An Ecological Study on Earth Sheltered Housing in Different Climates

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ABSTRACT

The purpose of this thesis was to illustrate the potential of the earth sheltered housing related to integration to the topography from the ecological viewpoint and sustainable holistic approach when they are applied to the different climatic regions.

Problems that modern world is currently faced with, includes the excessive consumption of non- renewable energy sources, environmental pollution and depletion of natural landscape and topography because of negative impacts of human activities. In this context, the role of conventional buildings particularly housing as a major source of energy consumption and polluting the environment is more than other building types. Therefore, earth sheltered housing is pointed out as a significant alternative to above ground housing due to decrease the environmental footprint and energy consumption. This research incorporates an analysis of earth sheltered houses in various climatic conditions by including the ecological potential of earth sheltered architecture such as building materials, daylighting and topography. The methodology of this research is applied through the comparison analysis via documents.

As a result, minimum environmental footprint, energy saving and natural landscape preservation are significant advantages of earth sheltered houses in order to promote the life quality with an approach to ecological architecture.

Keywords: Earth sheltered houses, ecological architecture, climate, daylight, building materials

ÖZ

Bu tezin amacı, sürdürülebirlik ve ekolojik bakış açısından değişik iklimlerde uygulanan toprak altındaki konutların potansiyelini, vurgulamaktır.

Dünyada şu an var olan ve yaşanan problemler insanların olumsuz yaşam tarzlarından ve aktiviterinden kaynaklanmaktadır.Örneğin yenilenebilir olmayan enerji kaynaklarının sınırsız şekilde tüketilmesi, çevre kirliliği, doğal peyzajın ve topoğrafyanın tüketilmesi olarak sıralanabilir. Bu bağlamda, konutların rölü diğer yapı türleri ile karşılaştırıldığında, yüksek enerji tüketimi ve çevre kirliği açısından daha belirgindir. Bu yüzden toprak altındaki konutların, çevresel etkiyi (çevresel ayak izi) ve enerji tüketimini aza indirmek için, yer üstü konutlara karşılık önemli bir konut alternatifi olarak vurgulanabilir.Bu araştırma; farklı iklim şartlarındaki toprak altı konutlarının ekolojik potansiyelini yapı konstrüksiyonu ve malzemelerini, günışığının kullanımını ve topoğrafya ya uyumunu belirgin kriterler olarak sınırlandırmak ve analiz etmektir. Değişik kaynaklarının karşılaştırılması ve irdelenmesi, araştırma metodu olarak kullanılmıştır.

Sonuç olarak, toprak altı evlerinin en önemli avantajları çevresel etkiyi (çevre ayak izi) en aza indirmesi, enerji tasarrufunu sağlaması ve peyzajı korumasıdır. Toprak altı evlerinin ekolojik mimarlığa yaklaşımı, yaşam kalitesinin korunması açısından önemli bir faktördür.

Anahtar Kelimeler: Toprak altı evler, ekolojik mimarlık, iklim, gün ışığı, yapı malzemeleri.

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TABLE OF CONTENTS

ABSTRACT iii

ÖZ iv

ACKNOWLEDGEMENT v

LIST OF TABLES viii

LIST OF FIGURES ix

1 INTRODUCTION 1

1.1 Research Problem 1

1.2 Research Objective and Questions 2

1.3 Research Methodology 3

1.4 Limitations and Scope 3

2 UNDERSTANDING EARTH SHELTERED HOUSING FROM THE PERSPECTIVE OF ECOLOGICAL ISSUES 4

2.1 Earth Sheltered Housing 4

2.1.1 Rocky Earth Sheltered Dwelling 4

2.1.2 Bermed Earth Shelter or the Shelter with Earth Mound 5

2.1.3 Underground Earth-Sheltered Construction 6

2.1.4 Historical Development of Earth Sheltered Housing 7

2.1.5 Contemporary Examples of Earth Sheltered Building 10

2.1.6 Advantages and Disadvantages of Earth Sheltered Housing 14

2.2 Ecological Issues in Architecture 17

2.2.1 Ecology 17

2.2.2 Inspiration from Nature in Architecture 18

2.2.3 Importance of Climate 20

2.2.4 Topography 24

2.2.5 Daylight Consideration 26

2.2.6 Building Materials and Construction 30

3 EVALUATION OF ECOLOGICAL CRITERIA FOR EARTH SHELTERED HOUSING IN DIFFERENT CLIMATES 36

3.1 Moderate Climate Zone 37

3.1.1 Integration into Topography 38

3.1.2 Daylight Consideration 39

3.1.3 Building Materials and Construction 41

3.2 Hot Humid Climate 43

3.2.1 Integration into Topography 44

3.2.2 Daylight Consideration 45

3.2.3 Building Materials and Construction 47

3.3 Cold Climate 49

3.3.1 Integration into Topography 51

3.3.2 Daylight Consideration 52

3.3.3 Building Materials and Construction 53

4 CONCLUSION 55

REFERENCES 61

LIST OF TABLES

Table 1: Advantage and disadvantage of earth sheltered building (Dronkelaar, C: 2013) 17

LIST OF FIGURES

Figure 1: Rocky earth sheltered structure 5

Figure 2: Prototypes of rocky earth sheltered dwelling 5

Figure 3: Earth mound structure 6

Figure 4: Underground earth sheltered structure 7

Figure 5: Three basic structures of underground earth shelter, (Ray G. Scott: 1979) . 7

Figure 6: Section of Cappadocia, (Urban, 1973) 9

Figure 7: Cappadocia, (Urban, 1973)... 9

Figure 8: The volcanic and smooth materials of Cappadocia,

http://www.geologyin.com/2014/12/cappadocia-fairy-chimneys-turkey.html............ 9

Figure 9: The rocky village of Kandovan, Iran.. 10

Figure 10: Sections of Kandovan 10

Figure 11: View of Earthship Brighton, https://en.wikipedia.org/wiki/Earthship..... 11

Figure 12: Edgeland House, Austin, Texas, USA,

http://www.homesgn.com/2013/19/edgeland-/ 12

Figure 13: The structure of Pit House in Native American architecture,

https://www.crowcanyon.org/ 12

Figure 14: Aloni House, http://www.dezeen.com/2010/09/17/aloni 13

Figure 15: Pachacamac House, http://www.homedsgn.com/2011/07/06/pachamac . 14

Figure 16: Villa Vals, Switzerland, http://openbuildings.com/buildings/villa-vals .. 14

Figure 17: Underground shelter of wild squirrel, https://baynature.org/articles/lord-of-the-burrows/.. 19

Figure 18: Inspiration from nature transferred to architecture, (Österlund. T: 2010) 20

Figure 19: Classification of main climate zones, (Bauer.M: 2007) 21

Figure 20: Effects of topography on earth sheltered housing, (Sterling.S:1980)....... 25

Figure 21: Daylighting,(Reffat.M:2004) 27

Figure 22: Natural light via atrium design and central yards,
www.inhabitat.com/office- 28

Figure 23: Circular design , courtyard(Ray G. Scott: 1979) 28

Figure 24: Section, (Ray G. Scott: 1979) 28

Figure 25: Environmental Effects of Recycling, (Thomas.R:1996) 31

Figure 26: Energy requirements of materials, (Thomas.R:1996) 32

Figure 27: Section of Earthship, (Simmons.C:2010) 39

Figure 28: Sections, Edgeland House,
http://www.homesgn.com/2013/19/edgeland-/ 39

Figure 29: Site plan, plan, Edgeland House,
http://www.homesgn.com/2013/19/edgeland-/ 39

Figure 30: Sun pipe in Earthship, http://www.lowenergyhouse.com/ 40

Figure 31: Daylight considering, Edgeland house,
http://www.homesgn.com/2013/19/edgeland-/ 41

Figure 32: Building materials, Earthship Brighton 42

Figure 33: Building materials, Edgeland house 43

Figure 34: Aloni House, http://www.dezeen.com/2010/09/17/aloni 44

Figure 35: Pachacamac House, http://www.homedsgn.com/2011/07/06/pachamac . 44

Figure 36: Site plan, Aloni house, http://www.dezeen.com/2010/09/17/aloni 45

Figure 37: Site plan, Pachacamac house,
http://www.homedsgn.com/2011/07/06/pachamac 45

Figure 38: Daylight consideration through courtyards of Aloni House,
http://www.dezeen.com/2010/09/17/aloni 45

Figure 39: Natural lighting of Pachacamac House,
http://www.homedsgn.com/2011/07/06/pachamac 46
Figure 40: Low impact materials, Aloni House 48
Figure 41: Building materials, Pachacamac House.. 48
Figure 42: Volcanic rock, tezontle and to rubble or pebbles,
http://openbuildings.com/buildings/villa-vals.. 49
Figure 43: South facing of rocky earth sheltered house,
http://openbuildings.com/buildings/villa-vals.. 50
Figure 44: 3D models of Villa Vals, cold climate 51
Figure 45: The entrance of Villa Vals,http://openbuildings.com/buildings/villa 51
Figure 46: Natural lighting, Villa Vals, http://openbuildings.com/buildings/villa 52
Figure 47: Building materials, Villa Vals 54

Chapter 1

INTRODUCTION

Earth sheltered architecture has it roots embedded in prehistoric times up to the present. Going underground and the utilization of caves as living spaces by early man covered a long part of mankind history. Throughout the history, mankind tried to prepare the needs of their tribes by using the earth in their construction in order to achieve healthy and safe spaces such as protection against the harsh climate and wild animals.

During that time, different countries of the world developed building constructions, details and techniques to adopt to the climatic conditions. Striking examples of these can be found in local architectural styles like the examples in Cappadocia in Turkey, Setenil de las Bodegas in Spain, Nooshabad, Kariz, Meymand in Iran and Coober Pedy in Australia which can set out examples for contemporary sustainable design.

1.1 Research Problem

Environmental pollution, the fragility of current ecosystems, the loss of green spaces and growing degradation of the landscape and nature, decreasing rapidly of land-surface resources and non- renewable energy sources and in a word, disregarding to the earth as a mother of nature are the negative accumulated impacts of human' s activity on the planet during this era. As the world today faces the problem of energy crisis, ecological architecture becomes more and more interested recently. Architects try to design ecological buildings together with high quality but with lower energy consumption. Currently, contemporary buildings are major sources of energy consumption and environmental pollution particularly in the residential buildings which contribute to unpredictable and disastrous climate change. Earth sheltered buildings have good performance in different climates but in contemporary architecture we cannot apply in efficient way. The level of energy consumption for heating and cooling demand is very high in conventional buildings for the maintenance of thermal comfort in interior spaces in comparison to earth sheltered houses.

1.2 Research Objective and Questions

In the recent years, the attention to ecological housing exemplified the use of earth-sheltered housing with an approach to sustainable holistic are known comprehensively as an essential solution for resolving the mentioned problems which were often neglected by the technology in the modern age. The main objective of this research consists of ecological criteria of earth sheltered architecture with innovative design in order to achieve thermal comfort and environmental sustainability.

- What is an earth sheltered house?
- What are the most significant ecological criteria for earth sheltered buildings?
- How can we achieve earth sheltered buildings according to these criteria in different climates?

As a result, there is no doubt that the earth sheltered architecture is pointed out as an alternative to non-earth sheltered and conventional above ground housing due to more effectively control of housing relationship with its surrounding landscape and environment. By respecting the natural topography, ecology and local materials the self-sustaining of new buildings and their ecological adaptation are possible to develop a new generation of smart and green buildings. The consideration of earth sheltered architecture and the influence of ecological factors can be identified as a positive step. Nowadays, this ecological architecture has become an advanced trend after energy crisis (1973) and after environmental protection discussion.

1.3 Research Methodology

The methodology of this thesis will be applied through the analytic comparison via literature research. Thus, this thesis will investigate selected five awarded earth-sheltered housing ones as case studies across a variety of traditional and contemporary examples in order to analyze their potential of ecological criteria such as harmony with the landscape and environment, building constructions and daylighting.

1.4 Limitations and Scope

Earth sheltered housing has accomplished through the ecological principles such as topography, building material and daylighting in different climates except hot and dry climate.

Chapter 2

UNDERSTANDING EARTH SHELTERED HOUSING FROM THE PERSPECTIVE OF ECOLOGICAL ISSUES

2.1 Earth Sheltered Housing

Earth sheltered houses have unique peculiarities which sometimes banked on one or more sides by the earth where the northern façade and roofs are covered and southern side are open to the sun for absorbing the solar energy . Thus, the degree of houses may vary in which the structure is covered partially or entirely below the surface of the earth.

The construction of earth sheltered dwellings is considered as energy conservation especially in the recent years of energy crisis. In the realm of energy efficiency, the typology of these constructions is different which depends on climatic condition of each region. For this reason, the classifications of earth-sheltered constructions consist of three major approaches to earth sheltered housing: rocky earth-sheltered construction, true underground earth-sheltered construction (chambered) and construction with earth bermed or banked.

2.1.1 Rocky Earth Sheltered Dwelling

In this type, the whole structure is excavated in the mountains or downhill. The orientation is toward the southern portions due to absorb the maximum solar energy. (Wendt.L: 1982). (Fig 1)

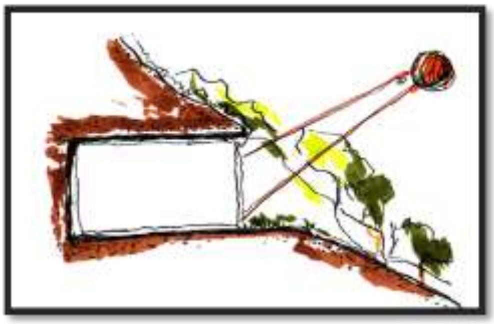


Figure 1 : Rocky earth sheltered structure

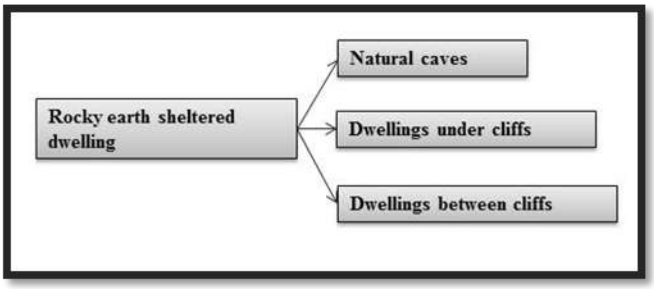


Figure 2: Prototypes of rocky earth sheltered dwelling

This prototype provides a strong shelter which integrated the natural rocks without other materials for unsuitable climatic condition. It acts as a protection against the earthquake. Because of the stone shape and natural features of this construction, internal temperature has a constant range .In fact, very little temperature fluctuation inside the conic structure provides a warm indoor temperature in comparison to outside during the winter and conversely during the summer. Thus, this structure can be considered as an appropriate insulator and energy preservation factors.

2.1.2 Bermed Earth Shelter or the Shelter with Earth Mound

The soil and ground is piled up against the outer walls of the house. The soil compact configuration of bermed earth sheltered housing is surrounded by the shaped external walls and the entire ceiling is covered completely or partial soil. (Fig 3) Proper orientation of the earth shelter by respecting the sun path and wind direction should be acted significantly towards energy efficiency.


Figure 3: Earth mound structure

In general, the construction of the bermed houses is constructed above grade or partly undergrade (close to original grade) and the side walls are mound or bermed to the ground. Typically, by covering the earth on top of the house as a roof, this construction is formed. The southern elevation is exposed to the open-air due to provide natural light and access onto the grade. (Roy.R: 1994)

2.1.3 Underground Earth-Sheltered Construction

In the underground earth sheltered construction, the house is fully excavated under the earth in which the main spaces are situated around a central courtyard in form of pit-shaped garden or atrium for natural light, ventilation, solar heat and views on the flat site. (Wendt: 1982).In this earth shelter dwelling, the abundant daylight and solar energy could be received through the central courtyard, roof aperture, the below ground atrium and also the horizontal channels or shafts which are constructed in the ground piles around the space. (Brown and Decky: 2008)The advantages of thermal mass of the earth are the main factor of this structure. Hence, this construction type is considered as an important sector in the realm of green and sustainable building movement, low-impact design, eco-home ideal and harmony with its environmental surroundings particularly in the recent years.

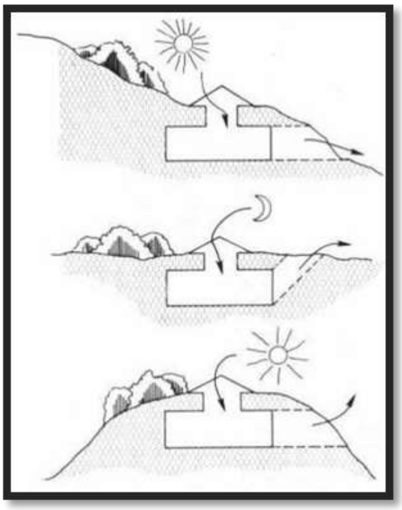
 

Figure 4: Underground earth sheltered structure Figure 5: Three basic structures of underground earth shelter, (Ray G. Scott: 1979)

In figure 5, there are three types of underground earth sheltered houses. The first one is located in a slope site with skylight and southern facing, the second one is located in a flat site with atrium design and the last one is in hill side with atrium design .In all of them atrium design has a significant role for using passive solar energy together with daylight.

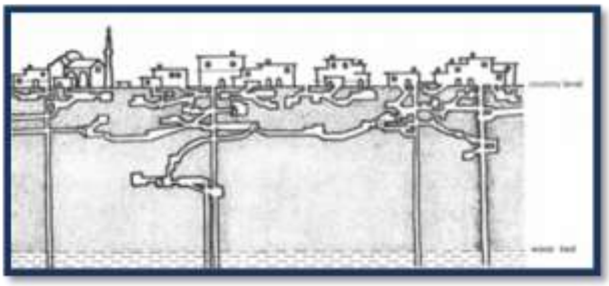
2.1.4 Historical Development of Earth Sheltered Housing

From the beginning of mankind, human tried to dig the earth due to act the various activities such as quarries for extracting the required materials, religious rites, protection against the wild animals and also military defense , the habitation for living and transportation. Earth construction techniques dated back to more than9000 years ago. The most utilization of mankind from the earth dated back to prepare dwellings and materials of shelters due to protect themselves against hazards and unsuitable climatic condition. In this context, numerous types of earth shelters were developed such as cliff dwellings, bermed earth houses and caverns from millennia ago in which the caves were the first and primary shelter for human living. During the dark ages, mankind turned to dig the earth for creating defense shelters. In the

19th century, quarries were developed for extracting the essential materials in the form of underground tunnels then these structures were used for other purpose such as store rooms or military activities. (Jannadi, M: 1998) Although several caves' structure has been used for living since along times before like the rocky earth sheltered of Kandovan in Iran.

After the arrival of industrial revolution, people's interest toward these structures has more increased because of the wide benefits of the earth sheltered houses such as energy preservation and eco-friendliness. Hence, during the years of 1972, pioneering and professional architects such as Philip Johnson, Frank Lloyd Wright and Malcom Wells tried to change the architectural styles toward the greenery and energy efficiency of architecture in which the two items of environment and ecology have become the principles of their design. Since then, many earth sheltered houses have been constructed, as examples in USA; approximately 5,000 earth sheltered houses have been fulfilled in 1985.During the recent years revise consideration to these structures have been increased because of the significant impact in both environmentally and visually. (Jannadi, M: 1998) Earth has been considered as a significant factor for architectural design in various climatic conditions. According to local climatic condition, vernacular architecture has been developed throughout the world due to provide comfortable living spaces.

Cappadocia in Turkey which is located in mountainous climate consists of cliff settlements such as rocky buildings, cone villages, underground dwellings and towns with redoubts and hydraulic tunnels. It is considered as a complex structure which is combined both as underground and rocky sheltered structures. Environmental reasons of cliff dwellings have a significant value in comparison to conventional buildings. The volcanic and smooth material with the natural and high potential of thermoregulation of the ground regarding to climatic behavior led to create a convenient shelter for the users. Stable indoor temperatures which are approximately between 12 to 15 degrees Celsius during the cold weather of winter season and dry summer season provides the thermal comfort for residents. (Stea and Turan, 1993)



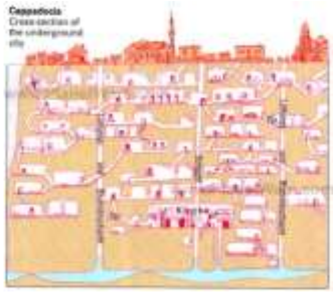


Figure 6: Section of Cappadocia, (Urban, 1973) Figure 7: Cappadocia, (Urban, 1973)

Figure 8: The volcanic and smooth materials of Cappadocia

The village of Kandovan in Iran is another example of rocky construction in conditional climatic zone. The features of Kandovan are like Cappadocia the thermal insulation, constant fluctuation of indoor temperatures and easily usage of stone as main building material for excavating. In the past, the volcanic melted stone and lavas of Sahand Mountain have formed the landscape by means of the natural forces such as wind, snow, storm and rain. Then the hard part of this structure gradually has been changed to current shapes. (Ghobadian.V: 2003)

Figure 9: The rocky village of Kandovan, Iran

Figure 10: Sections of Kandovan

Generally, the human adaptation to this unusual cone formations and natural surroundings can be considered as sustainable construction related to energy efficiency.

2.1.5 Contemporary Examples of Earth Sheltered Building

The underground spaces and earth sheltered architecture has become the significant value in recent years particularly after the energy crisis of 1970 and environmental pollution. According to the historical background of earth sheltered structures, the feature's utilization of them during the design process can be useful as a sustainable solution in contemporary era. The shortage of open and greenery spaces, high energy consumption, high density of conventional building and the negative footprints of above ground structure led to revise consideration toward the underground spaces as a valuable source in architectural design. In this trend, the function of subterranean structures move to various activities such as religious, residential, commercials, transportation, parking and so on. The underground structures have the great potentials for improving the urban environment and enhancing the human life via providing more greenery spaces, environmentally friendly construction and decreasing the energy consumption. As an example in several driest cities in Australia, a remarkable percentage of residential buildings buried into the earth due to avoid the hottest weather like White cliffs, Andamoka and Burra.(J.Karmody:1993) Unfortunately, after the 1980 this trend had the dramatic reduction. Nowadays, revise consideration to this vernacular and earth sheltered architecture lead to design the self-sustaining and environmentally friendly houses in various climatic conditions throughout the world. Earthship Brighton is one the prominent projects of eco houses and a well-known earth sheltered house in moderate climate which is inspired to respond the climate change in England between the years 2003 to 2006. This eco house is designed by Sustainable Community Center and Low Carbon Network and is located in Stanmer Park.

Figure 11: View of Earthship Brighton

Earthship construction is a type of heavyweight and low impact ecological construction with a pioneering design and technics which has been developed by the American architect Michael Reynolds since 1970′ s and recently stated as a successful prototype of low cost eco-housing in UK . The concept of 'Earthship' derived from the independent vessel which acts as a self-sufficient and autonomous structure and the materials consist of reuse, natural and reclaimed ingredient particularly reclaimed glass bottles and car tires (Raynolds. M: 1999). Living ecologically is a significant feature of Earthship Brighton. This low impact building demonstrates that how people can utilize the micro-renewable technologies such as wind, solar energy and biomass, how they can eliminate the most damaging materials, how to construct the self-sustaining building without compromising the quality and how to respect the surrounding environment and landscape.

Edgeland House is another successful example of ecological house in moderate climate which is located in Austin, Texas, USA by Thomas Bercy (architect) in 2012. The design of the house has been derived from native American Pit house from one of the ancient vernacular housing typologies which is dated back to the Upper Paleolithic era. The Pit House or sunken residence is a simple semi-subterranean dwelling with a round or rectangular form which is excavated into the earth with low walls and roof is chinked with mud and grass. All of them are covered with earth mound and are well adapted to the local climatic conditions. This construction type is fulfilling the heating demand in winter and cooling demand in summer. The construction takes the advantage of the earth's thermal mass due to achieve thermal comfort and is integrated into the surrounding environment.

Figure 12: Edgeland House, Austin, Texas, USA

Figure 13: The structure of Pit House in Native American architecture

Aloni house is another earth sheltered house type in hot and humid climate which is magnificently blended by their natural surroundings and it is nearly an underground construction. It is located on the Cycladic island of Antiparos, Greece with coastal views and without disrupting the landscape. Deca architecture (architectural company) designed the whole underground summer house regarding to ambivalentrepercussion to the particular topography and landscape of the site, climatic condition such as hot summer and also the traditional and rural construction and techniques in 2008. This construction type is inspired from traditional method. This typology derives from ancient Greek time which is dated back to the agricultural usage of dry-rubble stone. The retaining walls as a basic rural quality is developed due to shape the plane terraces towards the downhill. Therefore, the incorporation of this traditional feature of agriculture protects the land from erosion and provides an appropriate land for farming. The retaining wall from earth with contemporary design creates an ecological house design.

Figure 14: Aloni House

Pachacamac House is located in south of Lima, Peru with hot and humid climate. This subterranean house is buried into the slope of the hill surrounded by mountains in rural area with lack of electricity and water. This ecological house is designed by Longhi architects between the years 2006-2008. Creating the balance between landscape and architecture was the initial concept of the house. The construction of the house is inspired from the ancient Peruvian tradition (Aztec people).

Figure 15: Pachacamac House

Figure 16: Villa Vals, Switzerland

Villa Vals is a rocky earth shelter house in the slope of Alps, Switzerland. This fully underground house was designed by SeARCH (CMA) in 2009. The original concept of the house was to integrate it into the landscape and to provide thermal comfort. It is a successful example of earth sheltered house in cold climatic condition.

2.1.6 Advantages and Disadvantages of Earth Sheltered Housing

The significant feature of earth sheltered house is that the earth can be used as a natural high thermal mass. The thermal mass of a structure is the combination of the density and quantity of the building materials. The thermal mass has a certain ability to store the heat. When there is a thermal mass in the building, it can absorb the heat from the air or from direct solar radiation. After the storage period, the thermal mass can release the heat back to the air during the night. In an earth sheltered house, the process can be slow enough to keep the house in a comfortable thermal condition for hours without the heating or cooling. In conventional houses, in contrast, very little excess heat can be used and when the heat source is over, the heat will rapidly go away. The important benefit of earth sheltered architecture is related to energy saving through decreasing the cooling and heating loads compared with conventional structures. According to Behr, earth sheltered architecture has a high potentiality of energy efficiency rather than above-grade counterparts. (Behr.R.A:1982) The soil enclosing earth sheltered structures have the potentiality for lessening the heating and cooling energy demands of a building through reducing the heat transfer. In addition, the stable fluctuation of soil temperature creates a constant internal temperature during the year which includes 14 to 18 centigrade. Therefore, the interior spaces have a mild temperature in summer and winter seasons. Another merit related to maintain the natural landscape together with flora and fauna species and increases more greenery spaces. The soil existence on top of roof leads to create a green roof and additional green spaces for the house. Minimal visual impact by designing an earth shelter preserves the sensitive sites quality in which the encroachment of construction may be considered as unpleasant. Another feature is about vibration and noise or noise pollution which has a minimum effect on residents in earth-sheltered buildings in comparison to aboveground neighbors. In other word, a quieter environment is a significant feature of earth sheltered building for occupants. (Bligh.T: 1975) The upkeep and maintenance of earth sheltered building is very less than conventional buildings. The exterior building envelope of earth shelter is enclosed by the earth mass so earth-contact components of the house are preserved against the various climatic elements such as rain, freezing, wind, hail and other natural reasons. For instance, ultraviolet solar radiation fades and discolors the exterior painting of conventional building. As mentioned before, stable fluctuation of earth temperature is the significant feature which leads to decrease the contraction and expansion of building materials so thermal cracks will be minimized. (Lippsmeier.G: 1969) The percentage of safety environment in earth sheltered houses is more than above grade building against the naturally occurring disasters such as lightning strike, high winds, storm and collapse or falling in an earthquake. Because the reinforced structure of mentioned building covered and enclosed by the earth which creates maximum protection against natural disasters. (Baggs.S: 1991) The structure of earth sheltered house is more superior to conventional residence. As the ground moves, hence does the earth sheltered house. On the other hand, above ground home crumbles. Better fire-retardant of earth sheltered house is another benefit of this construction. Corporation of the earth with the reinforced concrete presents the well fire resistance. Environmental friendly behavior of these kinds of houses because of the ground as a local material is another advantage of them. By regarding to these advantages of autonomous earth sheltered houses and enjoying dual land use, energy reduction and the best integration into the topography are achievable in diverse climatic conditions whereby the magnitude encompass the combination of various and innovative design elements. Thereby, revise consideration to this kind of structure is necessary as a prominent issue in sustainable approach. Despite their environmentally friendly, energy efficiency and other advantages, earth sheltered architecture has some disadvantages and limitations. The important disadvantage of this structure is that this kind of houses are built in rural area and it is not possible to build in urban area, so it is necessary to find a way to move earth sheltered houses in urban part. The cost of excavation in earth sheltered buildings is higher than conventional buildings and need more equipment. Moreover, water drainage has more priority in underground structure in comparison to above grade buildings which increases the cost. Earth sheltered houses need most ventilation in comparison to conventional ones, so ventilation system is an essential demand of earth sheltered housing. Humidity is another disadvantage of earth shelter which needs more waterproof materials compared with above grade building. The shortage of appropriate site is another disadvantage of these structures in order to excavate the site for construction.

Table 1: Advantage and disadvantage of earth sheltered building (Dronkelaar, C: 2013)

ISSUES	CATEGORY	POTENTIAL BENEFITS	POTENTIAL DRAWBACKS
PSYCHOLOGICAL & PHYSIOLOGICAL	PSYCHOLOGICAL	Relief from severe climate (coolness in hot-climates)	Lack of spatial orientation Negative psychological reactions association death and burial, claustrophobia, fear of collapse/entrapment Lack of public acceptance
	PHYSIOLOGICAL	Isolation from surface noise and vibration Stable indoor temperatures	Excessive noise or lack of noise Lack of fresh air/indoor air pollution High humidity/condensation Lack of natural daylight and view Higher radon concentration Requirement for openings
ENERGY	ENERGY USE	Reduction conduction Heat storage capacity Stability ground temperatures Control on air infiltration Reduction of heat gain	Impact ventilation rate Slow response Lack of useful ground temperatures Heating/cooling compromises Lack of available data on the energy performance
LAND USE AND LOCATION	PROTECTION	Provide security limited access Fire protection Protection from severe climate Protection from natural disasters	Degradation underground environment
	LOCATION	Visual impact Preservation of surface space Lack of surface space Preservation of natural vegetation scenery/ecology Efficient use of scarce land	Aesthetics skillful design, building services Uncertain geology Unfavorable geology
	LAYOUT	Topographic freedom	Access limitations Sewage removal Water problems Adaptability
LIFE CYCLE COSTS	INITIAL COST	No need of external cladding Land cost savings No structural support. Weather independent	Increased structural cost requirements Ground excavation Cost uncertainty Confined work conditions Ground support
	OPERATING COST	Reduced maintenance Building and building material durability Energy use Insurance	Personnel access Ventilation and lighting

2.2 Ecological Issues in Architecture

2.2.1 Ecology

Ecology is defined as a relationship among the animals, plants and their hosting environment .It is considered as a privileged model in sustainable design because of the excellent connectivity, circulation of energy and materials between environment and organism. Earth includes wide variety of complex ecosystems which covers the living organisms. (Williams.D:2007) These ecosystems consist of different forms with hierarchical orders which capture and utilize energy resources and materials. The function of mentioned ecosystems is adaptation and combination of nature's processes. (Hoeller .N: 2007) Ecology is derived from the interactions and relationship between the natural environments with the living organisms or living systems. He believed that ecology can be studied in different levels such as individual organism to ecosystems or the entire biosphere. (Österlund,T: 2010). Exploring and understanding the relationship and interaction of various species of fauna and flora in the ecosystem help the architects to design more adaptable buildings which will be in harmony with nature or a building as an integrated component of environment which has less ecological damage. (Van der Ryn and Cowan: 1996)

2.2.2 Inspiration from Nature in Architecture

From millennia ago, caves were used frequently by human and animals as a shelter (Deffontaines.P: 1972). Human has always tried to analysis the nature such as animal's life and plants discovered the natural shelter and caves of animals. They observed the way of preparing shelters by animals like ants and birds in order to find the useful patterns of dwelling's construction and protection against the wild animals, natural disaster and harsh climate. As an example, a wild squirrel excavates the earth to prepare suitable shelter and to escape from unsuitable climatic condition. It has a nomadic life under the earth which lives in depth in winter season and then moves to top layers close to the surface area in summer season.(Terrin. J: 2008).

Figure 17: Underground shelter of wild squirrel

Therefore, these natural lives could obviously help the prehistoric mankind to build their shelters without the specific instruments. After a time, with the knowledge of mankind from natural surroundings, bioclimatic life and the suitable layers of the soil help to develop the best position of living, excavating the appropriate earth layers and the best quality of the ground for constructing the shelters. These earth layers were stronger than the soil and smoother than the stone. They have a strong resistance during the excavation alongside with the thermal mass. In other word, these subterranean shelters have a constant temperature to provide thermal comfort for habitants. Humans were preserved from hot and dry summer and cold winter and protected from wild animals. Sustainable design follows the nature as a main source of its concept. The natural forms are adaptable ones which can be used in architectural idiom and design because their morphology and metamorphoses resulted from the nature's infliction. Inspiration from these natural forms of nature leads to design more adaptable building to the local climatic conditions. Therefore, ecology can be considered as a significant element of sustainable living due to reduce the negative human impact on environment. By combining the ecology and their natural forces with the process of architectural design, architectural world can achieve a new generation of green architecture with respecting to the nature and the decrease of harmful footprint of human activities (Österlund. T: 2010).

Figure 18: Inspiration from nature transferred to architecture, (Österlund. T: 2010)

Aldo Leopold (1948)which is one the famous American ecologist believes that unfortunately people do not understand the philosophy of nature in order to create the harmonious environment. Therefore this issue leads to the increase of many ecological problems in various fields such as cities, houses and energy. As a term, the purpose of ecological design is establishing the civilization with consideration of natural environment protection and resources such as biodiversity, none renewable energy sources, forest and landscape alongside with expanding the local economies toward sustainability and removing the negative impacts of human activities on theplanet.(Orr. D: 1992) A successful sustainable design derives from harmony and incorporation of architecture with the environment and ecology.

2.2.3 Importance of Climate

From many millennia ago, building adaptation to prevailing local climatic conditions has been considered significantly during the design and constructions process particularly in housing design. From sustainable design point of view in order to create ecological buildings ,thermal comfort and energy efficiency have the priority in climatic adaptation .

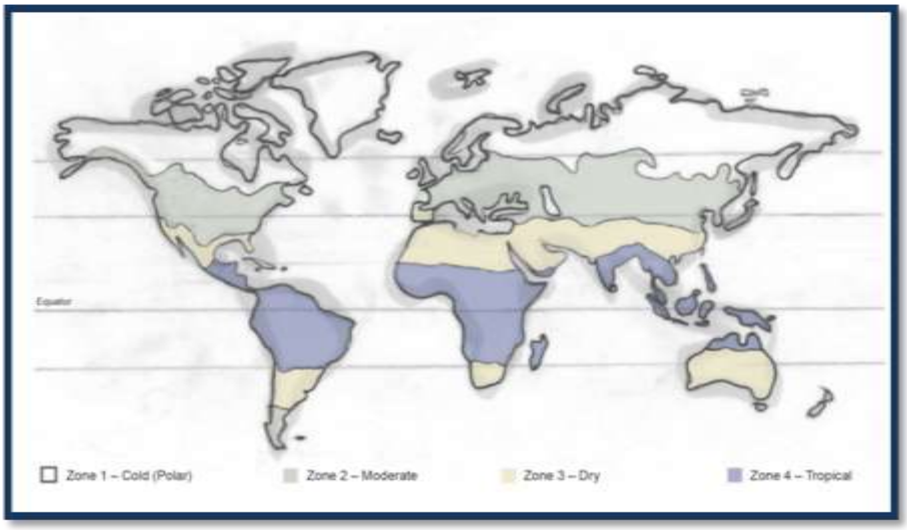


Figure 19: Classification of main climate zones, (Bauer.M: 2007)

According to the above figure; four main climatic zones are considered in regarding to local and regional climatic conditions. In this context, solar radiation, air humidity, daylight, temperature fluctuation, wind direction and annual amount precipitation supposed to have remarkable importance for the building design. From climatic point of view, the net impacts of beneficial microclimate like solar gain, wind and daylight in consideration with the hierarchy of the buildings (arranging spaces in a correct position) for natural ventilation, naturallighting, cooling and heating provide warmer spaces in winter and cooler spaces in summer (Thomas.R: 1996).

In order to protect against the unsuitable weather in hot arid climatic condition, going to earth is the best natural solution for escaping from the warm and hot weather besides the sun glare and more solar radiation. Furthermore, burring into the earth is suitable way in cold climatic condition because of using the thermal mass of the soil for having the comfortable spaces . Moderate climate zone enjoys more precipitation with warm not hot weather together with mild winter. The earth shelter in this region located in north to south and the whole part of the southern façade is covered with large windows for capturing solar energy .Utilization of courtyard and greenhouse can help the shelter for protecting the house against sun glare. Green roof is a significant feature of earth shelter in this region which acts as a roof insulation with high thermal performance as well as more harmony to surrounding environment. Allocating the courtyard helps the earth shelter for both lighting and ventilation. Mud and natural clay, timber and local stone are the major materials of the house for this climate.

The important feature of hot and humid climate is an extremely high temperature during the day with the greatest amount of sun radiation together with little or no precipitation in different seasons. Hence, the maximum energy demand for this zone is providing the cool temperature together with ventilation in sunny and hot days. Protecting the house against the intense radiation as well as providing human comfort and health is the primary needs of this region. This daily maximum temperature can be destructive for the materials of the building because of contraction and expansion during the day for the exposed surfaces. Hence, earthshelter is a proper solution for this area. (Al-Temeemi, A: 2004) First step is enclosing the house by soil or burring into the earth in order to escape from maximum solar radiation. Earth provides the comfortable indoor temperature in comparison to surface. Utilization of materials with high thermal capacity is not suitable for this era. Therefore, wood, straw bales and soil are the best ones because the heat loss in wood is very slow as well as heat transfer. A central courtyard is the significant feature of the earth shelter which can provide both lighting and ventilation for the house. Another feature is the orientation of earth shelter. Locating the earth shelter in west to east axes is the best position due to escape from extreme solar radiation while in cold climate exposing the house to the south is the best for capturing solar energy. Allocating the openings in the depth in order to protect the habitant from sun glare is another strategy of earth shelter. The height of ceiling is more than other zones because the heat transfers to the up so the cold temperature moves to down. By allocating windows near or in the ceiling, the mentioned heat transfers to outer spaces. Green roof is another advantage of earth shelter which can moderate the indoor temperature.

The climate of cold region is characterized by cold and long winter together with mild and short summer. Seasonal temperature of winter is varying from 3° to -40˚C so the essential energy demand is from heating. The energy consumption will be reduced by enclosing the house with soil or earth sheltered structure because of constant fluctuation of earth temperature which leads to provide mild internal temperature for occupants. In the region with cold climate, the rate of heat loss in earth sheltered structure is very little in comparison to the above ground buildings. The results of many experiments improved that underground structure has a low fluctuation of internal temperature. Because of the minimum heat loss of earthsheltered components to the earth and passive heat supply of the earth, this structure is considered as a factor for energy conservation in extreme cold climate.(Kumar .R :2007)The entire or some part of the house is buried into the earth and the openings are oriented to the south for capturing passive solar energy so southern façade is covered with large windows. Green roof is another feature of earth sheltered housing in this region which acts as an insulated blanket due to preserve the internal temperature of the house. The rocky structure or stone is the best material for this climate because of high insulation and proper potential of thermal capacity which preserve the heat for indoor spaces. Wood and clay together with the heavy mass of concrete are other materials of this region.

2.2.4 Topography

The site planning for an earth sheltered building is an integral part of the design. Topography plays a significant role for house construction. In other word, different topography forms with even the smallest changes lead to create remarkable effects on wind and temperature as well as water direction runoff around the building. (Sterling.S:1980). Local topography can present flat land or differently oriented slopes. Topography is an important factor which can influence the applicability of earth-sheltered houses. Unlike climate, topography tends to impact on a micro or site-specific scale. Slopes can change dramatically in short distances, and this fact precludes drawing any regional conclusions. However, if a region has many steeply sloped ridges running in a northeast/southwest direction, it may offer the opportunity for some ideal earth-sheltered building sites.

In the flat site the design is limited to one level under the surface mainly or in some part include the levels earth sheltered houses as single units while the steep sites takethe advantages of situating the dwelling into the side hill. In this context, determination of opening's orientation is depending on the direction of slope. Predominantly, the southern side of the hill is the best position to compromise of absorption of maximum passive solar energy. Thus, exposing the house to the south is the best way of designing the earth sheltered dwellings .(Sterling.S:1980) The topography of the site will affect wind flow and drainage patterns, and will determine how easily the building can be surrounded by earth. A modest slope requires more excavation than a steep one, and a flat site is the most demanding, needing extensive excavation. Buildings on flat ground are bermed more easily onone or more sides. Berming is the practice of banking earth up against the walls of the building.

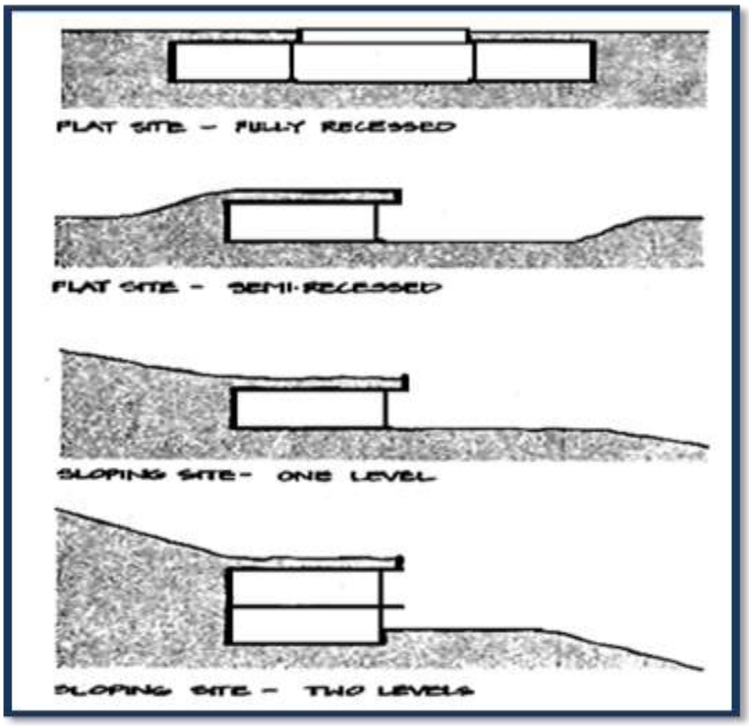


Figure 20: Effects of topography on earth sheltered housing, (Sterling.S:1980)

South-facing slopes can be utilized effectively to make the earth-sheltered house a passive solar structure. North-facing slopes may be beneficial in areas where the need to cool the structure is dominant. East- and west-facing slopes, in general, should be avoided since they offer little winter passive solar heating benefit and can be significant summertime liabilities. In general, single exposure elevational designs, particularly appropriate for colder climates, group all windows and openings on a single exposed elevation, preferably facing south in colder climates and north in hot climates, leaving the three remaining sides buried in the earth. When an earth-sheltered building is constructed on sloping area, the at-grade scheme has more advantageous since water drains in natural way, and it is easy access for residents, view and light. If the structure built on a southern slope, near to 100 percent passive solar energy is conceivable because of both the minimum heat loss and maximum thermal capacity of the earth. (Lechner. N: 2001) On the flat site, earth can be raised up to protect a house that is built above grade. This form is suitable for hot and dry climates in which daily time lag is very helpful. Plants growing on the earth shelter roof can help the shelter to provide a mild indoor temperature during cold winter and hot summer. By shading and evaporating, green roof can cool the earth in summer while in winter it acts as a blanket to preserve the internal heat temperature. For moderate climate, both sloppy and flat sites are appropriate due to construct the earth sheltered house. All of the earth sheltered buildings are blended into the earth due to utilize the thermal mass of the earth together with more harmony into surrounding environment. Protecting of natural landscape, preserving of local eco-system and minimalintervention of topography are some advantages of going underground .Hence, Earth sheltering makes good environmental sense too. Building into a hillside or below the earth’s surface preserves an attractive landscape while still allowing access to natural light. Green roof is an important ecological feature of all case studies due to integrate into landscape as well as act as super insulation.

2.2.5 Daylight Consideration

Daylighting is the practice of bringing light into a building interior and distributing it in a way that provides more desirable and better-quality illumination than artificial light sources. When a house is built almost entirely underground, the first consideration is to provide natural light and passive solar heat to the living and sleeping spaces. An exposed, glazed, south-facing wall is an excellent approach. This approach can be modified by building a greenhouse along the south wall. In either case, the floor plan is arranged so that the main living spaces share light and heat from the southern exposure. Another approach is the central atrium, allowing for a floor plan that surrounds an outdoor space on three or four sides in order to capture passive solar energy and matural daylighting. The southern exposure orients the front wall, usually containing a lot of window space, to strong sunlight which fills the upper level of the house. The sunlight can also drive solar-heating units to warm the building. The four basic types of daylight apertures are windows, skylights, roof monitors, and clerestories as shown in below figure which can be used for earth sheltered building . Skylights, roof monitors, and clerestories tend to be more effective than windows because their high location in a building affords penetration of light into the building core.

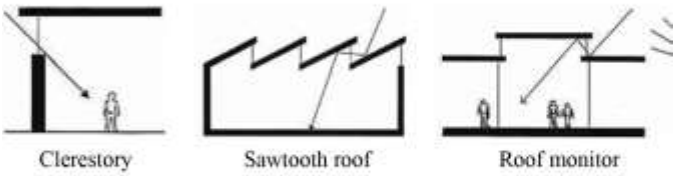


Figure 21: Daylighting,(Reffat.M:2004)

The main reason of utilizing the natural light is related to energy consumption by decreasing the utilization of artificial light. The building orientation and the opening orientation have great impact on receiving the natural light into the internal spaces. The lighting quality depends on window orientation particularly to the southern side. The skylights of earth sheltered constructions play a significant role especially for the shelter which is completely buried into the earth. In atrium design, daylight penetrating is more accessible from the roof. In addition, central courtyard is another natural element which can increase the natural light in the interior spaces. The arrangement of spaces around the central courtyard or sunken garden and atrium provide the proper access of natural daylight alongside with absorbing the passive solar energy due to create bright spaces and better-quality illumination even under the surface in a circular design. Skylights are also necessary for the house via covering the roof of internal spaces or indoor garden. (Ray G. Scott: 1979).Moreover, outdoor view is possible through the central yard. According to

Abraham, between 40 to 50 % of energy consumption is related to lighting of interior spaces for this reason the utilization of natural light can significantly reduce the energy consumption (Abraham. L: 1996).By preparing the windows to south orientation, earth shelter can benefit more from solar radiation alongside with receiving abundant natural light.

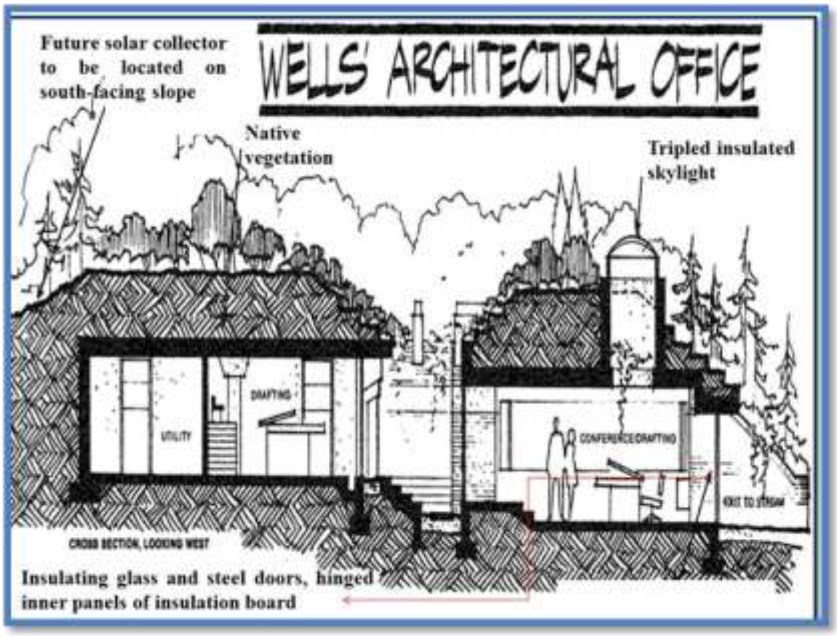
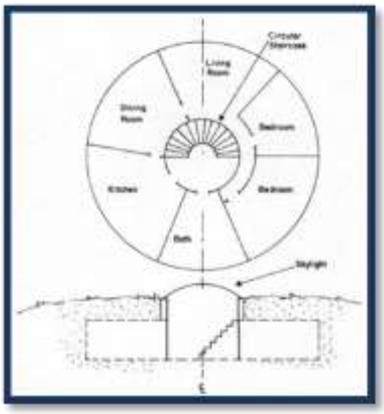


Figure 22: Natural light via atrium design and central yards



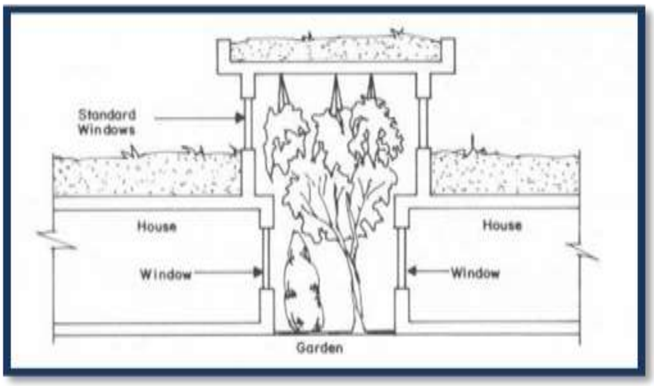


Figure 23: Circular design , courtyard(Ray G. Scott: 1979) Figure 24: Section, (Ray G. Scott: 1979)

The mentioned windows, skylight from atrium and sunken garden can bring the natural landscape with predominant topography into the internal spaces. Hence, the underground construction doesn’t face a limitation of nature in indoor environment. In addition, in some places the surrounding environment has undesirable view. This burring into the earth and creating small microclimate with private natural landscapelead to provide clear and calm exterior view for habitants without consideration to the ugly outer aboveground construction. The mentioned designs lead to peneterate more natural light into the internal spaces.Moreover, some techniques are used to promote the light quality for drawing daylight in eartsheltered buildings.For instace, sunpipe is used as a natural daylight system which directs the sunlight into the interior spaces from roof level.This system collects daylight through a diamond dome at ceiling then transfer it via aluminium tube (silverised mirror-finished) into the room.Another technique is utilizing the large expanses of windows in different forms such as triangular courtyard in vertical position in order to transmit sunlight or a glass box in front of a Pachacamac House. Other schemes is utilization of vertical shaft to transfer the daylight into the underground structure through a long and angled mirrors of shaft in top and bottom of it which provide a wide periscope.Utilization of daylight monitor is another technique to transfer the natural light for internal spaces. Daylight monitor includes the sloping glass pannels with south orientation on rooftop boxes for capturing maximum amount of daylight which collects and stores natural light during the day and use it at night.

In cold climate, the big opening of the window with south facing can keep the cave bright enough by letting as much as possible the natural light in. When the depth of the cave is big, the further area may be suffering from the darkness if the window on the façade is not big enough.For this situation, skylight can help the earth sheltered house for having more natural lightings.In moderate climate , the window with south facing are necessary due to capture passive solar energy as well as natural daylighting but propper shading system has significant role for protecting the house from sunglare or overheating in summer.Therefore, being one of the most effective devices in direct gain system, the shading should be able to stop the radiation in summer and pass the radiation in winter according to the actual needs.In addition, utilization of solar greenhouse in southern side can help the house which acts as a shading system. The greenhouse tends to generate excess heat in autumn, winter and spring due to the low angle of the sun and in the summer the greenhouse is cooler due to less solar insolation caused by the high angle of the sun and shade created by plant growth in the indoor greywater planters which tends to be more vigorous in the summer.Another strategy is designing a linear courtyard or central courtyard by arranging the important spaces around it which enhance the internal light quality.In hot and humid climate,escaping from solar radiation has priority so the earth shelter buried into the earth completely. For this climate and situation,atrium design is the best one due to bring the daylighting together with using skylight or arranging the windows in the depth for southern side with proper shading system.

2.2.6 Building Materials and Construction

One of the sustainability features of earth sheltered architecture includes the usage of materials which are ecologically benign ones or environmentally friendly in order to decrease the destruction of natural and global environment such as carbon dioxide emission, green gas houses, the toxic waste and environmental pollution. Therefore, in the viewpoint of environmental design, these kinds of materials have the substantial impact and minimum damages to ecosystems, natural environment and free resources such as ground level water, earth and air.

Utilizing environmental friendly materials is the significant way to construct an ecological building. The criteria can be listed to explain the ecological materials: natural material, local availability, environmental impact, high percentage ofrecycled/waste materials, collaboration in energy preservation of the building, utilization of renewable resources, low embodied energy and recyclability. Natural and eco-friendly materials are considered as a cornerstone of ecological design such as earth, timber and stone. Earth is considered as one of the oldest natural materials that human has ever used .It is a local and healthy material which can be found in anywhere and needs less energy demand for production as well as less pollution. Locally available materials lead to minimize the energy used for transportation (from the material‘s place of manufacturing). All materials should not pollute the environment or damage the earth. Material should be healthy and non-toxic as well as providing pleasant indoor air quality. Recycled and waste materials can be manufactured as building materials which lead to help the economy together with the environment. For instance, reducing the need for production with none renewable sources in order to save the energy and cost. Waste materials can be re-processed instead of landfill.

Material	Energy savings, [%]	Air pollution savings, [%]
Aluminium	95	95
Cardboard	24	–
Glass	5…30	20
Paper	40	73
Plastics	70	–
Steel	60	–

Figure 25: Environmental Effects of Recycling, (Thomas.R:1996)

Materials made from renewable resources such as wood or solar energy which are better than non-renewable like fossil fuels. Decreasing the earth’s resources is resulted because of more extraction of raw materials. Ecological footprint can be decreased through utilization of renewable energy sources as well as renewable materials. Embodied energy consists of the energy demand to produce building material. This energy is required for extracting raw materials from nature then transportation of these materials to the factory and the energy demand to provide finished materials. Embodied energy is a suitable measure of the entire environmental impact in building systems and materials.

Material	Energy requirements
Aluminum, plastics, copper and stainless steel	100 – 250 GJ/tone
Steel, lead, zinc, glass, cement	10 – 60 GJ/tone
lime, clay bricks and tiles, gypsum, timber	1 – 3.5 GJ/tone
Sand, aggregate, volcanic ash and soil	Less than 0.5 GJ/tone

Figure 26: Energy requirements of materials, (Thomas.R:1996)

According to the figure 26, the less energy requirement is related to the soil, sand, volcanic ash clay and timber which are considered as a natural and local material. Recycled and reused materials derive from different sources such as car tire and aluminum window. The important feature of these materials is saving more amount of processing energy .Moreover, decreasing environmental impacts because of reduction of greenhouse emissions is another benefit of reusing the materials. In earth sheltered houses, the earth is considered as a main material in whole of the building such as walls, ceilings and floor which preserve the house from harsh climate without utilization of expensive and unhealthy materials. Moreover, thermal properties of the earth play significant role for providing desirable temperature for habitants. Hence, earth as a building materials lead to be the house act as an integrated components of the nature with harmonious performance to the surrounding environment. In hot and dry climatic condition, soil and earth act as an efficient obstacle against the hot temperature because of constant fluctuation of earths' temperature. During the summer, soil which is cold enough acts as a heat absorber so that the internal space has the mild temperature. In general, thermal mass of the earth acts as a moderator for providing the heat for winter and coolness for summer. Classification of major materials which are utilized in earth sheltered architecture consists of three types: Local Materials, reclaimed materials and recycled materials. The local materials cover regional and environmental materials such as rocky stone and different types of wood. Reclaimed materials covered the reused materials without reprocessing like reclaimed wood. Recycled materials are considered as waste materials which were reprocessed for producing of new products. Car tires, glass bottles, local timber and earth are the materials which are used in sustainable construction as low impact materials instead of conventional ones. This kind of construction which is not ordinary is considered in the modern society for motivating people to have the less carbon lifestyles and respecting the natural resources.

Choosing the building materials are based on local availability, ecological properties, cost, climatic adaptation and maintenance requirements. For construction of earth sheltered building, extensive excavation will be done on the site. Reinforced concrete is the typical material for foundation of the shelter as well as the roof structure. A waterproofing system for covering the outside of concrete is necessary in order to preserve the house against moisture. Waterproofing system consist of one layer of liquid asphalt with a massy level of waterproof membrane. Then foam or insulation board layers are applied. After that, the remaining spaces are filled by earth and soil at the outer wall and roof to prepare a green roof. Concrete is considered as a strong, fire resistance and durable material which is used in walls, footings and floor slab.

Concrete masonry units or concrete block which reinforced by steel can be used for wall. Another structural material is wood which can be used for light structural work and interior. Wood is not strong like concrete so it is necessary to be pressure-treated by preservatives which protect the wood against moisture. Steel is another one for column supports which can be used both for interior and exterior. The important material for earth sheltered building is waterproofing ones such as pitch membranes or asphalt, bituthene, bentonite and liquid polyurethane. Pitch membranes is used for wall and roof which is hydrophobic and includes fiberglass. Bituthene is considered as a long life expectancy. It is rubberized asphalt which covered with polyurethane. Liquid polyurethane is appropriate for the joint or somewhere which is difficult to use membranes. It is also applied as a coating which is above the insulation. Bentonite or natural clay is shaped into panels or used as a liquid spray.

Earth sheltered architecture has different types of constructions .In first type, earth piled up against exterior walls and packed, a slope descending from the house. The roof may or may not be fully earth covered. Second type is in hill constructions which are set into a natural or artificial slope. In areas with varied reliefs, houses set into a slope or hill side were often erected. The ideal position is when the slope faces south (or north in the southern hemisphere). The last one is an underground, fully recessed constructions are built in excavated ground. For light and ventilation an atrium or inner courtyard are necessary.

In cold climate, the whole of the houses are situated in the southern side of the hill. The appropriate side for designing the house during the cold season is the south and northern side is suitable for hot days. High thermal storage capacity of stone provides thermal comfort of indoor space. The structure and loadbearing performance of the rock as main building materials is the significant feature for using the stone as main materials in this climate. In cold climate, heavy concrete mass with masonry is the best material of earth shelters because of high insulation which leads to decrease the heat loss in winter. Hill construction is the best structure for this climate. In hot and humid climate, timber framed type of earth sheltered house with cladding and infill panels is very appropriate because of low thermal capacity of wood. Timber framed walls have capacity of absorbing and releasing dampness freely in both external and internal. In addition, timber walls are thinner than masonry structure. Fully underground construction is the best type for this area in order to escape from sunny days. In moderate climate, timber, concrete and stone are the best materials for earth sheltered house. Timber because of low thermal capacity together with stone with high thermal capacity is combined to utilize in earth sheltered house in moderate climate. Like the cold climate, hill construction is the best position of earth shelter for this climatic condition.

Chapter 3

EVALUATION OF ECOLOGICAL CRITERIA FOR EARTH SHELTERED HOUSING IN DIFFERENT CLIMATES

In this chapter, five cases were selected in order to analyze earth sheltered houses in different climatic conditions.

The first case is Earthship Brighton which is located in England with moderate climate. This house is selected because of many awards in various fields such as Renewable Energy Awards 2005, National Energy Efficiency Awards 2007 and Green Apple Award. It is a successful example of earth sheltered house. The second case is the Aloni house (underground construction) which is located in Greece with hot and humid climatic condition. This underground house also wins awards such as Greek Architectural Awards 2009 and Piranesi Award 2009.The third one is Villa Vals in Switzerland with cold climate. Pachacamac House is another case which is located in Peru with hot and humid climate. The last case is the Edgeland House in Texas, USA with moderate climate. The project presents the example for integration into the landscape due to preserve surrounding environment. All of them enjoined ecological features in their design process. Energy efficiency, harmony with surrounding environment, low impact materials, water efficiency are the significant features of these five cases.

3.1 Moderate Climate Zone

For moderate climate, both cases (Edgeland House and Earthship Brighton) like the other ones are buried into the earth for enjoying the thermal mass of the earth. In addition, in both of them green roof plays a key role for keeping the indoor temperature constantly. The difference between the green roofs of the cases is that Earthship Brighton has a walk-able glass panels. Green roof protects the houses against the direct heat of the sun while the buried rear of the homes can absorb the cooler temperatures from the earth due to provide cooler temperatures for the spaces during the summer days. These circulations change during the winter season in which the warm temperature cannot disappear from the green roof to outer spaces and provide the warm temperature by thermal mass of the earth. These two earth-sheltered houses have earth-bermed construction but in Edgeland house both side of the house are buried into the earth and a linear courtyard divides the house in two separate spaces. This design strategy has a remarkable value for protecting the house against solar radiation and overheating during the summer. But in Brighton, the northern side is embedded into the earth and the southern façade completely exposed with huge openings for absorbing maximum solar energy which is called greenhouse. The greenhouse acts as shields (protection) of inner spaces during the hot summer when the sun has the highest position in the sky which protects the habitants from sun glare and overheating. During the cold winter season when the sun has the lowest position, passive solar energy gain throughout the large windows can penetrate into the internal spaces which heats the indoor spaces. Both cases use eco-technologies due to provide thermal comfort. In Brighton, solar panels can capture the passive solar energy for heating and electricity demand. Moreover, seasonal thermal energy storage, biomass heater generate additional power for the house. Wind turbine is another ecological feature of the house which is used in this case. Eco-technologies in Edgeland house include heat exchanger, PV panels and hydronic HVAC system. As mentioned before, geothermal design is used in all of the earth-sheltered houses. Brighton enjoys wind, sun and earth powers as renewable energy sources in comparison to other cases.

In general, in moderate climate, thermal comfort has a significant importance in both heating and cooling demands. Considering to both heating and cooling have same priority unlike the cold climate (heating demand is important) and hot climate (cooling is important). Utilization of thermal mass of the earth for having proper thermal comfort is the first step of design process which can be seen in all of the earth-sheltered house through burring into the ground. For capturing passive solar energy, whole of the southern façade should be covered with large windows for providing heating demand in cold seasons. Appropriate shading system is also necessary for protecting the habitants against sun glare in summer time.

3.1.1 Integration into Topography

The Earthship Brighton is located in Stanmer Park in an inclined topography. The significant feature of this earth sheltered house is preserving the natural landscape. Therefore, going to the hill together with green roof leads to create more harmony with landscape together with preservation of local ecosystem as well as minimal intervention. On the flat site, the earth covered and piled up in northern side completely and also for the roof which leads to create a green roof for the house. This green roof creates more harmony into topography.

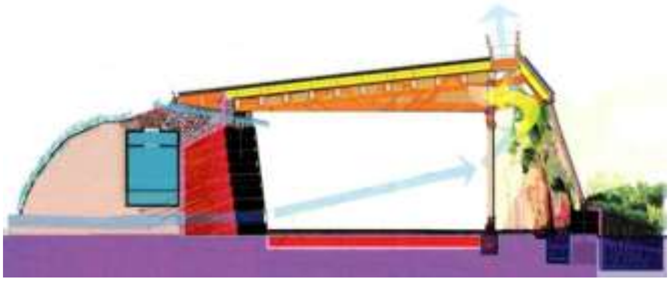


Figure 27: Section of Earthship, (Simmons.C:2010)

Initial concept of the Edgeland house is creating a balance between natural landscape and industrial zone in a sloppy site. Green roof of the house with native plants creates more harmony to surrounding and preserve the local ecosystem. So the house is completely integrated into the grassy landscape without destroying the surrounding environment. The project is designed to stop the demolishing of landscape and natural resources through creating a balance between natural river (on opposite side) and the surrounding industrial zone. As can be seen in both examples, in moderate climate, flat and slopey sites have the same priority for constructing the earth sheltered house.

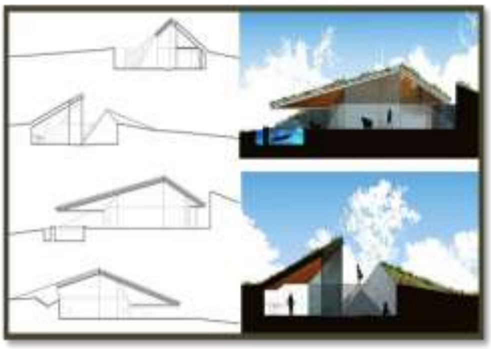


Figure 28: Sections, Edgeland House


Figure 29: Site plan, plan, Edgeland House

3.1.2 Daylight Consideration

In Earthship Brighton, the northern side of the house is completely buried into the earth while the southern side is covered with large windows and greenhouse. The form of the building is east to west so that all of the spaces are arranged between south and north. The majority of the south façade consists of windows and has also three aperture roof lights in living room, kitchen and side room which can provide natural light.

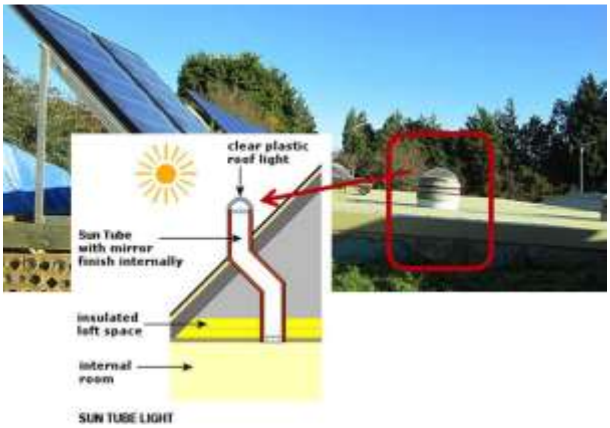


Figure 30: Sun pipe in Earthship

In order to decrease the need for artificial lighting, sun pipes or solar pipes are provided for reflecting the natural light down into the internal spaces. Sun pipe (sky tubes) is a clever little gadget of highly reflective tube which runs from the roof of the Earthship to the ceiling for conducting the natural light into the indoor spaces. In Edgeland house, the plan is divided through a narrow courtyard which leads to create two different zones (living spaces and sleeping room). The interior walls of these two spaces are covered with large double glazed windows which allow natural daylighting and fresh air into the internal spaces. To east and west directions, the building is buried into the earth without any openings. The north and south of the house is connected together with linear courtyard. In moderate climate, providing of daylight in case of Edgeland house is approximately similar to the Aloni house with courtyards. A linear narrow courtyard is a sustainable element which divides the indoor spaces into separate zones (living area and sleeping part) for creating brilliant internal spaces.

Figure 31: Daylight considering, Edgeland house

Whole of the southern side is covered with greenhouse and glass façade to allow the natural light together with the skylight of the ceiling. In addition, sun pipes or solar pipes reflect the natural light into the internal spaces. The orientation of Earthship Brighton to south-north axis in which the common spaces are faced to the greenhouse while in Edgeland House; all of the interior spaces are arranged around the linear courtyard which provides both passive solar energy gain and daylighting. In moderate climate, it is possible to arrange the opening in both south and north sides but the best one is the southern side for capturing more passive solar energy together with proper shading system like the Brighton rather than Edgeland house.

3.1.3 Building Materials and Construction

Earthship Brighton utilizes the low impact materials for their construction from timber and stone as local materials to cans, bottles and car tires as reused, recycled and waste materials instead of common building materials like steel. More than 20 tons of reused and recycled materials were used, including 1,000 car tires, 1,500 cardboard boxes, 35 reclaimed paving slabs, 2 tons of bottles, 90 reclaimed granite blocks, five reclaimed doors, 4 tons of marble with granite and 150m of floorboards. Car tires are the basic component of the materials for the wall with a 1m of rammed earth which is covered with a natural clay, adobe and cement. Every car tire is filled with compacted earth. Thus, the thick wall provides the thermal mass .Furthermore; these techniques decrease the use of concrete in constructions (combination of car tires, mud and concrete). Other recycled materials are glass bottles in the shape of glass bricks which are filled with eco-cement (waste ash from sugar cane). The portico and roof are made of timber as local material .Because of the unique exterior wall (car tires packed in the mud and earth), the walls are fireproof. Earth is the main building material of Edgeland house with mud and grass cover. Double pane glass in exterior walls, mud and natural clay for roof and exterior wall, eco-cement, local stone, timber, steel and reclaimed paving slabs are the environmentally friendly materials ,which is used in ecological house. As can be seen in both examples, combination of timber frame with local stone is the main materials of the houses.

Low impact materials	Exterior wall	Interior wall	Roof	Floor
Car tires Recycled material	*	*		
Glass bottles Recycled material	*	*		
Cans Recycled material	*			
Natural clay Natural material	*	*	*	
Timber Natural material		*	*	
Granite blocks Natural material		*		*
Marble Natural material	*			
Cardboard boxes Reused material	*			
Reclaimed paving slabs Reused material				*
Eco-cement Natural material	*	*		

Figure 32: Building materials, Earthship Brighton

Low impact materials		Exterior wall	Interior wall	Roof	Floor
Natural clay	Natural material	*		*	
Timber	Natural material			*	
Local stone	Natural material	*	*		*
Reclaimed paving slabs	Reused material				*
Eco-cement	Natural material	*	*		*

Figure 33: Building materials, Edgeland house

3.2 Hot Humid Climate

Among the cases, Pachacamac House and Aloni House have the warmest temperature in hot seasons, so cooling is very important item in these areas. Aloni House is embedded into the ground for escaping the maximum solar radiation and direct sun glare into the indoor environment which leads to decrease the use of cooling system together with providing constant temperature because of the stable fluctuation of earth’s temperature. Pachacamac House is similar to Aloni House for cooling demand which is completely buried into the hill. Both of them is using green roof which helps to keep the indoor temperatures constantly .The difference between these cases is related to the design strategy for avoiding solar radiation because of overheating in hot seasons and capturing passive solar energy for heating demands in cold seasons. Aloni House has four courtyards as sustainable elements to protect the house from sun glare .All of the interior spaces (with large windows) enclosed by courtyards protect the house from sun glare in hot seasons together with capturing passive solar energy in cold seasons. But in Pachacamac House, all of the openings in southern side are buried into the hill due to protect the interior spaces against the sun glare.

Figure 34: Aloni House

Figure 35: Pachacamac House

In general, the obvious features of hot and humid climate are high temperatures with high percentage of humidity (more than 70 %).Thus, providing the cool indoor temperature is the important demand of this climate zone. The first strategy is going to the ground due to escape from the sun glare and solar radiation. Earth with constant fluctuation leads to keep the internal temperature steadily. Green roof and geothermal design are also used for hot and humid climate due to provide comfortable spaces with pleasant internal temperature for habitants.

3.2.1 Integration into Topography

The Aloni house is located between two downhill in flat site which creates a bridge between mentioned slopes (the east-west axis). The east and west of the house are placed to the slope of hill. It is fully in underground. Due to integrate with the surrounding landscape, this stunning underground house is combined with the planted roof which is supported by two parallel stone walls. The plants species preserve the biodiversity of existing fauna and flora. .Green roof of the house helps to be part of the landscape, so the house is integrated part of the landscape. The proper utilization of the exiting landscape in the architectural design is converting to the integral part of the topography and creates strong relationship to the environment. The boundary between the house and natural environment is significantly imperceptible or minimized while maintained the client's privacy.

Figure 36: Site plan, Aloni house

Figure 37: Site plan, Pachacamac house

In order to create a balance between topography and architecture and response to the site, the Pachacamac house is fully embedded into the downhill with very small intervention of environment. The east part of the house is embedded into the hill. The hill is situated between mountains. Due to more harmony with landscape, the house is combined with local stone. In addition, green roof is another element to achieve more harmonious to topography. As can be seen in examples, they have different topography. The first one is located in flat site while the second one is located in the hill.

3.2.2 Daylight Consideration

The four courtyards Aloni House separate the living room into five interior spaces with large windows, flood the natural light and provide the spectacular and compact view to the outdoor spaces with relationship to the landscape and topography. Hence, natural lighting is achieved through these courtyards.

Figure 38: Daylight consideration through courtyards of Aloni House

Courtyard is considered as a sustainable element due to provide natural ventilation and daylighting for the indoor spaces. This enclosed yard acts as a ventilator for exhausting the warm air from interior spaces.

Figure 39: Natural lighting of Pachacamac House

Unlike the underground constructions, Pachacamac House is illuminated by natural light which reduces the need of artificial light. There are many openings and skylights (with proper orientation and location) which are prepared for allowing the light into the interior spaces. In addition, a huge glass box is situated in front of the house (western side) which reflects the natural light into the interior spaces.

In hot and humid climatic conditions unlike the cold climate, escaping from solar radiation is a remarkable feature due to avoid the sun glare and overheating in dry and hot seasons. The first strategy is that Aloni House and Pachacamac House are completely embedded into the topography and is considered as an underground earth-sheltered construction. Orientation of the Aloni house is to west-east like Pachacmac House. Although both of them are located underground but they don't face with lack of natural lighting. For providing the natural light, Aloni house is arranged by four courtyards which help to penetrate the abundant natural light down into the house so that the internal underground spaces have no lack of light which reduces the need for artificial light. Moreover, interior spaces with large windows help to flow natural light together with the spectacular view of the outdoor spaces. In Pachacamac House the southern side incorporated with more openings due to capture sunlight. These openings buried into the hill due to protect the interior spaces against the sun glare. Moreover, there is a huge glass box at the main entrance for reflecting the natural light into the house. In addition, large opening in southern façade with proper shading system leads to use passive solar energy gain. Plan hierarchy is based on arranging the common spaces in southern side. The best orientation of the plan is west-east elongation.

3.2.3 Building Materials and Construction

Construction of Aloni House is based on the atrium design in which the habitable rooms cluster around the atrium or courtyard to provide exterior exposure. The role of these central underground yards in atrium design is very important due to mitigate the wind speed, reduce the adsorption of solar radiation during the summer and increase it in winter. In other word, this natural element creates the micro-climate in order to modify the unsuitable effects of weather. Hence, the courtyards have been considered as an essential native element and as a passive cooling and heating strategy due to control the thermal behavior by generating the cooling in summer and heating in winter alongside with acting as an obstacle against the stormy wind while circulating the air for ventilation. The significant climatic adaptation of the Aloni House is related to utilize low impact materials. The underground construction with rustic (rural and local) materials such as local stone, clay and timber led to enhance energy efficiency and protect the house against the inclement weather.

Low impact materials	Exterior wall	Interior wall	Roof	Floor
Natural clay Natural material	*	*	*	
Timber Natural material		*	*	
Marble Natural material	*			*
Reclaimed paving slabs Reused material				*
Eco-cement Natural material		*		*

Figure 40: Low impact materials, Aloni House

Construction of Pachacamac House is based on use of earth as main material, local stone, natural clay and lime plaster for wall, timber for frame of doors, straw bales for super-insulation of roof and floor, reclaimed wood for floor, timber shelving of interior wall, eco cement for wall, concrete combined with wood for roof. Moreover, these embodied low energy materials have minimum footprint with high insulation potential.

Low impact materials	Exterior wall	Interior wall	Roof	Floor
Local stone Natural material	*	*		
Natural clay Natural material	*	*		
Timber Natural material		*		
Reclaimed wood Reused material				*
Eco-cement Natural material	*	*		
Concrete combined with wood Natural material			*	

Figure 41: Building materials, Pachacamac House

Pachacamac Hill House is a symbol of eco-sustainability of ancient construction of the Aztec people. They built their house from porous, tezontle (sand, magma, volcanic rock in slope), a light, volcanic rock which are mixed to rubble or pebbles. As a result, the house was durable, strong and light-weight. This construction keeps out cold from interior spaces in winter and heat in summer. Generally, the used materials derived from the Aztec constructions which include the clay, sand, stone, lime, local wood and straw.

Figure 42: Volcanic rock, tezontle and to rubble or pebbles

In general, in hot and humid climate, fully underground construction in flat site and atrium design is the best position for earth sheltered houses. Local wood and clay are also the best materials for this climate because of their low thermal capacity.

3. 3 Cold Climate

In comparison to other cases, utilization of passive solar radiation and thermal mass has a significant importance in Villa Vals because of the very cold winter. Hence, whole of the house is faced to the south for capturing solar energy. Generally, this climate needs small openings due to keep the warm temperatures but in Villa Vals, entire of the southern façade covers with large opening with double glazed windows to absorb more natural light, passive solar energy and to provide ventilation. This subterranean house utilizes eco technologies due to provide heating demand such as heat exchanger, radiant floors, hydroelectric power and firewood (wood pellet). In general, very cold winter and mild summer are important features of cold climatic zone. Therefore, heating demand has a significant priority for occupants. Like the entire earth-sheltered houses, burring to the earth particularly rocky mountains is the first strategy due to provide the thermal comfort against the harsh weather. Constant fluctuation of the earth temperature together with high potential insulation of the rock maintains the indoor temperature in the range of human comfort.

Figure 43: South facing of rocky earth sheltered house

The optimum earth-sheltered orientation is southern side for capturing more passive solar energy gain with large openings on facade. The mentioned windows are doubled or tripled pane for more energy efficiency. In addition, all of the important spaces should be arranged to the southern side of the plan for both passive solar energy utilization and natural lighting. A low impact material with high thermal capacity such as stone is another feature of this climate zone due to store the solar heat and release it to indoor spaces for heating demand. Moreover, green roof also keep the internal temperature constantly and acts as a beneficent insulation. Geothermal design is considered as an eco-technology for providing heating demand without any environmental footprint.

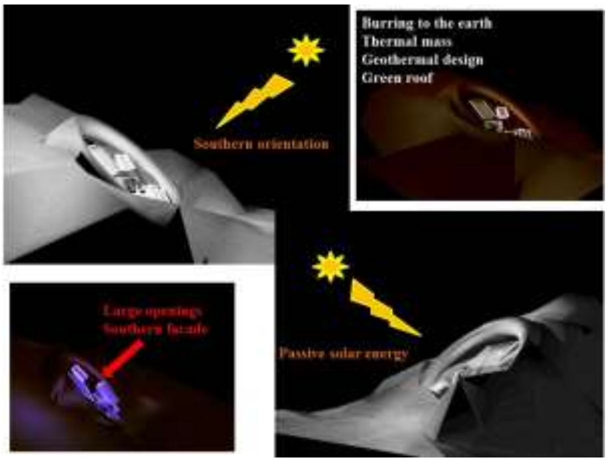


Figure 44: 3D models of Villa Vals, cold climate

3.3.1 Integration into Topography

The main geological component of the soil in the region is hard limestone, which enabled the people in this area to excavate and carve in such rocky topography. The nature of topography is strong enough to maintain ceiling and walls but easy to excavate. The initial design of the house was based on integration into the surrounding landscape due to avoid the demolishing of untouched nature and provide the panoramic view of the mountains. It is located in the sloped topography (rocky mountain) with south orientation due to capture passive solar energy gain. The design of the plan is based on integration into the landscape due to avoid demolishing the nature. That is why the main entrance of the house is only possible through wooden barn. In cold climate, the best topography is the slopey site with south facing orientation like the Villa Vals in order to absorb more solar radiation.

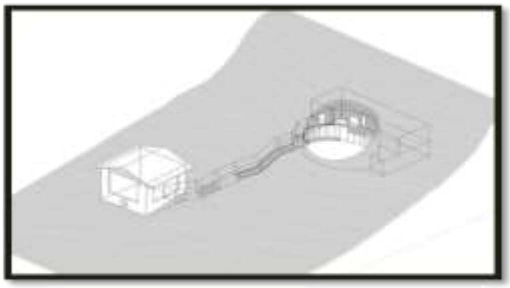


Figure 45: The entrance of Villa Vals

3.3.2 Daylight Consideration

The design concept was the use of central courtyard opened to sky, which was the main source of natural lightening and ventilation. The orientation of the house is based on accessing to the solar radiation. The southern side of the house is covered with large windows due to capture passive solar energy gain. A central patio with considerable potential of large window openings in façade provides natural lighting for internal spaces. The wide façade of the house is considered as the main sunlight resources, ventilation and outdoor view. The ground floor with common spaces and bedroom are faced to patio with full of natural light. There is no skylight in this house. In cold climate, orientation toward the south is a significant climatic adaptation which can be seen in Villa Vals. In Villa Vals, the southern façade consists of large double glazed windows to capture natural daylighting, passive solar energy gain, ventilation and outdoor view. Moreover, plan hierarchy is very efficient. All of the important spaces were arranged to the southern side due to enjoy solar radiation. Only staircases, bathroom and storage are situated in northern side which is the best arrangement of the plan for cold climate. Triple pane windows are used to protect the house against the coldness as well as provide the natural daylighting and spectacular view of mountains.

Figure 46: Natural lighting, Villa Vals

3.3.3 Building Materials and Construction

The design of Villa Vals is based on the organic structure in a rocky landscape with the utilization of environmentally friendly materials which is one of the significant features of ecological houses. An excavation of 10 meter deep was taken on the hill side when Villa Vals was built. With reinforced concrete wall construction, a total volume of 15.80 meter width and 7.90 meter depth box was installed for the main body of the building. One of the most common types of earth-sheltered housing is the elevational design like Villa Vals in which windows and openings are grouped on one side of the structure. The three remaining walls are earth-covered. When the windows face to south, a maximum amount of passive solar heating can be obtained. Those rooms are used frequently during daylight hours and are usually placed along the window wall. In winter, while the air temperature outside is 0℃, the temperature in a cave might be 18℃. It is because the earth stores the great solar energy during the summer, and slowly release the heat in winter, even there is very little solar gain in winter. While in summer, the air temperature outside is 24℃, it might be only 18℃ in a cave. Because the earth stores little solar energy in winter and it did not change much the temperature, meanwhile it stores enormous solar energy from the sun in summer. The house is provided with numerous of ecological materials such as cardboard (reused material) in interior walls and the ceiling of the library, veneered plywood (reused material) for sliding doors, rustic concrete and traditional timber (natural materials) for interior walls, triple pane windows, oak panels for interior walls and indigenous stone (Valser quartzite as a natural material) for façade, pitched roof, interior and exterior wall. Hence, these materials lead to protect the house against the cold climatic condition and improve the energy efficiency of this subterranean house.

Low impact materials	Exterior wall	Interior wall	Roof	Floor
Timber Natural material		*		*
Cardboard pannels Reused material		*	*	
Oak panels Natural material		*		*
Eco-cement Natural material	*	*	*	
Rustic concrete Natural material		*		
Indigenous stone Natural material	*	*	*	

Figure 47: Building materials, Villa Vals

Building materials such as stone and quartzite are available from the ambient environment and they are used as finishing for internal walls and fixed furniture as beds and storage cabinets. Alpine trees, which are widely planted in mountain areas are used for doors and some simple furniture. It is also used for supporting the roof of rooms and subterranean entrance tunnel. The façade as well as the interior of the building uses stones recovered from the site. The cave has advantages in using the thermal energy of the earth, but there are weaknesses for the quality of living, for example the bad ventilation and natural light, the weak insulation for the humidity in the earth, etc. In this house, these problems can be solved with better design such as large windows in southern side as well as central patio. In general, in cold climate, hill construction with rocky materials is the best building construction.

Chapter 4

CONCLUSION

The essential ambition of this thesis was to focus on ecological criteria of earth-sheltered houses to promote the value of earth-sheltered constructions which consist of integration into topography, daylight consideration and ecological materials.

Three main questions were drawn in introduction of research which includes the below items:

- What is an earth sheltered house?
- What are the most significant criteria for earth sheltered buildings?
- How can we achieve earth sheltered buildings according to these criteria in different climates?

Only the design that respects the natural environment and climate condition can achieve the goal of an eco-friendly house, while trying to maximize the living qualities of the people. The architectural design rules for the underground house include these issues: choose the right site and direction according to the Sun Chart, arrange the proper function surrounding the solar façade according to the importance, ensure there is at least one facade of the house can take advantage of direct sunlight and solar gaining, take methods to solve the light and ventilation problems of the backside rooms, for instance the light well and scuttle and utilizes of ecological materials during the constructions.

The cases were selected and studied through main climatic zones due to clarify the principal parameters of earth sheltered houses with respecting to environment for responding the mentioned questions and overcoming the problems which are presented in the chapter of introduction:

- The rocky earth-sheltered house of Villa Vals in cold climate
- Aloni House and Pachacamac in hot and humid climatic zone
- Earthship Brighton and Edgeland House in moderate climatic zone

Earth sheltering is considered as an architectural practice of utilizing earth against the outer walls of building for external thermal mass in order to decrease the heat loss together with keep a stable indoor air temperature. Earth sheltered architecture creates a simple pattern of integration to the nature and surrounding topography which is compatible to the people demands without contamination of environment. The houses are embedded in the earth as a coziness of the ground with exceptional insulation and melded in with its natural landscape. Decreasing the human impact on environment because of avoiding the demolishing of landscape, deforestation for construction and disrupting the habitat surrounding protect the native flora and fauna and provide more greenery spaces. Nowadays, the idea of underground structures has a great impact on more energy preservation by decreasing the annual cooling and heating loads throughout the earth's support in comparison to above ground and conventional buildings in which the thermal mass of the ground in earth sheltered spaces are conducted in order to diminish the heat loss and maintain the indoor temperature regarding to human comfort realm. Therefore, earth acts as a regulator which helps to more energy preservation. The other beneficial feature of the ground in earth sheltered structure comprises the recycling surface space in which the performance of the building relocates from above ground to underground. Going into the earth leads to minimize the negative impacts on the surrounding environment. As a result, increasing the useful land for agriculture, avoiding from demolishing the nature and landscape because of human construction, enhancing the visual environment of the earth surface, increasing the open spaces for landscaping, providing more greener atmosphere and in a word, environmental protection are the great impact on using the earth and underground spaces as prominent sources of human's habitat.

The most significant ecological criteria of earth sheltered building include the topography, daylighting and building materials which have specific features in different climates. Earth sheltered house can be constructed in various climatic condition such as intense heat or cold or some region with the high potential of hurricanes and huge differences between the day and night temperature (daily fluctuation) with considering to different topography. This type of house utilizes the natural free energy resources for heating and cooling demands which can meet the shelter demands of mankind for our future climate changes in where the weather will become more excessive and the use of none- renewable energy sources such as fossil fuels will be diminished. Buried into the earth and retained earth walls which benefits the thermal advantage of the ground can regulate the internal temperature for providing the comfort zone for habitant during the different seasons. The main reason that the house is buried into the earth is the climate conditions. For instance, in semitropical climate particularly in summer with hot days, the house is embedded into ground for escaping the maximum solar radiation and direct sun glare into the indoor environment which leads to decrease the use of cooling system together with providing the constant temperature because of the stable fluctuation of earth's temperature.

In cold climate, a single exposure elevational design in hill constructions is the significant position for this climate. The rocky earth sheltered architecture can modify the impact of extreme outdoor temperatures which provides relatively constant temperature in internal spaces. Thus, the stony underground shelter provides tremendous thermal mass and insulation due to preserve the internal temperature. Moreover, south-facing of the shelter lead to capture maximum passive solar energy particularly during the cold winter due to go up the internal temperature with corporation of thermal advantages of the earth. On the other hand, it can provide mild indoor temperature during the summer because of high potential of the rocky stone as local material as insulation. The house is better to locate on a south-facing slope rather than flat side due to take advantage of passive solar radiation. In addition, natural daylighting is possible via the big opening of the window with south facing. The orientation of openings comes in responding to energy conservation and solar utilization as the case in the cold climates. The solid north façade protect the space from cold wind and reduce infiltration. In cold climate, the house with heavy materials such as stone and concrete act as a high insulation material due to decrease the energy demand of heating. In hot and humid climate, north-facing slopes and fully underground construction are appropriate structures in order to preserve the habitant against excessed solar radiation and overheating .In a flat side, earth raises up and cover the roof due to create a mild indoor temperature during cold winter and hot summer. The important issue for this climate is escaping from solar radiation as well as providing natural daylighting for underground structure so atrium design and skylight are the best which allow penetrating natural lighting for the house. Central courtyard of this design is considered as a natural element for providing the natural daylight and ventilation of indoor spaces. Timber framed type with cladding is more efficient material in comparison to masonry structure because of the low thermal capacity of wood. In addition, timber is considered as a moisture-regulator together with structural and surface material. In moderate climate, south-facing slopes or flat side are suitable for constructing the house. Big southern windows with proper shading systems, skylight, a linear courtyard or central courtyard can enhance the internal light quality. The greenhouse is another beneficial strategy for this climate in order to create proper shading system with enough natural lighting as well as cold temperature in summer and warm weather in winter. Combinations of local stone with timber frame are the efficient materials. Predominantly, utilizing the reused, recycled and waste materials such as the glass bottles is the significant feature of the mentioned case study (Brighton) which decreases the energy consumption by water conservation and energy demands during the process. Also, the reduction of greenhouse emissions which derives from fossil fuels is the benefit of recycling and reusing of building materials (car tires).

The role of green roof as an eco-technology is very remarkable due to moderate the internal temperature, control the flood (heavy rainfall) and natural run-off, create the insulated blanket on top of the house and present the harmonious image within working by natural environment as a part of the topography. Green roof insulates the house against the direct heat of the sun whereas; the buried rear of the home can absorb the cooler temperatures from the earth due to provide the cooler temperature for the spaces during the summer days. On the other hand, these circulations changed during the winter in which the warm temperature cannot escape from the green roof to outer spaces and providing the warm temperature is possible with the assistance of thermal mass of the earth. Sunken garden, central courtyard of earth sheltered architecture and designing underground rooms or earth bermed room in eco house can create a mild temperature in different seasons for eco house by utilization of thermal capacity of the earth. Therefore, this type of construction could be considered as a specimen of today's innovative concept with an approach to ecological aspects. From ecological point of view, attention to the native landscape with minimum environmental footprint, the balance of the ecosystem, decent utilization of local materials and preservation of the natural resources because of passive design and natural daylighting are sustainable approaches of earth-sheltered architecture.

In order to conclude that the earth sheltered architecture is an appropriate solution for better comprehension and manage the design with considering to environmental performances and ecological issues. Therefore, it is necessary to have a serious look into the issue of earth sheltered dwelling as a possible future house with ecological approach. They were successful for centuries because of remaining the natural beauty of surrounding environment, ecological advantages, minimum environmental footprint, low impact materials, utilization of natural energy resources, the possibility of construction in every region and climate, high safety, seasonal adaptation and providing the comfortable spaces for residents.

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