HOSAIN MOSBAH M BAKOOSH

COMPARISON BETWEEN VERNACULAR ARCHITECTURE (UNDERGROUND HOUSE) AND MODERN HOUSING IN GHARYAN, LIBYA

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
HOSAIN MOSBAH M BAKOOSH

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

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To My Parents...

ABSTRACT

The effect of rapid population rise has led to substantial increase of urbanization mostly with the existence of modern style/contemporary housing schemes, hugely influenced by western styles throughout the world. However, modern buildings are associated with a lot of shortcomings such as consumption of excessive amount of non-renewable energy and resources, environmental pollution and depletion of natural landscape and topography etc. Using the knowledge achieved from vernacular buildings such as underground houses can certainly help in reducing environmental problems for local society.

Libya as a developing Arab country has also faced several urbanization problems in recent years. Vernacular architecture (underground houses) that the country owns may be a solution to combat such challenges. Thus the aim of this study is to make comparison between underground houses with modern style housing in Gharyan Libya with regards to thermal performance, environmental impact, energy consumption, construction materials, with above-ground building. After the theoretical overview, quantitative methodology was used for the accomplishment of the study. Questionnaire carried out with people who lived both in underground housing in the past and above ground (modern) houses in present. According to the participants, underground houses are more sustainable buildings in terms of thermal comfort, energy consumption, building material and adaption to the environment compared to modern houses.

In addition, thermal performance in both underground and above ground houses was measured with the instrument called hygrometer. Result from the thermal measurement that was done in one month of winter season (21/01/2019- 18/02/2019) demonstrates that the underground house has an indoor mean temperature and moisture of 16.12°C & %62.15 while the other house type has a temperature and moisture of 12.67°C & %70.13.

Keywords: Underground houses; vernacular architecture; modern architecture; Gharyan Libya

ÖZET

Dünya genelinde hızlı nüfus artışının etkisi, büyük ölçüde batı modellerinden etkilenen modern tarz / çağdaş konut programlarıyla şekillenen bir kentleşme olgusuna sebebiyet vermektedir. Halbuki modern binalar, aşırı miktarda yenilenemeyen enerji tüketimi, kaynak tüketimi ve çevre kirliliği ile doğal peyzaj ve topografya tahribatı gibi birçok eksiklikle ilişkilidir. Yeraltı evleri gibi yerel yapılardan elde edilen bilgileri kullanmak çevre sorunlarının azaltılması konusunda yerel topluma yardımcı olabilir.

Gelişmekte olan bir Arap ülkesi olarak Libya da, son yıllarda çeşitli kentleşme sorunlarına tanıklık etmektedir. Ülkenin sahip olduğu yöresel mimari (yeraltı evleri) bu tür sorunlarla mücadele etmek için bir çözüm olabilir. Bu nedenle, bu çalışmanın amacı, Gharyan Libya'daki yeraltı evlerinin, ısıl performans, çevresel etki, enerji tüketimi, yapı malzemeleri bağlamında, modern tarz konutlarla karşılaştırmasını yapmaktır. Teorik çerçeve sonrasında, bu çalışmada nicel araştırma yöntemi kullanılmıştır. Geçmişte yeraltı konutlarında ve günümüzde modern evlerde yaşayanların görüşlerini araştırmak için anket uygulanmıştır. Katılımcılara göre, yeraltı evleri; termal rahatlık, enerji tüketimi, yapı malzemesi ve çevreye uyum açısından modern evlere göre daha sürdürülebilir yapılardır.

Ayrıca, hem yeraltı hem de yer üstündeki evlerdeki termal performans, higrometre adı verilen cihazla ölçülmüştür. Kış mevsiminde bir ay zarfında (21/01/2019–18/02/2019) yapılan termal ölçüm, yeraltı evinin ortalama iç mekan sıcaklık ve neminin sırasıyla 16.12°C ve %62.15 olduğunu, modern evde ise sırasıyla 12.67°C ve %70.13 olduğunu belirlemiştir.

Anahtar Kelimeler: Yeraltı evleri; yerel mimari; modern mimari; Gharyan, Libya

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CHAPTER 1

INTRODUCTION

1.1 General Consideration

The underground dwellings have been the oldest form of the shelter known to human that could be traced back to ancient eras. These underground dwellings method are utilized in various parts of the world today through new technological approaches. Underground dwellings are designed and modelled for the conservation of the natural environmental as well as protection from pollution and saving of non-renewable energy resources as much as possible. This type of building is consistent in providing comfortable, moderate temperature to its inhabitants in different weather conditions.

Due to the industrial development and urbanization which led to a threat to human life and health, human beings started to worry about environmental damage, climate change, resultant energy cost, and high need of dealing with modern buildings and the environment. Moreover, we have reached to the fact that human endeavor and methods to generate energy have contributed significantly in polluting the environment as well as changing the global climate (global warming). Therefore, there is an urgent need to restore a clean and free diseased ecology. To achieve this, the human society as a whole must begin to change their philosophy and policies, so human race can survive on the earth.As a consequence, the concept of sustainability and benefit from vernacular architecture has become a critical subject having great importance within the environmental issues. These issues range from preservation of flora and fauna to the planning and design of cities and buildings.

Modern dwellings are associated with a lot of shortcomings such as consumption of excessive amount of non-renewable energy and resources, pollution and depletion of natural landscapes and topography etc. Thus, there is an urgent need to seriously evaluate and solve the problems and the high demand on energy. Therefore, we must make our share of contribution to help sustain the earth and the environment to help future generations. As a major step, a policy and a theoretical framework for sustainable earth sheltered houses in Libya must be established and implemented into practice .

This thesis endeavor is to compare earth sheltered housing (underground housing) and modern housings (above-ground housing). Therefore, there will be an evaluation of earth sheltered houses, the history of its existence, patterns, methods of their development, and the possibility of using modern technology to make such houses more desirable for living in today's world.

1.2 Aims and Objectives of the Research

Construction of modern housing contributes a major role in energy problem in the world. Libya just like any other developing countries (especially Arab countries) faced housing problems. Therefore, there is significant need to decrease environmental implications by execution of environmentally sustainable housing programs. Thus, the main aim of the research is to investigate and compare the vernacular architecture (underground housing) with modern architecture (above ground housing) in terms of thermal comfortability, energy usage, construction method and materials, and environmental implications so that projects in the future can benefit from the lessons learned. To accomplish these aims, the following objectives are required:

1. To analyze the characteristics of vernacular architecture and modern housing in Gharyan Libya as well as to examine the extent of peoples' satisfaction with both housing styles in terms of thermal comfortability, energy usage, construction method and materials, and environmental implications.
2. To make comparison between vernacular architecture and modern housing in respect to their suitability for thermal comfortability, energy usage, construction method and materials, and environmental implications.

1.3 Research Methodology

The method in this study firstly involves a related literature review and secondly information gathered in the field. Within the literature review, beside the relevant articles, books etc, as written scientific documents, and the thesis also uses varied digital sources: search engines, digital libraries and databases, all with the scope to create a credible speech and a coherent scientific knowledge to the theoretical demarche. In addition to the literature review, the study involves two different field studies.

In the first field work, a questionnaire was constructed. It involves items examining the participants' suggestions about house type, construction material, thermal comfort, energy type used for heating and cooling, ventilation and lighting, comfortability, social interaction among neighbors, humidity in the air etc. The findings from the study were grouped into three categories: construction materials and techniques, energy efficiency, and indoor/outdoor air quality.

The second field study was developed through practical field measurements of the thermal properties and performance of vernacular architecture (underground housing) and modern style (above housing) in Gharyan -Libya at the same time, and same zone. In this thesis, quantitative method will be used to measure the thermal performances, interview will be made with the people living in these houses. After that the data gathered, findings were all analyzed, presented graphically and discussed.

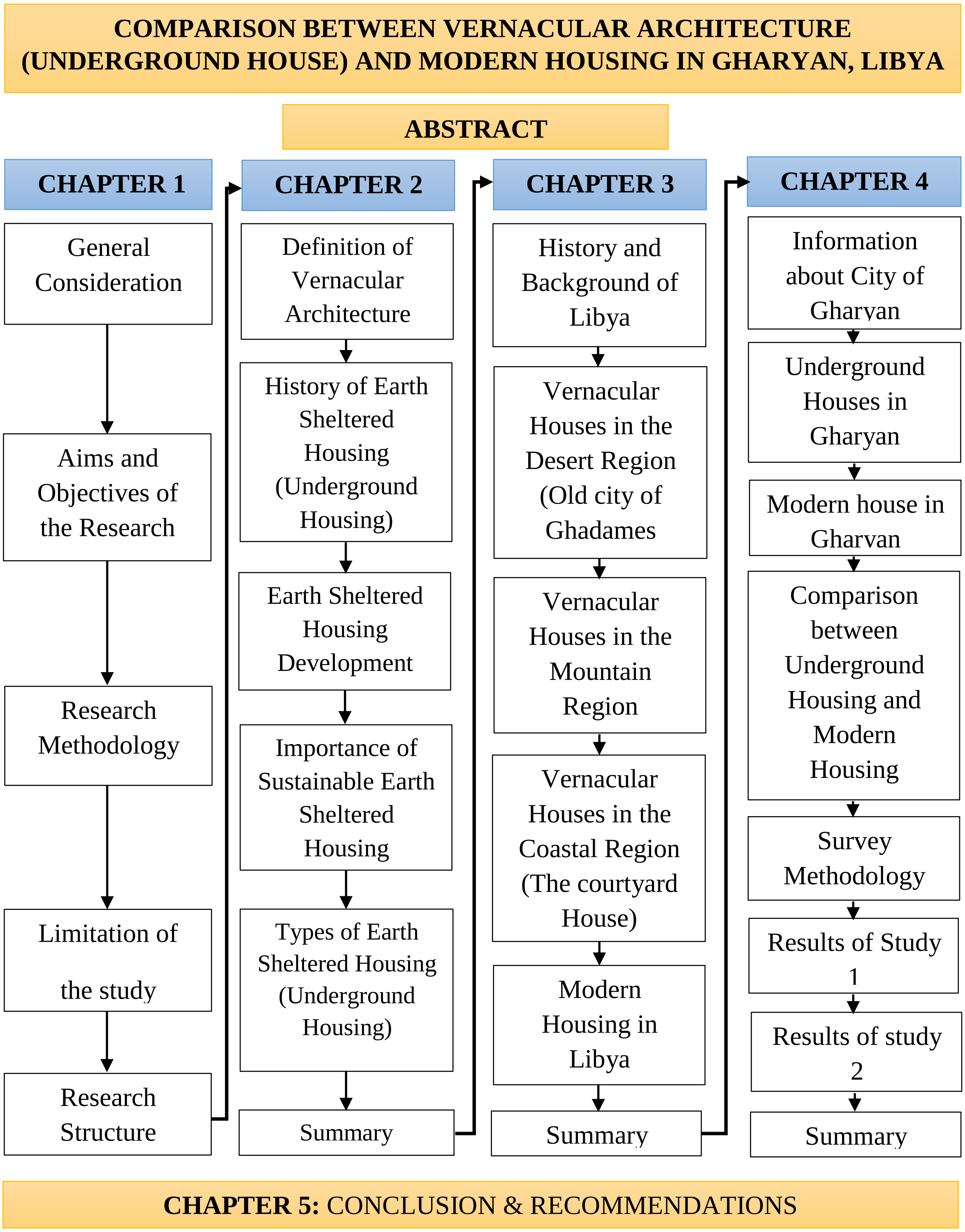
1.4 Limitation of the Study

This research will be in the city of Gharyan in Libya. The choice of this regional location is that this region is famous with its vernacular underground housing historically. The type of underground houses found in the city of Gharyan cannot be compared anywhere else in Libya except its surrounding areas in the Nafusa mount in the west. Moreover, the main advantage of these houses have been their ecofriendly to structure environment, it needs only simple and local building materials such as limestone and mud. They not require much material when compared to modern houses, as well as they are very economical in consumption of energy. As a fact, underground houses have many more advantages, since they are very economical to build, they are cool in summer and warm in winter.

1.5 Research Structure

The research are divided into five chapters .The first chapter contains introduction and the aims and objectives of the research, including limitation of the study and methodology. The second chapter contains a study of vernacular architecture in the world. The third chapter contains an overview of vernacular architecture and modern dwellings in Libya. The fourth chapter involves two disparate field studies with the findings. Finally, the fifth chapter contains the conclusion and recommendations as shown in Table 1.1.

Table 1.1: Thesis structure



CHAPTER 2

VERNACULAR ARCHITECTURE AND EARTH SHELTERED HOUSING IN THE WORLD

Vernacular architecture has been originated when humanity was compelled to make use of the natural resources around him for dwellings and comfort which would adapt to harsh the weather conditions. Ever since then, vernacular architecture has proven to consume lower energy and to be sustainable. In present time of rapidly increasing technological development and urbanization, there is still much to be learned from the conventional knowledge of vernacular construction approaches. These low-tech ways of creating underground housing which is perfectly appropriated to its locale, and is a reason make architects sometimes ignore the principles creating underground housing. The consideration in recording, arranging and naming different noteworthy or customary materials, shapes, plans and pattern has turned into a generous undertaking of the investigation of vernacular architecture. For instance, Paul Oliver gave himself to the gathering of abodes over the world (1987) and took an interest in the Encyclopedia of Vernacular Architecture of the world, which recorded and archived in detail, various sorts of vernacular design everywhere throughout the world (Oliver, 1997). Another unmistakable research figure, Douglas Fraser (1968) has additionally centered around gathering and examinations of town arranging in the vernacular world. Crouch and Johnson (2001) gathered some design traditionalism in America, Africa, while Vellinga and Oliver (2007) mapped out the vernacular engineering of the world in a chart book. The majority of these inquires about had utilized land and design research ways to deal with chronicle differing qualities of vernacular articulation, including typologies of structures, plans or subtleties, use of materials and their presentation, just as strategies for assortment structural system.

The vernacular buildings were designed and built by people without much knowledge of any type of formal architectural design or identifiable building techniques, instead, they relied upon lifestyle and the physical climatic status of the environment from the local and conventional development materials adjusted to geography, neighborhood atmosphere (sunlight based radiation, temperature, landscape, air developments, and humidity). Vernacular architecture is associated with climate, materials and people.

2.1 Definition of Vernacular Architecture

This is the most incorporated architectural style that aims to design structures that do not cause any damage to the environment it achieves. The indigenous environment, impeccable connection and comprehension of client's needs. The result of an intricate harmonic balance between the item's shape and regular setting, vernacular engineering could turn into an amazingly gainful model for mankind in this present day. Vernacular design items could be related with supportable building standards. This is on the grounds that the regular point of supportable structure and vernacular design is to deliver environmental-friendly structural developments that are proper with the encompassing circumstances and that can proceed for quite a long period of time.

Some of the importance of vernacular architecture has been the realized throughout the large part of history, but decreased during the modern era with development of modern architecture. However, nowadays, vernacular architecture is making a return through green architecture. In order to make vernacular architecture a headway in the future of architecture and sustainable building, must first gain knowledge of the vernacular architecture and use these strategies to achieve optimum renewable energy efficiency. Vernacular architecture is an architectural pattern that is designed and established on domestic urgent needs. Vernacular architecture was developed, with available local construction materials and tradition of the local people, Hence it is safe to say that the inventors of vernacular architecture did not have formal knowledge of any type of formal architectural design or identifiable building techniques, but it depends on the skills of domestic builders.

Vernacular architecture was first evidenced in the post-war period between 1950s and 1960s when architects endeavored to appropriate simple traditional buildings to legitimize prevailing functional theories of design. Vernacular architecture had been described as a functional shelter for people, animals and stores, ‘built to meet needs’, which is constructed according to response to environmental and climatic conditions and the availability and performance of materials that are employed to form it (Oliver 2006; Al Sayyad, 2006). There are many of ideas personally related to local architecture, for example, indigenous architecture, primitive architecture, traditional architecture, and un-institutionalized architecture. Oliver (2007) and Özkan (2006) endeavor to illuminate the difference between every time. It was understood that the expression "traditional architecture", puts accentuation on a procedure which has finished in assembled structure and which is limited to a particular time-frame. Primitive Architecture then again as per (Guidoni, 1975) is acknowledged by utilizing probably the most fundamental necessities of structures in their least difficult structure in a general public. While Folk Architecture implies that compositional issues become some portion of ethnographic suppositions while indigenous engineering lays underlines on the nearby association between specific structure frames and determinable topographical settings. Moreover, mysterious architecture shows that the design did not have any essentially definite building origin, and the term un-institutionalized architecture is utilized to characterize a similar marvel in some scholastic talk (Oliver, 1969; Özkan, 2006).

The etymological underlying foundations of the word "architect" is from the Greek word arkhi- and tekton, which signifies, "chief builder", while "architecture" is characterized as the investigation of structure. Vernacular then again is gotten from the Latin word "vernaculus" signifying "local". Consequently, the meaning of vernacular design can be fittingly thought as "native science of building" (Oliver, 2006).

This character exhibits that the point of examining vernacular architecture is to investigate and create comprehension of the art and science of structural practice in a vernacular community with an unmistakable local personality. In any case, this definition is confronting difficulties in a period of innovative headway and expanded correspondence (AlSayyad, 2006), and the first challenge we should defy is the etymological and epistemological impediments of the idea (AlSayyad, 2006).

The meaning of local architecture is endless in research, what is clear, nonetheless, is that with the expansion in correspondence occur inside the socio-social setting of vernacular design, the investigation of vernacular engineering should focus on its dynamic nature. Concentrates in this setting demonstrate an advancement in the comprehension of local architecture.

2.2 History of Earth Sheltered Housing (Underground Houses)

Since the early times, mankind has lived in underground spaces, people as well as other living creatures have often utilized earth for protection against climatic conditions or predators. Since the usage of caves as shelter, humanity had tried to prepare the needs of their tribes via usage of the earth in their construction ideologies in order to realize healthy and safe spaces such as protection against the harsh climate and wild predators. The cave was also used as a place for living or as building material (Albasha, 2010). Utilization of the underground housing system has protected humankind for a significant period of time and at the same time protected and improved the environment. See Figure 2.1.

Moreover, today's society has turned earth sheltered underground not only as a safe storage place, but also as a place for the disposal of undesirable waste or hazardous materials. Indeed, the presence of inhabited underground dwellings in the world today has proved that these dwellings can offer extremely comfortable living conditions with stable temperature. Hence, some countries of the world have already began developing underground constructions, to adapt to the unhealthy climatic conditions. Many striking examples could be cited to these significant age-old constructions.

Figure 2.1: The distribution of the underground houses in the city of Gharyan (Google earth, 2019)

The nature of the earth in the mountain region and the presence of slopes, hills and valleys had made underground dwellings a widespread building pattern. For centuries, inhabitants of Gharyan in Libya dug into the limestone to make underground houses by hand using with simple and locally made tools such as shovels and picks only. The underground houses in Gharyan consists of eight rooms of almost similar sizes. Traditionally in the past, each room in an underground dwelling was occupied by one family. The houses also include a courtyard approximately 10X10 meters and a depth of 8 meters allowing flows of air and entrance of sun light rays to the rooms during the day. See Figure 2.2. The primary reason for this kind of construction was to provide shelter from conditions such as harsh climate, blazing heat above ground and protection from night cold, as well as predators (Bukamur, 1985).

Figure 2.2: Underground house in Gharyan, Libya (photo by author)

Matmata in Tunisia is a village famous for its typical traditional houses, homes that have been restored in the underground soft clay rocks, providing residents with incomparable climatic comfort. It is a village located in the mountain, 600 meters above sea level, the subterranean town of Matmata, on the edge of the torrid Sahara in Tunisia. Most of the ancient dwellings were built around central courtyards. They are dug around a large open circular well to allow sunlight to enter rooms during the day, and ventilate the air, as well as to keep a relatively steady temperature throughout the year 15°C in January and 25°C in July.

As mentioned earlier, the houses themselves are used as hiding places especially during the Second World War, they were built to resist the desert harsh climate. Each house may be more or less wide as some may include several courtyards, and a sequence of rooms connected via corridors on different levels. See Figure 2.3.

Figure 2.3: Underground dwelling in Matmata, Tunisia
(https://www.amusingplanet.com.Last accessed December, 2018)

More than ten million people live in underground dwellings built in clay soil, earth is used both for agriculture and living. These homes give perfect conditions as they are warm in winter and cool in summer with temperatures going somewhere in the range of 10 and 20°C. The underground abodes building system has been recorded as a National Intangible Cultural Heritage since 2010. See Figure 2.4.

Figure 2.4: Underground dwellings in the city of Sanmenxia, China.
(https://www.rt.com/viral/334638-underground-homes-china-caves.Last Accessed December, 2018)

A city in Turkey known as Cappadocia, located in the mountainous climate, such as rocky buildings and underground dwellings, it is a complex structure that combined both as roky and underground buildings, and underground rooms were sculptured in the mountain on partly soft rocks due to the shortage of wood and other good building material. While the other part is formed in the mountain .The underground shelters provide stable and favorable temperature are about 12 to 15 through the cold weather of winter(Stea and Turan, 1993). For instance, during the severe winter season with dropping temperature, underground temperatures become warmer for its residents without requiring any additional heating support in the homes. Also, during summer with the hot weather condition, the temperature in underground housing become favorably cold. In this city of Turkey. See Figure 2.5.

Figure 2.5: Underground dwellings in Cappadocia, Turkey.
(https://travelatelier.com/blog/vast-underground-city-found-evsehir-cappadocia- turkey .Last accessed November 2018)

In the hot, arid outback in Australia, occupants of the opal mining town of Coober Pedy, for most part, in dug out dwellings. The primary function of these homes is to provide relief from the heat, but they also offer privacy and security. See Figure 2.6.

Figure 2.6: Underground dwelling in Coober Pedy, Australia:
(https://www.domain.com.au. Last accessed December, 2018)

2.3 Earth Sheltered Housing Development

For hundreds of years, underground housing construction has been in practice. It was majorly developed during the mining era, however, it is now being developed through transport, housing and commercial industries. The British Library and various shopping centers in Britain include some prominent examples of underground housing constructions. Underground building construction is also known as earth sheltered housing. This refers to houses built completely underground or partially submerged (i.e. partly underground and partly on ground). Underground housing has gained significant recognition through the end of the 20th and people were increasingly building underground houses. The underground houses also contributed largely to the green building construction. By the year 1970, there were several successfully built underground buildings across the world including USA, UK and China etc. One of the dominant factors in the consideration of earth sheltered housing is the question about conservation of energy. Earth sheltered housing is estimated to conserve about 80% or even more of energy in comparison to traditional aboveground houses. For this reason, more knowledge on how to conserve energy and the environment resulted in the continuous and rapid increase of the construction of underground houses (Boyer and Grondzik, 1987).

There are thousands of underground buildings with inhabitants in America and Europe. Underground housing construction has seen more evolution than aboveground housing in Russia. In Asian counties like Japan and China, evolution of underground buildings is at premium and more people are keen to building and developing underground houses. However, the place of underground housing development in UK is slow compared to the above mentioned countries with only around a hundred underground homes in existence.

One of the United Kingdom is earliest earth-sheltered houses is the Hockerton Housing Project in Nottinghamshire. It is an independent environmental dwelling structures. Individual construction staffs carry on with an all-encompassing lifestyle in consistency with the environment, wherein all biological impact had been considered and represented. Hockerton Housing Project, has five inhabitant houses that are self-sufficient as they produce renewable energy including personal domestic water as well as recycling waste produce to combat CO_2 (carbon dioxide emissions).

Dwellings in the Hockerton Housing Project were very energy efficient and are specially-constructed houses in the West. Brenda & Robert Val are the main mind behind the design of this earth-sheltered housing project. See Figure 2.7.

Figure 2.7: Hockerton Housing Project (http://seonottingham.blogspot.com/2012/03/hockerton-housing-project.html. Last accessed December, 2018)

Another important underground housing is the Villa Flower Petals located at Bolton, U.K, and this rural ecofriendly underground villa was built under a hillside. This huge 8,000 square feet flower-shaped dwelling is very interesting from above, particularly at night when it is lighted against a background of the green earth. The four-bedroom, single-storey family design serves as a modern residence equipped with high technology. The villa generates electricity with wind power and solar energy and operates the heating system with pumps. As a result, there is reduced carbon emission and increased conservation of environment unlike the conventional houses which are built by bricks and concretes in construction. See Figure 2.8.

Figure 2.8: Villa Flower Petals, UK. (Beverly, 2012)

2.4 Importance of Sustainable Earth Sheltered Housing

Underground houses systems are seen sustainable due to three major sustainability considerations namely environmental, social and economic. These three aims are discussed in the following subsections. Sustainability as a major significant concept involves four main dimensions, environmental, economic, social and cultural. Environmental sustainability deals with the protection of biodiversity, ecological balance and natural environments within the city. Additionally it targets to improve human health, and air, water and soil quality. Economic sustainability aims to obtain economic development and growth while maintaining the existing built environments and social, cultural and natural values. Social sustainability has a goal to provide equal access to basic needs such as health care, housing and employment for all citizens, as a must of social justice. Cultural sustainability deals with the characteristics of the society in relation to physical, cultural, socio-psychological aspects such as cultural heritage, lifestyles, creativity etc. Thus, it can be suggested that earth sheltered housing directly contributes to the three of four main sustainability pillars.

Until today, there still remain some major misconception surrounding underground housing. There are people who still believe these houses are dark, unclean, unpleasant and generally not fit for lifestyle. However in contrast, underground houses can be very healthy comfortable, safe and exciting living places. For example, there are several ways and layout to provide a sufficient quantities of air, light and pleasing views in this kind of housing. Also, underground housing systems provide opportunity for arranging windows in an appropriate orientation that will allow considerably free flow of light in to the entire house, placing vents in several locations can effectively consolidate the inner ventilation; designing slightly larger courtyard can certainly create a nice relaxing area .Moreover, an architect known as Malcolm Wells was a pioneer in this drive towards " building without destroying the earth", he stated that an earth sheltered house does not mean you stay in dark caves"(Wells,1998).See Figure 2.9 and See Figure 2.10.

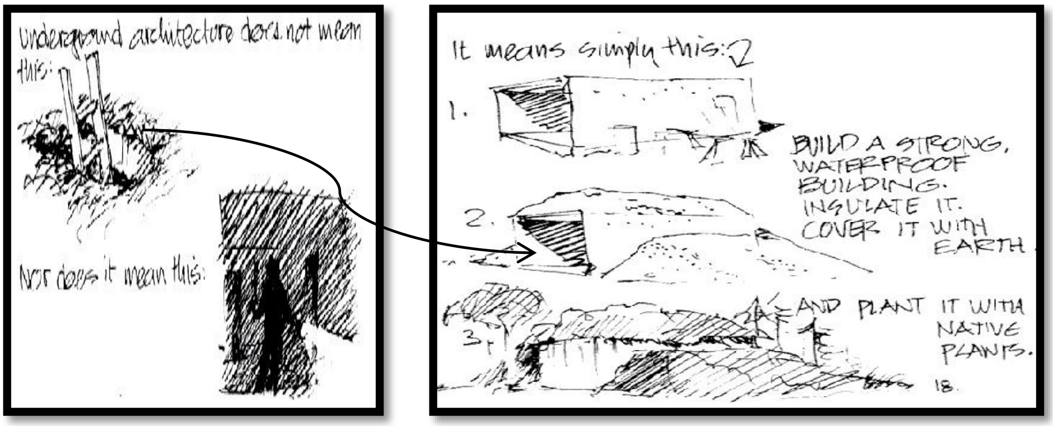


Figure 2.9: Building without destroying the earth (Wells, 1998)

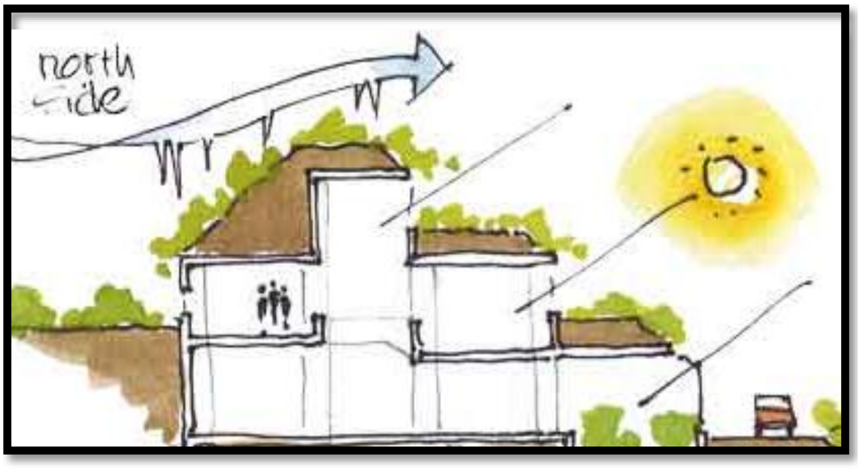


Figure 2.10: Earth sheltered with light (Wells, 1998)

Underground houses systems are seen sustainable due to three major sustainability considerations namely environmental, social and economic. These aims are discussed in the following subsections.

Table 2.1: The dimensions of the sustainable underground housing (wells, 1998)

Sustainable Earth Sheltered Housing

Environmental

- Decrease environmental interference
- Thermal constancy creates regular inner ambient temperature.
- Reducing carbon dioxide emissions.
- Solar Heating, due to the earth remains at a constant temperature, the earth sheltered home can use passive solar, without gadgets needed
- An Earth Sheltered House is comfortable all year round, stays cool in summer, cosy in winter.
- Unique and exhilarating, there is a new lifestyle.
- An Earth Sheltered House keeps safe from hail, tornadoes, etc.

Economic

- Energy Efficiency, provide up to 80% on heating and cooling.
- Lessen energy cost.
- Drastic low lifestyle cycle, lower than 1/4 of that of a conventional house.
- Little or no maintenance, this means decrease cost.
- Long lasting, built of concrete, earth sheltered homes will last well 100 years.
- Increased yard area makes a small lot larger. More room for lawn, gardens.
- Fire resistant, reinforced concrete with earth cover offers the better fire resistance available and protection from nuclear fallout.

2.4.1 Environmental benefits

To sustain the environment in a lay man's language is to simply conserve the land in its perfect situation for next generations. A positive support to actualizing the goal of conservation of the environment is underground housing which consumes its own wastes, keeping itself, support wildlife habitation, moderate climate and is simply beautiful for human habitation. In underground housing system, soil which is an environmental material, is used as building material for insulation, while the sun and wind are used to generate energy, thus, the emission of is significantly reduced and hence controlled. Furthermore, modern design of underground houses shows promising and extremely attractive designs of earth sheltered houses (Wells, 1988). This evident in some of the pictorial representation is presented in previous sections. Mac's view regarding underground architecture is building without destroying earth.

In any case, singular proprietors can profit by the natural underground methodology all alone locales, paying little respect to the size of neighboring application. Characteristic returns will appear as expanded usable land territory, and vitality advantages will be acknowledged as far as monetary investment funds. Malcom Wells has communicated the conclusion, "On the off chance that you can't improve the site, don't work by any stretch of the imagination." This is an extreme proclamation with regards to current America's dwelling systems. Avery good example of unground housing systems is the Hilton Hotel master minded by Tree hugger and is being developed in Bariloche, Argentina. It will be eco-friendly project. The hotel is designed in such a way that it will blend with the mountain's located to reduce optical effect, and the fact that through constructor process and later in its operational stages, the hotel will have efficient utilize of energy and water and "proper administration of soil and drainage. See Figure 2.11.

Figure 2.11: Hilton Hotel in Bariloche, Argentina
(http://landscapeandurbanism.blogspot.com.Last accessed December 2018)

2.4.2 Economic benefits

In the economic aspect, underground housing is promising. As the cost of living continues to rise up, rapid growing population and urgent need to housing, people everywhere are rethinking their needs for affordable ways to live. Houses become huge financial burdens to even think of. A beautiful underground dwelling can be affordable to build and maintain, when working in sync with the ecological systems. The whole building method is in support of the natural environment. That is environmentally friendly construction living. A hand build earth sheltered house will cost around 5000$. One young couple in Wales went ahead and built their own cheap home which was sustainable and was made mostly out of materials from "a rubbish pile". The result was their very low impact homemade house. Shows an earth sheltered house in use with cheap building costs. See Figure 2.12.

Figure 2.12: Hand-Build Earth Sheltered House
(https://greenbuildingelements.com. accessed December 2018)

Earl and Freida Woods constructed an economical underground earth sheltered home that uses solar energy and cost only $10,000. The house they built was located in the mountains of eastern Tennessee in 1977. The structure's walls composed of eight-inch cement blocks which were treated inside and out with surewall surface-bonding compound. Reinforcing rods were inserted in the blocks, and the remaining cavities were filled with cement. Steel I-beams support the overhead, which was composed of approximately five inches of concrete. The 960-square-foot house contains three rooms. It took Earl and Freida about two and half years to complete construction of the house entirely. The house has an open fireplace at present, and the Tennesseans report that a comfortable indoor temperature is maintained in all-weather condition. With a final construction bill of around $10,000, this do-it-yourself economical underground earth sheltered home dwelling proves once again that earth sheltered living is a practical alternative to the delimit of housing we are facing today. See Figure 2.13.

Figure 2.13: An Economical underground earth sheltered home (https://www.motherearthnews.com/nature-and-environment/economical-underground-earth-sheltered-home-zmaz82ndzgoe.Last accessed January 2019)

2.5 Types of Earth Sheltered Housing (Underground Housing)

Compared to the atmosphere, the earth offers a more stable and moderate an environment to buildings. Moreover, it decreases or even eliminates wind and storm effects. Earth is also a large thermal storage capacity that allows renewable energy sources, such as the sun, to be used effectively. An earth-sheltered building is either covered on one or more sides with earth or built partially or completely underground. Indeed, this kind of building is a method to effectively control a buildings interaction with its surrounding environment.

An underground house varies widely in design and layout. Some designs have only earth covered walls; while in some others, the earth also covers the roof. One of the most common types of earth-sheltered dwelling is the elevational design. Table 2.2 illustrates types of earth sheltered houses. See Table 2.2.

Table 2.2: Types of earth sheltered houses. (Albasha, 2010)

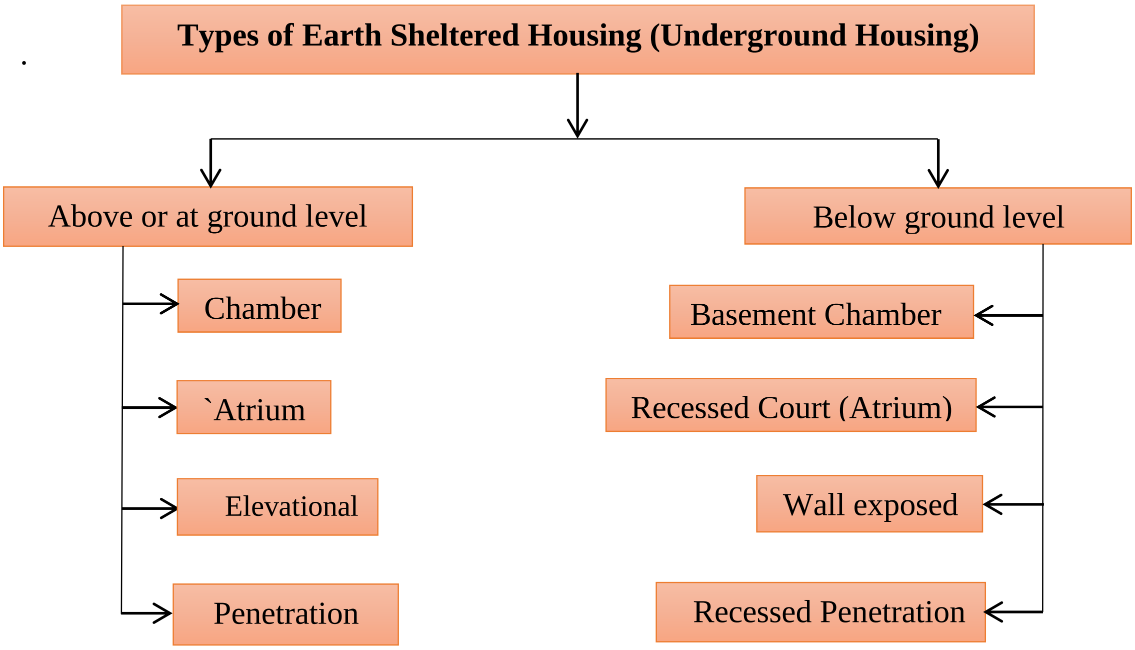
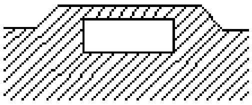
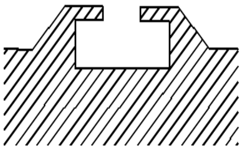
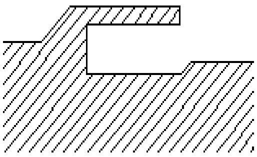
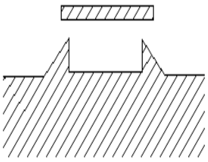
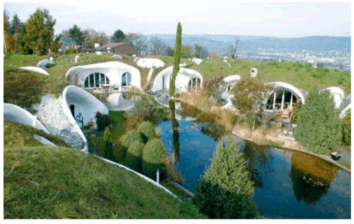
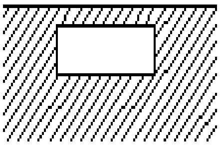
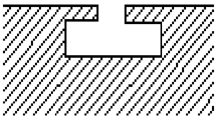
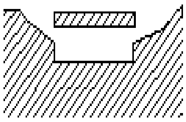
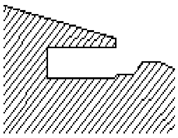


Table 2.3: Types of earth sheltered houses (Above or at ground level) (Moreland, 1975)

Type	Above or at ground level	Examples
Chamber: The home wholly underground without Frontages to the outside. The building is higher than the level of natural ground it is covered with grass roof.		 Ear Holmewood House is a villa designed by Robin Partington in London, (Beverly,2012)
Atrium: Ventilation and lighting are provided from the courtyard.		 Aloni, Antiparos Island, Greece. (https://www.archdaily.com/45925/aloni-ecaarchitecture.Last accessed January 2019
Elevational It has one side open and preferably from the south side to provide ventilation and light. This type of design is most commonly used to take advantage of the insulating properties of the earth.		 A troglodyte home built into a cave in France.(https://www.pinterest.co.uk.Last accessed February 2019)

Type	**Below ground level**	**Examples**
Penetrational: The openings were created on sides of building to provide light and ventilation.		 Nine Houses. Dietikon, Switzerland (Beverly,2012)
Basement Chamber: The building is under the natural earth level, and, the roofing at the same level natural earth .and it is covered with a grass.		 Underground home in the village of home in England(http://www.blueridgeapartments.com/interior-improvement.Last accessed February 2019)
Recessed Court (Atrium): The house wholly underground with Frontages in the courtyard, Ventilation and lighting are provided by the courtyard.		 Underground house Gharyan, Libya. (photo by author)

Type	Below ground level	Examples
Wall exposed: The building has side openings in wall for light, ventilation, access, view, expansion potential, with the roof is covered by grass.		 Underground Bolton Echo House-North West England. (https://mymodernmet.com/make-architects-bolton-eco-house/)
Recessed Penetration: The building is cut into the hillside and has (windows, doors) from one side to provide light and ventilation.		 Underground Houses: Vales House Switzerland.(Beverly ,2012)

2.6 Summary

This chapter addresses the vernacular architecture (underground housing) and also earth sheltered housing. Vernacular architecture (underground housing) in different countries was designed and built by people without much knowledge of any type of formal architectural design or existing building techniques; rather they relied on the physical and climatic conditions in that era, they utilized local conventional building products, adapted to the topography, local climate (solar radiation, temperature, air movements, and humidity) and landscape. In the last century, some countries of the world began to pay attention to developing underground buildings and to use modern technologies for the adaptation of different climatic conditions. The new sustainable type of housing is called as Earth sheltered housing having economic, environmental benefits.

CHAPTER 3
AN OVERVIEW OF VERNACULAR ARCHITECURE AND MODERN DWELLINGS IN LIBYA

3.1 History and Background of Libya

Libya is located in the north of Africa and covers 1,759,540 million km², it lies between latitudes 19N and 33N and between longitudes 9E and 26E. The country is bounded by the Mediterranean Sea to the north. Egypt lies to the east, Sudan to the southeast, Chad and Niger to the south, Algeria to the west and Tunisia (Amer, 2007). Libya is considered one of the largest cities in Africa by landmass, however, only 6% of the land is considered usable. It means that 94% of the landmass or total area is covered with sand (desert). After the discovery of oil, majority (three-quarters) of the population moved to live in urban areas because the urban areas achieve better job opportunity and better social amenities; in addition major agricultural cultivation of land is observed. Cultivation of land for agricultural use is observed in less than 2% of the country's total area (Ministry of Municipalities, 1979; Aburroush, 1996).See Figure 3.1.

Figure 3.1: Map of Libya (https://kids.britannica.com.Last accessed January 2019)

Libya has been invaded and occupied by foreigners for varying stages of invasion and, colonization and rule for a very long period of time (2500 years). Some of the ancient civilizations that invaded, conquered and ruled a part or all parts of Libya are the Carthaginians, Arabs, Phoenician, Greeks, Italians, British Empire, Romans, Vandals, Byzantines and the Turks for the last centuries (Birks and Sinclair, 1980; Fisher, 1978). Most of the countries that is rich by oil today, once had a weak economy. This was not different for Libya. As such, it was one of the poorest countries before the miraculous discovery of oil and agriculture was the backbone of the people. After oil was discovered, a rapid economic development in education and construction sectors has been recorded. The trend was to develop infrastructure by implementing a variety of housing projects and civic buildings; this growth was only in favor of modern construction, resulting in the emergence of a large number of structural buildings with similar styles built throughout the country. The architectural designs were prepared by architects from western countries who did not necessarily take in to account the cultural identity, local environment and climate of the regions found in diverse traditional houses in Libya.

3.2 Vernacular Houses in Libya

The traditional housing in Libya is considered the wealth of vernacular architecture representing knowledge and experience that is positively acquired through daily life and obtained from our ancestors who had discovered simple building techniques introduced into the construction of their dwellings from local material. For providing thermal comfort of both summer and winter season. This chapter addresses the three types of traditional vernacular dwellings in Libya, that are distributed in three regions of the country namely the mountain region (underground housing), the desert (compact dwelling), and coastal region (open courtyard) (Gabril, 2014).

3.2.1 Vernacular houses in the mountain region

The Mountain of Jabal in Nafusah region in Libya is famous for its underground dwellings especially in Gharyan city. These houses have a lot of characteristics, as such they are inexpensive to build, and less energy consumption compared to aboveground dwellings. There are other types of vernacular housing stone-built and aboveground which were built for hundred years by the local people. Using the locally available building materials such as stone, mud, gypsum, olive tree-trunks, and the type of soil in the mountain region made it easy to dig underground houses (Shaiboub, 1979). These houses have a lot of characteristics that are suitable for climatic conditions in both winter and summer, such that the temperature is almost moderate in both seasons, in order to create a comfortable internal microclimate. In other words, vernacular houses provide comfortable climate for their inhabitants over the years. There are three types of vernacular underground dwellings both of which provide comfort through annual temperature changes (Rghei, 1987). In the following section, these types of dwellings will be discussed.

3.2.1.1 Underground houses

Inhabitants of Gharyan in Libya excavated into the soil to build underground houses by hand using simple and locally made tools such as shovels and picks only. The underground dwellings consist of between 3 to 8 rooms of almost similar sizes, there are three small kitchens of trapezoidal shape with various spaces, and approximately 2.00m high, between each two rooms is a kitchen shared by the two families with open doors, in order to provide ventilation when cooking. The rooms were warm during the winter and cold in the summer. Traditionally in the past, each room in an underground dwelling was inhabited by one family opening on a courtyard approximately 10 x 10 m and a depth between 7 to10 m that allows flow of air and entrance of sun light rays to the rooms during the day. The primary reason for this sort of construction was to provide shelter from difficult conditions such as harsh climates and predators. See Figure 3.2.

Figure 3.2: Two of the underground dwellings one consists of 3 rooms, and the other 8 rooms (photo by author)

3.2.1.2 Types of underground houses

- **Aboskefa (First type):**

These kinds of dwellings (Aboskefa) are completely underground, except part of the main entrance door which opens above the ground. They consist of a square-shaped courtyard surrounded by rooms. The dimensions of the courtyard range from 7 x 7 m or more, and 7m to10 m deep depending on the area of the house, its function, availability of natural light and ventilation, and the daily activities of women. In the middle of the courtyard. a hole was dug deep enough and filled up with salt and organic materials for the purpose of collecting and draining rainwater from the courtyard during raining days. The courtyard is surrounded by iron fence or a small external wall forming an external courtyard built from the digging material to prevent people and animals from falling into the courtyard below (Daze, 1982; Bukamar, 1985). Further details will be provided in Chapter four. See Figure 3.3.

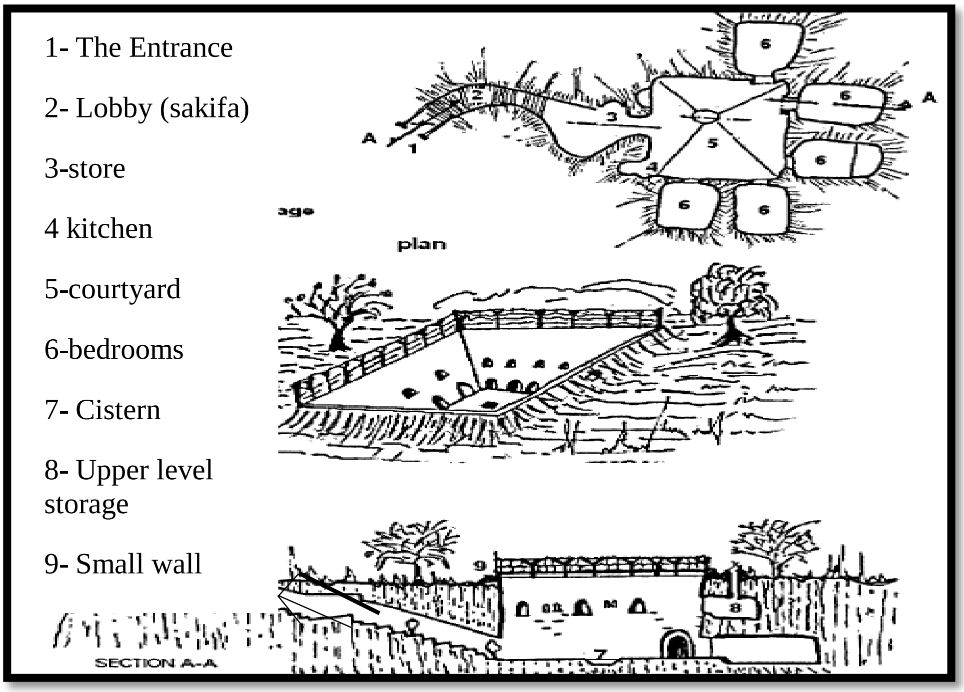


Figure 3.3: The first type of underground house, Aboskefa. (El-Dweb, 1995)

- **Al-Feseal (Second type):**

This kind is located into the foothills of the mountains on a steep slope. This dwelling has some elevation above ground, and open its rooms on the level of the ground, and they consist of a rectangular-shaped courtyard surrounded by rooms, which are dug in three sides, the fourth side were built by stone. The light and air enter the rooms directly from the exterior. This type may have a terrace in front that acts as a courtyard. See Figure 3.4.

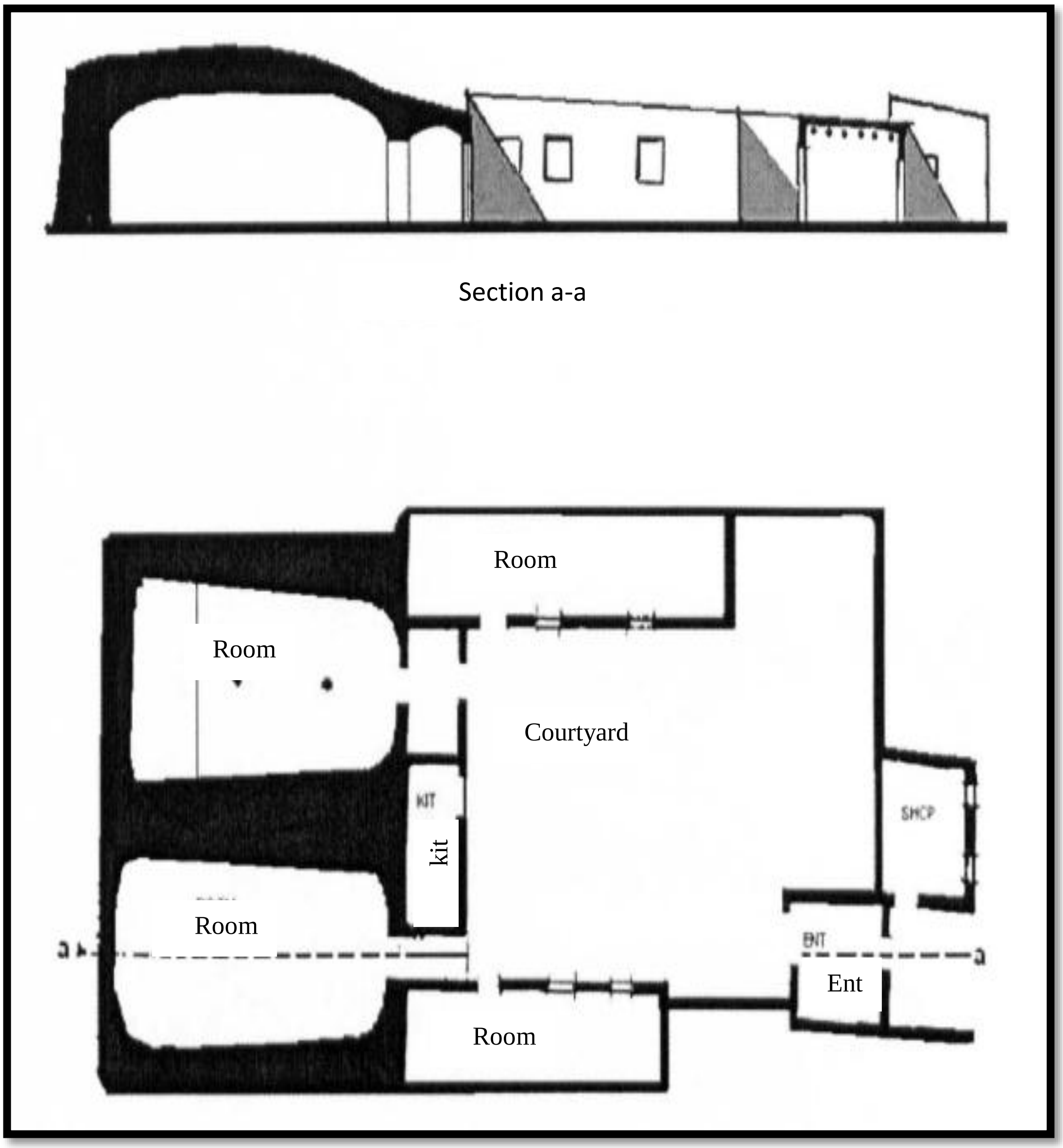


Figure 3.4: The second type underground house Alfasel. (Doxiadis, 1964)

3.2.2 Vernacular houses in the desert region (Old city of Ghadames)

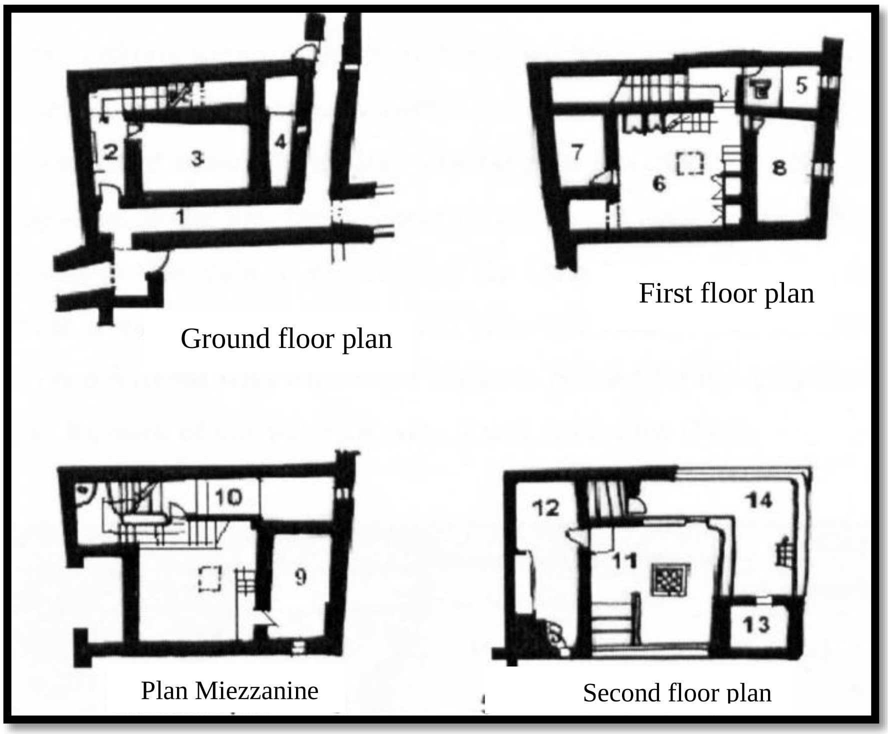
Ghadames is Libyan Desert city, located 630 km southwest of Tripoli with desert climate. The climatic condition ranges from harsh cold in the winter with almost no rainfall to hot weather in the summer with rainfall. There are high temperature variations between day and night in the summer, with the average temperatures in summer reaching up to 40ºC.

UNESCO declared in 1986 that the old city of Ghadames is a World Heritage site (Gabril, 2014). The dwelling of Ghadames is considered as one of the most important architectural components of the ancient city of Ghadames, with its unique and exquisite architecture, and its white walls from the abundance of inscriptions and decoration that give the place aesthetic visual. The construction of Ghadames dwellings takes into consideration of all geometric shapes, measurements, calculations, and local building materials appropriately obtained from the environment for the thermal comfort inside the dwellings. These houses are relatively cool through day and warm during the night (Mezughi and Dawib, 2003). The dwellings were built by domestic people who used locally available materials such as clay, soil, lime and gypsum, which are largely in harmony with the surrounding environmental conditions. Such measures can be clearly seen in the features of its houses and the method used for organization of their internal space. According to Ahmed (1985), the majority of houses in Ghadames have the same layout, and vary only in size, decoration according to the economic situation of the family. See Figure 3.5.

Figure: 3.5: Ariel view of the old city of Ghadames. (Photographer Georg Steinmetz Biography-National Georaphic, 2013)

3.2.2.1 The traditional house in Ghadames

The ground floor consists of covered passageway where the entrance is opening directly inside to the house. It is usually painted white and usually there are number of mirrors to reflect light and keep on bright space. On the ground floor, there is a space used as storage for agricultural tools or commercial goods. A staircase leads to the next (first) floor. The first floor consists of a space referred to Sadr el-beit which serve as a living room and at the same time a reception. It is located in the middle of this floor. With lighting and ventilation coming from a small-unglazed window (75 x 75 cm) in the ceiling, lighting is distributed by reflection mirrors into all parts of the house (Amer, 2007). Second floor or roof top, consists of a kitchen and terrace, for the storage of fuel. The kitchen is located at this top or roof floor in order to discharge the extra heat and smoke caused by cooking. See Figure 3.6.



House plan key /1-street 2- Entrance corridor 3-store 4- Latrine pit 5- Latrine
6- Guest room and living area (Sadr el-beit) 7- Girls room 8- Main bedroom 9- Boys room 10- Store room 11- Roof terrace 12- Kitchen 13- Children's sleeping 14- Steps leading to neighbor house.

Figure 3.6: The dwelling unit type in the traditional residential desert region (Chojnacki, 2003)

3.2.2.2 Materials and construction methods

Clay soil is generally not suitable for agriculture but good as a building material in Ghadames. Since most of the old houses were built using dried bricks made of mud soils, the bricks were made from a mixture of clay soil, water and straw, in dimensions 40x 30 x 10cm. The main materials used in the construction of the Ghadames house are mud, natural stones gypsum, and straw, palm trunks for the roofing while small stones, mud and limestone are laid over them (Shahran, 2018). See Figure 3.7.

Figure 3.7: The ceiling with stumps of palm trees, and small stones. The Bricks are made with clay materials which are dried in the sun, this ceiling has a dimensions of 40 x 30x 10 cm (Shahran, 2018)

The builders of Ghadames city have been able to use these materials economically and technically to build mud houses that have remained resistant to climate; these houses have been suitable for hundreds of years until today. In some of the houses there are small scaled windows which were constructed in rectangular shape of 30x30 cm dimension in the external walls of individual houses. This window design was specially designed to provide air for ventilation and light movement from the street. Also, an opening is created at the ceiling of the living room which serve to provide light and air ventilation to the lowers. See Figure 3.8. The light is reflected to other parts of the house via the reflection of mirrors placed in strategic positions on the walls of the living room to the walls of the male guest room (Gabril, 2014). See Figure 3.9.

Figure 3.8: The mirrors reflecting natural light into the rooms, and windows is opening at the roof (Shahran, 2018)

Figure 3.9: Day lighting distribution in Ghadames house (Gabril, 2014)

3.2.3 Vernacular houses in the coastal region (The courtyard house)

The courtyard dwellings are known in most of the Arabic cities, and as well as in Libya. They are widespread especially in the coastal cities such as Tripoli, Maserati, and Khoums built with locally available construction materials. The courtyard houses are usually constructed in rows in the cities and have only the front face opening on the narrow streets, while the other sides are connected to adjacent dwelling. The average area of these houses is 300 square meters, and the courtyard ranges in area from 70 to 100 square meters. The courtyard may contain a planted tree, and in the middle by an adorned water fountain (Amer, 2007). See Figure 3.10.

Figure 3.10: Fountain in the center the courtyard and tree in the middle of the courtyard (Shahran, 2018)

One of the functions of the courtyard is to collect air from the outer environment in to the inside of the houses and circulate. The courtyard house was fundamentally categorized into two types, two storeys which are more popular in the cities where meet to the needs of city inhabitants, for reasons of land restriction, and the other being built in rural surroundings where there are different environmental and social influences (Amer, 2007). The shape of a courtyard house may be rectangular or square (Zarrugh, 1976). These houses usually consist of set of rooms of different sizes means for different purposes and are distributed around the central courtyard. Most of the traditional houses in Tripoli constructed their rooms in rectangular shape, with men salon, bathroom, and sometimes stores (Shahran, 2018).

There are usually seven rooms on the first floor, bathroom, toilet, with arched porch surrounding the courtyard from the four sides that creates extra shade on the wall facing the south in ground floor, and giving access to the rooms on the same floor. See Figure 3.11.

Construction materials in these houses consist of locally available materials such as limestone and mud brick which is used in walls typically the inside walls up to 60 cm thick, the external walls thickness up to 90 cm (Shahran, 2018), and roofs were generally flat, concrete earth or clay and laid above a wood structure made from palm-tree trunks and joists from pine timber.

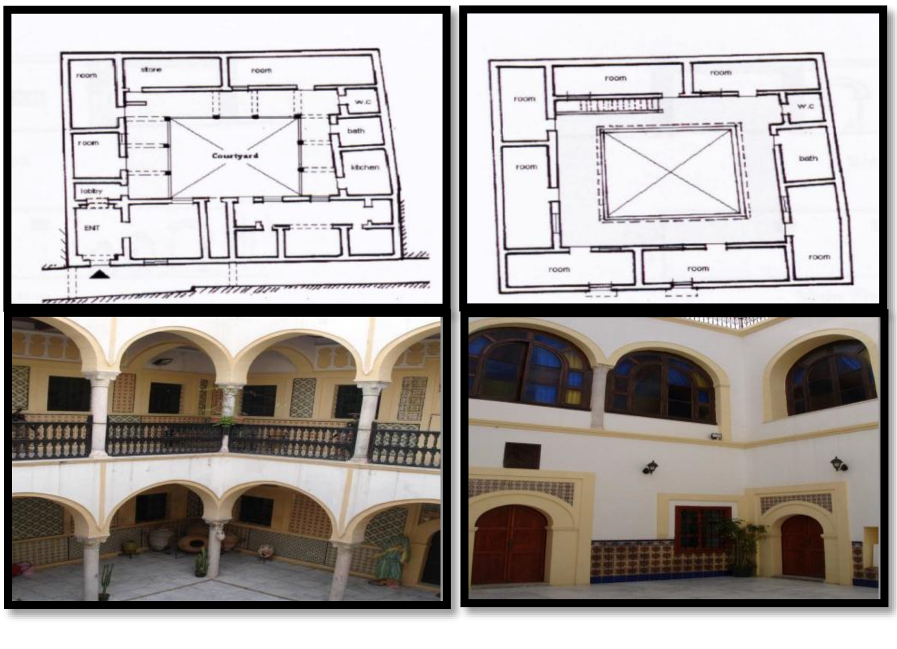


Figure 3.11: A two-story Libyan courtyard house in city of Tripoli. (Amer, 2007)

3.3 Modern Housing in Libya

Libya has experienced a lot of development in all sectors after the discovery and production of oil starting from the 1970s. There has been infrastructure development and public facilities such as hospitals, schools, hotels, and others. In particular, the housing sector is one of the most important sectors for Libyans. The modern buildings were designed by foreign architects from western countries such as England, Korea, Turkey and recently Indian and Chinese architectural firms with limited participation of Libyan architects involved. These foreign architects were given large number of building construction contracts; however, they failed to take into consideration of the climatic and social factors. As such, these factors should be considered among the most significant features in the design of houses in Libya. The vast majority of public housing in cities was constructed with similar design without considering the climatic conditions of the areas. Also, there were individuals who obtained real estate loan and they built private housing. Such that there are many modern housing projects in Libya ranging between one to 13-storeys with different designs, built in different periods (Amer, 2007).

3.3.1 Types of modern houses in Libya

Thousands of housing have been built by the government of Libya. There are many patterns of modern housing in Libya, some of them have been built by the government on different periods during the past decades, the others built were by citizens. There is a variety in design and construction system used both traditionally and prefabricated. Types of modern housing in Libya can be classified as follows:

- **Private Traditional Popular Houses**

According to Gabril (2014), the private traditional popular houses were built in the 1950s and 1960s developed in specific regions of cities in Libya are referred to as Taqasim where adjacent land were planned in areas of 120-140 square meters. According to Toskovic (2006), these houses were built by people in cities mostly with opened windows to the street, and abandon some vital characteristics such as the courtyard, lost its main significance as the center of household life. The primary rooms reach a hallway, and different rooms are situated in the back. The walls were built with concrete blocks or stone walls or loadbearing walls supporting mainly concrete or 'travetti' roofs. Aesthetically, it is as an unoriginal and uniform layout, but it neglects environmental factors. See Figure 3.12.

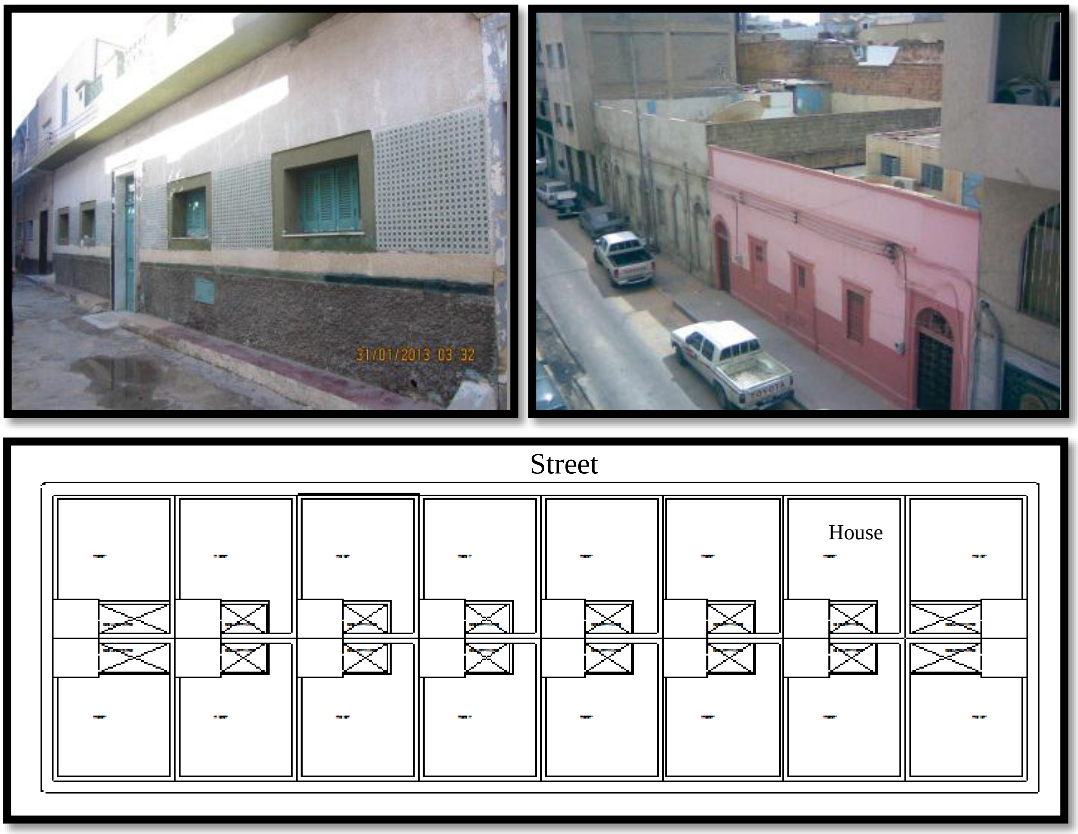


Figure 3.12: Traditional (popular) house type 1950-1960 (Gabril, 2014)

- **Public Housing**

This project was implemented in three phases in 1971 and was completed in 1975; it was distributed to twelve cities, including Gharyan, Misurata, Al-khoms, Elikhalij, and other cities (Bukamur, 1985). One of the examples of the public housing in the city of Gharyan (Popular house), this house consists of two stories, each storey for a family. Each floor has 2 to 3 bedrooms, men salon, kitchen, and bathroom, with an area ranging from 120-140 m^2, the ground floor has a garden in the shape of a letter L, the house opens on the street and some windows are open on the garden house. The ministry of housing and utilities carried out comprehensive maintenance for these houses in 2010. See Figure 3.13.

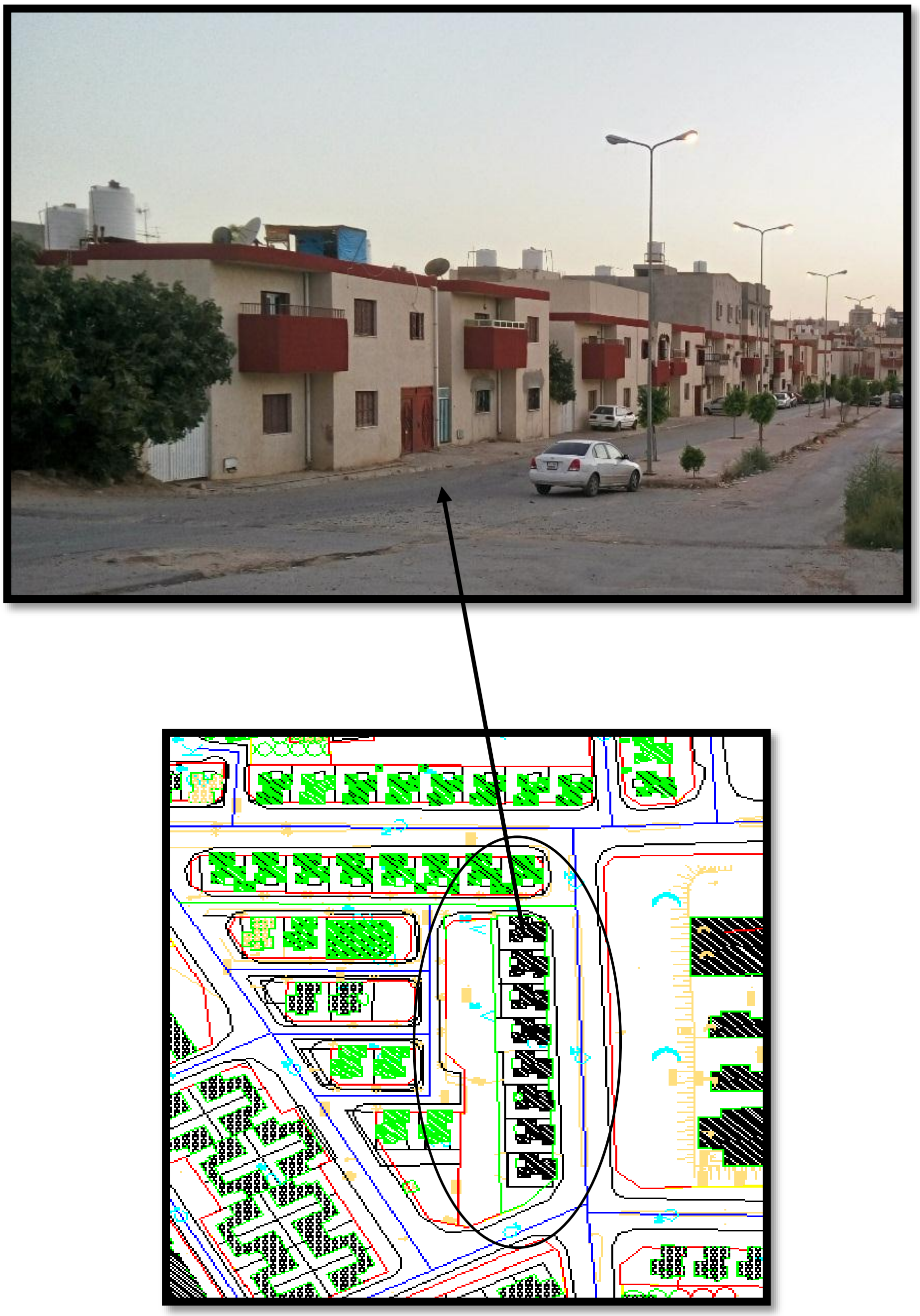


Figure 3.13: Plan for residential public houses in the city of Gharyan (photo by author)

- **The villa**

According to a description by Toskovic (2006), this type of houses is referred to as ‘Villa’. It is a modern type of habitation in Libya substitute by the old "Mansion" house. It is a separated house often surrounded by garden and high fences in order to ensure privacy. On the other aspects of functionally, it is seen as a reflection of western European pattern or those dwellings in USA. There is no central courtyard as a nucleus of daily life. This type of house has openings in the garden or road, and the main rooms can be reached through an entrance hall, and a small corridor reached up to utility rooms, bedrooms are often in the first floor.

The structure of this house has stone dividers, reinforced structure or concrete brick form load-bearing walls supporting mainly concrete or travetti' roofs. Villa houses can be classified in three major tendencies today as cosmopolitan, neo-classic, and a modern type of the desert pattern villa. All these models dominated the architectural trends of villa designs in Libya. The cosmopolitan villa pattern seems to be the dominating villa design. The cosmopolitan villas have beautiful aesthetic features; however, they are considered as aesthetic achieved through the method of "copy - paste" of so-called modern trend. An aesthetic measure of villas is achieved during modern architectural movements; however reasonable adjustment is made to adapt to the climatic environment, prompting a shortage of domestic flavor to stamp them as distinctly local designs. The neo-classical pattern uses to a narrow scale as a style that is not suitable environmentally and culturally in Libya. See Figure 3.14.

Figure 3.14: Villa- detached and semidetached houses (Gabril, 2014)

- **The Apartment Buildings**

This type of accommodation in Libya is similar to those found in European countries. With an area ranging from 120 to 140 sq.m of floor space, they are constructed starting from 3 to

12 storeys. Multistory houses are a type of accommodation that can be seen in Benghazi and Tripoli which where were implemented by the Government's Housing Program. However, absence of privacy is a noteworthy weakness.

In many apartment buildings, the blocks share party walls. This type consists of a seating room of nearly 30 m², one dining room, two-bedroom, bathroom, and a kitchen. The apartments are accessed by stairs. Every house is equipped with a balcony or two. There is an entry hall or corridor, sometimes it has two corridors linking rooms and utility rooms. The central courtyard loses its function significance, it begins to work in providing good lighting to the building. See Figure 3.15.

Figure 3.15: The apartment buildings in Tripoli city .Multistory houses (https://mapio.ne. Last accessed April 2019)

3.4 Summary

This chapter presented the vernacular and modern types of house designs in Libya evolved through the history of the country until the modern period. After the discovery oil, construction of new modern scheme housing projects increased instead of traditional style housing projects. Some of the traditional houses were built by ancient innovations created such as the Italian rule for instance, while others were completely constructed by cheap, available and locally made construction materials such as the traditional houses in Tripoli, Gharyan, and Ghadames. Most of the traditional houses were built for the sake of security and adaptation to the hot desert climate. One of the interesting points of those traditional houses is the underground house as the basis of this thesis. Thus it will be discussed comprehensively in the following chapter with compared to the modern houses.

CHAPTER 4
METHODOLOGY

4.1 Information about City of Gharyan

Gharyan is a city located in northwest Libya. Gharyan is the largest city in Mount Nafusa region. Gharyan region extend across the top of the plateau at the end of the Jebel Nafusa. It is located about 85 km south of the capital Tripoli and just before Yefren, the latitude of the Gharyan is 32°11' N, , and the longitude is13°00' E . With GPS coordinates of 32°10'18.462' N and 13 ° 1 '6.2832' 'E. The height of Gharyan is about 700 meters from sea level. See Figure 4.1 and Figure 4.2.

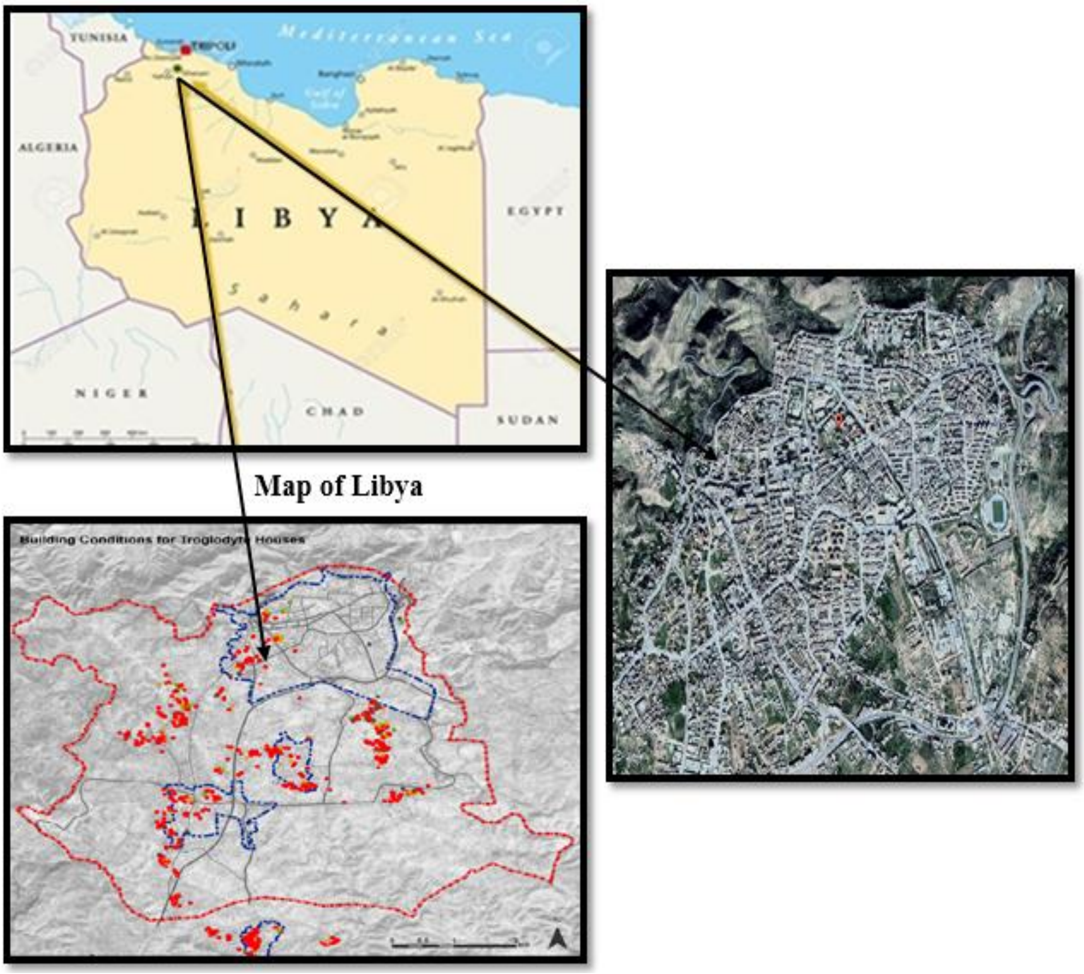


Figure 4.1: The administrative boundaries of the city of Gharyan (National Consulting Bureau, 2009)

Figure 4.2: City of Gharyan (photo by author)

Gharyan is famous for the underground dwelling. These underground dwellings were built hundreds of years ago by local ancient inhabitants of the area. They provided shelter from cold winter, hot summers and invaders. Gharyan city (Bughilan zone) is famous throughout Libya for their pottery. Shops line the road in selling everything things made from pottery from big serving bowls and dishes to small pots and storage jars pottery, production olive, it has many modern buildings such as administrative buildings and modern housing. See Figure 4.3.

Figure 4.3: Production pottery in Gharyan (photo by author)

- **Topography of Gharyan**

Libya’s ecological conditions have affected its physical structure, earth utilize, and distribution of its population to a huge extent. Around 94% of the total area of Libya is a desert, the vast majority of which is considered to be unproductive. Nearly 3/4 of the inhabitance live in the major urban regions and most of the cultivated land is concentrated in less than 2% of the country’s total area (Ministry of Municipalities, 1979; Aburroush, 1996). The mountain areas are divided into two main sections, Jabel Nufusa (the Western mountain), Gharyan city is located on this mountain, and Al-Jabel Al-Akhdar (the Green Mountain). The first mountain region is in the western part of the country, south of the Jefara region, rising steeply above it. Its average width is 20 km, and it runs due east for about 400 km from the Tunisian border in the west to Al-Khoms city, which is 110 km east of Tripoli. The height of the Jabal Nufusa range is between 500 to 960 m. consisting of many catchment areas and valleys. In this part, the land is composed of basalt, volcanic rock, limestone-loess and gypsum-marl (Bukamur, 1985).

- **The Climate in Gharyan**

Gharyan city is generally cool. In winter, the temperatures sometimes fall below freezing, snow falls occasionally. The coldest month is December. The highlands of Jebel Nafusa and Jebel Akhdar, areas have the best summer climate, because the relative humidity is much lower than that in the coastal zone (Ministry of Planning, 1964). In addition, the main temperatures of this zone are lower than those in other region in summer. The hottest month is July, when max temperature is about 32C, usually second week is the hottest. Gharyan has Mediterranean climate, but the mountains is the cold region (Gabril, 2014). The mean relative humidity of the air is 61 % in winter, the maximum reading for relative humidity could rise up to 80% and in summer the mean monthly relative humidity is nearly 28%, and the annual average is nearly 41%. See Figure 4.4.

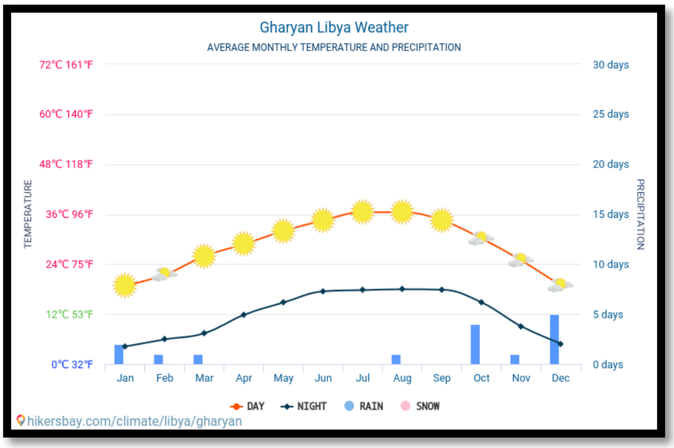


Figure 4.4: Climate and weather in Gharyan, Libya 2019
(http://hikersbay.com/climate/libya/gharyan.Last accessed May 2019)

4.2 Underground Houses in Gharyan

Gharyan is located on the southern edge of Jabal Nafusah, 300 meters above the Jifarah Plain. Unlike those in Tripoli and Ghadames, the vernacular underground houses in Gharyan are integrated with the modern settlement. New houses were built by owners over the underground houses or next to their old houses using the old house as a storage zone. Underground houses spread all over the southwest side of the new center, from south-east to south-west of the city, and there are also a few located outside the settlement to the north-east (National Consulting Bureau 2009). See Figure 4.5.

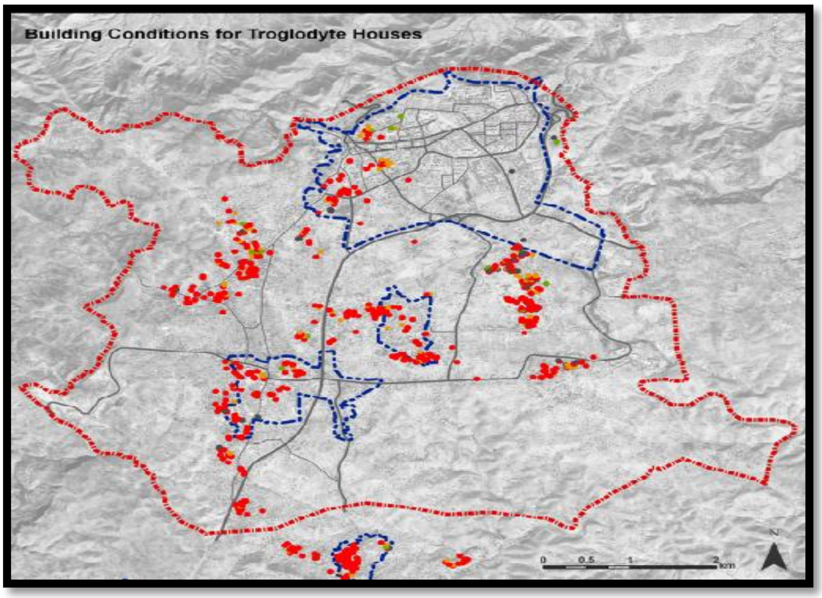


Figure 4.5: The distribution of the vernacular houses (Underground Houses) in the city of Gharyan. (National Consulting Bureau, 2009)

Dwellings in Gharyan region have rural characteristics, they were distributed according to the family origin and the land topography. Relatives usually live together or live as near neighbors. Families usually extended their dwelling by excavating a new dwelling next to their old one, such that five houses together or more can be found, creating a group of houses for brothers and their extended families. See Figure 4.6 and Figure 4.7.

Figure 4.6: The compact grouping of underground houses (El-Dweb, 1995)

Figure 4.7: The compact grouping of underground houses (Google Earth Pro, 2019)

Underground houses in Gharyan have its own characteristic and architectural features, the functional arrangements in underground house in Gharyan are as following:

1-The main entrance is the only way to the outside located in the northwest corner. It starts with semi- rectangular room (Almadwar) used as a shelter for sheep, goats and donkeys in winter.

2- There are 8 bedrooms into the four sides of the courtyard, each side of the courtyard faces one of the four main directions. Two bedrooms have different sizes. See Figure 4.8. The entrance of these houses in Gharyan often faces the east (Qibla) direction (Bukamur, 1985). Then width of the tunnel is about 1.2 to 1.5 m wide, which was about 1.8 m deep underground, it also reaches up to 10-15 m long. This tunnel consists of a staircase that leads to the underground house. The upper level of the entrance is often covered with olive wood and palm logs.

3-The vast majority of houses consists of a square courtyard of 6x6 m to 10x10 m with slight differences in terms of size, built into the ground from 7 to 10 m deep.

4- This house has three small kitchens without window (due to the fact that kitchen door is always open for ventilation). Each one is located in between the two bedrooms (each two families have one kitchen). See Figure 4.8.

5- The store is situated at the upper level of the house, with a small hole-entrance near one of the corner of the courtyard, which is accessed using a ladder. A hole or a slot (Zimmer) is also built underground, leading to the storage area.

6- Some families build their bathroom outside.

7- Some families build guestroom close to the entrance of their underground dwelling, near the entrance.

8- Children bedroom is a small room that is accessed through the main bedroom, though, not all the bedrooms have babies room.

9- A hole of about 2 m is built into the courtyard, deep enough to collect the rainwater from the courtyard and filled up with salt and organic materials (it is the middle of the courtyard). See Figure 4.8.

10- Bathrooms and guest rooms are usually on the ground level.

House plan key

1-main entrance

2- Bedrooms

3-Courtyard

4 -Kitchen

5 - Storage

6 -. Bathroom

7 - Guestroom.

8 - Children bedroom

9- Reservoir for rainwater drainage

10- Hole (Zimmer) leading to the storage areas.

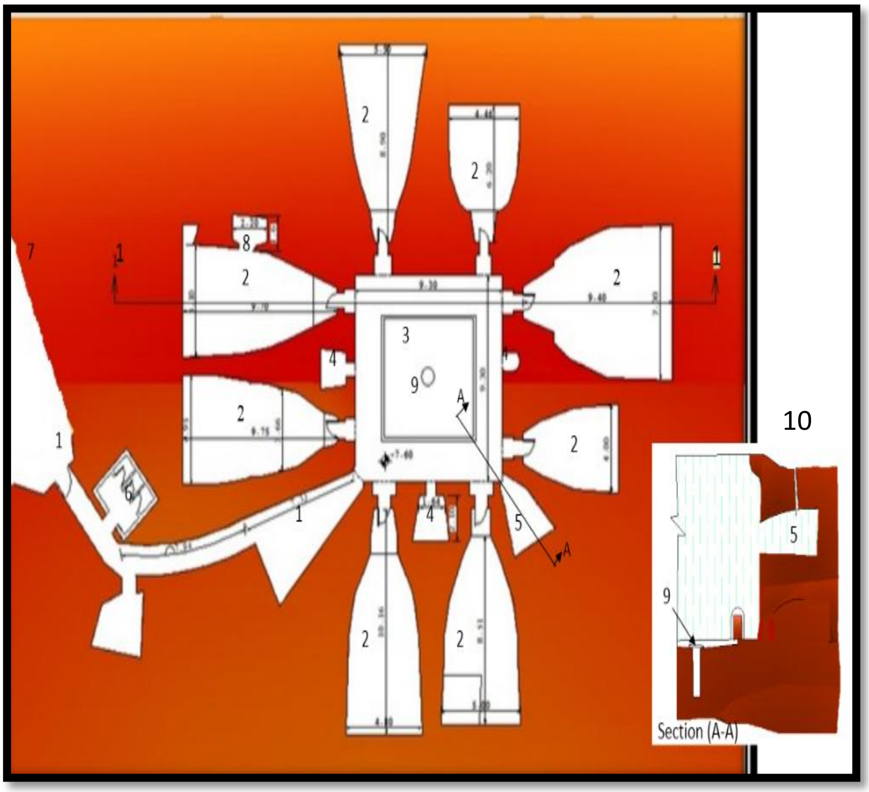


Figure 4.8: Plan of underground house in Gharyan (drawing by author)

4.2.1 Construction materials

A- Main entrance was built of natural stone and its height is approximately 2 m from level of the earth. The digging was made inside strong soil by local tools (shovel, axe). See Figure 4.9.

B - Materials were not used in the foundations (without foundations) due to the use of ground as foundation which has great bearing load capacity.

C - Walls were built inside the ground so there were no constructions except door wall which was built with stone, gypsum and lime; its width is about 40 cm.

D - The ceiling for the rooms was built in a vault shape in the clay soil which bears the ground pressure. See Figure 4.10.

E- The lime, sand and water were mixed to cover the rooms to eliminate insects and reflects light inside the rooms. See Figure 4.10.

F-Olive wood is used for making doors. See Figure 4.10.

G -The rubble stones were used to prevent soil collapse, at the top of the courtyard**.** See Figure 4.11**.**

Figure 4.9: A main entrance is built of natural stone (photo by author)

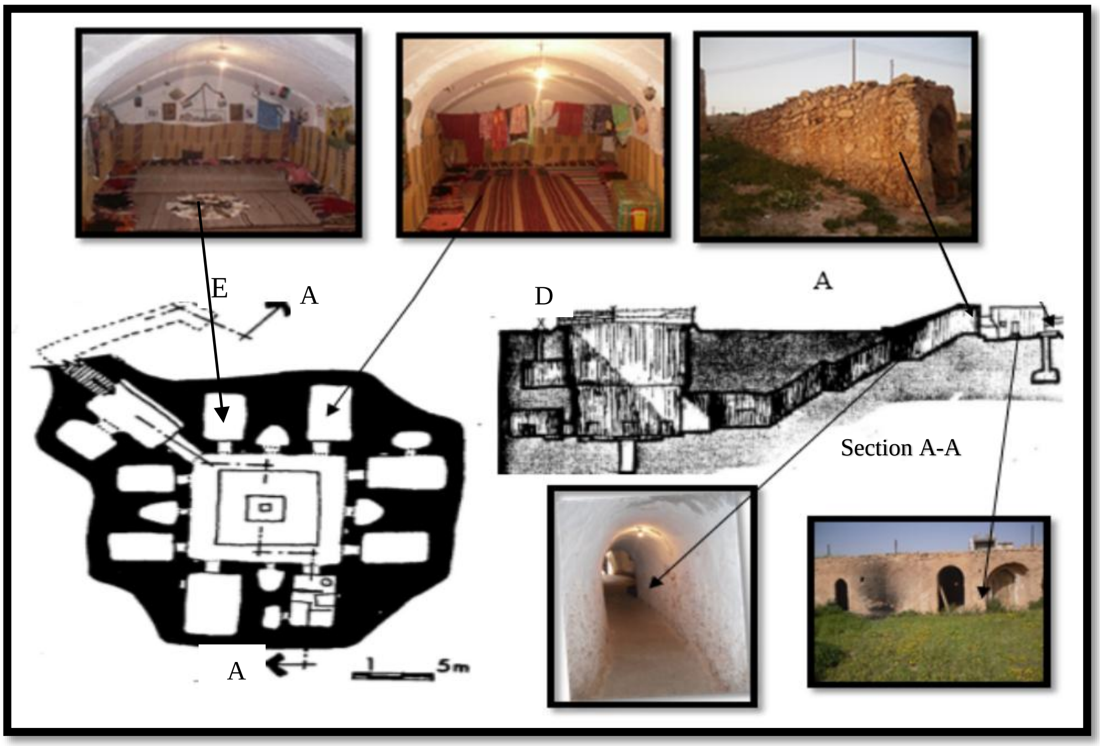


Figure 4.10: Plan of underground house (Bukamur, 1985)

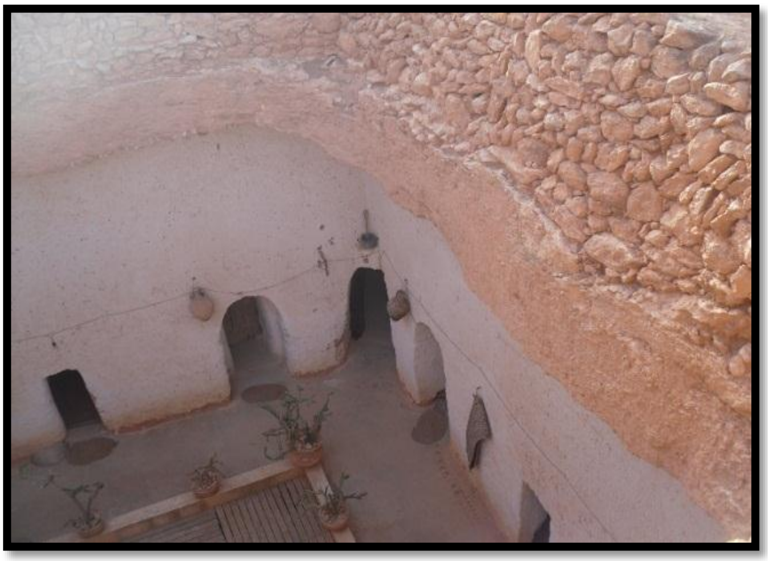


Figure 4.11: Use the rubble stones in top of the top of courtyard for preventing soil collapse. (photo by author)

4.2.2 The structural systems

The underground house has solid structural system consisting of layers of soil about 3-4 m thick to provide or obtain a strong soil layer above the rooms. Room spaces are dugged under these layers and have a vaulted ceiling to distribute the dead loads to the soil and to prevent the rooms from collapsing.

- **Phases of construction system**

The underground houses have three stages for construction as followings:

First phase is the digging of the courtyard by traditional tools (axe, shovel).

Second phase is the digging of the entrance from inside courtyard gradually up to the level of the outside ground.

Third phase the rooms are excavated on each side of courtyard .See Figure 4.12.

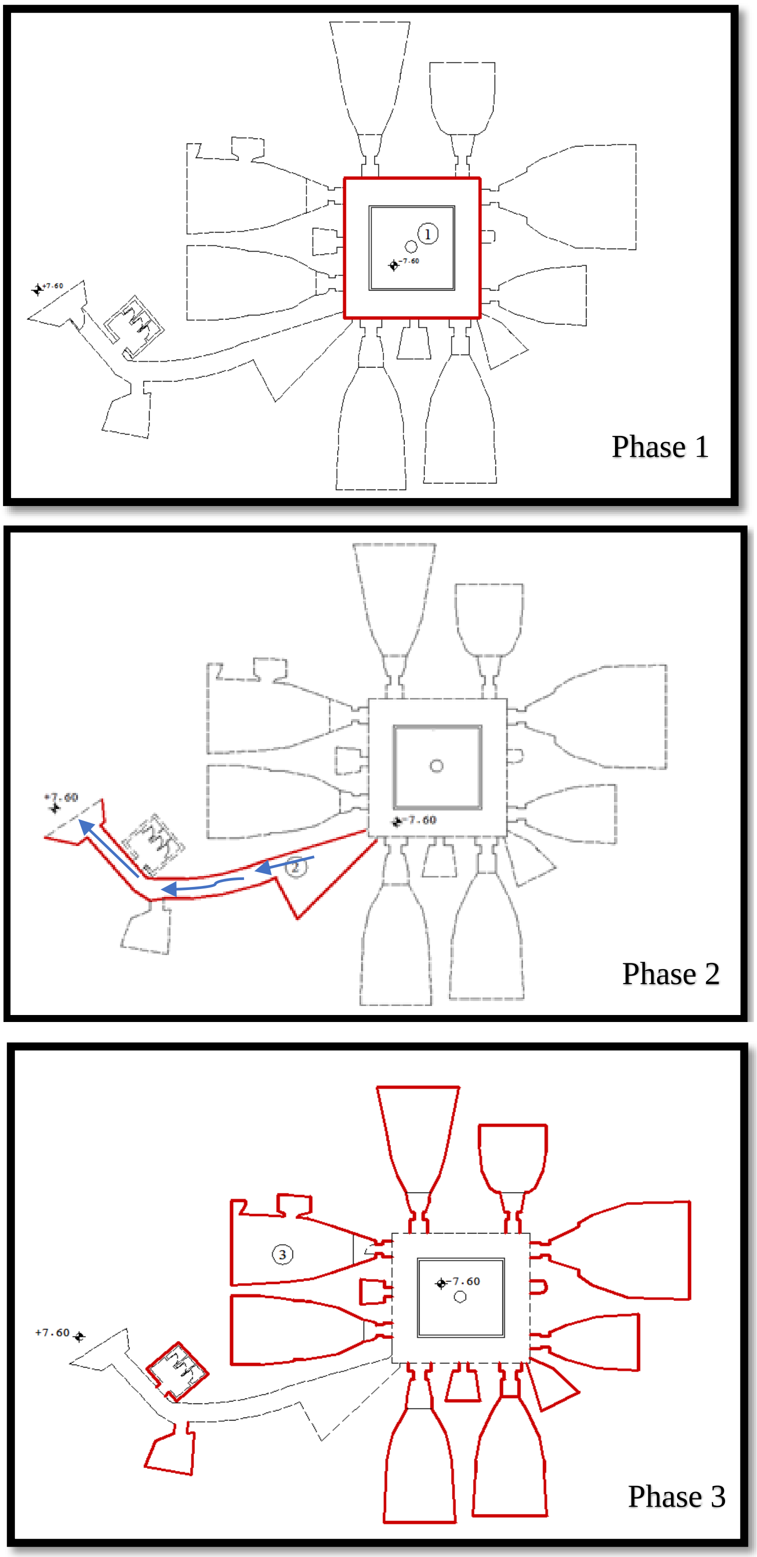


Figure 4.12: The construction phases of underground houses (drawing by author)

4.2.3 Sample analysis of underground house in Gharyan

General data

Location: Gharyan City it is located in area called (Abo Gelan in Algwassem) Approximately 18 km north of the center of Gharyan. See Figure 4.13.

Build Time: 1666

Owner: Belhaj Family

Designer: Belhaj Family

Areas: 375 m² without courtyard

Number of floors: 1

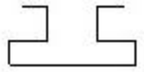
Building type: 

Figure 4.13: The location of Belhaj Family house in Gharyan. (Google Earth.pro, 2019)

- **Design details**

The underground house was built on the open courtyard design system as a square, with opened 8 rooms created on the sides of the central courtyard as well as three kitchens and room in the top wall of courtyard for storage. Guest rooms are usually on the ground level. See Figure 4.14.

1. Room length between 4 m to 9.00 m, width is from 3.5 to 7m.
2. Height ceiling in rooms is 2.25 to 2.60m.
3. Courtyard area is 9.30x9.30 meters and the depth is 7.60 m from natural earth level.
4. The main entrance was built on the north western side, it is a long channel (corridor) with a length of approximately 15 meters and has a curved ceiling with a width of 1.2 m and height is up to of almost 2.00 m, there is a slope downwards where there is a difference gradually between the level of the entrance and the courtyard of the house approximately 7.60 meters. See Figure 4.15.
5. A hole with a depth of 1.5m and a diameter of 1.00 m was digged for discharging storm water. See Figure 4.15.

6- The rubble stones were used to prevent soil collapse, and have walls was convex at the top of the courtyard used as provide to shading from sun and rain in zone close to the rooms. See Figure 4.15.

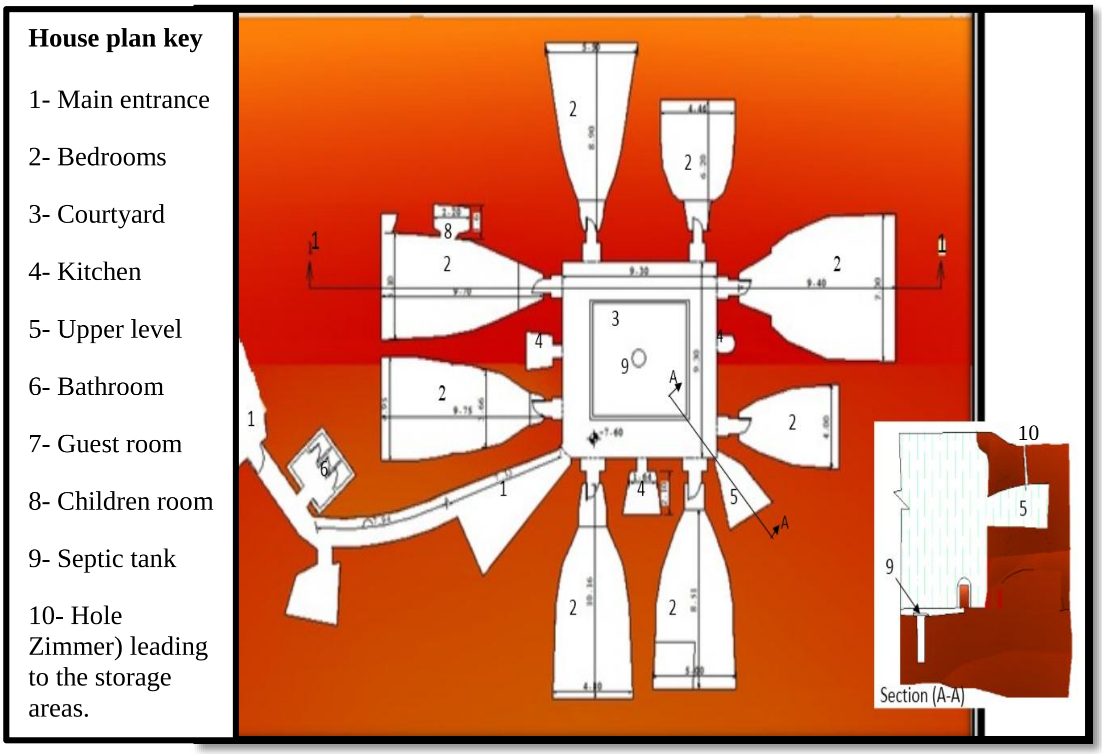


Figure 4.14: Plan and section underground house (drawing by author)

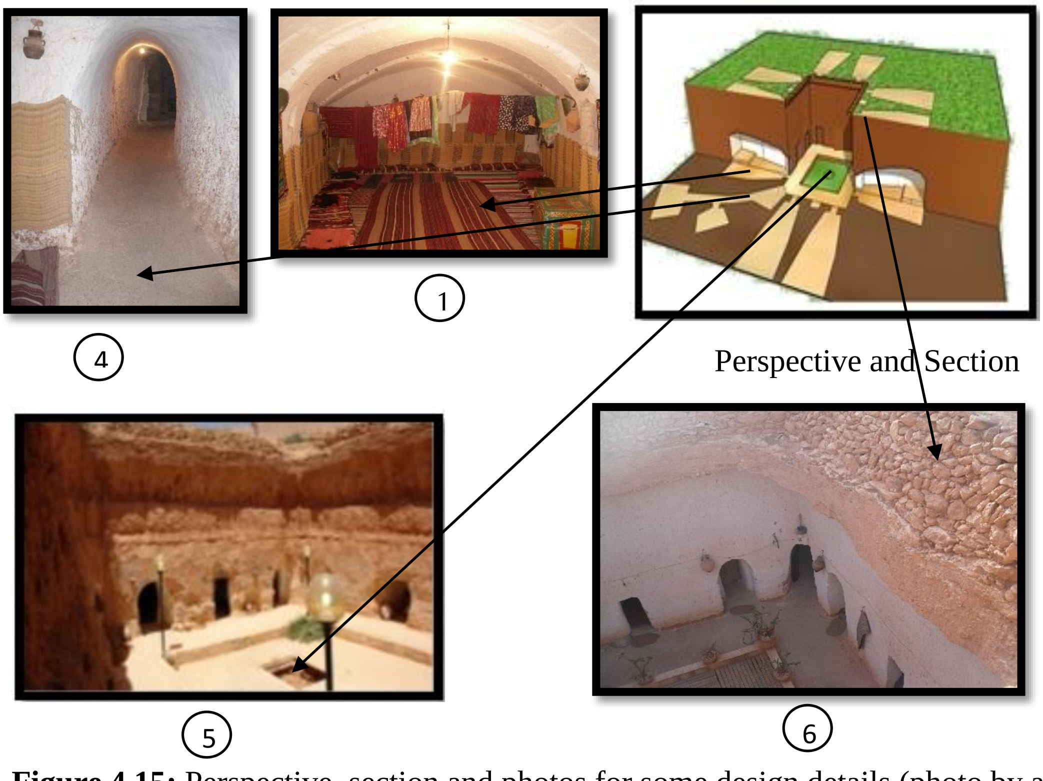


Figure 4.15: Perspective, section and photos for some design details (photo by author)

- **Design and orientation**

The external walls of a house are mass of soil surrounded via rooms. The rooms were placed into soil with depth almost 8 m, and they were opened into courtyard. It does not have any openings except doors; this courtyard was used by families for daily activity. See Figure 4.16 and Figure 4.17.

Figure 4.16: Perspective and Section

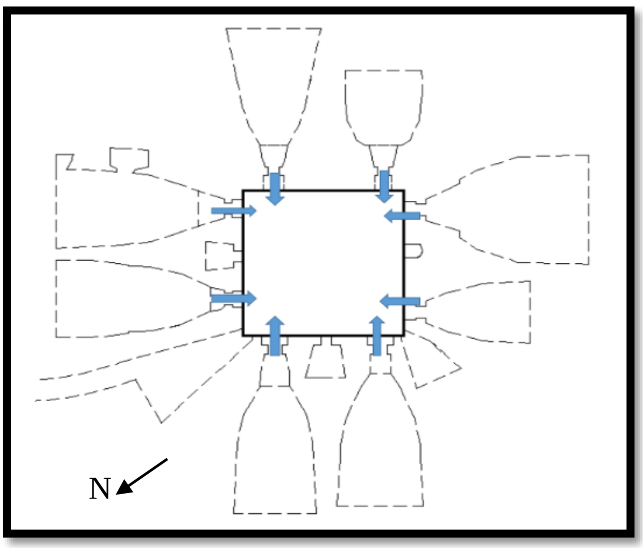


Figure 4.17: Design and orientation in an underground house (photo by author)

○ **The internal functional arrangements**

Main entrance: The main entrance was built on the north western side, it is a long channel (corridor) with a length approximately 15 m and has a curved ceiling with a width of 1.2 m and height is up to of almost 2 m, there is a slope downwards where there is a difference gradually between the level of the entrance and the courtyard of the house approximately 7.60 m. See Figure 4.18.

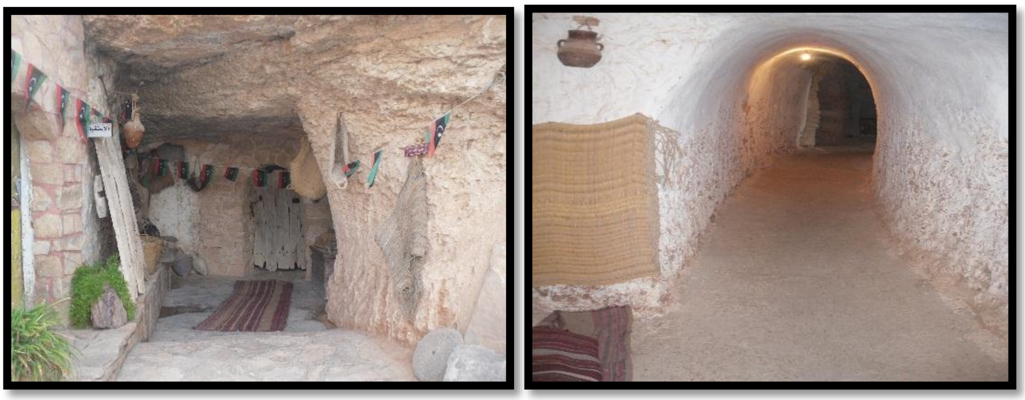


Figure 4.18: The main entrance and corridor of the underground house (photo by author)

Courtyard: Dimensions of courtyard 9.30x9.30 m, engraved into the ground 7.60 m deep. Courtyard provides air circulation to the inside spaces, also it is used by families for daily activity and social needs. The entrance and rooms were opened into the courtyard, the entrance is in the northwest corner of the courtyard. The courtyard is divided into two levels, creating for a 2 m width corridor. The remainder of the courtyard ground is approximately three steps below the corridor. In the middle of the courtyard, a septic tank is placed into the ground and filled up with salt and organic materials. It is built deep enough to collect the rainwater from the courtyard (Bukamur, 1985)**.** See Figure 4.19.

Figure 4.19: Photo of courtyard (photo by author)

Bedrooms: They are 8 bedrooms into the four sides of the courtyard, each side of the courtyard faces one of the four main directions. Bedrooms were as different sizes. See Figure 4.20. They were 8 families in this house, each family had a room. They are all engraved in soil, with difference size and dimensions from room to another in a shape (trapezoidal) extend in 1.5 to 5 m to inside, where the dimensions of the entrance area are about 1.50 m, and they is the smaller dimension. When I measured these rooms the interior, I have seen the width of some the room expands until it reaches between 4.5-7 m. In past, the room is sectioned with curtains into three parts as follows:

1- The living room part was located next to the entrance.

2-The children's room part was located in the middle of the room.

3-This part of room was for a married couple. There are difference between these three parts is only in the ground level about 10 cm .The height of the rooms are between 2.25 to 2.60 m in the middle. See Figure 4.20.

Kitchen: There are three small kitchens on trapezoidal shape with different spaces, and almost 2.00m high, between each two rooms is a kitchen shared by the two families, except for the North West aspect ,in order to provide to ventilation when cooking in past. As seen Figure 4.20.

Bathroom: The bathrooms were built after the main entrance before a few years by owner. In the past bathrooms are usually on above ground level (outside home).See Figure 4.20.

Store room: In about 3 m height upper level, there is a store space for crops built near one corner of the courtyard and extinction deeply 4-5 m and 2.00 m height in order to ensure that there are not rooms under it, causing it to collapse. This storage is reached using a ladder from the courtyard. A hole or opening (zimmer) is also built from land level, reaching up to the crop storage room and usually is secured by palm logs or olive wood (Bukamur, 1985). See Figure 4.20.

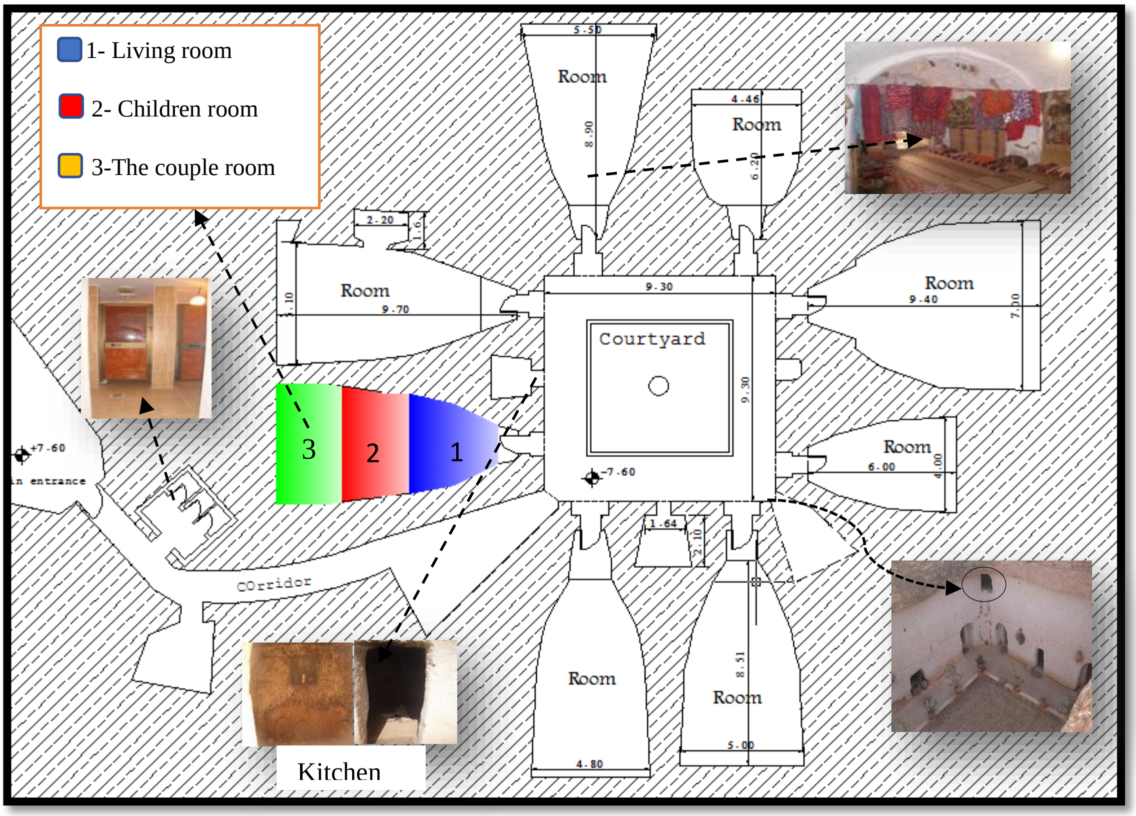


Figure 4.20 : The underground house have 8 bedrooms into the four sides of the courtyard and 3 kitchens (drawing by author)

- **Construction materials**

Types of materials

1-**Walls** from clay soil

2-**Floors** from clay soil.

3-**Roof** from clay soil.

4-**Doors** were made from palm and olive trunks. See Figure 4.21.

5-**Windows:** There are not windows in the room.

6-**Finishes**: The lime and sand, water were mixed for covering the rooms, for to eliminate insects and reflects light inside the rooms. See Figure 4.22.

7-**Decoration**: gypsum and lime were used for decoration.

Figure 4.21: The door made from wood olives **Figure 4.22:** Finishes and decoration

- **Construction**

1 - The main entrance is covered of natural stone and its height approximately 2 meters from level of the earth and corridor about12 m longer, the digging was made inside strong soil, and it was used local tools (shovel, axe) by vernacular people. See Figure 4.23.

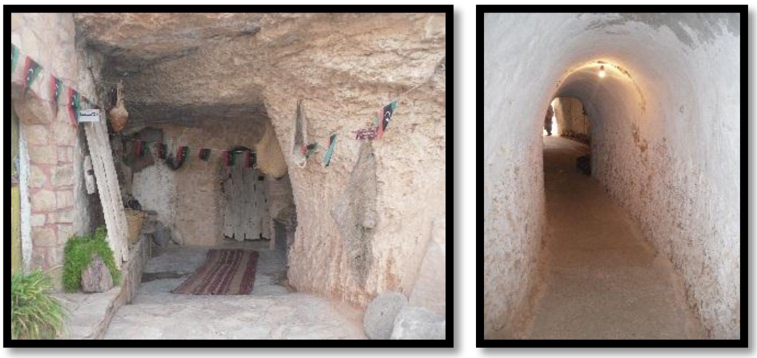


Figure 4.23: The main entrance covered with natural stone and corridor (photo by author)

2 - Materials were not used in the foundations due to the use of ground as foundation which has great bearing load capacity.

3- Walls were built inside the ground so there were no constructions except doors wall which was built with stone, gypsum and lime. It is width is about 45cm.

4 -The ceiling for the rooms was made in a vault shape in the clay soil. In order distribution of the loads of soil, Distance of this ceiling range from 4.5 to 7.00 m in rooms .See Figure 4.24.

5 -The rubble stones were used to prevent soil collapse at the top of the courtyard. See Figure 4.25.

Figure 4.24: The ceiling is shaped like a vault (photo by author)

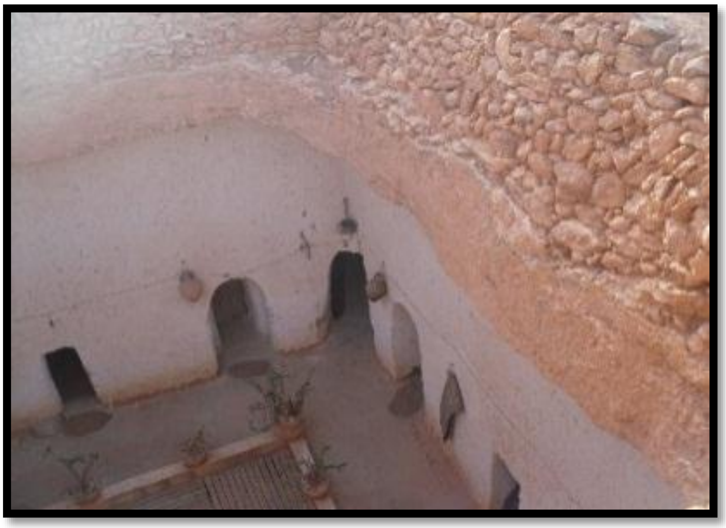
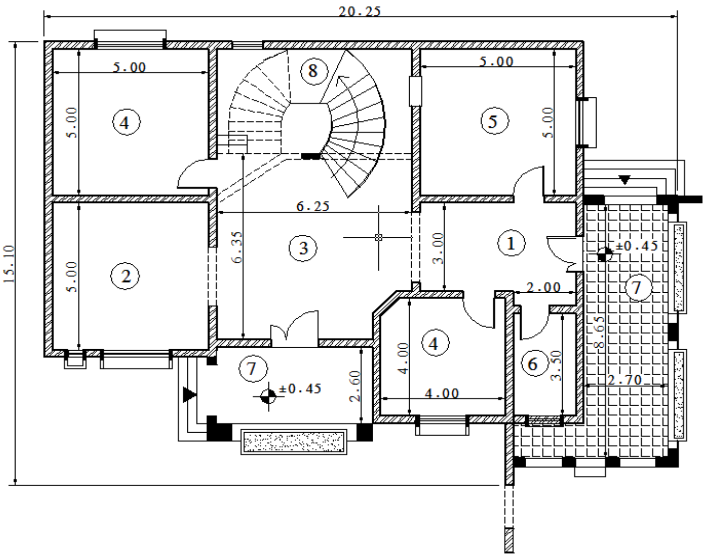


Figure 4.25: The rubble stones were used to prevent soil collapse (photo by author)

4.3 Modern house in Gharyan

There are many differences between the modern house and underground house, in terms of functional arrangements and design. The house shown in Figure 4.26 consists of entrance, a salon for men, a living room, two bedrooms, a kitchen, bathroom and external balconies. It is surrounded by a fence and external garden. Also, air conditioning is provided, both for cooling and heating, while it is not found in underground house.



Eastern facade

North facade

South Facade

South Facade

1 -Entrance 2- Men Salon 3- Living room 4- Bedroom 5- Kitchen 6- bathroom

7 - Verandas 8- Stair

Figure 4.26: Plan of modern house in Gharyan (photo by author)

1 -Entrance: It is mostly in the east, the most of entrances in modern houses doors are made of wood decorated with ornaments, and have terrace, whilst the floor is made ordinary tiles or marble**.**

2- Men Salon: It is a rectangular room with different dimensions from one dwelling to another. Usually separated from other interior rooms, it is usually close to the entrance.

3- Living room: It is a rectangular room with different dimensions from one dwelling to another, it is used for family sitting, the reception of the neighbors, relatives, and women.

4- **Bedroom:** In modern house, bedrooms are often square-shaped with dimensions from 3x3 m as three bedrooms. One of them is for parents, one for boys and one another for girls. Bedrooms are away from the entrance for privacy and to provide peace when the family is asleep (Amer, 2007).

5- Kitchen: It has different dimensions from one house to another, all walls are covered by ceramics. In the late 1990s, the kitchen became an external-looking zone with doors, windows opening to the garden or to the outside terrace (Shahran, 2018).

6- Bathroom: The appearance of the bathroom has evolved in recent years, where the main bathroom area is not less than 6 m^2. It has windows with suitable dimension for good ventilation in accordance with the demands of the residents.

4.3.1 Construction materials

A - Foundations: Iron is used in reinforcing the concrete for the foundations.

B - Walls as concrete bricks are used in building walls, which is a mass of treadmill inside, dimensions 20 × 20 × 40 cm.

C - Thickness of ceiling almost 15 cm from reinforced concrete.

D - Marble, tiles, and ceramics are used for flooring the floor of rooms.

E - Wood is used for making doors and PVC for windows.

F- The paint is used into inside house and external, gypsum is used for decorating the house.

4.3.2 The structural systems

Structural system is used in this house, it consists of columns and beams of reinforced concrete and walls from limestone or cement brick, the thickness of the walls is 20-25 cm. The height of ceiling is about 3 m. The house has foundations of reinforced concrete (separate foundations) with dimensions 1.1x1.1 m and the height of 50 cm. The loads from ceiling to columns then to foundation are transferred.

The house has foundations of reinforced concrete (separate foundations) with dimensions 1.1m x 1.1m and the height 50cm. The loads from ceiling to columns then to foundation are transferred.

4.3.3 Sample analysis of modern house in Gharyan

- **General data**

Location: Gharyan City it is located in area called (Abo Gelan in Algwassem) Approximately 18 km north of the center of Gharyan**.** See Figure 4.27.

Build Time: 1994

Owner: Arabi Belhaj

Designer: Unknown

Areas: 247 m²

Number of floors: 1

Type of building: structural system

Figure 4.27: The location of the underground house in Gharyan, Libya (Google Earth.pro, 2019)

Design details

The house structural designed system consists of 2 bedrooms, men salon, living room, kitchen, bathroom, a stair inside the house, and a surrounded fence from all sides of the house with measurement of about 2 m high as seen in Figure 4.28

1- The main entrance was built on the north eastern side.

2- Dimensions of bedrooms were 5x5 m and 4 x4 m.

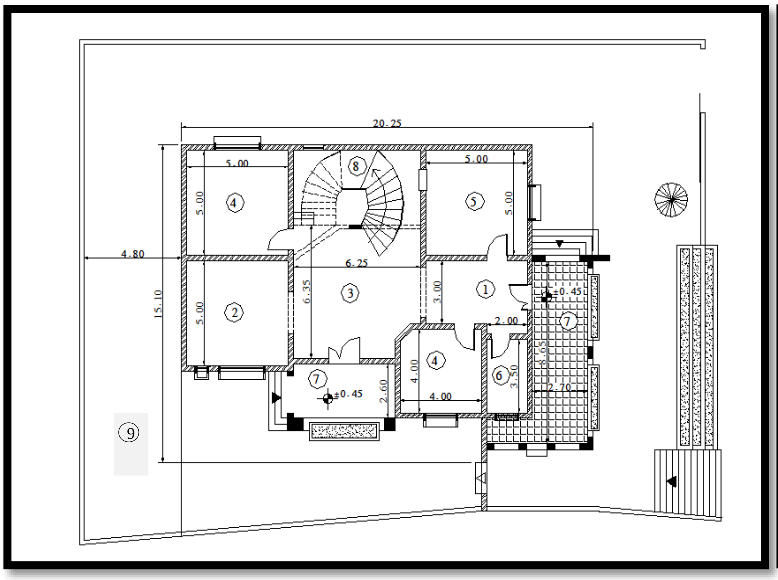
3- Dimensions of men salon and kitchen were 5 x5 m.

4- Dimensions of living room was 6.35x6.25 m.

5- Dimensions of bathroom was 3.50x2 m.

6- Height ceiling was 3 m.

7- Use of pharaonic bricks to cover the verandas facade located in the main entrance which is used for the provision of shade from sun and rain. See Figure 4.29.



House plan key

1-main entrance.

2- Men Salon

3-Living Room

4-Bedroom

5- Kitchen.

6-Bathroom

7- Verandas

8-Stair

9-cortyard

Figure 4.28: Plan of Arabi Belhadj House in Gharyan (photo by author)

Figure 4.29: Eastern and west facade for the house .Owner-Arabi Belhaj (photo by author)

- **Design and orientation in modern house**

The house was designed without internal courtyard in contrast to underground house and windows opened outward on garden surrounded by open spaces. The verandas are located at the eastern and southern facade of the house. It is surrounded from all sides with about 2 m high fence. See Figure 4.30.

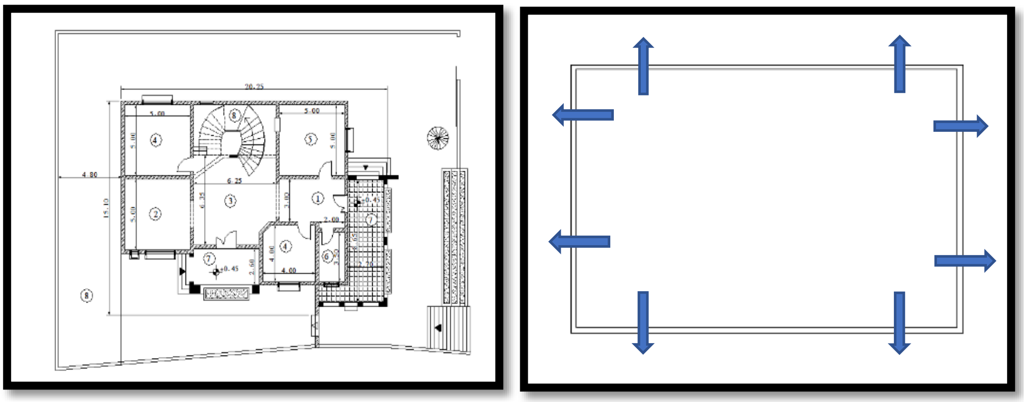


Figure 4.30: Design and orientation in modern house (drawing by author)

- **The internal functional arrangements**

Main entrance: with terrace, is located in the east, house door is made of wood decorated with ornaments, whilst the floor is made of marble. See Figure 4.31.

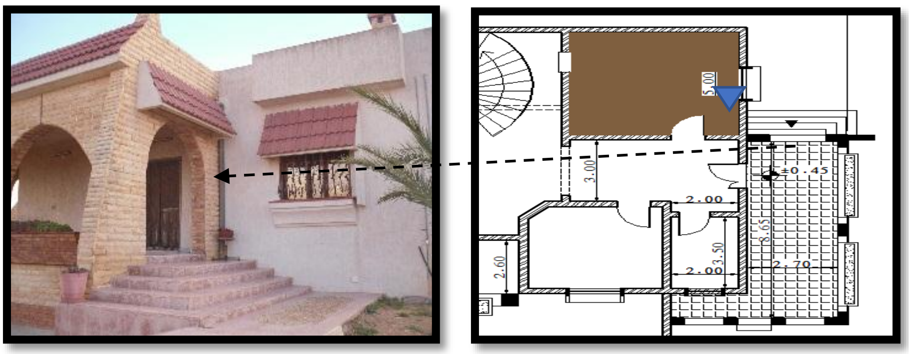


Figure 4.31: The main entrance

Men Salon: It is a square room with dimensions5 x 5 m, close to sub-entrance, it has large window opening in the south facade. See Figure 4.32.

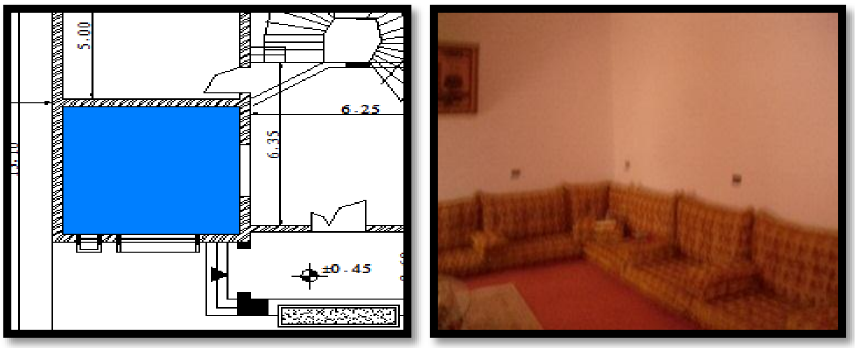


Figure 4.32: Men salon (photo by author)

Living room: It is a rectangular room with dimensions 6.35x6.25m.It is used for family sitting, the reception of the neighbors, relatives, it has an internal stair that reaches to the roof of house. See Figure 4.33.

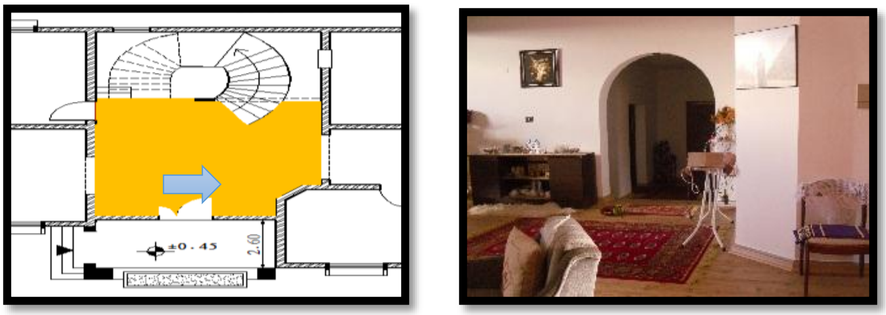


Figure 4.33: Living room (photo by author)

Bedrooms: This house have two rooms, dimensions of bedrooms were 5x5 m and 4 x4m.One room for parents, one room for sons**.** See Figure 4.34.

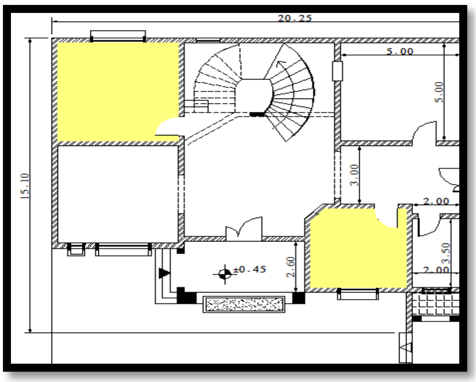


Figure 4.34: Bedrooms

Kitchen: It is square-shaped, with dimensions from 5m ×5m, and all walls are covered by ceramics. See Figure 4.35.

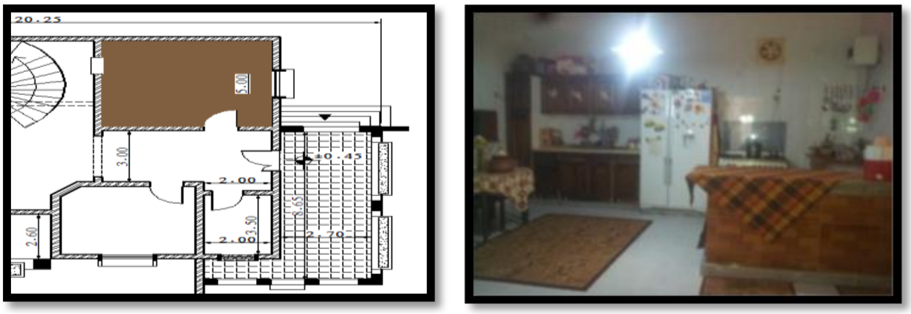


Figure 4.35: Kitchen

Bathroom: Dimensions of bathroom 3.50 x 2 m with all walls are covered by ceramics. It has window with suitable dimension for good ventilation, accordance with the demands of the residents. See Figure 4.36.

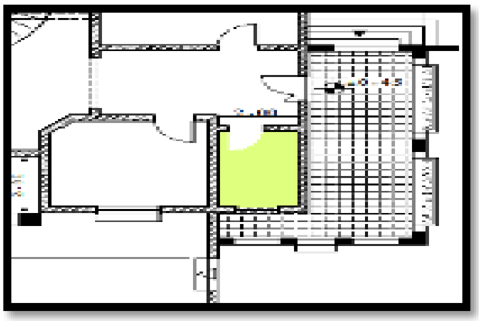


Figure 4.36: Bathroom (photo by author)

- **Construction Material**

1-Walls were built of limestone and columns from reinforced concrete.

2-The floors were covered with tiled, marble and wood.

3-The ceiling was constructed from reinforced concrete.

4-The doors were made from wood with dimensions were about 1 x 2.20m. See Figure 4.37.

igure 4.37: The door of the main entrance

5-The windows were made from PVC with different dimensions with steel fence or mesh for security .See Figure 4.38.

Figure 4.38: The windows made from PVC and steel

6- The finishes: the house has normal paint and inside house gypsum was used for decoration. Pharaonic bricks were used to cover the veranda's facade located in the main entrance. See Figure 4.39.

Figure 4.39: The house was painted with normal paint and pharaonic bricks of used in the verandas (photo by author)

- **Construction**

1 -Foundations: This house had separate foundations with dimensions about 1 x 1 m and height 50cm.

2- Walls were built from limestone with thickness 25 cm.

3-Columns with dimensions 25x25cm were constructed by reinforced concrete.

4- Beams with width 25 cm and depth 40cm were constructed with reinforced concrete.

5- The ceiling with thickness 15 cm was constructed by reinforced concrete.

6 -The gypsum is used for decorating inside the house, whilst pharaonic stone is use for decorating the external walls to cover the verandas facade located in main entrance.

4.4 Comparison between Underground Housing and Modern Housing

Table 4.1: Comparison between Underground Housing and Modern Housing

Underground Housing	Modern Housing
1- Houses have simple shape with square courtyard. The rooms are open into courtyard and they consist of one storey underground, and they are similar in design	1- House as enclosed cube, is different in terms of design according to the owner requirements. It has different style and sorts (two storey-, villa, ground house, flats), they are not similar in design.
2- It is built around courtyard with rooms and spaces looking inwards courtyard.	2- No courtyard replaced by balcony and terraced. Rooms look outwards to garden or road at front.
3- The height of ceiling varies between the rooms	3- Most of floors are at the same height
4- All openings inside to courtyard.	4- Most openings on to the garden and street
5- Materials were not used in the foundations (without foundations) due to the use of ground as foundation which has great bearing load capacity	5- This house has separate foundations built by reinforced concrete with dimensions about 1x1 m and height 50cm.
6- Walls were built inside the ground so there were no constructions except doors wall which was built with stone, gypsum and lime, it is width is about 45-60cm.	6- Walls were built from limestone with thickness 25 cm.
7- Roof construction: The ceiling for the rooms was made in a vault shape using clay soil. This vault shape distribute the loads of soil. The distance of this ceiling range from 4.5 to 7.00 m in rooms.	7- The roof with thickness12-15cm was constructed from reinforced concrete. It have not use insulation materials.
8 - Building of house took more than 12 months. Due to use of human effort for construction with traditional tools (the shovels, the axes) in the digged.	8 - Building takes a minimum of 6 months, in case of availability of workers and construction materials.

	Underground House		Modern Housing
9	Gypsum and lime were used for simple decoration	9	The gypsum uses for decoration inside house, whilst pharaonic stone is use for decorating the external walls and verandas façade .
10	All rooms have three parts multiple-purposes, each family have a room.	10	Each room has one separate purpose.
11	Lack of basic services in kitchen and bathroom.	11	The bathroom includes all facilities, the kitchen is equipped with all modern equipment. And their floor and walls are covered by ceramics
12	Consider of climatic conditions for designing	12	Climatic conditions were not considered for design.
13	It consume less energy due to do not have an air conditioner.(passive heating and cooling were used)	13	It is consume a large amount of energy especially in heating and cooling.

4.5 Methodology

For this study, two different researches are done. In the first research, a questionnaire was constructed for understanding residents' suggestions about both vernacular and modern dwelling. As the second study, for measuring the temperature and humidity, an instrument hygrometer was used. The fieldwork was carried out within the period of January (21/1/2019) to February (18/2/2019).

4.5.1 Survey design and measures

Firstly, before the survey, two types of house were selected for this survey. One of the house types was underground and the other type was aboveground (modern house). Both types of houses were surveyed comprehensively after which I drew the plan and layout of the houses. The drawing was instructed according to these measurements. The underground dwelling and modern house were located close to each other with a distance of not more than 100 meters. The reason for this choice is to provide equal comparison measure for both houses.

If the houses were in different locations, there may be inaccuracy as well as inconsistency in the measurement of temperature and humidity. Therefore, both houses were located not more than 100 meters from each other because they will share similar climate conditions. It is important to note that some of the underground homes were located close to each modern house because the owners who once lived in these underground homes constructed modern homes close to their previous underground homes.

In the collection of primary data, there were a total of 84 participants for this survey. All participants in this survey had previously lived in underground homes and are currently living in modern (above ground) homes in Gharyan. See Table 4.2.

The questionnaire contained 22 questions. The questionnaire was divided into two sections. The first section provides socio-demographic data including gender, age, and place of birth, marital status, occupation, education level and family size. The second section discusses the past and present house circumstances in comparison between underground housing and aboveground housing. The comparison was made in terms of house type, construction material, thermal comfort, energy type used for heating and cooling, ventilation and lighting rates, comfortability, social interaction among neighbors, rate of humidity in the air etc. For the analysis of the data from the questionnaire, the software program of SPSS 22 was used. The questionnaire can be found in Appendix 1 at the end of the thesis.

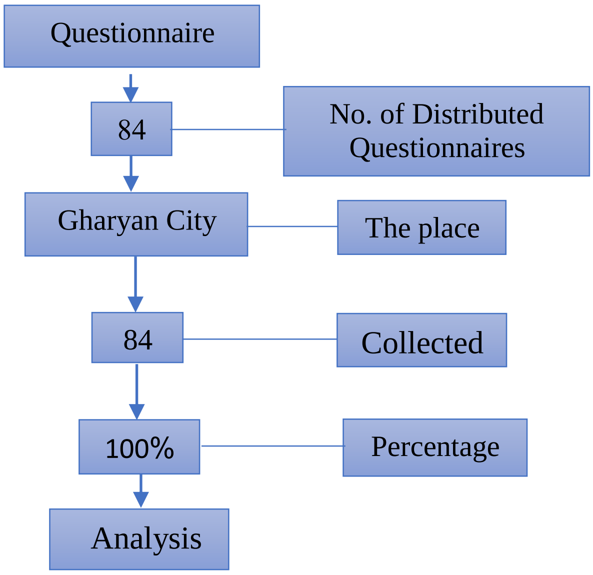


Table 4.2: Distribution and collected questionnaire and responses

4.5.2 Second research design and measures

For the measurement of temperature and relative humidity, two digital instruments called hygrometer (Beurer HM 16) were used. One of them was used in the underground house and the other one in the modern house. See Figure 4.40. The fieldwork, total measurement of temperature and humidity was carried out within the period between January (21/1/2019) to February (18/2/2019). Every day within this period, the measurement was carried out four times per day to record average temperature and humidity for both underground and modern (above) house manually. The measurement of temperature and humidity can be found in Appendix 2 at the end of the thesis, it is manual recording.

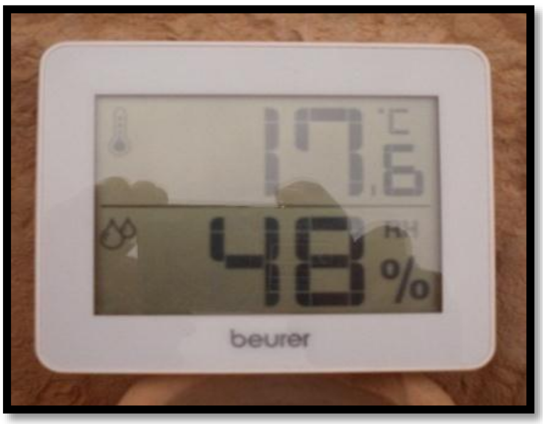


Figure: 4.40: Hygrometer Beurer HM 16

4.6 Results of Study 1

This part involves answers of the questionnaire items posed on participants. Based on the data collected from participants, the findings were analyzed and explained.

4.6.1 Results of section 1: Socio-demographic data

- **Gender**

There was a total of 84 respondents among which the men are 65 in number while the female respondents were 19 in number. This means that the valid percentage for the male respondent is 77.4% and for the female respondents have a percentage value of 22.6 %. See Table 4.3**.**

Table 4.3: Gender

Gender	Frequency	Percent
Male	65	77.4 %
Female	19	22.6 %
Total	84	100.0 %

- **Age**

The age range of both males and females is presented in the questionnaire from 16 to 66 years old. However, the age distribution of respondents in the result shows that respondents are within the age range of 41 to over 66 years old. The valid percentage of respondents within the age range 41-55 is 23.8%. For the age range 56-65, the frequency and valid percentage of respondents are 35 and 41.7 respectively. The frequency and valid percentage of the age range over 66 years old are 29 and 34.5% respectively. See Table 4.4.

.

Table 4.4 Age of participants

Age	Frequency	Percent
41-55	20	23.8 %
56-65	35	41.7 %
Over 66	29	34.5 %
Total	84	100.0 %

- **Place of birth**

All the respondents indicated that they were born in Gharyan, therefore the percentage is 100%. See Table 4.5.

Table 4.5: Place of birth

Place of Birth	Frequency	Percent
Gharyan	84	100.0 %

- **Marital status**

All of the respondents in this study are married. See Table 4.6.

Table 4.6: Marital status

Status	Frequency	Percent
Married	84	100.0 %

- **Occupation**

Today, most of the occupation of the people in Gharyan and Libya is government jobs in general. 41 respondents (48.8%) indicated that they are government employed in different sectors. 5 respondents (6%) suggested to be self-employed. Furthermore, 23.8% of them indicated that they are retired. Lastly, unemployed respondents have a percentage of 21.4% See Table 4.7.

Table 4.7: Occupation profile of participants

Occupation	Frequency	Percent
Government employee	41	48.8 %
Self-employed	5	6.0 %
Retired	20	23.8 %
Unemployed	18	21.4 %
Total	84	100 %

- **Education level**

20.2% of the respondents are not educated and 16.7% had a primary level respectively, and the percentages of respondents with education of intermediate level and the university level are 29.8% and 33.3% respectively. See Table 4.8.

Table 4.8: Education level

Education	Frequency	Percent
Uneducated	17	20.2 %
Primary	14	16.7 %
Intermediate	25	29.8 %
University	28	33.3 %
Total	84	100 %

- **Family size**

According to the survey, 1.2 % and 5%, of the respondents, indicated their family size is 2 and 3-4 respectively. Furthermore, 14.3 % and 74.4%, of the respondents suggested that their family size is 4-5 and more than 5 respectively. See Table 4.9.

Table 4.9: Family size of participants

size	Frequency	Percent
2	1	1.2 %
3-4	5	6.0 %
4-5	12	14.3 %
More than 5	65	77.4
5	1	1.2
Total	84	100.0

4.6.2 Result of section 2: Past and present house circumstances

- **Kind of housing in previous and present houses**

Participant's responses in terms of kind of housing in previous and present are displayed below. 100% of the respondents had previously lived in underground houses because respondents who had previously lived in underground houses were chosen for the research in order to provide information about their experience while compared with the modern dwelling. 44% of the respondents are living in the ground houses (one floor) while 27.4% live in villa. 23.8% of the respondents live in public houses and 3.6% live in a flat. See Table 4.10.

Table 4.10: Kind of housing in previous and present.

Kind of Housing`	Underground House		Modern House	
	Frequency	%	Frequency	%
Underground house	84	100	0	0
House	0	0	37	44.0
Villa	0	0	23	27.4
Courtyard house	0	0	1	1.2
Public house	0	0	20	23.8
Flat in a block	0	0	3	3.6
Total	84	100	84	100.0

- **Materials construction used for previous houses and present houses**

100% of the respondents suggested that their house was made as engraved into the soil since they all lived in underground houses and the principal material is soil. This can be compared with modern houses; 73.8% of respondents suggested they used limestone block in the construction of their present aboveground house which is as a result of cost-effectiveness and availability of limestone. 26.2% of respondents have used brick concrete. See Table 4.11.

Table 4.11: Materials construction used for previous houses and present houses

	Underground House		Modern House	
	Frequency	%	Frequency	%
Engraved in soil	84	100	0	0
Limestone block	0	0	62	73.8
Brick concrete	0	0	22	26.2
Total	84	100	84	100

- **Thermal comfort in house during summer and winter for previous and present houses**

90.5% of respondents who have previously lived in underground houses said the thermal comfort inside the underground dwellings during summer and winter season was comfortable. On the other hand in the modern dwelling, merely 27.4 % of respondents who presently live in above ground houses suggested that the thermal comfort inside the house during summer and winter season was comfortable while 48.8 % of respondents suggested the comfort was moderate. In addition, 23.8% of them suggested that modern houses were uncomfortable in relation to thermal comfort. There is a huge difference between the percentages of previous and present houses. See Table 4.12.

Table 4.12: Thermal comfort in house during summer and winter for previous houses and present houses

	Underground House		Modern House	
	Frequency	%	Frequency	%
Comfortable	76	90.5	23	27.4
Moderately comfortable	8	9.5	41	48.8
Uncomfortable	0	0	20	23.8
Total	84	100	84	100

- **The energy type used for heating**

77.4% of respondents did not use energy for heating the underground house. However, 6% and 16.7% of respondents said they used kerosene and natural coal respectively. While 54.8% of respondents are presently using electricity as energy for heating the house (above ground). In addition, 45.2% of the respondents said they used mutual energy which means a combination of several sources of energy like electricity, kerosene, and natural coal etc. This is a huge support to claim that above ground houses do require energy to heat up the house (no conservation of energy). See Table 4.13.

Table 4.13: The energy type used for heating

	Underground House		**Modern House**	
	Frequency	%	Frequency	%
Kerosene	5	6	0	0
Natural coal	14	16.7	0	0
Electricity	0	0	46	54.8
Mutual	0	0	38	45.2
Without energy	65	77.4	0	0
Total	84	100	84	100

- **The energy type used for cooling**

100% of respondents didn't use energy for cooling their underground houses since there was no need because underground house provides good temperature comfort both in summer and winter. But, 100% of the respondents use electricity as energy for cooling their above-ground houses. See Table 4.14.

Table 4.14: The energy type used for cooling

	Underground House		Modern House	
	Frequency	%	Frequency	%
Kerosene	0	0	0	0
Natural coal	0	0	0	0
Electricity	0	0	84	100
Mutual	0	0	0	0
Without energy	84	100	0	0
Total	84	100	84	100

- **Usage of air conditioning at previous houses and present houses**

100% of respondents didn't use air conditioning at home for cooling their underground houses since there was no need, because underground houses provide good temperature comfort without air conditioning. While 100% of respondents use air conditioning at home for cooling their houses as can be seen in Table 4.15

Table 4.15: Usage of air conditioning at previous houses and present houses

	Underground House		Modern House	
	Frequency	%	Frequency	%
No	84	100	0	0
Yes	0	0	84	100
Total	84	100	84	100

- **How many hours is it used per day**

100% of respondents are not using electricity for cooling their underground houses, because they do not have an air conditioner and underground dwellings provide good temperature comfort in all seasons. While compared to modern houses, 84.5% the most majority respondents used an air conditioner more than 4 hours per day to heat or cool their house indicating a high consumption of energy. See Table 4.16.

Table 4.16: Number of hours use air conditioner on per day

	Underground House		Modern House	
	Frequency	%	Frequency	%
Zero	84	100	0	0
2 Hours	0	0	6	7.1
3 Hours	0	0	7	8.3
More than 4 Hours	0	0	71	84.5
Total	84	100	84	100

- **The ventilation in previous houses and present houses**

81% of the respondents indicated satisfactory for condition of ventilation in their previous house. Whereas 6% were unsatisfactory and another 6% of the respondents indicated medium comfort of ventilation. This can be compared with modern houses where the satisfaction level was 83.3% while 14.3 % were unsatisfactory as can be seen in Table 4.17.

Table 4.17: The ventilation in previous houses and present houses

	Underground House		Modern House	
	Frequency	%	Frequency	%
Satisfactory	68	81.0	70	83.3
Unsatisfactory	5	6.0	12	14.3
Unsure	6	7.1	1	1.2
Medium	5	6.0	1	1.2
Total	84	100.0	84	100.0

- **The lighting in pervious and present houses.**

The participant's responses in terms of the lighting during the daytime in modern and underground houses are displayed below. 65.48% of respondents suggested that in their previous houses (underground), lighting was satisfactory while 25% indicated unsatisfactory. Compared with modern house, 94.05% of respondents suggested that in their present houses (above ground), lighting was satisfactory. This could be due to having windows and the availability of cheap electricity that is used for lighting. See Table 4.18.

Table 4.18: The lighting in pervious and present houses

	Underground House		**Modern House**	
	Frequency	%	Frequency	%
Satisfactory	55	65.5	79	94.0
Unsatisfactory	21	25.0	4	98.8
Unsure	4	4.8	1	1.2
Medium	4	4.8	0	0
Total	84	100.0	84	100

- **The feeling of comfortable in previous and present houses during summer and winter.**

The participant's responses in terms of their feeling about comfort in previous houses and present houses during summer and winter are displayed below. The majority of the respondents (92.9%) who previously lived in underground houses suggested that the thermal comfort inside the house during the summer and winter season was comfortable. This huge percentage is a confirmation of the thermal comfort that underground houses brings to its residents. Whereas compared with modern house, 56% of the respondents that presently live in above ground houses suggested that the thermal comfort inside the house during summer and winter season was comfortable while 26.2% of respondents said there is no comfort. There is a huge difference between the percentages of underground house and modern house. See Table 4.19.

Table 4.19: The feeling of comfortable in previous houses and present houses during summer and winter

	Underground House		Modern House	
	Frequency	%	Frequency	%
Yes	78	92.9	47	56.0
No	2	2.4	22	26.2
Unsure	2	2.4	9	10.7
Medium	2	2.4	6	7.1
Total	84	100.0	84	100

- **Satisfaction level in terms of' social interaction among neighbors in their previous and present dwelling**

The following table illustrates an outcome of householders' responses regarding the satisfaction level of social interaction among neighbors in their previous and present dwelling. All respondents in their previous underground house indicated satisfactory for social interaction among neighbors, compared with modern house where the satisfaction level is only 63.1%, while about 23.8 % indicated unsatisfactory as shown in Table 4.20.

Table 4.20: Satisfaction level in terms of' social interaction among neighbors in their previous and present dwelling.

	Underground House		Modern House	
	Frequency	%	Frequency	%
Satisfactory	84	100	53	63.1
Unsatisfactory	0	0	20	23.8
Unsure	0	0	5	6.0
Medium	0	0	6	7.1
Total	84	100	84	100

- **Rate air humidity in previous houses and present houses**

The respondent's responses in terms of their opinion about air humidity in their previous underground house and present modern dwelling are displayed below. For humidity in previous underground houses, 76.2% of the respondents indicated that the air is neither humid nor dry while 11.9% said it was humid. For the humidity in present above ground houses, 41.7% of respondents indicated that the air is humid while 23.8% said the air is neither humid nor dry. 10.7%, 14.3%, and 9.5% said the air was dry, very dry, and very humid respectively. See Table 4.21.

Table 4.21: Rate air humidity in previous houses and present houses

	Underground House		**Modern House**	
	Frequency	%	Frequency	%
Very humid	1	1.2	8	9.5
Humid	10	11.9	35	41.7
Very dry	3	3.6	12	14.3
Dry	6	7.1	9	10.7
Neither humid nor dry	64	76.2	20	23.8
Total	84	100	84	100

4.7 Evaluation of the Study 1 Results

The main summary of questionnaire questions posed on the data collected from participants about underground houses and modern houses is as follows:

- 90.5% of participants who have previously lived in underground houses suggested that the thermal comfort inside the underground dwellings during summer and winter season was very comfortable. 27.4 % of respondents who presently live in above ground houses suggested that the thermal comfort was comfortable.
- 77.4% of respondents did not use any energy source for heating the underground house. While compared with the modern house where 54.8% of respondents are presently using electricity as energy for heating the house.

- 100% of respondents didn’t use energy for cooling their underground houses since there was no need to because the underground house provides good temperature comfort. But in modern houses, 100% of respondents use electricity.
- 65.5% of respondents suggested that in their previous houses (underground) lighting was satisfactory, compared with the modern houses where 94% of respondents suggested that in their present houses (above ground) lighting was satisfactory.
- For relative humidity in previous underground houses, 76.2% of respondents indicated that the air is neither humid nor dry compared with modern house, the humidity in above-ground houses, 23.8% said the air is neither humid nor dry.

4.8 Results of Study 2

Table 4.22 shows the mean temperature recorded both in underground and modern house. The average temperature measured for underground houses with regards to the inside (indoors) is 16.2°C while the same measurement for modern house is 12.6°C. All these measurements were observed in winter during a month period. The outdoor (courtyard) average temperature of the underground house was recorded to be 9.85°C while the average temperature outside the modern house was recorded to be 9.35°C.

For comparative analysis, the underground house seems to have a relatively moderate temperature compared to inside of the modern house which is considered cool with an average difference of 3.6°. In the outdoor measurement of temperature, the result showed nearly same percentages without significant difference. This finding means that underground houses are better in terms of temperature compared to modern houses. It is also important to note that these measurements were observed for only a month in winter which may not be enough to reach a conclusive measurement. Future studies should extend the measurement period to a year or more.

Table 4.22: Average temperature in the underground house and modern house from 20/01/2019 to 18/02/2019

Date	Average temperature per day (Underground House)	Average temperature per day (Modern House)	Average temperature in the courtyard	Average temperature outside the house
20/01/2019	17.5	14.95°	14.9°	13.6
21/01/2019	16.9	16.7°	13.8°	14°
22/01/2019	14.7°	17.4°	12.75°	12.7°
23/01/2019	15.8°	11.6°	8.4°	8.2°
24/01/2019	16°	12.45°	°10.125	9.55°
25/01/2019	16.2°	11.15°	7.2°	5.45°
26/01/2019	14.1°	9.72°	6.5°	6.2°
27/01/2019	16.5°	11.6°	11.7°	7.75°
28/01/2019	15.6°	14°	11.9°	12.2°
29/01/2019	15.7°	13.3°	11.3°	7.9°
30/01/2019	15.85°	13.5°	10.9°	7.15°
31/01/2019	16.05°	14.82°	13°	11.25°
1/02/2019	17.1°	17.3°	15.22°	15.75°
2/02/2019	16.27°	20.3°	17.75°	18.97°
3/02/2019	15.92°	16.7°	9.75°	10.27°
4/02/2019	15.85°	12.48°	4.27°	5.9°
5/02/2019	16.45°	9.15°	6.52°	5.63°
6/02/2019	16.55°	9.32°	7.55°	7.3°
7/02/2019	16°	9°	8.4°	7.25°
8/02/2019	16.17°	11.85°	7.75°	7.55°
9/02/2019	15.9°	12°	8.65°	11°
10/02/2019	16°	13.83°	11.82°	11°
11/02/2019	15.85°	14.65°	10.97°	11.65°

12/02/2019	16.8°	12.55°	7.2°	7.25°
13/02/2019	16.6°	9.1°	5.3°	5.1°
14/02/2019	16.3°	9.5°	7.1°	6.35°
15/02/2019	16.47°	10.73°	7.52°	7.7°
16/02/2019	16.55°	9.27°	6.85°	6.15°
17/02/2019	15.9°	10.47°	10.2°	10.28°
18/02/2019	16.3°	11.27°	9.57°	9.47°
Average	16.12°	12.67°	9.82	9.35

Table 4.23 illustrates the mean relative humidity recorded in underground and modern houses. The indoor relative humidity recorded in an underground houses was 62.15% in winter. While in the modern houses record was up to 70.13% in the same period. The average humidity in outdoor (courtyard) for both underground and modern house in this study is 67% and 66% respectively. All these percentages were results according to humidity measurement in field work. For comparative analysis, the underground house seems to have reasonable humidity compared to the modern house in inside the house with an average difference of 8%. In the outdoor measurement of humidity, the result showed nearly same percentages without significant difference (only 1% difference).

Table 4.23: Average relative humidity inside and outside of underground and modern house from 20/01/2019 to 18/02/2019

Date	Average humidity inside underground house per day	Average humidity inside modern house per day	Average humidity in the courtyard	Average humidity outside the house
20/01/2019	41.25%	62.25%	43.25%	49.25%
21/01/2019	53.25%	52.25%	44.25%	40.75%
22/01/2019	54.75%	60.25%	58.25%	66.25%
23/01/2019	61.75%	72.75%	64.25%	72%
24/01/2019	53%	68.5%	60.5%	64.75%
25/01/2019	52.75%	66 %	61.75%	65.5 %
26/01/2019	48.5 %	70.75 %	57.25%	62%
27/01/2019	60.25%	71.5%	57.25 %	63.25 %
28/01/2019	48 %	66.25 %	49.5%	53.5%
29/01/2019	53.5%	61.25%	50.75%	63.75%
30/01/2019	55.5%	65%	60%	59.25%
31/01/2019	73 %	67 %	64.75%	60%
1/02/2019	57 %	57 %	52.75%	45.5 %
2/02/2019	41%	44.75 %	41.25%	39%
3/02/2019	44.25%	60%	60.25%	38%
4/02/2019	60.75%	69.25%	82.5%	71.75%
5/02/2019	76.75%	75.75%	96%	96.5%
6/02/2019	76.25%	85.75%	94.5%	89%
7/02/2019	66.5%	87%	73.25%	88.25%
8/02/2019	64%	77.25%	80.75%	77.25%
9/02/2019	61.25%	80.5%	82.25%	69.5%
10/02/2019	65.75%	74.75%	67%	69.5%

11/02/2019	65.75%	69.5%	63.25%	52%
12/02/2019	71.5%	74.5%	76.75%	79%
13/02/2019	76.75%	75.75%	87%	84.6%
14/02/2019	75.25%	81%	81.5%	77.5%
15/02/2019	77.25%	80%	78%	71.75%
16/02/2019	78.5%	79%	74.25%	74.25%
17/02/2019	73%	77.25%	78.5%	66.75%
18/02/2019	77.5%	71%	64.5%	65.75%
Average	62.15%	70.13%	67%	66%

4.9 Evaluation of the Study 2 Results

The main summary of this chapter through statistical analysis of the field survey is that the underground houses have noteworthy thermal performance compared with modern houses, while in both, average relative humidity is high in both:

- The average temperature measured for underground houses with regards to the inside is 16.2°C while the same measurement for modern is a house is 12.6°C.
- The relative humidity recorded in an underground houses indoor was 62.15% in winter. While in the modern houses recorded up to 70.13% in the same period.
- In the outdoor average measurement of temperature and humidity for underground and modern house, the result showed nearly the same percentages without any significant difference.

It can be argued that underground houses achieve thermal comfort (both in winter and summer) by the usage of local building materials as well as simple construction techniques. It is important to note that these measurements were observed for only between a month of 2019 in winter**.**

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The essential task of this research was to make comparison between vernacular architecture and modern housing in Gharyan Libya with regards to thermal comfortability, energy usage, construction method and materials etc. through field studies .

After explaining the research background, research problem, aim and methodology in Chapter 1, vernacular architecture and earth sheltered houses in the world were examined and evaluated in Chapter 2. Then, in Chapter 3, both vernacular architecture and the modern housing in Libya have been discussed and explained. In addition, two separate field studies are defined and the findings of these researches have been displayed in Chapter 4.

It can be argued that the findings from the field studies prove that underground houses are relatively more sustainable buildings in terms of thermal comfortability, energy consumption, building material and adaption to the environment compared to modern houses. In addition, most of the respondents as previous residents of underground houses indicated that they were more satisfied with vernacular houses (underground housing) than modern houses.

For instance, 90.5% of participants who have previously lived in underground houses suggested that the thermal comfort inside the underground dwellings during summer and winter season was very comfortable. But merely 27.4 % of respondents who presently live in above ground houses suggested that the thermal comfort was comfortable.

100% of respondents didn’t use energy for cooling their underground houses. But in modern houses, 100% of respondents use electricity.

For relative humidity, 76.2% of respondents indicated that the air is neither humid nor dry in underground houses, while for the humidity in above-ground houses, 23.8% said the air is neither humid nor dry.

In the light of these findings, it can be commented that underground houses are more sustainable and environmentally friendly houses. Further, it can be said that underground houses have several advantages over the modern houses such as the usage of local environmentally friendly construction materials and simple construction techniques to provide thermal comfort and stable temperatures inside the house in winter and summer. This means that underground houses have passive cooling and heating, where it meets the needs of people.

There are a few disadvantages associated with underground houses such as inefficient natural light and sewage systems. These problems have to be taken into account when planning such houses. However, such problems can be solved easily by careful design and the use of modern technology.

5.2 Recommendations

A comprehensive technical study on the local building materials should be conducted about construction of underground housing in Gharyan, for future studies. This will provide a better and comprehensive information to understand why the locals of Gharyan select these local construction materials. Such a knowledge can be useful for designing modern but environmentally friendly buildings in Libya.

The authorities in Gharyan should preserve vernacular architecture of the underground houses because they are considered as unique, architectural heritage features. These underground dwellings were built by our predecessors hundreds of years ago with high quality specifications from the local materials available, in order to resist the harsh climate in mountain region both in winter and summer. It is eligible to learn such simple techniques as passive heating and cooling which decrease energy consumption leading to ecological balance.

The second study was limited to only 30 days by measuring temperature and humidity four times a day during a month in winter (21/01/2019- 18/02/2019). So the research should be conducted during the rest of the seasons for an extended period of time in order to determine the thermal comfort criteria more comprehensively.

REFERENCES

Abd-El-Hamid Khair-El Din (1983). Earth Sheltered Housing: An Approach to Energy GideonsGolany .Earth sheltered habitat, history, architecture and urban design. New York: Van Nostrand Company Inc.

Aburroush, M. (1996). A cross-cultural study of locus of control and self-esteem as related to socio cultural factors among Libyan and British postgraduate student. *Unpublished PhD Thesis Manchester University*.

Ahmed, S. (1985). General Studies about the City of Ghadames and Design of Neighbourhood Unit; General Plan, Unpublished PhD Thesis, The Technical University of Krakow, Poland.
Ahmed, S. (1985). General Studies about the City of Ghadames and Design of Neighbourhood Unit; General Plan, Unpublished PhD Thesis, The Technical University of Krakow, Poland.

Akara, R. (2000).The Mountain of Housing in Libya, Unpublished MSc Thesis, University of Alexandria, Egypt

Albasha, M. (2010). Towards a Private Earth Sheltered Housing Technology in the Libyan Coastal Region. *Master Thesis*, *School of Applied Sciences*, Academy of Graduate Studies. Tripoli- Libya

AlSayyad, N. (2006). Foreword. In L. Asquith & M. Vellinga (eds). Vernacular Architecture in the 21st Century: Theory, Education and Practice. London: Taylor & Francis, p.xvii.

Amer, A. A. (2007). *Comparison study of traditional and contemporary housing design with reference to Tripoli, Libya* (Doctoral dissertation, University of Salford, UK).

Anselm, A. J. (2012). Earth shelters; A review of energy conservation properties in Earth sheltered housing. In *Energy Conservation*. Intech Open.

Aysan, Y., & Oliver, P. (1987). *Housing and Culture after Earthquakes: A guide for future policy making on housing in seismic areas*. Oxford polytechnic.

Beverly, J. (2012, February 22). "10 Amazing Underground Homes", ODDEE, Retrieved from http://www.oddee.com/item_98085.aspx.

Birks, S. and Sinclair, A. (1980). Arab Manpower: the Crisis of Development, Croom Helm London.

Boyer, L. L., & Grondzik, W. T. (1987). *Earth shelter technology*. Texas A&M University Press.

Bukamur, S. M. (1985). Design guidelines for Housing in Libya based on Climatic and Social criteria. MSc, University of Arizona USA.

China's mysterious underground cities. (2018, January 27). Retrieved March 12, 2019 from https://www.news.com.au/travel/world-travel/asia/chinas-hidden-subterranean-cities/news-story/4d9bd0b023c6efaff74576329617602d

Chojnacki, M. (2003). Traditional and Modern Housing Architecture and Their Effect on the Built Environment in North Africa. A Comparison of Traditional and Contemporary Housing Architecture as a Method of Assessing the Microclimatic Conditions of Housing Development in the Desert Zone (Ghadames case study). In *The International Conference Methodology of Housing Research. Stockholm, Sweden*.

Crouch, D. P., & Johnson, J. G. (2001). *Traditions in Architecture: Africa, America, Asia, and Oceania*. New York: Oxford University Press.

Daze, M. (1982). Understanding the Built Environment: Crisis Change and Issue FN Needs in the Concept of Habitations and Settlement in Libya, Unpublished Ph D Thesis, University of Pennsylvania, U. S. A.

Doxiadis Associates (1964 a). Housing in Libya: Vol.1- Existing Conditions, a Report prepared for the government of Libya.

El-Dweb, A. (1995). Study of Traditional Houses in Libya, unpublished MSc Thesis, University of Al-Khartoum, Sudan.

Fisher, B. (1978). The Middle East: A Physical, Social and Regional Geography, 7Th Ed, Methuen, London.

Fraser, D. (1968). Village planning in the primitive world.

Gabril, N. (2014). *Thermal Comfort and Building Design Strategies for Low Energy Houses in Libya: Lessons from the vernacular architecture* (Doctoral dissertation, University of Westminster).

Google earth pro, 2019

Golany, G. (1988). *Earth-sheltered dwellings in Tunisia: ancient lessons for modern design*. University of Delaware Press.

Guidoni, E. (1975). Primitive Architecture: History of World Architecture. *Electra/Rizzoli. New York*.

Hassan, H., & Sumiyoshi, D. (2018). Earth-sheltered buildings in hot-arid climates: Design guidelines. *Beni-Suef University journal of basic and applied sciences*, *7*(4), 397-406.

Heba, H. A., Aly, A., Akashi, Y., Arima, T., & Sumiyoshi, D. (2012). The Possibility of Applying the Earth-Sheltered Building Type for Housing Projects between Humid and Dry Climates-Case Study Egypt and Japan. In *International Society of Habitat Engineering and Design Conference, ISHED, Shanghai, China: Tongji University* (Vol. 8).

Huge Flower House in Bolton by Make Architects. (n.d.). Retrieved April 7, 2019 from https://www.home-reviews.com/huge-flower-house-in-bolton-by-make-architects\

Kaushik. "The Underground Homes of Matmata, Tunisia." *Amusing Planet*, www.amusingplanet.com/2017/05/the-underground-homes-of-matmata-tunisia.html.

Level, T. (2018, September 16). *TAG LEVEL*. Retrieved December 28, 2018 ,from TAG Level: https://www.taglevel.com/underground-homes-build-an-amazing-earth-

Liu, X., Wang, Z., Liu, J., & Yang, Z. (2015). Concept Design and Development Model of Underground Villas. *Journal of Engineering Science and Technology Review*, *8*(3), 46-52.

Mezughi, Mustafa, and Mohamed A Dawi.(2003). “Consultancy Report Submitted to the UNDP for Rehabilitation of the Old City of Ghadames.”

Ministry of Municipalities (1979). National Physical Perspective plans Tripoli, Libya.

Ministry of Planning and Development. (1964).Housing in Libya, Vol. 2, Athens, Greece: Doxiadis Associates, 1964

Mirrezaei, S. A. (2015). *An Ecological Study on Earth Sheltered Housing in Different Climates* (Master's thesis, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ)

Moreland, F. L. (1975). Alternatives in energy conservation: The use of earth covered buildings.

National Consulting Bureau. 2009. *Gheryan Planning.*

Ogden Publications, Inc., & Ogden Publications, Inc. (n.d.). An Economical Underground Earth Sheltered Home. Retrieved March 3, 2019 from https://www.motherearthnews.com/nature-and-environment/economical-underground-earth-sheltered-home-zmaz82ndzgoe

Oliver, Paul (2007). “Shelter and society, Vernacular Architecture in its Cultural Contexts”.*General Studies Lectures, Engineering Towards Development and Change*. Universityof Addis Ababa, Faculty of Technology.

Oliver, P. (2006). Built to Meet Needs: Cultural Issues in Vernacular Architecture, Architectural Press, Oxford

Oliver, P. H. (1969). Shelter and Society, Barrie Rokliff.

Özkan, S. (2006). Traditionalism and vernacular architecture in the twenty-first century. In *Vernacular Architecture in the 21st Century* (pp. 115-127). Taylor & Francis.

Rghei, A. (1987). Rural and Urban Domestic Architecture in Libya MSc Thesis, University of McGill, Montreal, Canada.

Roy, R. (2006). *Earth-Sheltered Houses: How to Build an Affordable Underground Home* (Vol. 4). New Society Publishers.

Shahran, A. (2018). A Study of Single Family Housing in Libya, (Doctoral dissertation, University of Novi Sad, Serbia).Retrieved from http://www.nardus.mpn.gov.rs/handle/123456789/9232

Shahran, A., Reba, D., & Krklješ, M. (2017). Thermal comfort, adaptability and sustainability of vernacular single family houses in Libya. *Tehnički vjesnik*, *24*(6), 1959-1968.

Shaiboub, A., (1979). "Domestic Architecture in Libya", unpublished PhD Thesis, University of Manchester, UK.

Shawesh, A. M. (1996). *Housing design and socio-cultural values in Libya: an investigation of traditional and contemporary housing* (Doctoral dissertation, Newcastle University).

Sheibani, G., & Havard, T. (2005). The government role in housing in Libya during the period 1970–2000. In *21 st Annual ARCOM Conference* (pp. 697-707)

Stea, Turan. (1993). *Placemaking: Production of Built Environment in Two Cultures*. *Working Paper* .Avebury Ashgate Publishing Limited, England.

"The Hockerton Housing Project." *Blog*, seonottingham.blogspot.com/2012/03/hockerton-housing-project.html. Retrieved January 5, 2019.

Tošković, D. (2006). Man-environment interaction: A review of modern architecture of Libya in transition. *Spatium*, (13-14), 47-54. Retrieved March 5, 2019, from https://scindeks-clanci.ceon.rs/data/pdf/1450-569X/2006/1450-569X0614047T.pdf

Vellinga, M., Oliver, P., & Bridge, A. (2007). *Atlas of vernacular architecture of the world*.

Wells, M (1998). Earth-Sheltered House, an Architect's Sketchbook, 1rd edn. United

Zarrugh, M. (1976). The Preservation of the People's Cultural and Urban Heritage in Libya: an Evaluation of the Current Situation and Recommended Framework for action, with Emphasis on the Old City of Tripoli, unpublished MSc Thesis, University of Michigan State USA.

APPENDICES

APPENDIX 1

The Questionnaire

My name is Hosain Mosbah Bakoosh. I am a postgraduate student, Department Architecture at the University Near East in North Cyprus. I am doing thesis on Comparison between Vernacular Architecture (Underground Houses) and Modern Style Housing in Gharyan, Libya. This will be performed by measuring people satisfaction and housing preferences, regarding of existing housing, from where thermal comfortability, energy usage, construction method and materials, and environmental implications.

....

Part 1: General Information about Household

Address: Sample No:

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SECTION 1: Socio-demographic data

Q 1: Gender

Male ☐ Female ☐

Q2: Age

16-25 ☐ 26-40 ☐ 41-55 ☐ 56-65 ☐ Over 66 ☐

Q3: Place of birth

Gharyan ☐ Out of Gharyan ☐

Q4: Marital status

Single ☐ Married ☐

Q5: Occupation

Government employee ☐ Self-employer ☐ Retired ☐ Unemployed ☐

Q6: Education level

Uneducated ☐ Primary ☐ Intermediate ☐ University ☐

Q7: Size of your family

2 ☐ 3-4 ☐ 4-5 ☐ more than 5 ☐

SECTION 2: Past and Present House Circumstances

Q1: What type of home did you live in just before to move out to your present house?

Underground house ☐ House ☐ Attached house ☐ Villa ☐

Apartment in a block ☐ (Other please specify) ………………………….

Q2: How many years did you live in your previous house?

1- 3 years ☐ 4-8 years ☐ 8 -12 years ☐ More than 12 years ☐

Q3: In present, what kind of housing do you live?

House ☐ Villa ☐ Courtyard house ☐ public house ☐ Flat in a block ☐

(Other please specify) ………………………….

Q4: What is construction material used for your previous house and present house?

A- (Previous) Adobe ☐ Natural Stone ☐ Limestone block ☐ Brick concrete ☐

(Other please specify)…………………………

B- (Present) Adobe ☐ Natural Stone ☐ Limestone block ☐ Brick concrete ☐

(Other please specify)…………………………

Q5: How would you rate your thermal comfort in your house during summer and winter?

A-(Previous) Comfortable ☐ Moderately comfortable ☐

Uncomfortable ☐ Unsure ☐

B-(Present) Comfortable ☐ Moderately comfortable ☐

Uncomfortable ☐ Unsure ☐

Q6: What is energy type used for heating?

A-(Previous) Kerosene ☐ Natural coal ☐ Electricity ☐ Mutual ☐

Without energy ☐

B- (Present) Kerosene ☐ Natural coal ☐ Electricity ☐ Mutual ☐

Without energy ☐

Q7: What is energy type used for cooling?

A-(Previous) Kerosene ☐ Natural coal ☐ Electricity ☐ Mutual ☐

Without energy ☐

B- (Present) Kerosene ☐ Natural coal ☐ Electricity ☐ Mutual ☐

Without energy ☐

Q8: Do you have air conditioning at home?

A- (Previous) Yes ☐ No ☐

B- (Present) Yes ☐ No ☐

Q9: How many hours is it used per day?

A-(Previous) Zero ☐ 1 hour ☐ 2 hours ☐ 3 hours ☐ more than 4 ☐

B-(Present) Zero ☐ 1 hour ☐ 2 hours ☐ 3 hours ☐ more than 4 ☐

Q10: How do you rate the ventilation in your house?

A-(Previous) Satisfactory ☐ Unsatisfactory ☐ Unsure ☐

B-(Present) Satisfactory ☐ Unsatisfactory ☐ Unsure ☐

Q11: How do you rate the lighting in your house?

A-(Previous) Satisfactory ☐ Unsatisfactory ☐ Unsure ☐

B-(Present) Satisfactory ☐ Unsatisfactory ☐ Unsure ☐

Q12: Do you feel comfortable in your house during summer and winter?

A-(Previous) Yes ☐ No ☐ Unsure ☐

B-(Present) Yes ☐ No ☐ Unsure ☐

Q13: How do you rate social interaction among neighbours in your previous and present dwelling?

A-(Previous) Satisfactory ☐ Unsatisfactory ☐ Unsure ☐

B-(Present) Satisfactory ☐ Unsatisfactory ☐ Unsure ☐

Q14: How do you rate air humidity in your previous and present dwelling?

A- (Previous) Very humid ☐ Humid ☐ Very dry ☐

Dry ☐ Neither humid nor dry ☐

B -(Present) Very humid ☐ Humid ☐ Very dry ☐

Dry ☐ Neither humid nor dry ☐

Q15: In your opinion, the underground dwellings are appropriate for housing or not?

Appropriate ☐ Inappropriate ☐ Appropriate but after reconstruction ☐ Unsure ☐

APPENDIX 2

Measurement of temperature in an underground house from 20/01/2019 to 18/02/2019

Time	7.00AM		1.00 PM		7.00 PM		1.00 AM	
Date	Inside house	Courtyard	Inside house	Courtyard	Inside house	Courtyard	Inside house	Courtyard
20/01/2019	20°c	17.2°c	19.9	17.7	15.2	13	15	11.8
21/01/2019	14.2	12.2	18.2	16.2	18	15.9	17.3	11
22/01/2019	13.3	12	16.5	15	16	13	13	11
23/01/2019	15.2	6.2	14	12.4	17	08	17	07
24/01/2019	17	10	16.2	13.3	14	09	16.8	8.2
25/01/2019	16.3	6.9	15.9	10	16	07	16.7	05
26/01/2019	13	05	15.3	7.3	12.9	8.2	15.3	5.6
27/01/2019	15.9	5.8	18.2	17	16.8	13	15.2	11
28/01/2019	15.4	11.8	15.8	13	15.7	10.8	15.5	12
29/01/2019	14.2	12.3	16.6	14.2	16.2	12.6	15.8	6.2
30/01/2019	14.6	11.8	16.8	13.2	15.2	7.1	16.8	11.5
31/01/2019	16.9	12.1	15.2	13.5	16.1	13.8	16	12.6
1/02/2019	16.9	13.1	17.3	14.8	18.1	17.3	16.1	15.7
2/02/2019	16.1	15.8	16	23	16.2	21	16.8	11.2
3/02/2019	16.3	12.1	15.7	11.1	15.8	10.7	15.9	5.1
4/02/2019	16	4.3	14.9	6.2	14.6	3.5	16.1	3.1
5/02/2019	16.3	3.5	16.6	8.5	16.8	7.2	16.1	07
6/02/2019	16.5	7.5	16.2	7.1	16.7	8.8	16.8	6.8

7/02/2019	15.8	8.1	15.8	9.2	16.2	8.5	16.3	7.8
8/02/2019	15.5	7.8	16.2	8.7	16.7	7.4	16.3	7.1
9/02/2019	15.5	7.8	15.8	9.3	16.3	9.1	16.1	8.4
10/02/2019	16.1	7.5	16.4	17.5	15.5	13	16.1	9.3
11/02/2019	15.4	8.8	16	9.2	15.8	10.2	16.2	8.6
12/02/2019	16.4	8.8	17	8.9	16.6	6.1	17.2	05
13/02/2019	16.5	5.2	16.4	5.4	16.7	5.6	16.8	5.1
14/02/2019	16.1	6.2	16.4	10.1	16.4	7.5	16.3	4.6
15/02/2019	16.5	4.3	16.4	11.5	16.5	9.2	16.5	5.1
16/02/2019	16.6	6.6	16.8	6.4	16.5	5.9	16.3	8.5
17/02/2019	16.3	8.5	14.5	13.3	16.1	12.5	16.8	6.5
18/02/2019	16.6	5.5	16.3	12.9	16.3	10.8	16.1	9.1

Measurement of temperature in a modern house from 20/01/2019 to 18/02/2019

Time	**7.00AM**		**1.00 PM**		**7.00 PM**		**1.00 AM**	
Date	**Inside house**	**Outside home**	**Inside house**	**Outside home**	**Inside house**	**Outside home**	**Inside house**	**Outside home**
20/01/2019	13°c	14°c°	17.9	19	14.7	9.8	14.2	11.6
21/01/2019	17.5	10.8	16.4	16.3	16	15	16.9	14.2
22/01/2019	18.4	10.9	15.7	17.8	17	9.4	18.4	12.6
23/01/2019	12.3	5.3	11.2	13.3	11.7	06	11.2	8.2
24/01/2019	12.9	10	11.8	13.2	13	07	12.1	08
25/01/2019	11.6	5.1	11	6.7	11	06	11	04
26/01/2019	9.5	03	8.6	7.9	10.2	07	10.4	6.8
27/01/2019	9.8	5.4	11.7	9.5	11.7	7.2	13.2	8.9
28/01/2019	12	11.4	14.5	14	15	12	14.7	11.3
29/01/2019	12.7	5.2	15.5	12.5	13	8.5	12	5.2
30/01/2019	11.5	04	14	7.8	14.3	06	14.3	10.8
31/01/2019	14.1	8.3	14.2	12.7	15.6	12.2	15.4	11.8
1/02/2019	14.8	13.2	18.8	17.3	17.9	16.3	17.7	16.2
2/02/2019	15.3	16.8	25	27	21	17.3	20.2	14.8
3/02/2019	17.7	12.6	17.9	11.3	17.8	9.7	13.4	7.5
4/02/2019	15.2	4.1	13.4	8.8	12.1	5.9	9.2	4.8
5/02/2019	9.4	3.4	8.8	06	9.1	07	9.3	6.1
6/02/2019	9.5	7.8	9.4	7.1	9.5	6.8	8.9	7.5
7/02/2019	8.4	6.2	8.6	8.5	9.6	7.2	9.6	7.1

8/02/2019	9.4	7.2	13.8	8.2	12.8	7.4	11.4	7.4
9/02/2019	11.6	7.4	12.2	6.7	12.8	6.6	11.5	7.4
10/02/2019	12.1	7.1	15.9	16.8	14.5	10.8	128.	9.5
11/02/2019	12.9	8.9	15.7	16.4	15.9	11.2	14.1	10.1
12/02/2019	13.7	8.6	13.1	8.8	12.7	6.4	10.7	5.2
13/02/2019	9.5	5	9.3	06	9.1	5.2	8.6	5.1
14/02/2019	8.4	6.1	10.8	9.7	10.5	05	8.3	4.6
15/02/2019	9.5	4.5	10.2	11.1	11.9	9.1	11.3	6.1
16/02/2019	9.3	6.5	9.5	6.3	9.2	5.8	9.1	06
17/02/2019	8.5	8	9.8	14.5	13.3	12.3	10.3	6.3
18/02/2019	10.8	5.3	12.8	12.7	9.7	10.2	11.8	9.7

Measurement of humidity in an underground house from 20/01/2019 to 18/02/2019

Time	**7.00AM**		**1.00 PM**		**7.00 PM**		**1.00 AM**	
Date	**Inside house**	**Courtyard**	**Inside house**	**Courtyard**	**Inside house**	**Courtyard**	**Inside house**	**Courtyard**
20/01/2019	55%	46%	35%	34%	38%	46%	37%	47%
21/01/2019	48%	44%	60%	35%	48%	36%	57%	62%
22/01/2019	53%	54%	48%	49%	61%	66%	57%	64%
23/01/2019	59%	76%	62%	53%	75%	61%	51%	67%
24/01/2019	52%	66%	54%	46%	52%	64%	54%	66%
25/01/2019	53%	61%	54%	67%	51%	65%	53%	54%
26/01/2019	39%	66%	65%	54%	42%	45%	48%	64%
27/01/2019	49%	66%	71%	73%	73%	45%	48%	45%
28/01/2019	57%	42%	49%	44%	49%	66%	37%	46%
29/01/2019	48%	44%	60%	42%	49%	55%	57%	62%
30/01/2019	45%	54%	55%	53%	48%	66%	74%	67%
31/01/2019	74%	69%	72%	66%	71%	57%	75%	67%
1/02/2019	75%	65%	55%	66%	57%	45%	41%	35%
2/02/2019	41%	40%	41%	37%	40%	43%	42%	45%
3/02/2019	41%	45%	42%	55%	50%	62%	44%	79%
4/02/2019	49%	81%	46%	61%	75%	92%	73%	96%
5/02/2019	75%	95%	78%	96%	79%	98%	75%	95%
6/02/2019	78%	96%	77%	95%	72%	92%	78%	95%

7/02/2019	76%	69%	56%	72%	66%	75%	68%	77%
8/02/2019	58%	89%	66%	77%	67%	78%	65%	79%
9/02/2019	58%	72%	59%	84%	62%	87%	66%	86%
10/02/2019	66%	78%	68%	45%	62%	68%	67%	77%
11/02/2019	68%	78%	72%	40%	69%	76%	54%	59%
12/02/2019	55%	56%	76%	84%	77%	88%	78%	79%
13/02/2019	76%	87%	76%	86%	77%	88%	78%	87%
14/02/2019	75%	84%	75%	88%	76%	66%	75%	88%
15/02/2019	77%	88%	77%	67%	78%	68%	77%	89%
16/02/2019	78%	69%	79%	72%	78%	79%	79%	77%
17/02/2019	78%	75%	76%	54%	76%	56%	79%	82%
18/02/2019	82%	88%	51%	52%	75%	66%	76%	57%

Measurement of humidity in modern house from 20/01/2019 to 18/02/2019

Time	7.00AM		1.00 PM		7.00 PM		1.00 AM	
Date	**Inside house**	**Outside home**	**Inside house**	**Outside home**	**Inside house**	**Outside home**	**Inside house**	**Outside home**
20/01/2019	69%	54%	48%	43%	66%	54%	66%	46%
21/01/2019	50%	47%	49%	34%	48%	41%	62%	41%
22/01/2019	57%	61%	64%	46%	58%	87%	62%	71%
23/01/2019	77%	93%	71%	65%	71%	75%	72%	75%
24/01/2019	64%	54%	68%	55%	69%	87%	73%	63%
25/01/2019	64%	65%	66%	67%	71%	60%	63%	70%
26/01/2019	70%	65%	74%	64%	70%	58%	69%	61%
27/01/2019	72%	66%	72%	58%	70%	62%	72%	67%
28/01/2019	66%	43%	64%	40%	66%	54%	69%	77%
29/01/2019	48%	79%	67%	64%	65%	55%	65%	57%
30/01/2019	67%	54%	64%	66%	64%	67%	65%	50%
31/01/2019	66%	68%	68%	58%	64%	56%	70%	58%
1/02/2019	72%	63%	53%	49%	51%	50%	52%	20%
2/02/2019	63%	48%	29%	23%	39%	52%	48%	33%
3/02/2019	52%	32%	53%	39%	54%	40%	81%	41%
4/02/2019	58%	81%	63%	58%	62%	59%	94%	89%
5/02/2019	67%	96%	75%	98%	79%	95%	82%	97%
6/02/2019	83%	97%	84%	90%	91%	88%	85%	81%

7/02/2019	86%	89%	86%	81%	90%	95%	86%	88%
8/02/2019	87%	86%	70%	81%	72%	76%	80%	66%
9/02/2019	80%	64%	81%	76%	79%	84%	82%	84%
10/02/2019	72%	82%	74%	54%	76%	77%	77%	65%
11/02/2019	78%	52%	64%	40%	65%	51%	71%	65%
12/02/2019	73%	82%	75%	65%	76%	83%	74%	86%
13/02/2019	75%	87%	74%	84%	75%	83%	79%	84%
14/02/2019	77%	84%	79%	63%	78%	80%	90%	83%
15/02/2019	79%	88%	83%	65%	80%	66%	78%	68%
16/02/2019	79%	69%	80%	72%	78%	79%	79%	77%
17/02/2019	78%	75%	76%	54%	76%	56%	79%	82%
18/02/2019	82%	88%	51%	52%	75%	66%	76%	57%