

UNDERGROUND DWELLINGS: THE COEXISTENCE OF MAN AND NATURE BENEATH THE EARTH

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Abstract

In the light of evolving global climate change, architecture's attempts to harmonise buildings with the climate, the natural environment and the needs of users seek insights into the principles of bioclimatic design. Bioclimatic, climate sensitive design is an essential tool for meeting the challenges of sustainability, addressing climate change effects and improving the quality of life in modern societies.

This paper examines subterranean architecture, from the past to the modern era, with emphasis on habitation and the main tools being soil and topography. The examples are analyzed in terms of design principles and energy efficiency of buildings. Issues related to both traditional and contemporary cave architecture are explored, focusing on design principles and bioclimatic features that have been incorporated or can be applied to cave structures. Answers are sought through comparative analyses of literature sources, combined with a systematic evaluation of examples in terms of their typology, terrain, climate and architectural practices.

Through the exploration of the evolution and applications of subterranean architecture over the centuries, it emerges that the use of natural resources and climatic conditions in the design of housing is not just a requirement, but a strategy for the harmonious integration of buildings into the natural environment, allowing people to create housing that combines functionality, aesthetics, and ecological sensitivity. This architectural model is emerging as one of the most effective solutions to the modern challenges of climate change and energy efficiency. At the same time, it encourages the revival of traditional techniques using modern tools and technologies. Underground architecture is a prime example of preservation and enhancement of quality of life, while offering sustainable perspectives for the future.

Key words: *Underground architectural heritage, types of subterranean architecture, energy efficiency, underground dwellings form and function, bioclimatic design*

Introduction

Underground architecture has long been a significant form of habitation, offering protection, energy efficiency, and a strong connection to the natural environment. This research explores how subterranean dwellings have evolved over time, from traditional settlements to modern bioclimatic structures, aiming to identify key design principles and sustainability strategies.

The study examines the spatial and environmental characteristics of underground architecture, focusing on its adaptability to different landscapes and climates. Through historical and contemporary examples, it seeks to understand the enduring appeal of underground living and the ways in which bioclimatic principles enhance its functionality. The research is guided by key questions: What factors have led people to live underground throughout history? How can bioclimatic strategies improve these spaces? What architectural elements contribute to their environmental performance?

To address these questions, the methodology combines theoretical analysis and case study research. Initially, fundamental concepts such as the relationship between built form and terrain are explored, followed by a historical overview of subterranean dwellings. The selected case studies- both traditional and modern- are analyzed based on climate data, thermal behavior, spatial organization, and bioclimatic features, such as passive ventilation, natural lighting, and green roofs. This approach highlights the potential of underground structures in creating energy-efficient, climate-responsive living environments.

By integrating qualitative and quantitative data, the study aims to offer a comprehensive understanding of underground dwellings as a sustainable architectural approach. The comparative analysis of case studies provides insights into their benefits, limitations, and potential improvements, demonstrating their relevance in contemporary bioclimatic design.

Literature Review of Research and Publications

Subterranean Heritage

Subterranean architecture has long offered shelter, climate control, and sustainability, fostering a deep connection between humans and their environment. Today, its modern applications integrate bioclimatic principles to enhance energy efficiency and spatial diversity.

Typologies of Earth Architecture

There are three main typologies of earth-sheltered structures, classified based on their relationship with terrain (Khodabakhshian, 2012):

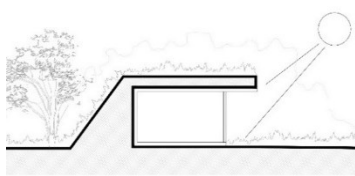
Type 1: Structures with Earth mount (Khodabakhshian, 2012), Bermed Design (Alkaff, 2016): These buildings are surrounded by compacted soil, with roofs fully covered by earth. Openings are carved into the walls, commonly found in Libya (Gharyan, Walout, Ghadami) (Khodabakhshian, 2012).

Type 2: Rocky Earth- Sheltered structures (Khodabakhshian et al., 2012), Terrain Contour Design (Alkaff, 2016): Built into hillsides or mountains, these structures optimize solar gains by orienting towards the equator. They are prevalent in temperate climates, such as Southern Europe. (Khodabakhshian, 2012).

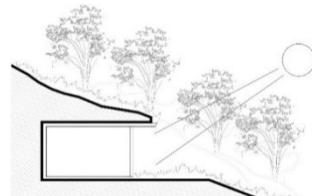
Type 3: Bellow ground Earth- Sheltered Structures (Khodabakhshian et al., 2012) Courtyard/Patio Design (Alkaff, 2016): Entirely excavated underground, these buildings rely on central courtyards for light and ventilation. Found in densely populated areas with hot, arid climates, they use underground patios and roof openings to regulate indoor conditions. (Khodabakhshian, 2012).

These typologies reveal how earth architecture adapts to environmental, cultural, and climatic conditions. The relationship between structure and terrain is fundamental, shaping functional and sustainable built environments. The study focuses on earth-protected dwellings, emphasizing their seamless integration with the land (Khodabakhshian, 2012).

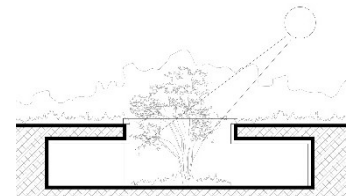
Type 1



Type 2



Type 3



Typology and Energy Efficiency

The increase in CO² levels has caused global warming, prompting a focus on reducing energy consumption. In building energy efficiency, the earth can act as a natural temperature regulator, supporting passive cooling techniques and sustainable development. Water scarcity and limited space in urban areas (Yu, 2020) have led to the development of underground buildings, improving energy efficiency, thermal comfort, and air quality.

The earth's subsurface temperature is lower in summer and higher in winter, acting as a thermal mass that stabilizes temperature fluctuations. The first ten layers of soil absorb and release heat slowly, providing thermal lag (Roy, 2006). This feature makes earth-sheltering ideal for cooling in hot and dry climates, with 30% of underground buildings located in such regions (Alkaff, 2016).

Hait's 1983 study on passive annual heat storage (PAHS) observed stable temperatures at a depth of six meters, reflecting an average air temperature of 21°C (Alkaff, 2016). The earth's thermal conductivity helps reduce cooling energy, especially in areas with high temperature variation and extreme radiation (Roy, 2006).

Factors Affecting Energy Efficiency

Energy efficiency in underground buildings is influenced by several factors, with climate playing a major role. Passive heat storage in the earth helps regulate temperature changes due to the earth's large mass, providing thermal stability (Shipp, 1980). Materials with long thermal lag times help absorb and release heat gradually. Additionally, the characteristics of the soil, such as moisture content and surface conditions, impact heat transfer to the building's shell, affecting overall energy performance (Shipp, 1980).

Bioclimatic Design Elements in Underground Architecture

Bioclimatic design is vital for sustainable underground architecture. It utilizes natural climatic conditions to create comfortable living spaces while minimizing energy use. The earth provides natural protection and thermal stability, and the use of natural materials reduces environmental impact (Wen, 2023). Aligning buildings with local winds allows for natural ventilation, reducing cooling needs. Renewable energy sources, like solar and wind power, enhance energy autonomy and reduce operational costs, promoting sustainability (Shipp, 1980).

Relationship Between Form and Function

Natural lighting is a fundamental technique of bioclimatic design that enhances the quality of life and the functionality of spaces. It reduces the need for artificial lighting, thereby conserving energy and lowering electricity costs (Andreadaki, 2017). At the same time, natural ventilation ensures air renewal by removing pollutants, odors, and moisture from indoor environments. It also helps regulate temperature, providing cooling during the summer months and reducing the need for mechanical cooling systems (Andreadaki, 2017).

Natural Lighting:

	Chamber	Earth Covering	On a Hillside Slope
Building Openings			
Skylight			
Atrium			
Free Facade			
Through			

Natural Ventilation:

	Chamber	Earth Covering	On a Hillside Slope
Building Openings			
Skylight			
Atrium			
Free Facade			
Through			

The Psychological Impact of Underground Structures on Users

Underground living influences psychology and social behavior, with concerns about isolation, control, cultural perceptions, and safety.

Historically linked to burial, underground spaces can evoke entrapment and claustrophobia due to limited openness and natural light. However, in places like Singapore, they serve as social hubs, while in the U.S. and Japan, they offer comfort and modern workspaces (Lee, 2017). Perceptions vary by culture and environment.

1. Isolation: Limited outdoor access can cause separation but may also strengthen community bonds. Architectural solutions like openings, skylights, and intermediate spaces improve connectivity and lighting (Lee, 2017).

2. Perceived Control: Lack of environmental control, such as fixed lighting and closed spaces, can induce stress. Windows and clear wayfinding enhance users' sense of autonomy and reduce anxiety (Lee, 2017).

3. Negative Associations: Ties to themes of death and primitiveness can create discomfort. Highlighting privacy, weather protection, and urban relief can improve perception. High-end amenities also increase attractiveness (Lee, 2017).

4. Perceived Safety: Underground spaces can offer security but may feel unsafe if poorly lit. Enhancing lighting and visibility is key to fostering a sense of safety (Lee, 2017).

Visual Escape:

	Chamber	Earth Covering	On a Hillside Slope
Building Openings			
Skylight			
Atrium			
Free Facade			
Through			

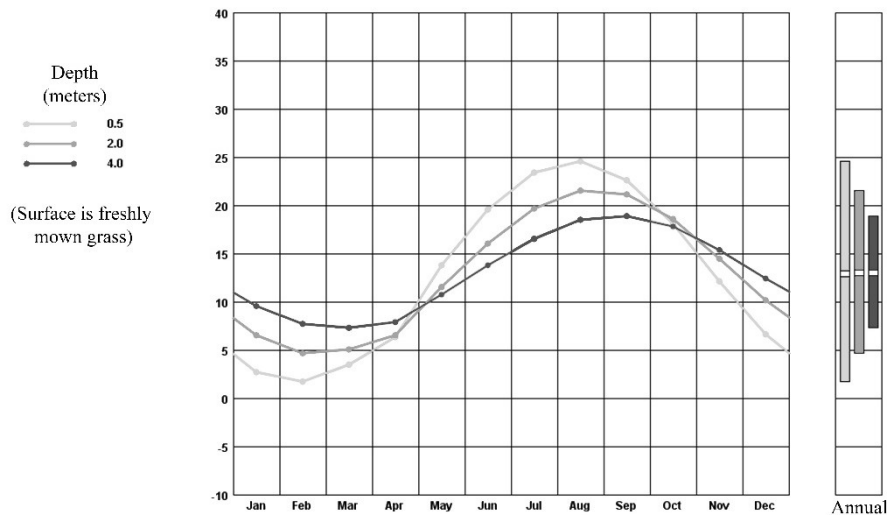
Case Studies:

1. Northern China Settlement/ Vernacular Architecture

Construction time	Estimated from The Neolithic Era
Designer/ Architect	Vernacular Architecture
Use/ Function	Inhabitation

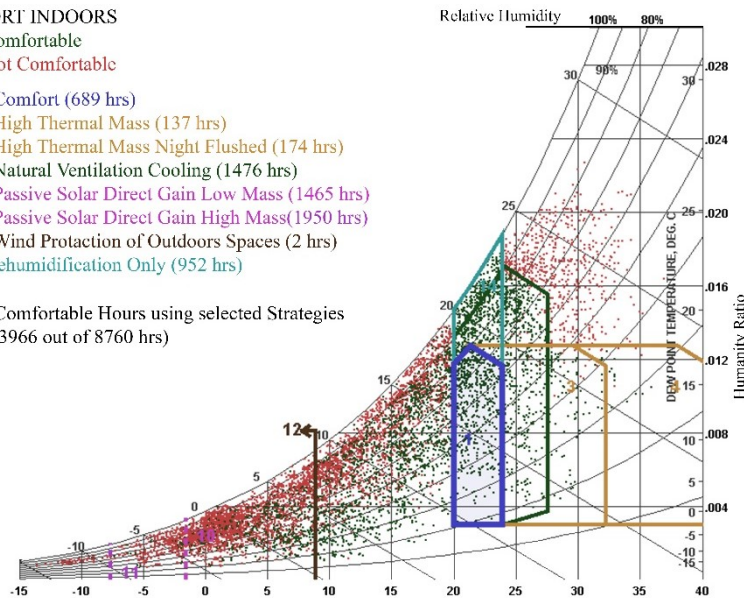
Climatic Data of the Study Area

a. Ground Temperature Diagram:



b. Psychrometric Chart:

- COMFORT INDOORS
- 45% Comfortable
- 55% Not Comfortable
- 5.8% Comfort (689 hrs)
- 3.3% High Thermal Mass (137 hrs)
- 4.0% High Thermal Mass Night Flushed (174 hrs)
- 10.8% Natural Ventilation Cooling (1476 hrs)
- 10.9% Passive Solar Direct Gain Low Mass (1465 hrs)
- 13.6% Passive Solar Direct Gain High Mass (1950 hrs)
- 0.2% Wind Protection of Outdoors Spaces (2 hrs)
- 8.4% Dehumidification Only (952 hrs)
- 45.3% Comfortable Hours using selected Strategies (3966 out of 8760 hrs)



The underground dwellings in the Loess Plateau region of China, known as Yaodong, represent a characteristic example of bioclimatic design that integrates traditional architecture with the optimal utilization of natural resources and environmental conditions. This region includes areas such as Shaanxi, Shanxi, and Henan, as well as Hebei, Ningxia, Inner Mongolia, and Gansu (Bouillot, 2008).

The climate in Northern China is classified as continental, with distinct characteristics: summers are hot and dry, with temperatures exceeding 30°C, while winters are cold and dry,

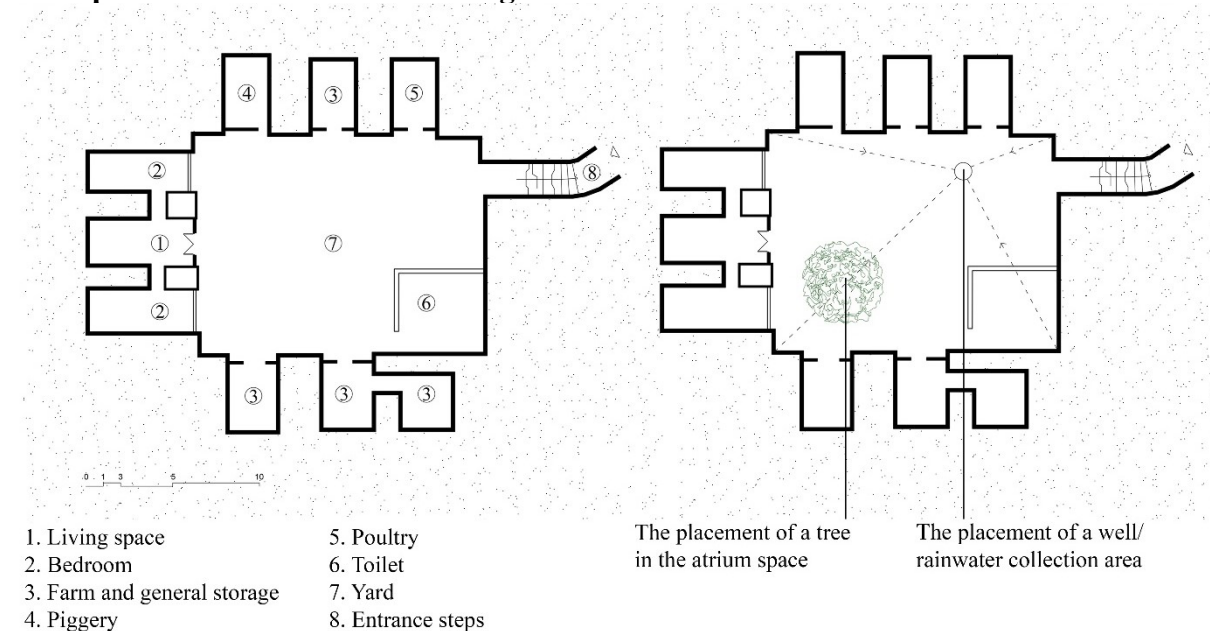
often dropping below freezing. Rainfall is limited and mainly concentrated in the summer. Prevailing winds come from the northwest in winter and the southeast in summer (FaviconRuqin China Travel, 2024).

The soil of the Loess Plateau consists primarily of loess (Bouillot, 2008), a fine-grained, lightweight, and easily erodible material with a thermal conductivity coefficient of $k = 0.918 \text{ W/(m}\cdot\text{K)}$ (Technical Guideline T.O.T.E.E 20701-2/2010, 2010). It allows for easy excavation and shaping while providing good insulation. However, it is highly susceptible to erosion from water and wind, requiring careful structural management and maintenance.

The housing type varies based on the dimensions of the central courtyard. This analysis focuses on the rectangular courtyard type. The dwellings are arranged around it, with the vertical walls reaching 7.5-9m in height. In Miao Shan village, this rectangular type is oriented north-south (Polydora, 2015).

The pit depth depends on the quality of the loess soil in each area and ranges from 2 to 22m. to create a sunken courtyard (Polydora, 2015). The four sides of the pit extend above ground level, forming slopes that prevent rainwater from flowing into the courtyard. These walls are not entirely vertical (90°) but slightly inclined to prevent collapse due to long-term erosion from weather conditions (Bouillot, 2008).

Floor plan of the Settlement dwelling:



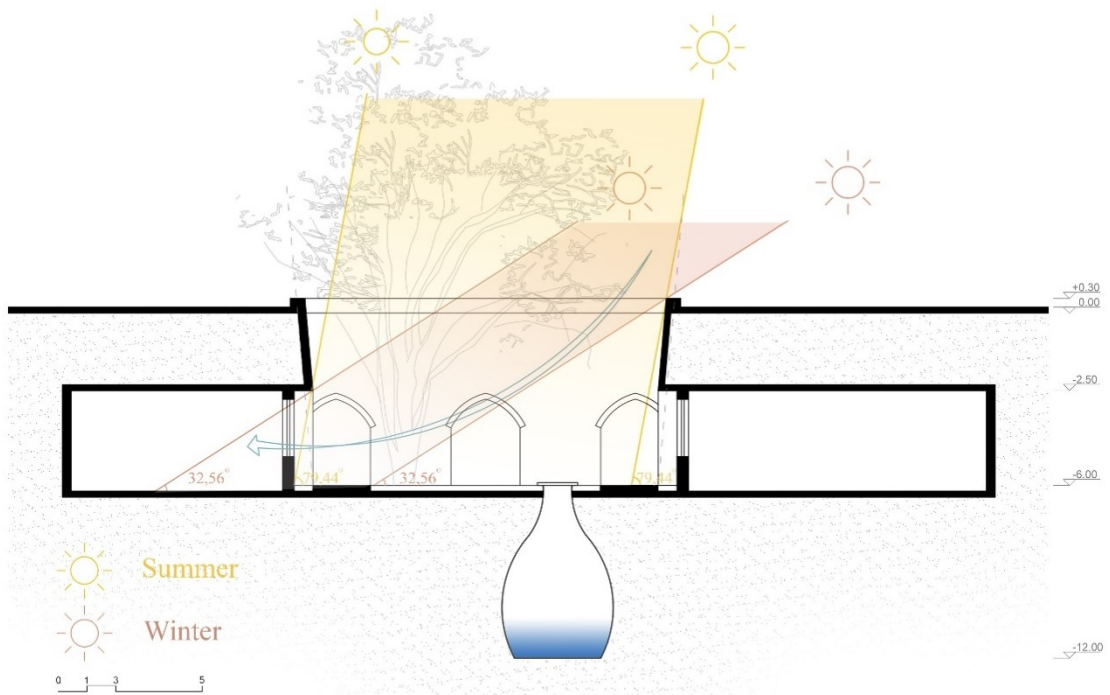
The rooms, carved into the perimeter of the courtyard, do not follow a uniform functional orientation across all housing types. Typically, bedrooms and common areas are located on the same side, while storage spaces and livestock areas are located opposite them.

A key design element is the central courtyard well, used for rainwater collection (Gao, 2021). The well has an opening diameter of approximately one meter, covered by a round stone. The facade materials vary brick and adobe are mainly used on the east-west sides, while adobe dominates the north-south sides. Additionally, the bases of the east and west openings are reinforced with bricks to prevent erosion (Gao, 2021).

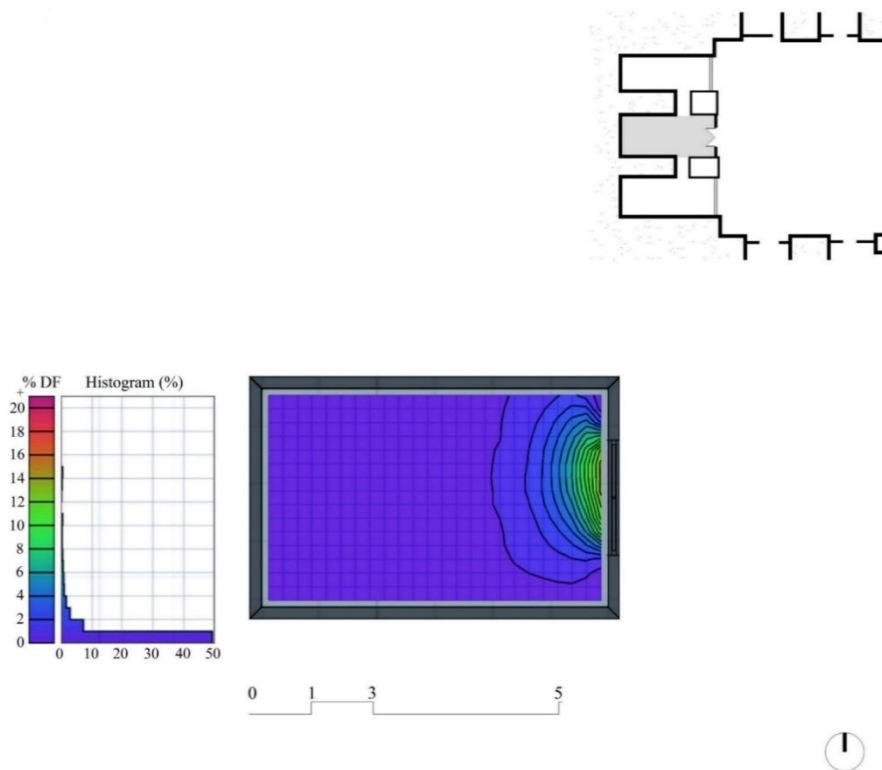
The roof has an approximate thickness of 2.20m, which slows down heat retention in summer and heat loss in winter, enhancing passive heating and cooling (Bouillot, 2008). Additionally, the placement of trees is crucial, as they provide shade for interior spaces during summer, when solar radiation is most intense.

Elements of bioclimatic design

a. Bioclimatic section of the underground house:



b. Diagram of the daylight factor for the western central room of the underground house:

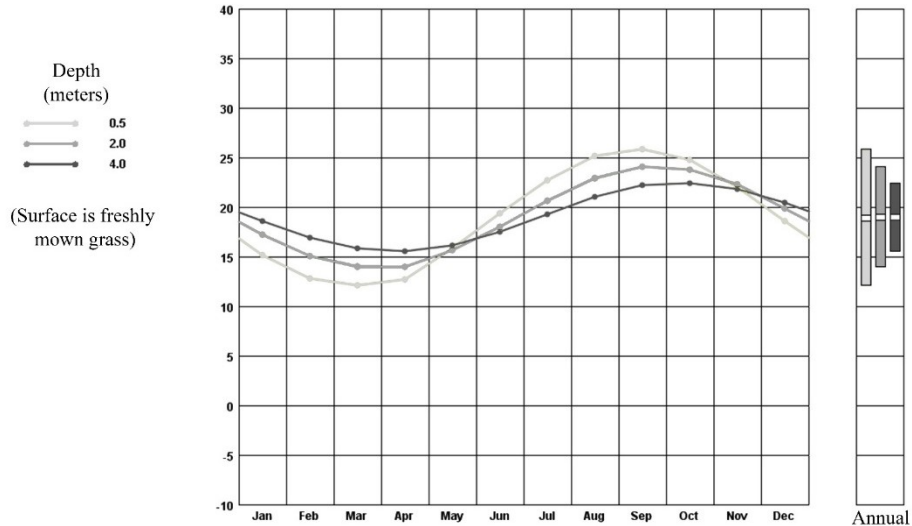


2. Oia Settlement, Santorini/ Vernacular Architecture

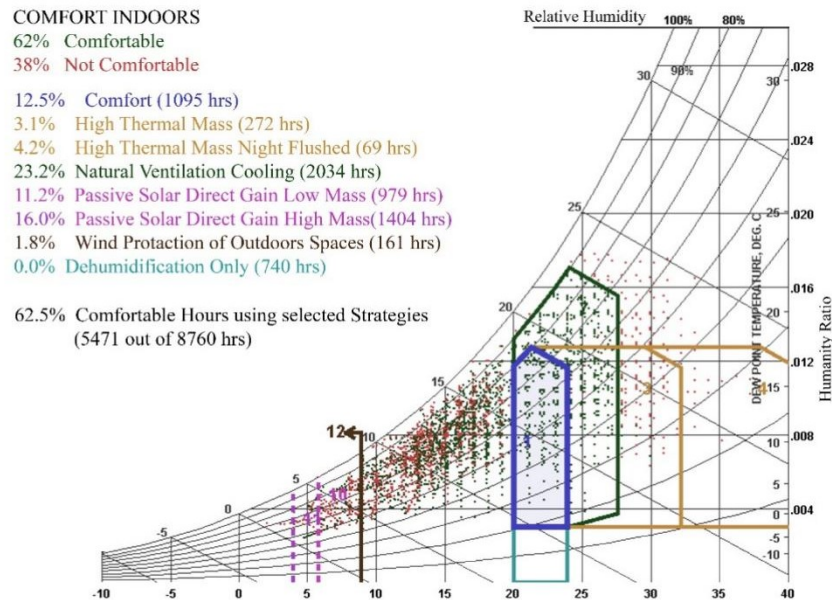
Construction time	19 th century- early 20 th century
Designer/ Architect	Vernacular Architecture
Use/ Function	Inhabitation

Climatic Data of the Study Area

a. Ground Temperature Diagram:



b. Psychrometric Chart:



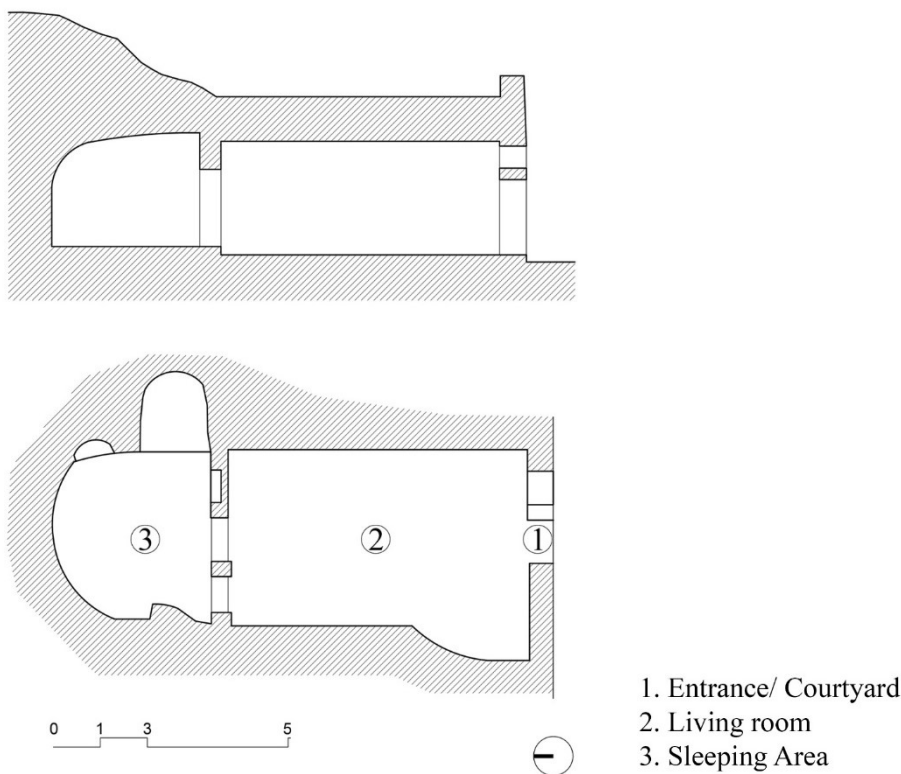
Santorini is a dry island with rich historical and architectural features. Formed by volcanic eruptions, it showcases Cycladic architecture while being deeply influenced by its geomorphology (Skye, 2024).

The island has a dry, warm Mediterranean climate with strong sunlight, minimal rainfall, and winds from the south-southeast in winter and the meltemi (northerly winds) in summer.

The need to protect the volcanic land from weather and pirate attacks led to the spread of underground settlements. The underground homes in Oia are a prime example of bioclimatic design, making use of the soft volcanic soil (Ovali, 2018).

Oia’s architectural identity developed with terraced layers following the area's topography. The settlement consists of narrow streets, steep ramps, and cave-like homes carved into volcanic rock, which has a thermal conductivity coefficient of $k = 0.05W/(m*K)$ (Technical Guideline T.O.T.E.E. 20701-2/2010, 2010). Domes were used due to the lack of timber, and rainwater cisterns were built, as the island lacks a water supply (Argyros, 2012). Local volcanic materials such as limestone, rocks, and pumice were used for construction, making the underground homes an economical solution in terms of resources and space (Manthou, 2020).

Floor Plan:



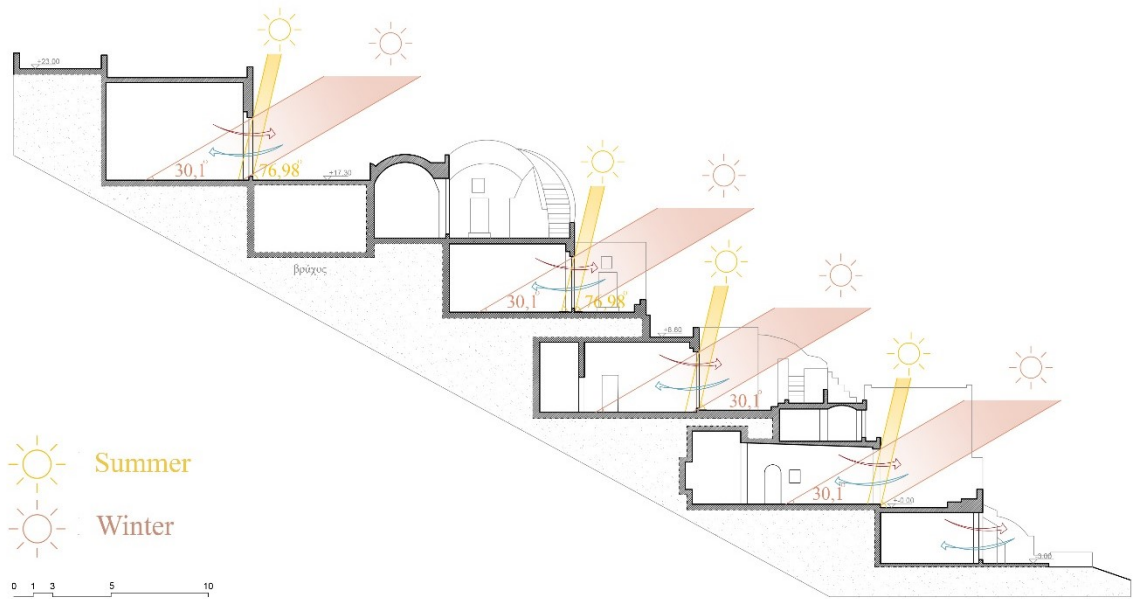
The dimensions of the homes are approximately ten meters in length and four meters in width. The dome extends along the narrow walls. The entrance is located at the center of the free stone facade, with small openings and a skylight (Argyros, 2012).

The interior of the dwelling is divided into two parts: the first houses the common area, a living room, while the sleeping area is located at the back (Argyros, 2012). The separation is made with an intermediate wall, like the one in the facade.

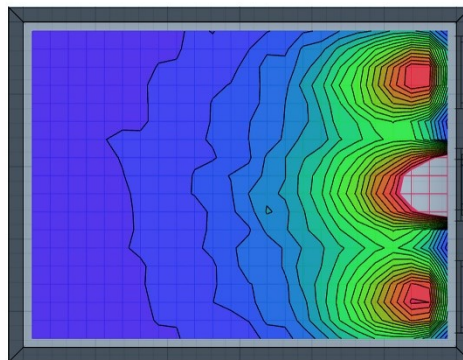
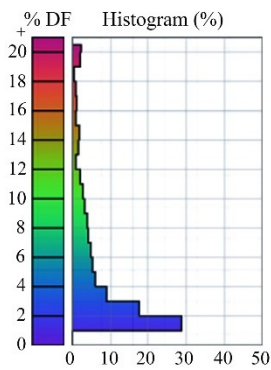
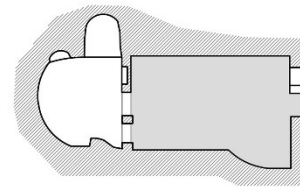
The free facades of the homes are oriented southeast and south. The white color of the facades protects the external shell by reflecting solar radiation, while the light is diffused into the interior due to the reflectivity of the internal surfaces. At the same time, the thermal load inside is reduced with the help of the vaulted covering (Ovali, 2018). Additionally, in some cases, chimneys are placed that penetrate the ground, allowing light to enter and air to flow into spaces without perimeter openings (Ovali, 2018). The thermal inertia is also ensured due to the underground technique, keeping the temperature relatively stable inside the structures.

Elements of bioclimatic design

a. Bioclimatic section of the underground house:



b. Diagram of the daylight factor for the southern central room of the underground house:

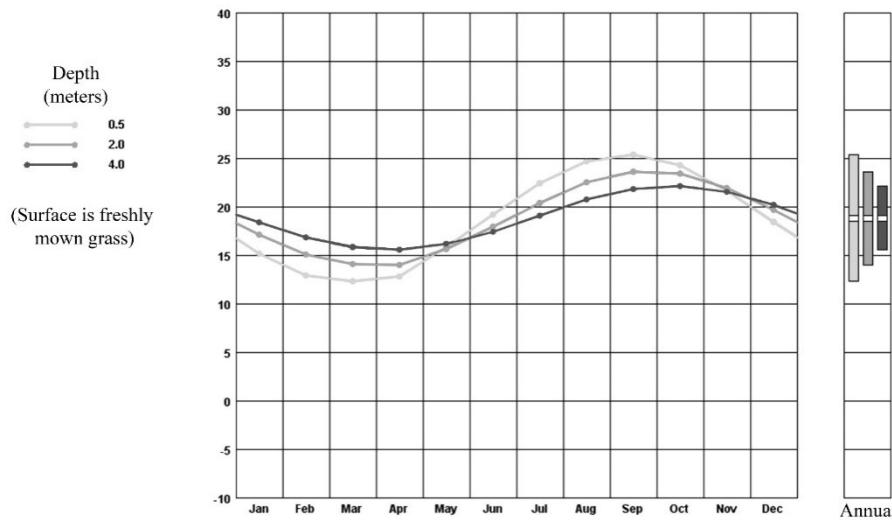


3. Yoma Suites in Zakynthos| by Urban Soul Project/ Contemporary Architecture

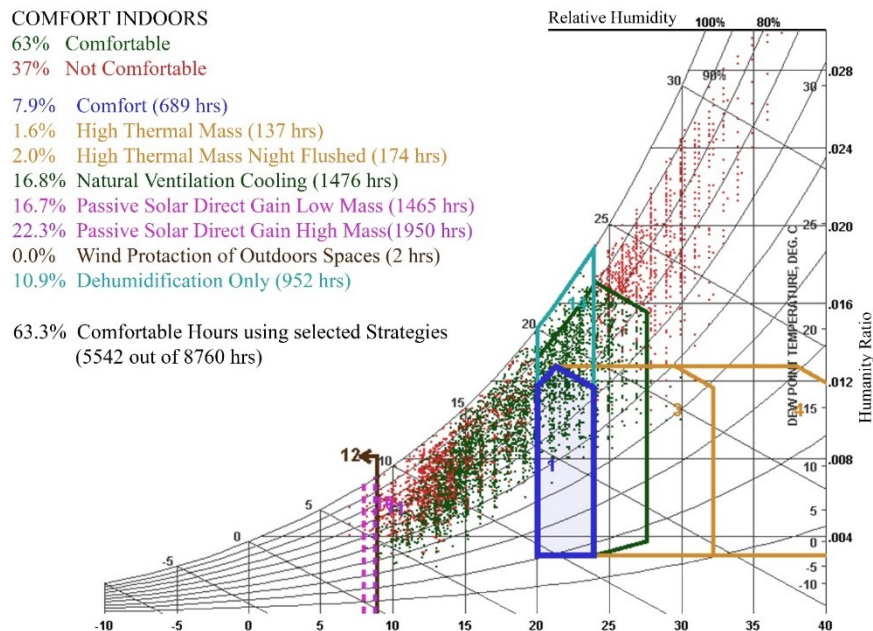
Construction time	2019-2021
Designer/ Architect	Maria Taftaki, Kwstas Flwros
Use/ Function	Inhabitation

Climatic Data of the Study Area

a. Ground Temperature Diagram:



b. Psychrometric Chart:

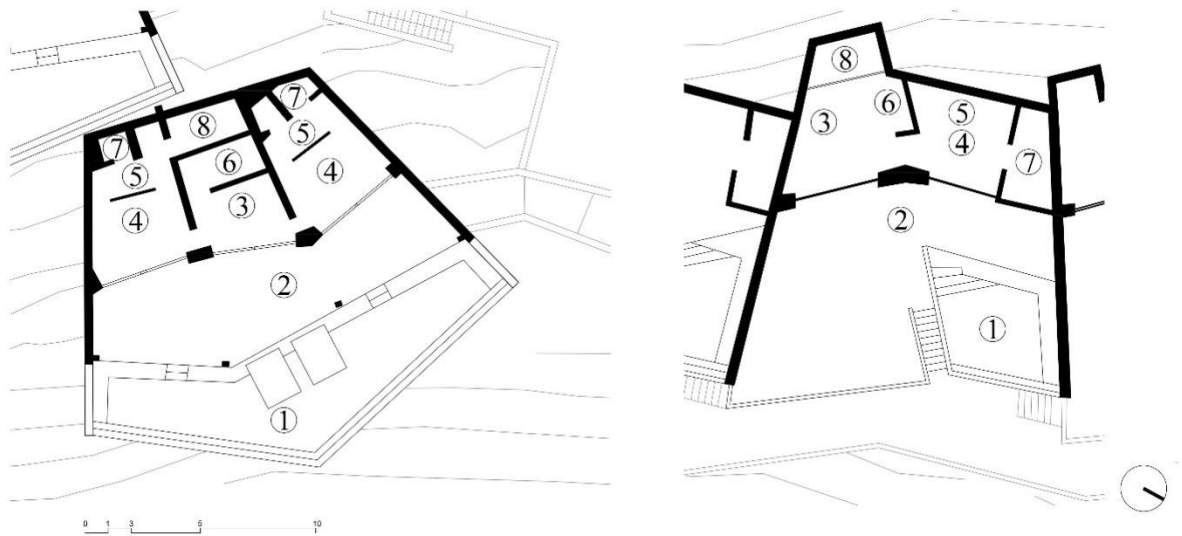


Zakynthos, an Ionian Island with an area of 406 square kilometers, has a Mediterranean climate with mild, wet winters and warm, dry summers (Versus Travel). The island’s terrain is varied, including flat, mountainous, and coastal areas. Winters bring more rain, while summers are dry. Winds are moderate from the west and northwest in summer and stronger from the south in winter.

The underground houses designed by Urban Soul Project architects are located in the northern, mountainous part of Zakynthos. The land, primarily limestone, is stable and suitable for underground construction. The buildings are integrated into four levels, with the reception area at the highest point and the rest of the residences across the lower levels (Panetsos, 2023).

The buildings have prismatic shapes with no right angles and east-facing openings. The design ensures both unobstructed sea views and privacy. Interiors include one or two bedrooms, a living room, kitchen, and small workspaces, while the exterior features a private pool, terrace, and pergola.

Types of housing:



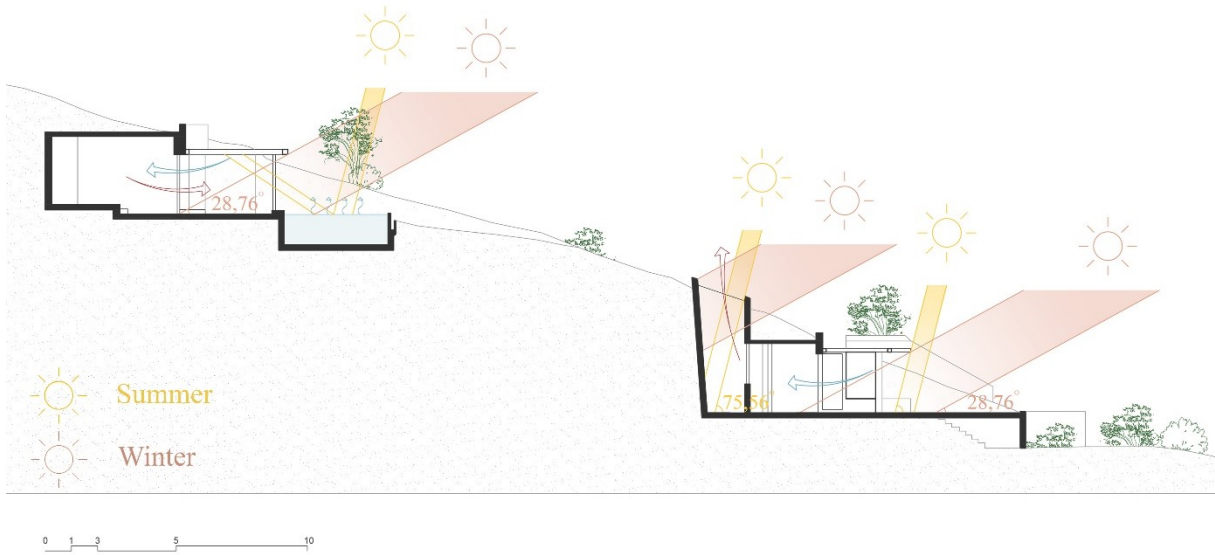
- | | |
|-------------------------|-------------------|
| 1. Private pool | 5. Storage space |
| 2. Terrace with pergola | 6. Kitchen |
| 3. Living room | 7. Sanitary space |
| 4. Sleeping area | 8. Workspace |

Natural lighting and the ventilation of warm air are achieved through the open western façades and additional skylights at the rear sections of the underground structures. The underground technique is realized by embedding the structures into the ground, respecting the existing landscape. The buildings' facing side functions as a single volumetric entity, while the surrounding outdoor spaces are also integrated as part of the design.

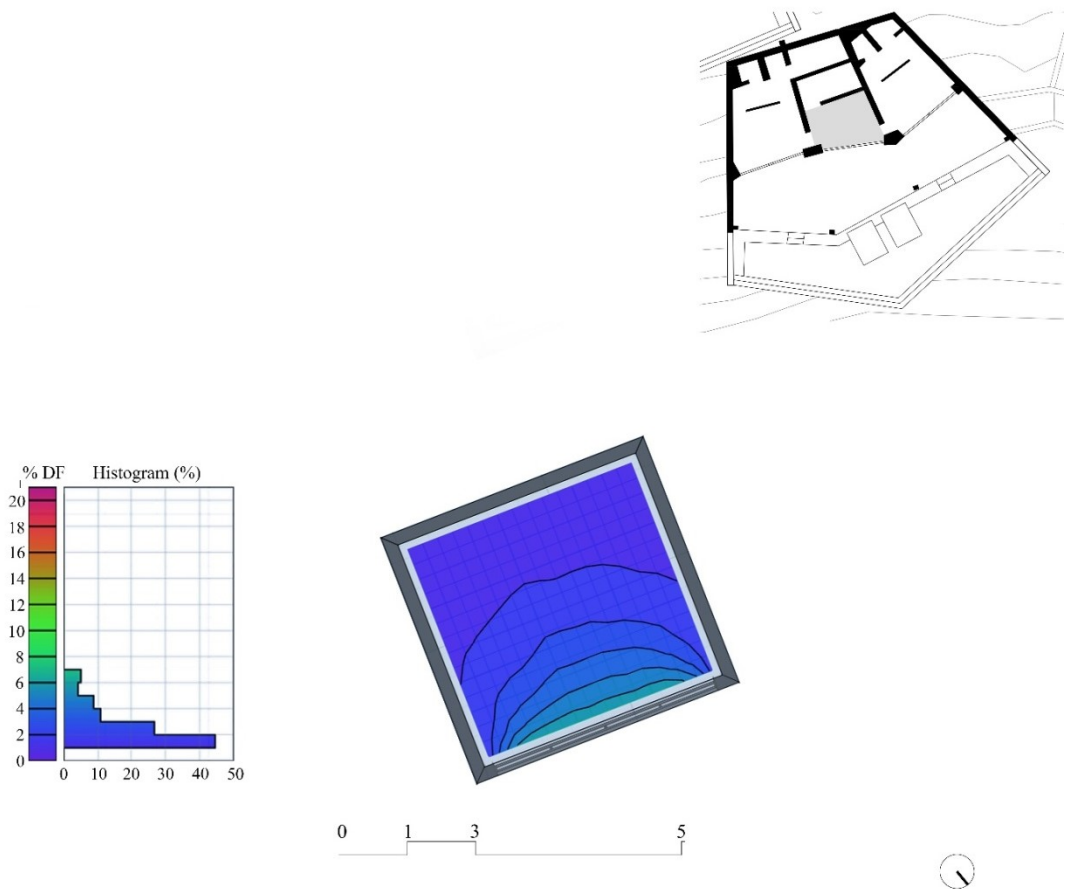
The choice of materials is carefully selected to harmonize with the environment and align with the island's traditional aesthetic. Local materials, such as stone and wood, are used in shades that reflect the natural surroundings and local vegetation, such as sand-colored tones (Panetsos, 2023).

Elements of bioclimatic design

a. Bioclimatic section of the underground house:



b. Diagram of the daylight factor for the northern central room of the underground house:

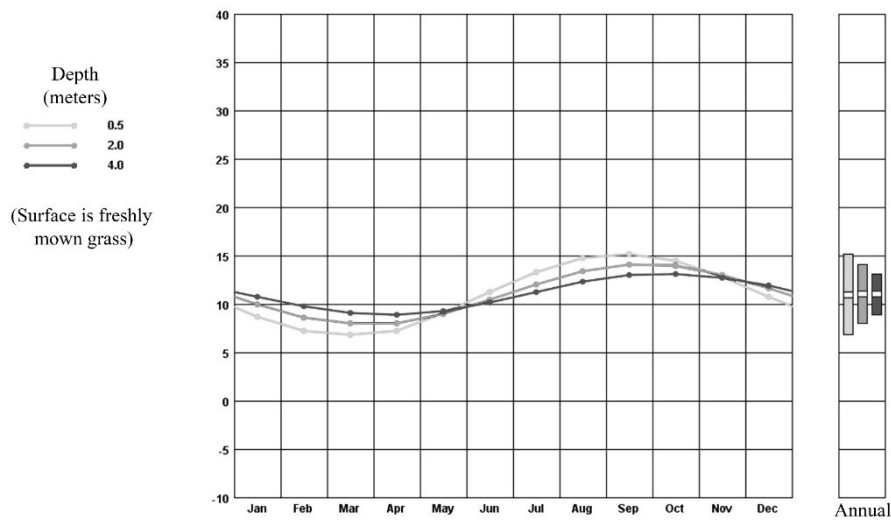


4. Malator House| Future System/ Contemporary Architecture

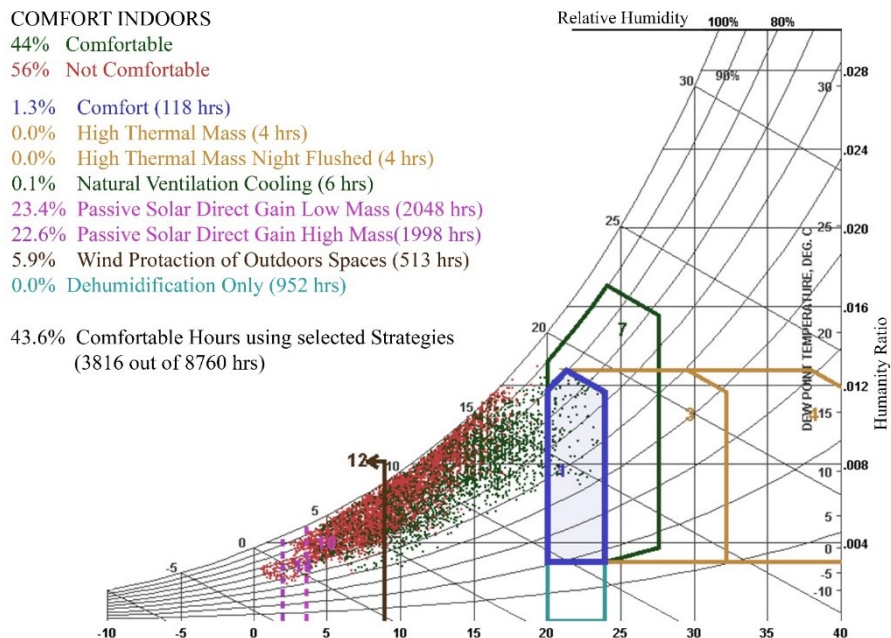
Construction time	1998
Designer/ Architect	Jan Kaplický, Amanda Leveté
Use/ Function	Inhabitation

Climatic Data of the Study Area:

a. Ground Temperature Diagram:



b. Psychrometric chart:

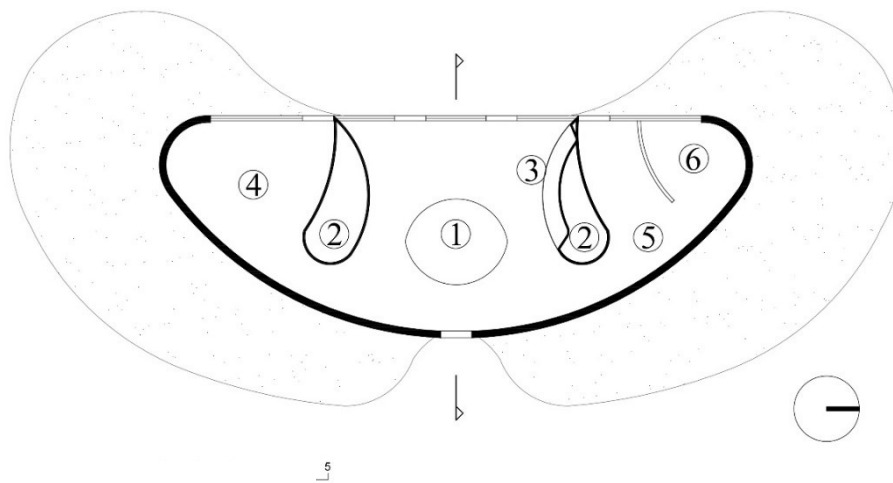


The Malator House, located in Pembrokeshire National Park, Wales, is designed to blend discreetly with the landscape. Built 150 meters from the sea, it covers 300 kilometers of coastline and faces a mild, maritime temperate climate. The house was created for Bob

Marshall-Andrews as a vacation home, replacing an old barracks (Rethinking the Future, 2022).

The building's design follows strict regulations to minimize environmental impact. Inspired by Northern Scandinavian architecture, the house is camouflaged with earth and turf, offering thermal protection (Bannikova, 2017). The roof, made of marine plywood and turf, is supported by steel beams and a concrete slab, eliminating the need for internal support. Some internal components, like the bathroom pods, were prefabricated, enhancing the house's lightness and brightness (Rethinking the Future, 2022).

Floor Plan:

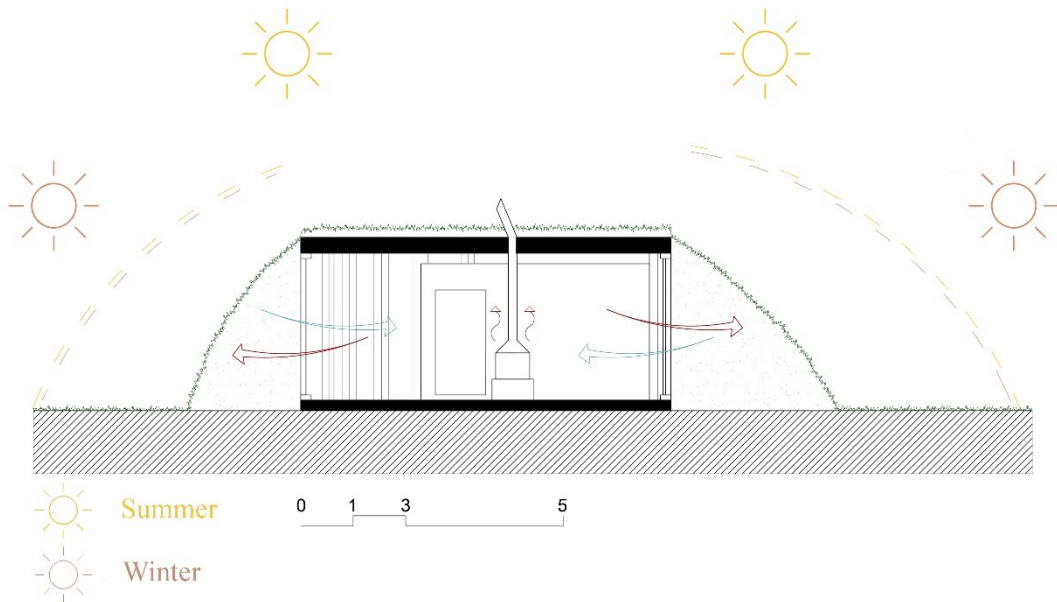


- | | |
|-------------------|------------------|
| 1. Living room | 4. Sleeping area |
| 2. Sanitary space | 5. Storage space |
| 3. Kitchen | 6. Empty space |

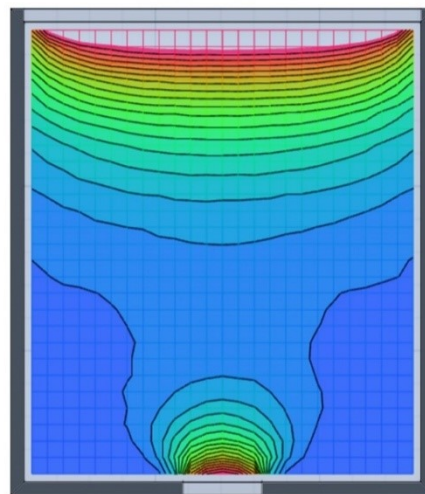
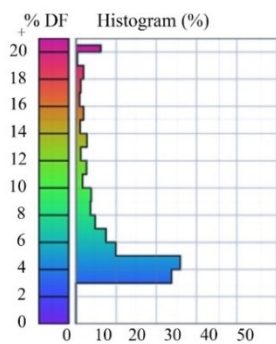
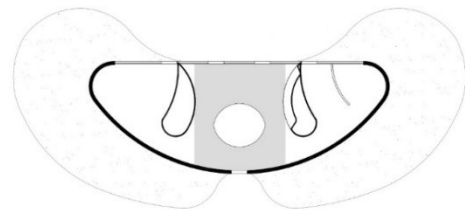
The simplicity combined with the organic curves of the floor plan reflects its harmony with the existing landscape. The layout is open, only limited by the prefabricated structures that also define the functionality of the spaces (Bannikova, 2017). Focus is placed on the living room area and the centrality of the chimney, which is oriented towards the horizon. Additionally, besides the organic floor plan, the playful character of the interior is enhanced by vibrant colors (Bannikova, 2017).

Elements of bioclimatic design

a. Bioclimatic section of the underground house:



b. Diagram of the daylight factor for the eastern central room of the underground house:



Conclusions of Case Studies

Northern China Settlement: Settlements protected by the earth, found in regions of northern China, Iran, Tunisia, etc., areas with dry and hot climates, are products of human efforts to protect against weather phenomena and other hazards (See Chapter [Typologies of Earth Architecture]). They combine elements of traditional architecture with features of the local climate and geographical conditions.

Thermal inertia is a characteristic effectively applied to manage large seasonal fluctuations between seasons. In this way, underground interior spaces ensure coolness in the summer and warmth in the winter, reducing the need for artificial heating and cooling. Additionally, the use of local materials, adaptation to the topography, and planting of trees for shading are elements of bioclimatic design. Finally, natural lighting and ventilation are provided inside, though not always effective.

Oia Settlement: This underground settlement offers a sustainable solution adapted to the unique climate and topography of Santorini. The use of local materials and traditional Cycladic techniques shape the dwellings, which incorporate bioclimatic principles. However, natural ventilation and lighting are not sufficient in all types of dwellings. Additionally, thermal inertia is ensured due to the underground form and the composition of the soil.

Yoma Suites in Zakynthos: The bioclimatic design principles that are evident include cross-ventilation and the enhancement of natural lighting throughout the interior, as well as solar protection due to the westward orientation of the dwellings, which shields them from summer radiation. Another feature is water. The water placed in the western part provides cooling through evaporation, and the water surfaces have high absorptivity, around 0.95, reflecting radiation during times when the solar radiation angle (solar altitude angle) is low (i.e., early in the morning and late in the afternoon). Lastly, the thermal delay provided by the thermal mass of the ground is not effectively utilized, as the dwellings do not make direct contact with the soil.

Malator House: The design principle behind the construction of the Malator House was focused on sustainability and harmonizing with the natural landscape. Its underground character, combined with the use of local natural materials, aims at energy efficiency, maintaining interior temperature, and reducing the need for air conditioning. Additionally, due to its low elevation and the absence of additional layers above the ground, it helps protect against the climatic conditions of the area, such as strong winds. The open facades of the house allow for cross-ventilation and sufficient natural lighting.

Comparative Analysis and Evaluation

Comparison of Soil Materials' Thermal Transmittance Coefficient

Theran earth has low thermal conductivity, making it an effective insulator, while its low heat capacity helps maintain stable indoor temperatures. Silty sand also delays heat transfer, whereas limestone and compact soil conduct heat quickly, potentially increasing heating and cooling demands.

Thermal Comfort and Energy Efficiency

Underground dwellings benefit from the soil's insulating properties, maintaining stable indoor temperatures and reducing energy needs for heating and cooling.

Protection and Safety

Subterranean structures offer strong resistance to extreme weather and seismic activity, providing natural protection and historically serving as shelters.

Economy

In some regions, natural materials are readily available, allowing the use of soil as a building material. Additionally, underground dwellings tend to be more durable and require less maintenance over time, depending on soil composition and climate. However, soil moisture may necessitate additional protective measures.

Aesthetics and Environmental Sustainability

Blending with the natural landscape reduces visual impact and minimizes environmental footprint by using fewer natural resources. The combination of architecture and bioclimatic design promotes sustainable and eco-friendly living.

Land Utilization

Subterranean structures allow for alternative land use, such as agriculture or urban development, particularly in areas with limited available space.

The choice of underground living, combined with these factors, offers a sustainable, comfortable, and safe housing solution. However, proper architectural and bioclimatic strategies—such as optimal orientation for natural light, ventilation openings, solar and wind protection, and moisture control—are essential to adapt to the specific climate and needs of each location.

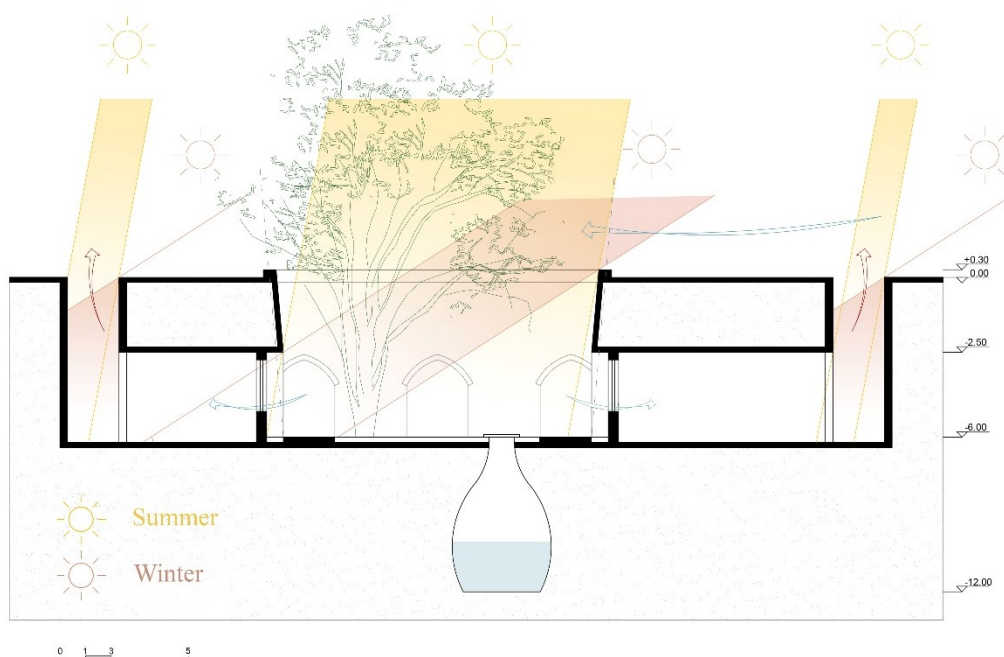
Weaknesses of Subterranean Constructions & Improvement Proposals

Settlement in Northern China

1. Natural Lighting
2. Natural Ventilation

To enhance both aspects, skylights can be added to facilitate the release of warm air from indoor spaces and improve natural light penetration.

Enhanced Bioclimatic section of the underground house:

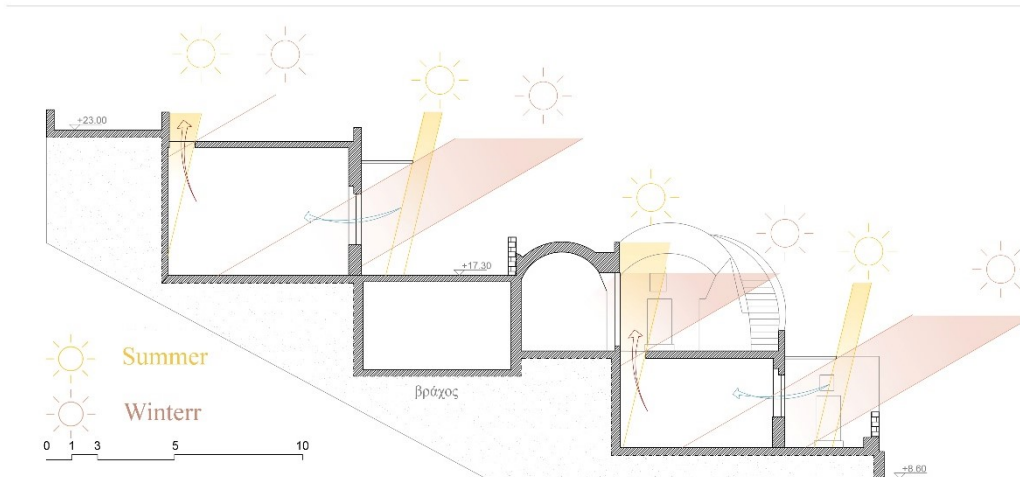


Settlement in Oia, Santorini

1. Wind Protection
2. Sun Protection
3. Natural Ventilation

Due to the settlement's southern orientation and prevailing winds, wind protection can be achieved by adding perimeter fences and adjusting the entrance door orientation to the east or west. Small canopies provide both sun and wind protection. Additionally, skylights enhance natural cross-ventilation and increase daylight in interior spaces.

Enhanced Bioclimatic section of the underground house:

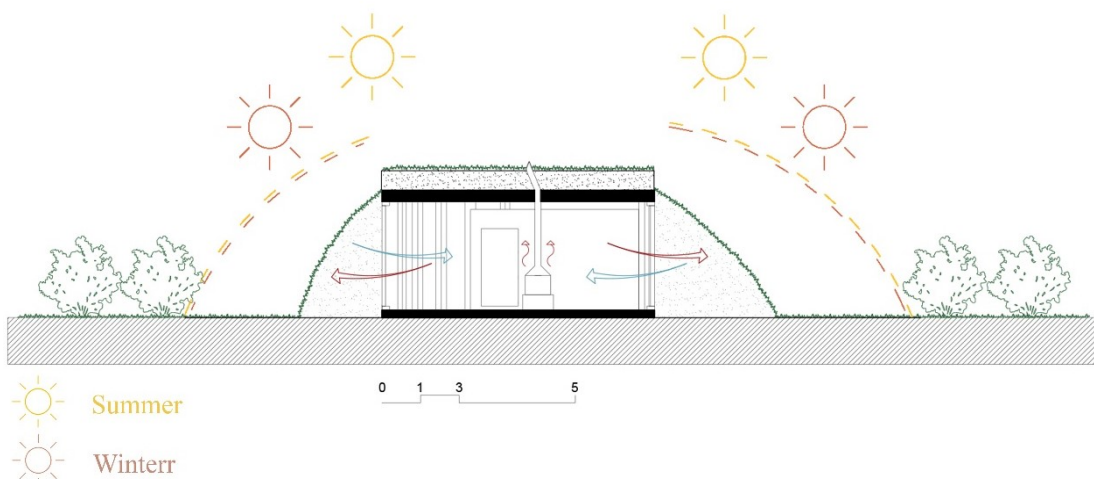


Malator House, Wales

Wind Protection

- A possible improvement would be a southern orientation for the building.
- With summer temperatures not exceeding 20°C, the mild soil temperature variations and prevailing westerly winds ensure natural cross-ventilation and help reduce indoor humidity.
- Low vegetation on the western and eastern façades could provide additional wind protection.
- Adding thermal insulation or increasing the soil layer on the roof would further enhance energy efficiency.

Enhanced Bioclimatic section of the underground house:



The study of the key characteristics of underground structures, their typology, their relationship with the climate, the concepts of place and terrain, the principles of bioclimatic design, and the analysis of traditional and contemporary underground constructions across different geographical zones has revealed enduring values of this architectural approach, as well as diverse ways of addressing specific challenges.

Sustainable Advantages of Subterranean Dwellings

Energy Efficiency

The thermal mass of the ground helps maintain a stable indoor temperature. Both traditional and contemporary underground dwellings utilize the thermal inertia of the soil to reduce heating and cooling demands, as the building envelope is in contact with the earth, which has a more stable temperature than the air and is shielded from solar radiation and wind exposure. However, modern constructions that incorporate additional insulation layers reduce heat transfer between the envelope and the ground, thereby diminishing the impact of thermal inertia.

Ecological Sustainability

Underground dwellings blend into the natural landscape, minimizing environmental impact (e.g., Malator House). Additionally, the use of locally available materials reduces transportation needs and associated carbon emissions. Traditional settlements, such as those in Oia (Greece) and Northern China, exemplify this approach, as their buildings were constructed using materials sourced from the immediate surroundings.

Aesthetic and Cultural Value

Due to their minimal visible surfaces and low visual impact, underground dwellings create a harmonious integration with the landscape. Notable examples include residences in Zakynthos and Oia. Furthermore, traditional construction techniques, as observed in Zakynthos and Northern China, contribute to preserving cultural heritage and local architectural traditions.

Economic Benefits

The natural insulation provided by the ground lowers energy demands, reducing heating and cooling costs. Additionally, underground structures are highly resilient to natural disasters, leading to lower maintenance and repair expenses.

Acceptance and Regulatory Incentives

Today, there are favorable regulations for underground structures that allow for higher building density, provided that specific design criteria are met.

Comfort and Well-being

Underground buildings offer a stable and comfortable indoor environment, provided that adequate ventilation ensures air quality and thermal comfort. Moreover, the ground acts as a natural sound barrier, enhancing indoor acoustic comfort.

Disadvantages of Subterranean Dwellings

Type of Underground Architecture

The choice of underground architectural typology depends on soil composition and local climatic conditions. Not all earth-based architectural typologies can be applied universally.

For instance, in regions with hot and dry climates or significant temperature fluctuations, earth-sheltered designs tend to offer the best performance.

Construction Challenges

Building underground dwellings is often more complex than conventional structures due to excavation requirements and structural reinforcements. Additionally, the presence of surrounding soil can lead to moisture-related issues, necessitating specialized waterproofing and insulation systems.

Design Limitations

Most underground homes have fewer openings (e.g., in Oia and Northern China), which may require artificial lighting solutions to ensure sufficient indoor illumination. Similarly, natural ventilation is often restricted, making mechanical ventilation systems necessary to maintain indoor air quality.

Economic Factors

The initial construction cost can be higher due to the complexity of excavation and the need for specialized techniques. Moreover, maintenance costs—such as those observed in Chinese settlements—can be significant, particularly concerning waterproofing and moisture management.

Regulatory Constraints and Promotion Measures

In many cases, building codes and local planning regulations impose restrictions on underground dwellings or require strict compliance with specific conditions, increasing construction complexity and costs (e.g., Malator House).

Comfort and Livability

Without adequate ventilation, soil moisture can create unfavorable indoor conditions, leading to high humidity levels and potential structural failures. Proper air circulation and humidity control are essential to ensure comfortable living environments.

Permanent footprint

Excavations for underground constructions can sometimes leave a permanent footprint on the landscape, altering the natural terrain and ecosystem.

Conclusions

Underground architecture offers notable advantages, including energy efficiency and environmental sustainability, but also presents challenges that require specialized knowledge and careful planning.

Key design considerations include proper building orientation for optimal daylight and thermal performance, as well as strategic placement of openings to enhance natural lighting and ventilation. Design constraints can be mitigated through solutions like skylights and courtyards. Additionally, selecting moisture-resistant and insulating materials is crucial for durability and comfort. By addressing these factors, underground dwellings can achieve a sustainable and livable balance between nature and built space.

A crucial aspect of underground dwelling design is its impact on the user's psychological and physical well-being. While these structures offer significant benefits in terms of energy efficiency and climate protection, they may also evoke feelings of isolation,

loss of perceived control, or cultural biases. Future research could explore architectural strategies that balance the advantages of underground living with the user's mental well-being.

Another complex issue for further investigation is the cost comparison between underground and above-ground structures. Excavation can be challenging depending on the terrain, while moisture-resistant materials and maintenance requirements add to the overall expense. However, underground dwellings offer long-term energy savings. A comprehensive analysis of excavation, foundations, insulation, and thermal efficiency is needed to determine which construction method is more cost-effective and sustainable in the long run.

Underground bioclimatic architecture is one of the oldest and most effective examples of human adaptation to the natural environment. The study of its evolution over the centuries highlights that integrating natural resources and climatic conditions into residential design is not merely a necessity but a sustainable strategy. It enables harmonious integration with the landscape while ensuring comfort, aesthetics, and ecological awareness.

This architectural approach provides valuable solutions to contemporary challenges such as climate change and energy efficiency, promoting the revival of traditional techniques through modern technologies. Ultimately, underground architecture demonstrates how humans can coexist with nature in a way that enhances quality of life while offering sustainable solutions for the future.

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