Architectural Design and Environmental Behaviour of Traditional Buildings in Mountainous Regions. The Case of Askas Settlement, Cyprus

E. Malaktou, M. Philokyprou, A. Michael, A. Savvides

Department of Architecture, University of Cyprus

Abstract

Bioclimatic features have been incorporated in traditional buildings around the world, as a result of local wisdom in addressing design issues related to the climate. Vernacular architecture of the mountainous regions of Cyprus represents an example of climate-sensitive architecture in the Mediterranean area. Up to now, only a limited number of studies have focused on the examination of the environmental design aspects of the vernacular architecture of such regions and, for this reason, a lack of onsite validation and systematic quantitative analysis has been observed. In the framework of the research presented herein, detailed field studies on the environmental behaviour of traditional buildings in the main mountainous region of Cyprus (the Troodos mountain range) have been undertaken. Specifically, the study includes a survey of the bioclimatic features of 30 high-mass traditional buildings and of onsite air temperature measurements in three typical building examples in the mountainous settlement of Askas, Cyprus. Air temperature measurements were undertaken in the hot, summer period of the year. This research demonstrates that the multiple floor levels of the buildings (i.e. ground partially subterranean, intermediate and upper floor levels) —a characteristic of traditional buildings in mountainous regions— create thermal diversity due to their division into distinct thermal zones. The ground partially subterranean floor level spaces present a greater ability to dampen the external thermal inflows demonstrating the positive thermal contribution of the earth mass. The intermediate floor level spaces result in more moderated heat transfer to the indoor spaces compared to the upper floor level spaces due to the buffering of the latter. The upper floor level spaces raise daytime indoor temperatures above other floor level spaces showing the limited thermal protection of the roof. The investigation and better understanding of the thermal behaviour and the parameters that affect indoor temperatures inside traditional buildings in mountainous regions would help towards the development of environmentally-based rehabilitation practices of vernacular architecture in such areas.

Keywords: mountainous settlements, traditional buildings, partially subterranean spaces, thermal mass, thermal behaviour, multi-level buildings

1. Introduction

Traditional building typologies, and construction methods in the mountainous regions, have resulted from social and cultural factors, as well as from the materials and methods of construction available in a particular region. Nevertheless, local climate also constitutes a significant factor that affects the design of traditional buildings in such regions and contributes to their shaping and evolution. Traditional buildings in mountainous regions of the Mediterranean area are mainly characterized by a thick, stone-built masonry construction and a limited number of windows, achieving daytime indoor temperatures lower than outdoors during the hot, summer period (Yannas, 2014; Philikyprou & Michael, 2012). On the other hand, the compact built form which is observed in these regions, contributes to the reduction of contact of the building envelope with the exterior environment, minimizing heat losses during the cold, winter period (Bodach, Lang & Hamhaber, 2014).

Based on empirical tradition, masons in mountainous settlements of the Mediterranean area created buildings in harmony with particular topographical features, such as the steep terrain and the scarcity of available land. These two topographical features enforced the development of multi-level buildings (Zhai & Previtali, 2010). The inhabitants organized daily activities in such a way so as to take advantage of the thermal adaptive opportunities of the multi-level traditional building, by exploiting the thermal lag of masonry construction, as well as the thermal buffering effect, caused by the upper floor level spaces.

Today, since most traditional design concepts and construction techniques have been abandoned, the valuable knowledge of traditional climate-sensitive architecture of the mountainous regions is gradually lost. For this reason, vernacular architecture in such regions should be thoroughly examined so as to rediscover and integrate the bioclimatic principles of this architectural approach into contemporary design and also to help towards the development of environmentally-based rehabilitation practices.

To this end, this study focuses on a mountainous traditional settlement of Cyprus — namely the village of Askas — with the aim to provide an environmental evaluation of its traditional buildings in qualitative and quantitative terms.

2. Research context

The mountainous settlement of Askas is located in the central part of the island, lying in the Troodos mountain area at an elevation of 900 m above sea level. Being mountainous, isolated and relatively far away from urban areas, this settlement has, to a great extent, preserved its original character and thus provides an appropriate example for the better understanding of the environmental aspects of vernacular architecture. The longitude of the village is 33° 40′ east and its latitude is 34° 55′ north. Askas village extends alongside the steep south-eastern slope of Askas river valley, taking advantage of southern solar exposure. Due to its location, the settlement pattern is directly related to the topography of the region. It is characterized by a linear development that follows the landscape contours, where streets are narrow, deep and curvilinear, and buildings are developed in multiple floor levels. The present study focuses on this prevalent organization of buildings in multiple floor levels, typical mostly in traditional mountainous settlements of the island. The mountainous settlement of Askas forms a typical example for investigation of this particular multi-level traditional building organization.

Due to its location in high-altitude, the village of Askas is characterized by mild summers and cold and wet winters with some snowfall. The mean minimum temperature in the coldest month of the year (February) reaches 3.0 °C, the mean average 6.7 °C and the mean maximum temperature 10.4 °C (Table 1). The corresponding mean average humidity is 68 %. Askas has high precipitation during the winter period reaching its peak at December, where average precipitation is 155.5 mm. The mean minimum temperature in the hottest month of the year (July) reaches 20.6 °C, the mean average 25.7 °C and the mean maximum 30.9 °C. The hot summer period extends from mid-June to mid-September. Mean average humidity in the same period reaches 39%. Rainfall is low, during the summer period, where average monthly precipitation does not exceed 22.6 mm (June).

Table 1. Monthly climatic data from the nearest weather station to Askas village from 1984 to 2003

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean min temp. (°C)	3.2	3.0	5.0	9.0	13.4	17.5	20.6	20.2	17.0	13.1	8.5	4.7
Mean avg temp. (°C)	6.7	6.7	9.1	13.6	18.4	22.6	25.7	25.6	22.5	18.1	12.6	8.1
Mean max temp. (°C)	10.1	10.4	13.3	18.3	23.3	27.8	30.9	30.9	28.0	23.0	16.7	11.6
Mean min RH (%)	9	12	7	6	5	7	7	7	6	7	8	7
Mean avg RH (%)	71	68	62	52	48	42	39	41	45	54	63	72
Mean max RH (%)	100	99	99	99	98	96	94	92	96	98	99	100
Avg precipitation (mm)	111.4	100.0	90.3	37.5	17.5	22.6	15.6	12.3	9.1	32.7	94	155.5

3. Methodology

The analysis of the environmental behaviour of traditional buildings in mountainous areas is based on both qualitative and quantitative investigation. The qualitative investigation concerns the study and documentation of the bioclimatic features of 30 traditional buildings of Askas settlement, Cyprus. The quantitative investigation is based on the analysis of onsite air temperature measurements undertaken in three representative multi-level traditional buildings during the hot, summer period of the year. Observations and hypotheses made through the qualitative examination, regarding the bioclimatic features integrated in traditional buildings, are juxtaposed with the quantitative results. An effort to explain the reasons of possible discrepancies between qualitative and quantitative results is undertaken.

3.1 Onsite observations

The methodology for the qualitative examination of this study consists of a survey of 30 traditional buildings in the mountainous settlement of Askas through topographical maps, onsite observations and photographical documentation of the traditional bioclimatic features. The bioclimatic features related to building typology, such as, open and semi-open spaces, window openings, the materiality of the building envelope and the occupants' habits related to the use of the building are registered and explained. This study leads to the formation of some initial observations and assumptions regarding the environmental behaviour, in terms of thermal comfort, of mountainous traditional buildings.

3.2 Quantitative investigation

The proposed research methodology for the quantitative investigation of this study consists of onsite air temperature measurements in three typical three-storey case studies of traditional buildings. A total of nine spaces are monitored — three in each case study building. Data loggers are placed at ground, intermediate and upper floor level spaces in each case study building, in order to record the thermal performance of the different floor level spaces. Data loggers for indoor air temperature measurements are placed 1.5 m above floor level and recordings are taken in 30-minute intervals. Measurements are carried out during the hot, summer period of the year, between the 1st and 31st of August 2014. Outdoor climatic conditions are also recorded with a weather station installed in the village, high above the skyline of neighbouring buildings. Mean diurnal temperature fluctuations and mean maximum, mean average and mean minimum temperatures of the spaces examined are tabulated for comparative analysis. The range of temperatures of each space under investigation is also calculated and visualized in graphs. The aim of this analysis is to evaluate indoor temperatures, to draw conclusions regarding the thermal performance of multi-level traditional buildings and to briefly indicate thermal improvements in such buildings. It is noted, that the differences in temperatures of the spaces examined can be attributed to orientation, plan layout configuration, window-to-floor ratio, exposed wall area, contact with the earth mass and contact with the roof. Nevertheless, here the results are considered taking into account only the differences in terms of contact of the rooms with the earth mass and roof.

4. Results

4.1 Settlement pattern and built form

Traditional buildings of Askas village are characterized by compact building configurations. The compactness of the settlement is related to topographical restrictions, aspects of safety, as well as, to economic limitations i.e. the limitations of labour and building materials (Sinos, 1976). The function of such configurations from the environmental perspective, concerns the minimization of heat losses during the cold, winter period and the avoidance of undesirable heat gains, through proper shading during the hot, summer period. Due to the steep terrain in which the village is located, a vertical, multi-level building layout, usually three to four floors, is developed. Consequently, the adaptation of the building in the steep terrain results in the creation of partially subterranean spaces on the ground floor level.

The main living areas are to be found on the intermediate and the upper floor levels for better solar exploitation during winter, while ground floor levels are used as shelters for the livestock and storage spaces for the food products. The contact with the earth mass and the minimal solar heat gains, in ground floor level spaces, leads to the assumption that such spaces would exhibit greater indoor thermal stability and lower temperatures than the intermediate and upper floor level spaces during the hot, summer period.

A large majority of the building stock of Askas village is configured by a combination of interconnecting deep plan layout rooms (rectangular or square in plan) known as *dichoro*, i.e. double space room, and by rectangular shaped, shallow plan layout rooms known as *monochoro*, i.e. single space room. Generally, *dichoro* rooms are the ones that dominate. The combination of *dichoro* and *monochoro* rooms leads to various building configurations representative of the rural vernacular architecture of the island. A limited number of buildings in the village follows a *trimeres* arrangement i.e. triple bay spaces that are, in turn, configured by a similarly subdivided plan layout into three parts that comprise of two rooms and a central transitional space called *portico.* This space is internally connected to the different rooms which are developed on its two sides. *Portico* is a distinctive environmental feature. Its openings at the ends, its central position and its elongated plan layout offers enhanced cross-ventilation to indoor spaces. The *trimeres* plan layout is usually found in the traditional urban buildings of the island and it was introduced in a limited number of dwellings in many traditional rural settlements, such as Askas, at the beginning of the 20thcentury. The height of most of the rooms in the village is generally lower compared to those in lowland regions, in order to reduce heat losses and the need for heating during the winter.

The incorporation of open and semi-open transitional spaces is fundamental in Mediterranean vernacular architecture. However, in the case of Askas village and other mountainous settlements, open and semi-open spaces are not as common as in lowland settlements of the island, mainly due to topographical restrictions but also due to socio-economic and climatic factors. Semi-open spaces in Askas village are usually found on the upper floor levels of the buildings. In the cases of flat roof tops, these semi-open spaces have usually the form of deciduous vine pergolas. Deciduous vine pergolas provide shading and cooling through the evapotranspiration of leafage during the hot summer period, allowing, in parallel, the solar penetration during winter period. Traditional buildings of Askas village are characterized by a limited number of windows. This is mainly attributed to privacy and safety reasons, as well as to structural limitations. From the environmental perspective, the limited number of windows offers protection from excessive solar heat gains. Furthermore, the typical exterior window timber shutters offer additional protection from intense daylight and sunshine during summer. Timber shutters are also used to prevent the penetration of cold air in indoor spaces and to reduce the heat losses through the glazing during winter. Another distinctive feature, related to bioclimatic design of the traditional buildings of Askas, is the roof eaves, which provide protection to the external masonry from the rain and snow.

4.2 Building materials

The building materials of the traditional buildings of Askas village are locally available. The availability of building materials depends on the geology of a location and on the climatic conditions, which determine the vegetation and thus, the availability of organic building materials. Stone found in the neighbouring mountains is used for masonry construction, while wood is extensively used in roof structures (Chrysostomou et al, 2003).

Thick stone masonry between 0.5 m and 0.7 m is typical in the traditional buildings of the village. Thick walls increase the insulating properties of

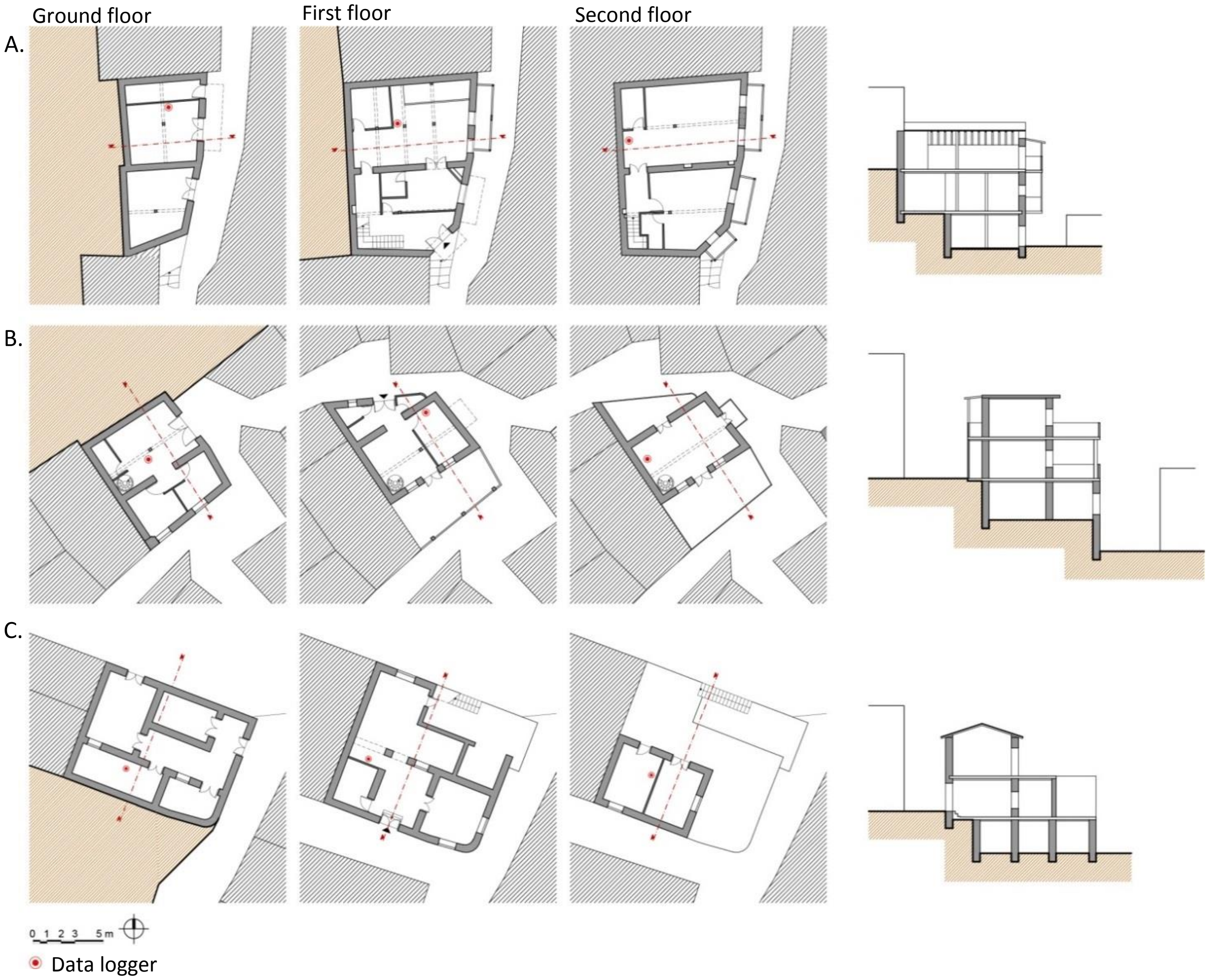

Figure 1. Plans and sections of traditional buildings showing the spaces where onsite air temperature measurements were carried out: A. Case Study A, B. Case Study B and C. Case Study C

the building envelope. The interior and exterior face of the masonry is constructed with rubble volcanic stone and the space in between the two faces is filled with mud and smaller stones. Volcanic stone, due to its high thermal mass, is expected to significantly moderate indoor temperature maxima. Fired brick is usually used as complementary material around windows, doors and below the roof. Fired bricks are produced locally from clay soil at brick kilns called *kaminia.*

Traditional roofs in Askas village were originally flat, and constituted a layer of beaten mud laid on brushwood on top of tree trunks (Jeffery, 1918). The original flat roof, due to the high thermal mass of the mud layers, provided sufficient protection from intense insolation. In recent years the high mass flat roofs were replaced by timber double-pitched roofs (Clerides et al, 1995). Double-pitched roofs are multi-layered, made with timber rafters which are covered with reed battens or matting, earth and a layer of clay tiles. Roof tiles, similar to fired bricks, were produced locally from clay soil at *kaminia*. The roof structure is usually supported by a central timber beam and a row of timber pillars. Timber pitched roofs warm up faster, compared to the high-mass flat roofs. Due to the lower thermal mass of the inclined timber roof, and the high exposure to solar radiation, spaces under the roof may be more susceptible to high daytime temperatures.

4.3 Description of case study buildings

Three representative multi-level buildings, i.e. Case Study A, Case Study B and Case Study C, are selected for onsite air temperature measurements (Fig. 1). The selected buildings are representative of the building materials and architectural

Table 2. Summary of registered temperatures between the 1st and 31st of August for Case Study A, Case Study B and Case Study C

	Mean avg Temp. (°C)	Mean max Temp. (°C)	Mean min Temp. (°C)	Mean Temp. Fluct. (°C)	Mean T_{max_out}- T_{max_in} (°C)	% of days in which max ind. temp. < max out. temp.	T_{max_out}- T_{max_in} during the hottest day (°C) – 34.1 °C	$Fluct._{out}$ /$Fluct._{in}$	Temp. limits (°C)
Outdoor	25.8	29.9	22.2	7.7	-	-	-	-	18.0–34.1
Case Study A									
Lower level (partially sub)	**25.9**	**26.3**	**25.6**	**0.7**	**3.6**	**97**	**7.1**	**11.0**	**24.5–27.5**
Intermediate (partially sub)	27.5	27.7 (+1.4)	27.3 (+1.7)	0.5 (-0.2)	2.2 (-1.4)	87 (-10)	5.1	15.4	26.5–29.0
Upper level	28.6	29.6 (+1.9)	27.7 (+0.4)	1.9 (+1.4)	0.3 (-1.9)	61 (-16)	2.1	4.1	26.5–31.0
Case Study B									
Lower level (partially sub)	**26.5**	**26.8**	**26.3**	**0.5**	**3.1**	**94**	**7.1**	**15.4**	**25.5–28.0**
Intermediate	28.7	29.0 (+2.2)	28.4 (+2.1)	0.6 (+0.1)	0.9 (-2.2)	74 (-20)	4.1	12.8	27.5–30.5
Upper level	28.6	29.8 (+0.8)	27.4 (-1.0)	2.3 (+1.7)	0.1 (-0.8)	61 (-13)	2.1	3.3	25.5–31.5
Case Study C									
Lower level (partially sub)	**25.0**	**25.5**	**24.5**	**1.0**	**4.4**	**100**	**7.6**	**7.7**	**23.0–26.5**
Intermediate	28.2	29.2 (+3.7)	27.4 (+2.9)	1.9 (+0.9)	0.7 (-3.7)	77 (-23)	1.6	4.1	26.0–32.0
Upper level	28.2	29.5 (+0.3)	27.0 (-0.4)	2.5 (+0.6)	0.4 (-0.3)	65 (-12)	2.1	3.1	24.5–31.5

typology of Askas village. These buildings comprise of three main floor levels: the ground floor level which is partially subterranean, the intermediate floor level (which is partially subterranean only in the case of Case Study A), i.e. the first floor level, and the upper floor level, i.e. the second floor level. Regarding the building typology, Case Study A and Case Study B consist mainly of *dichoro* (double-space) rooms. Specifically, Case Study A comprises of two attached *dichoro* rooms at each floor level, while Case Study B consists of one *dichoro* room and one *monochoro* at ground level and one *dichoro* at the first and second floor level. Case Study C comprises of interconnected *monochoro* rooms at the ground floor level, a *trimeres* configuration at the intermediate floor level and a *dichoro* room at the upper floor level.

Buildings under investigation are characterized by thick stone-built masonry construction (0.5 m) and a limited number of window openings. Case Study A and Case Study C have double-pitched roofs made of layers of timber rafters, reed battens, thermal insulation material, earth and clay tiles. Case Study B has a flat roof made of layers of timber rafters, reed battens, thermal insulation material and concrete.

4.4 Onsite air temperature measurements

Table 2 shows the results of indoor temperature measurements in the three case study buildings and of outdoor temperature measurements during a one-month period (August) in the summer. These results demonstrate the existence of a different thermal behaviour among the multiple floor level spaces of each building. Specifically, in the three case study buildings there are differences in the temperatures of the ground floor, as well as the intermediate and upper-floor level spaces (Fig. 2). In general, all spaces maintain stable indoor thermal conditions. Mean diurnal temperature fluctuation does not exceed 2.5 °C for all spaces under study (Fig. 2). A time delay is also observed between outdoor maximum and indoor maximum temperatures.

It is noted that, the ground floor level spaces exhibit lower mean maximum, average and minimum temperatures and smaller mean diurnal temperature fluctuations compared to the intermediate and upper floor level spaces. Mean diurnal temperature fluctuations on the ground floor level spaces are less than 1 °C. Mean

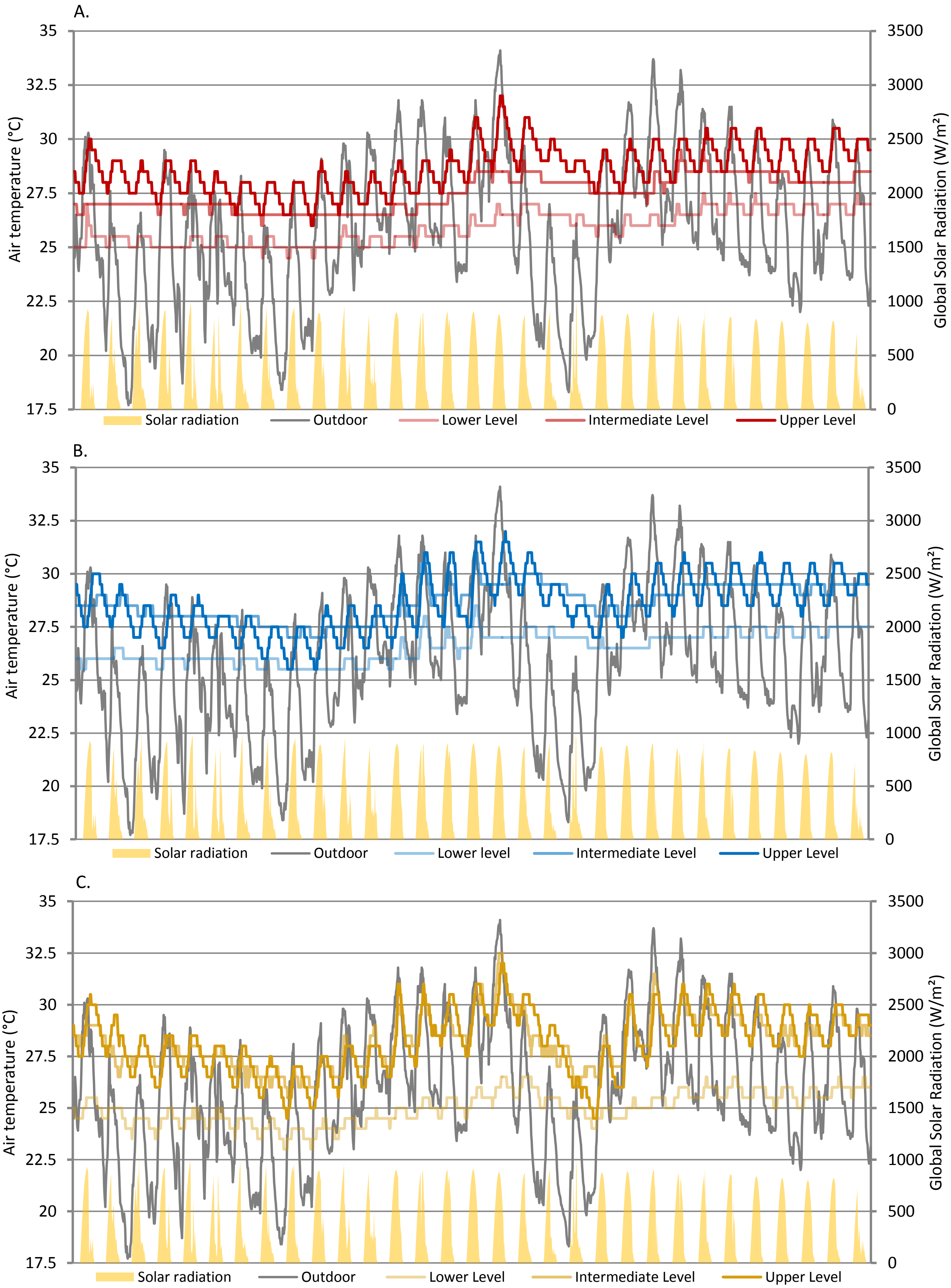

Figure 2. Profile of onsite air temperature measurementsbetween 1st and 31st of August for A. Case Study A, B. Case Study B and C. Case Study C

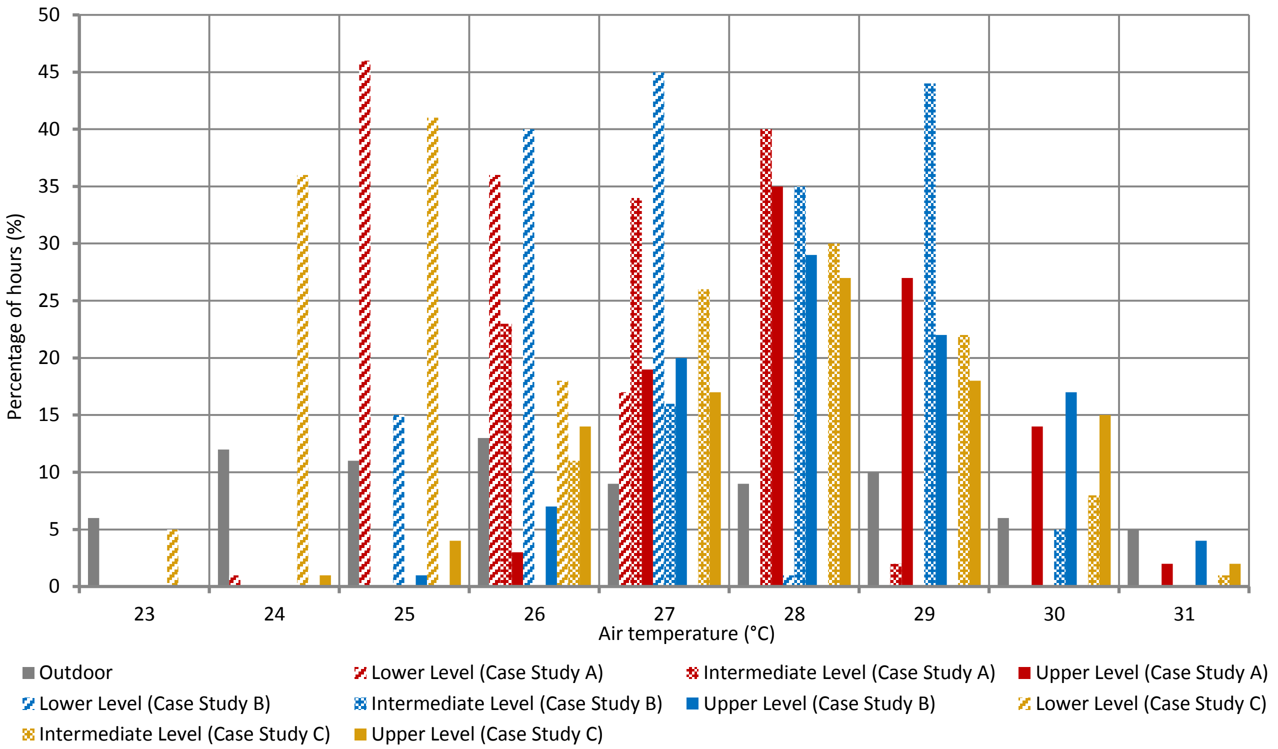

Figure 3. Range of temperatures between 1st and 31st of August for Case Study A, Case Study B and Case Study C

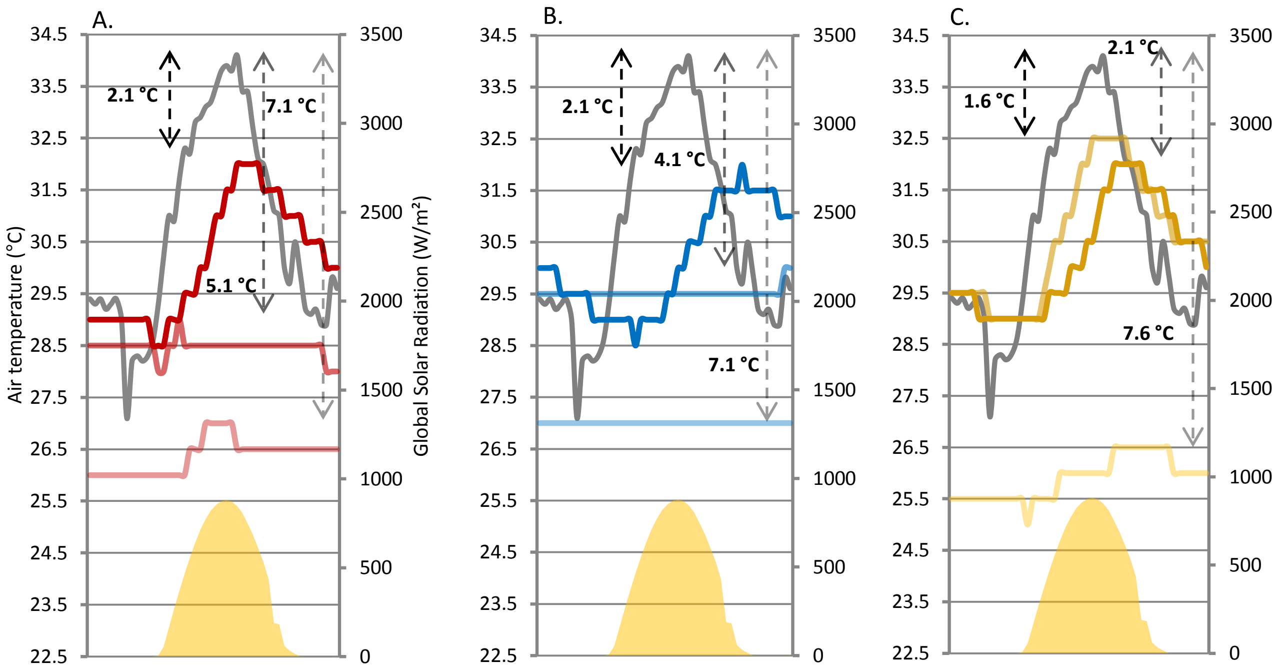

Figure 4. Profile of onsite air temperature measurements in the hottest day of August for A. Case Study A, B. Case Study B and C. Case Study C

maximum temperature in such spaces is 1.4 to 4 °C below the mean maximum temperature of intermediate and upper floor level spaces, while mean average temperature is 2 to 3 °C below the mean average temperature of intermediate and upper floor level spaces (Table 2). Ground floor level spaces exhibit a range of temperatures from 23 to 28 °C, whereas intermediate and upper floor level spaces show a range of temperatures from 24.5 to 32 °C (Fig. 3 & Table 2). Mean maximum temperatures in the intermediate floor level spaces remain lower than those of the upper floor level spaces, i.e. 0.3 to 1.9 °C lower (Table 2). Furthermore, mean diurnal temperature fluctuations in the intermediate floor level spaces are observed to be considerably lower than the temperature fluctuation of the upper floor level spaces, i.e. 0.6 to 1.7 °C lower. It is interesting that the mean minimum temperatures in the upper floor level spaces remain lower compared to the intermediate floor level spaces. The only exception is observed in Case Study A.

As shown in Table 2 the percentage of days, during which indoor maximum temperature drops below the outdoors' maximum temperature (T_{max_out}-T_{max_in}), is higher in the ground floor level spaces. In almost all days of August (above 90%), the ground floor level spaces present lower maximum temperatures than outdoor maximum temperatures. Furthermore, it is demonstrated that intermediate floor level spaces achieved a reduction of indoor maximum temperature below the outdoors' maximum for comparatively more days compared to upper floor level spaces. The reduction of indoor maximum temperature below the outdoors' maximum, for the hottest day of August, is around 7 °C for the ground floor level spaces while in the upper floor level spaces it is around 2 °C (Fig. 4). On the contrary, in Case Study C, the indoor maximum temperature reduction in the hottest day is higher in the upper floor level space, compared to intermediate floor level space — i.e. 1.6 °C for the intermediate floor level space and 2.1 °C for the upper floor level space (Fig. 4).

The ratio of the external to the internal temperature fluctuation is an index that expresses the indoor thermal stability of a space. As shown in Table 2, this ratio is significantly higher on the ground floor level spaces. This index, thus, shows that ground floor level spaces present a greater ability to provide indoor thermal stability.

5. Discussion

The above quantitative investigation of the environmental behaviour of traditional buildings in the village of Askas confirms that the high thermal mass and the thickness of the external stone masonry construction moderates outdoor temperature extremes and slows the heat transfer to indoor spaces. This is why a time delay between maximum outdoor and indoor temperatures is observed. The initial assumption, undertaken during the qualitative analysis about the thermal effect of the high thermal mass masonry construction, is thus, confirmed by the quantitative results. The further moderation of indoor temperatures on ground floor level spaces, compared to intermediate and upper floor level spaces, can be attributed to the contact of such spaces with the earth mass. The earth mass has the ability to further dampen the external thermal inflows maximizing the natural cooling effect during the hot, summer period. Other factors, however, such as the increased shading from neighbouring buildings, and the limited solar heat gains due to the absence of window openings at the ground floor level spaces, may have also contributed to this phenomenon. These results are in line with the initial observations undertaken during the qualitative investigation of this research and also with other publications (Zhai & Previtali, 2010; Meir & Gilead, 2002)

Furthermore, findings show that maximum temperatures in intermediate floor level spaces remain below those of upper floor level spaces. An explanation for these results is that the higher exposure of the spaces under the roof to intense solar radiation, increases undesirable solar heat gains at the upper floor level spaces. This point, which was addressed at the initial stage of this investigation, is confirmed by onsite temperature measurements. The only exception is observed in Case Study C, where during the hottest day of August maximum indoor temperature is lower in the upper floor level space than in the intermediate floor level space. This discrepancy can be explained by the heat dissipation from the roof of the space located next to the intermediate floor level space under investigation, which may have caused an increase of indoor maximum temperature. Moreover, this result can be related to the occupants' daily habits (e.g. opening of windows during daytime hours when outdoor temperature is above indoor temperature). The generally lower minimum temperatures of the upper floor level spaces, compared to the intermediate floor level spaces, can be attributed to the larger exposure of the roof to the exterior environment. This exposure allows larger amounts of heat losses during night-time, contributing to an increased natural cooling effect. The exception found in Case Study A can be explained by the fact that the intermediate floor level space is partially subterranean, and thus, has the ability to maintain lower indoor temperatures. In general, ground floor level spaces exhibit lower minimum and maximum temperatures, while upper floor level spaces are found to present higher maximum temperatures.

6. Conclusions

The design of traditional buildings of Cyprus is the result of social, cultural and economic factors, as well as, of available resources, topographical features and climatic parameters. The vertical, multi-level, and compact development of traditional buildings in the mountainous regions, is proven to be a key environmental feature that has led to the creation of diverse thermal behaviour within spaces at different floor levels. Partially subterranean spaces at the ground floor level exhibit a greater ability to moderate diurnal temperature fluctuations and show the lowest indoor maximum and minimum temperatures. It should thus, be highlighted that, beyond their current use as storage spaces, partially subterranean spaces could be successfully exploited as main living areas of the occupants during the refurbishment of traditional buildings.

Due to the excessive heat coming from the roof, the use of high thermal mass materials at roof level, or the installation of additional insulation in timber roofs should be considered, in order to minimize the undesirable heat gains. Alternatively, the active use of the building, during daytime hours, could be restricted to the ground and intermediate floor level spaces which proved to be more protected from extreme summer temperatures. Nevertheless, during night-time, it is demonstrated that upper floor level spaces have the potential to provide comfortable spaces due to the cooling effect of the roof.

Today, vernacular architecture in the mountainous regions of the Eastern Mediterranean area can be used as a source of knowledge in bioclimatic design. This knowledge can be incorporated in contemporary architecture and in environment-based rehabilitation practices. The use of locally available resources, of high mass materials, the exploitation of the thermal benefits of earth mass and of the multi-level and compact development of buildings, are some of the principles that can be implemented towards a more sustainable built environment.

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