bougiatioti, "Architectural structure and environmental performance of the traditional buildings in Florina, NW Greece," 2011, 669-689.

23. A. Mochida, H. Yoshino, T. Takeda, T. Kakegawa, and S. Miyauchi, "Methods for controlling airflow in and around a building under cross ventilation to improve indoor thermal comfort," *J Wind Eng Ind Aerodyn* 93 (2005): 437-449; A. Aflaki, N. Mahyuddin, Z. Al-Cheikh Mahmoud, and M. R. Baharum, "A review on natural ventilation applications through building façade components and ventilation openings in tropical climates," *Energy Build* 101 (2015): 153-162.

24. M. Santamouris, and P. Wouters (Eds.), *Building ventilation, the state of the art* (UK: Earth Scan, 2006).

25. P. Blondeau, M. Spérandio, and F. Allard, "Night ventilation for building cooling in summer," *Solar Energy* 61 (1997): 327-335.

26. B. Givoni, *Passive and low energy cooling of buildings* (Hoboken: John Willy & Sons, 1994); Blondeau, Spérandio, and Allard, "Night ventilation for building cooling in summer," 1997, 327-335; E. Shaviv, A. Yezioro, and I. G. Capeluto, "Thermal mass and night ventilation as passive cooling design strategy," *Renew Energy* 24 (2001): 445-452.

27. Kristianto, Utama, and Fathoni, "Analyzing indoor environment of Minahasa traditional house using CFD," 2014, 172-179.

28. Oikonomou, and Bougiatioti, "Architectural structure and environmental performance of the traditional buildings in Florina, NW Greece," 2011, 669-689.

openings. Summer living spaces were located on the upper floor (including the area of the *sachnisi*), where ventilation could be achieved due to an increased number of windows.

Regarding the materiality of the structures, many studies demonstrate the positive impact of using massive structural elements made from local materials (mainly stone and adobes) with high thermal mass in vernacular dwellings. This method constitutes a common bioclimatic technique in traditional Mediterranean architecture in areas such as Italy[29], Portugal[30], Turkey[31], Spain[32] and Greece.[33] When studying the thermal properties of earthen walls, Collet et al.[34] focused on the thermal inertia, as well as on the time delay of the thermal wave dissemination in traditional masonry. Researchers[35] relate the effectiveness of the thermal mass to many factors, i.e., the thermal properties of materials, thermal insulation, ventilation and occupancy.

Regarding the vernacular architecture of Cyprus, many qualitative and quantitative studies have been carried out recently.[36] More specifically the UCY research team has investigated a large number of cooling and heating strategies in detail.[37] These investigations cover both urban[38] and rural areas of the island.[39]

29. Cardinale, Rospi, and Stefanizzi, "Energy and microclimatic performance of Mediterranean vernacular buildings: the Sassi district of Matera and the Trulli district of Alberobello," 2013, 590-598.

30. J. Fernandes, R. Mateus, L. Bragança, and J. Júlio Correia da Silva, "Portuguese vernacular architecture: The contribution of vernacular materials and design approaches for sustainable construction," *Architectural Science Review* 58, no. 4 (2015): 324-336.

31. T. Basaran, "Thermal analysis of the domed vernacular houses of Harran, Turkey," *Indoor Built Environ* 20 (2011): 543-554.

32. S. Martin, F. R. Mazarron, and I. Canas, "Study of thermal environment inside rural houses of Navapalos (Spain): the advantages of reuse buildings of high thermal inertia," *Construction of Building Materials* 24 (2010): 666-676.

33. C. A. Balaras, "The role of thermal mass on the cooling load of buildings. An overview of computational methods," *Energy Build* 24 (1996): 1-10.

34. F. Collet, L. Serres, J. Miriel, and M. Bart, "Study of thermal behaviour of clay wall facing south," *Building Environment* 41 (2006): 307-315.

35. H. Cagnon, J. E. Aubert, M. Coutand, and C. Magniont, "Hygrothermal properties of earth bricks," *Energy Build* 80 (2014): 208-217.

36. M. Philokyprou, A. Michael, E. Malaktou, and A. Savvides, "Environmentally responsive design in Eastern Mediterranean. The case of vernacular architecture in the coastal, lowland and mountainous regions of Cyprus," *Build Environ* 111 (2017): 91-109; M. Philokyprou, A. Michael, S. Thravalou, and I. Ioannou, "Thermal performance assessment of vernacular residential semi-open spaces in Mediterranean climate," *Indoor and Built Environment* 27, no. 8 (2018): 1050-1068.

37. M. Philokyprou, and A. Michael, "Evaluation of the environmental features of vernacular architecture. A case study in Cyprus," *Int J Heritage Digital Era* 1 (2012): 349-354; M. Philokyprou, A. Savvides, A. Michael, and E. Malaktou, "Examination and assessment of the environmental characteristics of vernacular rural settlements. Three case studies in Cyprus," in *Vernacular Heritage and Earthen Architecture: Contribution to Sustainable Development* (eds.) M. Correia, G. Carlos, and S. Sousa (London, UK: Taylor & Francis Group, 2014), 613-618.

38. M. Philokyprou, A. Michael, S. Thravalou, and I. Ioannou, "Evaluation of sustainable design elements in the historic centre of Nicosia, Cyprus," in *Vernacular Heritage and Earthen Architecture* (eds.) M. Correia, G. Carlos, and S. Rocha (London: Taylor & Francis Group, 2013), 631-637; M. Philokyprou, A. Michael, and S. Thravalou, "Assessment of the bioclimatic elements of vernacular architecture. The historic centre of Nicosia, Cyprus," in *Le Vies dei Mercanti XI Forume Internationalle di Studi* (eds.) P. Argenziano, et al. (Aversa, Capri, Italy, Proceedings, La scuola di Pitagora editrice, Napoli, June 13-15 2013), 666-675.

The research also covered the urban scale of settlements such as streetscapes,[40] as well as the buildings' architectural scale,[41] specific architectural spaces and characteristics such as courtyards,[42] subterranean spaces,[43] semi-open space typologies and façade projections.[44] Some of the passive design strategies recorded at architectural and district level include the dense fabric of settlements, the massive stone and adobe walls, the appropriate orientation, the arrangement of spaces around the yards, the semi-open areas, the shutters, the vegetation and the lightweight shading structures (*pergolas*). Many studies have shown the environmental adaptability of Cyprus' vernacular dwellings in different climatic regions of the island.[45] The significant role of the size, as well as the arrangement and operation of windows in the vernacular dwellings of Cyprus were also noted. At the same time special studies were carried out to investigate the positive impact of night ventilation in different urban and rural areas,[46] and the thermal mass of adobe walls through the investigation of time lag.[47] The lighting level of closed areas and semi-open spaces was also investigated.[48] Furthermore, a

39. E. Malaktou, M. Philokyprou, A. Michael, and A. Savvides, "Architectural design and environmental behavior of traditional buildings in mountainous regions. The case of Askas settlement, Cyprus," in *International Conference Biocultural 2015, Sustainability in Architectural Cultural Heritage* (Limassol, Cyprus, 11-12 December 2015), 77-86; E. Malaktou, M. Philokyprou, A. Michael, and A. Savvides, "Environmental behavior of semi-open spaces in Mediterranean vernacular architecture. The case of rural traditional dwellings of Cyprus," *Renew Energy Power Qual J* 14 (2016): 599-604.

40. A. Savvides, A. Michael, E. Malaktou, and M. Philokyprou, "Examination and assessment of insolation conditions of street-scapes of traditional settlements in the Eastern Mediterranean area," *Habitat Int* 53 (2016): 442-452.

41. Philokyprou, Michael, Malaktou, and Savvides, "Environmentally responsive design in Eastern Mediterranean. The case of vernacular architecture in the coastal, lowland and mountainous regions of Cyprus," 2017, 91-109.

42. M. Philokyprou, and A. Michael, "Social and Environmental Aspects of Courtyards in Vernacular Architecture in Cyprus," Special Issue on Vernacular Architecture, From Tradition to the Future, *Serbian Architectural Journal SAJ* 8 (2016): 75-90.

43. E. Malaktou, M. Philokyprou, A. Michael, and A. Savvides, "Thermal assessment of traditional, partially subterranean dwellings in coastal and mountainous regions in the Mediterranean climate. The Case of Cyprus," *J Sustainable Architect Civil Eng* 3, no. 16 (2016): 82-96.

44. S. Thravalou, and M. Philokyprou, "Urban design considerations in the environmental assessment of vernacular buildings with timber projections (*sachnisi*): The case of Nicosia's historic center," *Frontiers of Architectural Research* 10, no. 1 (2021): 176-189.

45. Philokyprou, Michael, Malaktou, and Savvides, "Environmentally responsive design in Eastern Mediterranean. The case of vernacular architecture in the coastal, lowland and mountainous regions of Cyprus," 2017, 91-109.

46. A. Michael, D. Demosthenous, and M. Philokyprou, "Natural ventilation for cooling in mediterranean climate: A case study in vernacular architecture of Cyprus," *Energy and Buildings* 144 (2017): 333-345; S. Thravalou, M. Philokyprou, and A. Michael, "Natural ventilation performance of heritage buildings in the Mediterranean climate. The case of a two-storey urban traditional dwelling in Nicosia, Cyprus," in *Proceedings of the 9th International Conference on Making Comfort Relevant* (Windsor, UK, 7-10 April 2016), 328-339.

47. A. Michael, M. Philokyprou, S. Thravalou, and I. Ioannou, "The role of the thermal mass of adobe walls in the thermal performance of vernacular dwellings," in *XIIth world Congress of Eastern Architectures* (Terra, Lyon, France, 11-14 July 2016).

48. A. Michael, C. Herakleous, S. Thravalou, and M. Philokyprou, "Lighting Performance of Urban Vernacular Architecture in the East Mediterranean Area: Field Study and Simulation Analysis," *Indoor and Built Environment* 26, no. 4 (2017): 471-487.

holistic investigation regarding sustainability in the conservation of vernacular dwellings was carried out and published very recently.[49]

Methodology

Initially a general investigation into the vernacular architecture of Cyprus was carried out through the development of a digital database. This database constitutes the first effort to include all available information regarding the traditional settlements and dwellings of Cyprus, in digital form.[50] More detailed research findings presented in this paper derive mainly from two multidisciplinary research programmes (BioVernacular and BioCultural) carried out at UCY that examine the passive design features of traditional settlements in Cyprus. The BioVernacular programme focuses on the historic urban area of Nicosia, while the BioCultural programme focuses on traditional rural settlements.

Within the framework of the two aforementioned projects, the following procedure was followed for the investigation of the vernacular dwellings and settlements (Figure 1).

49. M. Philokyprou, and A. Michael, "Environmental Sustainability in Conservation of Vernacular Architecture. The case of rural and urban traditional settlements in the Mediterranean area," *International Journal of Architectural Heritage: Conservation, Analysis and Restoration* 15, no. 11 (2021): 1741-1763.

50. M. Philokyprou, "The VernArch Digital Database Project: Documentation and Protection of the Vernacular Architecture of Cyprus," in *Proceedings of the International Conference on Cultural Heritage. Digital Heritage. Progress in Cultural Heritage Documentation, Preservation and Protection (Euromed 2014)* (Limassol, Cyprus, 3-8 November, 2014), 635-642.

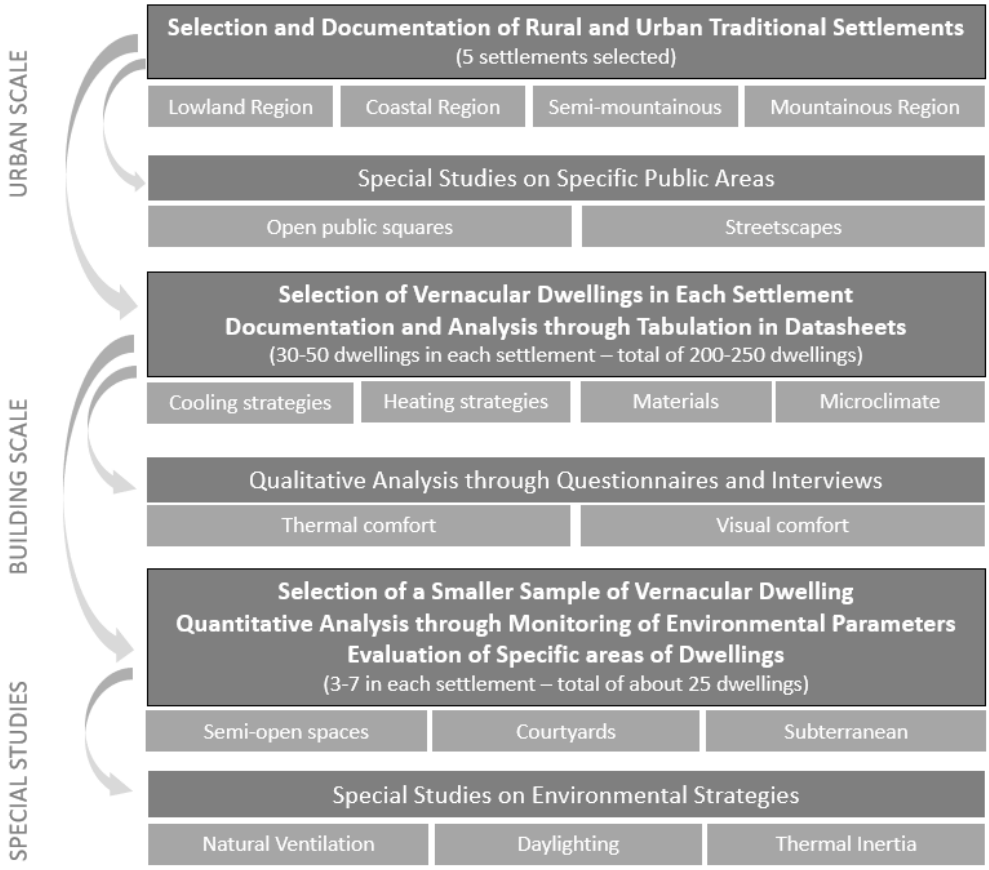

Figure 1. *Diagram Showing the Methodology Followed and the Different Steps of the Procedure from the Urban Scale to the Building Scale*

a) Initially five settlements were selected and investigated in detail (Figures 1 and 2), situated in different climatic areas – coastal, lowland, semi-mountainous and mountainous.[51] These selected settlements were situated either in rural or urban areas with different geomorphological characteristics. Specifically, two urban settlements situated in the lowland areas and three rural settlements – namely Maroni in the coastal area, Pera Orinis in the lowland area, and Askas in the mountainous region – were selected as case studies. The research initially included a qualitative investigation of various bioclimatic elements through a field survey.

51. M. C. Katafygiotou, and D. K. Serghides, "Bioclimatic chart analysis in three climate zones in Cyprus," *Indoor Built Environ* 24 (2015): 746-760.

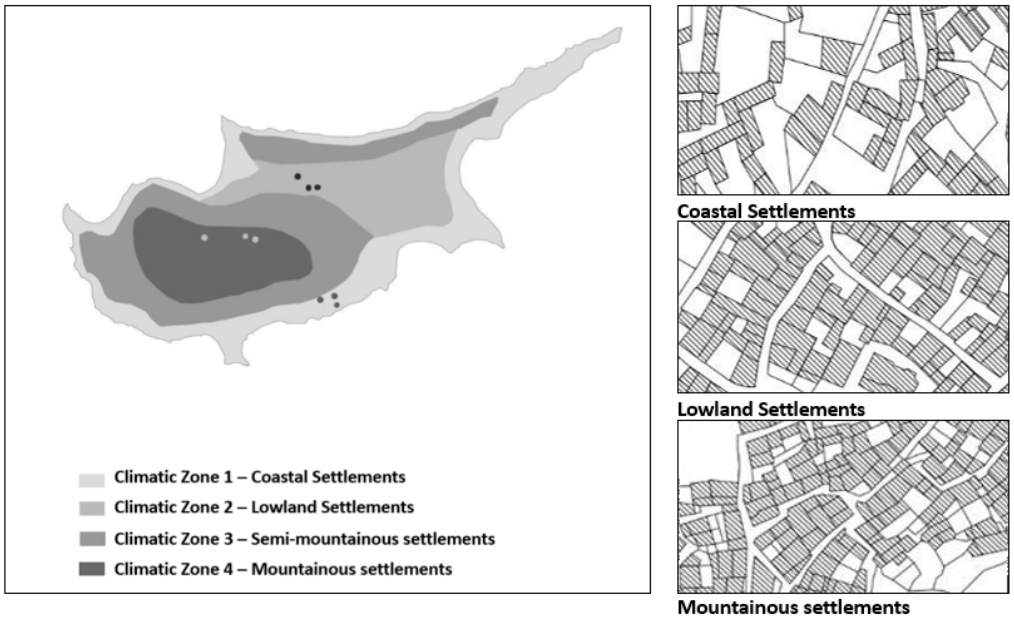

Figure 2. *Map of Cyprus Showing the Different Climatic Zones (Left) and Maps of Characteristic Settlements Located in Coastal, Lowland and Mountainous Areas (Right)*

b) In each case study settlement, a representative number (30-50) of vernacular buildings were selected in order to record and tabulate all of the environmental features of each dwelling in data sheets (Figure 3). The passive heating and cooling strategies, as well as strategies for outdoor microclimatic regulation, were recorded for each of the selected buildings. The data sheets also included architectural and urban characteristics for each case study. Overall tables were also prepared for each area under study, as well as comparison tables between the settlements situated in different climatic zones.

c) The above procedure was followed by a quantitative analysis through in situ monitoring of the various environmental parameters on a smaller sample of dwellings (about 3-7 dwellings in each of the 5 areas). Data loggers for recording temperature and relative humidity were placed inside the dwellings, as well as in semi-open spaces. Simultaneously, external environmental stations were placed in the different areas under investigation, in order to gather climatic data of the outdoor conditions for comparison reasons.

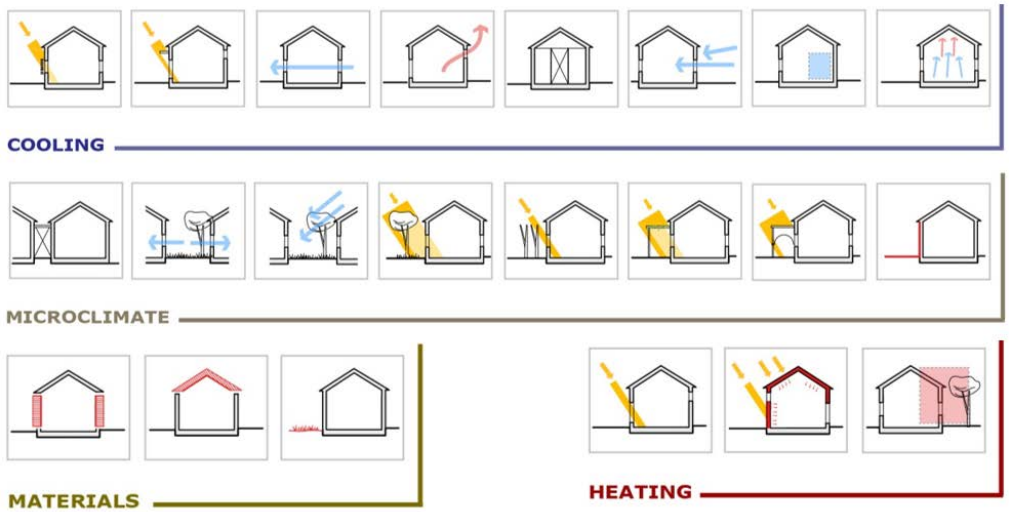

Figure 3. *Cooling and Heating Strategies, as well as Strategies Related to the Improvement of the Microclimatic Conditions and Materiality Investigated in Traditional Settlements*

d) The impact of the human behaviour on achieving thermal comfort inside vernacular dwellings has been also investigated through questionnaires and interviews.

e) At the same time special studies were undertaken (Figure 4) focusing on urban public open spaces (squares and streetscapes[52]) in the rural settlements mentioned in paragraph (a). In addition, special studies were carried out for specific spaces in the vernacular dwellings selected for quantitative investigation in the second phase of the investigation (paragraph c), such as semi-open spaces,[53] courtyards[54] and subterranean areas,[55] as well as on specific fields and environmental strategies such as ventilation[56] and lighting.[57]

52. Savvides, Michael, Malaktou, and Philokyprou, "Examination and assessment of insolation conditions of street-scapes of traditional settlements in the Eastern Mediterranean area," 2016, 442-452.

53. M. Philokyprou, A. Michael, and E. Malaktou, "A typological, environmental and socio-cultural study of semi-open spaces in the Eastern Mediterranean vernacular architecture: The case of Cyprus," *Front. Archit. Res.* 10, no. 3 (2021): 483-501.

54. Philokyprou, and Michael, "Social and Environmental Aspects of Courtyards in Vernacular Architecture in Cyprus," 2016, 75-90.

55. Malaktou, Philokyprou, Michael, and Savvides, "Thermal assessment of traditional, partially subterranean dwellings in coastal and mountainous regions in the Mediterranean climate. The Case of Cyprus," 2016, 82-96.

56. Thravalou, Philokyprou, and Michael, "Natural ventilation performance of heritage buildings in the Mediterranean climate. The case of a two-storey urban traditional dwelling in Nicosia, Cyprus," 2016, 328-339; Michael, Demosthenous, and Philokyprou, "Natural ventilation for cooling in mediterranean climate: A case study in vernacular architecture of Cyprus," 2017, 333-345.

57. A. Michael, C. Heracleous, E. Malaktou, A. Savvides, and M. Philokyprou, "Lighting performance in rural vernacular architecture in Cyprus: Field studies and simulation analysis," in

Results

The research revealed very interesting results regarding different aspects of vernacular settlements and dwellings situated in various areas around the island. The results presented here cover different scales of investigation – the urban scale of the settlements and the building scale – as well as the structural system of the dwellings and their materiality. This paper is a comprehensive overview of recent research on the various environmental aspects of vernacular dwellings. The aim of this article is the presentation of the methodology that was followed in different areas, as well as on different scales, using various tools and methods – both qualitative and quantitative.

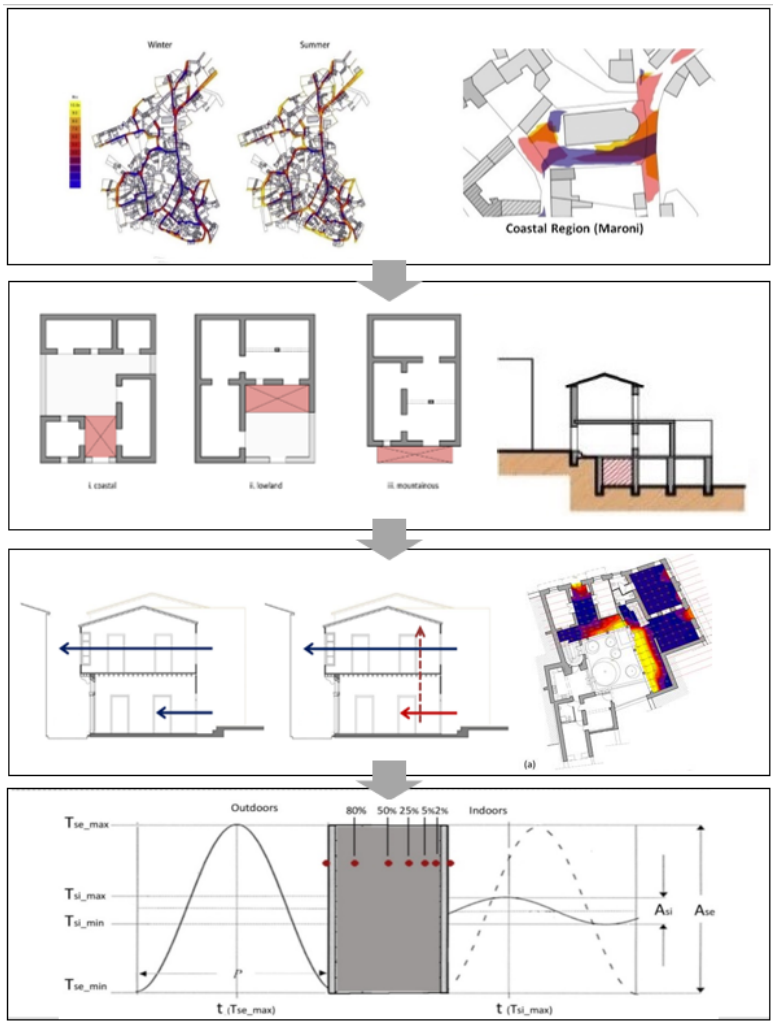

Figure 4. *Different Studies Undertaken on Urban Public Open Spaces, Private Dwellings, Specific Fields (Ventilation, Lighting) and Materiality*

The studies that focus on urban public open spaces such as open public squares and streetscapes (Figures 4-5), show the different environmental characteristics of the areas selected in different climatic zones. The study that examines the solar conditions of streets in three rural vernacular settlements (Maroni, Pera Orinis and Askas) situated in three different climatic zones, revealed the different shading patterns of each case. Through the investigation of the monthly insolation conditions of the streetscapes, with the help of software simulation in terms of sunlight hours, incident solar radiation, shading percentages and sky view factors,[58] it was revealed that the mountainous settlement increases shading patterns due to the dense fabric and deep street corridors. This in turn offers significant potential to improve the outdoor thermal comfort conditions during the cooling period (summer). The worst shading conditions of the three settlements investigated were found in the settlement in the lowland area, and especially in areas at the boarders of the settlement where wider streets can be found.

Figure 5. *Street Canyons in Rural (a, b) and Urban Settlements (c, d)*

In the same context, the outdoor microclimatic conditions of traditional public squares in all three rural settlements were investigated. An innovative methodology based on seasonal image processing techniques of solar, sky view factor and wind, was applied for this investigation. The mapping of the spatial thermal diversity of the squares is illustrated by overlaying the aforementioned microclimatic factors. A comparison between the three squares in the three case study settlements, based on results taken during winter (heating period), reveals that the square located in the lowlands performs best due to the combination of the southern aspect, high sky view and wind protection.

Moving now from the open to the built part of the settlements, the research carried out focusing on settlement pattern, as well as on building scale revealed different layouts of the built fabric across the three different climatic areas of Cyprus. The analysis of the urban fabric showed the protection of the spaces inside the dwellings from exterior environmental conditions due to the continuous attached building system (Figure 6) that is a very common characteristic in

58. Savvides, Michael, Malaktou, and Philokyprou, "Examination and assessment of insolation conditions of street-scapes of traditional settlements in the Eastern Mediterranean area," 2016, 442-452.

traditional settlements. Specifically, this building system entails the losses of heat during winter (heating period) and heat gains during the summer (cooling period).

Figure 6. *Settlement Pattern (Continuous Attached Building System)*

The typological analysis of vernacular dwellings in the different areas of study which followed, showed the common and different characteristics of the traditional dwellings in all of the settlements. The dwellings situated in the coastal areas typically combine single, elongated rooms that have a wide façade (Figure 7). These rooms are called *platimetopa makrinaria*. These elongated and shallow layouts enhance natural ventilation, reinforcing passive cooling during the summer (cooling period), and appropriate insolation and daylight penetration during the summer (heating period). Double-space rooms called *dichoro*, with high ceilings and single-banked rooms, are the most common rooms of the dwellings in the lowland regions (Figure 7). Passive cooling is enhanced in the aforementioned rooms, due to their high ceiling. Rooms with narrow deep plans (single-banked) called *stenometopa makrinaria* prevail in the mountainous settlements. The compact, low-ceilinged spaces of these areas offer protection from the cold.

The research showed that courtyards constitute important environmental features in all areas under study (Figure 8). In coastal regions, spacious interior courtyards can be observed. In the lowlands, courtyards have a compact form due to the denser layout of the areas. In the mountainous regions, courtyards if existent, are very small due to restrictions of topography and climate. The courtyard offers several environmental benefits in all periods of the year. The existence of a yard in the plot's centre offers direct solar gains in the heating period (winter), and ensures cross ventilation during summer in the surrounding rooms. The relatively small size of the courtyards, in combination with suitable plants, offer shading of the spaces surrounding the yard, as well as the floor surface of the yard during the summer. In addition, courtyards allow solar gains into the different spaces of the dwellings during winter, leading to a very successful bi-seasonal passive result.

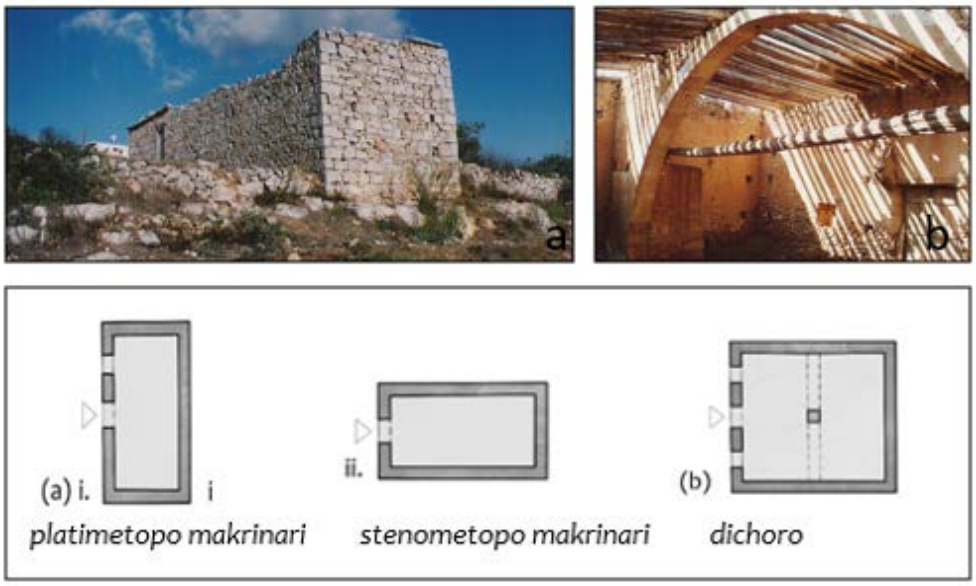

Figure 7. *The Two Main Typologies of Traditional Rooms (Makrinari – Platimetopo and Stenometopo and Dichoro)*

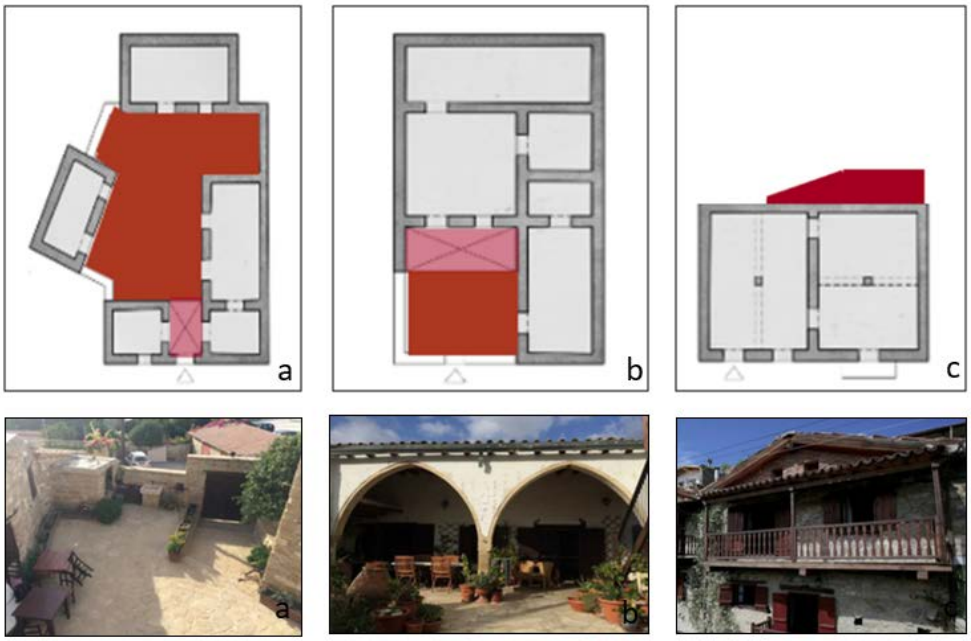

Figure 8. *Different Sizes and Layout of Courtyards in Different Climatic Zones (a. Coastal Areas, b. Lowland Areas, c. Mountainous Areas)*

The intermediate semi-open areas very often seen in lowland (rural and urban) regions and less in coastal and mountainous areas, constitute another very important environmental, social and functional element (Figures 4, 9-10). The *iliakos* – a semi-open space with a linear layout found adjacent to the indoor spaces and covering their main façade towards the yard – is very often observed in

lowland settlements. This is related to the high summer temperatures, as well as the solar radiation values that provide suitable shaded outdoor spaces. The *iliakos* offers shaded spaces, and serves circulation purposes, while also hosting several households, agricultural and social activities. Another type of semi-open space in the form of a through passage is the *portico*, located within the dwelling itself (Figure 9). This structure is more often found in rural coastal and urban lowland settlements. It permits sufficient cross ventilation, as well as sufficient air flow inside the dwelling. A common semi-open space found in dwellings in the mountainous areas and located on the upper floor, is the called *hayiati* (Figure 10). The existence of semi-open spaces on the upper floor in these areas is connected to the limited available land at ground level. Moreover, *vine pergolas* are quite common in all different climatic regions and provide either shade or sunlight entry in the summer and winter respectively (Figure 10). Following a holistic multicriteria approach, the positive attributes of the semi-open spaces in different climatic areas and topographies were identified and evaluated.[59]

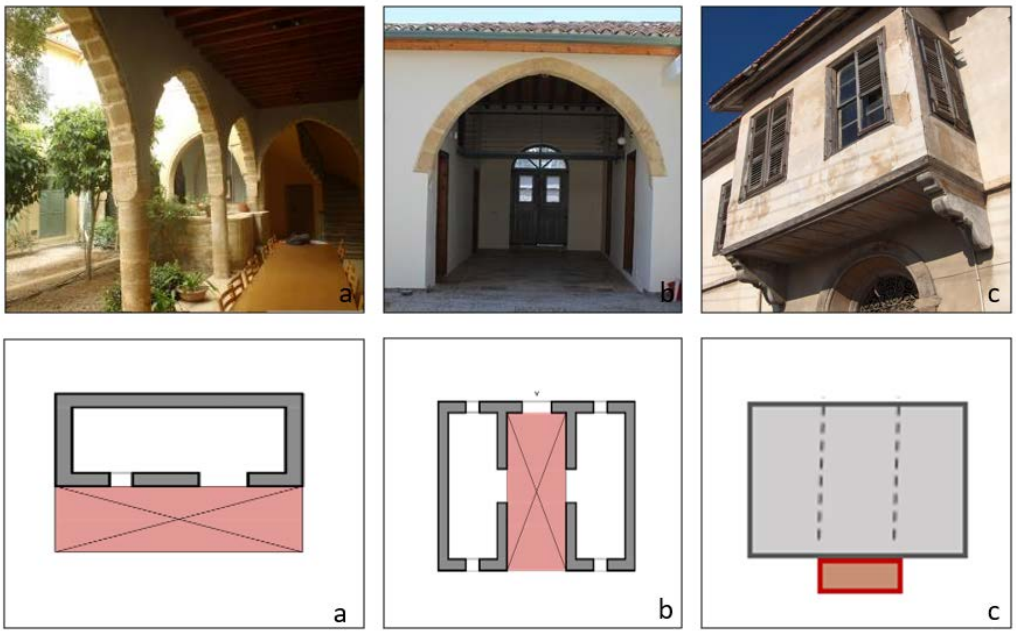

Figure 9. *Semi Open Spaces (a. Iliakos, b. Portico) and Light Structured Projections (c. Sachnisi)*

The role that semi-open spaces play in improving the thermal comfort of urban vernacular dwellings was studied in detail through field monitoring. Special attention was given to the impact of contemporary interventions carried out in these spaces (Figure 11). The research results show the positive contribution of these areas to the thermal comfort of the interiors of vernacular dwellings, especially during summer. The records of the temperatures showed the positive

59. Philokyprou, and Michael, "Environmental Sustainability in Conservation of Vernacular Architecture. The case of rural and urban traditional settlements in the Mediterranean area," 2021, 1741-1763.

impact when converting south oriented semi-open spaces into closed areas during the heating period. During the summer, extensive overheating phenomena can be observed. The analysis of recorded temperatures in semi-open areas with different orientations which had been converted into closed areas, showed very different thermal behaviour. North oriented areas act better during summer, whereas south oriented areas show a better thermal behaviour during winter.[60]

Figure 10. *Different Typologies of Semi-Open Spaces in Rural Traditional Settlements*

In the same context, systematic research examining partially subterranean coastal and mountainous vernacular dwellings was performed. Such spaces are very rare in lowland and urban areas due to the geomorphology of the areas. Air temperature and relative humidity were monitored. The results indicate significant cooling effects in partially subterranean areas during summer, especially in mountainous areas. During the heating period, air temperatures are higher compared to the temperatures of the spaces that were above ground. Overall, the research results highlight the environmental benefits of partially subterranean spaces resulting from the earth's high thermal inertia.

Figure 11. *Semi-Open Spaces Preserved in Their Original Character (Left) or Converted into Closed Areas with the Use of Glass Surfaces (Three Examples to the Right)*

Special studies focusing on ventilation were also carried out. Ventilation strategies are linked to the general layout of the dwellings and the arrangement of the openings. In vernacular settlements of all areas, the small number and size of the openings protect the interior space of the vernacular dwellings from external conditions, but at the same time offer opportunities for ventilation. The cross

60. Philokyprou, Michael, Thravalou, and Ioannou, "Thermal performance assessment of vernacular residential semi-open spaces in Mediterranean climate," 2018, 1050-1068.

arrangement of the openings is a very common feature of settlements situated in coastal and lowland areas and allows for natural ventilation (Figure 12).

In order to investigate natural ventilation, its influence on thermal conditions inside a vernacular dwelling during the summer was closely studied. The investigation involved different ventilation strategies assessed through field study. Specifically, ventilation during the day and night was monitored (Figures 4, 12). Moreover, in the case of night-time ventilation, different patterns of window openings – i.e., single window, single-sided and cross ventilation – were also examined. The very positive impact of night-time cross ventilation was demonstrated through this study. This strategy proved to be most effective compared to the other ventilation strategies.[61]

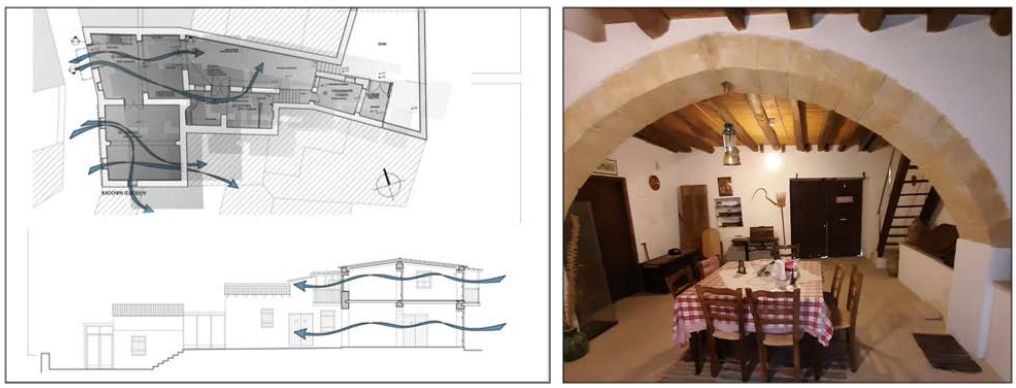

Figure 12. *Cross Ventilation in a Characteristic Rural Vernacular Dwelling*

Natural ventilation was also investigated in urban vernacular buildings in Nicosia. This study focused on the way that occupants interact with the building envelope in order to achieve thermal comfort. The investigation was conducted through software simulations on different window-operation patterns, which once again confirms the effectiveness of night-time cross ventilation.[62]

A special feature of urban vernacular dwellings related to ventilation strategies, is the *sachnisi* – a projection on the upper level of two-storey dwellings (Figure 9). This element plays an important environmental and social role, mainly due to the incorporation of a large number of openings in its structure.[63]

In addition to their role in ventilation, the openings (specifically their size and arrangement) also play a vital role in lighting. Within the same context, a detailed lighting performance investigation was carried out in an urban dwelling in a typical traditional complex in Nicosia. Field measurements and software simulations were carried out in selected indoor and semi-open spaces. The results

61. Michael, Demosthenous, and Philokyprou, "Natural ventilation for cooling in Mediterranean climate: A case study in vernacular architecture of Cyprus," 2017, 333-345.

62. Thravalou, Philokyprou, and Michael, "Natural ventilation performance of heritage buildings in the Mediterranean climate. The case of a two-storey urban traditional dwelling in Nicosia, Cyprus," 2016, 328-339.

63. Thravalou, and Philokyprou, "Urban design considerations in the environmental assessment of vernacular buildings with timber projections (sachnisi): The case of Nicosia's historic center," 2021, 176-189.

showed that lighting levels in the first-floor rooms are quite sufficient, whereas the ground floor spaces demonstrate insufficient lighting levels due to the dense urban fabric.[64] On the other hand, the study verifies the contribution and positive role of the central courtyard on the lighting levels of indoor as well as semi-open areas in the dwellings. At the same time, a detailed study was carried out of rural dwellings in the three different climatic zones.

A detailed investigation was carried out into the structural system of dwellings whose load bearing walls were mainly 50cm thick (with stone at the lower part and mudbrick at the upper parts – Figure 13). The research shows that the high thermal mass of the walls leads to a very small temperature fluctuation inside the vernacular dwellings compared to larger temperature fluctuations of the external environment during all different periods recorded. Some interesting conclusions regarding thermal comfort were reached using a structured questionnaire.

Figure 13. *Traditional Masonries (Stone, Adobes) in Rural Settlements*

In order to investigate the thermal inertia of the masonry walls in detail, a 50cm thick mudbrick wall was monitored (Figure 4). Recording the time, as well as the corresponding minimum and maximum values of temperature during the cooling period (summer), it was revealed that maximum temperature in the internal surface of the wall was recorded around 8pm. On the other hand, the maximum temperature recorded at the external surface occurred at 3pm. The aforementioned observation indicates a time lag of about five hours over the period of a day (24-hour).[65]

In the framework of a graduate study, the thermal properties of mudbricks were examined through experimental and literature research. The investigation showed that the thermal resistance, as well as the time lag of mudbricks, is increased when a wall becomes thicker. Another outcome of this research is related to the effect of the density of mudbricks on their thermal properties. It verifies that the increase in the density of earth materials leads to an increase in their thermal conductivity and heat storage capacity. On the other hand, the

64. Michael, Heracleous, Malaktou, Savvides, and Philokyprou, "Lighting performance in rural vernacular architecture in Cyprus: Field studies and simulation analysis," 2015; Michael, Herakleous, Thravalou, and Philokyprou, "Lighting Performance of Urban Vernacular Architecture in the East Mediterranean Area: Field Study and Simulation Analysis," 2017, 471-487.

65. Michael, Philokyprou, Thravalou, and Ioannou, "The role of the thermal mass of adobe walls in the thermal performance of vernacular dwellings," 2016.

increase in density also leads to a decrease in the time lag. The investigation shows that the addition of lightweight fibres into mudbricks can lead to an improvement in their thermal insulation capacity.[66]

The hydrothermal performance of a stone masonry wall was also investigated in detail. For the purpose of this study, a wall was monitored with temperature and moisture probes installed at various locations along its thickness and height. The graphical overview of the moisture content pattern shows that the moisture content differentiates along the height of the wall. Specifically, the wetting indicator decreases as the distance from ground level increases.[67]

The analysis of the environmental features and strategies of vernacular buildings, as described previously, shows the implementation of a variety of cooling and heating strategies. In coastal settlements, the hot climate along with high humidity and strong solar radiation, has led to the incorporation of a large number of cooling strategies. Contrarily, in the mountainous settlements the cold winters, with low temperatures and relatively mild summers, led to the incorporation of a large number of heating rather than cooling strategies in order to maximise solar exploitation. Finally, in the lowland rural and urban settlements, the equal incorporation of both cooling and heating strategies are the result of high summer temperatures and relatively low winter temperatures.

Discussion & Conclusions

The previously described investigations reveal the large number of environmental design features and strategies (heating, cooling, microclimatic conditions) that are incorporated in vernacular dwellings. The more detailed quantitative examination of vernacular dwellings and settlements through in situ monitoring, has shown the need to maintain these environmental elements when reusing these dwellings.

The research methodology described above shows the complexity of the process regarding the environmental features and strategies of vernacular settlements, and the need for a detailed study and investigation on different levels. Thus, a multicriteria approach is needed in close cooperation with stakeholders and users. In each research team dealing with heritage and sustainability like the project described in this paper, individuals from different disciplines and backgrounds (architecture, conservation, engineering, environmental studies, archaeology, social studies) should participate. All those involved should work in groups in order to have a holistic overview of the research. Interdisciplinary cooperation between the researchers from different disciplines is essential. Such

66. E. Malaktou, I. Ioannou, and M. Philokyprou, "Investigating the Thermal Properties of Earth-based Materials. The case of Adobes," in *Proceedings of the 10th International Symposium on the Conservation of Monuments in the Mediterranean Basin* (Athens, 20-22 September 2017. Springer), 95-103.

67. C. Heracleous, I. Ioannou, M. Philokyprou, and A. Michael, "Hydrothermal Performance of a Stone Masonry Wall in a Traditional Building in Cyprus," in *Proceedings of the 33rd PLEA International Conference on Passive Low Energy Architecture, Design to Thrive*, Volume III (Edinburgh, 3-5 July 2017), 5030-5037.

projects often have a duration of 1-2 years in order to extract environmental data from all the different periods of the year.

The procedure of this research can be followed in similar cases. This methodological approach should include the investigation of: a) the urban scale of selected settlements in different climatic and geomorphological areas and b) the building scale of representative vernacular dwellings in each settlement. Qualitative as well as quantitative studies should be carried out in the various types of dwellings and in different areas of a selected number of case studies, such as closed, semi-open and open spaces. The in-depth analysis of specific traditional passive strategies such as ventilation is essential, as this is related to human behaviour and to the comfort inside the dwellings. The investigation of the materiality of the structures is also very important in order to have a holistic view of the thermal performance of the dwellings.

In conclusion, the necessity of following such holistic approaches towards the study of vernacular architecture should be underlined, taking into serious consideration all the different values that each approach involves (tangible and intangible). It should also be noted that the connection of heritage values with aspects of environmental technology gives this field of investigation a multidisciplinary character, offering opportunities for further research and innovation.

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