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Towards Sustainability: Developing Earth-Sheltered Housing by Integrating Modern Technologies with Traditional Architecture

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Abstract
This paper aims to present an effective solution to global environmental challenges by sustainably reintroducing ancient earth-sheltered buildings in Libya. Libya has long-standing traditional environmental techniques in many of its cities, particularly in mountainous areas such as Gharyan, Zintan, and Nalut. The research includes a theoretical review of this type of housing, as well as an **analytical framework** that evaluates selected local and international case studies. The study focuses on definition, history, typologies, evaluation, and development potential, highlighting opportunities to modernize these buildings by integrating contemporary technology. This approach enhances sustainability, addresses modern housing needs, and improves livability and appeal. At the conclusion of the paper, a set of future recommendations is presented, focusing on design improvements, advanced construction techniques, and context-specific adaptations to ensure these homes are suitable for contemporary living.

Key words: Earth sheltered, Sustainable, Environment, Libya.

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نحو الاستدامة: تطوير المساكن المحمية بالأرض بدمج التقنيات الحديثة مع العمارة التقليدية

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الملخص

تهدف هذه الورقة إلى تقديم حل فعّال للتحديات البيئية العالمية من خلال إعادة تبني المباني المحمية بالأرض القديمة بشكل مستدام في ليبيا. تمتلك ليبيا تقنيات بيئية تقليدية منذ زمن بعيد في العديد من مدنها، خاصة في المناطق الجبلية مثل غريان والزنتان ونالوت. يشمل البحث استعراضًا نظريًا لهذا النوع من المساكن، بالإضافة إلى إطار تحليلي يقيم حالات دراسية محلية ودولية مختارة. يركز البحث على التعريف، التاريخ، الأنواع، التقييم، وإمكانات التطوير، مع إبراز الفرص لتحديث هذه المباني بدمج التقنيات المعاصرة. يعزز هذا النهج الاستدامة، ويستجيب لاحتياجات الإسكان الحديثة، ويزيد من جاذبية هذه المساكن وصلاحيتها للمعيشة .وفي ختام الورقة، تم تقديم مجموعة من التوصيات المستقبلية التي تركز على تحسين التصميم، وتطوير تقنيات البناء الحديثة، وتكييفها مع السياق المحلي لضمان ملاءمتها للمعيشة العصرية.

كلمات مفتاحية: الاستدامة، البيئة، ليبيا، البيوت المحمية بالأرض، العوازل.

1. Introduction

Earth-sheltered houses are increasingly presented as a sustainable and energy-efficient building solution. This research explores how these houses have evolved from traditional techniques into modern, technologically enhanced models. It investigates the key reasons that make earth-sheltered housing sustainable, their environmental and economic advantages, and the factors contributing to—or limiting—their wider adoption.

The study follows a comparative analytical approach, examining three case studies:

- A traditional earth-sheltered house in Gharyan, Libya.

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- A modern above-ground house in Al-Zawiya, Libya.
- A modern earth-sheltered house in Cumbria, United Kingdom.

The aim is to evaluate their performance in terms of thermal comfort, energy efficiency, and environmental integration, while correcting misconceptions such as these houses being dark, damp, or unhealthy.

1.1. Study Problem

Modern construction faces growing environmental and economic challenges, including pollution, excessive consumption of non-renewable energy, and rising operational and maintenance costs. In Libya, traditional architectural solutions, such as earth-sheltered houses, are largely overlooked despite their proven ability to provide natural thermal comfort and reduce energy consumption. Integrating modern technologies with this traditional building type could enhance performance and efficiency, yet studies documenting its feasibility are limited. This underscores the need for an analytical study of selected local and international earth-sheltered housing models to assess their potential for architectural and economic sustainability in Libya.

1.2. Research Objectives:

1. **Increase Awareness**
   Enhance understanding of the traditional building systems in Libya as sustainable environmental systems.
2. **Identify the Systems**
   Study the traditional earthen protected buildings and extract lessons learned from them.
3. **Promote Environmental Solutions**
   Emphasize the importance of returning to these systems as effective and sustainable environmental solutions

1.3. Methodology

The research adopted a comparative analytical approach, which included:

Case Studies:

- A modern above-ground house in Al-Zawiya (Libya).
- A modern earth-sheltered house in Cumbria (United Kingdom).

Criteria: Thermal insulation, energy consumption, operating costs, carbon emissions, thermal comfort, lighting, privacy.

Tools: Field measurements, review of energy bills, analysis of images and drawings, comparison tables.

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1.4. Previous Studies:

Several architectural and environmental studies have addressed the topic of earth-sheltered housing from various perspectives, particularly regarding thermal performance and its potential as a sustainable solution in hot climates:

1– The study by Elkady and Rashed (2016) titled "Thermal Performance of Earth-Sheltered Buildings: A Review" aimed to evaluate the thermal efficiency of such buildings. The study confirmed that the surrounding soil acts as natural insulation, helping to reduce energy consumption by up to 60%, making these structures a highly effective option for energy conservation.

2– The study by El-Hafeez (2021) titled "Earth-Sheltered Housing: A Sustainable Approach to Energy Efficiency in Architecture" focused on the application of earth-sheltered housing in arid climates such as North Africa. It showed that this building approach offers strong environmental and economic integration and is a promising solution for achieving sustainable development goals, especially in hot regions like Libya.

1.4.1. Data Sources:

1. Renewable and Sustainable Energy Reviews, Volume 65, 2016. https://doi.org/10.1016/j.rser.2016.07.036
2. International Journal of Architecture and Urban Development, Volume 11, Issue 1

2. Theoretical Framework

The theoretical framework defines earth-sheltered housing, outlines its history, typologies, and rationale for sustainability, and synthesizes key literature on benefits, barriers, and contemporary developments to frame the analysis.

2.1. Overview of Earth-Sheltered Housing

Earth-sheltered housing refers to residential spaces designed to provide comfort, protection, and privacy. It is considered a sustainable architectural solution due to its low environmental impact. Construction involves partially or fully covering the building with earth, which naturally insulates it from climatic conditions and reduces heat loss or gain. Show figs. 1,2.

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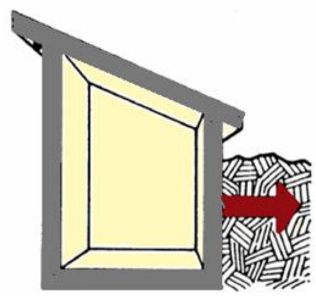


Figure 1: Control a building's interaction with its surrounding environment. (Author's work, 2025)

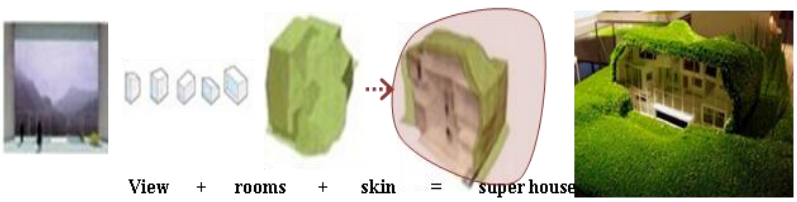
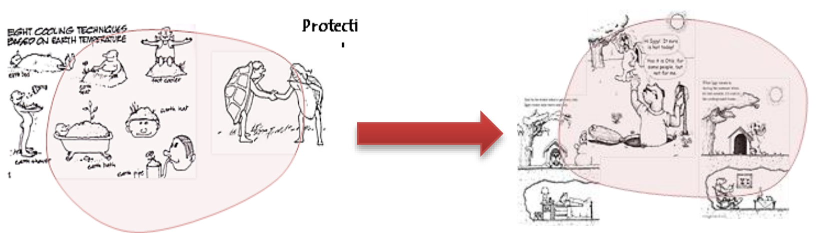


Figure 2. It is supposed to be built by stacking a pile of cubes in whatever form you want and then drape a shell over it. (Author's work, 2025)

2.2. Definition of Earth-Sheltered Housing

It is an ancient concept that has been reintroduced using modern techniques and contemporary amenities to achieve energy efficiency. It incorporates passive solar energy strategies that regulate ventilation, heating, and cooling. Many pioneering architects, such as Malcolm Wells and Arthur Quarmby, have encouraged the revival of this approach due to its environmental integration and natural protection. Show fig. 3.



Use earth-sheltered buildings to integrate passive solar strategies, with orientation optimized for daylighting and views.

Figure3: Animals and humans have long used earth insulation to maintain thermal comfort in winter and summer. Source:(IGSHPA & Oklahoma State University ,2005)

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2.3.History of Earth Sheltered Housing

Since ancient times, humans and other creatures have used the earth as shelter against harsh climates and threats. These shelters evolved from natural caves to excavated dwellings made of soil and rock. Underground spaces also served for safe storage and waste disposal. Examples such as the houses of Gharyan, Libya, and the dwellings of Matmata, Tunisia, demonstrate the suitability of this housing type for comfortable living under favorable geological and hydrological conditions. shoes in Fingers: 4, 5.

Figure 4: Sloped terrain and soft rock in Ghirian, Libya, enabled traditional underground atrium houses. Source: (Photo Researcher)

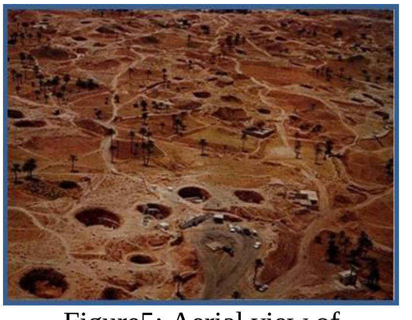

Figure5: Aerial view of traditional underground dwellings in Matmata, Tunisia. Archnet, n.d. Source: (https://www.archnet.org/).

2.4. Barriers to the Adoption of Earth-Sheltered Homes

Despite its effectiveness in thermal insulation and protection, the widespread adoption of earth-sheltered housing has been limited by the availability of modern building materials, construction techniques, and cheap energy in previous decades. People shifted to above-ground housing in pursuit of comfort and social status.

2.4.Earth Sheltered Housing Development

Since the 1970s, underground construction has emerged as an effective strategy to reduce environmental impact, saving up to 80% of energy compared to conventional buildings. This approach is increasingly adopted worldwide to support environmental, social, and economic sustainability (Boyer & Grondzik, 1987), Fig. 6,7.

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Figure 6. Hockerton Housing Project, Britain's first earth-sheltered eco-village.
Source: McGlashan Architecture, 2010, p. 25

Figure 7. California hillside home by McGlashan with planted roofs and natural ventilation.
Source: ArchDaily – McGlashan Architecture

2.6. Detailed Information on Earth Sheltered Houses

There are many different designs in earth sheltered houses, and each region has its own design.

2.7. Different Types of Earth Sheltered Houses

Earth covered buildings can be separated into the following basic types: (See Fig 8)

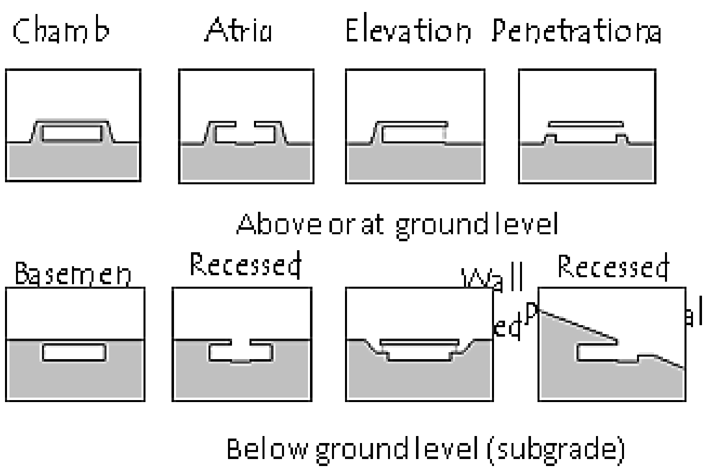

Figure 8. Types of Earth Sheltered Houses (Source: Yeang, 1987, p. XX

2.8. Description of Earth Sheltered House

The earth provides a stable thermal environment, reduces wind effects, and acts as a thermal mass for effective use of solar energy. Designs may feature only earth-covered walls or include roof coverage, offering flexibility in layout and site integration. Figures 9,10.

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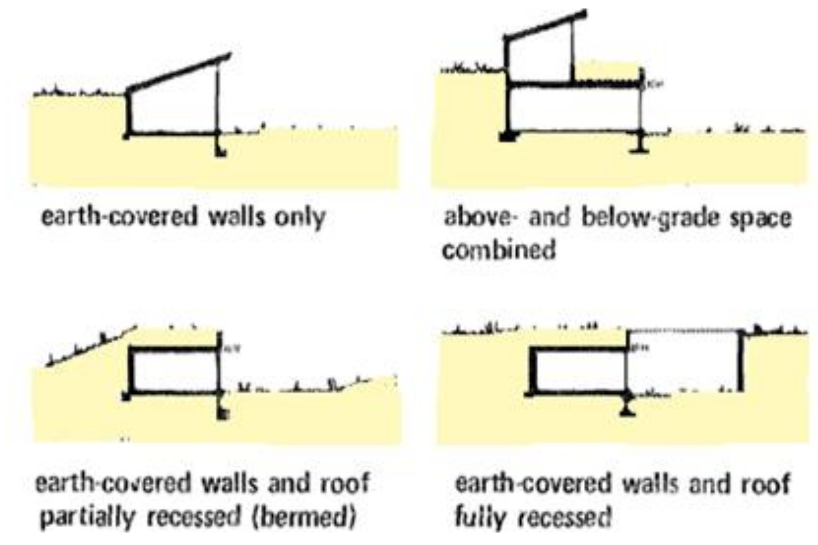


Figure 9. Typical relationships to the groiinall surface (Source: Yeang, 1987).

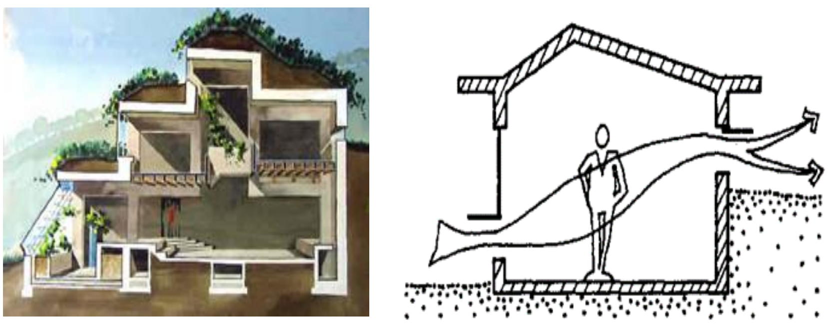
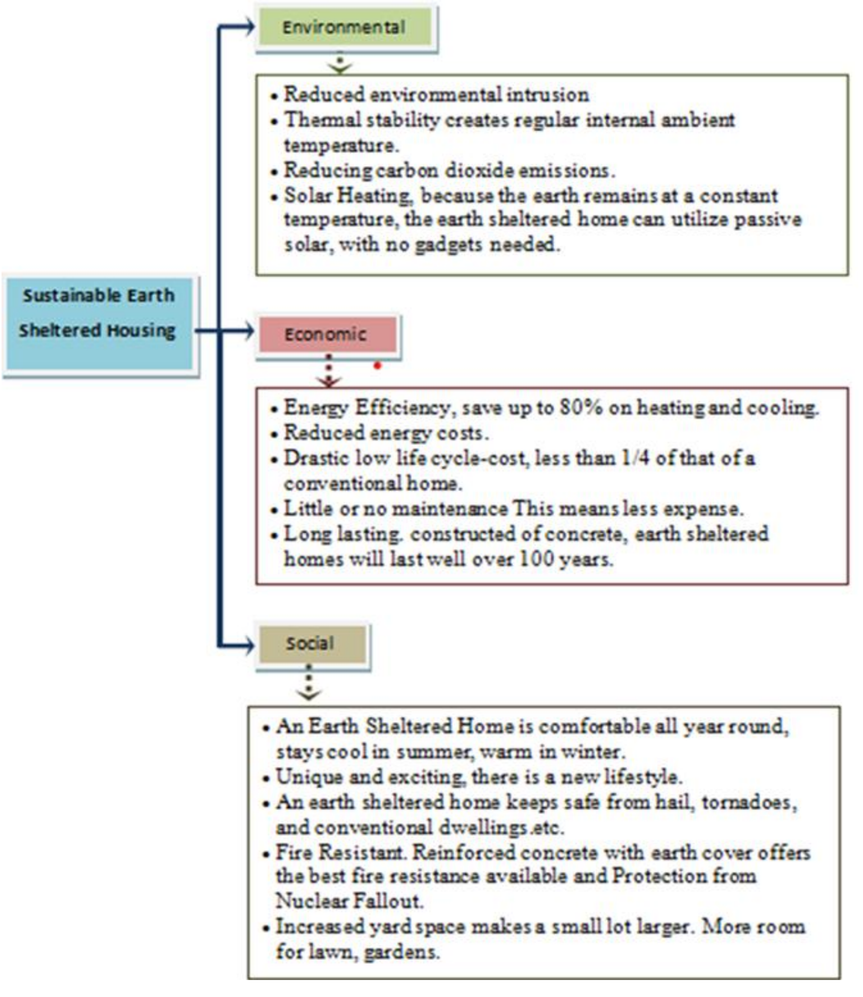


Figure 10. Natural light (Source: MoMA – Malcolm Wells, Earth-sheltered suburb project (Section), c. 1965

2.9. Three Dimensions for Sustainable Earth Sheltered Housing
Erath sheltered houses are sustainable because the meet the three sustainability considerations environmental, social, and economical goals. (Diagram 1) shows the three dimensions for the sustainable earth sheltered housing.



(Diagram 1) shows the three dimensions for the sustainable earth sheltered housing. SA
.(Source: Author, 2025; adapted from United Nations, 1987; OECD, 2001)

2.10. Conclusion:

Building on the theoretical framework, modern earth-sheltered housing exemplifies a sustainable architectural approach that integrates technological advancements to optimize natural light, ventilation, thermal efficiency, and overall environmental performance. By bridging traditional knowledge with contemporary design strategies, this approach not only enhances energy efficiency and harmony with nature but also demonstrates significant potential for modern applications in Libya. This research highlights the importance of raising awareness about such sustainable solutions

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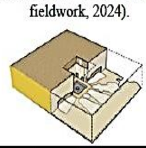
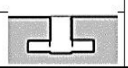
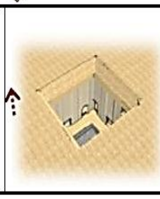
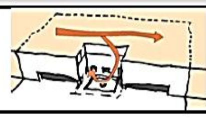
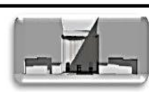
and underscores the need for future studies to focus on innovative design improvements, advanced construction techniques, and context-specific adaptations to ensure these dwellings meet the demands of contemporary living while promoting long-term environmental and social benefits.

3. Study and Analysis Sites.

The study compares a traditional underground house in Geryan, a modern house in Zawia, and a modern earth-sheltered house in Cumbria, UK, while assessing their sustainability.

3.1. Building A (An Old Earth Sheltered House in Geryan City)

Table 1: General data and Site Analysis. (*Source:* Author, 2024)

Building A	The underground house in Geryan City (The researcher site visit)			
General data	Location	Geryan city and it is located in an area called Abo Gelan in Al gwasem		 Figure 11: Traditional house in Geryan (Source: Researcher's fieldwork, 2024). 
	Build Time	1666		
	Owner	BelHaj family		
	Designer	BelHaj family		
	The number of persons	(5 Persons)		
	Areas	500 seq. m		
	Number of floors	1		
	Building type	Recessed Court		
Design Details	The house follows an open-yard layout with a central square courtyard (10 × 10 m, 8 m deep), surrounded by 8 rooms (Damoos), three kitchens, and two storage towers. Damoos dimensions: 10 m length, 3.5–6 m width, 2.8 m height. A 1.5 m diameter, 1.5 m deep hole manages stormwater. The main entrance is on the northwest side			Hole 
Environment	Terrain	Climate		(Meteorological
	Mountain	Air temperature	8 - 35 c	Centre Libya)
		Relative humidity	30 - 80	
Site Analysis				
Orientation	*Sun*	*Wind*		
	Latitude: 32.75 N Longitude:12.72W	Turbulence may occur (through the study)		
Vegetation	Not Available, there are some scattered shrubs at the site.			
Topography	The general site is not leveled The house site is flat site – fully recessed			

This traditional compound house features high insulation levels and accommodates eight related families. It is situated among similar neighboring houses "All sketches and tables in this section are prepared by the author unless otherwise stated.

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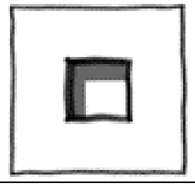
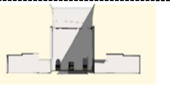
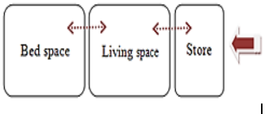
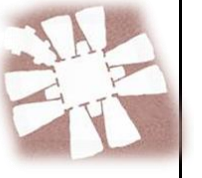
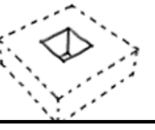
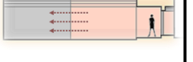
Table 2: Design Strategies. (*Source:* Author, 2024)

Design Strategies			
Design concept	**1. L to W Ratio** 	**2. Built underground** 	**3.Built within natural site** 
	4. Open inside. 	**5. Aldamos is divided into three activity spaces** 	**6. Area used is quite large** 
	7. No guardrail at roof edge 		
Natural light	**Insufficient amount of natural light in rooms**		
Energy Use	**Passive heating and cooling were used**		

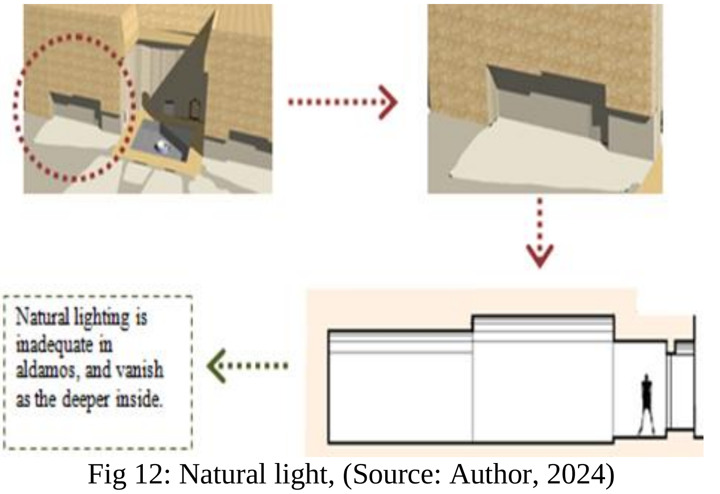


Fig 12: Natural light, (Source: Author, 2024)

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(a)

(b)

Fig 13: picture (a) shows a dark room in natural lighting only.
Picture (b) shows the room in an industrial lighting.
(Source: Researcher's fieldwork, 2024).

Results:

- The courtyard design offers notable energy savings and wind protection but lacks storm resistance, effective shading, and daylight due to no windows. The house features proper insulation, thermal mass suited to climate, light-colored surfaces to reduce heat gain, and a large floor area.

Table 3: Technology Variables. (*Source:* Author, 2024)

Technology Variables			
Construction material			**Notes**
Type of Soil	**Clay soil :** Crystalline non organic		Good Environment materials and Locally available
Types of materials			
1. Walls	Clay soil.		
2. Floors	Clay soil.		
3. Roof	Clay soil.		
4. Doors	Palm tree trunks		
5. Finishes	1cm of Limestone.	Inappropriate finishes	Disadvantage
6.Decoration	Gypsum and lime		
Specification of basic construction materials			Advantage
1. Clay soil		**Properties**	
Locally available. It does not need regular maintenance Has a good thermal insulation property		• The soil is very hard clayey • It consists of a very small grains • It has a good thermal isolation (through the study)	
2. Limestone			
(Sand + water + salt) and stay for ten days			

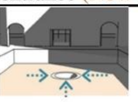
Construction			
1. Tools	1. Human 2. Axes.	 *fig14:(Source: Researcher's fieldwork, 2024).*	Disadvantage 
2. Construction			
The house was excavated in strong soil, using the ground as foundation due to its high bearing capacity. Walls were mostly dug into the ground, except for door walls built with stone, gypsum, and lime (40 cm thick). Room ceilings were constructed in a bunker shape within the clay soil to withstand ground pressure.			
Drainage &Waterproofing			
1.Bathroom drainage (Not Available)	There is no bathroom There is no drainage system There is a bathroom at the top next to the entrance (Now)		Disadvantage
2. Rains water It's discharged through the center of the courtyard to the well(matmor).(See fig 6.6)		**Drainage tools** Salt , Food Ant 	Disadvantage
3. Kitchen	The floor and walls in the kitchen are not suitable due to the lack of drainage system		
2.Waterproofing	Not Available		

Fig. 15: The newly added dawamees show that constructing technology still the same using human effort.
(Source: Researcher's fieldwork, 2024).

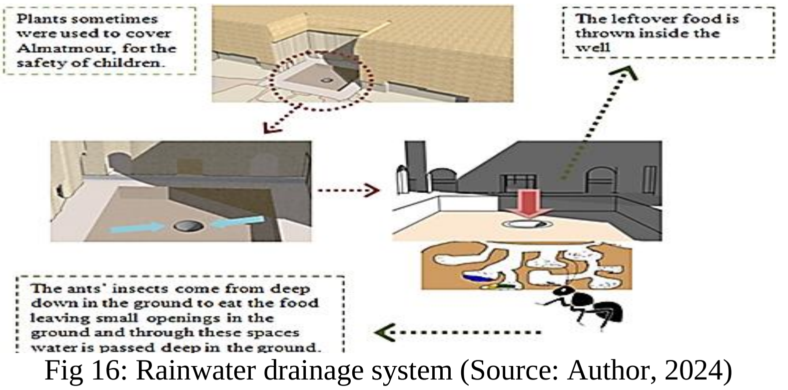


Fig 16: Rainwater drainage system (Source: Author, 2024)

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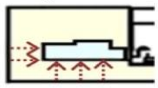
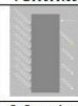
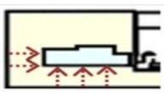
Table 4: Environmental Analysis

Renewable Energy 50%				**Notes**
•	**Passive Cooling**			Good energy efficiency (through the study)
s o	**Conduction**	**Convection**	**Radiation**	
Control strategies	**Earth**	**Atmosphere**	**Materials**	
	• Reduces heat flow • Increases cooling	• Reduces infiltration • Increases ventilation	• Redues solar gain • Increases ventilation	
				
	The earth works as an insulator:	Natural ventilation from the yard	Massive materials.	
•	**Passive Solar Heating**			
s o	**Conduction**	**Convection**	**Radiation**	
Control strategies	**Earth**	**Atmosphere**	**Materials**	
	• Minimize conduction heat flow.	Minimizes external air flow. Minimizes infiltration.	• Increase solar gain	
				
	Thermal stability by surrounding soil	By Atrium-Style	Massive materials	
Notes	***Temperature*** (See Table 6.6)	Temperatures range between 21, 26 (A degree of thermal comfort for humans)		
	Indoor Air Quality	The air inside the rooms is not fresh		Survey
	Humidity Control	Damp signs were noticed in the house. (The researcher site visit)		
	Temperature	The yard gains heat due to sun exposure so the air gets hot gradually and affects all the house spaces.		
Non renewable energy 50% (GECOL)	Kerosene Coal and natural		Daily consumption without cooling & heating. (Before)	Survey
•	Electricity	Electricity consumption /day = 41.66KW h / day= 41.66 *30 days= **1250 Kwh / m** (GECOL "electricity bills")	Daily consumption without cooling & heating (Now)	Survey
	Coo king gas			
Renewable Energy	90%		Only (cooling & heating) Without Daily consumption	
Non renewable energy	10%			
Active Solar Heating			Not Available	
Environment	• A viable natural environment • There is no damage to nature.		Energy saves up From 60% to 80%	excellent
	Environmental impact : **1.23 ton co2 /year** (www.carbonindependent .org.) See (Appendix- I & Diagram 2)			

Results:-

Earth-sheltered houses maintain thermal stability year-round, reducing air-conditioning energy use by 50–80% and cooling load by about 20% in Libya. They have no windows, avoiding heat loss in winter, heat gain in summer, and daily temperature fluctuations.

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Table 5: Economic- Socio- Dimension

Economic	***Cost construction***	Human effort		Disadvantage
		But now estimated at about	**86000Ld.**	(E. Mohsen Abosnina)
	Cost energy (Now)	Energy saves up to 80%	Save money	Advantage
		Cooking gas	**2 LD**	**27 LD per M** (Daily consumption without cooling & heating)
		Electricity monthly rate = 1250 Kwh / month *0.02 DL=25 LD (GECOL "electricity bills")		
		Electricity	**25 LD**	
Social	***Privacy***	8 Families	NO Privacy	Disadvantage
	1 Families	Good	(Now)	Advantage
	Healthy	Bad finishing, & unhealthy environment		
	Security	No guardrail at roof edge		Disadvantage
		Danger to children		
		No security against thieves and curious		
		Fire : - Good fire safety due to the absence of air flow , but in case of a fire it is difficult to evacuate people		
		Considerable safety from noises, air pollution and dust.		
	Psychological	No natural views nor vision extension		Disadvantage
		As if descending to dark caves or underground graves		
	20%			Survey (Appendix-H)

Results:-

- The underground houses in Geryan are energy efficient, and they can be developed with the modern technology available in Libya to meet our needs and modern life requirement.

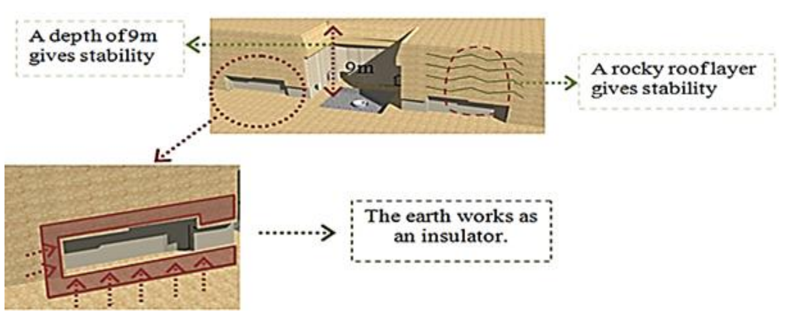


Fig 17: Passive Cooling by Earth (**Source: Author, 2024**)

http://www.doi.org/10.62341/mfrt0709

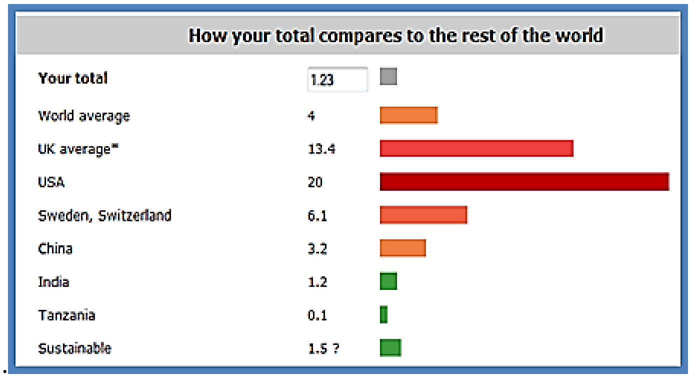


Diagram 2: Rates of carbon dioxide emitted from the house and compare it with the sustainability:- 1.23 tons co2/year

3.1.1.Data and Analysis:-

Data was recorded inside and outside the earth-sheltered house at 2 p.m. on the 10th day of selected months in 2008.. (See Table 6).

Table 6:- At 2 p.m. on the 10th day of selected 2008 months, indoor temperature was stable while outdoor temperature fluctuated.

Months	Inside temperature	Outside temperature
10 January	21	15
10 March	22	16.5
10 April	22.5	23
10 May	21	33
10 August	25	37
10 September	24	30

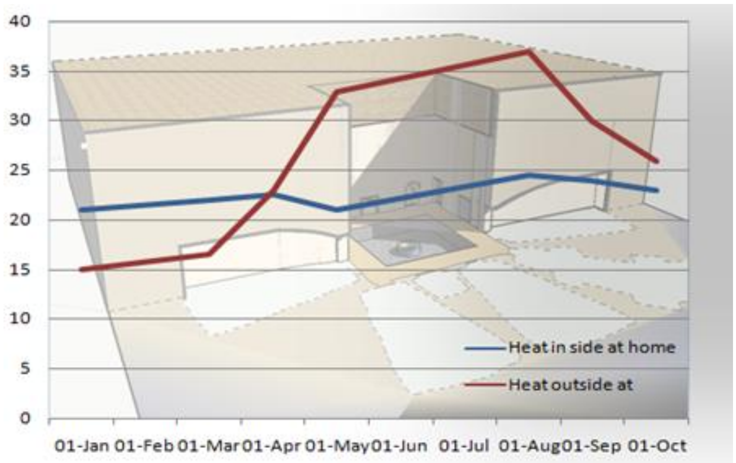


Diagram 3: Temperature inside and outside

http://www.doi.org/10.62341/mfrt0709

<u>The results:-</u>

Graph 6.2 shows that:

The graph shows that the earth-sheltered house maintains a nearly constant indoor temperature

within the thermal comfort range (21–26 °C), while outdoor temperatures fluctuate by up to 7 °C.

3.2. Building B (A Modern House in Zawia City)

The recently built house in Zawia lacks insulation and is not classified as sustainable; it is attached to three similar houses. See figures18 **(Source: Researcher's fieldwork, 2024).**

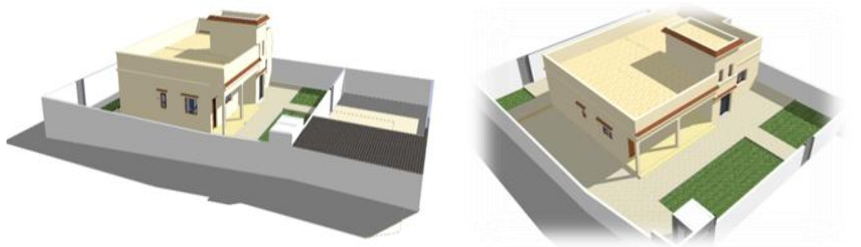
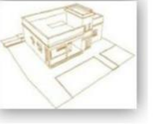
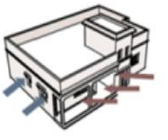
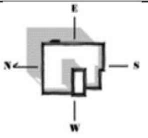
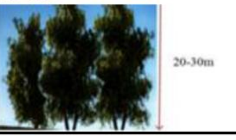


Fig 18: Alfitori House (Model B)

Table 7: General and Site Analysis

Building B	**Alfitori House** (The researcher site visit)			
General data	**Location**	Located in Zawia city in Judaem area.		
	Built in	1995		
	Owner	Ali Alfitori		
	The number of Persons	(5 Persons)		
	Areas	180 seq. m		
	Number of floors	1		
	Type			
Design Details	**The house has; (**Three bedrooms, two bath rooms, a living room in the heart of the house, a guest room, a kitchen, a garage for the car)		 	
Environment	**Terrain**	**Climate**	Air temperature	8 - 35 c
	coastal		Relative humidity	30 - 80

http://www.doi.org/10.62341/mfrt0709

Site Analysis			
Orientation	***Sun***	***Wind***	 
		Turbulence may occur **Types of Wind** N W winds N E wind S wind	
	Latitude : 32.75 N Longitude:12.72 W		
Vegetation	Different trees + different sizes		Existing trees in the west of the site
	Types	Shade trees	
Topography	The site is not completely leveled and has insignificant different slops		

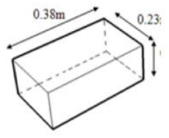
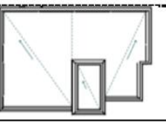
- **<u>Results</u>** The house is exposed to several kinds of dust – laden winds

Table 8: Design Strategies.

Variables Technology		
Construction materials		Disadvantage
Type of Soil	**Fertile agricultural soils:** It is combination of sandy and clayey	
Types of materials		
1.Main. walls	Lime bricks (lime stone)	
2.Interior. Walls	Briquette	
3.Floors	Clay soil.	
4.Roof	Reinforced concrete with a thickness of 15cm	
5.Doors	Wood	Good finishes
6.Windows	Wood & glass	
5.Finishes	White cement, plashes, different paints	
6.Decoration	Gypsum and lime	
7.Floor tiles	Mosaico	
8Tiles kitchen & bathroom	Ceramics	
9. Waterproofing	Bitumen	
10.Thermal Insulation	Not Available	Disadvantage

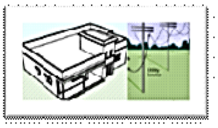
http://www.doi.org/10.62341/mfrt0709

Table 9: Variables Technology

Specification of basic construction materials			Not Environment materials' locally available
1. Limestone			
a. Dimensions	b. Form	d. Location	
			
2. Reinforced concrete			
Component	**Concrete**	C4omponents	
		coarse sand + gravel phased + Portland cement + water	
	Steel		
Construction			
1. Tools	Human – Axe - hand shovel - Concrete Mixer - Wheelbarrow		
2. Construction	The house was constructed on a net of concrete columns where the roof was fixed on the top of these columns		
Drainage &Waterproofing			
1. Drainage			Advantage
1. Bathroom drainage		**2. Rainwater**	
The level of the house is at a height of 1.50 m this eased the discharge of sewage and rain		Available 	
Waterproofing			
Component	**Material**	**Aim**	
Walls	The outside is plastered with cement	Was done to control moisture	
Roof	Bitumen on Reinforced concrete		
Components & properties of materials used			
Bitumen	Bitumen+ coarse sand		

http://www.doi.org/10.62341/mfrt0709

Table.10: Environment, Economic and Social

Renewable Energy 23.75%			
Passive Cooling	Redues Solar gain	Through building material for a short and limited period. (Time loge) See Tables (11, 12)	Disadvantage 20% Show is 6.2.2.1
Passive Solar Heating	• Increases ventilation		
Indoor Air Quality	Fresh air, 100%		
Humidity Control	No sign of humidity		
Active Solar Systems	Not Available		
Nonrenewable energy 76.25% (GECOL)	Electricity	Electricity consumption /day =136.5 Kw h / day 136.5*30= **4095 Kwh / month** (GECOL "electricity bills")	Survey
	Cooking gas		
Environment	Environmental impact: **1.53 tons co2/year** See (Appendix- I & Diagram 6.3) (www.carbonindependent .org,)		Disadvantage (Daily consumption with cooling & heating)
Economic	***Cost construction***	**60,000 L.D**	
	Cost energy	No conservation of energy More cost	Disadvantage
		Electricity monthly rate = **4095 Kwh / month*0.02LD** = **81.900 LD** (GECOL "electricity bills")	**83.900 LD/M** (consumption with cooling & heating)
		Electric power: **81.900 LD**	
		Cooking gas: **2 LD**	
Social	***Privacy***	Only one family Privacy 100 %	Advantage
	Security	Security against thieves and curious is available.	
	Healthy	Good finishing, and good aspects of health	
	psychological	Natural views nor vision extension	
	100%		Survey (Appendix H)

Results

The house is not sustainable due to climate-related energy loss; modern houses in Libya are not energy-efficient but are built to meet lifestyle needs.

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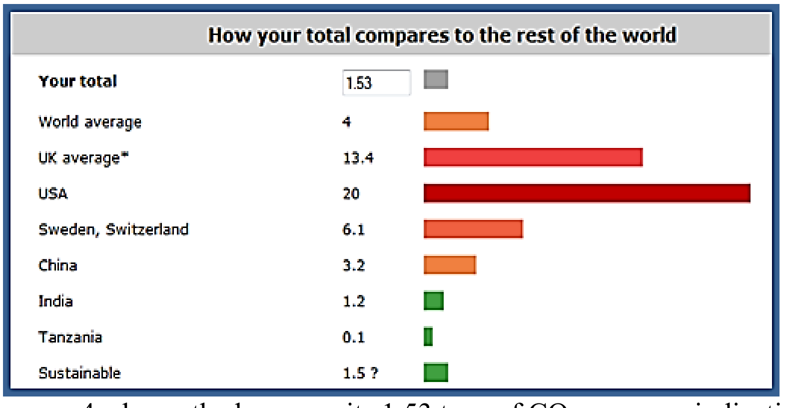

Diagram 4: shows the house emits 1.53 tons of CO_2 per year, indicating low

3.2.1. Data and Analysis: -

Table 11: - From April 11–17, 2009, at 2 p.m., indoor temperatures remained stable while outdoor temperatures fluctuated.

Table 12: - At 2 p.m. on the 10th day of selected 2008 months, indoor temperatures were less stable, while outdoor temperatures fluctuated

Table 11: Temperature measured at two o'clock from 11 to 17 on the April month in the year of 2009

Month (4)	Heat in side at home	Heat outside at home
11 April	22	23
12 April	22	22
13 April	22.5	23
14 April	21	24
15 April	24.5	24
16 April	24	27
17April	24	30

Table 12: - shows temperatures measured in other months

Months	inside temperature	outside temperature
10 January	18	15
10 march	20.5	16.5
10 April	24	23
10 may	23	33
10 August	38	37
10 September	35	30
10 October	29	26

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The results: -

Table 11 shows stable indoor temperatures due to materials that delay heat transfer, while Table 12 shows the opposite, indicating the house lacks environmental materials and indoor temperatures closely follow outdoor changes.

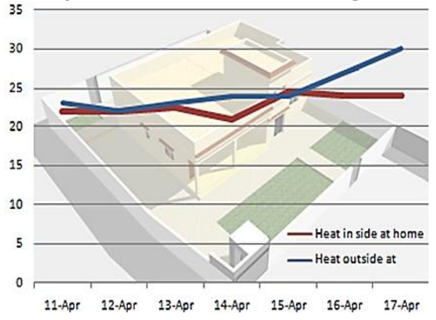


Diagram 5: Stability of the internal temperature

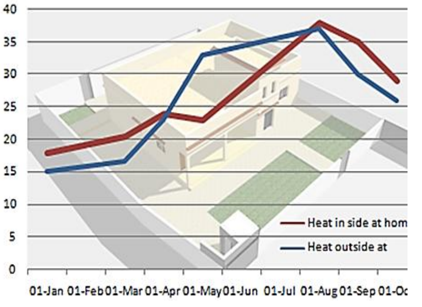


Diagram 6: The instability of the internal temperature

3.3. Building C, (A Modern Earth Sheltered House Outside of Libya)

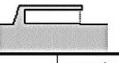
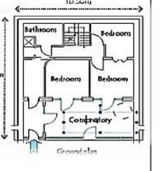
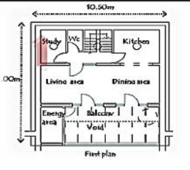
Building C, an underground eco-house in Cumbria's Eden Valley, is built in an old quarry and uses high and natural earth insulation to eliminate heating, while offering scenic views. (Ledingham, 2008).

Fig 19: The Underground House, Great Orm side, Cumbria, UK

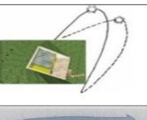
(Source: Arch. John Bodger). Photo: Simon Ledingham – Wikimedia Commons (CC BY-SA 2.0).

http://www.doi.org/10.62341/mfrt0709

Table 13: General and Site Analysis

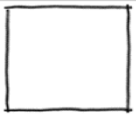
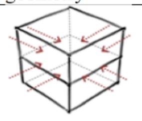
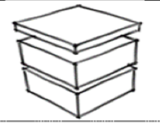
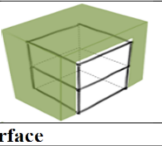
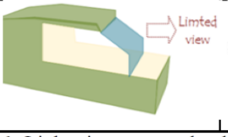
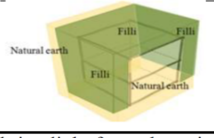
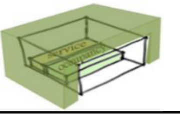
Building C	Cumbria's Earth Sheltered House (www.theundergroundhouse.org.)		
General data	Location	In an old quarry on a slope of the Eden valley in the east of Cumbria, it is on north Britain	 
	Project components	2 buildings (Residential building + Vet building)	
	Main building	Residential building side which is the study case.	
	Build date	April 2002	
	Execution time	Over six months	
	Owner	Reddy family	
	Designer	Architect John Bodger	
	The number of Persons	(4 Persons)	
	Total areas	314 seq. m	
	Number of floors	2	
	Type	Elevational 	
Design details	**Main building: -** **The house has;** Three bedrooms, Two bath rooms, a living room, a kitchen, An energy room. [10]. **Secondary building: -** Used partly as a garage/store, and partly as a veterinary workspace for treating small farm animals		
	Figure 6.12: The architect's plans , site and elevations		

Environment	Terrain	Climate		
			Air temperature	8 – 35 c
	Quarry		Relative humidity	30 – 80

Site Analysis			
Orientation	***Sun*** 	***Wind*** Turbulence may result	Earth protects the house from winter winds by orientation (through the study)
	Latitude: 54 55N Longitude: 3 15W		 
Vegetation	Types	Grass Small bushes and far	The Image show some ineffective trees on the site.
Topography	Flat site – semi recessed		

http://www.doi.org/10.62341/mfrt0709

Table 14: Design Strategies

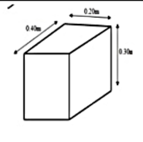
Design Strategies			
Design concept	**1. Impact of energy conservation**		
	a. L to W Ratio	b. Compact plan geometry	c. Flat roof
			
	Lengh: 10.5m Width :12m Ratio : 1:1,14	Floor area:157 seq. m Total surface area:5652m	
	d. Maximization of the earth mass around the structure		**Result :-**
			A building with a smaller surface area
	2. Relation to the surface		**3. Spatial layout considerations**
	a. Fully recessed	b. Built above the ground	
			
Natural	1. Light pipes are used to bring light from above into the kitchen, stairwell and study. (See Fig20) 2. The south facing elevation is entirely glass		
Energy Use	1. Passive earth energy for cooling and heating. 2. Active and passive solar. 3. Wind power.		

Results: The house is well-oriented for winter heating and wind protection, with good zoning, suitable windows, and effective energy-saving design, but lacks trees and shading for summer sun. It has good lighting, and its small size reduces sun exposure and energy loss.

Figure 20: Shows the methods of natural light penetration.
(Source: Arch. John Bodger). Photo: Simon Ledingham – Wikimedia Commons (CC BY-SA 2.0).

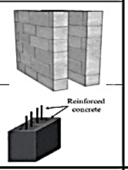
http://www.doi.org/10.62341/mfrt0709

Table 15: Variables Technology.
Source: **(www.theundergroundhouse.org.)**

Technology Variables				**Notes**
Construction material				
Type of Soil	Sandstone … varies in color from the rich red to a very pale grey .350 million years ago			Not good Environment materials
Component	**Types of materials**			
1. Main .walls	Hollow block cement			
2.Interior.walls	Hollow block cement			
3. Floors	Clay soil			
4. Roof	Reinforced concrete			
5. Doors	Wood			
6. Windows	Aluminum & glass			
5. Finishes	white cement, plashes, different paints			
6.Decoration	Gypsum and lime			
7. Floor tiles	mosaic			
8.Tiles kitchen & bathroom	ceramics			
Specification of basic construction materials				
1. Hollow block cement				
a. dimension	biform	c. component	d.Reinforced concrete	
		Portland cement Coarse sand Aggregates water	 Reinforced concrete To increase the bladder of the against soil strength	
e.stages of manufacturing		f.		
1.Processing materials 2. Mixing 3. Transfer of manufacturing components to the piston 4.Pressing stage, manufacturing 5.Stage of discharge 6.Assembly phase			 Fig 6.14 Hollow block cement	
2. Reinforced concrete with a thickness of15cm				
Components	**a. Concrete**	Components	**b. Steel**	
		Coarse sand+ aggregates+ Portland cement + water		

Construction		**Notes**
1. Tools	Human-Axe-hand shovel-Concrete Mixer Wheelbarrow	Disadvantage
2. Construction (See Fig. 6.15)		
The problem		

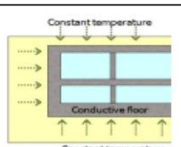
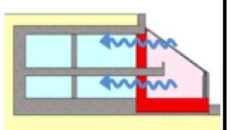
http://www.doi.org/10.62341/mfrt0709

1. The need to counter lateral pressure from the soil 2. Provide support to the walls on either side of the conservatory			
The insulations			
1. Main structural walls	High-density hollow blocks filled with reinforced concrete		
2. The front wall.	Made of solid blocks with insulation filled cavity		
3. Intermediate floor and roof	Made of poured and reinforced concrete		
The result	Very strong building that was relatively straightforward to produce		
Drainage & Waterproofing			**Notes**
1. Drainage Available.		Fig: Sewage collected in septic tank at site's lowest point.	Advantage

2. Waterproofing (See Fig. 6.16)			Advantage
Components	**Material**	**Aim**	
Walls	1.Membrane (1)	To keep water out	
	2. 300 mm layer of insulation	Heat insulation	
	3. 2 membranes	To keep water out	
Roof	1.Membrane (2)	To keep water out	
	2.150 mm layer of insulation.	Heat insulation	
	3.Drainge layer.	To retain and drain water	
	4.Filter sheet.	Prevents migration of fines into drainage.	
	5.Gowing medium.	Soil for plants	
Floor	1.Membrane (2)	To keep the water out	

Components & properties of materials used in waterproofing			
Membrane (1)	**Type**	Bitumen (Bitumen + coarse sand)	
Membrane (2)	**Type**	Polyester membrane	
Insulation (See Fig. 6.17)	**Type**	Formed blather	
	Thermal conductivity	Chemica 0.027	
Drainage layer	**Components:** Holes for evaporation and ventilation.		

Table 16: Renewable energy
Source: (www.theundergroundhouse.org)

Renewable energy				
Passive Cooling				Advantage
	Conduction	**Convection**	**Radiation**	
Source	**Earth**	**Atmosphere**	**Materials**	
Control strategies	1.Reduces heat flow 2. Increases earth cooling.	1. Reduces infiltration 2. Increases ventilation	1.Reduce solar gain. 2.Increase ventilation.	
				
	The earth works as an insulator.	Natural ventilation from front wall.	Massive materials.	
Indoor Air Quality	A roof-mounted ventilation system continuously supplies fresh air, recovering ~90% of heat from exhaust, and can renew the house's entire air volume within 2 hours.			
○ ***Humidity Control***	The ventilation system has played an important role in keeping moisture at acceptable levels			

http://www.doi.org/10.62341/mfrt0709

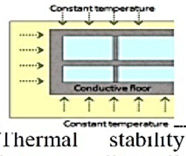
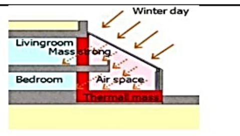
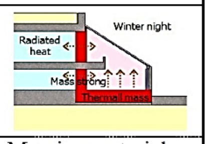
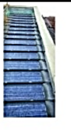
Passive Solar Heating				
Source	Earth	Atmosphere	Materials	
Control strategies	Minimize conduction heat flow	1. Minimize external air flow 2. Minimize infiltration	Promote solar gain	
				
	Thermal stability by surrounding soil	By Atrium-Style	Massive materials	
Active Solar Systems				
1. A row of PV cells (~500 W) generates electricity. 2. Hot water system: 300 L tank, larger than standard. 3. Immersion heater in top 100 L provides backup heating. 4. Solar cells operate mainly in summer				
Wind Turbines				
Help to generate electricity. Now wind turbines are not used, but they will be used in the future.				

Table 18: Environment, Economic, and Social
Source: (www.theundergroundhouse.org)

Nonrenewable energy	Electricity	Daily average electricity consumption =10 KW h per day (refer to p.159) Monthly average electricity consumption in the house= 10*30=**300 KWh per month** (www.theundergroundhouse.org)		
Environment	Energy saves up to	From 60% to 80%		(The study)
	A negative environmental impact: **1.13 tons co2/year** See (Appendix- I & Diagram 6.6) (www.carbonindependent .org.)			Appendix- I
Economic (Daily consumption with cooling & heating)	***Construction cost***	1. Cost of site:	£23,000	High cost
		2.Budget for build:	£197,000	
		3.Final cost of build:	£217,000	
		4.Total cost of project:	£240,000	
	Energy cost	Energy saves up to 80%	Save money	Advantage
	Monthly electricity bill in the house = **300 Kwh per month *0.11pound =33 Pound** Price of electricity per month = 33 **pound** (UK price) = 62.7 LD. (www.theundergroundhouse.org) Price of electricity per month = **6LD per M** (Libya price)			**6 LD per M**
Social	***Privacy***	Only one family	Save money	Advantage
	Security	security against thieves and curious is available		
	Healthy	Good finishing, and good aspects of health		
	psychological	Natural views and visual extension are present		
	100%			Survey Appendix-H

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Results: -

- We have gradually moved up in the world, out of caves.
- It is a sustainable house and has economic, environmental and social factors.

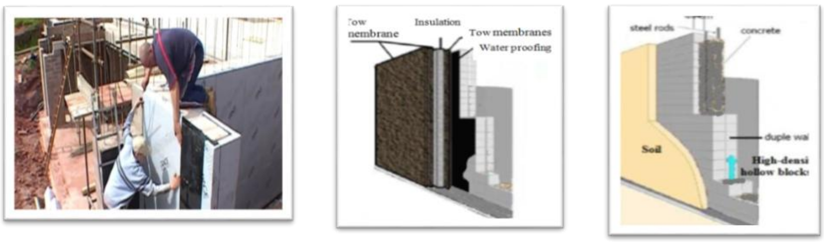

Fig 21: images show the insulation of waterproofing and its layers used in walls.

Source : (www.theundergroundhouse.org.)

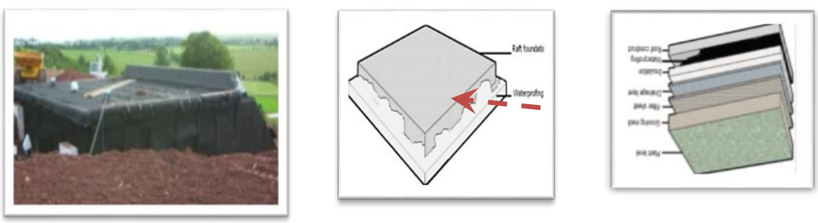

Fig 22: images show the insulation of waterproofing and its layers used in roofe and floor.

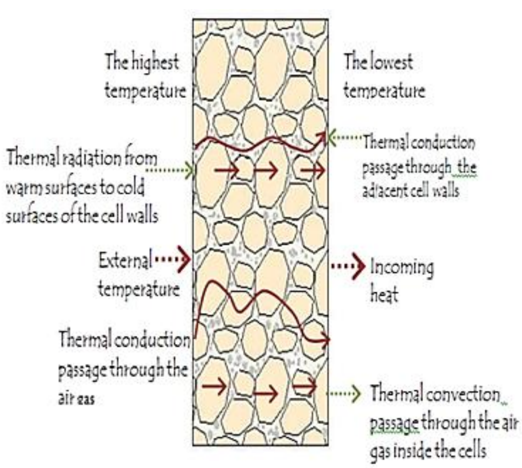

Fig:23: Insulation used in the building (The transition temperature during the insulation)

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Results:

Key features include proper windows for ventilation and heat control, suitable insulation, high thermal mass for large diurnal ranges, low thermal mass for small ranges, and light-colored roofs and walls to reduce heat gain.

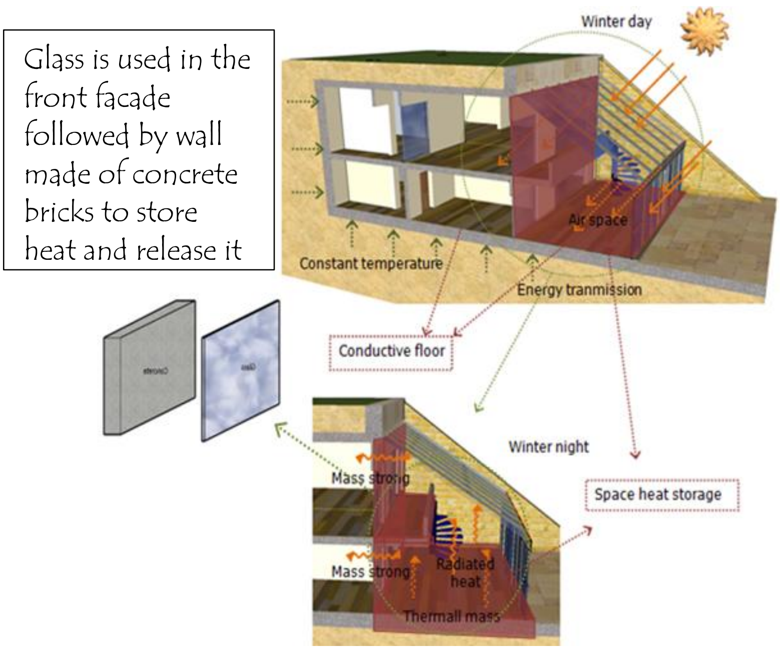

Fig: 24: Passive solar heating mechanisms

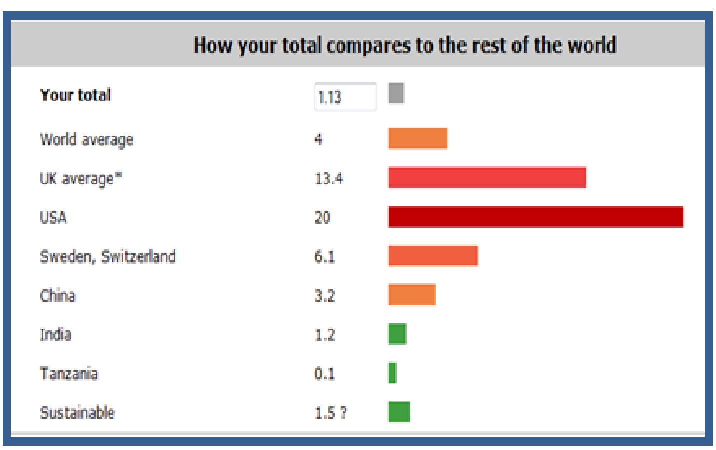

Diagram 7: Rates of carbon dioxide emitted from the house and compare it with the sustainability: - **1.13 tons co2/year**

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3.3.1. Data and Analysis: -

1. **In Table 19: -** summarizes the graphs, highlighting differences between the two periods in indoor temperature
2. **Table 20**: shows a 16% rise in average air temperature vs 7% in the conservatory, effective window control, and energy use reduction from 16 to ~10 kWh/day (1.3 kWh from PVs, ~48% drop).

Table 19: difference in the impact on indoor temperatures between the two periods (www.theundergroundhouse.org.)

Table 19: difference in the impact on indoor temperatures between the two periods (www.theundergroundhouse.org.)

	Average Temperature	
	Air In	***Conservatory***
12-29 March 03	13.14	19.61
12-29 May 03	15.24	20.99

Table 20: Temperature Air in and Conservatory (www.theundergroundhouse.org.)

	Temperature, c	
	Hall	***Living room***
12 Mar 03	14.58	15.60
29 Mar 03	18.76	20.64
Temperature rise	4.18	5.04
12 May 03	18.79	20.41
29 May 03	19.54	20.88
Temperature rise	0.75	0.47
Rise between 29 March and 29 May	0.78	0.24
Rise between 12 March and 29 May	4.96	5.28

Data and Analysis: -

Diagrams 8 and 9 show six-hourly average temperatures (12–29 March and 12–29 May 2003). In March, energy inputs raised living area temps by ~5 °C and hall by ~4 °C, aided by open doors and limited window use. In May, indoor temps were more stable despite higher incoming air and conservatory temps, due to closed doors, open conservatory windows, and adjusted ventilation.

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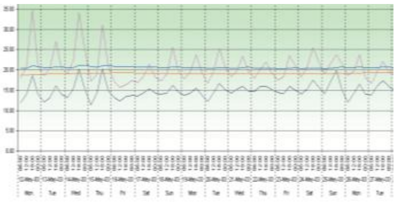


Diagram 8: Shows the average six-hourly temperature www.theundergroundhouse.org.

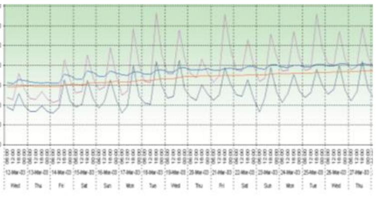


Diagram 9: Shows the average six-hourly temperature for the period from 12 to 29 May 2003

Table 20: Results

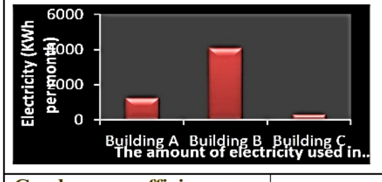
3.4. Results and Discussion		
Building A (Geryan)	**Building B (Zawia)**	**Building C (Cumbria)**
		
Materials		
Local environmental materials	**Local materials**	**Local materials**
●●●	●●	●●
Energy		
Non Renewable Energy (Electricity)		
1900 Kwh per month Daily consumption without (cooling & heating)	**4095 Kwh per month** Daily consumption with (cooling & heating)	**300 Kwh per month**
		Diagram:- Rates of types of energy used in houses
Good energy efficiency		**Good energy efficiency**
●●	●	●●●
Economic		
Energy cost per month		
27.000 LD per month	**83.900 LD per month**	**6 .000 LD per month**
		Diagram:- Rates of Energy cost per month in houses
	Electric power increased the economical cost	
●●	●	●●●
Building A (Geryan)	**Building B (Zawia)**	**Building C (Cumbria)**
		
Environment		
Environmental impact		
1.23 ton co2 /year	**1.53 tons co2/year**	**1.13 tons co2/year**

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Table 21: Results and Discussion

Building A (Geryan)	Building B (Zawia)	Building C (Cumbria)
		
Sustainability		
		

4. Summary

The comparative analysis of the three housing models revealed that the traditional earth-sheltered house in Gharyan (Model A) offers significant economic and thermal comfort advantages over the modern above-ground house in Zawia (Model B), primarily due to reduced energy consumption, lower construction costs, and the use of environmentally friendly materials. Model B, however, provides better natural ventilation, abundant daylight, and modern finishes. The modern earth-sheltered house in Cumbria, UK (Model C), demonstrated the highest sustainability performance, combining energy efficiency, environmental integration, and privacy.

The findings suggest that adapting the design principles of Model C to the Libyan coastal context—while incorporating the positive features of Models A and B—can yield a sustainable housing solution suitable for various terrains, provided that appropriate technology and local resources are available.

Key recommendations for implementation include: ensuring natural light and ventilation, using durable and locally available eco-friendly materials, applying modern finishes, integrating reinforced concrete for structural stability, utilizing clay for its insulation properties, implementing waterproofing systems, installing solar panels, planting green roofs, and incorporating water treatment facilities. Additional design considerations involve grouped housing to reduce costs, double-wall insulation, sunshades, and strategically placed windows for ventilation.

Overall, the study confirms that sustainable earth-sheltered housing can be successfully applied in Libya's coastal regions and other areas, achieving energy efficiency, environmental compatibility, and improved living comfort.

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