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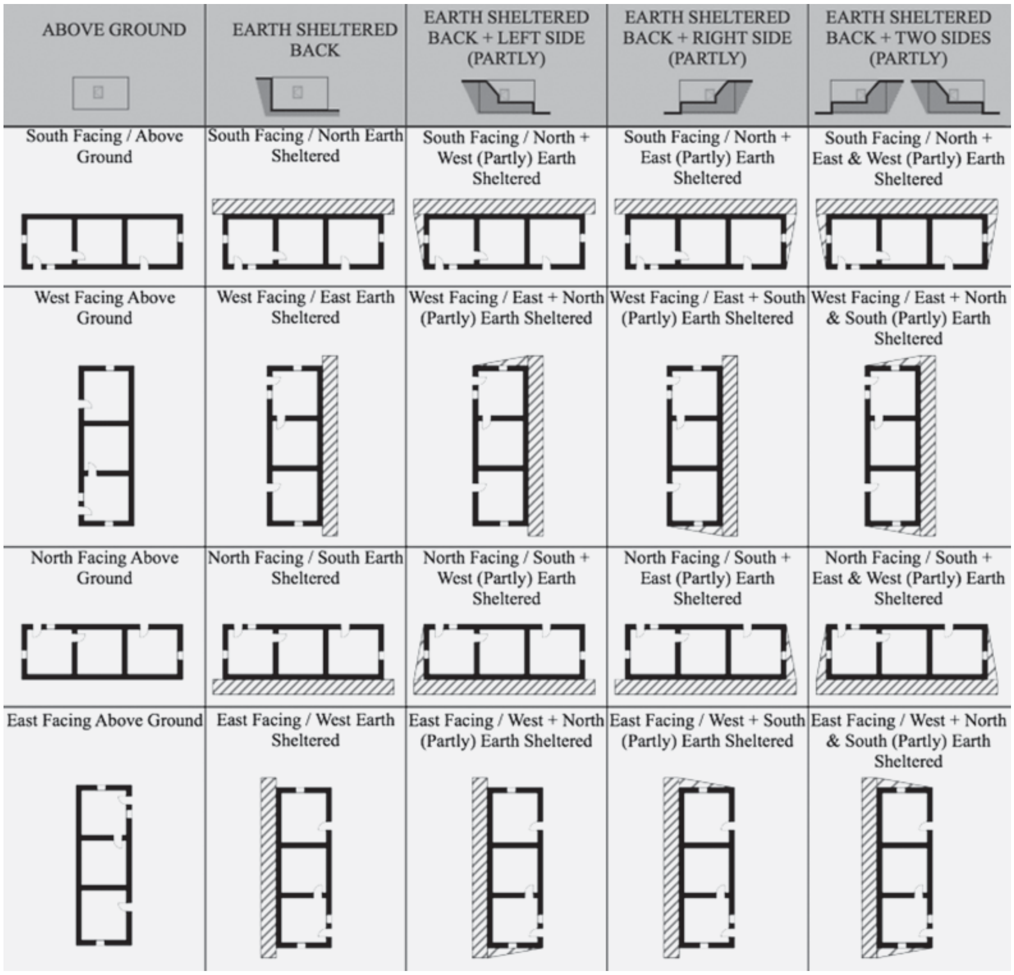

Table I Energy simulations methodology of linear (rectangular plan) typology for collecting data

Tabl. I. Metodologija energetske simulacije linearne (pravokutno-tlocrtne) tipologije građevina za prikupljanje podataka

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Traditional Earth Sheltered Buildings on Five Finger Mountain (Cyprus)

Evaluation of the Energy Efficiency by Computer Simulating the Rectangular Plan Typology

Tradicijske, zemljom izolirane građevine na planini Five Finger (Cipar)

Procjena energetske učinkovitosti pomoću računalne simulacije pravokutne tlocrtne tipologije

computer simulation of building
Cyprus
earth-sheltered
energy efficiency
Five Finger Mountain

računalna simulacija građevine
Cipar
izoliran zemljom
energetska učinkovitost
Five Finger Mountain

The earth-sheltered structures play a vital role in providing long-term constant temperature for indoor environment. It is aimed to reveal that earth-sheltered structures have better thermal performance than above ground structures. Typology study and energy simulation have been carried out for the mountainous region of Cyprus. It showed that the total energy consumption for earth-sheltered structure is lower than above-ground structures.

Građevine izolirane zemljom imaju ključnu ulogu u osiguravanju dugotrajne postojane temperature njihovih unutrašnjih prostora. Cilj je ukazati na činjenicu da zemljom izolirane građevine proizvode bolji toplinski učinak od onih iznad razine tla. Tipologija i računalna simulacija izvedene su za planinsku regiju Cipra. Analiza pokazuje da je ukupna potrošnja energije za zemljom izolirane građevine niža negoli za one iznad razine tla.

Introduction

Uvod

Energy consumption began in the early history of mankind with the burning of wood for heating and cooking. As part of a consumer society, we are still causing an increase in the consumption of energy and make it a fundamental problem for the whole world. In this paper, earth-sheltered buildings are reviewed in order to reduce the energy consumption for heating and cooling loads. It is a very cheap and passive way of cooling due to the natural properties of soil. As earth is a good insulator and temperature retarder, the temperature of earth becomes higher at 10 m depth in winter.[1] The main objective of this study is to investigate the potential of earth-sheltered buildings in the mountainous areas of Cyprus focusing on Five Finger Mountain and to promote the awareness of such strategies for energy saving in buildings.

In this study, a thorough review of earth-sheltered structures for Cyprus weather conditions is done. However, there are limited researches made for this type of structures in Cyprus. Particularly, there is no other research carried out for mountainous regions of the Five Finger Mountain which is (Πενταδάκτυλος /Pentadaktylos/ in Greek and Besparmak in Turkish). In a study with similar context the researchers studied to emphasize the benefits of underground structures by comparing it with above-ground structures in Greece.[2] In another study the researchers have conducted a study to find out the heating and cooling energy consumption of south-facing earth-sheltered structure. Afterwards, the result is compared to above ground structure. As a result, energy consumption is lower for earth-sheltered structures as it was expected by the researchers.[3] In another research it is mentioned that the energy consumption is also dependent on the different latitude from 50 to 1500 m for mountainous region.[4]

This study involves the qualitative and quantitative research in terms of earth-sheltered structures in Five Finger Mountain region. In the qualitative research, the floor plan layouts of the houses are evaluated and typology study is done. For the quantitative method, energy simulation is carried out for different types of earth-sheltered structures. The results indicate that energy demand for heating and cooling of the above-ground are annually higher than underground above-ground structures.

Literature Review

Pregled literature

The use of earth is not a new idea for building material. The direct contact between earth and part of the building envelope has played a vital role in terms of energy saving in buildings for some time. It is important to understand that, below a certain depth, the earth has a constant temperature, which is equal to the average temperature of that location. It has a high specific heat capacity, and therefore can store and conduct heat efficiently. Earth temperature changes slowly creating a significant time lag.[5] This means that since it takes time to lose and gain heat, earth is cooler in summer and warmer in winter.

Earth Sheltering – Earth sheltering involves the covering of some part of the building, such as one or more walls or roof, with soil or as an underground building.[6] It may be built into an excavated earth, fully or semi-bermed, built into hillside or combining rooms below and above ground (Fig. 1).

Earth-sheltered buildings are categorized as underground, having a central courtyard or atrium, and openness to view with one-two or three facades (Fig. 2).[7]

Earth-sheltered building plays a vital role in passive cooling methods because of reduced energy requirements for cooling. It is caused by minimizing the need for a mechanical cooling system and thereby, reducing the cooling bill. Earth-sheltered building also provides constant temperature in the living space, privacy from neighbours, acoustic privacy and protection from extreme weather conditions, in particular direct sunlight and strong winds. Buildings can be built on a south-facing slope to benefit from sun or on a north-facing slope if heating is not essential. Although they have many advantages, there are also some problems with underground buildings. The main drawback is related to water. The humidity level can be increased or condensation can be observed on elements of the building. Other considerations are ventilation, day lighting, visual relation and radon problem.[8] In light of this information, underground dwellings can be appropriate in hot-dry climates since moisture and ventilation problems more commonly occur in the humid regions.

History of Earth-Sheltered Living Environment – At the very beginning of the period before recorded history, early man used caves for hunting, praying, being in a secure environment and for protection against enemies or extreme weather conditions. Apart from providing such environment with the use of less energy, caves were also used as semi-buried shelters to enhance thermal comfort conditions of the indoor environment.

The evolution of earth-sheltering first started in the Americas, western/eastern Mediterranean, Egypt, Iran, China and Tunisia where the climatic conditions are extremely high. In China, natural caves were used for short-term dwellings. Afterwards, it is believed that pit type shelters were developed by the use of natural materials for building shelters in the late Paleolithic Age.[9] These pits were shaped according to the slope of mountains to take advantage of earth (Fig. 3a). By digging into the mountain, two or more stories cliff cave dwellings were created and terraces or courtyard were also formed according to the site topography (Fig. 3b).

In Cyprus, the first settlement was recorded in Khirokitia in the Neolithic Age between 7000-6500 BC (Fig. 7). Due to this, Khirokitia represents the ancient human and architectural settlement of Cyprus. Providing defence and fertile land, the foothills of the Troodos Mountain were chosen as dwelling areas.[10] The general context of the village was a compact configuration with narrowing streets to allow wind penetration through the settlements. The buildings were composed of heavy sun-dried mud brick walls and dome structure. They were circular in shape and similar to beehive.[11] Lofts were found in the houses which were supported by pillars. The lower part of the floor was used as pit graves for burial. The size of graves was 80×50×20 cm and 40 cm in depth.[12]

After the prehistoric age, the nomadic lifestyle changed into permanent settlements, leading to improvements in the social environment after the invention of metal in the fabrication of tools. People started living in big groups during ancient period when civilization began in Mesopotamia at about 4000 BC.[13] In that period, one upper Mesopotamian city, Mardin (first named Maride), was

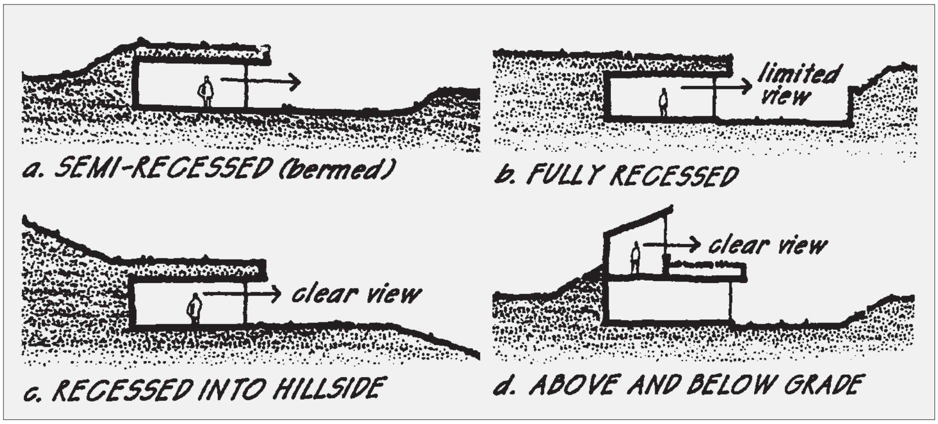


Fig. 1 Earth-sheltered design strategies
Sl. 1. Načini projektiranja građevina izoliranih zemljom

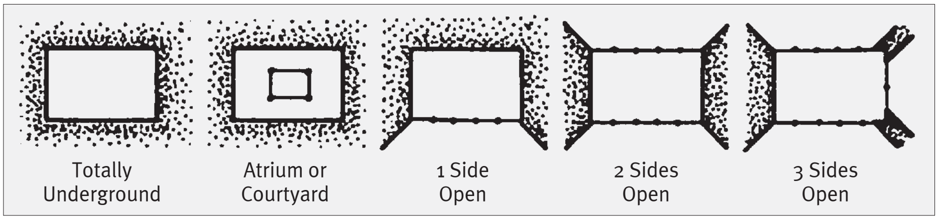


Fig. 2 Earth-sheltered plan types
Sl. 2. Tipovi tlocrta građevina izoliranih zemljom

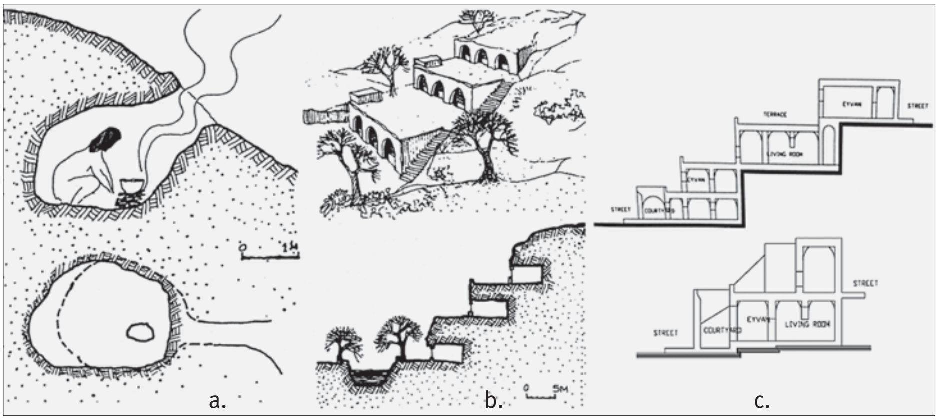


Fig. 3 History of earth-sheltered buildings
Sl. 3. Povijest građevina izoliranih zemljom

1 Golany, 1996: 455-465
2 Benardos, et al., 2014: 46-52
3 Staniec, Nowak, 2009: 221-235
4 Katsoulakos, Kaliampakos, 2016: 174-188
5 Brown, Dekay, 2001: 56
6 Moore, 1993: 212
7 Boyer, Grondzik, 1987: 8
8 Lechner, 2009: 497-501
9 Golany, 1992: 1-2
10 Karageorghis, 1982: 13-20
11 Karageorghis, 1968: 103
12 Wright, 1992: 61
13 Wigram, 1929: 3

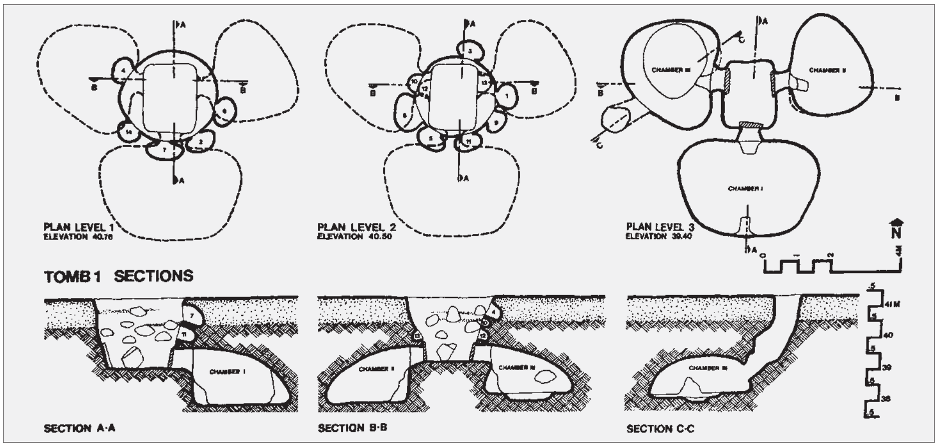


Fig. 4 Plans and sections of Toumba tou Skourou
Sl. 4. Tlocrti i presjeci Toumba tou Skourou

built by the Sumerians. Buildings were shaped according to the topography of the land and thus, some parts of the buildings, in particular storage, barn, daily rooms, etc. had contact with the earth. Additionally, flat roofs were created to benefit from the sun, especially during the winter months (Fig. 3c).

In the case of Cyprus, archaeological findings showed that there was a site named Toumba tou Skourou where houses and particularly earth-sheltered chamber tombs were sited in the 1500 BC (Fig. 4). The tomb structure included a round shaft and burial-like pits for adults and infants.

Different topographical formations provided different types of earth-contact dwellings. There are different types of terminology for earth-contact buildings in relation to the space used, height of space or soil properties.[14] These are: earth-covered, semisubterranean, subsurface, subterranean and below ground. Bulla Regia in Tunisia or Ghadames in Libya (first century BC and AD) were subsurface settlements, which were completely in the soil in lowland regions, leading to protection from the outdoor environment. In this respect, heat loss and heat gain were minimized.

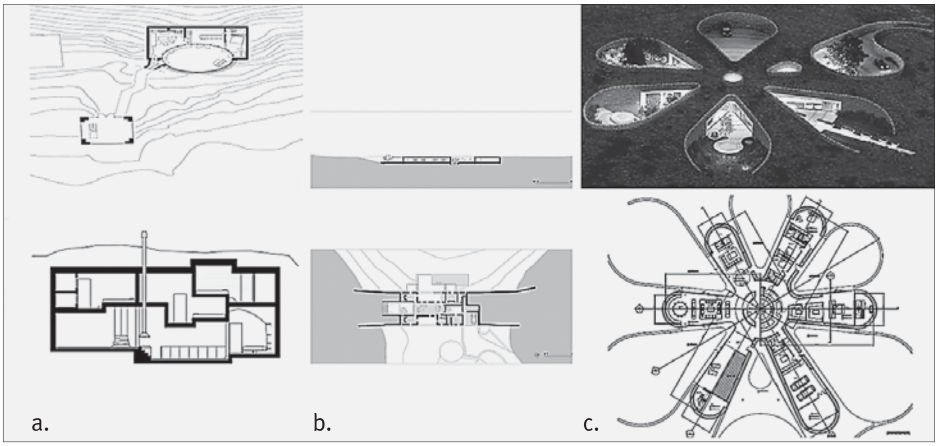
The next settlement was Fikardou, located on the south-eastern slopes of the Troodos Mountain Range in Cyprus (Fig. 7 and 8). It is cited that the region was controlled by clans in 700 AD and the name of earliest family was recorded after 1450.[15] Houses were generally one or two storeys high with semi-bermed dwellings. It is obvious that since the rainfall level is higher, the roofs were hipped. However, houses with flat roofs were also used for drying vegetables or fruits where it was reached from the upper floor. Generally, this floor was used as a living area whereas the lower part was for storage or stable.[16]

Dating back to the Industrial Revolution, energy saving design was stimulated for buildings, because the world had suffered from a lack of resources by the end of World War II.[17] Eco-awareness in building design was promoted by young environmentalists such as Lewis Mumford, Ian McHarg and James Lovelock in the 1960s and at the beginning of the 1970s. Furthermore the American architect, Malcolm Wells, worked against architectural ostentation and the destruction of natural land for buildings in the 1980s and early 1990s.[18] His house in Brewster, Massachusetts became a typical example of energy saving, earth-sheltered buildings.

Another architect Don Metz, in the majority of his work took into consideration the principles of earth-sheltering. He designed the award winning Pinnacle House in New Hampshire in 1971, which was the year the heating oil price became 19 cents per gallon.[19] The north facade of the building was built into the hill and the south facade was exposed to the sun and view.

An example of contemporary earth-sheltered building is from Vals Village in Switzerland; this was designed in 2009 by the architects of SeArch and Christian Müller at the lower level of a mountainside. Visual effect, natural light and thermal comfort were provided in winter/summer in terms of energy saving design approach (Fig. 5a). Aloni House in Greece was built in 2008. This house was built into the ground to control sun and to prevent

Fig. 5 Contemporary earth sheltered buildings
Sl. 5. Suvremene građevine izolirane zemljom



14 Golany, 1988: 19

15 World Heritage Encyclopedia, 2001

16 Egoumenidou, Floridou, 1987: 3-16

17 Prinz, 2015: 75-80

18 May, 2008: 423-430

19 Metz, 2007: 104-105

20 Department of Meteorology – Climate of Cyprus, 2016

21 Alkaff, et al., 2016: 692-713

22 Katsoulakos, 2016: 174-188

23 Abohorlu, 2010

Fig. 6 Air temperature
Sl. 6. Temperatura zraka

Fig. 7 Cyprus
Sl. 7. Cipar

glare. In addition to this, it was built to minimize the use of cooling systems (Fig. 5b). Another contemporary earth-sheltered building was designed by Make Architects which was almost built into the hillside. It is called zero-carbon underground home since it was aimed to minimize energy consumption. The architects were inspired from a Neolithic underground settlement in Scotland Skora Brae (Figure 5c).

Cyprus Climate – Cyprus has a very hot summer and mild winter. The daily maximum temperature was 41.3 °C in 2015. In January the mean daily temperature is 10 °C on the central plain 3 °C on the higher parts of Troodos Mountains with an average minimum temperature of 5 °C and 0 °C respectively. Besides being a very hot country, there is a large diurnal temperature range between day and night. In summer, the temperature difference is 16 °C in the central plain and 9 to 12 °C elsewhere. These differences are in winter 8 to 10 °C on the lowlands and 5 to 6 °C on the mountains.[20] The maximum, average and minimum temperatures are shown in Fig. 6.

There are two distinctive mountain ranges, The Troodos, rising to 1.952 m, covers the south and west part, whereas (Five Finger) Kyrenia Mountains (at 1.024 m) are in the northern part of the island (Fig. 7). They prevent wind and moisture from the Mediterranean Sea from reaching the inner part of the island, creating hot and dry climate in summer. Thus, the inner part of the island is cooler in winter. The Mesaoria plain (between two dominant mountains) is in between these dominant mountains.

Soil temperature is affected by the height from sea level which is important for feasibility of earth-sheltered structures.[21] The soil temperature in Cyprus at 10 cm depth is 10 °C in January and 33 °C in July. Altitude above sea level also affects the climatic parameters such as solar radiation, wind flow, temperature, etc. Temperature becomes lower in relation to altitude.[22] In Five Finger Mountain, temperature becomes lower by 5 °C at 1.000 m above sea level. Even if frost occurs at the highest point of mountains, there will be no problems at ground level. It is obvious that the deeper into the ground, the greater the temperature difference between ambient and earth temperature.

Features of Cypriot Traditional Houses and Building Materials – Due to the topographical location of the mountains, the southern slopes are exposed to the sun, creating hot and sunny weather conditions. On the other hand, as the sun has a low angle in January, the northern slopes of the mountains are cool and shaded.[23]

Fig. 8 a) and b) Khirokitia, Fikardou; c) Kozan (Larnakatis – Lapitos)
Sl. 8. a) i b) Khirokitia, Fikardou; c) Kozan (Larnakatis – Lapitos)

FIG. 9 RECTANGULAR-SHAPED BUILDING IN AGIRDA (AGIRDAG; UP-LEFT) AND BELLAPAIS (UP-RIGHT); L-SHAPED BUILDING IN KORNOKIPOS (GORNEC; DOWN-LEFT) AND DISPERSED BUILDING IN MELOUNTA (MALLIDAG; DOWN-RIGHT)

SL. 9. KUĆE PRAVOKUTNOG OBLIKA U AGIRDI (GORE LIJEVO) I BELLAPAISU (GORE DESNO); KUĆA U OBLIKU SLOVA L U KORNOKIPOSU (GORNEC; DOLJE LIJEVO) I DISPERZIRANA KUĆA U MELOUNTU (MALLIDAG; DOLJE DESNO)

Cyprus includes a wide range of considerable studies in terms of architectural approaches. Since it is made up of mountains, a plain and coastal region, this apparently has resulted in different types of housing configuration. Topography, climate and views are key factors for building design in mountainous regions.

The configuration of buildings in mountainous region tends to be compact shaped in order to prevent heat loss since the temperature fluctuation is greater in winter. Mostly, the buildings are built vertically because of the topographic formation and, therefore, the lower levels of the roofs are used as flat roofs.

The village of Larnakatis – Lapitos (Kozan) in Cyprus is located on the south-western slopes of the Five Finger Mountain (Fig. 8). As the buildings are oriented to the south and semi-buried, low north facades are exposed to strong winds and shading is maximized. In Bellapais, on the northern slope of Five Finger Mountain, the semi-buried buildings face the north, which means shading is provided and the tall south face of the buildings is exposed to a significant amount of wind (Fig. 8). Both villages are located at nearly the same elevation above sea level. Larnakatis – Lapitos (Kozan) is located on the lower part of the slope exposing the cold airflow, which is a favourable microclimate location for hot regions. However, Bellapais can be localized at the top of the slope for wind exposure. They can be both oriented to the east to migrate solar exposure in the afternoons.[24]

Natural materials, which are taken from nature, are commonly used in the construction of traditional buildings in Cyprus (Fig. 8). As these materials are easily obtainable and buildings are constructed by local people, the cost of construction is economical. The use of man-made construction material began before 1960 with the development of new manufacturing processes.

In deciding which material can be employed in building construction, the availability of the material plays a vital role. As stones are extracted from the mountainous areas, it is necessary to use them with wood or earth. Regarding the topography, the buildings did not destroy the natural land. For the inland region (Mesario) earth, straw, bushes are used as available materials, which are environmentally friendly, cheap and provide better thermal conditions. When these materials are mixed together, they act as thermal masses, which are used in the walls or foundations of buildings.

RESEARCH DESIGN AND METHODOLOGY

ISTRAŽIVANJE I METODOLOGIJA

Typology study of Five Finger Mountain buildings – As aforementioned above, Cyprus is composed of two dominant mountains where settlements are configurated by topography. In Troodos Mountain, some settlements are analysed according to the building shape and plan type. As is cited by Philokyprou et al. [2016], building layouts are firstly formed by a single room named as monochoro. Afterwards, increasing demand of daily activities and number of occupants in the buildings led to progress of monochoro layout, thus dichoro plan layout is formed in the Troodos Mountain. These two storey buildings are square shaped with large width. In the village of Askas (Fig. 7), linear and compact shaped floor plan layouts are mostly seen.[25] In the settlement of Pera Orinis, on the high plains at an elevation 400 m, dispersed plan type is seen as providing protection from excessive sunlight. However, as the larger surface area is exposed to the atmospheric conditions, the more heat loss or gain is observed.

This research is mainly focused on the villages located on the Five Finger Mountain. On Five Finger Mountain, the floor plan layout of the houses as seen in Agirda (Agırdag), Krini (Pınarbasi), Bellapais, Klepini (Arapkoy), Kornokipos (Gornec), Melounta (Mallidag) is generally developed linearly due to the shape of the land and is configurated as compact and rectangle shaped. These buildings are

24 ABOHORLU, RIFFAT, 2015

mostly seen as one or two storeys (Fig. 9). The lower level is partially earth-sheltered due to the topographic features of the mountain. The buildings consist of two or three rooms in linear shape. According to this, the buildings are exposed to less amount of sunlight and wind flow since it is compact in shape. Having less surface area provides comfortable indoors especially during the summer months.

L-shaped building layout is observed in Five Finger Mountain ranges because of the provision of a shaded area which causes a reduction in the ambient temperature (Fig. 9). Moreover, the dispersed plan type of building is also seen in Five Finger Mountain ranges which was built by land form (Fig. 9).

The plan typology of the residential buildings which includes both above-ground and earth-sheltered buildings in Five Finger Mountain area of Cyprus is defined. In this light, three different types of floor plan layouts are identified by on-site observation in the aforementioned region. In this stage of the study, the typology study of the main buildings in the Five Finger Mountainous region of Cyprus is done in order to define similarities and differences of these houses in a systematic approach as it is obvious that topography of the region affects the plan layout of these buildings (Table II).

Consequently, the vast majority floor plan layout is the linear building (rectangular shaped) with two or three rooms. On the other hand, there are some examples of L-shaped and dispersed plan layout. Due to this, in the following stage of study, the linear plan (rectangle shaped) configuration is selected as the case study of building type for energy simulations.

Simulations and energy evaluation for differently oriented above-ground and/or earth sheltered buildings – Regarding this typology study, the simulations of above-ground buildings and earth sheltered buildings are done for determining the energy values by the help of Archicad 19 software (Fig. 10). The buildings studied are located on the Five Finger Mountain having the coordinates of 35.30. N, 33.13. E. According to the results, the energy consumptions are described in terms of the characteristics of Five Finger Mountain.

A typical linear plan layout is taken as a basis for calculation (Table I, Fig. 10). The calculations are done considering earth sheltered sides of the building and the sun direction.

The construction materials employed in the buildings are masonry block for the walls and sun-dried earth with plaster for the slabs and roof. For the energy evaluation U-value of walls is taken as 2.95 W/m²K whereas U-value of the sun dried earth is taken as 0.65 W/m²K. Energy Model is designed and Net Heating Energy, Net Cooling Energy, Total Net Energy, Energy Consumption, Fuel Consumption for producing electricity, and CO_2 emission values are calculated (Fig. 11).

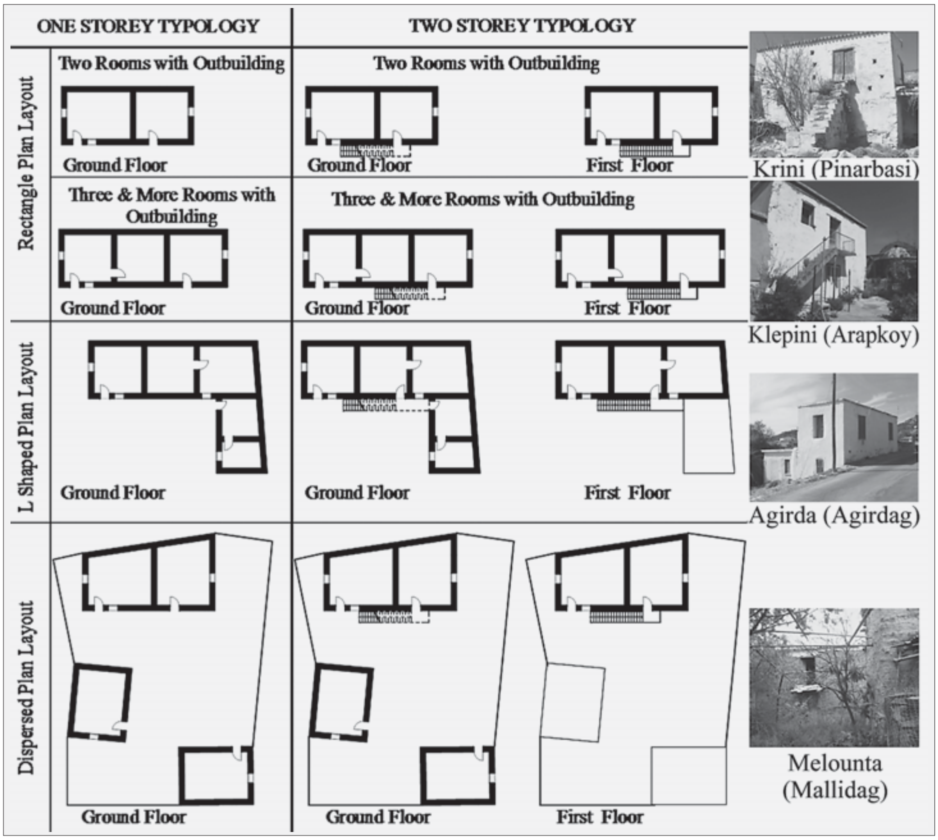


Table II Typology study of above-ground and earth sheltered buildings on Five Finger Mountain

Tabl. II. Studija tipologije nadzemnih građevina i onih izoliranih zemljom na planini Five Finger

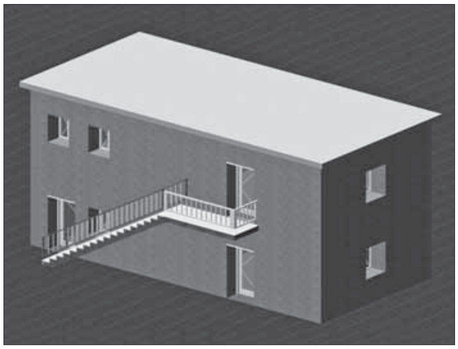
Results and Discussion

Rezultati i diskusija

Simulations and Energy Evaluation of Above Ground Buildings – As seen in the Table III, the south-facing buildings have lower energy consumption level at 167.63 kWh/m²K compared to the west, east and south orientations. Table IV shows the CO_2 emission values of above ground building which have different orientations. It is clearly grasped from the graphics that south-facing houses have the lowest CO_2 emission values in all at 39.77 kg/m²a. Regarding these results, it is possible to claim that, as Cyprus has a dry and hot climate, the south-facing residential buildings can be considered as having the best orientation according to climatic conditions of the region selected for this study. Since the sun angle is higher at summer and

Fig. 10 Simulations of buildings on Archicad 19 screen

Sl. 10. Simulacije građevina pomoću programa Archicad 19



25 Savvides, et al., 2016

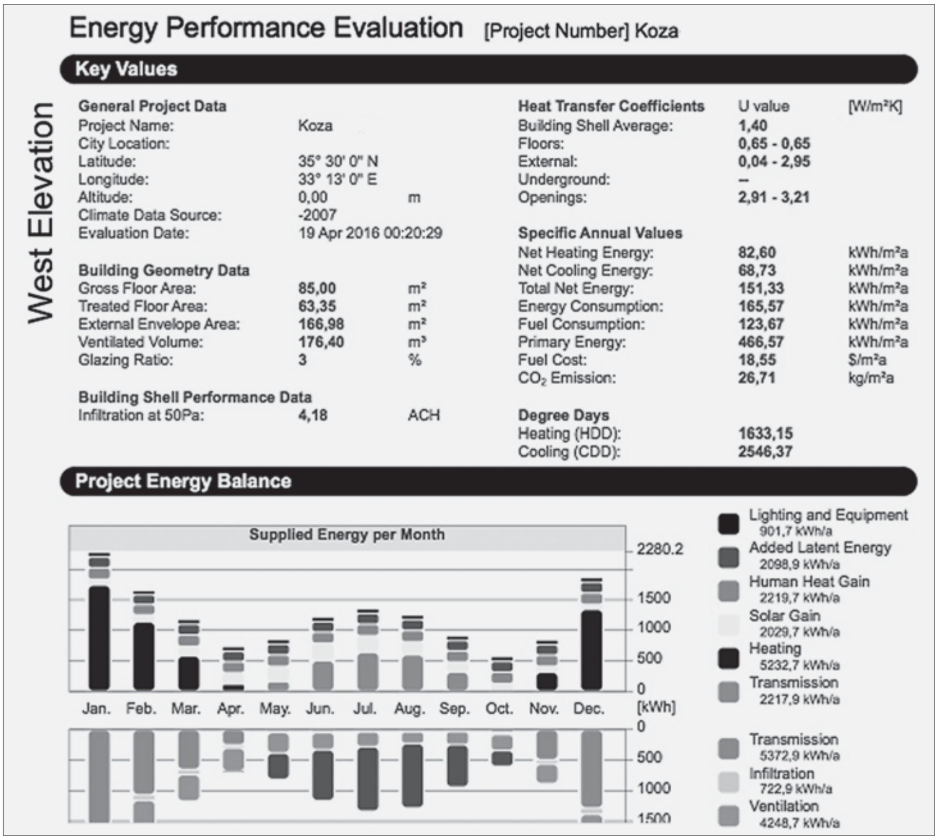
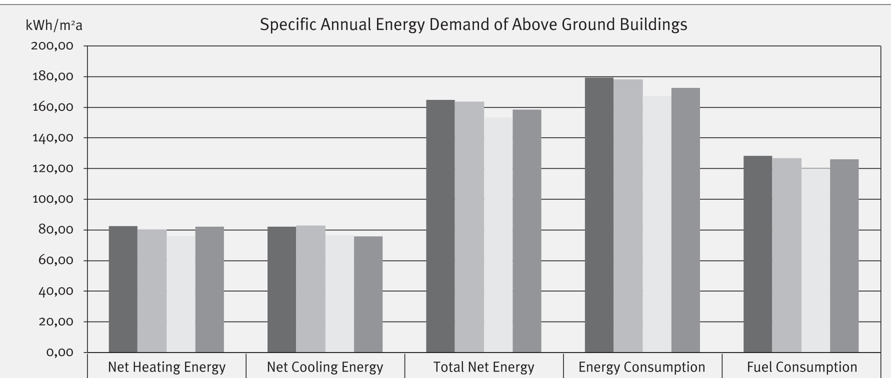


Fig. 11 Energy performance evaluation screen on Archicad 19 software
Sl. 11. Procjena energetske učinkovitosti (Archicad 19)

lower in winter, the south facade is exposed to sunlight in winter and the roof area is exposed to the sun in summer. It is also obvious that north, south and west-facing residential buildings have slight difference as being the second best orientation in terms of climatic conditions (Table III and Table IV). Accordingly, this research is basically designed to compare energy values of the differently oriented residential buildings. In addition, the influence of earth sheltering is also examined to define the effective way of reducing energy consumption and CO_2 emission. In the case studies it is observed that most of the buildings are partly earth-sheltered in the selected areas. The classification of the earth sheltered buildings include back side earth-sheltered; back & left side (partly) earth sheltered; back & right side (partly) earth sheltered and back & two sides (partly) earth sheltered buildings.

Table III Specific annual energy values of above ground buildings
Tabl. III. Specifične godišnje energetske vrijednosti nadzemnih građevina



	Net Heating Energy	Net Cooling Energy	Total Net Energy	Energy Consumption	Fuel Consumption
West - Facing	82,76	82,38	165,14	179,37	128,76
East - Facing	80,72	83,35	164,07	178,30	127,07
South - Facing	76,40	76,99	153,39	167,63	120,50
North - Facing	82,64	76,02	158,66	172,89	126,38

Simulations and Energy Evaluation of One Side Earth-Sheltered Buildings – When analysing the energy consumption of buildings having one-side sheltering, it can be noticed from Table V that south-facing building where the north facade is earth-sheltered, has the largest difference in heat consumption than that of the one side earth-sheltered ones. Since the largest facade or roof have contact with sunlight, earth sheltering for the other direction cannot affect the reduction of the cooling energy in total. When compared to heating energy consumption for above-ground structures, it is reduced by 53.1% with the lowest CO_2 emission at 26.86 kg/m²a (Table IV). As expected, the cooling demand for one side earth-sheltered building is definitively higher at 80.90 kWh/m²K.

The annual energy consumption of north-facing building where the south facade is earth-sheltered, is illustrated as the highest value of 163.68 kWh/m²a with the highest value of fuel consumption at 121.00 kWh/m²a (Table V). It is clearly analysed from the figure that the heating demand is higher since south side is protected from the sun.

The results for energy consumption in east and west facing buildings have little changes (Table V). However, it should be mentioned that cooling energy consumed by east and west facing building is higher than the heating consumption since east and west facades are exposed to more sunlight during summer than the cooler season. On the other hand, in winter east and west facades are exposed to less amount of the sun energy due to the behaviour of the sun. Accordingly, heating consumption is also increased in summer. The total net energy and fuel consumption for both facing building have nearly similar values.

Simulations and Energy Evaluation of Two Side Earth-Sheltered Buildings – The relations of energy consumption with three side earth-sheltered buildings are depicted in Table VI.

Cooling demand for north-facing buildings that have their south & east earth-sheltered and south & west earth-sheltered is the lowest since the heat gain is not obtained from the north side. Therefore, the building is naturally cooler. Accordingly, the net heating energy used for these buildings are the high-

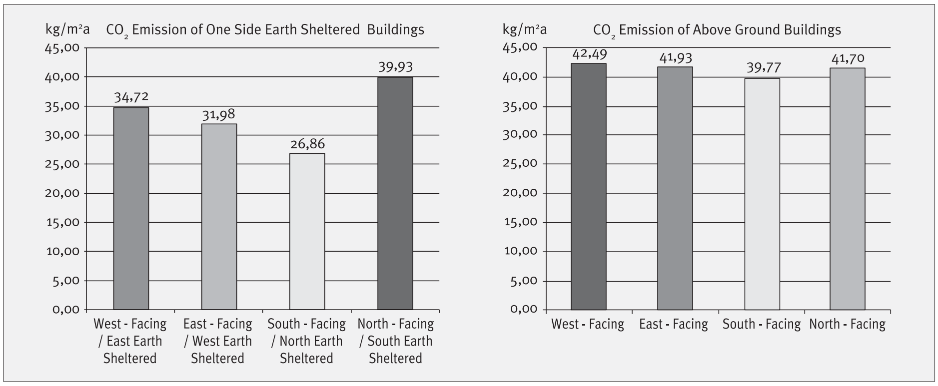
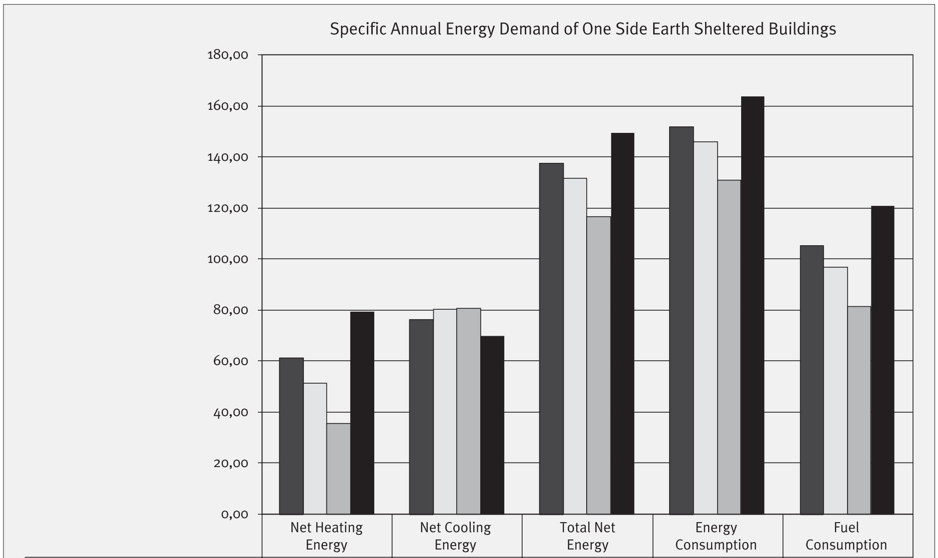


Table IV CO_2 emission of "above ground" and "one side earth sheltered" buildings

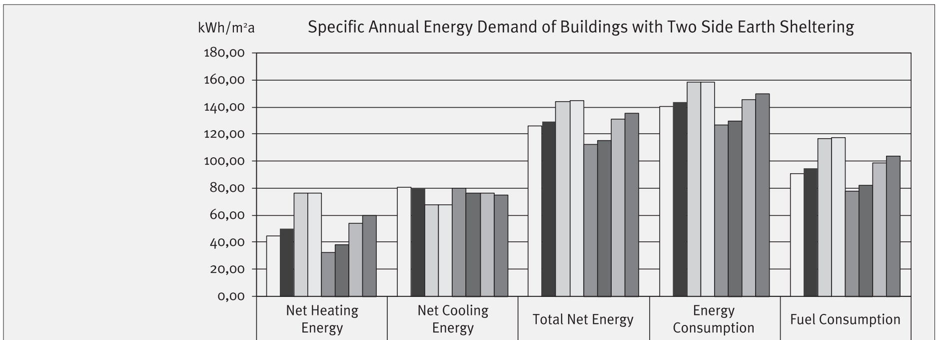
Tabl. IV. Emisija CO_2 nadzemnih građevina i onih izoliranih zemljom s jedne strane



	Net Heating Energy	Net Cooling Energy	Total Net Energy	Energy Consumption	Fuel Consumption
West - Facing / East Earth Sheltered	61,42	76,24	137,66	151,89	105,21
East - Facing / West Earth Sheltered	51,61	80,29	131,90	146,14	96,90
South - Facing / North Earth Sheltered	35,88	80,90	116,78	131,02	81,38
North - Facing / South Earth Sheltered	79,48	69,96	149,45	163,68	121,00

Table V Specific annual energy values of one side earth sheltered buildings

Tabl. V. Specifične godišnje energetske vrijednosti građevina izoliranih zemljom s jedne strane



	Net Heating Energy	Net Cooling Energy	Total Net Energy	Energy Consumption	Fuel Consumption
East - Facing / W& N Earth Sh.	45,23	81,17	126,40	140,64	90,84
East - Facing / W & S Earth Sh.	50,21	79,74	129,95	144,19	95,30
North - Facing / S & E Earth Sh.	76,43	68,25	144,69	158,92	117,32
North - Facing / S & W Earth Sh.	76,99	67,76	144,75	158,98	117,71
South - Facing / N & E Earth Sh.	32,59	80,23	112,82	127,05	77,86
South - Facing / N & W Earth Sh.	38,74	76,68	115,42	129,65	82,74
West - Facing / E & N Earth Sh.	54,72	76,87	131,59	145,83	98,74
West - Facing / E & S Earth Sh.	60,31	75,26	135,57	149,81	103,74

Table VI Specific annual energy values of two side earth sheltered buildings

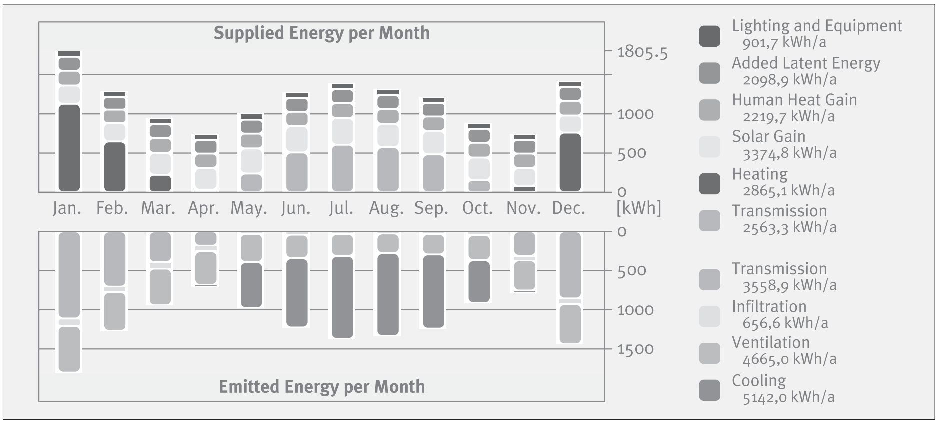
Tabl. VI. Specifične godišnje energetske vrijednosti građevina izoliranih zemljom s dvije strane

est at 76.99 kWh/m²a. However, there is a distinctive difference of heating consumption for south-facing two side earth-sheltered building. The net heating energy is 32.59 kWh/m²a for north & east and 38.74 kWh/m²a for north & west earth-sheltered building. Compared to above ground building, the heating demand is lowered by 57%, 49% respectively.

Although the energy consumption for east and west facade with two side earth-sheltered building is slightly different, west-facing shows higher energy consumption due to the cooling demand in that direction. As seen in Table VII, solar gain for east-facing building with west & north side earth sheltered is higher at 3374.8 kWh/m²a than west-facing building with east & north side earth-sheltered (Table VIII). Thus, cooling demand is higher.

The carbon dioxide emission is the lowest for south-facing with north & east earth-sheltered building. Following this, south-facing with north & west earth-sheltered and west-facing east & north earth-sheltered are the second lowest values. However, the "north-facing south and east earth sheltered" building's carbon dioxide emission is at 38.72 kg/m²a and the "north-facing south and west earth sheltered" building's carbon dioxide emission is at 38.84 kg/m²a (Table IX).

Simulations and energy evaluation of buildings with three sides earth-sheltered – As illustrated in Table XII, the significant changes for south-facing earth-sheltered building with three sides are clearly seen in terms of heating demand at 28.62 kWh/m²a. It is clearly seen that this type of building provides better orientation in terms of energy consumption. The energy consumption is gradually decreased to 122,76 kWh/m²a by increasing the number of walls, which are in contact with the soil. Compared to above ground building, energy consumption is reduced by 27% and heating consumption is also decreased by 63%. The less cooling energy is consumed by north-facing buildings with three side earth-sheltering as the larger facade is not exposed to the sun.



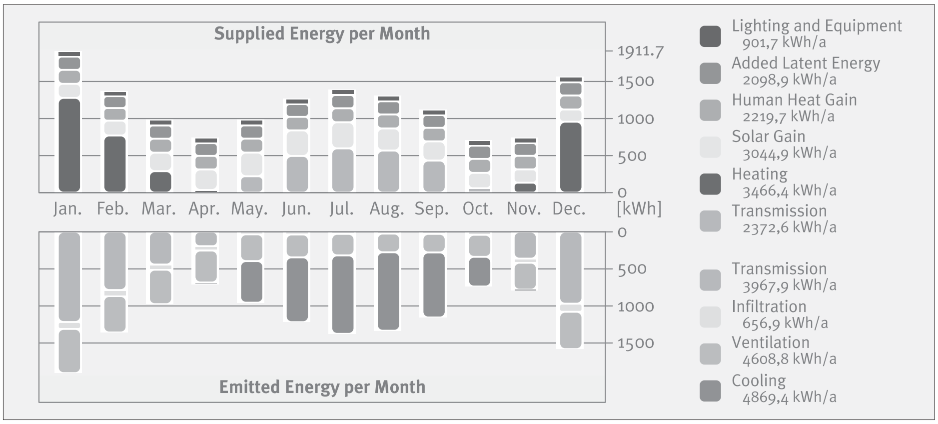


Table VII Energy balance of east-facing building with west & north earth sheltering

Tabl. VII. Energetska bilanca istočno orijentiranih građevina sa zapadnim i sjevernim zemljanim zaklonom

Table VIII Energy balance of west-facing building with east & north earth sheltering

Tabl. VIII. Energetska bilanca zapadno orijentiranih građevina s istočnim i sjevernim zemljanim zaklonom

Conversely, east-facing buildings consumed more heating energy than cooling energy.

It is obvious that south-facing buildings with three side earth-sheltering consumed less amount of energy at 122.76 kWh/m²a. As it is expected, the highest energy consumption is seen on the north-facing earth-sheltered buildings.

Conclusion

Zaključak

Based on the analysis of the simulations on a rectangular plan typology, this study shows that earth sheltered traditional buildings can be considered as having larger capability of energy efficiency. Thus they can provide more appropriate interior comfort quality to the users so that this healthy environment enables people to be healthier in general.

There are various factors which affect the energy efficiency capacity of the buildings such as construction material, typology of the building, the location of the building, earth sheltering, the climate and the sun direction. This study focused on the linear plan typology of Five Finger Mountain's buildings and investigated the effects of different sun directions

The west-facing building with three side earth-sheltering causes more cooling energy consumption than heating consumption due to the higher solar heat gain as compared to east-facing buildings (Table X and Table XI).

Table IX CO_2 emission of building with "two-side" and "three-side" earth sheltering

Tabl. IX. Emisija CO_2 građevine s 'dvostranim' i 'trostranim' zemljanim zaklonom

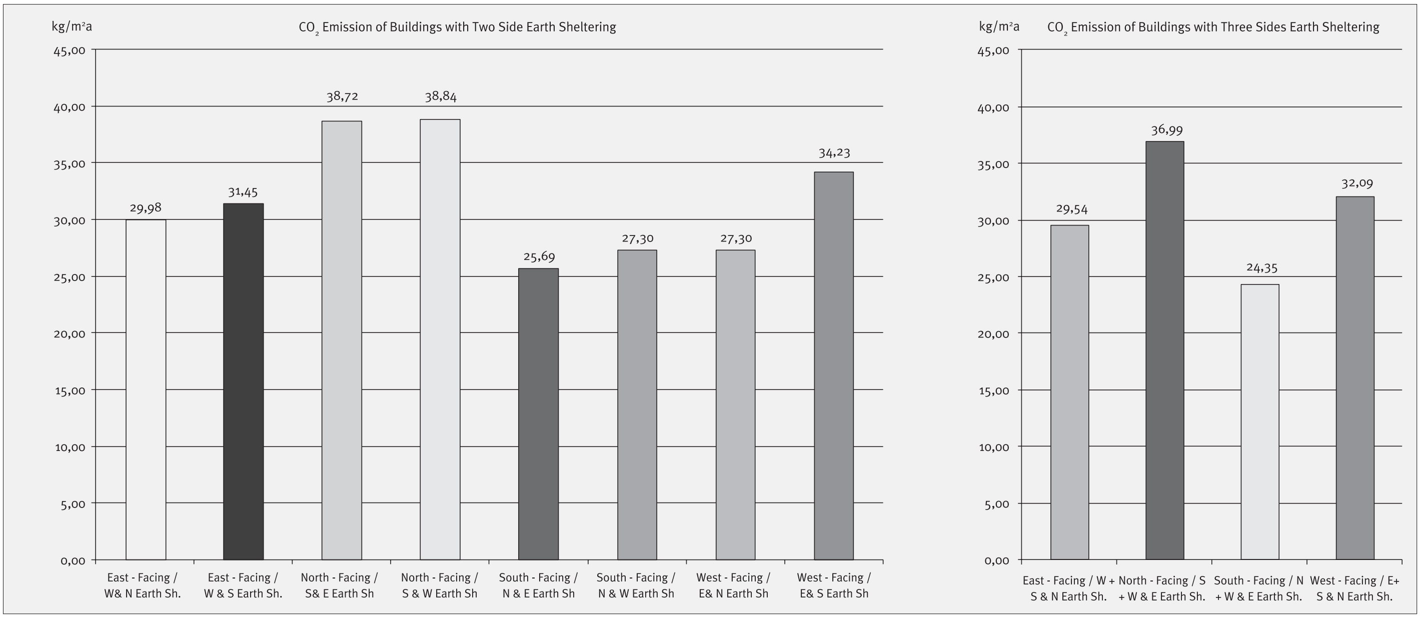


Table X Energy balance of east-facing building with west, south & north earth sheltering

Tabl. X. Energetska bilanca istočno orijentirane građevine sa zapadnim, južnim i sjevernim zemljanim zaklonom

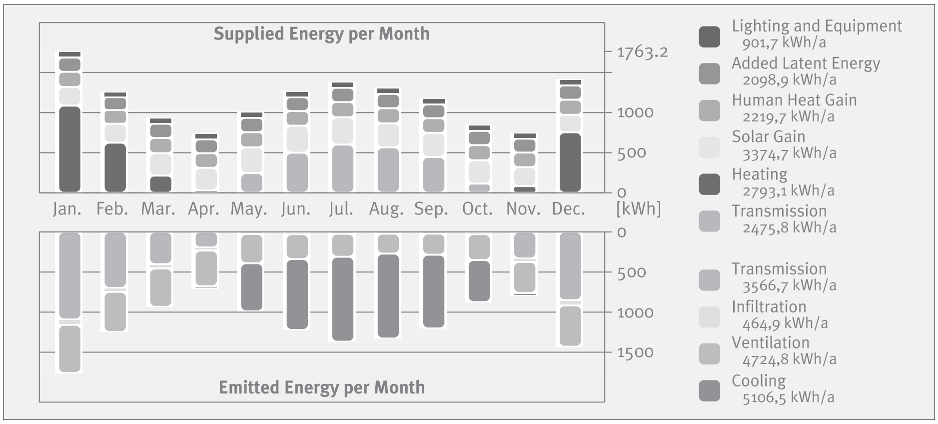
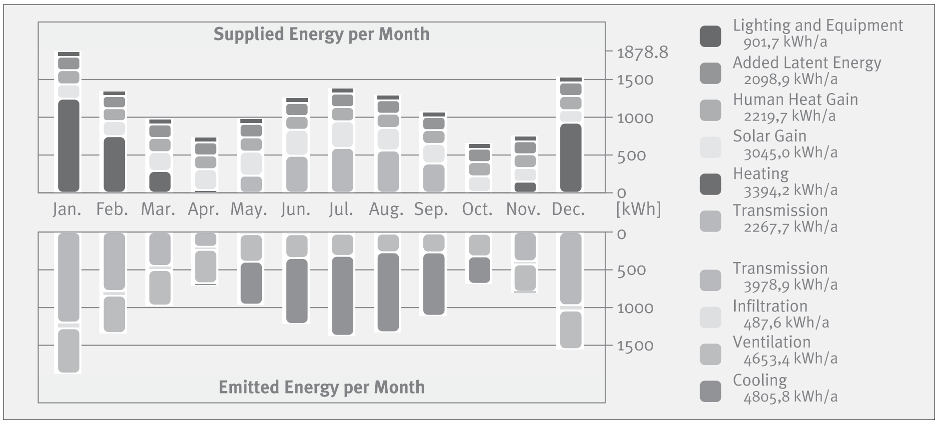


Table XI Energy balance of west-facing building with east, south & north earth sheltering

Tabl. XI. Energetska bilanca zapadno orijentirane građevine s istočnim, južnim i sjevernim zemljanim zaklonom



and earth-sheltering in the context of energy consumption. This study proved that the earth sheltered buildings have less energy consumption compared to the above ground buildings.

South-facing above ground buildings are more energy efficient compared to the north facing above ground buildings in terms of overall energy consumption. South facing north earth sheltered buildings need least amount of energy for heating compared to the other one side earth sheltered buildings with different orientations. However north-facing earth-sheltered buildings have better capacity for cooling.

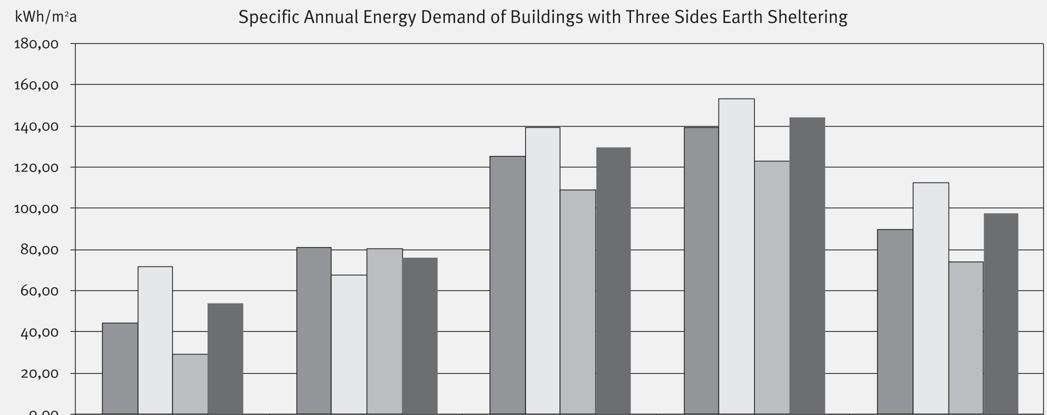
Buildings, which are earth sheltered by two sides, south facing north and east earth sheltered buildings need less energy for heating. However, north facing south and west earth sheltered buildings need less energy for cooling. South facing north, west and east earth sheltered buildings demand the smallest amount of energy for heating whereas north facing south, west and east earth sheltered buildings demand the minimum energy for cooling.

As a conclusion it can be claimed that earth sheltered traditional buildings on Five Finger Mountains have better energy efficiency and passive heating and cooling capacity.

[Translated by authors; Proofread by *Research Centre for Applied Linguistics* (RCAL), Nicosia, Cyprus]

Table XII Specific annual energy demand of buildings with three-side earth sheltering

Tabl. XII. Specifićne godišnje energetske potrebe građevina s trostranim zemljanim zaklonom



	Net Heating Energy	Net Cooling Energy	Total Net Energy	Energy Consumption	Fuel Consumption
East - Facing W+ S & N Earth Sh	44,09	80,61	124,70	138,94	89,51
North - Facing S + W & E Earth Sh	71,63	67,04	138,66	152,90	112,09
South - Facing / N + W & E Earth Sh	28,62	79,91	108,53	122,76	73,78
West - Facing E+ S & N Earth Sh	53,58	75,87	129,45	143,68	97,23

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Illustration and Tables Sources

Izvori ilustracija i tablica

Fig. 1	Moore, 1993: 213
Fig. 2	Boyer, Grondzik, 1987: 8
Fig. 3, 5-11	Authors
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Summary

Sažetak

Traditional Earth Sheltered Buildings on Five Finger Mountain (Cyprus)

Evaluation of the Energy Efficiency by Computer Simulating the Rectangular Plan Typology

U razdoblju prije pisanih povijesnih zapisa čovjeku je špilja služila kao životni prostor pružajući mu sigurnost i zaštitu od neprijatelja i nepovoljnih klimatskih uvjeta. Špilja je također, kao poluukopani zaklon, osiguravala ugodne toplinske uvjete u svojoj unutrašnjosti. Razvoj građevina zaštićenih odnosno izoliranih zemljom započeo je na prostorima sjeverne i južne Amerike, zapadnoga i istočnoga Mediterana, Egipta, Irana, Kine i Tunisa.
Različite topografske karakteristike rezultirale su različitim tipovima građevina izoliranih zemljom. Za njih postoje različiti nazivi s obzirom na korišteni prostor, visinu prostora ili svojstva tla. Uobičajeni nazivi koji se koriste za opise takve građevine jesu: pokrivene zemljom, poluukopane, ispod površine tla, podzemne i ispod razine zemlje.
Glavni dio zemljom izoliranih građevina jest tzv. 'zemljani zid' koji ima najvažniju ulogu u osiguravanju dugotrajne postojane temperature unutrašnjosti tijekom različitih godišnjih doba. Zaštita (izolacija) zemljom odnosi se na pokrivanje dijelova građevine, kao što su jedan ili više zidova, krov ili pak na cijelu građevinu koja je pod zemljom. Takva se građevina može sagraditi u iskopanome dijelu zemlje, može biti u cijelosti ili poluukopana, ugrađena u brežuljak ili može činiti kombinaciju prostora iznad i ispod razine tla. Usto, u takvim je građevinama potrošnja energije za grijanje ili rashlađivanje smanjena. Kako je zemlja dobar izolator koji zadržava temperaturu, temperatura zemlje zimi je viša na 10 m dubine.
Glavni cilj ovoga istraživanja jest ispitati potencijal građevina izoliranih zemljom u planinskim regijama Cipra, s osobitim osvrtom na regiju *Five Finger Mountain,* te potaknuti svijest o potrebi razvijanja strategija za štednju energije. Na Cipru postoje dva odvojena planinska lanca: Troodos (1952 m) koji se proteže na sjeveru i zapadu te (Five Finger) Kyrenia (1024 m) na sjeveru otoka. Oni priječe prodor vjetrova i vlage s Mediterana u unutrašnjost otoka, zbog čega je ljeti klima vruća i suha. Stoga je unutrašnji dio otoka zimi hladniji. Ravnica Mesaoria smještena je između ta dva dominantna planinska lanca.
Na temperaturu tla utječe nadmorska visina, što je važno za izvedivost građevina izoliranih zemljom. Temperatura tla na Cipru na 10 cm dubine jest 10 °C u siječnju, a 33 °C u srpnju. Očito je da se razlika u toplini zemlja i okoliša povećava s dubinom tla.
Na Cipru postoje različiti pristupi gradnji u arhitekturi. Različiti geografski uvjeti, tj. planine, ravnice i obalni pojas, uvjetovali su i različite tipove kuća. Topografija, klima i vizure ključni su čimbenici u projektiranju građevina u planinskom području. Konfiguracija zgrada u takvoj regiji pretežno je kompaktna kako bi se izbjegli gubici topline, jer su fluktuacije temperature veće zimi. Većinom su zgrade građene vertikalno zbog topografske formacije i stoga su niže razine krovova korištene kao ravni krovovi.
Metodološki, ova analiza uključuje kvalitativno i kvantitativno istraživanje zemljom izoliranih građevina u regiji *Five Finger Mountain*. U kvalitativnom dijelu istraživanja istraženi su tipovi tlocrta kuća i izvedena je njihova tipologija. U pogledu kvantitativne metodologije izvedena je energetska simulacija za različite tipove zemljom izoliranih građevina.
Cilj je analize dokazati da zemljom izolirane građevine proizvode bolji toplinski učinak i imaju manju potrošnju energije negoli one iznad razine tla. Izvedena je tipologija za tri različita tipa tlocrtne organizacije u selima regije *Five Finger Mountain* na Cipru: pravokutni tip, u obliku slova L i disperzirani tip. Tlocrtna dispozicija kuća u mjestima Agirda (Agırdag), Krini (Pınarbasi), Bellapais, Klepini (Arapkoy), Kornokipos (Gornec) i Melounta (Mallidag) uglavnom je linearna s obzirom na konfiguraciju terena, kompaktna i pravokutna.
Analiza energetske učinkovitosti građevina u pogledu različite orijentacije građevine i njihovih strana koje su izolirane zemljom u ovome je radu izvedena na primjeru pravokutnoga tlocrtnog tipa. Pomoću računalnog programa Archicad izrađena je energetska simulacija u cilju analize učinaka koje građevine izolirane zemljom imaju na energetsku učinkovitost. Na temelju razrađenoga modela izračunate su vrijednosti neto potrošnje energije za grijanje, rashlađivanje, ukupna neto energija, potrošnja energije, potrošnja goriva za proizvodnju električne energije i emisija CO_2.
U studijama slučaja uočava se da je većina građevina djelomično zaštićena zemljom u odabranim područjima za analizu. Klasifikacija zemljom izoliranih građevina obuhvaća: građevine izolirane zemljom sa stražnje strane, djelomično izolirane zemljom sa stražnje i lijeve strane, djelomično izolirane zemljom sa stražnje i desne strane, te djelomično izolirane zemljom sa stražnje i dvije strane. Ova klasifikacija obuhvaća građevine orijentirane prema istoku, zapadu, jugu i sjeveru.
Različiti su čimbenici koji utječu na kapacitet energetske učinkovitosti: građevni materijal, tipologija građevine, lokacija, zaklanjanje (izolacija) zemljom, klima i pozicija u odnosu na osunčanje. Ova se analiza bavi linearnom tlocrtnom tipologijom građevina na planini *Five Finger* u pogledu učinaka različitih pozicija osunčanja i zaklanjanja zemljom u smislu potrošnje energije. Rezultati analize pokazuju da je ukupna potrošnja energije za građevine izolirane zemljom niža negoli za one iznad razine tla te da su potrebe za energijom za grijanje i rashlađivanje na godišnjoj razini niže nego za one iznad razine zemlje. Vrijedi spomenuti da zemljom izolirane građevine troše manje energije od onih iznad razine zemlje, kako to i pokazuje računalna simulacija.

Biographies

Biografije

Pervin Abohorlu, MArch, is a Ph.D. candidate at the University of Nottingham (UK), Department of Built Environment and Architecture. She is an instructor in the Faculty of Fine Arts, Design and Architecture at Cyprus International University in Cyprus. Research area: climate responsive architecture, traditional architecture, sustainable development, environmental control, environmental psychology, sustainable energy technology, energy simulation.

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Pervin Abohorlu, magistrica arhitekture, doktorand na Sveučilištu u Nottinghamu (UK), Odsjek za izgrađeni okoliš i arhitekturu. Nastavnica je na Fakultetu likovnih umjetnosti, dizajna i arhitekture na ciparskome međunarodnom sveučilištu na Cipru. Istraživačka područja: arhitektura u odnosu na klimu, tradicijska arhitektura, održivi razvoj, kontrola okoliša, psihologija okoliša, tehnologija održive energije, energetska simulacija.

Sevinç Kurt diplomirala na Middle East Technical University, Odsjek za arhitekturu te magistrirala i doktorirala na Sveučilištu Gazi u Ankari, Turska. Izvanredna je profesorica na Odsjeku za arhitekturu na ciparskome međunarodnom sveučilištu na Cipru. Područja istraživanja: obrazovanje u području arhitektonskog projektiranja, održivost, tradicijska arhitektura, projektiranje u velikom mjerilu u urbanom kontekstu, arhitektonska teorija i projektiranje interijera.