Contribution of Bioclimatic Elements to Thermal Comfort:
Heritage CaseStudy in Nicosia, Cyprus

AIMILIOS MICHAEL, MARIA PHILOKYPROU, STAVROULA THRAVALOU, IOANNIS IOANNOU

School of Engineering, University of Cyprus, Nicosia, Cyprus

ABSTRACT: The present paper aims at the study of the contribution of bioclimatic elements of vernacular architecture to human thermal comfort. To achieve this, an area of the historic centre of Nicosia, which has kept its original traditional character without significant alterations, has been studied. Two buildings were selected as case studies. These are representative samples of the 18th century local architecture. At present they host the Student Hostel and the Cultural Centre of the University of Cyprus. The study refers to a series of design principles including passive heating and cooling, natural lighting and improvement of microclimatic conditions of the surrounding environment. Continuous monitoring of the temperature and relative humidity in various places within these buildings and their courtyards is presented. The data loggers were placed on internal spaces, semi-open spaces and courtyards. External environmental data were also recorded in order to achieve a comparative evaluation. The investigation of the parameters which affect the conditions of interior thermal comfort aims at the establishment of a bioclimatic-driven approach in the conservation of traditional buildings.
Keywords: building thermal performance, thermal comfort, vernacular architecture

INTRODUCTION

Vernacular architecture incorporates a series of environmental features, the identification and conservation of which constitutes a main objective in contemporary conservation policies. The present paper provides insight on the contribution of the bioclimatic elements (heating, cooling, natural lighting and microclimatic strategies) of traditional urban buildings to human thermal comfort. The findings hereby presented are preliminary quantitative and qualitative results of the research project "BIOVERNACULAR" which began in July 2012 and is funded by the Republic of Cyprus and the European Regional Development Fund.The study area is the historic centre of Nicosia in Cyprus, which has kept its original character without significant alterations. Following an overall architectural investigation of this area, specific dwellings were selected for monitoring purposes, based on their typology, bioclimatic elements and construction materials. The study refers to a series of design principles including passive heating and cooling, and improvement of the microclimatic conditions of the surrounding environment. The investigation of the parameters which affect the conditions of interior thermal comfort aims at the establishment of a bioclimatic-driven approach in the conservation of traditional buildings.

RESEARCH METHODOLOGY

For the purposes of the research, two areas in the old city of Nicosia were selected for study. A sample of 50 buildings, in their majority residential ones, was initially studied in each area. Twelve representative buildings were selected for detailed investigation and monitoring of temperature and relative humidity levels. The selection of the specific traditional buildings was based on the following parameters: relationship of buildings to their immediate environment, building typology (arrangement and combination of covered and semi-open spaces around the central yard), building orientation, existence of sun shading projections, cross ventilation and stack effect (number, size and location of openings) and type, material and quality of building shell (wall and roof construction, thermal insulation, building mass). In addition, a weather station has been installed in the selected study area to record external climatic conditions. Another weather station has been placed in the centre of a traditional courtyard in one of the study buildings. Data loggers have been installed in the main rooms, the semi-open spaces, the courtyard, and on the first floor of the study buildings, to record temperature and relative humidity levels.

STUDY AREA

The selected study area presented in this paper is the neighbourhood of Chrysaliniotissa (Fig. 1), located in the west of the walled city of Nicosia.

This area is among the best preserved traditional parts of the old city centre and has been among the most heavily populated Christian communities during the 1stOttoman period [1].

Figure 1: Chrysaliniotissa area and buildings under study.

The focus is on the investigation of two specific traditional buildings in this area that are now hosting University of Cyprus facilities (Fig. 2). The first building under study, known as "Axiothea", hosts the cultural centre of the University. It has a plan of an irregular "U" with 3 different accesses from the surrounding streets leading towards the central large courtyard. The building used to cover a larger area in the past [1]; however, the original building was later divided and some of its parts were sold. The building's plan differs from the typical residential architecture in terms of typology and size, and gives the impression of monastery architecture. All rooms, including three large halls, are arranged around a very large courtyard. The rooms are situated behind semi-open spaces ("iliakos" or loggias) with pointed stone arches in the ground level and timber posts on the first floor. Communication between the rooms is achieved through the courtyard. In the exterior facades of the building, small windows are positioned at a relative height. The small entrances and the kiosk on the south elevation that belong to the original phase of the building underline the introverted character of the mansion. Larger windows of neoclassical style and balconies were later added on the exterior facades, changing the authentic character of the building.

The second building, now used as a student hostel, constitutes a unification of two original two-storey urban houses. This unification led to a very interesting building complex with rooms arranged in a "U" shape around a central yard. The original northern house of the complex has a typical triple bay arrangement (tripartite division), with two rooms arranged on both sides of a central semi-open space ("portico" or gallery) [2]. The eastern house has a two bay arrangement with a large "portico" giving access through the street to the largest room of the building (dichoro). Access to the first floor is achieved through two staircases, one for each house, arranged in the semi-open spaces (iliakoi) that enclose the yard.

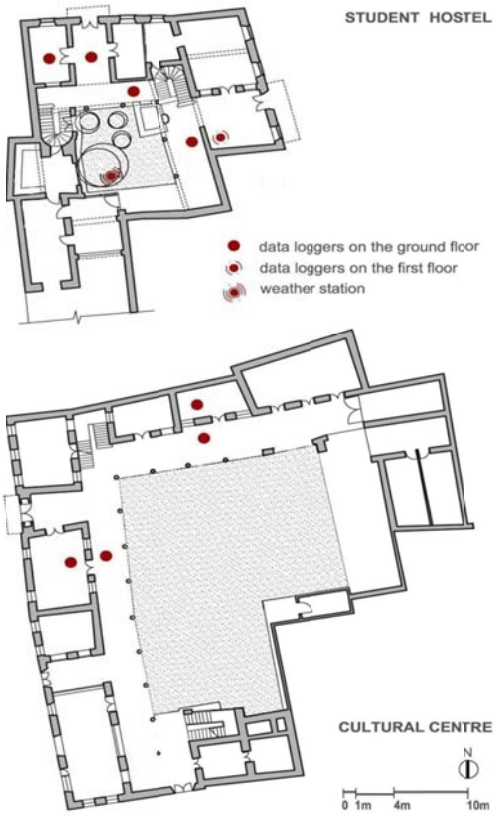

Figure 2: Plans of the buildings under study showing the indoor and outdoor measuring points.

The detailed investigation of the two aforementioned buildings (Fig. 3) indicates the incorporation of a series of bioclimatic elements in both dwellings. Regarding heating, direct solar gains are derived from the openings towards the south, while indirect solar gains are derived through the heavy building envelope. Additionally, in "Axiothea" the closed western façade reduces the thermal losses of the building and protects it from the western and north-western strong and cold winds during the winter period.

Both buildings incorporate the majority of the cooling strategies commonly found in the vernacular urban architecture of Nicosia [3]. Sun shading is provided by semi-open spaces (iliakoi) in front of the south side of the buildings, roof overhangs, balconies and external shutters (solid plank or adjustable louvers)(Fig. 3b, c). Cross ventilation is ensured through small size openings (called "arseres") on the building envelope. These are located at a considerable height, mainly on the façades on the streets and contribute to forced ventilation and extraction of hot air from the building, due to the difference in temperature and density of the air (stack effect) [4]. The semi-open spaces ("iliakos" or "portico") also enhance air flow through the building volumes.

Figure 3: General views of exterior and semi-open spaces of the selected study buildings. (a, b and d:Student Hostel c: Cultural Centre).

With regard to microclimatic environment strategies, the existence of central courtyards in both buildings reveals the importance of this element in local urban vernacular architecture [5]. Courtyards are usually shaded by plants and vegetation or by the surrounding building volumes (Fig. 3a). Vegetation ensures a naturally protected environment, which reduces the high temperatures and regulates the relative humidity levels during the summer period. In addition, the existence of a well in the student's hostel courtyard (Fig. 3d), as well as the watering of the plants, provides evaporative cooling during the summer period.

Regarding building construction, thermal inertia is secured by the thick wall materials (stones and mud bricks), which offer high thermal mass. The roof construction is composed of different layers (beams, reeds/mats/timber planks, earth, ceramic tiles) [6], thus offering high thermal insulation to the dwellings.

THERMAL PERFORMANCE ANALYSIS

Monitoring methodology: The quantitative analysis of the traditional buildings under study is comprised of the investigation and documentation of the applied design strategies for the improvement of thermal comfort conditions of the indoor and outdoor living spaces. For data acquisition, two weather stations (Vantage Pro2) and 18 data loggers (USB-2-LCD, USB-1-PRO) were placed in selected indoor and outdoor spaces of the buildings under study (Figure 2). The weather stations were installed (a) on the roof of the cultural centre for the recording of the external environment climatic data, and (b) in the hostel's central courtyard for the recording of the climatic data in the open space of the dwelling. The data loggers for the measurement of temperature and relative humidity were installed (a) in semi-open air spaces, ("iliakos" or "portico") with different orientations for the recording of the climatic data in the outdoor semi-open living spaces and (b) in internal spaces of the buildings under study. In all cases, the data loggers were installed at a height of 200 cm above finished floor level. All measurements were recorded every 10 minutes for an initial period of about 2 months (March-April, 2013).

The measurements of temperature and relative humidity for the time span of one week are analysed for the period from 20th of March 2013, 00:00 hrs until 26th of March 2013, 24:00 hrs. The specific period of monitoring includes the spring equinox on the 21st of March. The internal spaces of the buildings under study had no technical support for heating or cooling during the aforementioned period.

Climatic data of outdoor spaces of buildings under study: This specific investigation aims at assessing the contribution of semi-open (i.e. iliakos and portico) and open (i.e. courtyard) spaces to the improvement of microclimatic conditions of the intermediate building environment, in comparison to the overall regional environmental climatic data (Fig. 4).

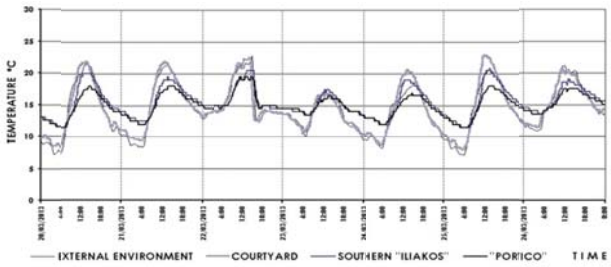

Figure 4: Temperature data of the buildings' outdoor spaces.

The maximum temperature of the southern "iliakos" is 20.5 ºC, while the respective temperature of the southern "portico" is 19.5 ºC, i.e. 2.3 ºC and 3.3 ºC lower than the maximum temperature of the external environment (22.8 ºC), respectively. The maximum temperature of the courtyard is ranging at the same levels as the respective temperature of the external environment. The minimum temperature of both the southern "iliakos" and the southern "portico" is 11.5 ºC, i.e. 4.4 ºC higher than the minimum temperature of the external environment. The minimum temperature of the courtyard is 0.8 ºC higher than the respective temperature value of the external environment. At the same time, the mean temperatures for the outdoor spaces are similar, ranging from 14.4 ºC to 15.5 ºC.

The temperature fluctuations of the southern "iliakos" and the southern "portico" are 9.0 ºC and 8.0 ºC, respectively, significantly lower than the temperature fluctuation of the external environment which is 15.7 ºC. The recorded temperature data are reasonable and confirm the positive contribution of the semi-open spaces as sun shading elements. The temperature fluctuation of the courtyard is 15.0 ºC, i.e. 0.7 ºC lower than the temperature fluctuation of the external environment (Fig.5a). This reduction in temperature fluctuation ensures improved thermal comfort.

The relative humidity fluctuations of the southern "iliakos" and the southern "portico" are 35.5 RH% and 42.5 RH% respectively. The relative humidity fluctuation of the courtyard and the external environment is 63.0 RH% and 64.0 RH% respectively. The recorded relative humidity of the semi-open spaces is significantly lower, compared with the relative humidity fluctuation recorded at the courtyard and the external environment; this indicates the positive contribution of the semi-open spaces as relative humidity regulators (Fig.5b).

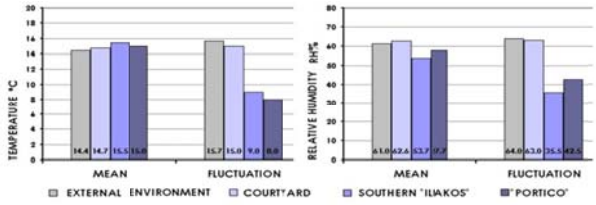

Figure 5a, b: Comparison bars of temperature and relative humidity values of the buildings' outdoor spaces.

Climatic data of semi-open spaces and internal spaces with eastern, southern and western exposure: The investigation of climatic data recorded at a semi-open space ("iliakos") and at an internal space of the same orientation aims at assessing the contribution of semi-open spaces to the thermal conditions of the rooms situated immediately behind them. The specific analysis is hereby performed for semi-open spaces and internal spaces with eastern, southern and western exposure.

Climatic data of eastern semi-open space "iliakos" and eastern internal space: The temperature data are shown in Figure 6.

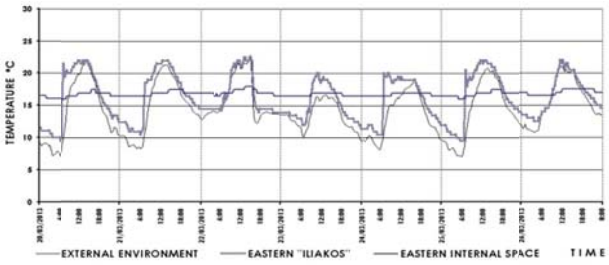

Figure 6: Temperature data of eastern "iliakos" and adjacent internal space.

The maximum temperature of the eastern "iliakos" is 22.5 ºC, i.e. 0.3 ºC lower than the maximum temperature of the external environment. The respective temperature value of the eastern internal space is 18.0 ºC, i.e. 4.8 ºC lower than the maximum temperature of the external environment and 4.5 ºC lower than the maximum temperature of the eastern "iliakos". The minimum temperature of the eastern "iliakos" is 9.5 ºC, i.e. 2.4 ºC higher than the minimum temperature of the external environment. The respective temperature value of the eastern internal space is 16.0 ºC, i.e. 8.9 ºC higher than the minimum temperature of the external environment and 6.5 ºC higher than the minimum temperature of the eastern "iliakos". At the same time, the mean temperature for the eastern internal space is 16.8 ºC, while the respective values for the eastern "iliakos" and the external environment are16.2 ºC and 14.4 ºC. The temperature fluctuation for the eastern internal space is 2.0 ºC, i.e. 9.0 ºC lower than temperature fluctuation of eastern "iliakos" and 13.7 ºC lower than the external environment (Fig. 7a). The recorded temperature data for the eastern "iliakos" again confirm the positive contribution of the semi-open spaces as sun shading elements. Moreover, the significantly lower temperature fluctuation in the eastern internal space confirms the high performance thermal insulation and the thermal inertia of the building envelope.

The relative humidity fluctuation for the eastern internal space is 21.5 RH%, i.e. 31.5 RH% lower than relative humidity fluctuation of eastern "iliakos" and 42.5 RH% lower than the external environment. The lower relative humidity fluctuation recorded in the eastern internal space ensures more comfortable living conditions throughout the day (Fig. 7b).

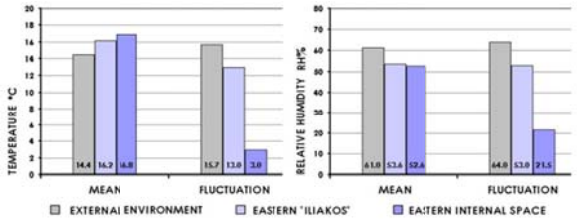

Figure 7a, b: Comparison bars of temperature and relative humidity valuesof eastern "iliakos" and internal space.

Climatic data of southern semi-open space "iliakos" and southern internal space: The temperature data are shown in Figure 8.

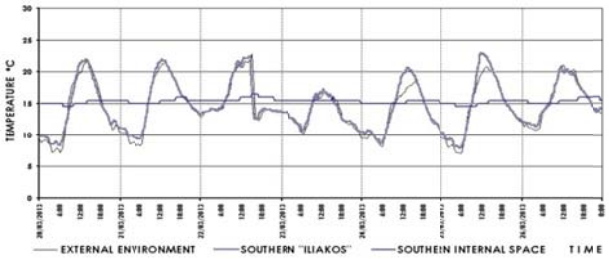

Figure 8: Temperature data of southern "iliakos" and adjacent internal space.

The maximum temperature of the southern "iliakos" is 20.5 ºC, i.e. 2.3 ºC lower than the maximum temperature of the external environment. The respective temperature value of the southern internal space is 16.5 ºC, i.e. 6.3 ºC lower than the maximum temperature of the external environment and 4.0 ºC lower than the maximum temperature of the southern "iliakos". The minimum temperature of the southern "iliakos" is 11.5 ºC, i.e. 4.4 ºC higher than the minimum temperature of the external environment. The respective temperature value of the southern internal space is 14.5 ºC, i.e. 7.4 ºC higher than the minimum temperature of the external environment and 3.0 ºC higher than the minimum temperature of the southern "iliakos". At the same time, the mean temperature for the southern internal space is 15.5 ºC, while the respective values for the southern "iliakos"and the external environment are 15.5 ºC and 14.4 ºC. The temperature fluctuation for the southern internal space is 2.0 ºC, i.e. 7.0 ºC lower than temperature fluctuation of southern "iliakos" and 13.7 ºC lower than the fluctuation for the external environment (Fig. 9a). The recorded temperature data for the southern "iliakos" and the significantly lower temperature fluctuation in the southern internal space further confirm the positive contribution of the semi-open spaces as sun shading elements and the excellent thermal insulation and thermal inertia of the building envelope.

The relative humidity fluctuation for the southern internal space is 10.5 RH%, i.e. 25.0 RH% lower than relative humidity fluctuation of southern "iliakos" and 53.5 RH% lower than the external environment. This observation is in line with the observations made for the eastern rooms and semi-open spaces (Fig. 9a).

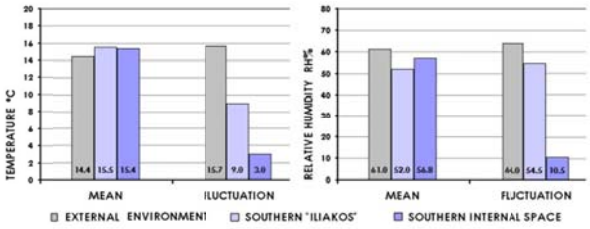

Figure 9a, b: Comparison bars of temperature and relative humidity valuesof southern "iliakos" and internal space.

Climatic data of western semi-open space "iliakos" and western internal space: The temperature data are shown in Figure 10.

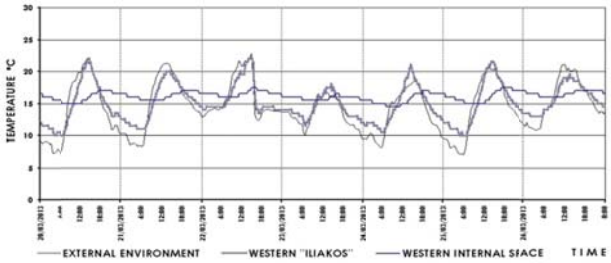

Figure 10: Temperature data of western "iliakos" and adjacent internal space.

The maximum temperature of the western "iliakos" is 22.0 ºC, i.e. 0.8 ºC lower than the maximum temperature of the external environment. The respective temperature value of the western internal space is 17.5 ºC, i.e. 5.3 ºC lower than the maximum temperature of the external environment and 4.5 ºC lower than the maximum temperature of the western "iliakos". The minimum temperature of the western "iliakos" is 10.0 ºC, i.e. 2.9 ºC higher than the minimum temperature of the external environment. The respective temperature value of the western internal space is 14.5 ºC, i.e. 7.4 ºC higher than the minimum temperature of the external environment and 4.5 ºC higher than the minimum temperature of the western "iliakos". At the same time, the mean temperature for the western internal space is 16.1 ºC, while the respective values for the western "iliakos"and the external environment are 15.0 ºC and 14.4 ºC. The temperature fluctuation for the western internal space is 3.0 ºC, i.e. 9.0 ºC lower than temperature fluctuation of western "iliakos" and 12.7 ºC

lower than the external environment (Fig. 11a). The recorded temperature data for the western rooms and semi-open spaces generally agree with the observations made for the respective eastern and southern building spaces.

The relative humidity fluctuation for the western internal space is 15.5 RH%, i.e. 32.0 RH% lower than relative humidity fluctuation of western "iliakos" and 48.5 RH% lower than that of the external environment (Fig. 11b).

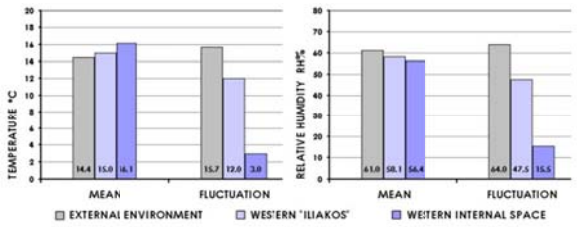

Figure 11a, b: Comparison bars of temperature and relative humidity valuesof western "iliakos" and internal space.

CONCLUSIONS

The thermal performance (i.e. temperature and relative humidity) analysis of the two traditional urban dwellings located in Nicosia, hereby presented for an intermediate period (20th-26th March), provides valuable information about their thermal behaviour and underlines the significant environmental features of local vernacular architecture.

The analysis focuses on the behaviour of open and semi-open spaces. The temperature data recorded, confirm the positive contribution of the semi-open spaces as sun shading elements. Moreover the reduction in temperature fluctuation observed in all cases studied, compared to the respective temperature fluctuation of the external environment, helps towards the achievement of more comfortable living conditions within these traditional dwellings. The "portico" generally shows smaller temperature fluctuations, compared to "iliakos", due to its greater "depth". The recorded relative humidity fluctuations of the semi-open spaces are significantly lower compared with the relative humidity fluctuations recorded at the courtyard and the external environment; this indicates the positive contribution of the semi-open spaces as relative humidity regulators.

The positive contribution of semi-open (iliakos and portico) and enclosed open (courtyard) spaces to the improvement of the microclimatic conditions of the intermediate environment, results in better thermal comfort conditions of the internal spaces. The significantly lower temperature fluctuations recorded in the internal spaces with eastern, southern and western exposure, ranging from 2.0 ºC to 3.0 ºC, confirms the high thermal insulation characteristics of the building envelope and the thermal inertia secured by the thick wall construction materials, which offer high thermal mass. The significantly lower relative humidity values recorded, ranging from 10.5 RH% to 21.5 RH%, reinforces the improvement of the interior living conditions throughout the day.

Through this research, preliminary quantitative results on the thermal performance of vernacular dwellings in the historic centre of Nicosia have been presented. A more thorough and systematic investigation of traditional architecture, covering the period of an entire year, will definitely lead to valuable information regarding the cooling and heating periods. An investigation of the parameters which affect the conditions of interior thermal comfort will lead to the establishment of a bioclimatic-driven approach in the conservation of traditional buildings.

ACKNOWLEDGEMENTS

The research described in this paper is based on the findings of the research programme ΑΝΘΡΩΠΙΣΤΙΚΕΣ /ΑΝΘΡΩ/0609(BIE) funded by the Republic of Cyprus and the European Regional Development Fund through the Cyprus Research Promotion Foundation's Framework Programme for Research, Technological Development and Innovation (Δέσμη 2009-2010). The Host Organisation of the programme is Nicosia Municipality and the Partners are the University of Cyprus, ICOMOS, Cyprus and the Frederick Research Institute.

REFERENCES

1. Papadouris, G. and Igoumenidou, F. (1992).The mansion of Axiotheas Street in Nicosia, Cypriot Studies, v. Ν.Δ΄- ΝΕ΄: p. 351-367.
2. Danilo, D. (1997). The Walled City of Nicosia.UNDP United Nations Development Programme. Nicosia.
3. Philokyprou, M., Michael, A. and Thravalou, S. (2013). Assessment of the Bioclimatic Elements of Vernacular Architecture.The Historic Centre of Nicosia, Cyprus. In Le VieideiMercanti XI Forum Internazionale di Studi, Aversa, Capri, Italy, June 13-15.
4. Goulding, J., Lewis, O. and Steemers, T. (1992). Energy in Architecture: The European Passive Solar Handbook. Brussels: Commission of the European Communities.
5. Philokyprou, M. and Limbouri, E. (2012). The Role of the Central Courtyard.Surveys in the Vernacular Architecture of Cyprus. In International Conference Surveys on Vernacular Architecture., Porto, Portugal, May 17-19.
6. Ionas, I. (1988). La Maison Rural de Cypre (XVII-CC Siècle). Aspects et Techniques de Construction. Publications of the Science Research Centre. Nicosia, Cyprus.