The Role of Semi-open Spaces as Thermal Environment Modifiers in Vernacular Rural Architecture of Cyprus

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Abstract

Semi-open spaces are widely used in vernacular architecture across the world. In the Mediterranean area, they are usually developed along the south side of the building, permitting direct solar gains during the heating period, while providing shading during the cooling period. Thus, semi-open spaces create a protected microclimatic environment that hosts various activities throughout the year. Semi-open spaces constitute one of the main bioclimatic elements of vernacular architecture and, as such, they are worth protecting. However, the built heritage is subject to adaptive interventions in response to social needs. The conversion of semi-open spaces into indoor spaces, with the use of extended glass surfaces, is one of the most commonly applied interventions in rehabilitation and conservation projects in Cyprus, due to the different social needs that they have to meet. However, such actions affect the overall energy performance of the premises substantially. This study provides insight and documentation on the role of south orientated semi- open spaces, as thermal environment modifiers, and highlights the impact of their conversion into indoor spaces. Experimental and simulation tools are used in order to investigate south oriented semi-open spaces encountered in the Mediterranean, focusing on a representative case study that reflects the typical arrangement of rural vernacular dwellings in Cyprus. The results of this research indicate the positive environmental contribution of the semi-open spaces in traditional dwellings as they provide acceptable thermal comfort for a considerable period of time. As far as the conversion of semi-open spaces into indoor spaces is concerned, excessive temperature levels are noticed during the cooling period, in the absence of any shading and natural ventilation, due to the greenhouse effect. On the contrary, during the heating period a positive contribution to the thermal environment of the main building is observed. This can be attributed to the creation of the greenhouse effect and the function of the semi-open space as a thermal buffer zone, reducing heat losses. Conclusions are drawn concerning the proper use and seasonal manipulation by the occupants of the glass openings framed in these spaces, so as to adapt to varying environmental conditions.

Keywords: semi-open spaces, vernacular architecture, thermal comfort, conservation

1. Introduction

Transitional spaces comprise, in many cases, an urban filter that creates a transition sequence from the public to the private space (Vegas & Mileto, 2013). Life and sociocultural relationships seem to flourish and prosper in these interstitial spaces, as they provide warmth and shelter. Their important role to everyday life can also be associated to their bioclimatic and environmental virtues. They can be found in many different forms; closed, such as in an atrium, semi-open, such as in a balcony or porch, or open, such as in a courtyard or a patio (Taleghani, Tenpierik & Dobbelsteen, 2012). In all these cases, they form architectural elements which moderate outdoor and indoor climatic conditions without the use of technical systems.

From a theoretical point of view, Alexander, Ishikawa & Silverstein (1997) addressed these spaces as 'outdoor rooms', that is, spaces that are open and closed at the same time. Such semi-open spaces are usually elements annexed to the dwelling by extending the protection provided by the roof, such as in large eaves, porches or pergolas. They can be found in many different types of dwellings, in warm and cool climates, while they are very common in places with hot and sunny summers such as the Mediterranean regions. In these areas, they are usually found along the south side of buildings, enabling direct solar gains during the winter, while providing shading during the summer (Philokyprou et al, 2013).

While many studies focus on closed or open transitional spaces, the energy performance of semi-open transitional spaces is much less documented. Recent studies quantify the contribution of transitional spaces in the energy performance of buildings, with the use of simulation tools (Qadir, 2013; Taleghani, Tenpierik& Dobbelsteen, 2012; Aldawoud & Clark, 2008; Aldawoud, 2008). Qadir (2013) and Taleghani, Tenpierik & Dobbelsteen (2012) used EnergyPlus and Design Builder software for modelling and simulating courtyard and atrium spaces in different climates, while Cardinale Rospi & Stefanizzi (2013) employed the same tools to investigate the thermal performance of vernacular dwellings in the south of Italy.

The effect of the position of semi-open spaces in various types of buildings, in hot dry climate has been investigated by Sanaieian et. al. (2013), employing EnergyPlus and Design Builder software in order to estimate annual cooling and heating energy demands in various building types in Tehran, Iran. The findings confirm that, the position of a semi-open space has a significant impact on cooling loads. It is also confirmed that the most efficient solution is to position the courtyard and semi-open spaces on the south side of a building, which is in line with traditional architecture design principles.

Indeed, the built vernacular heritage incorporates exceptional examples of integrations of semi-open spaces based on environmental design principles. However, vernacular heritage is not perceived as a static environment, but as an ongoing process of adaptation, in response to social and environmental challenges. The growing need for indoor spaces in the housing sector induces architectural interventions. One of the most common interventions is the conversion of semi-open spaces into indoor spaces. However, such actions affect the overall energy performance of the building.

The current study highlights the impact of such architectural interventions, providing further documentation on the role of semi-open spaces as thermal environment modifiers. Experimental and simulation tools are used in order to investigate south adjacent semi-open spaces encountered in the Mediterranean, focusing on a representative case study building that reflects the typical arrangement of rural vernacular settlements in Cyprus. The impact of common contemporary interventions is investigated with the aim of enriching the open discussion towards conservation practises across the Mediterranean, in relation to the conservation of the environmental elements of vernacular architecture.

2. Methodology

2.1 The case study

The study focuses on rural vernacular architecture as it has evolved in the settlement of Pera Orinis, in the Mesaoria plain, at an elevation of 400m above sea level. The local climatic conditions are characterised by short mild winters and hot dry summers followed by high summer aridity. Minimum temperatures reach 5.7°C whereas maximum temperatures reach 35.5°C. A representative traditional dwelling, located in the particular settlement, is selected as a case study for in depth investigation. Semi–open spaces, locally referred to as *iliakos*, are frequently encountered across the settlement and play a fundamental role in the everyday life of the locals (Philokyprou et al, 2014). The semi-compact configuration of the settlement of Pera Orinis, and the prevailing southern (S, SE, SW) orientation of dwellings, allow direct and indirect solar gains during heating period (winter), while they provide desirable shading from neighbouring surrounding buildings during the cooling period (summer).

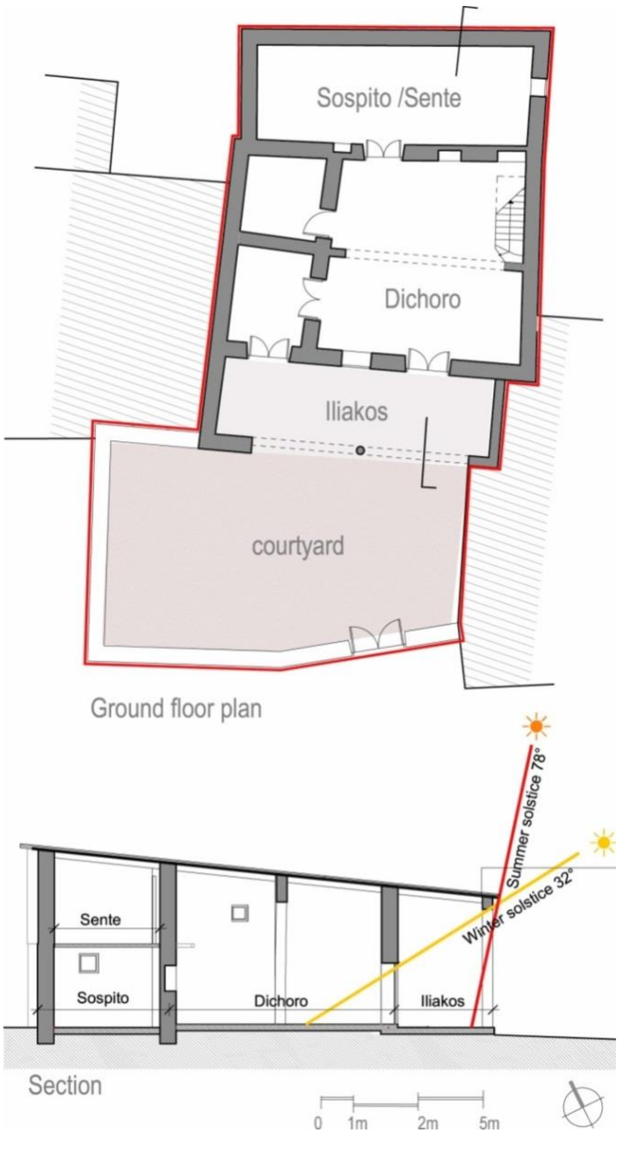

Figure 1. Plan and section of the case study building.

Figure 2. Starting from left side: south facade of *iliakos* space, *iliakos* space and *dichoro*

An overview of the vernacular architecture of Cyprus reveals several architectural features and passive design techniques, which cool or warm indoor spaces through the exploitation of local natural resources. Such strategies concern the orientation of the building, the existence of semi-open spaces (courtyards, semi-open spaces, etc.), the proper location and size of openings, the existence of shading devices such as window shutters, possibilities for natural ventilation, i.e. cross ventilation or stack effect, as well as materiality and methods of construction (Philokyprou et al 2013).

The building under study is a representative dwelling of vernacular architecture on the island (Figure 1 and 2). It consists of a double space main room (*dichoro)* with an arch dividing the space into two parts, an inner space (*sospito)* with a mezzanine for storage purposes *(sente)* and two small auxiliary spaces (*monochoro*).

The courtyard, and the semi-open space (*iliakos),* lie on the southern part of the plot in order to ensure desirable solar access to indoor and outdoor spaces during the heating period. The *iliakos* is built with traditional construction methods and with materials of high thermal mass. Specifically, the walls, of approximately 50cm width, are made of adobe bricks laid on a stone base, the floor is covered by traditional gypsum slabs and the roof is made of timber and traditional ceramic tiles. During recent renovation works on the roof, a thermal insulation material, 5cm wide, has been added.

2.2 Simulation tool

This study employs the building energy analysis simulation tool EnergyPlus v8.3. The graphic interface of Design Builder v4.3 software is used for modelling the geometry and for inputting data. Natural ventilation and infiltration measurements are calculated based on window openings, cracks, buoyancy and wind driven pressure differences. The ventilation control mode is set to constant, enabling windows to open for fresh air-supply, regardless of inside or outside temperature and enthalpy. The airtightness of the building is considered as good. Simulations employ full interior and exterior solar distribution, calculating the amount of solar radiation falling on each surface of the building zone including the floor surface and walls and windows, while accounting for direct solar and light transmission through internal windows. The thermal properties of the construction materials, as well as the thermal transmittance of the building components, were identified with the use of non-destructive experimental methods as presented in Table 1 and Table 2.

Table 1. Thermal properties of building materials

Material	Density ρ (kg/m^3)	Thermal conductivity λ(W/mK)	Specific heat capacity Cp (J/kgK)
Adobe	1405	0.55	996
Calcareous stone	2370	1.05	620
Lime mortar	1766	0.61	866

Table 2. Thermal transmittance of building components

Building Component	Thermal transmittance U-value (W/m^{2}K)
Adobe Wall	0.87
Renovated Roof	0.47
Traditional Roof	2.16
Ground floor	1.10

Measurements of indoor temperature and relative humidity levels, as well as external weather data, were monitored on site in order to confirm the digital model. For the verification of the model, the inequality coefficient (IC) was calculated according to equation 1 (Williamson, 1995):

$$IC = \frac{\sqrt{\frac{1}{n}\sum_{t=0}^{n}\left(D_{sim,t}-D_{exp,t}\right)^2}}{\sqrt{\frac{1}{n}\sum_{t=0}^{n}\left(D_{sim,t}\right)^2}+\sqrt{\frac{1}{n}\sum_{t=0}^{n}\left(D_{exp,t}\right)^2}} \quad (1)$$

where $D_{sim,t} = \left(T_{int,t} - T_{ext,t}\right)_{sim}$ is the simulated and $D_{exp,t} = \left(T_{int,t} - T_{ext,t}\right)_{exp}$ the experimental temperature differences. IC presents the degree of agreement between experimental and simulated data, ranging in value between 0 and 1, with 0 indicating a strong correlation. The IC for *dichoro* was calculated as 0.15 and for *sente* as 0.19, which indicates the level of efficiency of the simulation tool for the study of thermal performance for the building under study.

2.3 Thermal comfort assessment background

Given that most vernacular buildings are naturally ventilated, this study is based on the adaptive approach to thermal comfort, which is, itself, based on the Adaptive Comfort Standard (ACS), integrated within ASHRAE Standard 55 (ASHRAE, 2004). According to ACS, the acceptable indoor operative temperature, T_{comf}, is expressed as a function of the mean monthly outdoor air temperature, $t_{a\ (mean)}$. A mean comfort zone band of 5°C is estimated for 90% acceptability and 7°C for 80% acceptability, around the optimum indoor comfort temperature, calculated as in equation 2:

$$T_{comf} = 0.31 * t_{a(mean)} + 17.8 \quad (2)$$

2.4 Case study scenarios

Depending on whether they are open or closed, the openings on the south façade of *dichoro* regulate the amount of air exchange through the transitional space of *iliakos*, while the state of the openings (open or closed), in the arched façade of *iliakos,* defines whether the space is indoor or semi-open. Considering that thermal insulation of the roof is among the most efficient energy saving retrofits, the following key parameters are compared during the heating and cooling period: a) whether openings in *Iliakos* are open or closed, b) whether openings in the south facade of *dichoro* are open or closed, and c) the existence of thermal insulation at the roof level of *iliakos*. Accordingly, the configurations presented in Table 3 are simulated and discussed.

Table 3. Case scenarios under study

	Cooling/Heating Period	State of *iliakos*	State of *dichoro* openings	Thermal insulation in *iliakos* roof
1	C / H	Original	Closed	No
2	C/ H	Original	Closed	Yes
3	C	Original	Open	No
4	C	Original	Open	Yes
5	C / H	Closed	Closed	No
6	C / H	Closed	Closed	Yes
7	C/ H	Closed	Open	No
8	C/ H	Closed	Open	Yes

3. Thermal performance assessment

3.1 The use of Iliakos in its original state

Vernacular dwellings, in their original form, correspond to the use of *iliakos* as a semi-open space with no thermal insulation on its roof. According to field study surveys, occupants maintain the south openings of *dichoro* open during the summer and closed during the winter, i.e. case 3 and case 1 respectively.

The semi-open space (*iliakos)* has a high height/width ratio of 1.5, represented by a space height of 4.20m, and a rather narrow width of 2.80m. Its geometrical features allow sun rays to penetrate into the *iliakos* and *dichoro* during the heating period, while providing protection during the cooling period. This is due to the higher altitude of the noonday sun, during the summer solstice, i.e. 78° compared to the relative altitude during the winter solstice, i.e. 32° (Figure 1).

The hourly simulation report indicates that the mean maximum and minimum temperatures observed in the semi-open *iliakos* remain at higher levels than the exterior environment throughout the entire year (Figure 3). This is mainly attributed to the thermal mass of the building envelope that absorbs thermal energy during the day, when the surroundings are at a higher temperature than the building mass, and releases thermal energy during the night, when the surroundings are cooler. During the heating period, the difference in the mean daily operative temperature of *iliakos,* and the air temperature of the exterior environment, can reach 2.5°C. This is quite beneficial, as it ensures better thermal conditions for *iliakos*, while, at the same time, it acts as a thermal buffer zone for the inner main living spaces. However, the same phenomenon (of thermal heat accumulation) is not beneficial during the cooling period, as *iliakos* exhibits overheating, compared to the exterior environment by 1-2 °C.

Dichoro is a deep space with a high ceiling, at approximately 4.5m. The height, and inclined roof, reduce the negative effect of excessive solar heat gains through the roof; while, at the same time, they enhance the potential for natural ventilation through the stack effect. *Sente* exhibits overheating during the cooling period as a consequence of being directly affected by solar heat gains through the roof, as well as by the rise of the warm interior air from the lower level of *dichoro*. The mean operative temperature during the cooling period at the *sente* rises 2°C higher than *dichoro*. However, this space is the most comfortable room during the heating period. *Sospito* is the room that preserves the most stable thermal environment, as its daily temperature fluctuation is as low as 0.5 -1°C throughout the entire year (Figure 3). Temperatures drop below comfort level during the heating period, as it is a room with extensive walls exposed to the north, east and west, as well as with limited potential of solar gains. It is worth noting that the building volumes adjacent to *sospito* no longer exist. Its original state would exhibit better thermal performance in *sospito* (reduced heat losses) due to higher urban density.

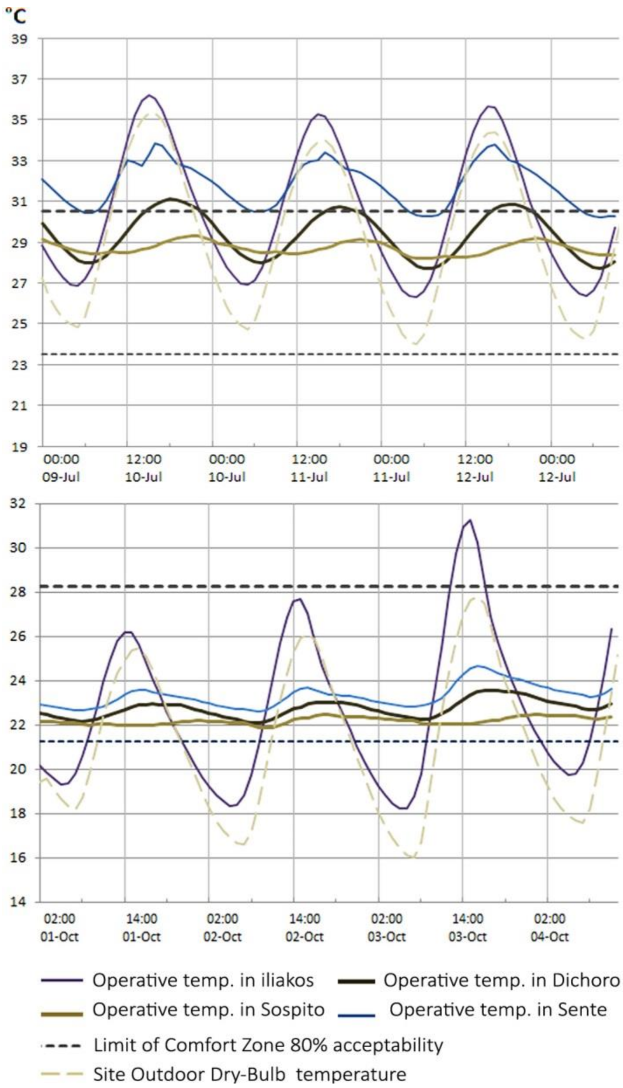

Figure 3. Hourly temperature distribution of interior, semi-open and exterior spaces of the case study building, during July and October.

The addition of thermal insulation material (5cm thick with conductivity λ=0.03 W/mK), at the roof of *iliakos,* reduces maximum operative temperature levels by 2 °C during the cooling period (i.e. case scenarios 1 and 2, as well as, case scenarios 3 and 4). In the case of scenario 1, when the windows in *dichoro* remained closed, the percentage of time when operative temperature levels in *iliakos* lay within the comfort zone for 80% acceptability during the cooling period (June to September) is 56.8%, while, in case scenario 2, the addition of thermal insulation results in a percentage value of 63.4%. Respectively, in case scenario 3, when windows in *dichoro* are open, the aforementioned percentage value is 58.4%, while in case scenario 4 the value rises to 65.9% when thermal insulation is added on the roof of *iliakos*.

Given that the openings of *dichoro* remained closed during the heating period and thus the *iliakos* was isolated, the addition of the thermal insulation material has no significant impact in the operative temperature of *dichoro* (i.e. comparison of case scenarios 1 and 2).

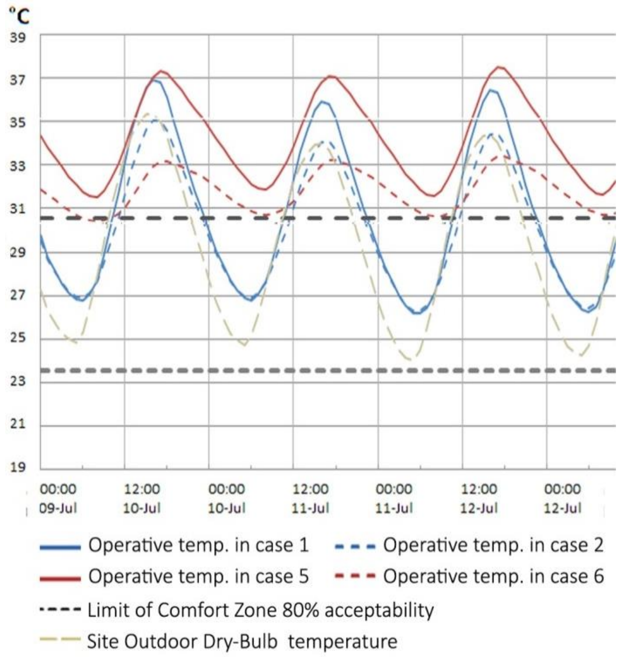

Figure 4. Hourly temperature distribution in *iliakos* space during summer period (July).

The full-day ventilation of the *dichoro* during the cooling period (i.e. case scenario 3) ensures better air circulation and thus, provides better thermal performance in the semi-open *iliakos*. However, the full-day ventilation of the *dichoro* results in heat gains from the external environment and thus results in a smaller percentage of time falling within the comfort zone. In particular, the percentage of time in *dichoro* when the operative temperature levels are within the comfort zone for 80% acceptability is 93.8% in case scenario 1 (i.e. *dichoro* with no ventilation) and 86.2% in case scenario 3 (i.e. *dichoro* with ventilation).

3.2 The use of Iliakos as an indoor space

One common architectural need included in renovation projects is the acquisition of more functional indoor spaces. The installation/insertion of operable windows on the arches of the façade of *iliakos* is a common practice applied in renovation of vernacular heritage buildings in Cyprus.

The conversion of *iliakos* into an indoor space, during the heating period (i.e. case scenarios 5 to 8), has a significantly beneficial impact on the thermal performance of both *iliakos* and *dichoro*. Hourly operative temperatures occurring in an *iliakos,* whose inserted windows are kept closed (closed *iliakos*), can reach significantly higher levels than those recorded in the original, semi-open state of *iliakos* (Figure 5). Specifically, the percentage of time in *iliakos* when the operative temperature levels are within the comfort zone for 80% acceptability during the heating period (December to March) is 14.9% in case scenario 1 (i.e. *iliakos* in its original state) and 66.0% in case scenario 5 (i.e. closed *iliakos*). This is attributed to the extended glass surface of *iliakos* that ensures direct solar gains which, in turn, convert the *iliakos* into a solar space.

Consequently, the thermal performance of *dichoro* is positively affected, since the closed *iliakos* acts as a thermal buffer zone, reducing heat losses. Specifically, the percentage of time in *dichoro* when the operative temperature levels fall within the comfort zone for 80% acceptability during the heating period (December to March) is 10.4% in case scenario 1 (i.e. *iliakos* in its original state) and 15.9% in case scenario 5 (i.e. closed *iliakos*). Keeping the openings of the south façade of *dichoro* open, (i.e. case scenario 7) allows heat flow from the closed *iliakos* and more efficient exploitation of solar heat gains. In this case, the aforementioned percentage of time, falling within the comfort zone in *dichoro,* expands to 31.4%.

The addition of thermal insulation material on the roof of the closed *iliakos,* and the preservation of high ventilation rate between *dichoro* and *iliakos* (i.e. scenario 8), produces the most efficient results concerning thermal comfort conditions during the heating period (Figure 5). The percentage of time in *iliakos* and *dichoro* when the operative temperature levels fall within the comfort zone for 80% acceptability is 73.1% and 39.3% respectively. This is the best performance recorded in *dichoro* during the heating period.

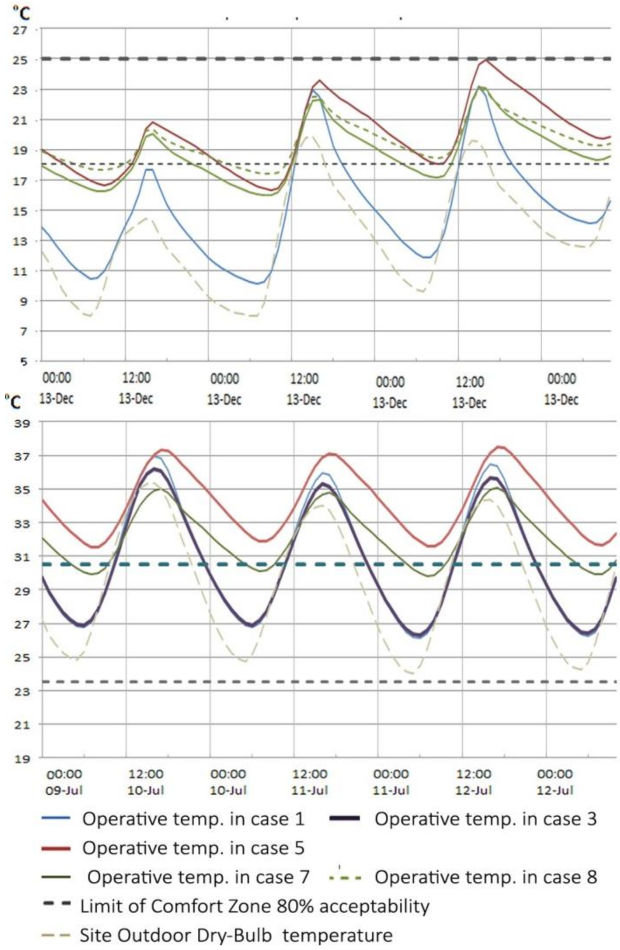

Figure 5. Hourly temperature distribution in *iliakos* during the winter and summer period.

As far as the cooling period is concerned, all the examined cases of the conversion of *iliakos* into an indoor space, with windows closed (i.e. scenarios 5 to 8), exhibit worse thermal performance compared to the original state of *iliakos* operating as a semi-open space. Specifically, in case scenario 3, when *iliakos* is at its original semi-open state, and the windows in *dichoro* are open, the percentage of time when operative temperature levels in *iliakos* are within the comfort zone for 80% acceptability is 58.4%. The respective percentage in the case of the closed *iliakos* (i.e. case scenario 7) drops to 30.9%. Similar performance is noticed in the space of *dichoro*. In case scenario 3, (*iliakos* at its original semi-open state), the percentage of time when the operative temperature levels in *dichoro* fall within the comfort zone for 80% acceptability is 86.2%, dropping to 77.1% in the case of the closed *iliakos* (i.e. case scenario 7).

Finally, it is worth mentioning that the worst thermal performance during the cooling period is exhibited when both *dichoro* and *iliakos* openings remain closed (i.e. case scenario 5). In this case, the percentage of time, when operative temperature levels in *iliakos* fall within the comfort zone for 80% acceptability, is only 11.4%. This occurs due to the accumulation of solar gains, as a result of the absence of natural ventilation (especially night ventilation) and, thus, cooling of the building envelope (Figure 5).

4. The open discussion on conservation policy

It is acknowledged that traditional buildings respond perfectly to both environmental and climatic constraints, as well as to socio-economic and cultural aspects of societies. Indeed, the built vernacular heritage represents an important resource that has significant potential to define principles for sustainable design and contemporary architecture (Coch, 1998). Thus, all the environmental design elements ought to be recognised and protected in contemporary conservation projects.

European declarations on restoration and conservation policy refer to alterations which legitimately respond to the demands of contemporary use, pointing out the importance of proper material selection, in terms of consistency of expression, appearance, compatibility with the integrity of the structure and the premise of being easily distinguished from the original fabric (Venice Chapter, Burras Charter). Respecting the principles above does not necessarily assure the climate responsive function of the envelope, which may result in a significant impact to the building energy demand. The research showed that, in the case of a south oriented *iliakos* in vernacular architecture of Cyprus, and notwithstanding aesthetic interventions in terms of materiality, improper occupant behaviour, and inappropriate interaction with the buildings' elements, can produce overheating and high levels of discomfort.

The study highlights the important role of occupant behaviour for establishing user comfort in built heritage conservation. Consequently, for conservation practices to meet recent trends toward sustainability, they should prioritize two main directions: initially, to identify the contribution and significance of environmental design elements in the building shell and secondly, to raise awareness regarding the behaviour of the occupants.

5. Conclusions

This paper focuses on the environmental performance of south oriented semi-open spaces, widely encountered in Cypriot rural built heritage, as well as in the wider region of the Mediterranean. Experimental and simulation tools are used for the estimation of the positive contribution of semi-open spaces in establishing thermal comfort and in calculating the impact of their conversion into indoor spaces with the addition of extended glass surfaces in the open south façades of these spaces.

The results reveal that semi-open spaces are major thermal environment modifiers, the effect of which goes far beyond a simple sunshade. In response to the theoretical approach of Alexander, Ishikawa & Silverstein (1997) who address these spaces as 'outdoor rooms', it is confirmed that, due to their mass and geometry, they affect immensely the main living spaces situated behind them. Thus, they ought to be approached as part of the building and modelled accordingly in numerical studies that use simulation tools.

The estimation of thermal performance of the original building form, with semi-open *iliakos,* presents a good climate adaptation strategy that provides acceptable thermal comfort for a certain period of time. *Sospito* presents the most stable thermal environment, with daily fluctuation of an operative temperature of 0.5-1°C throughout the year. *Sente* presents signs of overheating during the cooling period. However, this space is the most sought-after room during the heating period. *Dichoro* is well suited for use during the cooling period, falling 86.2% of the time within the extended comfort zone.

The conversion of *iliakos* into an indoor space leads to its overheating during the cooling period, due to the greenhouse effect, in the absence of ventilation. More specifically, the percentage of time within which it falls in the comfort zone of 80% acceptability in the cooling period with a semi-open *iliakos,* and with the windows of the *dichoro* open, is 58,4% (i.e. scenario 3). The corresponding percentage with a closed *iliakos* drops to 30.9% (i.e. scenario 7). Closing the windows between *dichoro* and *iliakos* leads to a further decrease of the comfort zone, at 11.4% (i.e. scenario 5).

By contrast, during the heating period, the closed *iliakos* has a positive contribution to the thermal environment of the main building, due to the creation of the greenhouse effect. In this case, *iliakos* serves as an amplified buffer zone, reducing heat losses. The percentage of time, when semi-open *iliakos* is found within the extended comfort zone, with the windows of *dichoro* closed, is 14.9% (i.e. scenario 1), rising to 66% when *iliakos* is converted into an indoor space (i.e. scenario 5). The improvement of the thermal environment in *dichoro* is also noteworthy. The percentage of time falling within the extended comfort zone, when *iliakos* is used as a semi-open space, with the windows of *dichoro* closed, is 10.4% (i.e. scenario 1). The corresponding percentage, when *iliakos* is converted into an indoor space, rises to 15.9% (i.e. scenario 5), while, in the case of preserving the windows of *dichoro* open, so that the heat gains are better distributed, it reaches 31.4% (i.e. scenario 7). In this case, the addition of thermal insulation on the roof of *iliakos* has a considerable impact on *dichoro*, recording a percentage of 39.3% within the comfort zone.

The results demonstrate that, in the case of extended glass surface windows installation in semi-open spaces, special attention should be paid to the seasonal operation of such windows. While during the heating period the above intervention is beneficial, during the cooling period it has negative results and should thus, be removed. The above observation highlights key points on the open discussion concerning built heritage conservation practices, underlining the contribution of users in achieving thermal comfort in the interior of vernacular dwellings.

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