LIGHTING PERFORMANCE IN RURAL VERNACULAR ARCHITECTURE IN CYPRUS: FIELD STUDIES AND SIMULATION ANALYSIS.

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Fig 1: Buildings under study: in Maroni, Pera Orinis and Askas respectively.

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

The research presented aims to investigate the natural lighting performance of indoor and semi-open spaces in rural vernacular settlements in Cyprus and to propose solutions to improve the lighting performance of these spaces with respect to their unique cultural character. Specifically, three representative buildings located in different settlements in Cyprus were selected based on their building typology, orientation and components of rural vernacular architecture. Each building is located in a different climatic zone as the topography of Cyprus varies between regions affecting the built fabric. The first case-study is located in the coastal zone, the second case-study in the lowland region and the third case-study in a mountainous region. For the evaluation of the lighting levels of each building, in-situ lighting measurements as well as software simulations were employed. In-situ illuminance data were compared to simulations in order to validate the digital model. The subsequent lighting simulation addressed representative indoor spaces and was performed for an entire year, based on dynamic climatic variations. Simulations were carried out using Ecotect software v.5.2, Desktop Radiance v.2.0 software and Daysim v.3., while the weather files were extracted from Meteonorm v.7.1.3 software. The results of the analysis enabled an evaluation of daylighting in different typologies in the rural vernacular architecture of Cyprus within various climatic zones. Conclusions regarding potential improvements were proposed in the three selected case studies in order to meet the contemporary daylight needs of potential occupants.

Keywords: Natural Lighting Levels, Field Measurements, Simulation, Static and Dynamic Analysis, Improvements, Rural vernacular architecture, Cyprus.

1. Introduction

Cyprus has a significant heritage with regards to its vernacular architecture. The environmental design features that have been incorporated in the design of vernacular buildings vary and depend on the different locations (climatic conditions and topography) in which the rural settlements have been developed.

In vernacular architecture natural lighting was the main source of light available. Nevertheless a series of limitations related to the surrounding natural and built environment, the available building materials and techniques, as well as the social behaviour patterns of the occupants did not encourage traditional dwellings to be exposed to the outdoors and thus did not allow for the optimum exploitation of natural daylighting.

Courtyards and semi-open spaces constituted vital parts of traditional buildings. A series of every day domestic as well as agricultural activities were hosted in these spaces. These spaces also constituted the main social space of the residences. The indoor spaces were used mainly for rest and sleep; therefore the need for high lighting levels was not necessary.

Until now the daylight performance of traditional vernacular dwellings in Cyprus has not been investigated and there are only very few and limited numbers of references regarding the role of the windows as a source of light in the island's vernacular architecture.

The aim of this study is the multi-evaluation of the lighting levels of traditional buildings in Cyprus using in-situ illuminance measurements and software lighting simulation and the investigation of proposed solutions in the selected representative spaces in order to meet the contemporary daylighting needs with respect to the unique architectural character of traditional buildings.

For the needs of this research study, three representative buildings with regards to the typology and orientation of rural vernacular architecture in Cyprus were selected for in-depth research i.e. field study and simulation analysis. Each building is located in a different topographical location in Cyprus thus exhibiting varying building typologies. Given the similarities in vernacular architectural components found in the broader architectural landscape of the Mediterranean region concerning typology, construction methods and climate, the results can be exploited beyond the geographical limits of Cyprus.

2. Methodology of research

Three characteristic settlements in Cyprus that have preserved their original architectural character were selected for detailed investigation. A study based on topographical and architectural plans as well as on-site investigations was carried out on a significant sample of 90 traditional dwellings, analyzing spatial characteristics and typological configurations of the buildings. This was followed by a selection of three representative dwellings, one in each settlement for an in-depth investigation. The first case-study is located in the coastal zone in the village of Maroni. It is a two-storey residential building currently used as an agrotourist lodging in the loosely packed fabric of the settlement. The second case-study is located in the lowland area, in the village of Pera Orinis. It is a single storey building with a loft currently used as a residential building in the semi-compact configuration of the village. The third case-study is located in a mountainous region, in the village of Askas. It is a three-storey building currently used as an agrotourist lodging in the compact configuration of the village.

2.1. Description of case studies

Orientation, semi-open spaces and courtyard: In vernacular architecture semi-open spaces and courtyards play an essential role in users' daily life as most of the everyday activities take place. The dwellings of Pera Orinis (high plain) and Maroni (coastal) incorporate different enclosed and semi-open spaces (*iliakos*) arranged around a central courtyard. On the other hand the third example in Askas (mountainous area) follows a different typological arrangement. The inclined topography resulted in more limited building footprints and consequently a configuration of multiple floor levels without courtyards and semi-open spaces. With regard to their orientation, south facing buildings dominate the settlements in Maroni and Pera Orinis with 35% and 29% respectively, whereas the southern and eastern orientation is predominant among buildings in Askas at 29% and 37% respectively.

Building typology: Most of the spaces in the dwelling of Maroni are longitudinal rooms (*monochoro*) which are the archetypal room type in Cyprus vernacular architecture. The small width (3m) of these rooms and their arrangement towards their wide frontage (*platymetopo*) enables the placement of openings in both longitudinal walls ensuring sufficient lighting levels to the spaces. On the other hand, in Pera Orinis and Askas most of the rooms are almost square in plan following the typology of *dichoro* i.e. a double space room (Philokyprou et al., 2014). This type of space, with dimensions ranging from 6 to 8 m, enables the placement of openings only at the wall facing towards the courtyard. This arrangement did not allow sufficient light into the interior and thus these rooms are mostly used for resting and storage purposes.

Openings: Vernacular buildings are characterized by a small number and size of windows especially on the ground floor due to the introverted character of the buildings, construction constrains and topography restrictions. The shape of the windows is usually rectangular with an approximate 1:1.5 ratio of width to height. Smaller windows located at a higher level (*arseres*), mainly used for ventilation purposes, are also found in vernacular architecture. In the case of Maroni there are 4 openings (i.e. 1 window, 1 door and 2 *arseres*) appearing in both sides of the building shell. The space under study at Pera Orinis has 3 openings (i.e. 1 window, 1 glazed door and 1 *arsera*) while the space under study at Askas has 4 openings (i.e. 1 window, 1 glazed door and 2 *arseres*). The façade opening to floor area ratio for Maroni, Pera Orinis and Askas are 14.8%, 11% and 7.7% respectively. According to Givoni (1998), in order to avoid overheating, window to floor ratios should not exceed 10-15% in hot and arid climates like that of Cyprus.

Field daylight measurements were undertaken in all individual spaces of each building studied, followed by simulations that focused on the most typical rooms of each dwelling. Figure 2 shows the selected spaces (a) *monochoro* on the ground floor at Maroni (b) *dichoro* on the ground floor at Pera Orinis and (c) *dichoro on* the second floor at Askas. The selected spaces from their inception until now have been used as multi-purpose living spaces.

Fig 2: Plans of typical spaces in (a) Maroni, (b) Pera Orinis and (c) Askas settlements respectively.

The building materials in these spaces and their reflectance properties are presented in the Table 1.

Table 1 Material properties of selected spaces.

Location		**Description**	**Reflectance**
Maroni	Wall	Stone	0.350
	Ceiling	Straw	0.435
	Floor	Gypsum Slab	0.592
Pera Orinis	Wall	White asbestos cement	0.561
	Ceiling	Straw	0.435
	Floor	Cement screed	0.450
Askas	Wall	White asbestos cement	0.561
	Ceiling	Straw	0.435
	Floor	Brown gypsum tiles	0.450

2.2. Natural lighting levels monitoring and simulation

Natural lighting measurements were conducted on the three sites during an autumn day, September 30th at 09:00, 12:00 and 15:00 respectively (local time GMT +2). During the measurements, the spaces were free from users; artificial lighting was not used, curtains and window shutters were wide open. The lighting levels were registered at an 85 cm height from the finished floor level on a grid of 1m in each direction. The equipment, a Testo 545 Light Meter was employed, with a range of measurement up to 100,000 lux and accuracy of 1 lux within the range 0-32.000 lux.

In order to extract results with regards to the visual comfort in these spaces, for the equivalent of one year, a software application with simulation models was used. Three models were built in Ecotect software v.5.2 taking into consideration the geometry and structure of the buildings as well as the urban context. The exercise was carried out with a high level of accuracy towards the digital representation of the real built environment. Calculations for the analysis grid, at 0.85m height from the finished floor level, were performed with the use of Desktop Radiance v.2.0 software and Daysim v.3.1. The daylighting simulation was conducted setting the proper reflectance values based on the properties of the on-site materials.

The sky model for autumn simulation was set as intermediate at 09:00 and 12:00 and cloudy at 15:00 in the three cases, based on the climatic data during field recording (CIE Illumination Standards). Referring to climatic data, the reference standard year of the nearest meteorological station (i.e. Larnaca, Athalassa and Saitas) for each of the three settlements, was used. The weather files were extracted from Meteonorm v.7.1.3.

In order to verify the accuracy of the software simulation, a validation process was conducted via Desktop Radiance for the above-mentioned day and times. For the purposes of validation, the model was treated for all the necessary corrections in geometry and internal surfuce reflectances so that the simulation results would match the distribution of in-situ measured illumination levels.

Figure 3 shows the simulated illuminance data on a particular day and time i.e. September 30th at 12:00, on the ground floor of the buildings in Maroni and Pera Orinis and on the second floor of the building in Askas village. Graphic representations of the illuminance on the floor plans are shown in the form of isolux contour diagrams. The natural illuminance fluctuated from 0 to 1000 lux with contours every 100 lux.

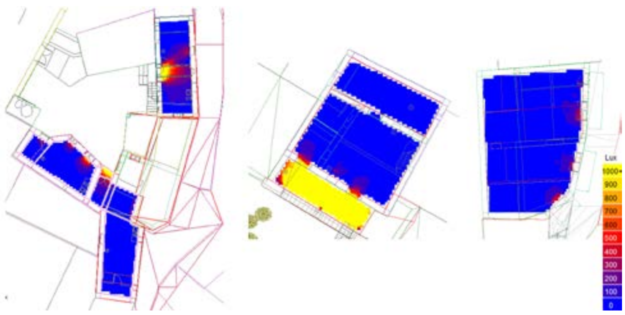

Fig 3: Simulated illuminance measurements in each settlement on 30th September, at 12:00.

2.3. Evaluation criteria of lighting performance

According to the European Standard, moderately easy visual tasks can be undertaken at 300 lux, while a level of 200 lux is deemed sufficient to undertake main activities in residential buildings (BS 8206-2008). Considering the fact that the evaluation is carried out in traditional buildings built under different lifestyle conditions and hosting different activities compared to the current uses, a level of 200 lux is set as a limit of acceptable lighting levels.

Another indicator of daylight performance, which is static, is the daylight factor (DF). It is the most widely used index which defines the ratio of interior illuminance on a horizontal surface to the exterior illuminance on a horizontal surface under an overcast CIE sky. CIBSE (2006) recommends an average DF of 1.5% for living and multi-purpose rooms. Even if the minimum daylighting requirements are met, the limit to room depth rule and uniformity criterion should also be met in order to provide successful daylighting. To be successfully daylit the uniformity ratio (minimum DF/ average DF) should be 0.25 to 0.3 and the room depth (L) should be limited to meet the following conditions, where:

$$\frac{L}{W} + \frac{L}{h} \leq \frac{2}{(1 - Rb)}$$

L = depth of the space,

W = width of the space,

h = height of the window head above the floor,

R_b = area-weighted average reflectance in the back half of the space.

Finally, the dynamic daylight performance metrics are based on timed series of illuminances in buildings which take into consideration the entire year, the quantity and character of daily and seasonal variations of daylight for a given building as well as irregular meteorological events. Such indicators are i) Daylight Autonomy (DA), defined as the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylight alone, (ii) Useful Daylight Illuminances (UDI) which represents the percentage of time in which the daylight level is useful for the occupants and is divided into three intervals: too dark (<100 lux), useful daylight (100-2000 lux) and too bright with the possibility of glare issues and discomfort (>2000 lux) and (iii) Maximum Autonomy which is defined as a sliding level equal to ten times the design illuminance of a space and is often used as the percentage of a workplane in which the DAmax, the maximum accepted illuminance was exceeded for more than 5% of the time (Reinhart, Mardaljevic and Rogers 2006). The minimum illuminance required for the buildings under study is 200 lux.

2.4. Proposed improvements

The investigation led to improvements and was implemented in selected spaces. The proposed solutions included (a) the material properties i.e. colour and reflectance of surfaces (b) the addition of roof opening and, (c) the combination of the above (Table 2). An increase of wall openings was not considered as a feasible option due to regulatory restrictions regarding the potential change to the traditional characteristics of vernacular architecture.

Table 2 Proposed solutions.

Material properties	Wall	White emulsion paint (0,804)	M_W1
		Yellow emulsion paint (0,604)	M_W 2
		Light green, grey emulsion paint (0,471)	M_W 3
		Dark green, blue emulsion paint (0,15)	M_W 4
	Ceiling	Light coloured paint (0,702)	M_C 1
		Light coloured paint on wood-wool slab (0,5)	M_C 2
	Floor	Polished gypsum marble (0,651)	M_F 1
		Cement screed (0,45)	M_F 2
		Timber: pine (0,35)	M_F 3
Opening	Roof	+2.5% opening to floor ratio	O_R 1
		+5% opening to floor ratio	O_R 2
Combinations	C_M 1	M_W1+ M_C 1+ M_F 1	C1
	C_{OR}1	M_W1+ M_C 1+ M_F 1+O_R1	C2

For each suggested scenario, which was carried out using Desktop Radiance software, the average illuminance and the percentage of space that exceeds 200 lux was calculated for the summer solstice (June 21st), the winter solstice (March 21st) and the autumn equinox (September 21st) at 09:00, 12:00 and 15:00. The sky conditions were defined as sunny, cloudy and intermediate respectively for the aforementioned periods. For the combinations of proposed improvement solutions, scenarios leading to the best contribution to the lighting performance in these spaces were selected in terms of material properties.
The base case scenario and the proposed remedies for each building were also analysed using climate-based daylight modeling in order to evaluate the lighting performance for the entire year.

3. Results of evaluation

The results of the multi-criteria evaluation of the lighting levels of traditional buildings in Cyprus are presented below.

3.1. Assessment through field measurements

The field measurements which were conducted, on September 30th, mostly under an intermediate sky (3-4/8 clouds) (i.e. the sky conditions that represented the greatest percentage of the year in all climatic zones) indicated that the lighting levels were sufficient in semi-open areas (i.e. in Pera Orinis and Maroni) but relatively low in the enclosed areas of the buildings under study in the three settlements (Figure 3). Specifically, the average illuminance of all indoor spaces of the buildings in Pera Orinis and Askas never exceeded 50 and 100 lux respectively. The lighting levels were insufficient due to deep spatial layouts and openings on only one side of the spaces. Both spaces did not meet the limit to room depth and uniformity criteria. Conversely, the lighting levels of some indoor spaces in Maroni village were adequate (average illuminance > 150 lux) as a result of openings present on both sides of the space, the not-so-compact building form, and the shallow plan layout of the spaces. Although spaces at Maroni meet the limit to depth criterion, problem of uneven distribution of natural lighting was observed.

3.2. Evaluation through Static and Dynamic indicators in selected spaces

The results of both static and dynamic daylight indicators were executed using Daysim v.3.1 software. The simulation for the buildings assumed daylight savings time from April 1st to October 31st. Static and dynamic simulation results of the base case scenario for each case study are shown in Table 3. As observed, the average DF in all indoor spaces in the three examined settlements showed values below the acceptable DF of 1.5%. Indoor spaces in Pera Orinis and Askas with average DFs of 0.1% and 0.2% respectively, remaining far from accepted minimum levels. The space at Maroni had a better average DF of 0.8%.
Considering the climate-based simulation and the DA, a space which receives sufficient daylight (> 200 lux) at least for half of the time is considered a well day-lit space (Reinhart and Wienold 2011). The indoor space in Maroni can be characterized as almost well-lit, since it had an average Daylight Autonomy for 42.1% of the year and for the largest part of the year (56.5%) it lies within the Useful Daylight Index of 100-2000 lux. On the contrary, indoor spaces in Pera Orinis and Askas had an average DA for 5.7% and 15.7% of the year respectively, with their largest percentage of the year having daylight below 100 lux (85.6% and 69.2% of the year respectively).

4. Results of Proposed solutions

The results of the simulated combinations strategies are summarized in Table 3. Combination 1 (C1) sought to highlight the contribution of material properties for the improvement of lighting performance. Specifically, white emulsion paint was specified for the walls, light coloured paint for the ceiling and polished gypsum slabs for the floor surface, improved the average DA of the space at Maroni from 42% to 67.0%, while in the respective spaces at Pera Orinis and Askas these proposals improved the average DA from 5.7% to 10.8% and from 15.7% to 33.2%. Based on this combination of strategies, the indoor space at Maroni could be considered a well day-lit space; consequently no additional strategies were considered.

Combination 2 (C2) considered improved material properties and the addition of roof openings (+2.5% of floor area), a strategy implemented only in Pera Orinis and Askas case studies. The results showed that the roof opening drastically increased the lighting levels in both cases increasing average DA from 5.7% to 57.1% and from 15.7% to 79.8% of the year respectively. Specifically, at the space at Pera Orinis, 38% of the time at the back of the space and 96% of the time at the front of the space received useful daylight. The space at Askas received useful daylight for 41% of the time at the back of the space and 98% of the time at the front of the space. The DF under an overcast sky in the space at Askas approached acceptable DF levels (from 0.2% to 1.4%). However, the DF in Pera Orinis was still relatively low i.e. rising from 0.1 to 0.6%. In order to achieve better lighting performance, larger roof openings should be considered.

To summarize, *monochoro* (shallow spatial layout) in Maroni with openings located on both sides representing 14.8% of window to floor area and improved material properties achieved sufficient lighting levels with 67.0% of the time meeting the minimum illuminance by daylight alone. In *dichoro* (deep spatial layout) in Pera Orinis, with openings, located only in one side of the space, representing 7.7% of window to floor area ratio plus 2.5% opening to floor area ratio combined with improved material properties achieved daylight autonomy for 57.1% of the year or even higher autonomy depending on the qualities of the surrounding environment. Finally, in *dichoro* (deep spatial layout) in Askas, with openings, located only on one side of the space, representing 11% of window to floor area ratio plus 2.5% opening to floor area ratio combined with improved material properties achieved daylight autonomy for 79.8% of the year or more according to the surrounding

Table 3 Static and Dynamic Simulation results of base cases and proposed solutions.

		Average DF [%]	Average DA [%] (>200 lux)	DA range[%] (Back- Front)	Average $UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{100-2000}$ range [%] (Back-Front)	$UDI_{>2000}$ [%]	% of area where DAmax>5% of time
MARONI	BASE CASE	0,8	42,1	0-99	40,2	56,5	0-96	3,3	14,0
	C1	1,3	67,0	10-100	16,3	75,8	10-98	7,9	36,0
PERA OREINIS	BASE CASE	0,1	5,7	0-95	85,6	13,8	6-91	0,6	3,0
	C1	0,2	10,8	0-96	73,6	25,9	6-92	0,6	4,0
	C2	0,6	57,1	13-93	19,8	79,2	38-96	1,0	10,0
ASKAS	BASE CASE	0,2	15,7	0-97	69,2	30,4	5-97	0,4	1,0
	C1	0,3	33,2	0-97	44,6	54,8	10-96	0,6	3,0
	C2	1,4	79,8	19-99	8,4	87,8	41-98	3,8	16,0

environment. Consequently, the findings of this study indicate the positive impact of roof openings in the improvement of daylighting conditions in traditional building interiors.

5. Conclusion

Vernacular architecture is characterized by its adaptability to the local climatic conditions, available resources and topography and incorporates a variety of bioclimatic concepts in the design of indoor spaces. This study has appraised the natural daylighting performance of indoor spaces in three representative typologies of traditional buildings in Cyprus within different climatic context and proposed potential improvements in relation to lighting performance. The research highlights how the range in lighting levels of the different spaces is linked to the number and arrangement of openings showing the different purposes that every area serves that are also affected by social and other factors (introverted and defensive character of vernacular architecture, compact urban fabric), reflecting the cultural behaviour of the occupants and expressing the needs of people. Semi-open spaces showed sufficient lighting levels justifying their frequent use for daily activities. Spaces with shallow spatial layouts (*monochoro*) showed better performance than the double spaces (*dichoro*) with a deep layout. Deep layouts offer insufficient occupant daylighting comfort most of the year and required improvements in order to meet the contemporary daylighting needs of occupants. Renovation suggestions such as changes of material properties and the addition of roof openings were considered feasible solutions that could be implemented without changing the character of traditional buildings.

Beyond the implementation of the strategies mentioned above, suggested improvements in the building envelopes of traditional dwellings may constitute feasible strategies for the refurbishment or design of current or new-built structures.

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