SHELTERED BY THE EARTH

A RESILIENT HERITAGE IN HOT-ARID CLIMATE



FATEMEH ZARNOOSHEH

Politecnico di Torino
Politecnico di Bari

Department of Architecture, and Design
Master of Architecture for Heritage

SHELTERED BY THE EARTH

A Resilient Heritage in Hot-Arid Climate: Participatory Conservation and Reimagining Iranian Yakhchals as Community Cooling Hubs

Author:
Fatemeh Zarnoosheh - S329600

Supervisors:
Manuela Mattone
Umberto Berardi

Thesis - Laurea Magistrale 2026/2027

Abstract

Traditional Iranian ice-houses (yakhchals) show centuries of environmental knowledge, as they make use of earth, shade, thermal mass, controlled airflow, and underground space in order to achieve cooling in hot-arid climates. This thesis looks into the possibility of reactivating these historical infrastructures as community cultural cooling hubs. Focusing on Yakhchal-e-Barzan in Abarkuh, Yazd Province, the research develops a conservation-led adaptive reuse proposal that gives the site a new role as a naturally conditioned community cooling hub.

The study combines photographic documentation, material and deterioration mapping, building-energy modelling, thermal simulation, adaptive-comfort evaluation, and participatory conservation research. The state of conservation assessment finds there is considerable erosion, cracking, moisture related deterioration, material loss, and damage affecting the dome, shading walls, openings, and surrounding ground. This information forms the basis for a conservation strategy which is carried out in phases and includes structural stabilization, better drainage, the use of compatible earthen mortar for repair, controlled access, and long-term maintenance.

The proposal builds on the passive cooling strategy already present in the yakhchal and reinterprets this for contemporary public use. Earth sheltering, shaded areas, thermal mass and natural ventilation, provide relief from extreme heat with low energy demand. The proposed function also includes heritage interpretation, guided tours, workshops on adobe and clay, local craft activities and cooperation with nearby tourism businesses and thus supports residents, outdoor workers, and visitors while providing opportunities for cultural activities and small-scale local development.

In the end, the thesis presents the yakhchal as a form of living infrastructure, something in which conservation, cultural memory, passive cooling, and community life combine to enhance climate resilience.

Acknowledgments

This thesis was made possible with the support of many people who helped me throughout this journey. First of all, I would like to thank my family for always supporting me, encouraging me to follow my passion, and standing beside me through every stage of my studies.

I am deeply grateful to my supervisor, Professor Manuela Mattone, from the Department of Architecture and Design at Politecnico di Torino. I first had the opportunity to attend her Restoration Project course during my first semester. That experience introduced me to earthen architecture and created an interest that later became central to this research. I feel very fortunate to have completed this thesis under her supervision. Her guidance, comments, and continuous feedback helped me improve the work throughout the whole process.

I would also like to sincerely thank Professor Umberto Berardi from the Department of Architecture, Construction and Design at Politecnico di Bari. His encouragement during my Erasmus programme gave me the confidence to move outside my comfort zone and explore new methodologies. His support opened new possibilities for my research that I could not have explored alone, and I am truly grateful for the opportunity to work with him.

My sincere appreciation also goes to Politecnico di Torino for providing me with an inspiring academic environment and the opportunity to learn from a wide community of scholars. I am also grateful to EDISU Piemonte and to Arch. Mauro Meneghetti for his support during my internship. I especially thank him for giving me the opportunity to write and publish my first book chapter, which I had the privilege of co-authoring with him.

I am deeply grateful to the people of Abarkuh, whose kindness and hospitality made my fieldwork a very meaningful and memorable experience. I sincerely thank everyone who shared their time, knowledge, experiences, and stories with me. I hope this research can honour their trust by proposing an adaptive reuse framework for revitalizing the yakhchals, preserving their cultural heritage, and at the same time serving the community.

Finally, I feel fortunate that this journey has been filled with passion, curiosity, learning, challenges, and hope. Through both rewarding and uncertain moments, this project encouraged me to grow, challenge myself, and give the best of what I could offer.

Contents

01
Introduction **01**

1.1 Vernacular Infrastructures and Traditional Cooling Systems in Iran
1.2 Research Question
1.3 Methodology and Research Framework

02
Context and Analysis **17**

2.1 Yakhchals (ice-pits) in Iran
2.2 Historical Framework of the Iranian Yakhchals
2.3 Territorial Framework of the Iranian Yakhchals
2.4 State of Conservation of the Iranian Yakhchals

03
Case Study: Yakhchals of Abarkuh City **53**

3.1 Historical, and Territorial Framework of Abarkuh
3.2 Cultural Framework of Abarkuh
3.3 Field Survey
3.4 Construction Technique
3.5 State of Conservation
3.6 SWOT Analysis

04
Community and Social Practices **93**

4.1 UNESCO and Faro Convention: Community Participation in Heritage Conservation
4.2 The Role of Communities and Social Practices in the Conservation of Earthen Architecture
4.3 History of Community and Social Practices around Yakhchals
4.4 Abarkuh Community's Perspectives and Needs

05
Bioclimatic Performance of Yakhchals **119**

5.1 Natural Ventilation and Passive Cooling
5.1.1 Wind-Driven Ventilation
5.1.2 Stack Effect Ventilation
5.2 Thermal Mass and Thermal Inertia
5.3 Night Cooling and Radiative Heat Loss
5.4 Earth Sheltering and Subterranean Cooling
5.5 Guidelines from Earth-Sheltered Buildings in Hot-Arid Climates
5.6 Adapting Balaguer's Bioclimatic Framework to Yakhchals
5.7 Thermal Comfort and Adaptive Comfort Models
5.8 Climate Analysis of Abarkuh
5.9 Dynamic Thermal Simulations and Results
5.10 Adaptive Comfort Assessment

06
Adaptive Reuse Proposal: Reimagining Yakhchals as Cultural Cooling Hubs **147**

6.1 Concept: Sheltered by the Earth
6.2 Design Development: Plans, Sections, Axonometrics, Perspectives

07
Appendix **159**

08
Bibliography **173**

01
INTRODUCTION



Figure 1. Aerial photograph of Qanat and ice-house of Aqa, 1963.

Source: Archive of the Central Library, Research Institute of Cultural Heritage and Tourism, Tehran.

1.1 VERNACULAR INFRASTRUCTURES AND TRADITIONAL COOLING SYSTEMS IN IRAN

The Iranian plateau is characterized by large desert areas, strong solar radiation, and significant temperature differences between day and night. Living in these conditions required architectural solutions that could respond to heat, water scarcity, and seasonal changes. Over time, local builders developed passive systems based on available materials and a close understanding of climate. Qanats, windcatchers, ab-anbars (water cisterns), and yakhchals are some of the most important examples of these traditional infrastructures. Although they had different functions, they all show how architecture, water management, and environmental strategies were closely connected in Iran's hot-arid regions.

Qanats: Hydraulic Foundations of Cooling

Qanats are among the most important traditional infrastructures developed in the arid regions of Iran. They transport groundwater from underground aquifers to settlements and agricultural lands through gently sloping subterranean tunnels. Because most of the water flows below ground, evaporation is reduced compared with open canals, which was particularly important under the intense sun and dry climate of the Iranian plateau [1]. This system made agriculture and permanent settlement possible in areas where surface water was limited or unavailable.

Qanats were also strongly connected to the social organization of villages and towns. Their construction and maintenance required cooperation between local people, as well as systems for managing and distributing water. These shared responsibilities became part of everyday life and helped create strong relationships between communities and their environment [2]. Honari describes qanats as part of a wider human ecosystem, where water management, social organization, and local ecological conditions were closely connected [3]. For this reason, the qanat can be understood not only as a hydraulic system, but also as an infrastructure that supported both settlement and community life.

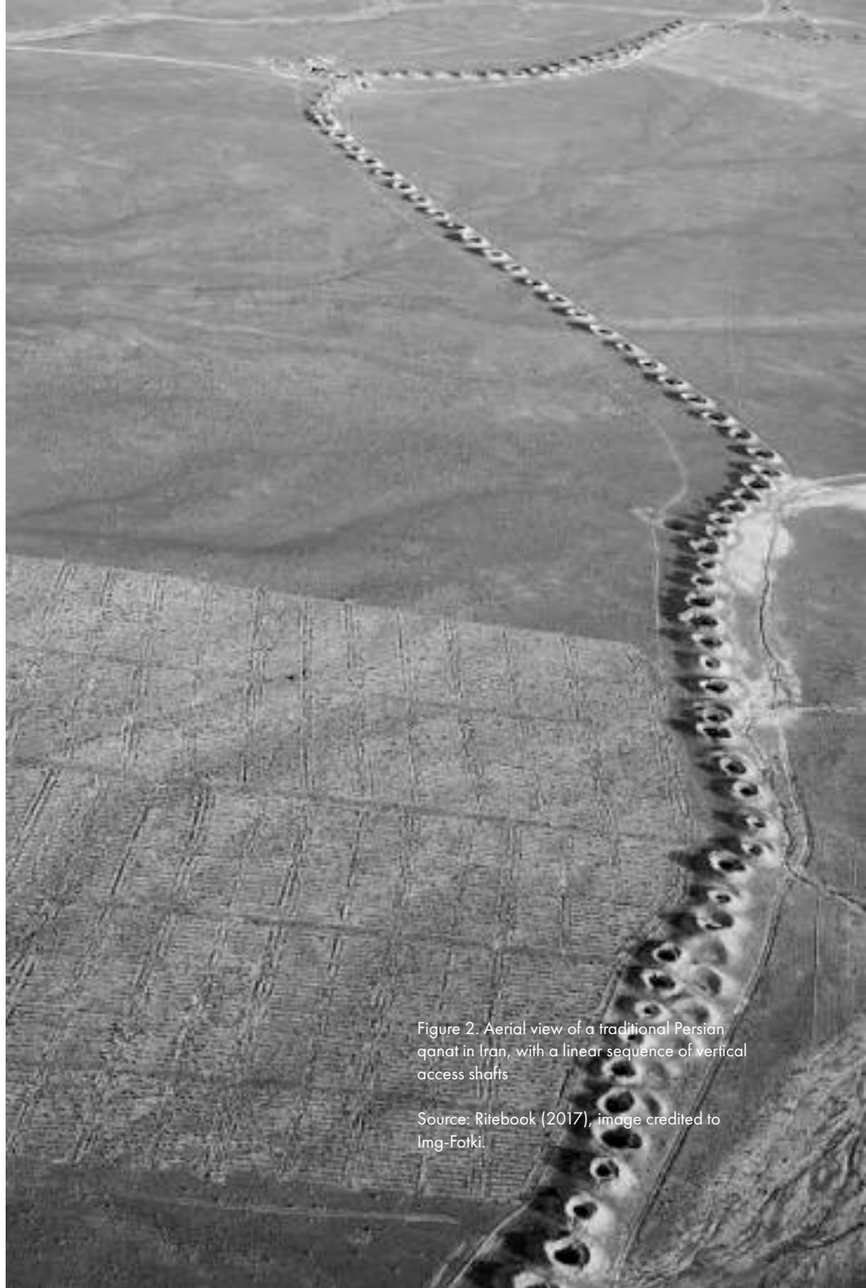


Figure 2. Aerial view of a traditional Persian qanat in Iran, with a linear sequence of vertical access shafts

Source: Ritebook (2017), image credited to Img-Fotki.

Windcatchers (Badgirs): Natural Ventilating Infrastructures

Windcatchers, or badgirs, are among the most recognizable passive cooling infrastructures in the hot-arid regions of Iran. They are designed to improve natural ventilation by capturing prevailing winds and directing them into interior spaces without the use of mechanical systems. Their performance is based on differences in air pressure and temperature. Wind enters through the upper openings of the tower and moves down through vertical shafts, while warmer indoor air can escape through other openings. This movement helps create continuous air circulation and improves indoor conditions during both daytime and nighttime [4].

The performance of windcatchers is also closely related to the thermal properties of traditional earthen buildings. A study on preventive conservation in Yazd highlights the important relationship between windcatchers and adobe walls, since the thermal mass of the walls slows down heat transfer and helps maintain cooler indoor conditions for a longer period [5]. For this reason, the windcatcher is a part of a wider environmental system.

In many traditional houses, windcatchers were connected to a hozkhaneh, an underground summer room containing a central water basin. Air entering through the badgir passed over the water surface before reaching the occupied space. This increased the cooling effect through evaporation and created more comfortable conditions during hot summer periods [4]. The combination of airflow, water, and underground spaces shows how different passive cooling strategies were used together rather than separately.

Windcatchers were also used in public buildings, including mosques, caravanserais, ab-anbars, and bazaars. This shows that they played a significant role in domestic comfort, and public and communal buildings. In cities such as Yazd, windcatchers became an important part of the urban identity and skyline, reflecting the close relationship between architecture and climate [6].

Today, windcatchers are studied both as an important part of Iranian architectural heritage and as a reference for contemporary sustainable design. Their use of natural airflow and, in some cases, evaporative cooling demonstrates how thermal comfort can be improved through simple climatic strategies with very low energy demand. Their conservation and careful reinterpretation can therefore provide useful lessons for architecture in hot-arid regions facing increasing temperatures.



Figure 3. (2024). Badgir,(windcatcher). TasteIran. By Amin Karimi

Water Cisterns (Ab-anbar)

Ab-anbars are traditional underground water cisterns developed in Iran to store drinking water in hot-arid climates. They were commonly built in desert cities such as Yazd, Kashan, and Qazvin, where water scarcity and very hot summers made reliable storage essential. The main chamber was usually constructed below ground and covered by a thick brick dome, which helped protect the water from direct solar radiation and reduce evaporation. These cisterns were generally supplied by qanats, canals, and in some cases rainwater, allowing communities to store water throughout the year.

Architecturally, ab-anbars included several climate-responsive features. Access was usually provided by a long staircase leading down toward the storage level, while many examples were also equipped with windcatchers to improve ventilation and help cooling the stored water. Materials such as brick and waterproof Sarooj mortar*[a] were commonly used because of their durability and resistance to moisture. Their underground position, thick construction, and natural ventilation made ab-anbars an effective response to both water scarcity and extreme heat in Iran's desert regions.

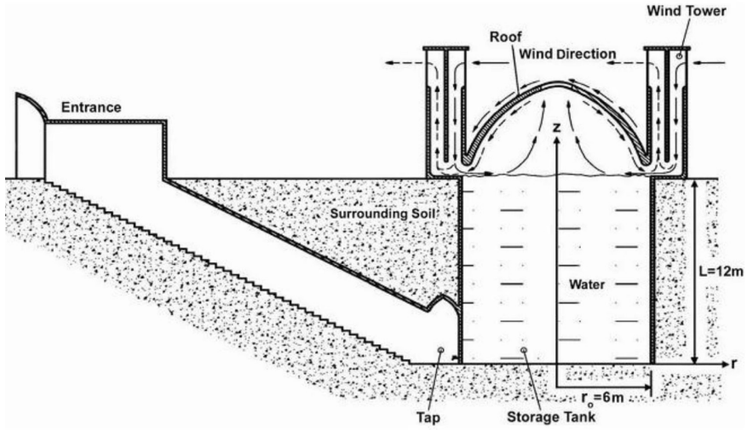


Figure 4. Vertical section illustrating ab-anbar architectural components. Source: Shiri, Didehban & Taban (2022).

*[a] Sarooj mortar: A highly durable, water-impermeable traditional mortar made of lime, clay, sand, egg whites, goat hair, and ashes

Ice-pits (Yakhchal): Ice Production and Storage in the Desert

The yakhchal was a large earthen infrastructure developed to produce and store ice in hot desert climates. During winter, ice was produced and stored inside the underground chamber for the warmer months. For this reason, the yakhchal was not only a technical solution for cooling, but also an important public infrastructure that helped communities manage seasonal scarcity. As discussed in recent studies, this type of vernacular architecture shows how resilience was closely connected to local materials, construction knowledge, and community practices [8].

Earthen construction played an important role in the performance of these infrastructures. Thick adobe walls helped reduce rapid temperature changes by absorbing heat during the day and releasing it more slowly later. Their thermal mass, together with the form of dome, contributed to more stable internal temperatures. From a conservation point of view, this also means that interventions should respect the original behaviour of the material, especially its breathability and compatibility with the surrounding earthen fabric [7].

The value of yakhchals is also connected to the communities that used and maintained them. Research on adobe heritage in Yazd shows that earthen infrastructures are vulnerable to environmental damage, seismic risk, and lack of maintenance, but local knowledge and regular care can play an important role in their protection [5]. In the same way, community involvement is increasingly recognized as an important part of heritage conservation [10]. For this reason, the yakhchal can be understood not only as a passive cooling infrastructure, but also as a form of heritage where material conservation, environmental performance, and community involvement are closely connected.

Comparison between yakhchals and ab-anbars

Yakhchals were traditional infrastructures designed to produce and store ice during winter for use in the summer. They usually included a deep underground pit covered by a large conical adobe dome, together with shallow freezing pools and long shading walls that helped water freeze during cold winter nights. Ab-anbars, on the other hand, were underground water cisterns used to store drinking water throughout the year. Even though they were also built below ground and often covered with domes, their main purpose was different. Instead of producing ice, they protected stored water from heat, reduced evaporation, and helped to preserve its quality.

The two infrastructures also worked differently from an environmental point of view. Yakhchals relied mainly on thermal mass, night-time freezing, shading, and the stable temperature of the underground space to produce and preserve ice. Ab-anbars often included windcatchers to ventilate the interior and help cool the stored water through natural airflow. Both infrastructures used local materials such as adobe and Sarooj mortar and were often connected to qanat systems. However, yakhchals were mainly seasonal infrastructures for ice production and storage, while ab-anbars provided long-term water storage for the community.

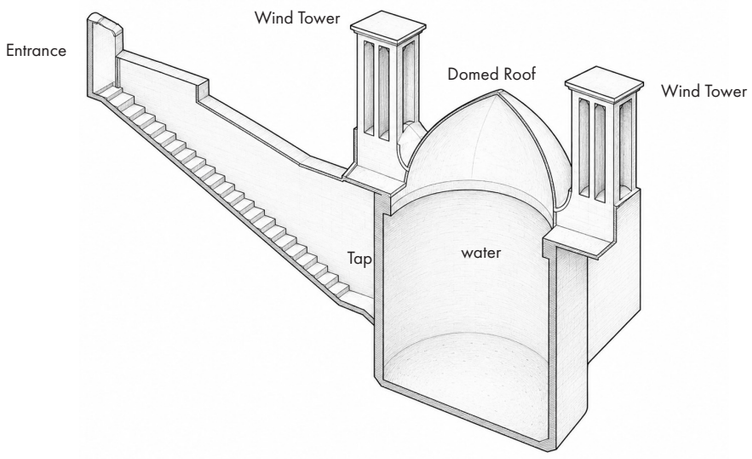


Figure 5. Section-Perspective of ab-anbar
By Author.

Figure 6. Yakhchal-e Heg" (Icehouse of Heg)
By Author, dated 13 April 2025

1.2 RESEARCH QUESTIONS

Although Iran has a rich body of vernacular infrastructures developed for arid climates, yakhchals have received relatively limited academic attention compared with other systems such as qanats or windcatchers. Existing studies [11] have mainly focused on the historical process of natural ice-making and the architectural form of these structures. However, less attention has been given to their current conservation problems, thermal performance, and potential for adaptive reuse.

Today, many yakhchals face environmental damage and long-term neglect. Rising temperatures, desertification, changes in land use, and the loss of their original function have all contributed to the deterioration of their earthen fabric. At the same time, recent conservation approaches emphasize the importance of sustainable and compatible interventions in earthen heritage [7], as well as the need to involve local communities in the future of historic places [10]. These approaches, however, have not yet been widely applied to yakhchals.

At the same time, people who spend long hours outdoors in hot-arid regions, especially construction workers and other outdoor workers, are increasingly exposed to extreme summer heat. In many cases, there are few public spaces where people can rest in a cooler environment or organize cultural activities. This creates an interesting connection between two current issues: the need to conserve abandoned yakhchals and the need for more climate-responsive public cultural spaces.

For this reason, the thesis investigates whether the original environmental qualities of the yakhchal can support a new function today. Its thick adobe walls, underground spaces, limited openings, and large thermal mass were originally designed to keep ice cold for long periods. The main question is whether these same characteristics can now contribute to a cultural and cooling function for the local community.

The main research question is:

How can the thermal inertia, earth-sheltering characteristics, and social value of yakhchals in Abarkuh be reactivated through conservation, environmental performance assessment, and community involvement to support their adaptive reuse as cultural cooling infrastructures in a warming hot-arid climate?

The research considers conservation and adaptive reuse as closely connected processes. The aim is to preserve the physical structure of the yakhchal, and explore how it can gain a new social and environmental role without losing its material and cultural value.

Previous studies on Iranian ice houses have mostly focused on historical description, psychrometric analysis, or simplified interpretations of their underground thermal behaviour. In this thesis, the environmental performance of the yakhchal is studied through a more detailed performance-based approach. The methodology is partly inspired by the work of Stasi, Ruggiero, and Berardi on natural ventilation and passive cooling in hot-arid low-income housing. Their approach combines climate analysis, building-energy modelling, and adaptive comfort assessment to evaluate how architectural form can improve indoor conditions without depending on mechanical cooling.

The main research question is supported by the following sub-questions, which also follow the structure of the thesis:

RQ1. How did Iranian vernacular infrastructures, especially yakhchals, respond to the environmental challenges of hot-arid climates?

RQ2. What are the main typological, material, construction, and climatic characteristics of the yakhchals of Abarkuh?

RQ3. How have environmental exposure, urban expansion, and abandonment affected the current conservation condition of the yakhchals of Abarkuh?

RQ4. How can thermal inertia of the massive adobe envelope and the earth-sheltered configuration of the yakhchals reduce, delay, and stabilize indoor operative temperatures during hot periods?

RQ5. Under which natural ventilation and operational conditions can the yakhchal provide acceptable thermal comfort for temporary public use?

RQ6. How can local residents, workers, heritage experts, and tourism actors participate in the conservation, management, and future reuse of the yakhchal?

RQ7. How can conservation assessment, environmental analysis, and community involvement be translated into an adaptive reuse proposal for a cultural cooling hub?

1.3 METHODOLOGY AND RESEARCH FRAMEWORK

This research combines historical study, conservation analysis, thermal simulation, and community participation to evaluate the possibility of adapting Abarkuh's yakhchals as climate-responsive cultural cooling spaces. The methodology is organized into five connected phases, moving from understanding the historical and physical characteristics of the yakhchal to testing its environmental performance and finally developing the adaptive reuse proposal.

Phase 1 - Contextual and Typological Analysis

The first phase focuses on understanding the historical, architectural, and environmental background of Iranian yakhchals. A literature review was conducted on vernacular cooling systems in Iran, traditional ice-making methods, and the typological, material, and climatic characteristics of yakhchals, with particular attention to the examples in Abarkuh [11].

The research also considers principles for the conservation of earthen architecture [7] and participatory approaches to heritage management [10]. In addition, bioclimatic strategies identified in traditional earthen architecture [13] and guidelines for earth-sheltered buildings in hot-arid climates [14] are used to better understand the environmental behaviour of the yakhchal.

Phase 2 - Analysis of the State of Conservation

The second phase is based on fieldwork carried out in Abarkuh, with a more detailed investigation of Yakhchal-e-Barzan. The purpose of this phase is to document the current physical condition of the structure and identify the main conservation problems that could affect its future reuse.

The analysis includes:

photographic documentation of the exterior and accessible interior spaces;
mapping of deterioration affecting adobe, sarooj, and other building elements;
identification of cracks, erosion, material loss, damaged openings, and other conservation issues;
assessment of the main risks and priorities for intervention.

Phase 3 – Participatory Heritage Conservation Research

The third phase investigates the relationship between the yakhchal and the local community. Since the proposed reuse is intended to serve local people as well as visitors, it was important to understand how different stakeholders perceive the yakhchal, what they expect from its future use, and how they could participate in its conservation and management.

Semi-structured interviews were carried out with local actors, including a traditional construction worker, a cultural heritage expert, a tourism manager, and a local custodian. The interviews focused on local knowledge, conservation needs, possible adaptive uses, heat-related challenges, responsibilities for maintenance, and willingness to participate in future activities.

Based on participatory heritage principles [10], the research also develops a possible management framework that connects local custodianship, municipal support, and professional heritage expertise. The aim is to avoid treating community participation only as voluntary labour and instead consider local people as part of the decision-making and long-term management process.

Phase 4 – Bioclimatic and Thermal Assessment

In the fourth phase, the thermal behaviour of Yakhchal-e-Barzan is evaluated by climate analysis, dynamic thermal simulation, and adaptive comfort assessment.

First, the climatic conditions of Abarkuh are analyzed using the local EPW weather file, including temperature, solar radiation, humidity, wind, and ground-temperature data. The thermal model of the yakhchal is then developed using the thermophysical properties of adobe and sarooj.

Dynamic thermal simulations are used to study indoor temperature stability and the effect of the massive earthen envelope, underground pit, and natural ventilation. Different opening conditions are compared in order to understand how the operation of the lower doors influences the indoor environment.

The simulated indoor operative temperatures are also considered in relation to the adaptive comfort model [16]. The purpose is not to demonstrate conventional air-conditioned comfort, but to evaluate whether the yakhchal can provide a more thermally moderated environment for temporary public use.

Phase 5 – Conservation-Led Adaptive Reuse Proposal

The final phase brings together the results of the conservation analysis, thermal simulations, and community interviews in the design proposal titled “Sheltered by the Earth.”

The proposal reinterprets Yakhchal-e-Barzan as a cultural cooling hub while trying to maintain the character and material integrity of the historic structure. The main design priorities are:

- improving passive thermal conditions without relying on mechanical cooling;
- using minimal and compatible interventions;
- compatibility of the intervention;
- providing safe access and spaces for community and cultural activities;
- considering the needs of users who are more exposed to extreme summer heat.

The proposal is considered through three main aspects: environmental performance, conservation compatibility, and social use. Environmental performance is related to the thermal behaviour of the space; conservation compatibility concerns the protection of the existing materials and structure; and the social aspect considers community involvement, accessibility, and possible long-term management.

By connecting these five phases, the methodology allows the yakhchal to be studied not only as a historic monument, but also as an environmental and social infrastructure. The research therefore combines conservation, building-performance analysis, and community participation to explore whether this traditional structure can take on a new role under present climatic conditions.



Figure 7. Abarkuh city center.

By Author, dated 13 April 2025.

02
CONTEXT AND ANALYSIS



Figure 8: Historic photograph of a yakhchal near Ashgabat, present-day Turkmenistan, c. 1910.

Source: Lead Adventure Forum, secondary online reproduction; original photographer and date unknown.

2.1 YAKHCHALS IN IRAN

The design of yakhchals was closely related to the climatic conditions of Iran's hot-arid plateau, where cold was a limited seasonal resource. Unlike other vernacular infrastructures that mainly improved daily thermal comfort, yakhchals were designed to use the cold conditions of winter to produce and store ice for the warmer months. Their form and operation show how local builders responded to climate by combining landscape, materials, and simple environmental principles.

Ice-making and Storage

The operation of a yakhchal followed two main stages. During winter, water from qanats or seasonal streams was directed into shallow freezing pools located beside tall east-west shading walls. These walls reduced direct solar radiation during the day, while the open pools remained exposed to the cold night sky. This helped thin layers of ice to form during winter nights [11]. The ice was then collected, broken into smaller pieces or blocks, and transferred into the underground storage pit. The pit was commonly lined with sarooj, a traditional water-resistant mortar made from materials such as lime, ash, clay, and organic fibres, which helped protect the storage area from water infiltration [18].

Above the underground pit, the yakhchal was covered by a large conical adobe dome, which in some examples reached more than ten metres in height. The thick earthen walls reduced rapid heat transfer and helped keep the interior temperature more stable during hot periods. The conical form also limited direct solar exposure on parts of the surface during the day. In addition, layers of straw or reeds were sometimes placed between the stored ice to provide extra insulation and to make it easier to separate the ice during summer use [19].

YAKHCHAL DISTRIBUTION IN IRAN

CITY-LEVEL LOCATIONS



PROVINCE KEY

1 Alborz
2 Ardabil
3 Bushehr
4 Chahar Mahal & Bakhtiari
5 East Azerbaijan
6 Fars
7 Gilan
8 Golestan
9 Hamadan
10 Hormozgan
11 Ilam
12 Isfahan
13 Kerman
14 Kermanshah
15 Khuzestan
16 Kohgiluyeh & Boyer-Ahmad
17 Kurdistan
18 Lorestan
19 Markazi
20 Mazandaran
21 North Khorasan
22 Qazvin
23 Qom
24 Razavi Khorasan
25 Semnan
26 Sistan & Baluchestan
27 South Khorasan
28 Tehran
29 West Azerbaijan
30 Yazd
31 Zanjan

YAKHCHAL KEY

• ONE RECORD

SAME CITY

57 RECORDS · 34 CITIES

0 250 500 km

Field studies identify four main types of yakhchals across Iran. The first is the domed type, found in places such as Yazd, Meybod, and Abarkuh, where a deep underground ice-storage pit is covered by a large adobe dome. The second is the underground type, more common in Kerman and Kashan, where the storage space is almost entirely below ground and covered by barrel vaults or ribbed roofs. The third is the open-pit type, recorded in parts of Isfahan, where ice was preserved in exposed pits using layers of straw and soil. The fourth type includes yakhchals without shading walls, often built in pairs or groups next to each other, especially in the northeast of Iran [18].

These different types show that yakhchals were not built according to one fixed model. Their form and operation changed according to local conditions such as water availability, topography, climate, and local practices.

Contemporary Relevance

Although yakhchals lost their original function after the spread of industrial refrigeration in the twentieth century, many surviving examples still have an important value today. Recent studies discuss them as references for low-energy cooling because of their use of thick earthen mass, underground spaces, and climatic orientation [8]. Their conservation, however, should respect the environmental behaviour of the original materials and construction methods [7], while also considering the role of local communities in their future use and maintenance [10]. Examples in Abarkuh, Meybod, and Yazd show that these infrastructures are both fragile and adaptable, and that they can still be part of contemporary cultural and heritage activities.

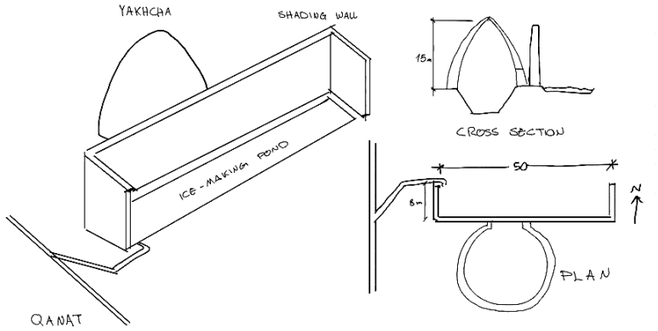


Figure 9. Sketches of the Iranian yakhchal. By Author.
Based on Pochee, H., & Gunstone, J. (2018, March 27). Max Fordham LLP Journal / Practice People.

The different forms of shading walls also show how the ice-making system was adapted to local needs. One configuration uses several parallel walls to create a number of narrow freezing basins, increasing the amount of water that could be frozen. Another combines a long main wall with projecting elements and a perpendicular end wall, which helped extend the shaded area and protect the basin from direct sun and wind. A third, more compact configuration uses a main wall with shorter return walls, creating a smaller protected freezing area. Although their forms are different, all three configurations follow the same basic principle: reducing solar exposure during the day while keeping the water exposed to the cold night sky to support radiative cooling and ice formation.

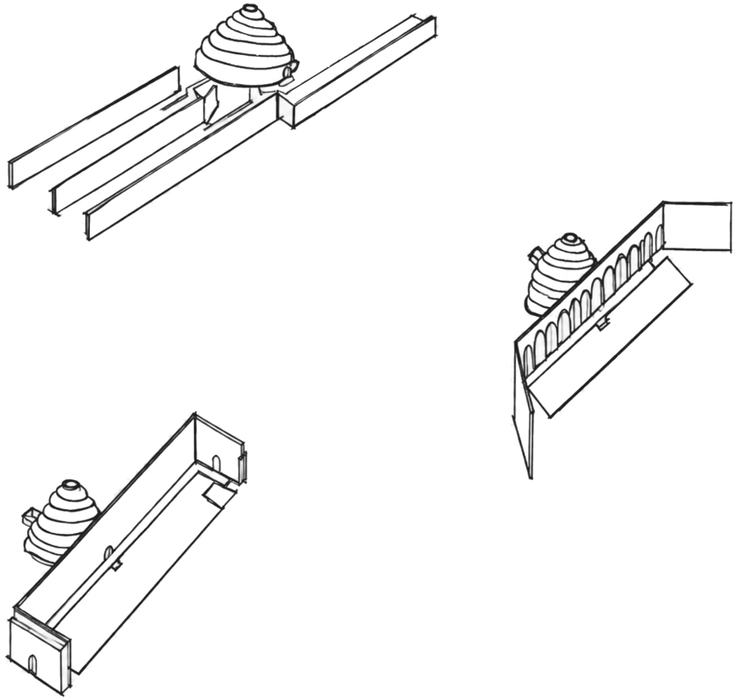


Figure 10. Three domed Yakhchals with different types of Shading walls in Yazd province
By Author

2.2 HISTORICAL FRAMEWORK OF IRANIAN YAKHCHALS

The yakhchal, whose name comes from the Persian words “yakh” meaning “ice” and “chal” meaning “pit,” is one of the most typical vernacular infrastructures of Iran. It was designed to produce and preserve ice in desert regions where summer temperatures could rise above 40°C. Examples can be found in provinces such as Yazd, Kerman, Isfahan, and Fars. Their design shows how local builders combined climatic knowledge, water management, and earthen construction in response to harsh environmental conditions.

Yakhchals were part of a wider technical and cultural system that included night-time radiative cooling, qanat-fed freezing basins, and underground ice-storage spaces. Their use became especially widespread from the Safavid to the Qajar periods, when ice had an important role in everyday life and public use. Earthen heritage reflects a long process of adaptation to climatic and social conditions [8], and yakhchals are a clear example of this relationship between material, climate, and local practice.

Yakhchals were also public infrastructures, often supported through waqf* [b] endowments or communal investment. The stored ice was used during summer in households, public gatherings, and medical practices. Its production, storage, and distribution also depended on cooperation between local communities and guilds. For this reason, the yakhchal was connected to cooling, as well as shared resource management and community life.



Figure 11. Ice-house in Qom (1703). Travel illustration by Krenlin Bervin, depicting a stepped conical dome and shading wall of a traditional yakhchal.

Source: Bahadorinejad, M., & Dehghani, A. (2005). [Traditional and Natural Ice-Making in Iran]. Tehran: Cultural Heritage Organization. p, 151

*[b] Waqf: an Islamic charitable endowment through which property or income was permanently dedi-



Figure 12. A Safavid-period icehouse and caravanserai, drawing by Jules Laurens.

Source: Iranian Cultural Heritage Organization. (2000, July). National heritage registration notification for Agha Yakhchal, Abarkuh [Unpublished archival document]. Library and Archives of the Iranian Cultural Heritage Organization, Tehran, Iran.

The yakhchal, from the Persian words *yakh* meaning “ice” and *chal* meaning “pit,” is one of the traditional vernacular infrastructures found in Iran. It was developed to produce and preserve ice in desert regions where summer temperatures could rise above 40°C. Examples can be found in provinces such as Yazd, Kerman, Isfahan, and Fars. Their design shows how local builders used climatic knowledge, water management, and earthen construction together to respond to difficult environmental conditions.

Yakhchals were part of a larger technical and cultural system that included night-time radiative cooling, qanat-fed freezing basins, and underground ice-storage spaces. Their use became more widespread from the Safavid to the Qajar periods, when ice was important for daily life and public use. Earthen heritage reflects a long process of adaptation to both climatic and social conditions [8], and yakhchals are a clear example of this connection between material, climate, and local practice.

Yakhchals were also public infrastructures, often supported through *waqf* [b]* endowments or communal investment. The stored ice was used during summer in households, public gatherings, and for medical purposes. Its production, storage, and distribution also required cooperation between local communities and guilds. For this reason, the yakhchal was not only related to cooling, but also to shared resource management and community life.

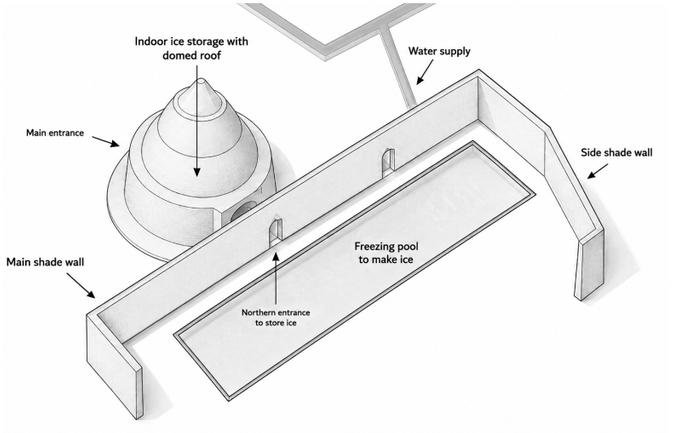


Figure 13. Schematic diagram of a traditional Iranian ice-house (yakhchal), showing the shading walls, freezing pool, and domed storage chamber.
By Author.

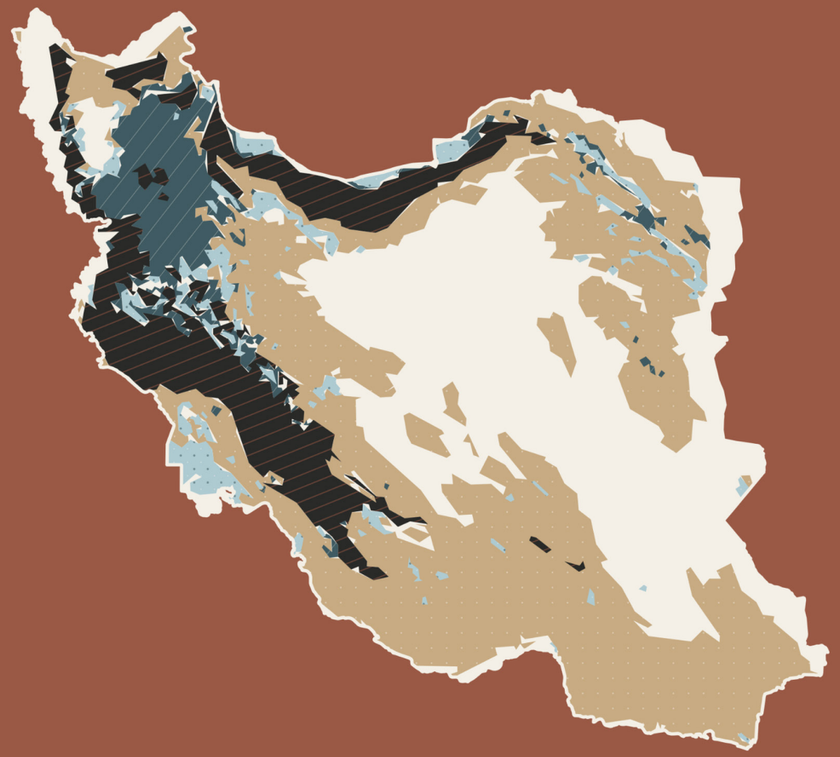
2.3 TERRITORIAL AND CLIMATIC FRAMEWORK OF IRANIAN YAKHCHALS

Iran is mainly characterized by arid and semi-arid landscapes, with around 82% of the country affected by desert or steppe climatic conditions. The central plateau includes large desert areas such as Dasht-e Kavir and Dasht-e Lut, where low rainfall, strong solar radiation, and large day-night temperature differences have influenced the way settlements and buildings developed over time. The Alborz Mountains in the north and the Zagros Mountains in the west also affect the climate by acting as natural barriers, while the more humid and forested areas are mostly concentrated along the Caspian region and parts of the western highlands.

Within this dry territorial context, vernacular infrastructures such as qanats, windcatchers, and yakhchals developed as practical responses to climate and limited natural resources. Their distribution across desert and semi-desert regions shows how closely they were connected to local environmental conditions. Understanding this wider climatic and territorial context is important for explaining the development of yakhchals as climate-responsive earthen infrastructures.

NATURAL SETTINGS OF IRAN

LANDSCAPE REGIONS



N

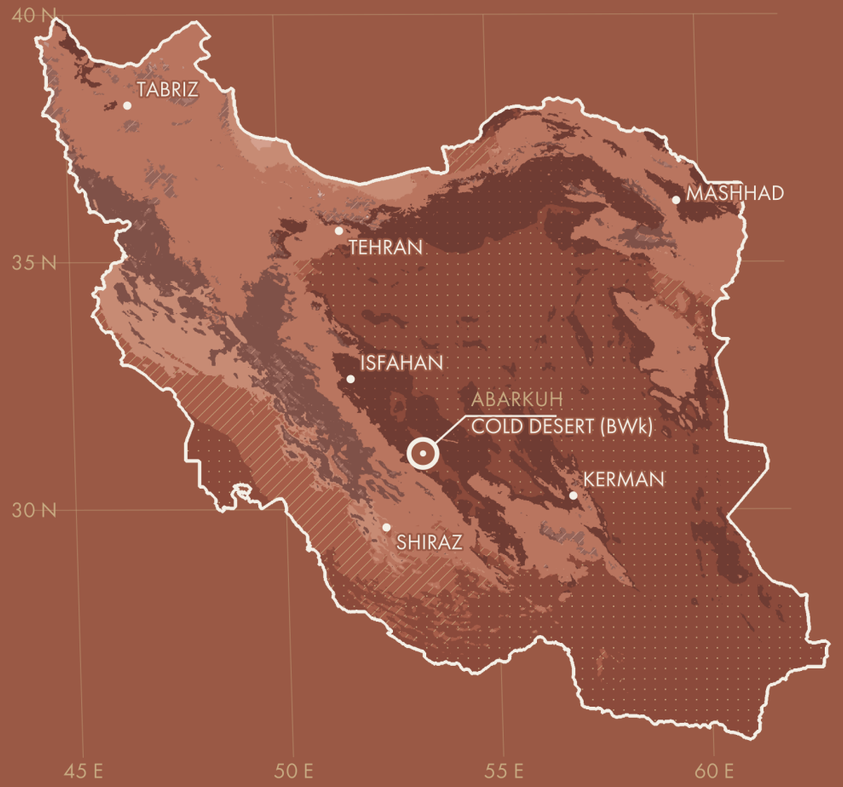
MAP KEY

- Mountains
- Steppe
- Desert
- Dry farming
- Irrigated land

0 250 500 km

CLIMATE REGIONS OF IRAN

KOPPEN-GEIGER CLIMATE CLASSIFICATION



N

CLIMATE REGIONS

- HOT DESERT (BWh)
- COLD DESERT (BWk)
- HOT STEPPE (BSh)
- COLD STEPPE (BSk)
- TEMPERATE, DRY-SUMMER HOT SUMMER (Csa)
- TEMPERATE, NO DRY SEASON HOT SUMMER (Cfa)
- COLD, DRY-SUMMER HOT SUMMER (Dsa)
- COLD, DRY-SUMMER WARM SUMMER (Dsb)
- COLD, DRY-SUMMER COLD SUMMER (Dsc)
- COLD, NO DRY SEASON WARM SUMMER (Dfb)
- POLAR TUNDRA (ET)

ABARKUH CLIMATE

COLD DESERT / BWk

31.13 N / 53.28 E

0 250 500 km

YAZD PROVINCE

IRAN · REGIONAL CONTEXT

N



0 250 500 km

Yazd Province

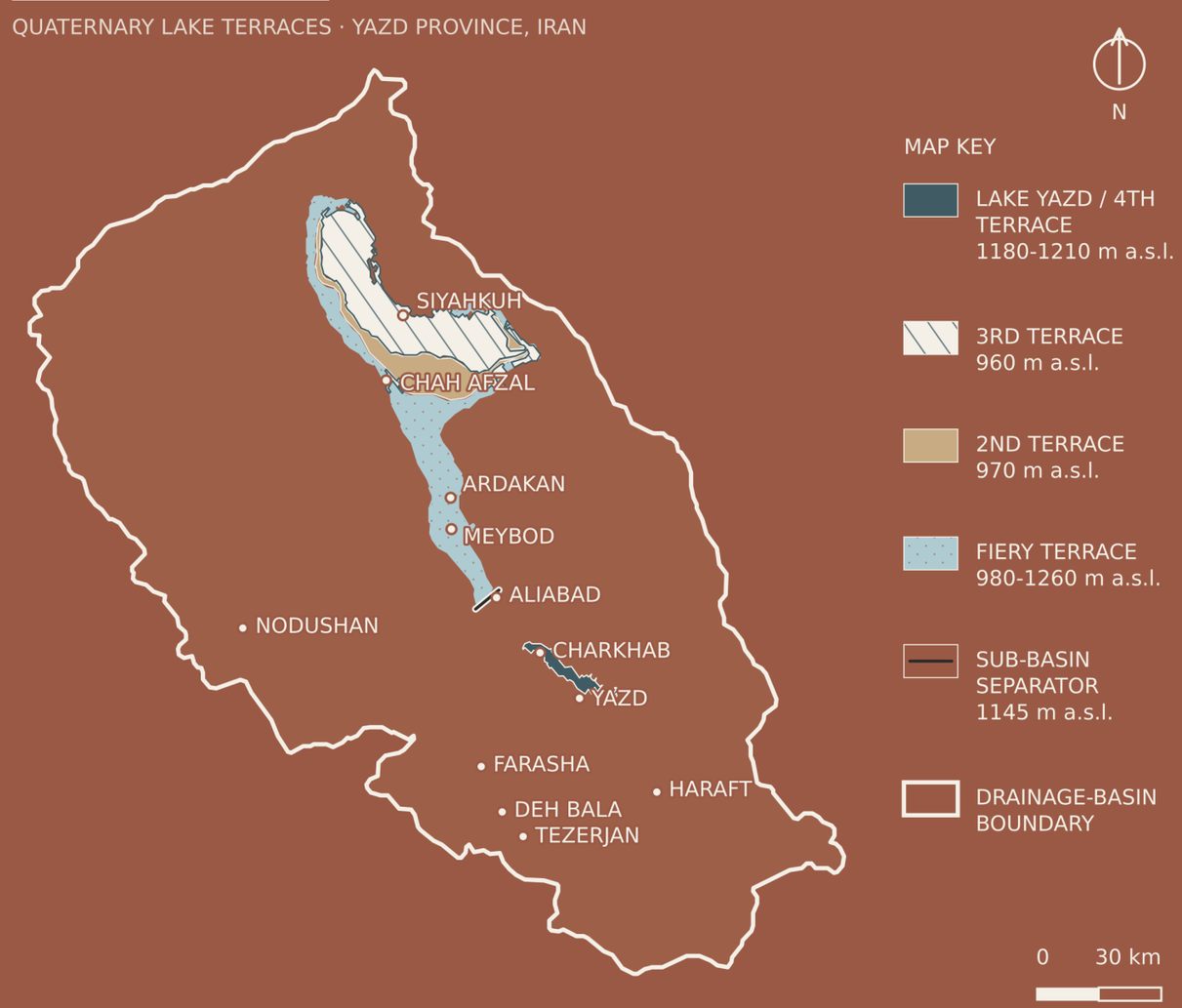
Yazd Province is located between the Lut Desert and the Dasht-e Kavir and has historically been connected to long-distance caravan routes, including branches of the Silk Road. Settlements in this region, especially the city of Yazd, developed as qanat-based oases in response to the extremely dry climate. Adobe buildings, sunken courtyards, narrow shaded spaces, and partially underground rooms became common ways of creating more stable indoor and outdoor conditions. The combination of water-management systems and earthen construction became an important part of the identity of Yazd and is still recognized as a major value of its historic urban landscape.

Within this arid context, vernacular infrastructures such as qanats, windcatchers, ab-anbars, and yakhchals were designed as practical responses to limited water resources and extreme temperatures. Their presence across Yazd Province shows how architecture and infrastructure were connected to climate. This wider territorial context is important for understanding why yakhchals developed in the region and how their form and operation responded to local environmental conditions.

Geomorphology and the “Lake-Made” Territory

Recent geomorphological studies show the development of Yazd within the larger Yazd–Meybod–Siyahkuh drainage basin. During the Quaternary period, different lake phases created a stepped landscape of terraces that later influenced the location and development of settlements. The wider basin covers almost 20,000 km^2 and previously included a lake area of around 7,000 km^2. In this drainage system, the Yazd sub-basin remained partly independent, with former lake levels measured at approximately 1,210 m and 1,180 m above sea level. Traces of these terraces can still be identified around areas such as Rezvanshahr.

Over time, a drying climatic, tectonic activity, sedimentation, and changes in the drainage system gradually separated the Siyahkuh terraces from the Yazd lake system and reduced the remaining lake area. Water-flow modelling also shows that the runoff generally flows in an east–west direction towards the Yazd and Meybod basins. These landforms helped shape the territorial development of the region and provided an important physical base for later settlement and urban growth.



Hydro-Territorial Organization and Qanat Urban System

Within this terraced landscape, qanat networks had an important role in shaping the urban development of Yazd. Historic districts often developed around specific qanats and their related community spaces. The use of thick earthen walls, sunken courtyards, and below-ground rooms was closely connected to this water-based urban system. In this way, water management and thermal comfort became part of the same spatial logic that influenced the formation of neighbourhoods.

Chronology, Toponyms, and Shifting Urban Cores

Historical and archaeological evidence suggests that earlier urban centres, such as Harfteh and Fahraj, were located on terrace areas different from the present qanat-based city of Yazd. This shows that the former lake terraces were not only natural landforms, but also influenced where settlements developed over time. As water supply gradually became more dependent on underground qanat systems, the urban centre also shifted, while the earlier terrace pattern continued to influence the wider territorial form of the region.

2.4 STATE OF CONSERVATION OF IRANIAN YAKHCHALS

Iran historically had a large number of yakhchals, although many have been damaged, destroyed, or remain poorly documented. This section presents an overview of the current conservation condition of documented yakhchals in different provinces of Iran.

The tables include recorded examples from Kerman, Razavi Khorasan, South Khorasan, Yazd, Tehran, Semnan, Isfahan, Markazi, East Azerbaijan, West Azerbaijan, Fars, Qom, and Hamadan, together with their historical periods and present condition. Some yakhchals are still standing and have received restoration or conservation work, such as the examples in Meybod, Jalali, and Moradian. Others are partially damaged, severely deteriorated, or have completely disappeared because of neglect, urban development, natural disasters, or changes in land use. This comparison gives a general picture of the surviving, damaged, and lost examples and shows the need for continued documentation, conservation, and maintenance of this heritage.

Ice-pit Name	City	Historical Period	State of Conservation
Meybod Ice House 1	Meybod	Safavid period	Restored and well preserved 1999–2002
Meybod Ice House 2	Meybod	-	Totally ruined
Aqa Ice House	Abarkuh	Qajar period	The principal conical earthen structure remains standing and previously restored in March 2015 and underground ice-storage chamber survive, while shading walls are partially preserved. Threatened by adjacent construction and reported encroachment on its protected heritage buffer in 2025. Field survey in April 2025 by author revealed partial collapse around the opening at the apex of the dome
Heg Ice House	Abarkuh	Likely Qajar period	Historical structure still exists but partially damaged-Protective restoration began in 2020 by the Cultural Heritage Office of Abarkuh
Barzan Ice House	Abarkuh	Qajar period	Semi-ruined; only parts of the structure remain
Fath Abad Ice House	Abarkuh	Qajar period	Illegal excavations were reported around it in November 2025
Tabas Ice House	Tabas	Qajar period	Many historical structures in Tabas were severely damaged during the 1978 Tabas earthquake

Table 1. Ice Houses in Yazd Province. By Author.
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.
2) Kalantari, M. M. (2025, July 31). Concerning reports on the condition of Abarkuh's historic ice houses [Field video report in Persian]. https://novin-shahrsaz.ir/2025/07/31/

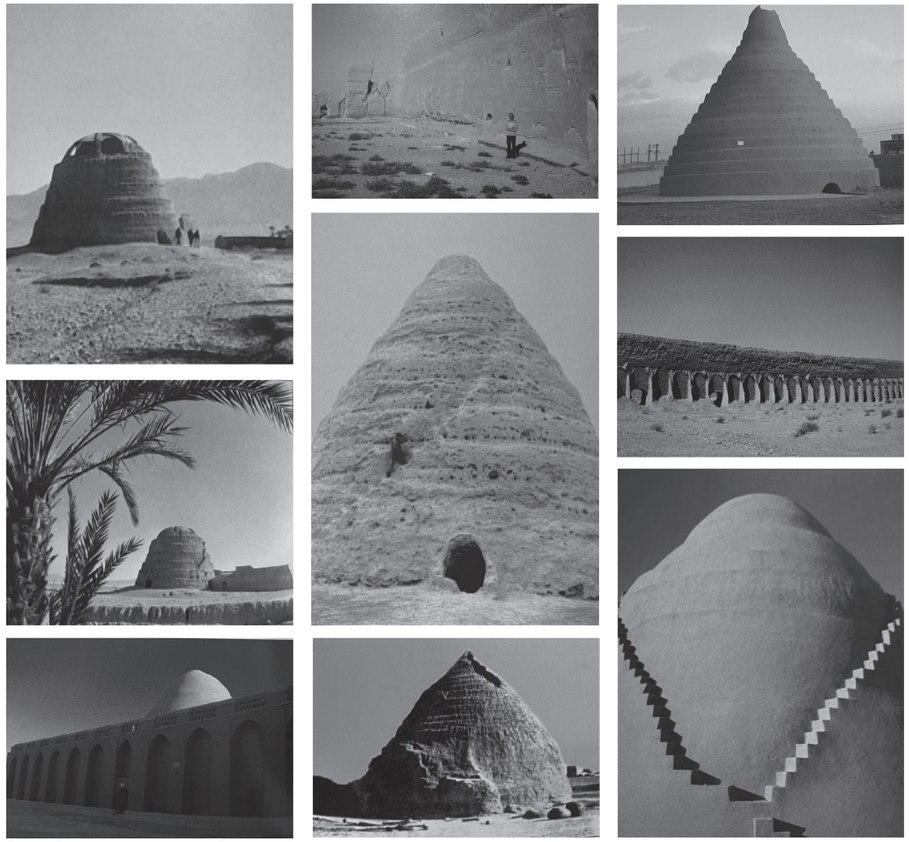


Figure 14. Ice Houses in Yazd Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism

Ice-pit Name	City	Historical Period	State of Conservation
Moayedi Ice House	Kerman	Safavid period*	Structure still standing in central Kerman; used for cultural activities-2022
Rig-Abad Ice House	Kerman	Safavid period	Structure preserved but damaged sections recorded-2018
Zarisf Ice House	Kerman	Qajar period*	Structure still exists. Latest documented restoration work was underway in November 2022 (repair of plaster and damaged parts)
Mahdi Ice House	Kerman	-	-
Haj Agha Ali Ice House	Rafsanjan	Qajar period	still exists
Kabutar Khan Ice House	Rafsanjan	Qajar period	severely deteriorated
Anar Ice House	Rafsanjan	Qajar period	-
Ravar Ice House	Ravar	Qajar period	-
Haj Rashid Ice Houses	Sirjan	Qajar period	still exists. Parts of the walls restored by ICHHTO
Mahmoudabad Ice House	Sirjan	Qajar period	-
Arg-e-Bam Ice House	Bam	Qajar period	-
Langar Ice House	Mahan	-	still exists

Table 2. Ice Houses in Kerman Province. By Author.
Sources: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.(ICHHTO) 2) Islamic Republic News Agency. (2018, December 19) https://www.irna.ir/news/83140200/ 3) Heritage Aria News Agency. (2022, January 15). Emergency restoration of the Zarisf Yakhch I in Kerman to begin within two weeks https://www.chn.ir/news/1400102545914 5/

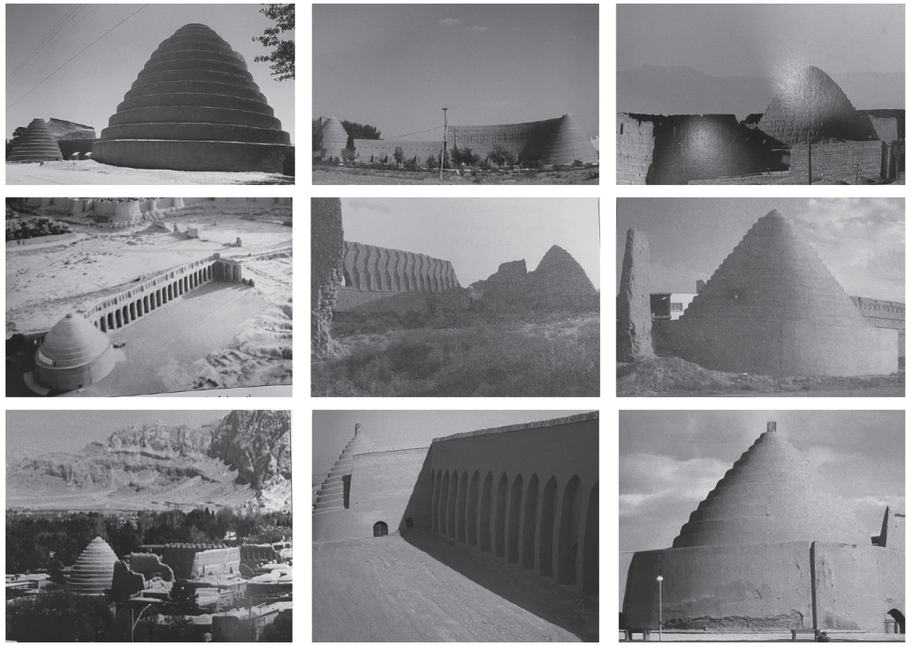


Figure 15. Ice Houses in Kerman Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism

Ice-pit Name	City	Historical Period	State of Conservation
Abbasabad Ice House	Shahroud	Safavid period	-
Bastam Ice House	Shahroud	Qajar period	-
Dowlatabad Ice House	Shahroud	Qajar period	-
Dehnamak Ice House	Garmsar	Safavid period	Structure still exists near the historic Dehnamak caravanserai; remains of two mud-brick ice houses visible
Qatoul Ice House	Garmsar	Qajar period	Structure exists; Restoration project started October 2021 by Cultural Heritage of Semnan
Kordvan Ice House	Garmsar	Qajar period	-

Table 3. Ice Houses in Semnan Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.

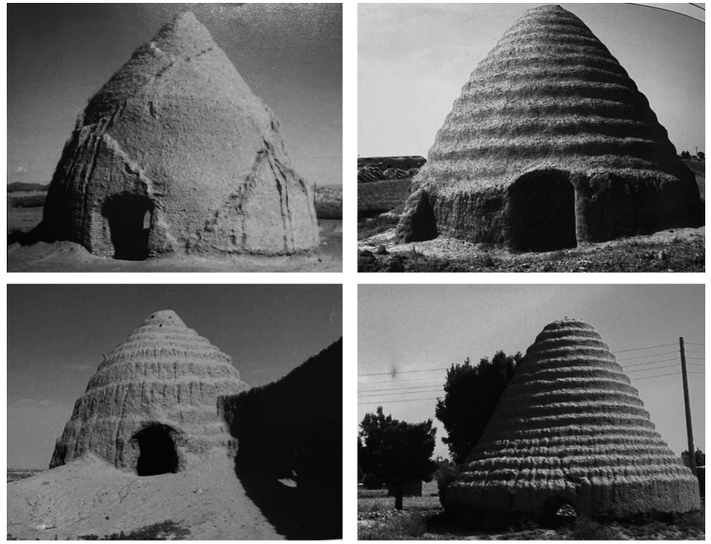


Figure 16. Ice Houses in Semnan Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.

Ice-pit Name	City	Historical Period	State of Conservation
Jalali Ice Houses	Kashan	Safavid period	Structure still exists next to the Jalali Fortress; part of a historical complex with city walls. Restoration of the ice house reported 2012; repairs included roof and wall restoration
Zavareh Ice House	Ardestan	Qajar period	-
Mahabad Ice House	Ardestan	-	-
Twin Ice House (Do-Qolu)	Khor & Naeen	Safavid period	-
Jushqan Ice House	Jushqan		

Table 4. Ice Houses in Isfahan Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.



Figure 17. Ice Houses in Isfahan Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism

Ice-pit Name	City	Historical Period	State of Conservation
Moradian Ice House	Maragheh	Qajar period	Structure still exists but has suffered deterioration due to improper use and lack of maintenance. Restoration carried out 2008 by the Cultural Heritage Organization; previously rehabilitated and reused as a traditional restaurant

Table 5. Ice Houses in East Azerbaijan Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.

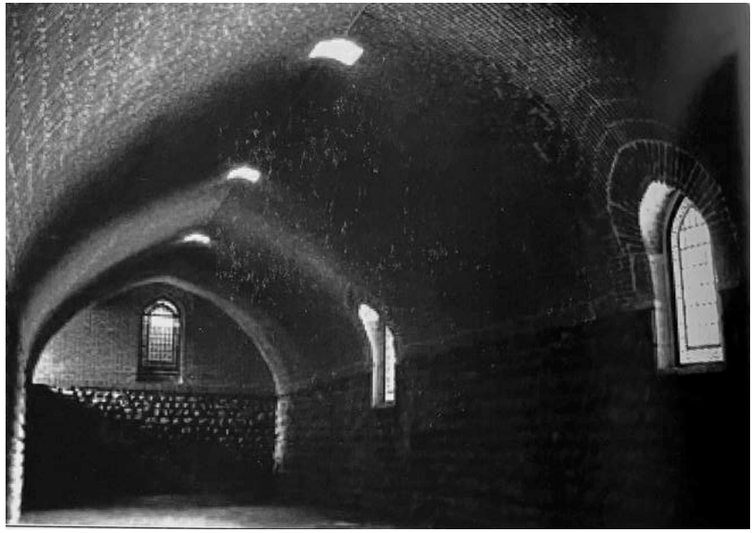


Figure 18. Ice Houses in East Azerbaijan Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.

Ice-pit Name	City	Historical Period	State of Conservation
Nine-Step Ice House (Noh-Peleh)	Urmia	Qajar period	Structure still exists in the Asgar-Khan district of Urmia but reported to be neglected and deteriorating. Registered as a national monument 2001
Churs Ice House	Khoy	Safavid period	-
Olghe-Beik Ice House	Takab	Qajar period	-

Table 6. Ice Houses in West Azerbaijan Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.



Figure 19. Ice Houses in West Azerbaijan Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism
Organization.

Ice-pit Name	City	Historical Period	State of Conservation
Mahdiabad Ice House	Saveh	Qajar period	Structure still exists near Khorshidabad village. Restoration project began May 2021
Nimvar Ice House	Mahallat	Qajar period	Structure still standing but no longer in use; dome shows weathering and erosion. Registered as National Heritage 19 March 2007

Table 7. Ice Houses in Markazi Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.

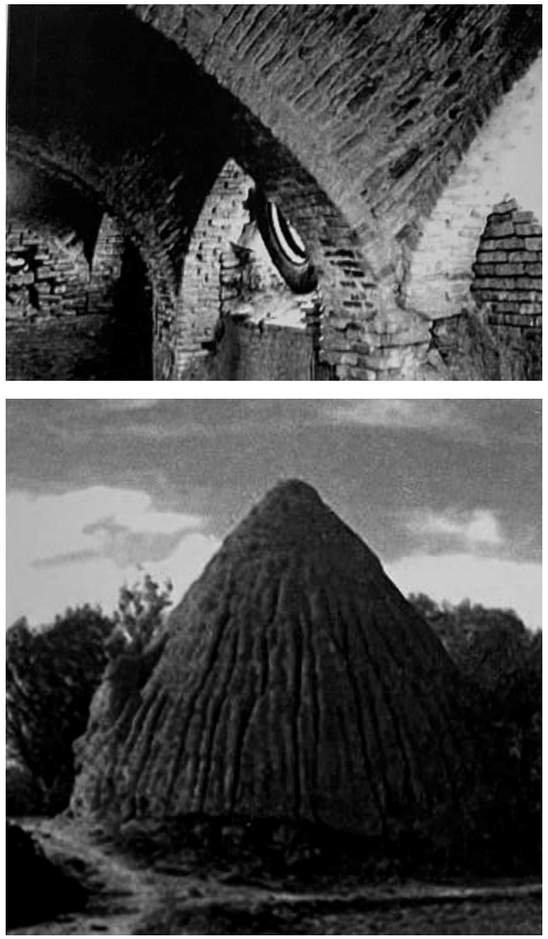


Figure 20. Ice Houses in Markazi Province
Source: 1)Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism
Organization.

Ice-pit Name	City	Historical Period	State of Conservation
Triple Ice Houses (Se-Qolu)	Sabzevar	Qajar period	Three adjacent historic ice houses still exist along the southern belt road of Sabzevar; part of a larger group of historical ice pits. Emergency restoration began 2023 and one of the ice houses was restored Feb 2024
Mazinan Ice House	Sabzevar	-	-
Zafranieh Village Ice House	Sabzevar	-	-
Kowsar-e Bidokht Ice House	Gonabad	Qajar period	-
Ardoghsh Ice House	Neyshabur	Qajar period	-
Dowlatabad Ice House	Neyshabur	Qajar period	-
Khaf Ice House	Khaf	Qajar period	-
Namadmalha Ice House	Quchan	Qajar period	-
Kashmar Ice House	Kashmar	-	-

Table 8. Ice Houses in Razavi Khorasan Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.

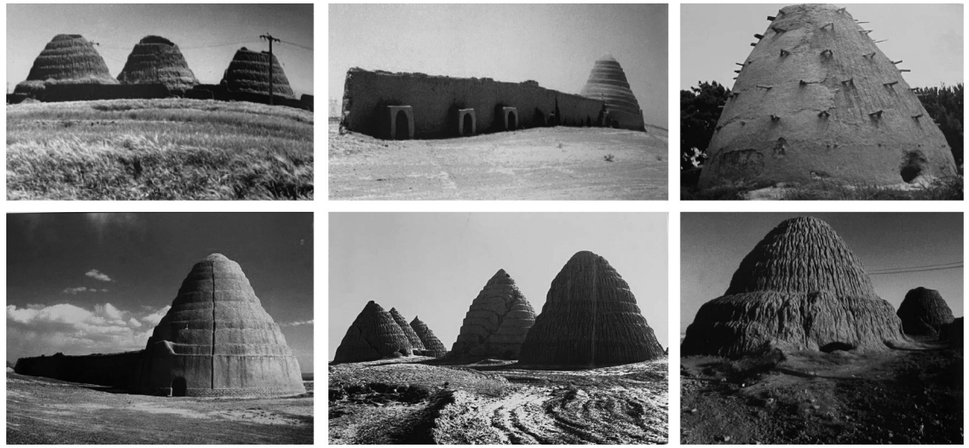


Figure 21. Ice Houses in Razavi Khorasan Province
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian].

Ice-pit Name	City	Historical Period	State of Conservation
Rahimabad Ice House	Birjand	Qajar period	The protective buffer was approved in 2016, and the documented urban rehabilitation project was completed in March 2021.
Shokatabad Ice House	Birjand	Qajar period	-
Kalateh Nayeb Ice Houses	Birjand	Qajar period	-
Bahlgerd Ice House	Birjand	-	-
Kashmar Ice House	Kashmar	-	-

Table 9. Ice Houses in South Khorasan Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.



Figure 22. Ice Houses in South Khorasan Province
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran

Ice-pit Name	City	Historical Period	State of Conservation
Khalili Ice House	Tehran	Qajar period	Completely destroyed; the structure no longer exists
Kan Ice House	Tehran	-	-
Torsh Anbeh Ice House	Eslamshahr	Qajar period	-
Aliabad Ice House	Eslamshahr	Qajar period	-
Rey Ice House	Rey-Kelin	-	-

Table 10. Ice Houses in Alborz Province
By Author.
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian]. Tehran: Iranian Cultural Heritage, Handicrafts and Tourism Organization.



Table 23. Ice Houses in Alborz Province
Source: Bahadori-Nejad, M., & Dehghani, A. (2005). Natural and Traditional Ice-Making in Iran [In Persian].

03
CASE STUDY: ABARKUH YAKHCHAL-E-BARZAN



Figure 24: Yakhchal-e Heg" (Icehouse of Heg)
By Author, dated 13 April 2025

3.1 HISTORICAL AND TERRITORIAL FRAMEWORK OF ABARKUH

The history of Abarkuh goes back to the Islamic period, though its exact foundation date is unknown. Medieval sources preserve traditions connecting the settlement with the legendary Kayanian period, but these accounts cannot be understood as archaeological evidence. In medieval geographical sources, Abarkuh was generally associated with the region of Estakhr and Fars, while other accounts placed it close to the frontier between Fars and Isfahan. This suggests that the city historically occupied an intermediate territorial position and did not always belong to the administrative geography of Yazd as it does today.

The importance of Abarkuh was strongly connected to regional mobility and trade. Routes from Shiraz toward Yazd, Isfahan, and Nishapur passed through the city, and during the Mongol period it was located on a major caravan route extending from the Persian Gulf toward the Black Sea. Medieval descriptions present Abarkuh as a developing settlement with cultivated land, running water, a mosque, and extensive qanat systems. Agriculture included grain, fruit, and cotton, while cotton textiles were also produced and exported. These accounts show how closely the development of the settlement was connected to water infrastructure, agriculture, and regional commerce. The name of the city may also reflect a change in its location. Hamdallah Mustawfi and later authors explain Bar-kuh or Abarkuh as referring to a settlement originally located near or on a mountain and later transferred to the plain.

The city became more politically important during the Kakuyid and Seljuk periods. In 1051 CE, after Tughril Beg took Isfahan, the Kakuyid ruler Faramarz was given Yazd and Abarkuh. The Gonbad-e Ali, built in1056–1057 CE, survives from this period and is one of the oldest monuments of the city. Abarkuh continued to be important during the Ilkhanid and Muzaffarid periods. Around 1340 CE, Hamdallah Mustawfi described it as a small but prosperous town with crafts, grain and cotton production supported by both surface water and qanats, and recorded a fiscal revenue of 140,400 dinars together with its dependencies. At the same time, the city also experienced periods of conflict and destruction. In 1351 CE it was plundered and partly destroyed during conflicts involving Malik Ashraf and Yaghi-Basti. It later passed under Muzaffarid, Timurid, Safavid, and subsequent rule.





1963: Oasis-Based Territorial Structure

In the 1963 aerial photographs, Abarkuh appears as a compact oasis settlement surrounded by agricultural land. One of the clearest features is a linear sequence of circular marks across the landscape, corresponding to the shafts of an underground qanat. Their regular spacing makes the route of the qanat visible and shows how groundwater was carried from the surrounding foothills toward the fields and the settlement.

The qanat network had an important role in organizing the territory. Agricultural plots, vegetation, and access paths developed in close relation to the water system, showing that water management strongly influenced the spatial form of the oasis. The 1963 landscape therefore shows a close connection between settlement, agriculture, and traditional hydraulic infrastructure.



Figure 25. Aerial photograph of the agricultural landscape and ice-making structures associated with the yakhchal system, 1963.

Source: Archive of the Central Library, Research Institute of Cultural Heritage and Tourism, Tehran.

1994: Transitional Landscape

By 1994, the aerial photographs show the beginning of a transition in the territorial form of Abarkuh. The road network had become more developed, and new residential areas were starting to appear around the edges of the historic settlement. These changes indicate the early stages of urban expansion beyond the compact oasis-based core.

Agricultural land was still an important part of the surrounding landscape, but some areas had been gradually converted to residential and infrastructural uses, showing the beginning of peri-urban development. Compared with 1963, the relationship between the settlement, agricultural land, and traditional water infrastructure had started to change as the urban area expanded.

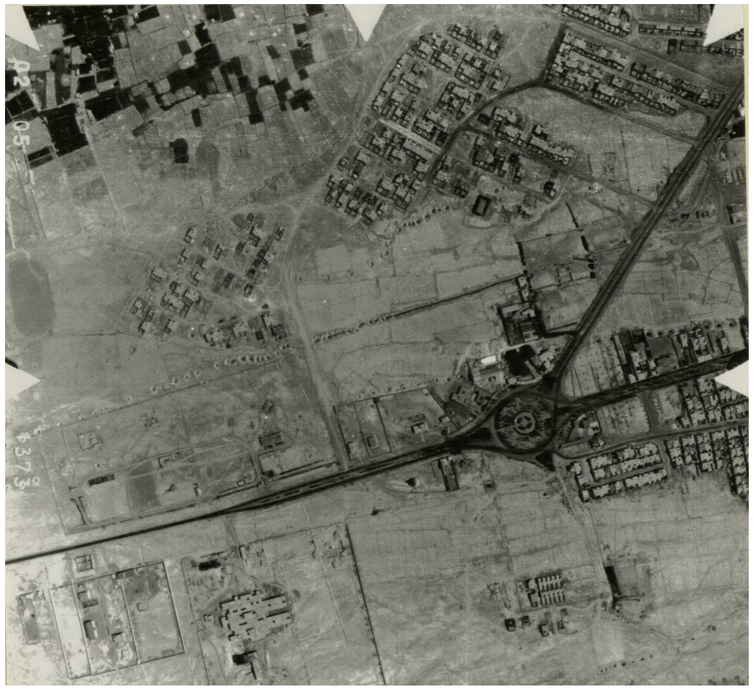


Figure 26. Aerial photograph of the agricultural landscape and ice-making structures associated with the yakhchal system, 1994.

Source: Archive of the Central Library, Research Institute of Cultural Heritage and Tourism, Tehran.

Today: Urban Expansion and Spatial Reconfiguration

The recent satellite image shows that Abarkuh has expanded significantly beyond its earlier compact form. Large areas that were previously used for agriculture have been converted to residential neighbourhoods with more regular street patterns. Wider roads, roundabouts, and new infrastructure now organize much of the contemporary urban area.

Even with this expansion, some historic infrastructures, including the yakhchals, are still visible within the modern city. Their presence creates a direct connection between the current urban landscape and Abarkuh's earlier oasis-based development, while also showing how historic infrastructures have become increasingly surrounded by new construction.



Figure 27. Aerial photograph of Abarkuh City 2026

Source: Google Earth

3.2 CULTURAL FRAMEWORK OF ABARKUH

One of the most important elements of Abarkuh's cultural landscape is the ancient Cypress of Abarkuh, which is estimated to be more than four thousand years old and is recognized as a natural monument. The tree has become an important symbol of the city and represents continuity between its natural and cultural history. Its long presence has also influenced the development of religious and public spaces around it, including mosques, shrines, and gardens.

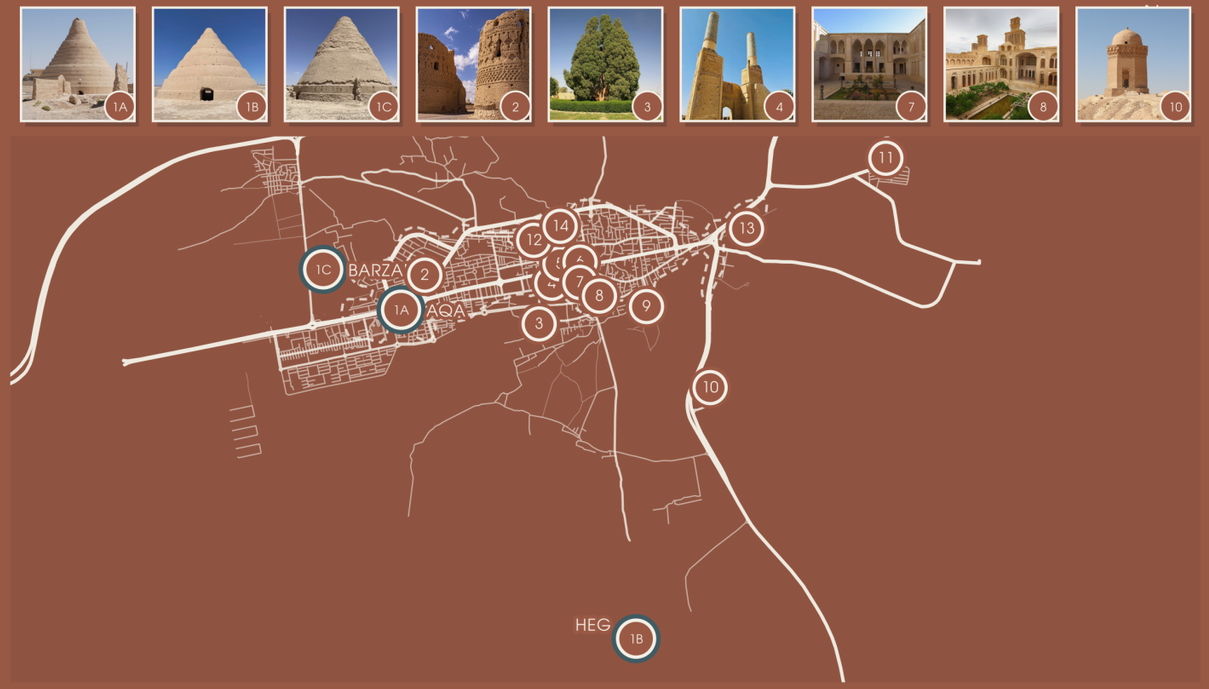
Abarkuh also preserves an important group of historic monuments and traditional buildings. The Friday Mosque*[c] of Abarkuh is one of the main religious landmarks of the city, together with shrines, bazaars, and historic adobe houses. The widespread use of adobe, brick, and sarooj mortar reflects the local construction tradition and its close relationship with the hot-arid climate.

The historic yakhchals of Abarkuh, including Aqa, Heg, and Barzan, are another important part of the city's cultural and architectural heritage. Their conical adobe domes, underground ice-storage pits, and associated ice-making areas show how local environmental knowledge was used to produce and preserve ice before mechanical refrigeration. These infrastructures supported everyday and community life during the hot summer months and today remain important evidence of the climatic knowledge, local practices, and cultural identity in Abarkuh.

*[c] Friday Mosque or Masjed-e Jame': it refers to the main mosque of a city or town, especially the mosque where the Friday congregational prayer is held.

MAP X. CULTURAL HERITAGE SITES IN ABARKUH

YAZD PROVINCE · IRAN



1A AQA · 1B HEG · 1C BARZAN · URBAN LIMIT DASHED

1. ADOBE YAKHCHALS · AQA / HEG / BARZAN
2. ROBAT CASTLE
3. 4,000-YEAR-OLD CYPRESS TREE
4. NEZAMIEH MINARET
5. AZIZ AL-DIN NASAFI
6. JAME' MOSQUE
7. SOWLAT HISTORICAL HOUSE
8. AQAZADEH HISTORICAL HOUSE
9. BEYROON MOSQUE
10. GONBAD-E ALI
11. THE CITADEL OF SHAHR-E SAB
12. STONE MOAT
13. PAVILION OF EZZATABAD
14. GHAYOUMI HISTORICAL HOUSE

Icehouse of Aqa

National Registration Number: 7752
Date of Inscription on Iran's National Heritage List: 2003/03/07
Construction period: Qajar period (1789–1925 CE)
Height: 20 m
Floor depth: 5 m below ground level
Restoration intervention: external facade earthen renedering renewed in 2015
Current use: abandoned
Materials: Adobe, stone, timber, Sarooj mortar, earthen plaster
Ownership at the time of registration: No identifiable owner

According to local narratives, the name "Yakhchal-e Aqa" may be connected to Seyyed Hossein Abarqoui, a well-known figure in Abarkuh who was known locally as "Aqazadeh." However, the official heritage registration file does not identify a legal owner and records the property as ownerless. For this reason, the name "Aqa" is better understood as a local name that has become part of Abarkuh's collective memory rather than as evidence of formal ownership. The exterior facade, and entrances were restored in March 2015 by Cultural Heritage Organization. underground ice-storage chamber survive, while shading walls are partially preserved.



Figure 28. Shading wall of Yakhchal-e Aqa" (Icehouse of Aqa)
By Author, dated 13 April 2025



Figure 29. Shading wall of Yakhchal-e Aqa" (Icehouse of Aqa)
By Author, dated 13 April 2025

Icehouse of Barzan (Maryam Abad)

National Registration Number: 15145
Date of Inscription on Iran's National Heritage List: 2005/03/15
Construction period: Qajar period (1789–1925 CE)
Restoration intervention: no intervention has been done, currently abandoned
Current use: abandoned
Entrances: East and West
Materials: Adobe, stone, timber, Sarooj mortar, earthen plaster
The yakhchal is currently in a critical state of conservation. The oculus is at risk of partial collapse due to missing parts and material loss. The domefaces widespread network cracks and surface eroision. No documented restoration project by the Iranian Cultural Heritage Organization was found.



Figure 30. Yakhchal-e Barzan" (Icehouse of Barzan)
By Author, dated 13 April 2025

Icehouse of Heg

National Registration Number: 6321
Date of Inscription on Iran's National Heritage List: 2002/09/29
Construction period: Qajar period (1789–1925 CE)
Restoration intervention: facade earthen renedering renewed in 2020
Current use: abandoned
Entrances: East and West
Materials: Adobe, stone, timber, Sarooj mortar, earthen plaster
The yakhchal still exists but is partially damaged. Restoration of the exterior facade began in 2020 by the Cultural Heritage Organization of Abarkuh, and the earthen renders of the facade were renewed. However, the interior dome, shading walls, and oculus remain deteriorated.



Figure 31. Yakhchal-e Heg" (Icehouse of Heg)
By Author, dated 13 April 2025

Robat Castle

Robat Castle of Abarkuh dates to the Safavid period (1501–1736 CE) and reflects the continuation of early Islamic defensive building traditions. It is a fortified complex with nine circular towers, constructed mainly from adobe, mud, and stone using local techniques. It was probably first used as a protected residential complex and later took on other functions, similar to other robats that gradually shifted from military to more civilian uses. Today, the castle is particularly vulnerable because of its earthen construction and its lower position in the surrounding landscape to flooding, surface erosion, and gradual material deterioration.



Figure 32. Robat Castle Shahi, R. (n.d.). Wikimedia Commons. Licensed under CC BY-SA 4.0.

4000 years old Cypress Tree

The Cypress of Abarkuh (Sarv-e Abarkuh) is one of the oldest living trees in Iran and is often considered among the oldest cypress trees in the world. Located in Abarkuh, Yazd Province, it is estimated at around 4,000 to 4,500 years old. The tree is almost 25 metres high, with a trunk circumference of about 11-12 metres. Because of its exceptional age and cultural importance, it has been registered as a National Natural Monument of Iran.



Figure 33. Abarkuh Sarv (Cypress of Abarkuh).

By Author, dated 13 April 2025

Nezamieh Minarets of Abarkuh,

The Nezamieh Minarets of Abarkuh are a pair of brick minarets from the Ilkhanid period, dating to around 1297–1298 CE. They stand on both sides of the remains of a monumental entrance portal that once belonged to a religious complex, probably a mosque or madrasa* [d] known as Nezamieh. The minarets are mainly built of baked brick and rise from large rectangular bases connected by a pointed arch.

Although most of the original religious complex has disappeared, the two minarets and the entrance portal are still preserved and remain an important landmark in Abarkuh. They are registered on the Iran National Heritage List and represent one of the significant surviving examples of medieval monumental entrance architecture in the Yazd region.

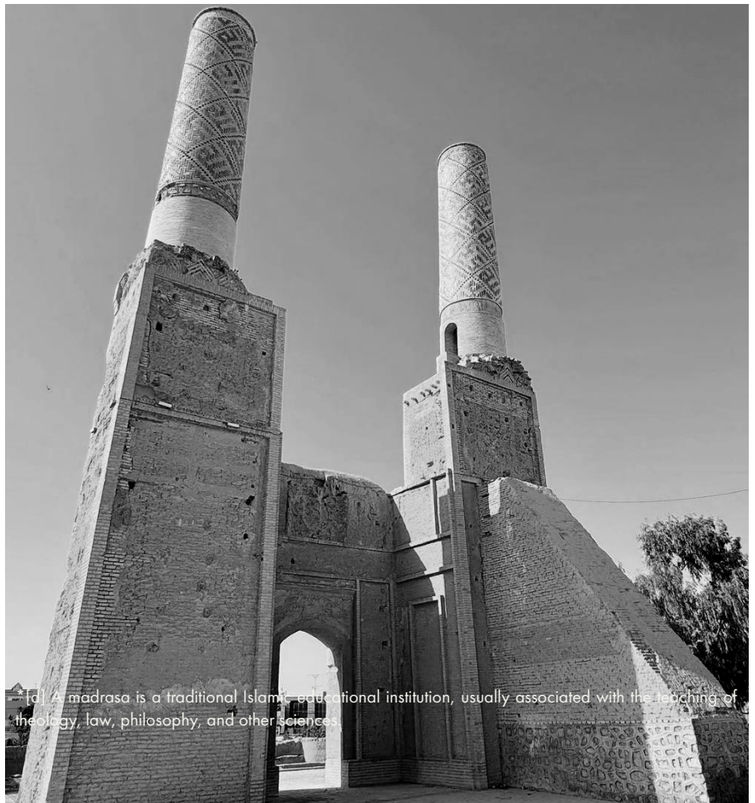


Figure 34. Nezamieh Minarets of Abarkuh

By M.H.Asgari Biahamsafarshavim.

*[d] A madrasa is a traditional Islamic educational institution, usually associated with the teaching of theology, law, philosophy, and other sciences.

Aqazadeh House

The Aqazadeh House was built in 18th century by Haj Hossein Abarquhi and covers around 820 m² within a plot of approximately 1,500 m². The two-storey courtyard house includes a rectangular pool, orsi* [e] windows with coloured glass, and a chalipa*[f] shaped main hall. It was constructed mainly with adobe, mud, and brick, using local materials and traditional building techniques suited to Abarkuh's hot-arid climate. One of the most distinctive features of the house is its large windcatcher, which is considered among the tallest in Iran. Together with the courtyard, thick earthen walls, and shaded spaces, it forms part of the passive climatic design of the house.



Figure 35. Aqazadeh Boutique Hotel, Abarkuh

Retrieved from Dad Hotel

*[e] Orsi: A traditional Persian wooden sash window, usually made with fine latticework and coloured glass.

*[f] Chalipa: A room whose plan or spatial organization extends in four directions, creating a cross-like geometry.

Solat House

Solat House is one of the important surviving examples of Qajar-period residential architecture in Abarkuh. It was built in the late 19th century for the Solat family, reflecting the prosperity of the city during that period and the high level of craftsmanship used in traditional construction. It is especially known for its detailed plaster decorations and is considered one of the valuable historic houses of Yazd Province. The house is located on Bahonar Street in the Darvazeh Meydan neighbourhood and was registered as a National Heritage Site of Iran on 12 February 1997 under registration number 1839.

The house follows the traditional introverted layout of Iranian courtyard houses in hot-arid regions, with rooms arranged around a central courtyard and spaces used according to the season. It is mainly constructed from adobe, brick, timber, and lime plaster. Thick earthen walls, shaded courtyard spaces, and natural ventilation helped create more comfortable indoor conditions in the hot-arid climate. Decorative elements include stucco work, muqarnas, carved columns, and coloured-glass windows. After restoration and conservation, Solat House was adapted to a new use and today functions as the Museum of Anthropology of Abarkuh.

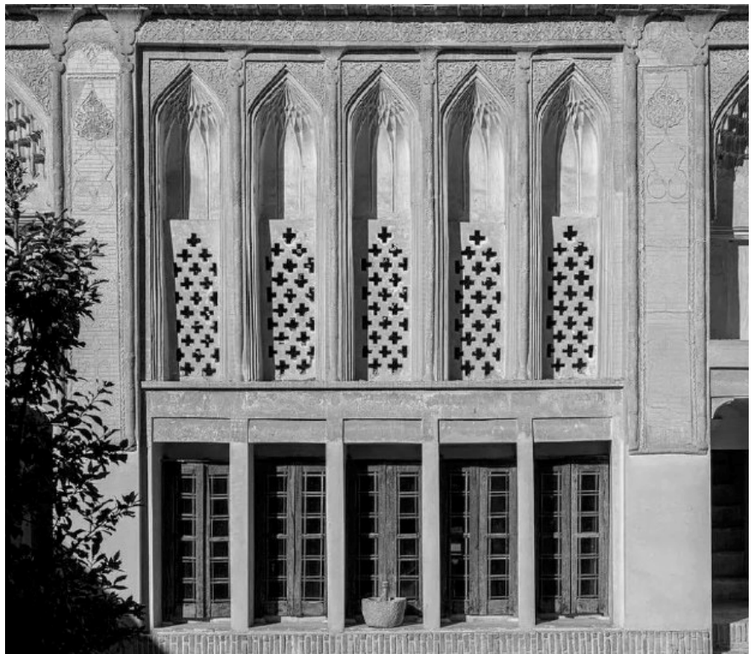


Figure 36. Solat House (Khaneh-ye Solat), Abarkuh, Yazd Province, Iran.

By Sadegh Miri



Figure 37. Solat House (Khaneh-ye Solat), Abarkuh, Yazd Province, Iran. A Qajar-period courtyard house now functioning as the Abarkuh Anthropology Museum.

Source: Wikipedia.



Figure 38. Gonbad-e Ali Wikipedia contributors. (n.d.). Retrieved February 19, 2026, from https://fa.wikipedia.org

Gonbad-e Ali

Gonbad-e Ali (Gonbad-e Aali) in Abarkuh is an11th-century CE monument from the Seljuk period and is considered one of the best-preserved Seljuk monuments in Iran. Located about 130 km from Yazd, it was registered as a National Heritage Site of Iran on 31 July 1934 under registration number 195. The building has an octagonal form and is constructed mainly from stone and sarooj. It rises from a chamfered square base and reaches a total height of about 22 metres. The upper part is covered by a dome with an araqchin form, while the interior height is approximately 12 metres.

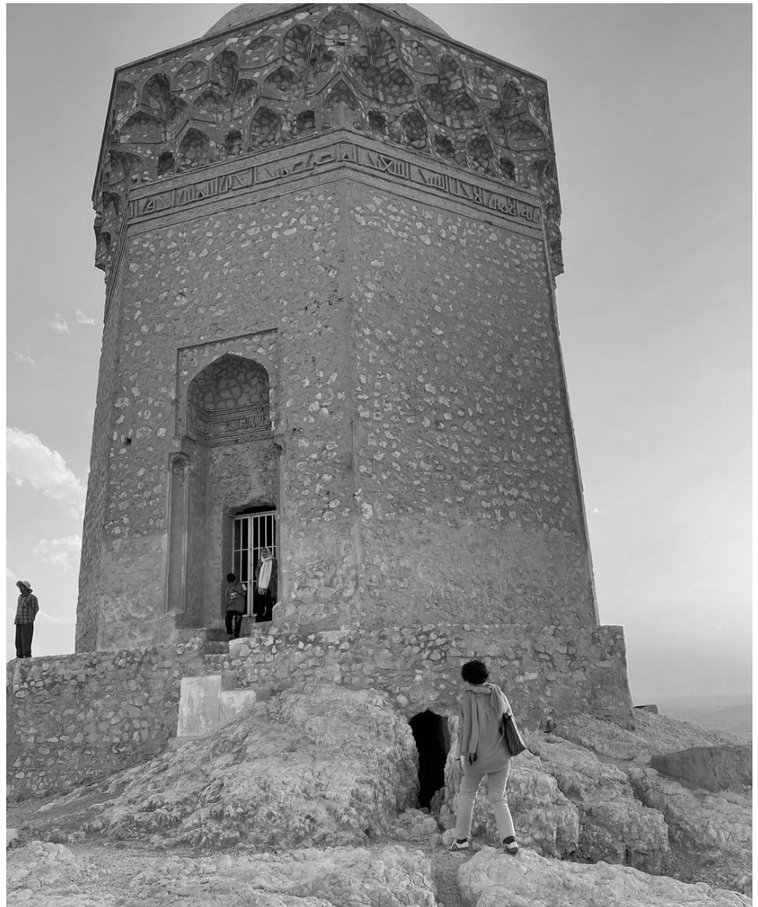


Figure 39. Gonbad-e Ali

By Author, dated 13 April 2025

3.3 FIELD SURVEY

I conducted the field survey in Abarkuh on 13 April 2025, visiting the three historic yakhchals of Aqa, Barzan, and Heg. The purpose of the survey was to document their location, architectural characteristics, construction materials, present state of conservation, and relationship with the surrounding urban context.

At each site, I used direct observation and photographic documentation to record the main architectural elements, including the conical dome, circular plan, entrances, lower base, apex opening, interior dome, underground ice-storage pit, and surrounding area. I also recorded the visible deterioration affecting each yakhchal. The condition of the surrounding ground, accessibility, and possible safety risks related to uncontrolled entry were considered as part of the survey. These observations allowed me to compare the current condition of the three infrastructures.

The field survey was supported by archival plans, sections, heritage registration documents, and historical photographs obtained from the archives of the Iranian Cultural Heritage, Handicrafts and Tourism Organization and the Research Institute of Cultural Heritage and Tourism. In particular, the archival plan and section of Yakhchal-e Aqa helped me better understand its original spatial configuration. Earlier photographs of the Aqa and Heg yakhchals were also useful for comparing their previous and present conditions.

Among the three yakhchals, Yakhchal-e Barzan was selected for a more detailed investigation as the main case study of this thesis. I documented its exterior and accessible interior spaces and examined its construction technique, material stratigraphy, dome, entrances, underground ice-storage pit, and apex opening through direct observation. The visible deterioration patterns were then mapped and used as the basis for the conservation condition and risk assessment presented in the following section.



Figure 40. Field Survey of Yakhchal-e Heg"
(Icehouse of Heg)
By Author, dated 13 April 2025

ABARKUH CITY

IRAN · YAZD PROVINCE



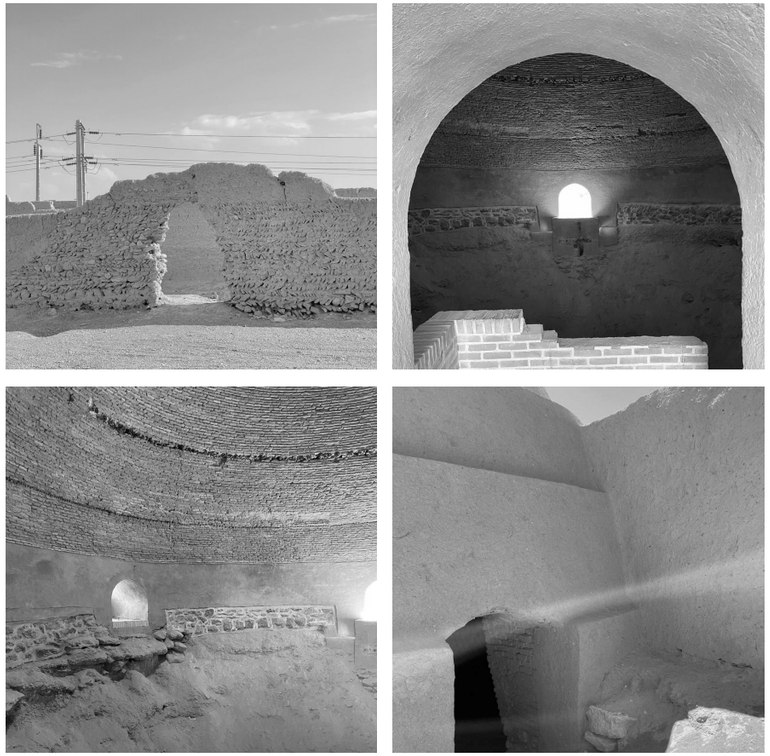


Figure 41. Field survey photographs of the Aqa and Heg Ice House, taken in April 2025.
By Author.

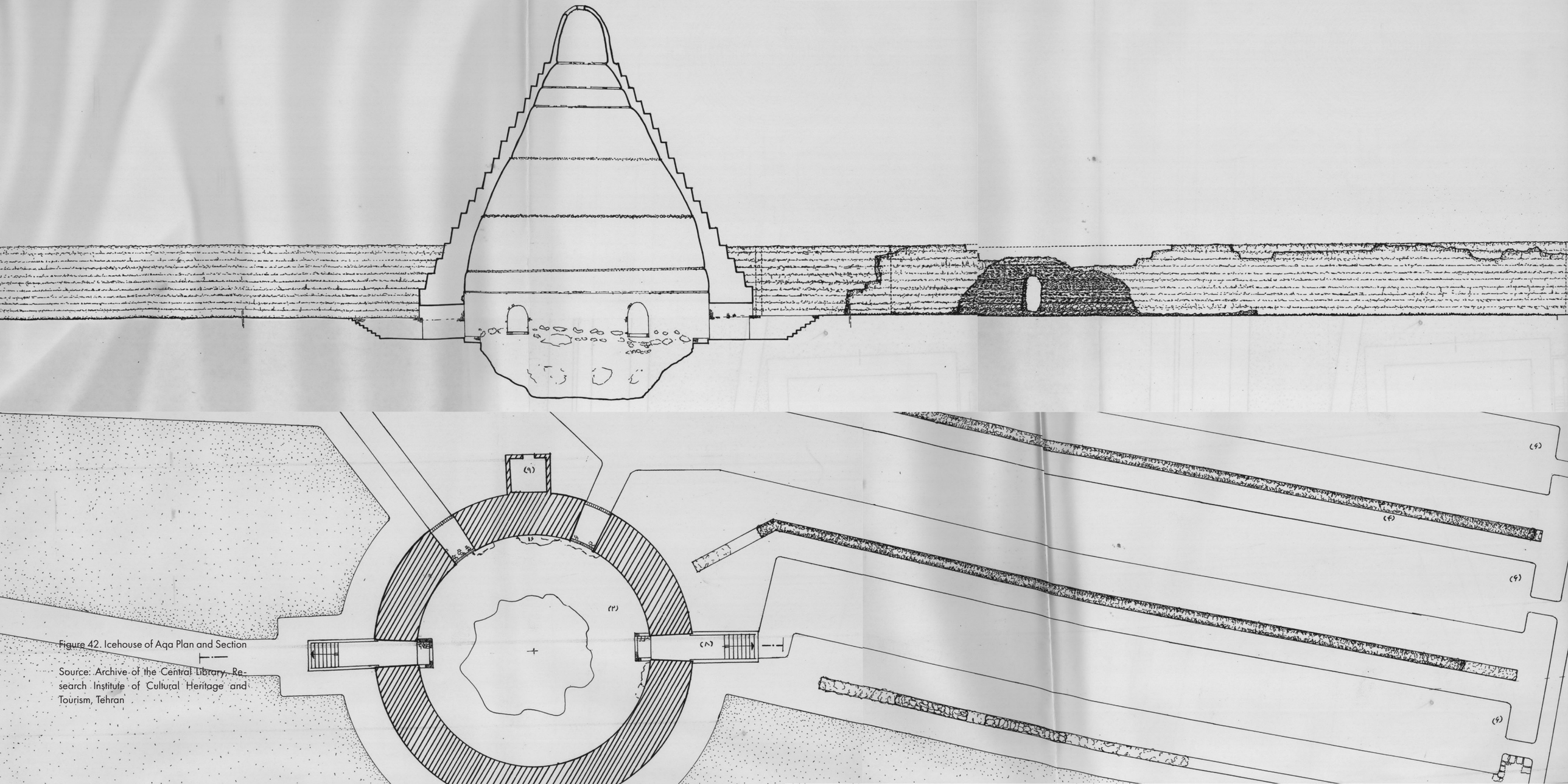


Figure 42. Icehouse of Aqa Plan and Section

Source: Archive of the Central Library, Research Institute of Cultural Heritage and Tourism, Tehran

3.4 CONSTRUCTION TECHNIQUE IN YAKHCHALS OF ABARKUH

1. Concentric Ring Construction (Corbelled Conical Dome)

The dome is constructed using horizontal concentric rings of masonry, with each course projecting slightly inward toward the centre. As the courses rise, their diameter gradually decreases, creating the conical form without the need for centering or timber formwork.

Above approximately +1.70 m, the dome wall is composed of an adobe or mud-brick masonry core, earthen mortar joints, and an external protective sarooj render approximately 0.02 m thick.

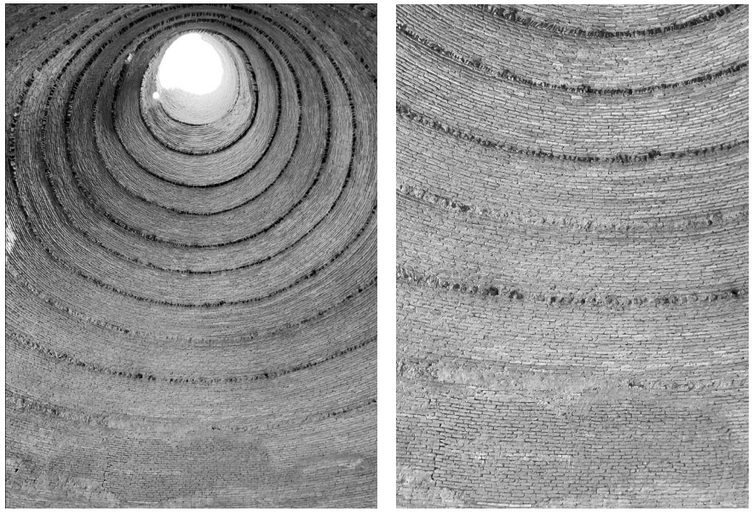


Figure 43. interior of Yakhchal-e Barzan dome

By Author, 13 April 2025, Abarkuh, Iran

2. Stone Masonry

From ground level (z = 0.00 m) up to approximately z = +1.70 m, the wall has a different construction from the adobe dome above. This lower part is made of about 1.70 m of stone masonry bonded with sarooj mortar, while the external surface is protected by a sarooj render approximately 0.02 m thick. This stone-and-sarooj base has several functions. It helps protect the adobe construction above from ground moisture and capillary rise, transfers the weight of the massive dome toward the ground, and provides greater stability and resistance to impact at the lower part of the wall.

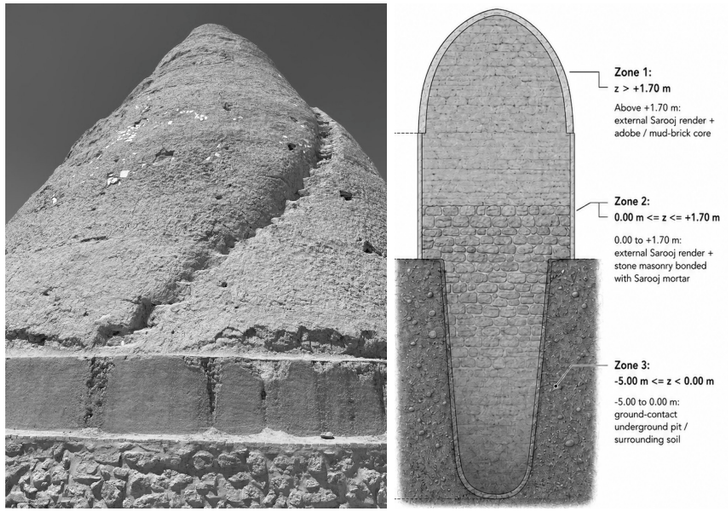


Figure 44. Exterior of Yakhchal-e Barzan dome/Stratigraphy Diagram of the Yakhchals

By Author
Based on field observations and photographic documentation

3. Adobe Core with Protective Earthen Plaster

The dome is formed by thick earthen walls made mainly of adobe bonded with earthen mortar. At the base, the wall thickness varies between approximately 1.5 and 2.5 m and gradually decreases to about 0.40 m near the oculus.

The wall is composed of an adobe masonry core, earthen mortar joints, and an external protective plaster, usually clay-based or sarooj. The continuous outer sarooj coating protects both construction zones from rain, erosion, and gradual surface deterioration.

4. Apex Oculus for Ventilation and Construction

A small opening is located at the apex of the conical dome. Its main environmental role is to allow warmer air to rise and escape naturally through buoyancy-driven airflow.

The apex opening therefore supports stack-effect ventilation and helps remove warm air that accumulates in the upper part of the dome.

5. The Underground Storage Pit

The underground storage pit extends from ground level to approximately z = -5.00 m. Unlike the dome above, this part was excavated directly into the natural soil and therefore has a different material relationship with the surrounding ground.

The earth around the pit helps keep the interior more thermally stable by coupling the space with ground temperatures and reducing the effect of daily outdoor temperature changes.

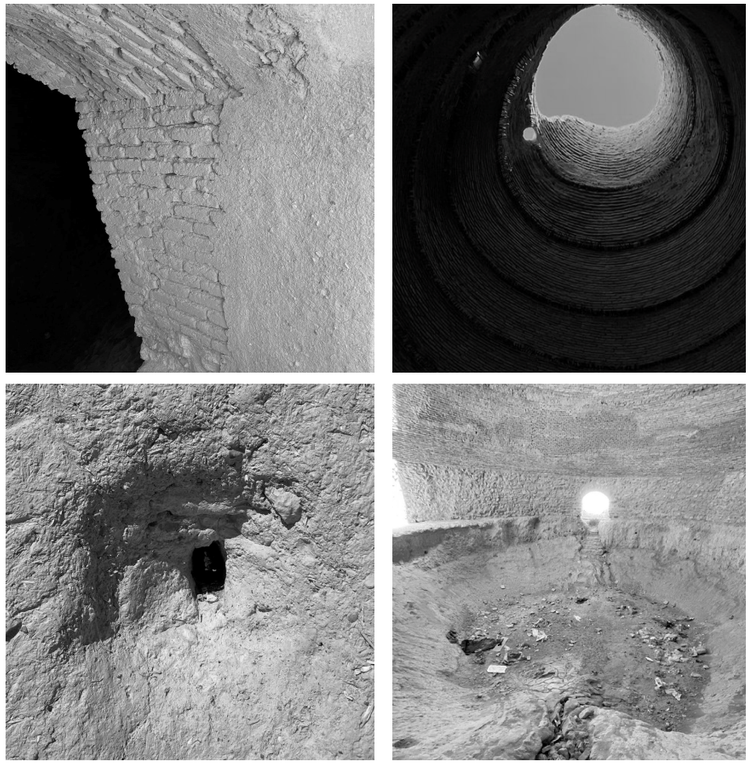


Figure 45. interior of Yakhchal-e Barzan. By Author, 13 April 2025, Abarkuh, Iran



Figure 46. Yakhchal-e Barzan
By Author, 13 April 2025, Abarkuh, Iran.

3.5 STATE OF CONSERVATION OF YAKHCHALS IN ABARKUH

Barzan Ice-House

State of conservation: deteriorated with visible erosion of the earthen surface, loss of protective plaster layers, and structural cracks at the base. The deterioration is concentrated particularly in the lower dome zone and at the junction between the dome and the base platform, which is typical in earthen structures exposed to desert environments without regular maintenance.

Risk-rating method:

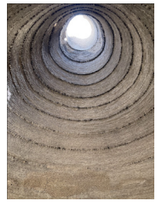
Probability: 1 Rare, 2 Unlikely, 3 Possible, 4 Likely, 5 Almost certain.
Impact: 1 Negligible, 2 Minor, 3 Moderate, 4 Major, 5 Severe.
Risk score = Probability Impact; 1–4 Low, 5–9 Moderate, 10–15 High, 16–25 Critical.

Element	Observed condition	Indicative risk	Immediate priority
Main dome	Still standing, but with widespread surface erosion/network cracking and severe, locally continuous loss at the lower dome/interface. Crown and entrance require close inspection.	High-Critical	Structural survey; protecting crown and lower interface; restrict access beneath unstable zones.
Shade walls / ancillary fabric	Extensive crest loss, basal coving, granular disintegration and partial collapse.	Critical	Establishing exclusion zone, capping and drainage before repair.
Entrance and interior	Damaged openings, loose masonry, enlarged/open crown, floor loss and uncontrolled waste deposits.	Critical	Close access, shore openings, investigate floor voids and remove waste.

Table 11. Overall state of conservation of Yakhchal-e-Barzan

By Author

Deterioration	Location	Possible Causes	Probability	Impact on Structure	Risk Level	Final Score	Recommended Action
	Main exterior dome and base drum	Widespread network cracks; erosion/roughening; continuous horizontal material loss at the dome base; missing render on the base drum.	Shrinkage and thermal cycles; wind-driven rain; runoff collecting at the horizontal transition; prolonged lack of maintenance.	5	5	**25 Critical**	Undertaking full condition mapping and sounding of detached zones. Repair the weathering layer with compatible Sarooj render. Protect the drum base from runoff and monitor crack development.
	Exterior dome beside maintenance stair/rib and plinth	Erosion and roughening; localized missing parts and fragmentation along the stair/rib; network cracking; small cavities; deterioration of earlier patches.	Water concentration along the projecting stair/rib; wind/sand abrasion; poor repair adhesion; repeated drying and wetting.	4	4	**16 Critical**	A survey is necessary on the stair/rib junction and cavities. Stabilize edges, improving runoff paths and replacing failed patches with compatible earthen materials.
	Localized exterior repair/render area	Delamination/detachment; flaking/scaling; fragmentation and exposed earthen substrate; deterioration of a previous repair layer.	Incompatible or dense repair material; poor adhesion; moisture trapped behind the repair; differential shrinkage and thermal movement.	4	3	**12 High**	Carrying out tapping/adhesion tests and material analysis. Removing unsound repair material. Applying a compatible breathable earth-based repair and protect edges.

Deterioration	Location	Possible Causes	Probability	Impact on Structure	Risk Level	Final Score	Recommended Action
	Interior dome; upper courses and crown/oculus	Localized missing parts and fragmentation around the crown opening; possible enlargement of the original oculus; open joints in upper courses.	Direct weather entry through the crown; mortar decay; thermal cycling; loss of upper brick courses;	4	4	**16 Critical**	Excluding visitors from beneath the crown. Inspecting the crown by scaffold/drone and compare the oculus with historic geometry. Stabilize loose brick courses and provide reversible rain protection that preserves ventilation.
	Eastern entrance façade; lower dome/entrance transition	Differential erosion and major loss at the lower dome; network cracks (craquelure); detachment and missing render; local fragmentation around the arch.	Concentrated runoff from the dome; loss of sacrificial earthen render; wind abrasion; repeated wetting/drying; neglect and local impact.	5	5	**25 Critical**	Restrict access below loose areas. Inspecting the arch and dome springing. Mapping cracks and losses. Improving rainwater shedding; stabilize loose edges and reinstate compatible earth-based masonry/render.
	Site-wide view: setting	Debris and uncontrolled ground disturbance.	Long-term abandonment; unrestricted access; visitor/vehicle activity and dumping.	5	3	**15 High**	Creating a protected buffer. Control vehicles, clear debris under archaeological supervision.

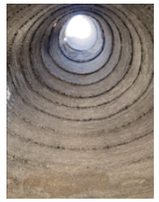
Deterioration	Location	Possible Causes	Probability	Impact on Structure	Risk Level	Final Score	Recommended Action
	Ventilation brick-lined opening	Major loss and missing parts; displacement, fragmentation and chipping of bricks; loose debris at the threshold.	Removal or vandalism; impact; mortar deterioration; unsupported alteration; moisture and salt action.	5	5	**25 Critical**	Restricting access to the buffer-zone and install Support framework. Record and inventory fallen units. rebuilding and remove hazardous debris.
	Interior dome shell	Localized erosion and missing mortar; open joints; small holes.	Moisture penetration; mortar decay; thermal cycling; prolonged exposure through the crown and lack of maintenance.	4	4	**16 Critical**	Laser-scan on the inner shell. Inspecting continuity of brick courses, stabilize loose bricks and repointing with compatible mortar.
	Ice pit	Major loss/missing part and apparent collapse of the floor; fragmentation, loose blocks and extensive deposits/rubbish .	Water scour or drainage failure; settlement or subsurface void; past excavation; uncontrolled dumping and foot traffic.	5	4	**20 Critical**	Restricting access. Removing rubbish, investigate drainage and stabilize exposed edges; providing a safe visitor route.

Table 12. State of conservation of Yakhchal-e-Barzan By Author

Based on field observations, photographic documentation, and ICOMOS-ISCEAH terminology for earthen materials deterioration

Figure 47. The Dome of Yakhchal-e Barzan
By Author, 13 April 2025, Abarkūh, Iran

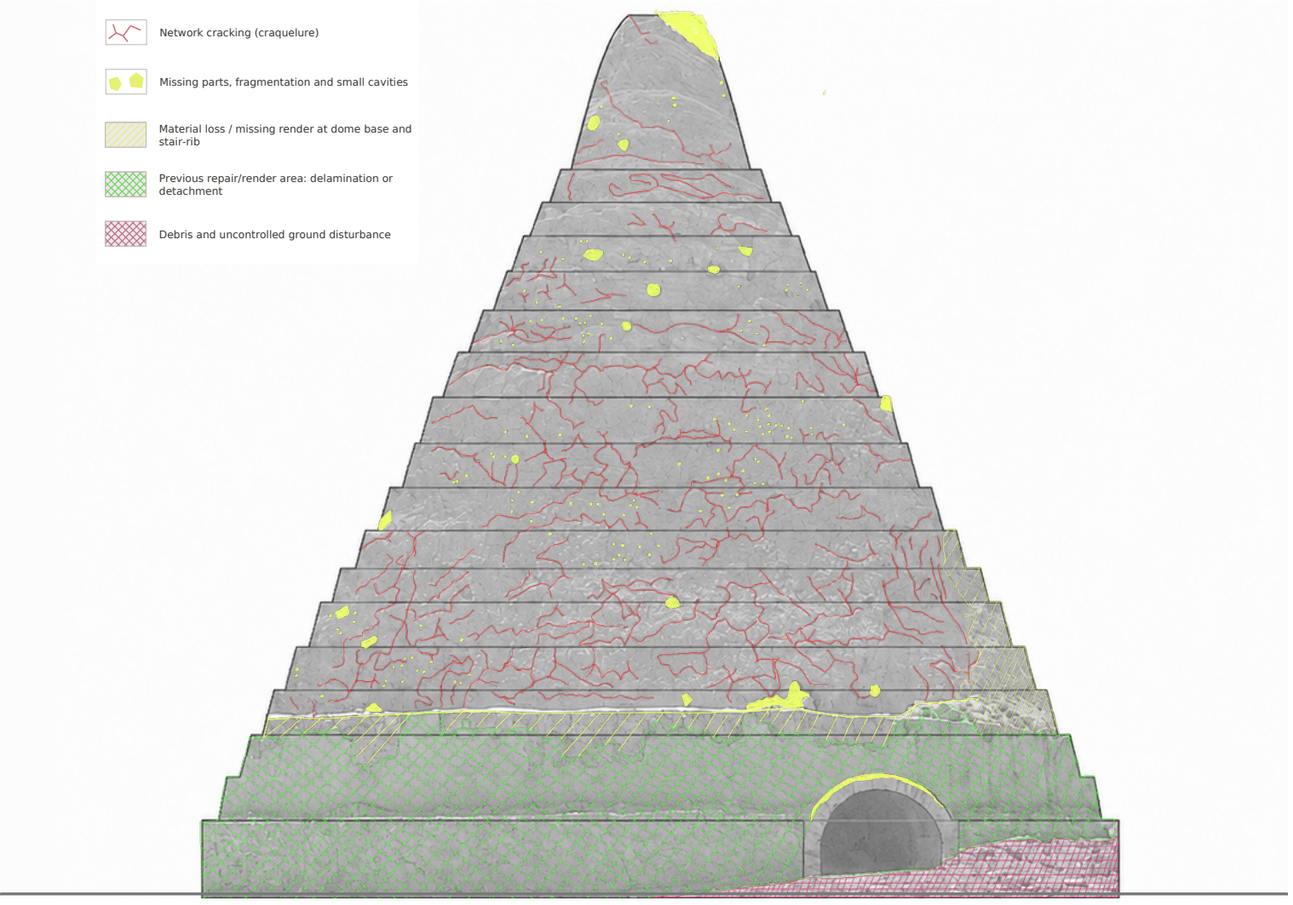


Figure 48. Decays representation on Western facade of Yakhchal-e-Barzan

3.6 SWOT Analysis

S

- Geometry: The conical dome of the yakhchāl minimizes solar exposure while maximizing structural stability. The ice-pit below ground level, takes advantage of naturally cooler subterranean temperatures.
- Yakhchāls are built from thick adobe and sarooj walls with high thermal inertia which maintains a stable, cool interior climate.
- oriented along east–west axes, so that high shading walls cast long shadows usable for social outdoor functions
- Location within a rich heritage landscape (mosques, historical houses, 4000 years old cypress)

W

- Advanced material decay: erosion, cracking, loss of Sarooj (traditional water resistant mortar)
- Lack of regular maintenance by authorities and absence of traditional vernacular craftsmen
- Hydraulic systems (qanats) no longer functional, leading to the loss of hydraulic foundations and environmental integration
- Social detachment: local communities no longer identify yakhchāls as useful spaces
- Fragmented ownership and unclear management between public and private institutions

O

- Potential for adaptive reuse as community cooling hubs for cultural activities to reconnect people with traditional environmental knowledge; even without active ice production, the same passive principles can be reused to create naturally cool interior spaces for rest, workshops, or gatherings which is crucial in Iran's increasingly hot climate.
- Spatial Potential: Many are located within or near settlements, making them accessible for public reuse.
- Abarkuh lies on the Yazd–Shiraz cultural route, a recognized historic axis connecting major UNESCO-listed heritage cities in Iran.

T

- Rising temperatures and desertification accelerating erosion. This leads to micro-cracking, especially in domes and vault junctions.High heat increases evaporation of bound water within the clay particles, leading to surface dusting (powdering).
- Sand and dust storms causing surface abrasion and loss of earthen fabric.
- Loss of traditional knowledge about sarooj production and maintenance techniques.
- Urban expansion and land-use changes encroaching on buffer zones.
- Insufficient national funding and bureaucratic delays in restoration projects.

04
COMMUNITY AND SOCIAL PRACTICES



Figure 49: Yakhchal in a Village landscape near the Turkish border, Iran, 1955.

Photograph by Marc Riboud.

4.1 UNESCO AND FARO CONVENTIONS: COMMUNITY PARTICIPATION IN CONSERVATION OF HERITAGE

International heritage policies increasingly recognise that communities should have an active role in identifying, conserving, managing, and passing cultural heritage to future generations. The 1972 World Heritage Convention established the responsibility of States Parties to protect heritage, while later developments gave more attention to the role of people and local communities. This shift is visible in the recognition of "Communities" as the fifth strategic objective of the Convention and in the Operational Guidelines, which encourage the participation of communities and other stakeholders in heritage processes [42,43].

The 2003 Convention for the Safeguarding of the Intangible Cultural Heritage gives an even clearer role to communities. Articles 11 and 15 call for the involvement of communities, groups, and individuals in identifying, safeguarding, and managing the heritage they create and transmit. The UNESCO Recommendation on the Historic Urban Landscape also supports participatory approaches, where communities, professionals, authorities, and other stakeholders work together to identify heritage values and define conservation priorities. These ideas are especially important for vernacular heritage, where the built fabric is closely connected to traditional knowledge, construction skills, maintenance practices, and cultural meanings [44,45].

The Faro Convention develops this idea further by understanding heritage as something that gains value through the relationship between people, places, and shared memories. Its concept of a "heritage community" refers to people who value certain aspects of heritage and want to preserve and pass them on. An important point in the Faro approach is the difference between participation and cooperation. Participation can mean being consulted or helping with a project after the main decisions have already been made. Cooperation, however, means that stakeholders are involved from the beginning, help define the objectives, and share responsibilities. For earthen heritage, this means that local residents and craftspeople should not only be involved as workers during restoration, but should also contribute their knowledge, discuss possible future uses, and take part in decisions about maintenance and management.

The Faro methodology therefore supports a continuous process of identifying stakeholders, sharing different views, defining common goals, taking action, and evaluating the results. This is particularly relevant for earthen heritage, which depends on regular care and maintenance rather than one-time restoration. In the case of the yakhchals of Abarkuh, the Faro framework can support a more cooperative management model involving residents, local craftspeople, custodians, heritage professionals, tourism actors, the municipality, and cultural heritage authorities. Public institutions would remain responsible for legal protection and technical standards, while local stakeholders could have a stronger role in interpretation, maintenance, and future use [46].

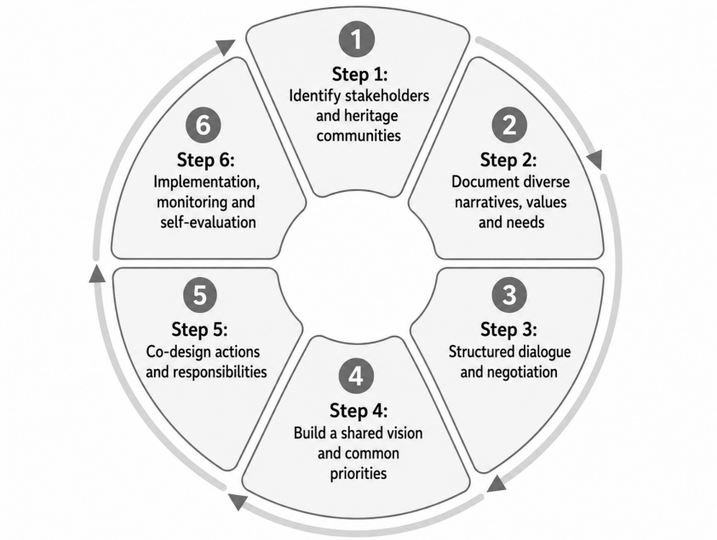


Figure 50. The Faro Convention Methodology for cooperative Heritage Governance.

By Author.

4.2 THE ROLE OF COMMUNITIES AND SOCIAL PRACTICES IN CONSERVATION OF EARTHEN HERITAGE

The conservation of earthen heritage is not only about repairing materials or protecting the physical fabric. In many cases, its long-term survival also depends on the people who use, maintain, and understand these places. The studies reviewed in this section show that technical conservation and cultural continuity are closely connected. Local participation, traditional skills, social practices, and suitable forms of management can all influence whether earthen heritage remains active or gradually loses its meaning. The seven case studies discussed here, from North America, South Asia, Latin America, North Africa, and Europe, show different ways in which communities can contribute to conservation, but also some of the difficulties involved.

A: Beyond Participation in Tribal Housing

Chi examines tribal housing projects in the United States, where traditional earthen building practices have sometimes been treated as outdated or "primitive." Through examples such as Taos Pueblo and projects in the Navajo Nation, the study argues that community participation should go beyond simply involving local people in a project. Instead, professionals should work together with communities and exchange knowledge rather than acting only as outside experts. The study shows that conservation becomes more sustainable when traditional skills are passed from one generation to another and remain part of everyday life. [47]



Figure 51. Participants in a mud plastering workshop at Ohkay Owingeh, New Mexico (2012), part of the Owe'neh Bupingeh Restoration Project. These workshops reinforced intergenerational transfer of earthen knowledge.

Photo: Tania Hammidi.

B: Ethics of Representing Stakeholders in Ladakh

Dhar looks at the conservation of wall paintings in Ladakhi monasteries and focuses on the differences that can appear between scientific conservation methods and local religious values. The study criticizes situations where local communities are not fully included in decision-making and are treated only as beneficiaries of conservation work.

Instead, Dhar supports a "living heritage" approach, where local rituals, beliefs, and community understanding of the site are considered as part of the conservation process. The case shows that focusing only on the physical material can be problematic if the cultural meaning of the heritage is ignored. For long-term conservation, technical decisions therefore need to be balanced with the values and practices of the communities connected to the site [48].



Figure 52. Meeting with village elders in Shey, Ladakh (2002) to discuss the proposed conservation of wall paintings at the temple of Dorje Chenmo. The dialogue highlights the role of stakeholders in shaping conservation decisions.

Photo: Dhar, 2002.

C: Community Custodianship in Kunotambo, Peru

Cancino discusses the role of Raul Cardenas and the local community of Kunotambo in the conservation of the Santiago Apostol temple. The case shows that the project was not limited to technical seismic strengthening. Local leadership, community organization, and the continuation of rituals and festivities were also important parts of the conservation process.

The work was supported through local committees, training activities, and the continued use of the church for religious and community events. This helped keep the temple connected to everyday life instead of treating it only as a monument. The case suggests that earthen heritage can remain active and meaningful when local communities continue to take responsibility for its care and use [49].



Figure 53. Workers of the Direccion Desconcentrada de Cultura and residents of Kunotambo transporting adobe prepared on-site using local materials and traditional techniques. This practice reflects participatory conservation in Peru.

Photo: Juan Carlos Mellado, 2017

D: Co-Creation in La Casa-Hacienda de Susudel, Ecuador

This study looks at the participatory restoration of a colonial adobe hacienda in Susudel, Ecuador. Instead of following a top-down approach, the project was developed through cooperation between universities, local communities, and municipal actors. The process included participatory surveys, training workshops, and community meetings where local people could discuss priorities and take part in decisions.

Teran et al. show that conservation becomes more meaningful when communities are involved in defining what is important and in discussing possible solutions. In this case, the restoration process did not only protect the earthen heritage, but also supported stronger social connections and local development [50].



Figure 54. Community members of Susudel engaged in hands-on training for traditional adobe brick production, revitalizing ancestral techniques through participatory conservation.

Photo: Cristian Abad, 2019.

E: Knowledge Transmission and Participatory Conservation in Spain

Research carried out in Spain by Camilla Mileto, Fernando Vegas Lopez-Manzanares, and their colleagues provides useful examples of how earthen heritage can be documented and conserved over time. Through projects such as RES-TAPIA, SOS-TIERRA, and RISK-Terra, the researchers developed inventories, maps, construction classifications, case-study databases, and evaluations of conservation interventions across the Iberian Peninsula. RES-TAPIA studied more than 200 interventions on rammed-earth architecture, while SOS-TIERRA expanded the research to a wider range of traditional earthen buildings and rehabilitation projects. These studies show a gradual shift away from extensive reconstruction and incompatible cement-based repairs toward the conservation of existing fabric and the use of more compatible traditional materials [51].

The research also shows that the vulnerability of earthen heritage is not only related to material decay or environmental conditions. Abandonment, population decline, the loss of traditional skills, reduced appreciation of earth as a building material, lack of maintenance, and the use of inappropriate industrial materials can also create serious risks. In many vernacular buildings, repairs were carried out according to immediate economic needs and the knowledge available at the time. This shows that conservation results are closely connected to local skills, financial conditions, and access to suitable technical guidance [52].

Mileto and Vegas organise conservation around six connected areas: knowledge, valorisation, protection, conservation, training, and innovation. Community participation can support all of these areas. Residents and craftspeople can provide information about past uses, construction methods, previous repairs, and maintenance practices, while training can help local workers continue using compatible techniques. Public activities can also improve awareness of earthen heritage, and the use of local materials and crafts can support both the local economy and the transmission of traditional skills [53].

The VerSus+ / Heritage for People project develops this idea further through education, public communication, community participation, and the transmission of vernacular knowledge. Its aim is to make the environmental, social, and cultural values of vernacular architecture more understandable to residents, students, professionals, and decision-makers. In this approach, restoration is not only about protecting the physical fabric, but also about keeping traditional knowledge active and creating new uses that remain connected to the local context [54].

These findings are directly relevant to the yakhchals of Abarkuh. Their conservation should combine technical investigation with the knowledge and participation of residents, craftspeople, heritage authorities, local organisations, and future users. Community involvement can help document former uses and maintenance practices, identify cultural values, discuss possible adaptive-reuse options, support training activities, and define realistic responsibilities for future maintenance. At the same time, technical specialists remain essential for structural assessment and material conservation. Bringing these two forms of knowledge together can support a more balanced and locally grounded approach to the conservation of the three yakhchals.



Figure 55. Children participating in hands-on earthen architecture activities at the UPV Children's and Summer Schools, Universitat Politecnica de Valencia, Valencia, Spain.

June-July 2016.

Comparative Insights

Looking across these seven case studies, several common ideas can be identified.

From Participation to Cooperation:
Communities should not be involved only as beneficiaries or as labour during conservation work. The studies by Chi, Teran, and Heinsen show the importance of allowing locals to contribute their own knowledge and priorities.

Living Heritage:
Rituals, memories, religious meanings, and everyday practices are also part of the value of earthen heritage, as shown in the cases discussed by Dhar and Cancino.

Leadership and Custodianship:
Local leaders, custodians, and community groups can have an important role in keeping heritage active over time. The studies by Cancino and Heinsen show how local responsibility and trust can support continuity after the main conservation project has finished.

Connection with Local Development:
Conservation can become more sustainable when it is connected to training, local crafts, employment, knowledge transmission, and small-scale economic opportunities. This relationship appears in the studies by Teran, Mazirh, Heinsen, Mileto, and Vegas.

Conclusion

The case studies from different regions show the importance of combining professional knowledge with local practices, regular maintenance, compatible materials, and the transmission of traditional skills. For the yakhchals of Yazd and Abarkuh, this suggests that conservation should not focus only on physical repair, but also on local knowledge, community participation, and the practices that historically supported their maintenance.



Figure 56. Community gathering during the Festival Arica Barroca 2018 in Pachama, Chile. The event illustrates how cultural festivals strengthen collective identity while reinforcing the social value of earthen heritage.

Source: Fundacion Altiplano.

4.3 HISTORICAL COMMUNITY AND SOCIAL PRACTICES AROUND YAKHCHALS

Yakhchals were collective infrastructures, often supported through communal labour or charitable endowments. Their role went beyond simply producing and storing ice. The winter preparation of the freezing pools and the summer distribution of stored ice depended on cooperation between local people. In towns, ice could be sold in bazaars or used during public events, weddings, and for medical purposes, making the yakhchal part of everyday community life [2,3].

The long-term use of yakhchals depended on these social arrangements as much as on their physical design. Ice production required environmental knowledge, regular maintenance, and coordination between families, guilds, and local authorities. The management of water, freezing, storage, and distribution therefore became a shared responsibility rather than an individual activity.

This relationship between infrastructure and community can also be seen in other Iranian vernacular systems. Research on drought-resistant communities shows that water and cooling infrastructures were supported by both material solutions and local forms of management. In the case of yakhchals, the shading walls, freezing pools, and underground storage pit worked together with social agreements, local knowledge, and systems of maintenance. This reflects what Marchi and Mazzoni describe as a "preparedness culture," where communities developed ways to deal with scarcity before it became a crisis [57].



Figure 57. Workers preparing ice in shallow freezing ponds at the yakhchal complex of Jolfa, Isfahan. Seasonal labor and communal effort were essential for producing and storing winter ice.

Source: Bahadorinejad & Dehghani, Yakh-sazi-ye tabi'i va sonnati dar Iran, p. 144.



Figure 58. Workers preparing ice in shallow freezing ponds at the yakhch l complex of Jolfa, Isfahan. Seasonal labor and communal effort were essential for producing and storing winter ice.
Source: Bahadorinejad & Dehghani, Yakhs zi-ye tabi'i va sonnati dar Iran, p. 144.



Figure 59. Transport of harvested ice blocks by mule from a yakhchal in Iran. Such practices highlight the logistical and social systems surrounding vernacular cooling infrastructure.
Source: kalaboroodat.com

4.4 ABARKUH COMMUNITY PERSPECTIVES AND NEEDS

The yakhchal should be understood not only as a historic earthen infrastructure, but also as a climate-responsive system shaped by environmental knowledge, local materials, and collective use. For this reason, the interviews are an important part of the research. They connect the architectural, conservation, and environmental analysis of the previous chapters with the people who may use, manage, and maintain the yakhchals today.

If the yakhchals of Abarkuh are to be reactivated as cultural cooling hubs, their potential cannot be evaluated only through thermal simulation or material analysis. It is also necessary to understand how local people see these infrastructures, which forms of reuse they consider acceptable, what risks they are concerned about, and how they would like to participate in future conservation and management.

During the field survey, four semi-structured interviews were conducted with local actors representing different types of knowledge and experience. As a future step of this research, a larger number of structured interviews with a wider range of stakeholders could be carried out before the restoration project begins. This would allow the participatory framework to be tested and developed further. The full interview transcripts are included in the Appendix. The participants were:

- a Cultural Heritage Expert from the Iranian Cultural Heritage Organization;
- the Custodian of Gonbad-e-Ali, representing local custodial knowledge;
- a Traditional Adobe Construction Worker;
- a Tourism Ecolodge Manager.

The participants were selected through purposive sampling, together with site-based recruitment during the field visit in April 2025. The aim was not to create a statistically representative sample, but to speak with people whose work, daily activities, local knowledge, and exposure to heat made their perspectives relevant to the possible need for community cooling hubs in Abarkuh.

A meeting was arranged in advance with a cultural heritage expert from the Abarkuh branch of the Iranian Cultural Heritage Organization. The custodian of Gonbad-e-Ali was approached during visits to other heritage sites because of his custodial experience and strong local memory. The traditional adobe worker was encountered while carrying out earthen rendering near Yakhchal-e Heg and was selected for his practical knowledge of local materials and construction techniques. The tourism ecolodge manager was interviewed because of his involvement in local tourism, and visitor experience.

Stakeholders classified based on Faro	Interviewee
Heritage community/Local residents	Traditional adobe construction worker /Custodian of Gonbad-e-Ali
Public institutions/Technical actor	Cultural Heritage Expert from the Iranian Cultural Heritage Organization
Private sector	Tourism ecolodge manager
Operational Community	Custodian of Gonbad-e-Ali

Table 13. Stakeholders Mapping

By Author
Based on Faro Convention Action Plan Handbook 2018

When interpreted through the Faro framework, the interviews suggest the presence of a potential heritage community, but they also show the need for a clearer system of cooperation and management. Most participants supported shared responsibility between local people, professionals, the municipality, and heritage authorities. However, their responses also showed different levels of trust toward institutions. Some participants accepted the involvement of outside experts only if there was community or ministry supervision, while the custodian expressed distrust because of an alleged past incident involving heritage artefacts.

Adaptive reuse was generally supported when it could provide shade, gathering space, cultural activities, employment, tourism income, or better comfort during hot summer periods. At the same time, participants raised concerns about structural collapse, inappropriate interventions, vandalism, poor maintenance, and the risk of the yakhchals falling into neglect again. These findings support a conservation-led form of reuse based on structural assessment, compatible interventions, and a clear long-term maintenance plan. Most importantly, the interviews show that local people expect to be involved in decision-making, not only in carrying out the work.

The diagrams translate the four interviews into a preliminary Faro-based assessment of the current potential for cooperative conservation of the Abarkuh yakhchals. The WHO diagram shows a relatively strong presence of community and public-sector actors, together with some private-sector involvement. At the same time, it highlights the absence of a clearly identified local facilitator who could coordinate communication and cooperation between these different groups.

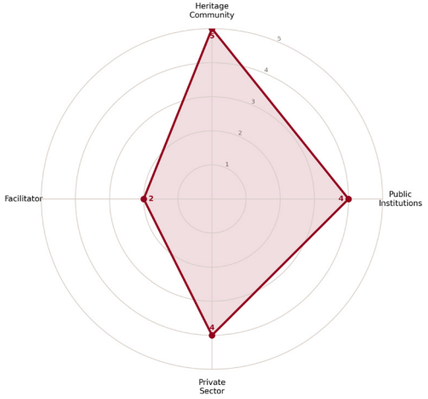


Figure 60. WHO Diagram

By Author
Based on Faro Convention Action Plan Handbook 2018

The HOW diagram shows strong agreement on the cultural value of the yakhchals and their conservation and reuse. The lower score for resource mobilisation reflects the need for funding, tools, materials, official permission, professional recognition, and continued institutional support.

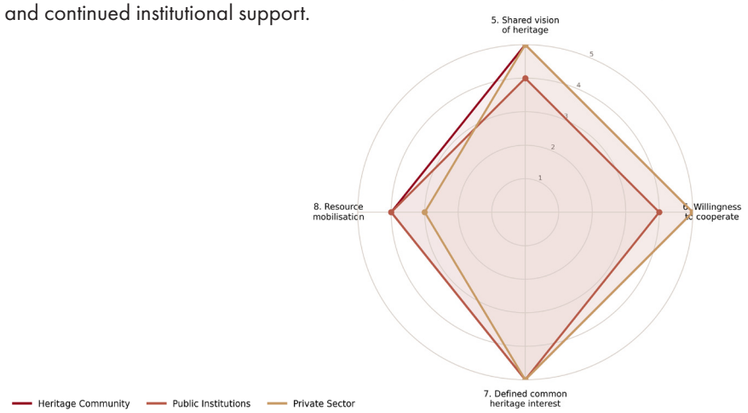


Figure 61. HOW Diagram

By Author
Based on Faro Convention Action Plan Handbook 2018

The WHAT diagram shows that the heritage community is most ready to share local knowledge, support useful reuse, and take part in decisions. Institutional and private-sector capacities are less consistent. The final governance diagram therefore proposes a shift from participation to cooperation through stakeholder mapping, joint planning, community supervision, training, maintenance, and monitoring.

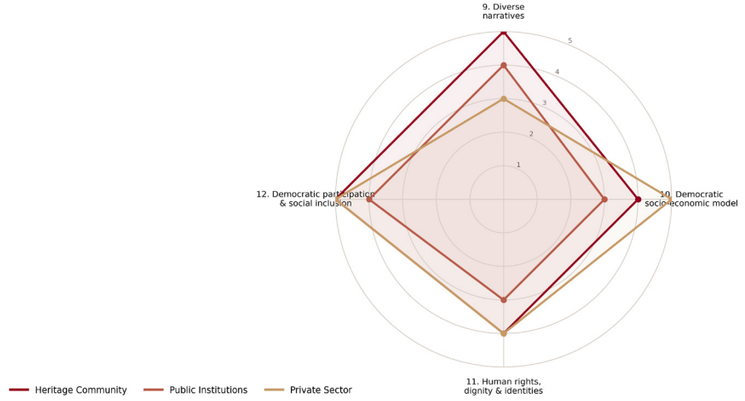


Figure 62. WHAT Diagram

By Author
Based on Faro Convention Action Plan Handbook 2018

Governance implications

The adaptive reuse of the yakhchal as a cultural cooling hub involves several actors with different roles and responsibilities. Understanding these relationships is important for the long-term management of the site.

Stakeholders and Actors Mapping

The first group includes local residents, local craftspeople, and nearby communities. They are the main potential users of the cooling hub and also hold important knowledge about the history and social value of the site. Their involvement can help define acceptable uses and support everyday care.

The second group includes public institutions, especially the Iranian Cultural Heritage, Handicrafts and Tourism Organization (ICHHTO), the Municipality of Abarkuh, and regional planning authorities. These institutions are responsible for conservation regulations, site protection, and urban infrastructure. Their support is necessary to make adaptive reuse possible while protecting the heritage value of the yakhchal.

The third group includes technical and academic actors. These may include conservation architects, earthen construction specialists, environmental engineers, and university researchers. Their role is to provide expertise in conservation, structural assessment, and thermal performance.

The fourth group includes operational and community-support actors, such as maintenance workers, NGOs, and cultural organisations. They can contribute to daily management, repair activities, and community programmes.

The stakeholder mapping shows that the project depends on cooperation between public institutions, technical experts, and the local community. A single governing body would not be enough for the long-term management of the cultural cooling hub.

Needs Assessment

The interviews identified several needs for the conservation and future reuse of the yakhchals in Abarkuh.

1. Preservation of Traditional Knowledge

Knowledge about yakhchals is not equally shared among local stakeholders. The cultural heritage expert and the custodian showed a strong understanding of their historical function and environmental logic. The ecolodge manager had more limited knowledge and sometimes confused yakhchals with other underground infrastructures such as sardabs. This suggests that traditional knowledge is becoming fragmented.

At the same time, important local knowledge is still present. The custodian of Gonbad-e-Ali, for example, showed a detailed understanding of traditional construction methods and climatic adaptation.

Key Need:
Documentation and transmission of local knowledge about earthen construction and traditional cooling techniques.

2. Training in Traditional Earthen Construction Techniques

Three interviewees supported training for local builders and workers in traditional earthen construction. The cultural heritage expert was the exception, explaining that trained adobe specialists already work with the Iranian Cultural Heritage Organization in Abarkuh.

Local craftspeople also noted that some traditional materials and techniques are no longer widely used. This could create problems for the authenticity of future restoration work. At the same time, the interviews showed that local knowledge still exists. One construction worker explained that many people in Abarkuh have experience with adobe construction and plastering.

Key Need:
Practical training workshops on adobe construction, sarooj mortar, and traditional earthen plastering.

3. Institutional Support and Resources

Although participants showed interest in taking part in restoration, they also mentioned practical barriers. These included a lack of materials and tools, limited financial support for workers, and the absence of organised restoration programmes.

Key Need:
Funding, materials, and technical guidance from heritage authorities and the municipality.

4. Protection from Current Threats

Interviewees pointed out that many yakhchals are already in poor condition and exposed to everyday risks. These include garbage accumulation, vandalism and graffiti, and gradual material deterioration caused by neglect. One participant also noted that the main risk is not restoration itself, but the lack of protection and maintenance.

Key Need:
Basic protection measures and regular maintenance programmes.

5. Climate Adaptation and Public Use

All participants agreed that extreme summer heat affects daily life in Abarkuh. Some interviewees saw the yakhchals as possible passive cooling spaces or shaded community areas. The cultural heritage expert also suggested tourism and educational uses, such as a sharbat-khaneh serving traditional cold drinks.

These responses suggest that the yakhchals could support several contemporary uses, including heritage interpretation, climate-responsive public space, and tourism activities.

Key Need:
Adaptive reuse proposal that remain compatible with conservation principles.

Management and Maintenance Plan

Based on the interview findings, a participatory management and maintenance framework is proposed for the future use of the yakhchals as community cultural and cooling hubs. The framework brings together public institutions, local communities, and technical actors, with shared responsibilities for the long-term care of the site.

1.1 Ministry of Cultural Heritage (ICHHTO)

The Iranian Cultural Heritage, Handicrafts and Tourism Organization (ICHHTO) acts as the main authority responsible for heritage protection.
Primary responsibilities include:
approval of restoration and adaptive reuse interventions
supervision of conservation standards
documentation and monitoring of the monument
ensuring compatibility of materials and reversible interventions
providing conservation guidelines for earthen structures
The organization ensures that the project respects national heritage protection regulations and conservation ethics.

1.2 Municipality of Abarkuh

The municipality plays a key role in connecting the cooling hub with the urban and social infrastructure of the city.
Responsibilities include:
maintenance of surrounding public space
waste management and site cleanliness
installation of lighting, signage, and public access routes
coordination with tourism infrastructure
safety monitoring of the site
Municipal support is essential for preventing the current problems identified in interviews, such as garbage accumulation and neglect.

1.3 Local Community and Residents

Local residents are the main social actors in the management system, acting as users, custodians, and active participants in the restoration process. The interviews showed that the community still has useful construction knowledge, especially in earthen building techniques. One construction worker explained that many households in Abarkuh include people who work in construction, particularly in adobe building and gypsum plastering. This suggests that collective restoration work could be organised if the necessary materials and support were available.

The community can therefore contribute not only to the daily care of the site, but also to some parts of the restoration process. Community repair activities or organised workdays could support conservation while also creating a stronger sense of responsibility toward the site.

The role of the community could include:

participation in restoration and conservation works;
contribution of local construction knowledge;
daily monitoring and informal guardianship of the site;
participation in management meetings and decision-making.

1.4 Technical and Academic Experts

Technical actors provide the scientific and professional knowledge needed for the conservation and adaptive reuse of the yakhchal.

These actors include:

conservation architects;
earthen construction specialists;
environmental engineers;
academic researchers.

Their responsibilities include:

structural assessment of the dome and underground pit;
design of compatible restoration interventions;
development of conservation guidelines for earthen materials.

05
BIOCLIMATIC PERFORMANCE OF YAKHCHALS

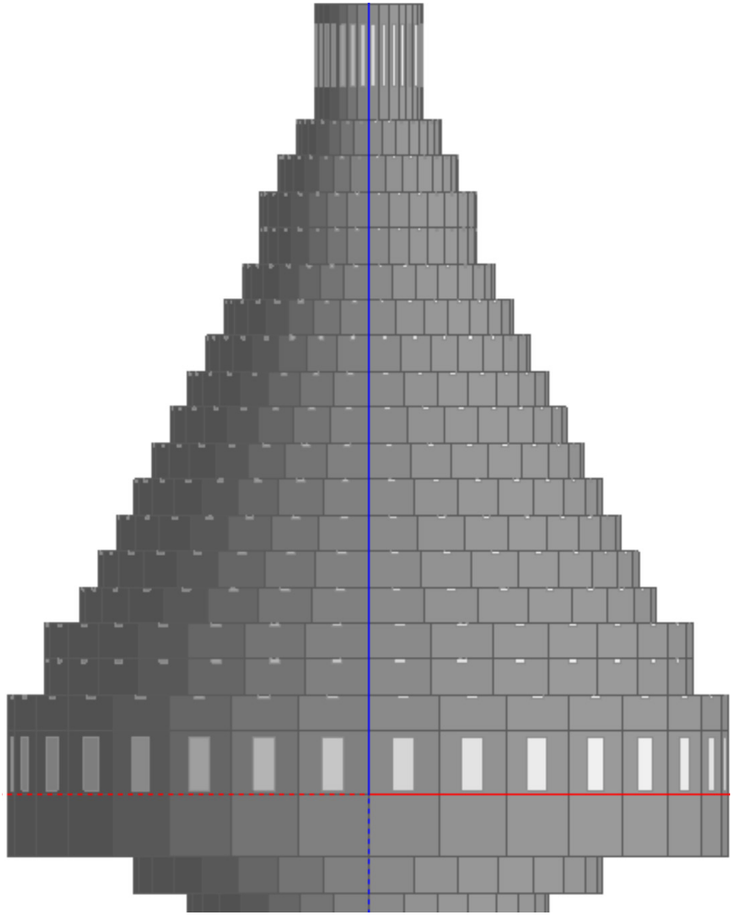


Figure 63. The model of Yakhchal in Design-Builder Software

By Author

5.1 NATURAL VENTILATION AND PASSIVE COOLING

Natural ventilation is one of the main passive cooling strategies in architecture. It is based on the movement of air through and around a building without mechanical systems, using natural pressure differences caused by wind, temperature variation, or both. In this sense, ventilation is not only a technical process but also a spatial and architectural one. Air needs a clear path to move from an inlet to an outlet through connected spaces, openings, cavities, shafts, courtyards, or vertical volumes. For this reason, the effectiveness of natural ventilation depends not only on the presence of openings, but also on the overall configuration of the building.

Natural ventilation is closely related to space because its driving forces depend on pressure differences around the building, inside rooms, and across openings or vertical shafts. Air movement requires a three-dimensional path that allows fresh air to enter and warmer or stale air to leave. Therefore, the shape, height, orientation, internal organisation, and spatial connections of a building directly affect its ventilation performance. A building can act as an obstacle to wind, but at the same time it can redirect, accelerate, slow down, or filter airflow [58].

This is particularly important in hot-arid climates, where passive cooling is becoming not only an environmental strategy but also a social need. As global temperatures increase, mechanical cooling is becoming more necessary, while it is still not accessible to many vulnerable populations. More than one billion people are exposed to highly uncomfortable indoor temperatures because of rising outdoor temperatures, inadequate building design, and limited access to air-conditioning [12]. In this context, natural ventilation can respond to both climate change and energy poverty by improving thermal comfort and reducing dependence on mechanical cooling.

Natural ventilation can cool buildings mainly in two ways. First, it can remove accumulated indoor heat by replacing warmer indoor air with cooler outdoor air when the climatic conditions are suitable. Second, it increases air movement around the human body and improves convective and evaporative cooling. Even when the air temperature does not decrease significantly, higher air velocity can improve the thermal sensation of occupants. In hot climates, air speeds of up to 1.5 m/s may still be acceptable. Studies cited by Stasi et al. show that air velocities between 0.42 and 0.67 m/s can produce an operative temperature reduction of about 3°C, while velocities between 0.92 and 1.08 m/s may create a perceived reduction of around 6°C.

The effectiveness of natural ventilation depends on several factors, including outdoor wind speed and direction, relative humidity, the indoor–outdoor temperature difference, surrounding urban conditions, opening size and position, and the internal airflow path. For this reason, natural ventilation cannot be applied as the same solution in every building. It needs to be designed according to the specific climate, site, building form, and use.

In relation to yakhchals, natural ventilation needs to be interpreted carefully. These infrastructures were not designed to maximise air exchange in the same way as contemporary naturally ventilated buildings. Their main purpose was to preserve cold conditions and reduce unwanted heat gain. Therefore, airflow inside the yakhchal was probably controlled and limited rather than continuous and strong. Its environmental performance depended on the combined effect of air movement, thermal mass, earth sheltering, night cooling, and protection from solar radiation. In this way, the yakhchal can be understood as a passive cooling infrastructure in which ventilation is only one part of a wider climatic system.

5.1.1 WIND-DRIVEN VENTILATION

Wind-driven ventilation happens when wind creates pressure differences on the surfaces of a building. The windward side is usually under positive pressure, while the leeward side and roof areas often experience lower or negative pressure. When openings are placed between these pressure zones, air can move through the building from areas of higher pressure to areas of lower pressure.

Cross-ventilation occurs when openings are located on different or opposite sides of a space. This creates a clearer airflow path and usually produces higher air change rates and a stronger cooling effect.

Cross-ventilation is generally more effective than single-sided ventilation. It can provide comfortable conditions for a greater percentage of time and may produce much higher air change rates. The study of Charles Correa's Tube House in Ahmedabad also shows that spatial continuity and the position of openings are important for effective airflow. The building form, opening configuration, and internal spatial organisation work together to determine how easily wind can move through the space.

However, the same study also shows that more ventilation is not always beneficial [12]. During the hottest hours of the day, if the outdoor air is extremely hot, excessive ventilation can increase overheating instead of reducing it. For this reason, the operation of openings is important. Openings should be controlled according to outdoor temperature, wind conditions, and the thermal condition of the building. Natural ventilation is most effective when combined with shading, thermal mass, and night cooling.

5.1.2 STACK EFFECT VENTILATION

Stack effect ventilation, also known as buoyancy-driven ventilation, is caused by differences in temperature and air density. Warm air is lighter and tends to rise, while cooler air is denser and remains at a lower level. When a building has lower inlets and higher outlets, warm air can escape from the upper openings and cooler air can enter from below. The strength of stack ventilation mainly depends on the vertical distance between the inlet and outlet and the temperature difference between indoor and outdoor air.

Buoyancy is one of the main natural forces that creates air movement. Even when airflow is not directly noticeable, air is continuously affected by thermal energy. From an architectural point of view, this means that sections, building heights, shafts, domes, courtyards, atria, and chimneys can have an environmental function in addition to their spatial or formal role. These elements can help guide and organise air movement through a building [58].

In yakhchals, the stack effect should be understood as part of a controlled thermal system. The tall conical dome creates a large vertical volume where warmer air can rise above the cooler underground chamber. Small upper openings may allow this warmer air to escape, while the lower storage area remains protected by earth sheltering and thermal mass. The aim is not to create strong ventilation, but to maintain thermal separation and stable conditions. This makes the yakhchal different from buildings where stack ventilation is mainly used to ventilate occupied spaces. In the yakhchal, buoyancy can help maintain cooler conditions in the lower part by allowing warmer air to move upward and away from the storage area.

5.2 THERMAL MASS AND THERMAL INERTIA

Thermal mass refers to the ability of a material to absorb, store, and slowly release heat over time. Materials with high thermal mass, such as adobe, rammed earth, mudbrick, and stone, can reduce indoor temperature fluctuations by slowing down heat transfer between outdoor and indoor environments. Thermal inertia is especially effective in climates with large differences between daytime and nighttime temperatures. In these conditions, buildings can absorb heat during the day and release it during the cooler night.

Thermal mass can significantly improve thermal stability in hot-arid climates by reducing peak indoor temperatures and limiting overheating. Research shows that high-mass building envelopes, when combined with passive cooling strategies, can improve indoor comfort and reduce the need for mechanical cooling [59].

Traditional earthen architecture strongly depends on thermal inertia. Thick walls absorb solar heat slowly during the day and release it gradually at night. This delayed heat transfer, known as thermal lag, helps reduce rapid changes in indoor temperature and creates more stable internal conditions.

The walls of Iranian yakhchals often exceeded 2 metres in thickness and were mainly built with adobe and sarooj mortar. These materials have low thermal diffusivity and good heat-storage capacity, helping the yakhchals maintain cooler internal conditions even during periods of extreme outdoor heat.

The conical form of the yakhchal also contributes to its thermal performance by limiting solar exposure and reducing direct heat gain. Together, the geometry and materials create an integrated passive system that depends on thermal inertia rather than mechanical refrigeration.

5.3 NIGHT COOLING AND RADIATIVE HEAT LOSS

Night cooling is a passive strategy that uses lower nighttime temperatures to remove heat stored during the day. In hot-arid climates, the difference between daytime and nighttime temperatures is often large, so nights can be much cooler than days. This makes night cooling particularly effective. When cool night air moves around or through high-mass buildings, it helps remove stored heat and prepares the interior for the following day.

Traditional Persian architecture made strong use of these nighttime cooling cycles. During the cooler hours of the night, buildings could release the heat stored during the day through ventilation and radiative exchange with the night sky.

Radiative cooling happens when surfaces release long-wave infrared radiation toward the colder sky. In clear desert conditions, where humidity and cloud cover are usually low, this heat loss can be very effective. As a result, surface temperatures can sometimes fall below the outdoor air temperature.

This principle was very important in the operation of yakhchals. During winter nights, water placed in shallow ice-making pools lost heat by radiation toward the night sky. This process could allow ice to form even when the outdoor air temperature was slightly above freezing.

The shading walls around the pools were also important. Their orientation reduced direct solar exposure during the day while keeping the pools open to the night sky. In this way, they protected the water from daytime solar radiation while supporting heat loss during the night.

Night cooling also worked together with thermal mass. During the night, the thick earthen walls released part of the heat stored during the day, allowing the yakhchal to cool again before the next daytime cycle. This repeated process of heat storage during the day and heat release at night was one of the main passive cooling principles used in traditional architecture.

5.4 EARTH SHELTERING AND SUBTERRANEAN COOLING

A study by Hassan and Sumiyoshi investigates the performance of earth-sheltered architecture in hot-arid climates, using Egypt as a representative case [14]. The research combines expert evaluation with simulation studies to examine the effectiveness of subterranean and semi-subterranean typologies. The results show that placing buildings partly or fully within the ground can improve thermal stability by reducing daily temperature fluctuations through the insulating effect of the soil. Compact forms, lower window-to-wall ratios, and careful orientation, especially toward the north, were also found to improve thermal performance. The study also highlights the importance of site selection and building arrangement. Buildings integrated into sloped terrain or organised in dense clusters can achieve better climatic performance. In addition to technical aspects, Hassan and Sumiyoshi discuss cultural perceptions of earth-sheltered architecture. They suggest that public acceptance may increase when these typologies are first introduced through communal or tourism-related functions. The study therefore provides design guidelines that show the continued relevance of earth-sheltered architecture in hot-arid regions.

In conclusion, the guidelines presented in [14] show that earth-sheltering remains an effective strategy for hot-arid climates because it can provide thermal stability, reduce energy demand, and be adapted to different scales of design. Through compact underground forms, clustered development, and careful site selection, the research supports principles already found in vernacular architecture while showing how they can still be applied in contemporary sustainable design.

5.5 GUIDELINES FROM EARTH-SHELTERED BUILDINGS IN HOT-ARID CLIMATES

1. Architectural Scale
Form: Compact, semi-subterranean or fully subterranean typologies are most effective in hot-arid regions.
Orientation: North-facing orientations maximize thermal stability and minimize solar heat gain.
Openings: Small window-to-wall ratios (around 20–30% in very hot climates, up to 50% in milder ones) balance daylight with reduced heat infiltration.
Materials: Heavy earthen construction provides thermal mass, while soil cover adds insulation.

2. Urban Scale
Clusters: Detached or compact groupings of buildings are more efficient than dispersed layouts.
Street patterns: Narrow pathways and shaded passages reduce solar exposure and create cooler microclimates.
Integration: Public facilities such as communal halls or tourist facilities can increase acceptance of earth-sheltered typologies, making them more socially viable before wider adoption in housing.

3. Site-Selection Scale
Topography: Sloped sites of around 30% inclination are ideal for embedding structures into the ground.
Exposure: Sites with minimal direct solar exposure and protection from prevailing winds enhance performance.
Vegetation & landscaping: Use of greenery and shading around entries improves microclimate at the surface.

5.6 ADAPTING BALAGUER'S BIOCLIMATIC FRAMEWORK TO YAKHCHALS

Arid climates are characterised by low rainfall, strong solar radiation, and large temperature differences between day and night. In these environments, architecture has historically needed to do more than provide shelter. It has also worked as a climatic regulator between harsh outdoor conditions and human comfort. Earthen construction has been one of the most effective responses to these conditions because it combines local availability, low embodied energy, and high thermal inertia. Over time, communities developed building methods that helped stabilise indoor temperatures and reduce resource use, making everyday life more manageable in difficult climatic conditions.

Bioclimatic Framework of Earthen Architecture

Balaguer, Mileto, Vegas, and Garcia-Soriano (2019) proposed a framework of ten bioclimatic strategies (S1–S10) found in traditional earthen dwellings across Mediterranean regions [13]. These strategies show how vernacular builders used thick earthen walls, compact urban forms, solar orientation, limited openings, and controlled ventilation to respond to climate. Thick adobe walls helped regulate temperature by absorbing heat during the day and releasing it at night. Compact layouts and narrow streets also created mutual shading and reduced solar exposure. This framework shows that traditional earthen architecture was developed through long-term adaptation to local environmental conditions rather than through random or improvised solutions.

The study of earthen architecture in arid climates has increasingly focused on its role as a bioclimatic system that can regulate temperature, reduce resource use, and support community resilience. In this context, the framework developed in [13] is particularly useful because it identifies ten main strategies (S1–S10) used in traditional earthen dwellings across the Mediterranean region. These strategies include saving materials and resources, solar capture, solar protection, thermal insulation, energy conservation, protection from rain and moisture, wind control, and controlled ventilation. Together, they provide a clear framework for understanding how vernacular architecture responds to environmental pressures.

This approach also shows the flexibility of bioclimatic strategies. Principles such as compactness, orientation, and thermal inertia are not limited to one building type or function, but can be adapted to different environmental and cultural conditions. By analysing the yakhchals through the S1–S10 framework, it becomes possible to understand how local builders combined material knowledge, climatic understanding, and social practices into a climate-responsive system. In this way, the Abarkuh yakhchals can be understood not only as important examples of Iranian vernacular heritage, but also as relevant references for sustainable architecture in arid climates.

The following table applies Balaguer's framework to the Abarkuh case and analyses the strategies at three levels: territorial integration, architectural form, and construction solutions.

Strategy	Territorial / Landscape Integration	Architectural Formalisation	Constructive Solutions
S1. Saving on means and materials	Located near clay-rich soils to minimize material transport effort and allow easy access for communal labor; often placed at settlement edges or caravan routes.	Excavation of deep subterranean pit reduces above-ground construction volume and optimizes use of natural terrain. .	Use of local adobe and mudbrick, stabilized with sarooj mortar (lime, ash, clay mix) and occasional timber for openings.The entire structure relies on local, low-carbon resources.
S2. Solar capture	Ice-making basins oriented east–west with high shading walls on the south side, capturing cold from the nocturnal sky and preventing daytime solar gain.	Orientation of basins precisely aligned with the solar trajectory, ensuring full exposure to the night sky for radiative cooling in winter months.	Reflective water surfaces and smooth earthen finishes enhance longwave heat loss; basin geometry optimized for nocturnal freezing cycles.
S3. Solar protection	The east-west orientation of shading walls minimizes solar exposure during the day while maintaining open northern views for radiation.	Conical dome geometry minimizes direct solar exposure; allowing only diffuse light to reach the surface.	Massive wall thickness (>2 m) and a limewashed sarooj coating act as thermal and reflective barriers against direct sunlight.
S4. Thermal insulation	Partial embedding of the dome into the ground stabilizes interior temperature through natural soil buffering.	Monumental conical dome with compact mass enhance internal thermal inertia.	Thick adobe walls, Sarooj waterproofing (up to 10 cm), and layers of straw/plant material placed over stored ice to reduce melting.
S5. Conservation of energy (cold retention)	Compact grouping of basins, shading walls, and dome reduces surface area exposed to the environment.	The ice storage chamber functions as a sealed thermal reservoir with restricted access to limit heat exchange.	Double walls with Sarooj coating; minimal openings; organic coverings such as straw mats or soilplaced directly above the frozen layers to preserve cold.

Table 14. Adapting Balaguer's strategies to the case of Yakchal in Abarkuh

By Author

Strategy	Territorial / Landscape Integration	Architectural Formalisation	Constructive Solutions
S6. Reduction of interior heat	Preference for shaded microclimates near settlements or gardens benefiting from residual humidity.	Deep subterranean chambers eliminate exposure to direct sunlight and wind.	Earth floors and soil cover act as thermal buffers; the earthen mass dampens diurnal temperature swings, maintaining a stable cool interior.
S7. Protection from rain	Sites positioned on gently sloped terrain to ensure rainwater drainage away from the base.	The dome's convex channels rainwater away rainfall outward, avoiding ponding at the base..	Continuous sarooj waterproof layer with drip eaves at the dome base protects walls from runoff and erosion.
S8. Protection from damp	Constructed above groundwater level to avoid capillary moisture infiltration	A raised stone or brick plinth separates the dome wall from soil contact.	Application of sarooj as a capillary barrier prevents rising damp. The lower courses occasionally reinforced with fired brick for greater durability.
S9. Protection from wind	Strategic orientation of shading walls and dome openings perpendicular to prevailing winds (typically from the northwest).	The compact, conical form disperses wind pressure and prevents turbulence near the base.	Perimeter masonry bands or thicker dome ribs increase resistance to wind erosion; external limewash smooths surfaces to reduce abrasion from sandstorms.
S10. Ventilation (controlled)	Minimal external air exposure to maintain interior thermal stability.	Small vents near the dome apex facilitate limited air exchange and release of hot air when necessary.	Openings occasionally covered with wooden trapdoors or clay flaps, allowing micro-adjustment of ventilation while preventing dust infiltration.

Analytical Discussion

The application of Balaguer's bioclimatic framework to the Abarkuh yakhchals shows how carefully Iranian vernacular builders responded to local environmental conditions. At the territorial scale, locating the yakhchals close to clay sources (S1) and above groundwater levels (S8) supported efficient use of local materials and improved stability. The orientation of the shading walls and ice-making basins supported winter nocturnal freezing (S2) while also reducing the effect of prevailing winds (S9). This shows a close relationship between architectural form and local climatic conditions.

At the architectural scale, the conical dome is one of the main elements influencing environmental performance. Its geometry reduced solar exposure (S3), while the thick earthen mass and partial connection with the ground provided high thermal inertia (S4). The underground chamber (S6) created a naturally cooler space for ice storage, while the absence of large openings (S5) reduced unwanted heat exchange. Ventilation was limited to small openings where needed (S10), showing that the yakhchal depended more on controlled enclosure than continuous airflow.

At the construction scale, adobe and mudbrick provided thermal mass, while sarooj rendering helped protect the surfaces from moisture (S7, S8). Another important technique was the use of straw, reeds, or soil directly over the stored ice as an additional insulating layer [11]. This temporary covering worked together with the permanent heavy earthen fabric to reduce heat transfer and slow down ice melting during the warmer months.

In conclusion, the Abarkuh yakhchals show that the bioclimatic strategies identified by Balaguer et al. (2019) are not limited to domestic architecture in Mediterranean climates. They can also be applied to communal infrastructures developed for survival in arid regions. By combining local materials, climatic adaptation, and cultural practices, the yakhchals functioned as active climate-responsive infrastructures. Their study is therefore relevant not only to the conservation of Iranian earthen heritage, but also to wider discussions on sustainable and low-energy design in extreme climates.

5.7 ADAPTIVE THERMAL COMFORT

Thermal comfort refers to the condition in which occupants feel satisfied with their thermal environment. According to ANSI/ASHRAE Standard 55-2017, thermal comfort depends on both environmental and personal factors, including air temperature, mean radiant temperature, humidity, air velocity, clothing insulation, and metabolic activity [16].

Traditional comfort models, such as PMV and PPD, were mainly developed through climate chamber studies under controlled conditions. These models are useful, but they often assume relatively stable indoor environments and may be too limited for naturally ventilated buildings. Naturally ventilated spaces are more variable and allow occupants to experience seasonal changes, air movement, and a closer connection with the outdoor climate. Because of this, people in naturally ventilated buildings often accept a wider range of temperatures than occupants in mechanically conditioned spaces.

Adaptive comfort models respond to this difference by recognising that thermal comfort is also influenced by climate, behaviour, expectations, and personal control. If occupants can open windows, change clothing, move to shaded areas, or adjust their activity, they may accept higher temperatures. Passe and Battaglia also emphasise that higher air speed can increase the acceptance of warmer conditions, which is especially relevant for naturally ventilated buildings.

Stasi, Ruggiero, and Berardi also use adaptive comfort as an important part of their methodology [12]. In their study, operative temperature is compared with adaptive comfort limits rather than only with fixed temperature thresholds. This is important because passive cooling strategies do not always create uniform indoor temperatures. Instead, they produce more dynamic conditions where comfort depends on the interaction between climate, airflow, thermal mass, and user adaptation.

For the yakhchal, the adaptive comfort approach is particularly relevant. The aim of adaptive reuse should not be to transform the yakhchal into a fully air-conditioned interior with standardised comfort conditions. This approach could affect the material authenticity of the heritage and would not follow its original passive environmental logic. Instead, the yakhchal can be evaluated as a naturally conditioned cooling refuge, where comfort is supported by cooler surfaces, air movement, shaded transition spaces, earth sheltering, and user adaptation.

5.8 CLIMATIC ANALYSIS OF ABARKUH

Climate data for Abarkuh were analysed using the CBE Clima Tool developed by the Center for the Built Environment at the University of California, Berkeley. The tool was used to understand the main climatic conditions of the case study area and to support the environmental analysis of the yakhchal.

Location: Abarkuh, Yazd Province, Iran
Latitude: 31.13 N
Longitude: 53.25 E
Elevation: 1527 m
Climate data source: ERA5-TMYx / EPW weather file, period of record 1940–2025.

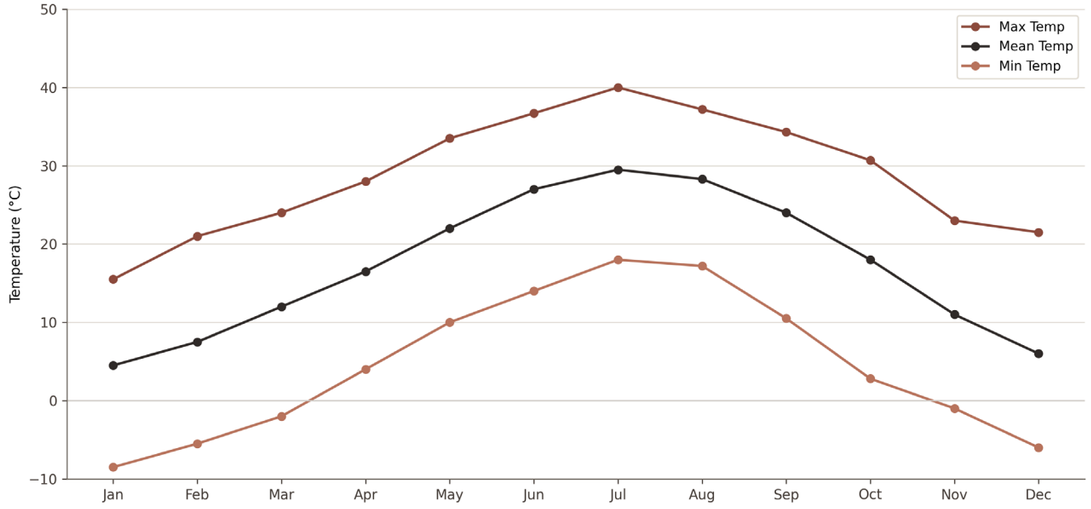


Figure 64. Monthly mean, maximum and minimum air temperature (C). By Author

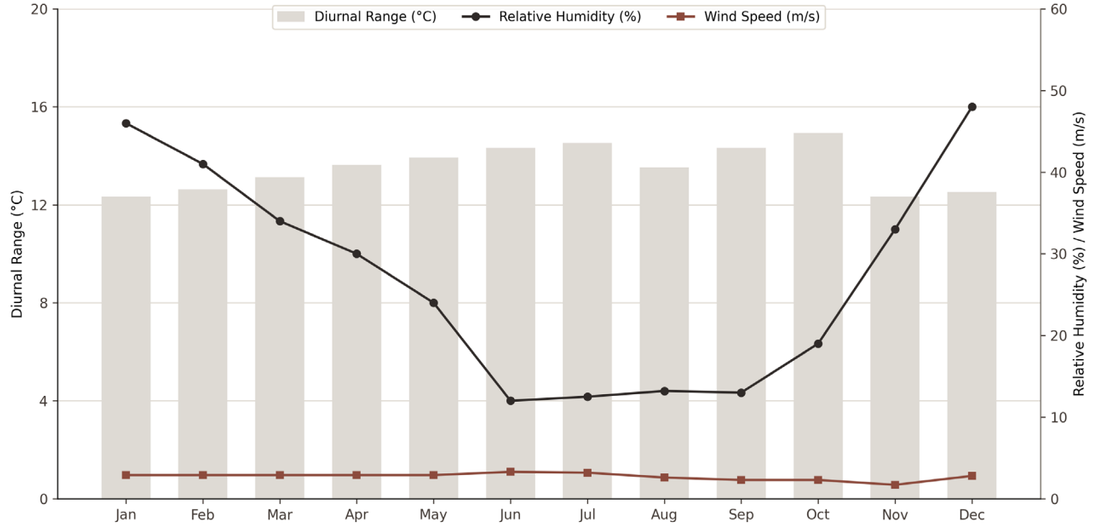
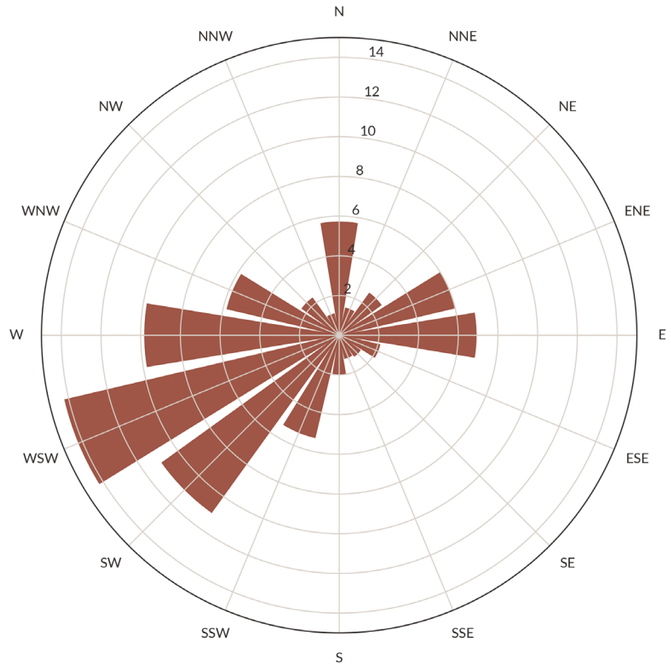


Figure 65. Monthly mean daily diurnal range(C), relative humididty(%),and wind speed (m/s)

Parameter	Value
Annual mean dry-bulb temperature	17.5°C
Maximum dry-bulb temperature	40.3°C
Minimum dry-bulb temperature	-9.1°C
Mean relative humidity	28.90%
Hours with RH below 30%	62.8% of the year
Hours above 30°C	1247 hours/year
Hours above 35°C	326 hours/year
Hours below 0°C	316 hours/year
Mean wind speed	2.19 m/s
Maximum wind speed	9.8 m/s
Annual global horizontal radiation	2223 kWh/m²/year
Average daily global radiation	6.09 kWh/m²/day
Mean daily diurnal temperature range	14.0°C
Maximum daily diurnal temperature range	19.3°C
Cooling Degree Days, base 18°C	1521.5°C·days
Heating Degree Days, base 18°C	1701.8°C·days

Table 15. Annual Climate Summary

By Author



DIRECTION	FREQUENCY (%)
N	5.7
NNE	1.4
NE	2.6
ENE	6.0
E	6.9
ESE	2.1
SE	1.3
SSE	1.2
S	2.0
SSW	5.3
SW	11.0
WSW	14.2
W	9.8
WNW	5.8
NW	2.3
NNW	1.1
CALM	0.3

(= <0.5 m/s)

Figure 66. Annual wind rose of Abarkuh showing the frequency(%) of wind occurance by direction. The dominant wind directions are mainly from the west and southwest sectors.
By Author.

Depth	Annual Behavior
0.5 m	More responsive to seasonal air temperature
2 m	More stable, summer peak around 25.9°C
4 m	Most stable, summer peak around 23.3°C

Table 16. Ground Temperature Data from EPW

By Author

Month	Mean Temp °C	Max °C	Min °C	Mean Diurnal Range °C	RH %	Wind m/s	Avg Daily GHI kWh/m²/day
Jan	4.3	15.7	-9.1	12.6	48	2.2	3.9
Feb	7.4	20.9	-6.1	13.1	40.3	2.4	4.9
Mar	11.9	24.5	-2.7	13.4	35	2.5	6.2
Apr	16.9	28.4	4.4	14.1	32.2	2.4	7
May	22.7	34.4	9.8	14.3	26.9	2.3	7.8
Jun	27.9	37.5	14.4	14.8	12.9	2.6	8.2
Jul	29.8	40.3	18.7	15	13.4	2.5	7.8
Aug	28.6	37.8	17.6	14.1	15.1	2	7.5
Sep	24.3	35	10.7	15.2	15.3	1.8	6.6
Oct	18.1	30.6	3	15.8	22.1	1.8	5.5
Nov	11.1	23.1	-1.1	12.6	37.1	1.7	4.2
Dec	6.3	21.4	-6.6	12.7	49.2	2	3.5

Table 17. Monthly Climate Table. By Author

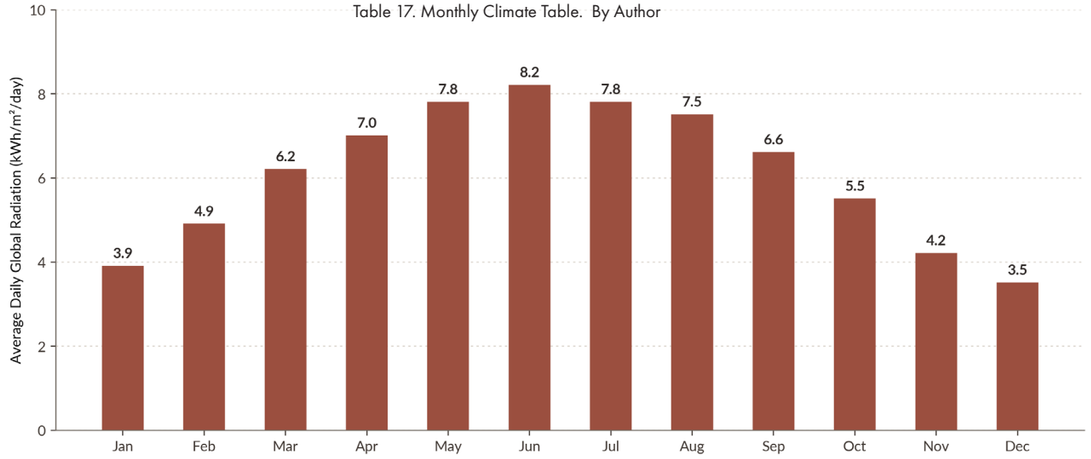


Figure 67. Monthly average daily global horizontal radiation. Abarkuh recieves very high solar energy throughout the year, peaking in June. By Author

Analytical Discussion

Abarkuh has a clearly hot-arid climate, with low humidity, strong solar radiation, and large temperature differences between day and night. The annual mean relative humidity is only 28.9%, and for around 62.8% of the year, relative humidity remains below 30%. These dry conditions increase the potential for evaporative and radiative cooling, which were both important for the historical operation of yakhchals.

The summer period, especially from June to August, is very hot, with mean monthly temperatures between 27.9°C and 29.8°C and maximum temperatures reaching 40.3°C. At the same time, the mean daily temperature range remains high, at around 14–15°C during the warm months. This shows the strong potential for night cooling. The thermal mass of adobe and Sarooj, a traditional water-resistant lime-based mortar made with lime, clay, sand, ash, and sometimes organic materials such as straw, fibres, or hair, can release stored heat during the cooler nighttime hours.

The solar radiation data also shows the importance of solar protection. Abarkuh receives approximately 2,223 kWh/m²/year of global horizontal radiation, while peak daily radiation in June reaches around 8.2 kWh/m²/day. These conditions help explain the environmental role of the yakhchal's conical dome, thick earthen envelope, and shading walls, which reduce direct solar heat gain.

The wind data shows that the dominant winds mainly come from the WSW, SW, and W directions. The mean annual wind speed of 2.19 m/s indicates a moderate potential for natural ventilation. At the same time, the dry climate and large daily temperature range make passive cooling strategies particularly suitable. Overall, the climate analysis shows that Abarkuh provides favourable conditions for the operation of yakhchals: high solar exposure requiring protection, dry air supporting evaporative and radiative cooling, strong nighttime cooling potential, and relatively stable underground temperatures supporting earth-sheltered thermal regulation. The climate data were analysed using the CBE Clima Tool developed by the Center for the Built Environment at the University of California, Berkeley.

5.9 DYNAMIC THERMAL SIMULATIONS AND RESULTS

The thermal performance of Yakhchal-e Barzan was evaluated using EnergyPlus. The geometry was modelled as one connected and well-mixed thermal zone, including the domed chamber and the underground ice pit. Three construction bands were used to represent the ground-contact pit, the thick lower wall, and the gradually tapering upper dome. The envelope was defined using adobe and Sarooj, while the underground surfaces were connected to monthly ground-temperature schedules at different depths, derived from the Abarkuh EPW weather file. The model was simulated under free-running conditions to evaluate the passive effects of thermal mass, earth coupling, and natural ventilation without mechanical conditioning or internal heat gains.

Experimentally measured thermal properties were not available for the historical Sarooj used in Yakhchal-e Barzan. For this reason, the engineered Sarooj-rich 80NK mortar was used as a dry-state proxy [63]. The assigned properties were a thermal conductivity of 1.292 W/m·K, a density of 2141 kg/m³, and a specific heat capacity of 794 J/kg·K. The adobe properties were defined as 0.669 W/m·K, 1435 kg/m³, and 1109 J/kg·K, respectively. Two operational scenarios were tested: one with the two wooden entrance doors continuously closed and another with the same openings continuously open. The apex opening remained open in both scenarios. Two consecutive weather years were simulated. The first year was used for thermal stabilisation, while the second year was used for the final analysis.

The annual mean zone-air temperature was 18.57 °C with the lower doors closed and 18.01 °C with the doors open. The slightly lower annual mean in the open scenario was mainly caused by greater exposure to cold outdoor air during winter, rather than better summer cooling. In the closed condition, temperatures remained between 6.71 °C and 29.9 °C. In the open condition, the temperature range became much wider, from −2.32 °C to 35.53 °C. The closed scenario recorded no hours above 30 °C, while the continuously open scenario produced 836 hours above 30 °C and eight hours above 35 °C.

The summer results show the strong thermal-buffering capacity of the massive earthen envelope. During June, July, and August, the outdoor environment had an average daily temperature range of 14.27 °C. With the doors closed, the indoor daily range was only 0.35 °C, giving a damping factor of 0.025. This means that only about 2.5% of the outdoor daily temperature variation reached the interior. When the lower openings were continuously open, the indoor daily range increased to 6.78 °C and the damping factor rose to 0.475. During the hours when the outdoor temperature was above 30 °C, the closed yakhchal remained on average 6.11 °C cooler than outdoors, compared with 2.82 °C in the open condition. These results show that continuous summer ventilation reduced the cooling effect created by thermal mass and ground coupling.

The airflow results help explain this difference. The annual mean air-change rate increased from 0.021 h with the wooden doors closed to 2.246 h with the doors open, which is an increase of about 105 times. In the closed condition, the interior was more protected from rapid outdoor temperature changes, allowing the massive adobe envelope and the underground pit to control the thermal response. During winter, the open condition produced 624 hours below 5 °C and 14 hours below 0 °C, with a minimum temperature of −2.32 °C. This suggests that opening the lower doors during sufficiently cold periods could allow the entry of low-temperature air needed for traditional ice formation.

Overall, the simulation shows that the environmental performance of the yakhchal depended on both its architectural form and the seasonal control of its openings. Opening during winter could support cold-air entry and freezing, while closing during summer could help preserve cool conditions and keep the interior more stable. The results therefore support a controlled seasonal strategy rather than keeping the openings continuously open throughout the year. The model represents the empty yakhchal under dry material conditions and considers sensible heat transfer.

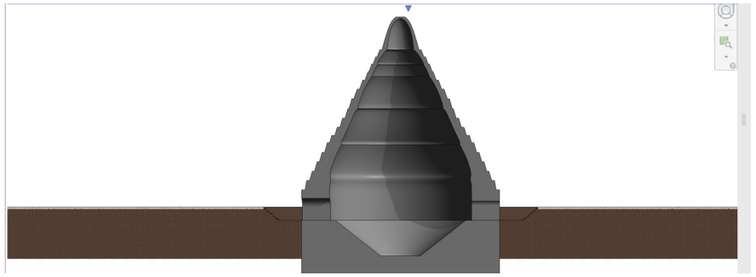


Figure 68. A connected thermal zone comprising the domed chamber and underground ice pit.

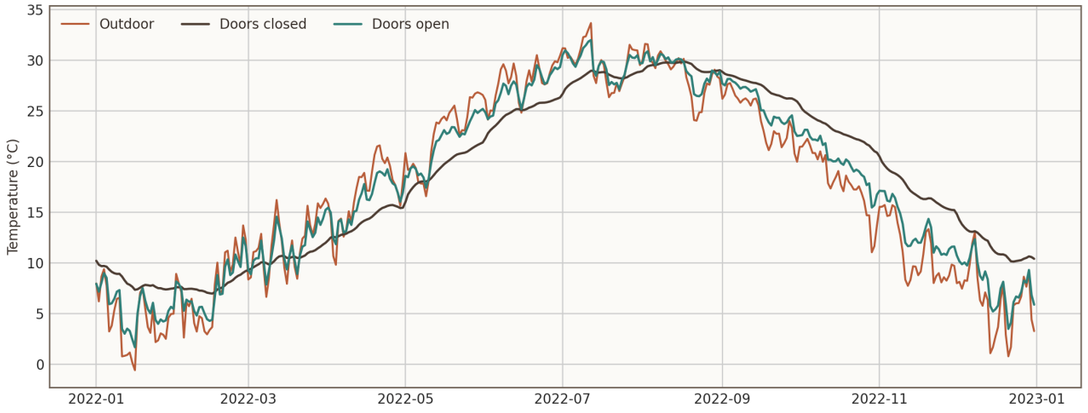


Figure 69. Daily Mean Temperature- Year Analysis

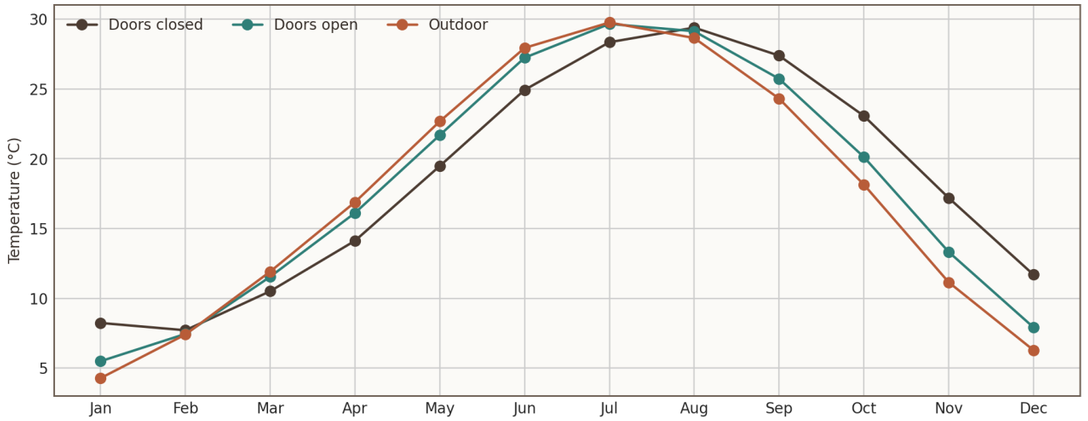


Figure 70. Monthly Mean Temperature

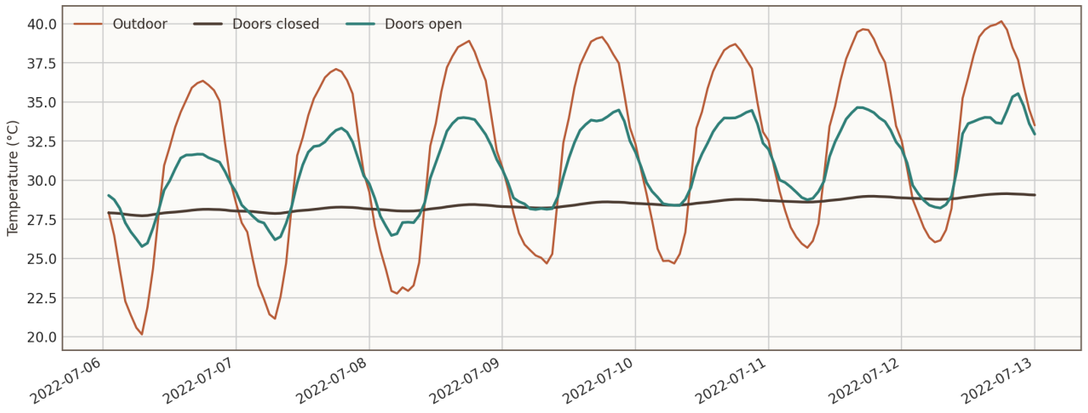


Figure 71. EPW Summer Extreme Week (6-12 July)

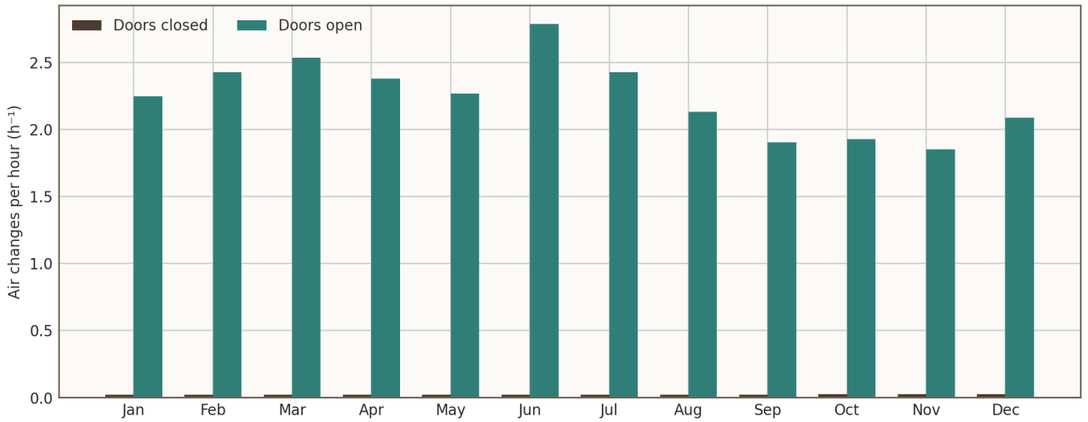


Figure 72. Monthly Mean Outdoor-Air Exchange

5.10 ADAPTIVE COMFORT ASSESSMENT

The simulated temperatures were evaluated using the occupant-controlled naturally conditioned spaces method in Section 5.4 of ANSI/ASHRAE Standard 55-2017 [16]. This method is suitable for Yakhchal-e-Barzan because it is free-running and depends on thermal mass, earth coupling, and controllable openings rather than mechanical cooling. Its application assumes that no mechanical cooling is installed, no heating is operating, occupants undertake near-sedentary activities between 1.0 and 1.3 met, clothing can be adapted between 0.5 and 1.0 clo, and the prevailing mean outdoor temperature remains between 10°C and 33.5°C. The proposed cooling-hub activities are compatible with these conditions, provided that users retain control over the entrance openings.

For each day, the prevailing mean outdoor temperature, T_pma(out), was calculated as the arithmetic mean of the seven preceding mean daily outdoor temperatures from the Abarkuh EPW weather file. The equations below define the adaptive comfort temperature and the lower and upper limits. The 80% acceptability range is the primary criterion specified by ASHRAE 55, while the 90% range is included as a stricter reference. No elevated-air-speed adjustment was applied because the simulation reports air-change rate rather than air speed within the occupied zone.

$$
\begin{aligned}
T_{\text{comfort}} &= 0.31T_{\text{pma(out)}} + 17.8 \\
T_{\text{lower,80}} &= 0.31T_{\text{pma(out)}} + 14.3 \\
T_{\text{upper,80}} &= 0.31T_{\text{pma(out)}} + 21.3 \\
T_{\text{lower,90}} &= 0.31T_{\text{pma(out)}} + 15.3 \\
T_{\text{upper,90}} &= 0.31T_{\text{pma(out)}} + 20.3
\end{aligned}
$$

The adaptive model was applicable for approximately 269 days of the simulated year. During June-August, the closed-door scenario remained within the 80% adaptive range on approximately 98.9% of days, compared with 93.5% for the open-door scenario. The difference became clearer during the 6-12 July extreme week, when the 80% acceptable range was approximately 23.7-31.0°C. With the lower doors closed, indoor temperature remained between approximately 27.7°C and 29.1°C, placing all 168 plotted hours within both the 80% and 90% ranges. With the doors continuously open, indoor temperature varied from approximately 25.8°C to 35.4°C; only 48.2% of hours remained within the 80% range and 38.7% within the 90% range.

The results identify the closed-door condition as the stronger summer operating mode for the proposed community cooling hub. Limited air exchange allows the massive adobe envelope and underground pit to moderate indoor temperature, whereas continuous opening admits hot outdoor air during daytime peaks and weakens this thermal buffering. Ventilation should therefore be controlled seasonally, with openings used during cooler night-time or transitional periods rather than continuously during hot weather. This is a screening assessment because the current model represents an empty, dry yakhchal and reports zone-air rather than operative temperature; a formal ASHRAE 55 assessment should use raw hourly operative-temperature data together with realistic occupancy, internal gains, opening schedules, and occupied-zone air speed.

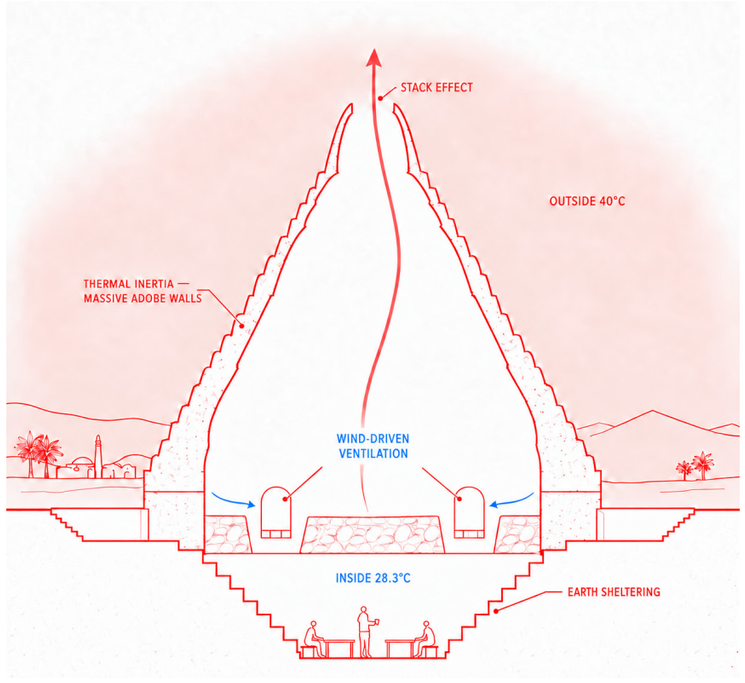


Figure 73. Thermal Section of Yakhchal Illustrating Passive Cooling Mechanisms

06
ADAPTIVE REUSE PROPOSAL: YAKHCHALS AS CULTURAL COOLING-HUBS

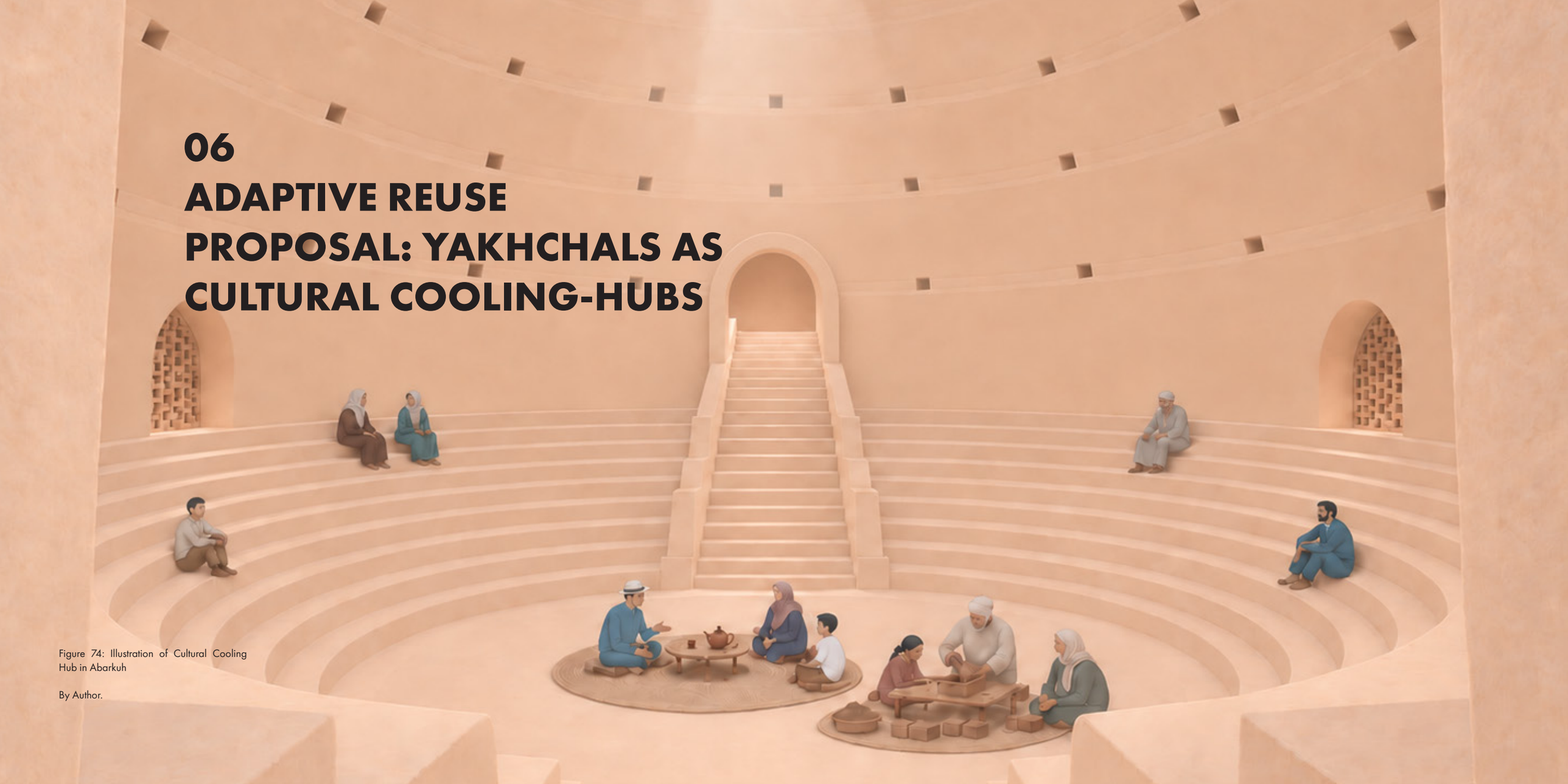


Figure 74: Illustration of Cultural Cooling Hub in Abarkuh

By Author.

6.1 CONCEPT: SHELTERED BY THE EARTH

Earthen Architecture

Cooling Hubs

Passive Cooling

Microclimate landscape

Flexible Spaces



Climate-responsive heritage

Participatory Preservation

Desert Architecture

Vulnerable Populations

Proposed Adaptive Reuse Functions for the Yakhchal

1. Cooling Hub (Climate Refuge)
The main function of the project is to reactivate the yakhchal as a passive cooling refuge during periods of extreme summer heat. The underground chamber and thick earthen walls create a more stable microclimate that can provide a shaded resting space for local residents, outdoor workers, elderly people, and visitors.

2. Cultural and Educational Center
The yakhchal can also be used as a small cultural and educational space focused on vernacular earthen architecture.

Educational activities may include:

interpretation panels explaining the traditional ice-making process;
workshops on earthen construction techniques;
demonstrations of adobe brick making and earthen plastering;
exhibitions about local architectural typologies.

Workshops could also use physical models to help participants understand the different types of earthen architecture found in Yazd Province and their climatic functions.

This educational use can support the transmission of traditional knowledge that is gradually being lost, as also highlighted in the interviews.

3.Tourism and Local Economy Integration
The project also has the potential to support the local tourism economy, especially because Abarkuh is receiving increasing attention as a heritage destination.

Possible strategies include:

guided heritage tours explaining traditional climate-responsive architecture;
craft workshops for visitors, such as adobe modelling or clay sculpture;
collaboration with local ecolodges and tourism businesses;
small-scale sale of locally produced crafts related to earthen architecture.

This approach could allow tourism to support the economic sustainability of the site while remaining compatible with its cultural and environmental value.

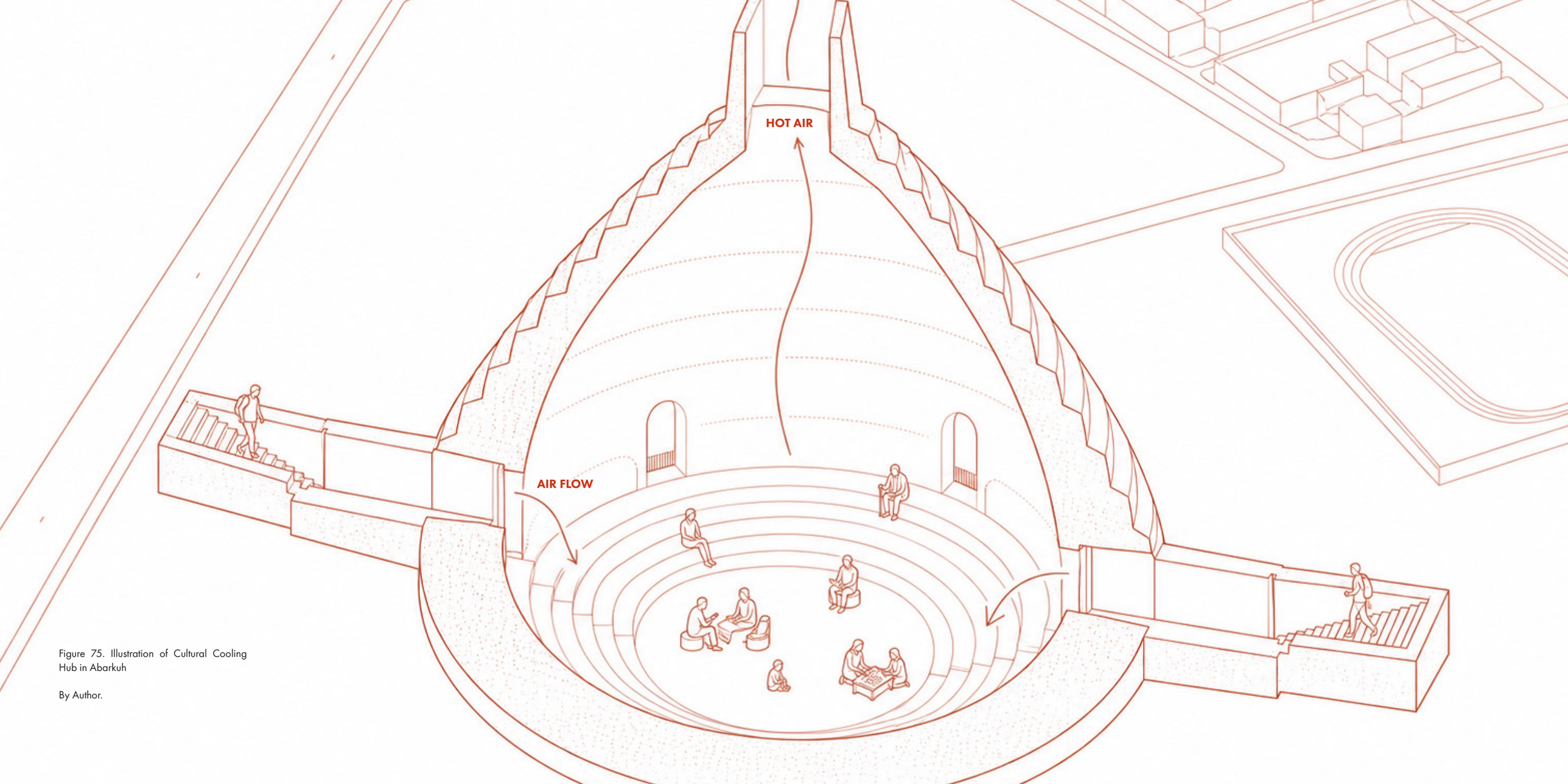
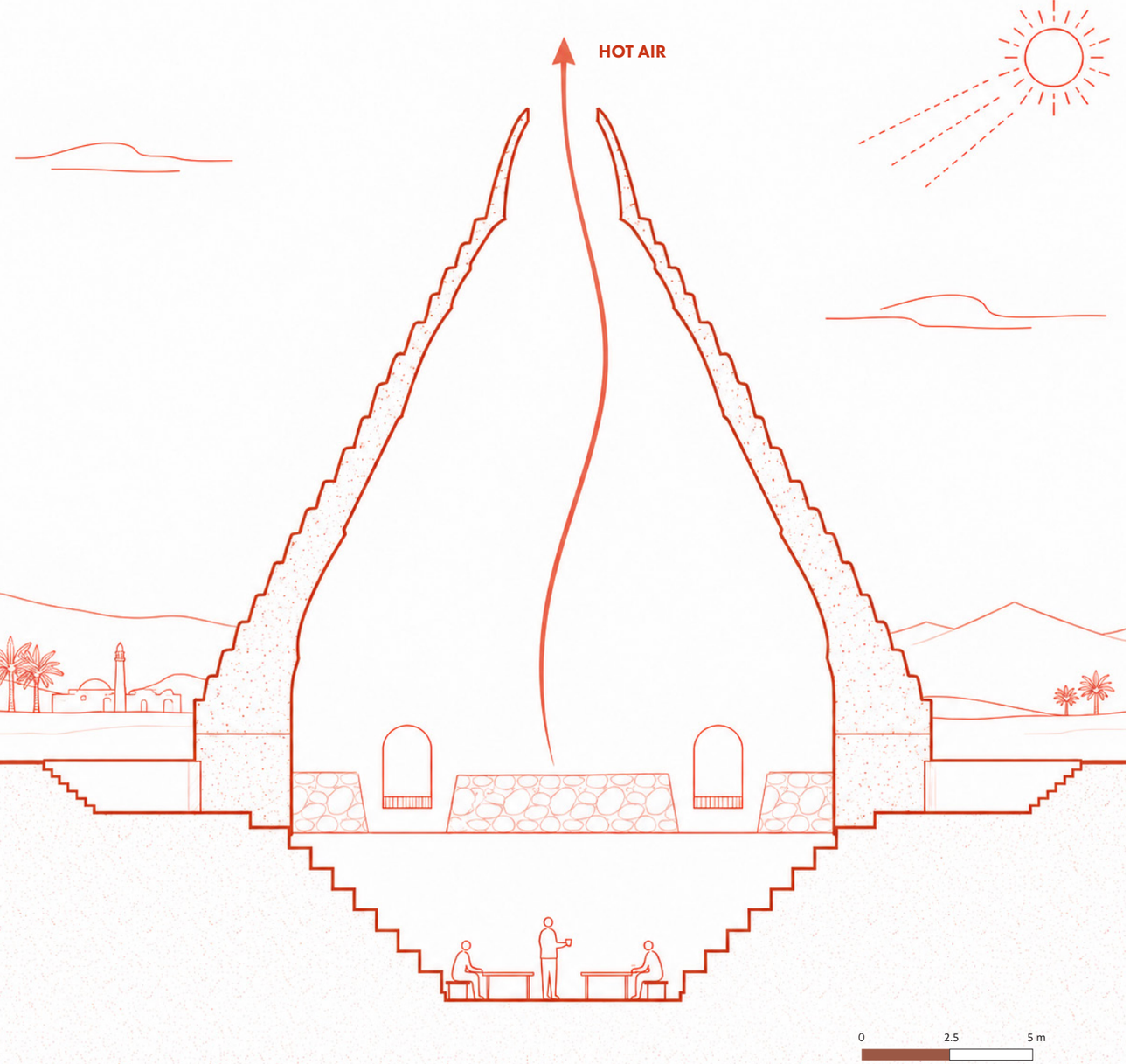


Figure 75. Illustration of Cultural Cooling Hub in Abarkuh

By Author.



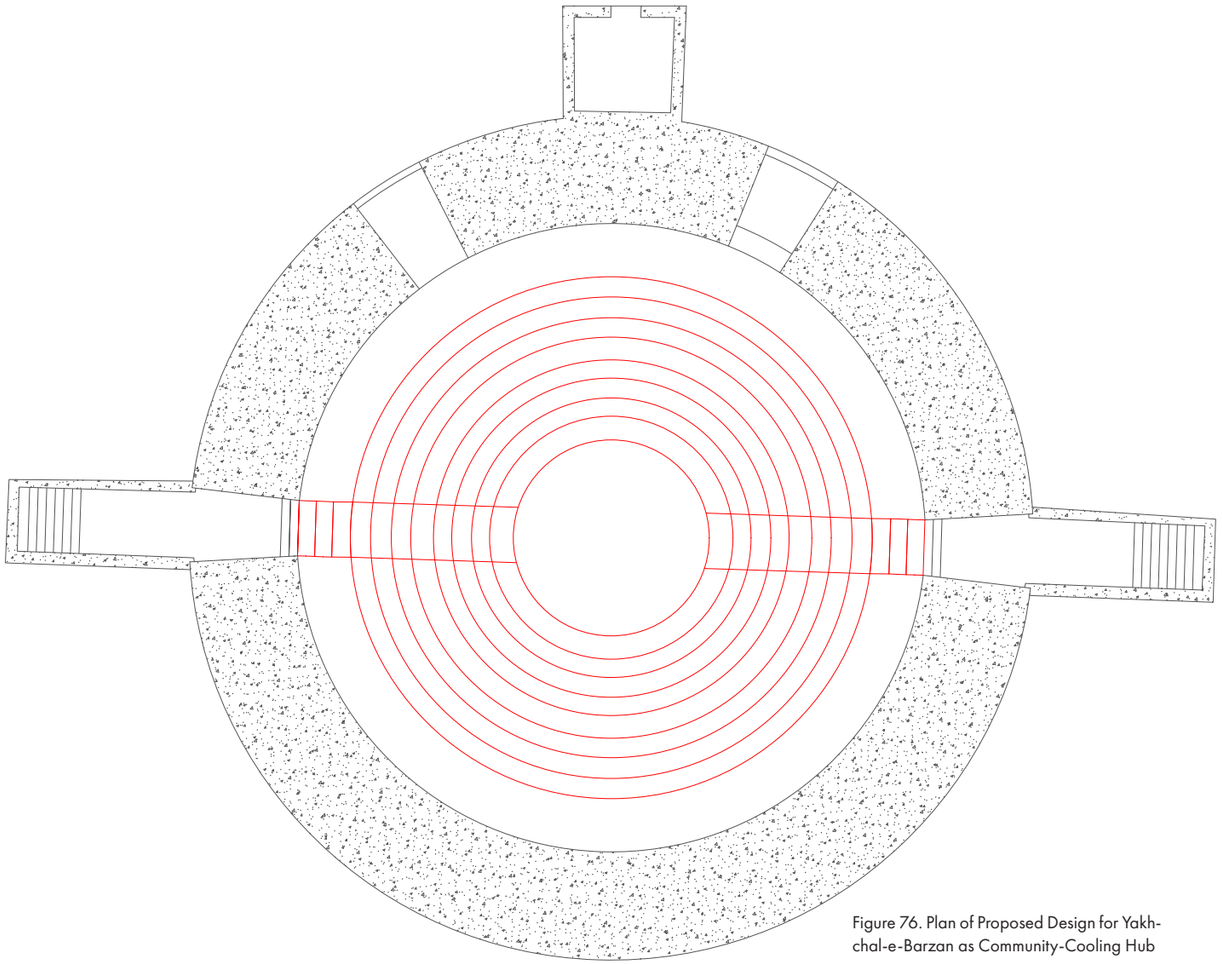


Figure 76. Plan of Proposed Design for Yakh-chal-e-Barzan as Community-Cooling Hub

by Author.



Figure 77. Illustration of Cultural Cooling Hub in Abarkuh

By Author.



Figure 78. adobe and gypsum face sculptures made by a local artist

Photo by Author During the Site Visit, 2025



Figure 79. Adobe and Gypsum hand-made figures of passive cooling infrustructures in Abarkuh made by a local artist.

Photo by Author During the Site Visit, 2025

07
APPENDIX



Figure 80. A Local Construction Worker While Doing Adobe Plastering Near the Yakhchal-e-Heg

By Author, 13 April 2025, Abarkuh, Iran.



FIRST INTERVIEW

Participant Profile

Age: 59
Gender: Male
Occupation: Local Construction Worker — Adobe/Earthen Builder

SECTION 1 — KNOWLEDGE AND PERCEPTIONS OF YAKHCHALS

Q: How familiar are you with the history and function of the yakhchals in Abarkuh?
A: Somewhat familiar.

Q: In your opinion, what is the cultural or personal value of yakhchals for the community?
A: They show the knowledge and skills of our ancestors in building for the hot climate.

Q: Do you see yakhchals mainly as heritage monuments, potential cooling infrastructure for today, tourist attractions, or something else?
A: Forgotten heritage monuments.

SECTION 2 — COMMUNITY PARTICIPATION IN RESTORATION

Q: Would you be willing to participate in the restoration or maintenance of yakhchals?
A: Yes, of course. It is our own neighborhood, so I would help as much as I can. Even if I am busy, I could participate for two or three days without payment. In this city, almost every household has two or three people who work in construction, especially in earthen building or gypsum plastering. If we all work together, we could finish the work in one or two days.

Q: What type of involvement would you prefer?
A: Manual work, including building and mud plastering.

Q: Do you think local builders and workers should be trained in traditional earthen construction techniques?
A: Yes.

Q: What support would make it easier for you to participate?
A: Providing materials, tools, and permission.

SECTION 3 — CLIMATE CHALLENGES AND HERITAGE

Q: How much does extreme heat affect your daily life and work?
A: Very much.

Q: Do you think restored yakhchals could provide solutions for cooling and public relief during hot summers?
A: Yes.

Q: Would you support adapting yakhchals as community cooling hubs, for example with shaded areas and gathering spaces? Why or why not?
A: Yes. These structures were built to keep ice frozen, so they could help people like me, who work outside, rest in the shade during hot working days.

SECTION 4 — TRUST AND COOPERATION

Q: Who should be responsible for maintaining yakhchals today?
A: A mixed partnership.

Q: Do you trust outside experts and authorities to respect community needs in restoration projects?
A: Yes, but with community supervision.

Q: What do you expect from collaboration between community members and professionals in conservation projects?
A: Experts should work with local builders. We know traditional materials and building methods, and together we can restore the yakhchals properly.

SECTION 5 — BENEFITS AND FUTURE

Q: How could the restoration of yakhchals benefit your community?
A: By strengthening cultural pride and identity and providing cooling and comfort during summer.

Q: What risks or problems do you fear if yakhchals are reused or restored?
A: I do not see risks in restoring them. Right now, they are already under threat. Sometimes there is garbage inside them, and children write on the walls. These buildings need to be protected and taken care of before they are damaged even more.

Q: Would you like younger generations to learn about and participate in the care of yakhchals?
A: Yes.

SECOND INTERVIEW

Participant Profile

Age: 50
Gender: Male
Occupation: Manager/Owner of a Tourism Ecolodge



SECTION 1 — KNOWLEDGE AND PERCEPTIONS OF YAKHCHALS

Q: How familiar are you with the history and function of the yakhchals in Abarkuh?
A: Somewhat familiar.

Q: In your opinion, what is the cultural or personal value of yakhchals for the community?
A: Yakhchals reflect the culture and civilization of Abarkuh.

Q: Do you see yakhchals mainly as heritage monuments, potential cooling infrastructure for today, tourist attractions, or something else?
A: Heritage monuments.

SECTION 2 — COMMUNITY PARTICIPATION IN RESTORATION

Q: Would you be willing to participate in the restoration or maintenance of yakhchals?
A: Yes, as a volunteer.

Q: What type of involvement would you prefer?
A: Manual work, including building and mud plastering.

Q: Do you think local builders and workers should be trained in traditional earthen construction techniques?
A: Yes.

Q: What support would make it easier for you to participate?
A: Support for ecotourism would encourage my participation.

SECTION 3 — CLIMATE CHALLENGES AND HERITAGE

Q: How much does extreme heat affect your daily life and work?
A: Somewhat.

Q: Do you think restored yakhchals could provide solutions for cooling and public relief during hot summers?
A: Yes.

Q: Would you support adapting yakhchals as community cooling hubs, for example with shaded areas and gathering spaces? Why or why not?
A: Yes, because they are our legacy.

SECTION 4 — TRUST AND COOPERATION

Q: Who should be responsible for maintaining yakhchals today?
A: A mixed partnership between local people and the Ministry of Cultural Heritage.

Q: Do you trust outside experts and authorities to respect community needs in restoration projects?
A: Yes, but with community supervision.

Q: What do you expect from collaboration between community members and professionals in conservation projects?
A: The community should be allowed to participate in decisions and be included in the decision-making process.

SECTION 5 — BENEFITS AND FUTURE

Q: How could the restoration of yakhchals benefit your community?
A: Through tourism income and by strengthening cultural pride and identity.

Q: What risks or problems do you fear if yakhchals are reused or restored?
A: A possible problem could be poor maintenance after restoration. If there is no clear management plan, this cultural heritage could fall into neglect again.

Q: Would you like younger generations to learn about and participate in the care of yakhchals?
A: Yes.



THIRD INTERVIEW

Participant Profile

Age: 44
Gender: Male
Occupation: Cultural Heritage Expert at Iranian Cultural Heritage Organization in Abarkuh

SECTION 1 — KNOWLEDGE AND PERCEPTIONS OF YAKHCHALS

Q: How familiar are you with the history and function of the yakhchals in Abarkuh?
A: Very familiar.

Q: In your opinion, what is the cultural or personal value of yakhchals for the community?
A: The yakhchals reflect the rich culture and indigenous knowledge of the people of Abarkuh, and they are recognized as national heritage sites.

Q: Do you see yakhchals mainly as heritage monuments, potential cooling infrastructure for today, tourist attractions, or something else?
A: Heritage monuments and tourist attractions.

SECTION 2 — COMMUNITY PARTICIPATION IN RESTORATION

Q: Would you be willing to participate in the restoration or maintenance of yakhchals?
A: Yes, as a volunteer.

Q: What type of involvement would you prefer?
A: Supervising and decision-making.

Q: Do you think local builders and workers should be trained in traditional earthen construction techniques?
A: No. Abarkuh already has trained conservation professionals.

Q: What support would make it easier for you to participate?
A: Financial compensation and recognition.

SECTION 3 — CLIMATE CHALLENGES AND HERITAGE

Q: How much does extreme heat affect your daily life and work?
A: Very much.

Q: Do you think restored yakhchals could provide solutions for cooling and public relief during hot summers?
A: Yes.

Q: Would you support adapting yakhchals as community cooling hubs, for example with shaded areas and gathering spaces? Why or why not?
A: Yes, if there is a good design proposal. Functions such as a sharbat-khaneh could work well. There are successful examples, such as the Meybod Yakhchal and the yakhchal in Arg-e Bam, which are now used as exhibition spaces. Moreover, their maintenance becomes easier after restoration.

SECTION 4 — TRUST AND COOPERATION

Q: Who should be responsible for maintaining yakhchals today?
A: The Ministry of Cultural Heritage.

Q: Do you trust outside experts and authorities to respect community needs in restoration projects?
A: Yes, but with supervision by the Ministry of Cultural Heritage.

Q: What do you expect from collaboration between community members and professionals in conservation projects?
A: To collaborate as effectively as possible.

SECTION 5 — BENEFITS AND FUTURE

Q: How could the restoration of yakhchals benefit your community?
A: By strengthening cultural pride and identity.

Q: What risks or problems do you fear if yakhchals are reused or restored?
A: They may suffer further damage under the guise of development and restoration.

Q: Would you like younger generations to learn about and participate in the care of yakhchals?
A: Yes.

FOURTH INTERVIEW

Participant Profile

Age: 63
Gender: Male
Occupation: Custodian of Gonbad-e-Ali



SECTION 1 — KNOWLEDGE AND PERCEPTIONS OF YAKHCHALS

Q: How familiar are you with the history and function of the yakhchals in Abarkuh?
A: Very familiar.

Researcher's note: The participant demonstrated a particularly strong collective memory compared with the other interviewees.

Q: In your opinion, what is the cultural or personal value of yakhchals for the community?
A: The yakhchals are a legacy inherited from our ancestors and possess significant cultural value.

Q: Do you see yakhchals mainly as heritage monuments, potential cooling infrastructure for today, tourist attractions, or something else?
A: Heritage monuments and tourist attractions.

SECTION 2 — COMMUNITY PARTICIPATION IN RESTORATION

Q: Would you be willing to participate in the restoration or maintenance of yakhchals?
A: Yes, if paid.

Q: What type of involvement would you prefer?
A: Sharing local knowledge and memories.

Q: Do you think local builders and workers should be trained in traditional earthen construction techniques?
A: Yes.

Q: What support would make it easier for you to participate?
A: Financial support for workers.

SECTION 3 — CLIMATE CHALLENGES AND HERITAGE

Q: How much does extreme heat affect your daily life and work?
A: Very much.

Q: Do you think restored yakhchals could provide solutions for cooling and public relief during hot summers?
A: Yes.

Q: Would you support adapting yakhchals as community cooling hubs, for example with shaded areas and gathering spaces? Why or why not?
A: Yes, because they could improve people's comfort and quality of life.

SECTION 4 — TRUST AND COOPERATION

Q: Who should be responsible for maintaining yakhchals today?
A: The local community.

Q: Do you trust outside experts and authorities to respect community needs in restoration projects?
A: No. The authorities sold some valuable golden artifacts from Gonbad-e-Ali in the past, which reduced the community's trust in official authorities.

Q: What do you expect from collaboration between community members and professionals in conservation projects?
A: They should respect each other. Working together will lead to better results.

SECTION 5 — BENEFITS AND FUTURE

Q: How could the restoration of yakhchals benefit your community?
A: In all of these ways: employment opportunities, tourism income, cultural pride and identity, and cooling and comfort during summer.

Q: What risks or problems do you fear if yakhchals are reused or restored?
A: Safety risks or the collapse of the structure.

Q: Would you like younger generations to learn about and participate in the care of yakhchals?
A: Yes.

08 BIBLIOGRAPHY

Chapter 1 — Introduction
[1] Labaf Khaneiki, M. (2020). *Qanat knowledge: Construction and maintenance. Springer.*

[2] English, P. W. (1998). *Qanats and lifeworlds in Iranian Plateau villages. In P. Wagstaff (Ed.), Landscape and culture: Geographical and archaeological perspectives* (pp. 69–98). Oxbow Books.

[3] Honari, M. (2008). *Qanats and human ecosystems in Iran, with case studies in a city, Arcadia, and a town* [Doctoral dissertation, University of Edinburgh].

[4] Eiraji, J., & Akbari Namdar, R. (2011). *Sustainable systems in Iranian traditional architecture*. Procedia Engineering, 21, 553–559. https://doi.org/10.1016/j.proeng.2011.11.2032

[5] Azizi-Bondarabadi, H., & Haji Sadeghi, N. (2025). *Preventive conservation of vernacular adobe architecture at seismic risk: Evidence from Yazd, Iran. Sustainability.*

[6] Roaf, S. (1982). *Windcatchers of Yazd* [Doctoral dissertation, University of Oxford].

[7] Mattone, M. (2016). *Sustainable interventions for the preservation of earthen heritage*. Procedia Engineering, 161, 2155–2160. https://doi.org/10.1016/j.proeng.2016.08.808

[8] Fuchs, K., Milchin, M., & Krist, G. (2024). *Preserving earthen architecture: Lessons learned from two case studies.* Journal of Archaeological Science: Reports, 55, 104449. https://doi.org/10.1016/j.jasrep.2024.104449

[9] Azizi-Bondarabadi, H., & Haji Sadeghi, N. (2022). *Local seismic culture in Iranian vernacular architecture: Evidence from Yazd earthen architecture. Built Heritage, 6(5).*

[10] Frullo, N., & Mattone, M. (2024). *Preservation and redevelopment of cultural heritage through public engagement and university involvement. Heritage*, 7(10), 5723–5747. https://doi.org/10.3390/heritage7100269

[11] Bahadori-Nejad, M., & Dehghani, A. (2005). یخ سازی طبیعی و سنتی در ایران*[Traditional and natural ice-making in Iran]*. Iranian Cultural Heritage Organization.

[12] Stasi, R., Ruggiero, F., & Berardi, U. (2024). *Natural ventilation effectiveness in low-income housing to challenge energy poverty*. Energy and Buildings, 304, 113836. https://doi.org/10.1016/j.enbuild.2023.113836

[13] Balaguer, L., Mileto, C., Vegas, F., & Garcia-Soriano, L. (2019). *Bioclimatic strategies of traditional earthen architecture.* Sustainability, 11(22), 6347.

[14] Hassan, A. S., & Sumiyoshi, D. (2018). *Earth-sheltered buildings in hot-arid climates: Design guidelines*. Renewable & Sustainable Energy Reviews, 82, 2166–2175.

[15] Cecafosso, V. (2017). *La fluidodinamica in architettura*. Altralinea Edizioni.

[16] ANSI/ASHRAE. (2017). *ANSI/ASHRAE Standard 55-2017: Thermal environmental conditions for human occupancy.* American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[17] Shiri, T., Didehban, M., & Taban, M. (2022). *Analyzing the amount of radiation absorption related to the form of Ab Anbars dome in a hot and dry climate in Yazd.* International Journal of Energy and Environmental Engineering, 13(3), 929–942. https://doi.org/10.1007/s40095-021-00437-6

Chapter 2 — Context and Analysis
[18] Mehdipour, A., & Namazian, A. (2012). *Yakhchal: Climate responsive Persian traditional architecture.* In 2012 2nd International Conference on Environment Science and Biotechnology (IPCBEE, Vol. 48). IACSIT Press. https://doi.org/10.7763/IPCBEE.2012.V48.33

[19] Hosseini, B., & Namazian, A. (2012). *An overview of Iranian ice repositories, an example of traditional indigenous architecture.* METU Journal of the Faculty of Architecture, 29(2), 223–234. https://doi.org/10.4305/METU.JFA.2012.2.10

[20] Mahdavinejad, M., & Javanrudi, K. (2012). *Assessment of ancient fridges: A sustainable method to storage ice in hot-arid climates.* Asian Culture and History, 4(2), 133–139. https://doi.org/10.5539/ach.v4n2p133

[21] Shahri, S., Ramesht, M. H., Karam, A., & Owlia, M. R. (2023). *Space identity of Yazd (Iran) and the formation of its urban civilization.* Geography and Natural Resources, 44(1), 81–89. https://doi.org/10.1134/S1875372823010109

[22] Research Institute of Cultural Heritage and Tourism. (2002). *National Heritage registration file of Yakhchal-e Aqa (Registration No. 7752)* [Archival document]. Central Library Archives, Tehran, Iran.

[23] Zarnoosheh, F. (2025, April). *Field survey and photographic documentation of Agha Yakhchal, Abarkuh [Unpublished field notes and photographs]*. Personal archive.

[24] Kalantari, M. M. (2025, July 31). گزارش‌های نگران‌کننده از وضعیت یخچال‌های تاریخی ابرکوه [*Concerning reports on the condition of Abarkuh's historic ice houses] [Field video report in Persian]*. Novinshahrsaz.

[25] Islamic Republic News Agency. (2018, December 19). یخدان ریگ‌آباد محوطه‌سازی می‌شود *[Rig-Abad Ice House to undergo landscaping*].

[26] Heritage Aria News Agency. (2022, January 15). مرمت اضطراری یخدان زریسف کرمان تا ۲ هفته دیگر آغاز می‌شود *[Emergency restoration of Zarisf Ice House in Kerman to begin within two weeks*].

[27] Heritage Aria News Agency. (2008, November 22). یخچال قاجاری شهرستان مراغه همچنان استوار است *[The Qajar-period ice house of Maragheh remains standing].*

[28] Quds Online. (2023, May 20). مرمت اضطراری یخدان‌های تاریخی سبزوار آغاز شد *[Emergency restoration of Sabzevar's historic ice houses has begun]*.

[29] Islamic Republic News Agency. (2024, February 6). مرمت یخدان تاریخی سبزوار پایان یافت *[Restoration of the historic Sabzevar Ice House completed].*

[31] Islamic Republic News Agency. (2016, September 25). حریم اثر تاریخی یخدان رحیم‌آباد بیرجند به تصویب رسید *[Protective buffer of the historic Rahimabad Ice House in Birjand approved].*

[32] Tasnim News Agency. (2021, March 16). پروژه بهسازی دیوار یخدان بیرجند بهره‌برداری شد *[Birjand ice-house wall improvement project inaugurated].*

Chapter 3 — Case Study: Yakhchals of Abarkuh

[33] Islamic Republic News Agency. (2020, March 5). سرو کهنسال ابرکوه در انتظار ثبت جهانی است *[Ancient Cypress of Abarkuh awaits World Heritage registration].*

[34] Iran Deserts Group. (2012, February 14). یخچال برزن، ابرکوه *[Barzan Ice House, Abarkuh].*

[35] IRIB News. (2020). یخچال تاریخی ابرکوه جانی دوباره می‌گیرد *[Historic Abarkuh ice house comes back to life].*

[36] Destination Iran. (n.d.). بازدید قلعه رباط ابرکوه *[Visiting Robat Castle of Abarkuh].*

[37] Heritage Aria News Agency. (2020, August 15). پیشرفت ۷۵درصدی مرمت منارەهای نظامیه ابرکوه [*progress in restoration of the Nezamieh Minarets of Abarkuh].*

[38] Islamic Republic News Agency. (2025, May 16). خانه آقازاده در ابرکوه، تنها خانه جهان با بادگیرهای دو طبقه *[Aghazadeh House in Abarkuh, the world's only house with two-storey windcatchers]*.

[39] Heritage Aria News Agency. (2024, February 4). خانه صولت ابرکوه؛ نمونه کامل و شگفت‌انگیزی از اوج هنر گچ‌بری و مقرنس‌کاری *[Solat House of Abarkuh: A complete and remarkable example of the pinnacle of stucco and muqarnas art].*

[40] Heritage Aria News Agency. (2023, March 13). پذیرش مقاله تحلیلی گنبد عالی ابرکوه در هشتمین کنگره سالانه بین‌المللی عمران؛ معماری و توسعه شهری *[Analytical study of Gonbad-e Ali accepted at the 8th International Congress of Civil Engineering, Architecture and Urban Development].*

[41] Aching Vasquez, J., Marcus, B., & Vila-Cha, E. (2022). *ICOMOS–ISCEAH glossary of earthen materials deterioration patterns [Conference poster].* Terra 2022: 13th World Congress on Earthen Architectural Heritage, Santa Fe, NM, United States.

Chapter 4 — Community and Social Practices

[42] *UNESCO. (1972). Convention concerning the protection of the world cultural and natural heritage.*

[43] *UNESCO World Heritage Centre. (2025). Operational guidelines for the implementation of the World Heritage Convention.*

[44] *UNESCO. (2003). Convention for the safeguarding of the intangible cultural heritage.*

[45] *UNESCO. (2011). Recommendation on the historic urban landscape, including a glossary of definitions.*

[46] *Council of Europe. (2018). The Council of Europe framework convention on the value of cultural heritage for society: Faro Convention Action Plan Handbook 2018-2019.* Council of Europe.

[47] Chi, T. S. (2025). *Beyond participation in tribal housing and perpetuation of earthen architectural traditions.* In L. Rainer, L. F. Guerrero Baca, F. Matero, & L. Meyer (Eds.), Terra 2022: Proceedings of the 13th World Congress on Earthen Architectural Heritage, Santa Fe, New Mexico, USA, June 7–10, 2022 (pp. 142–148). Getty Conservation Institute. https://doi.org/10.2307/jj.32155379.25

[48] Dhar, S. (2025). *The ethics of representing stakeholders in conservation decision making: Some questions and a probable solution from the Himalayan region.* In L. Rainer, L. F. Guerrero Baca, F. Matero, & L. Meyer (Eds.), Terra 2022: Proceedings of the 13th World Congress on Earthen Architectural Heritage, Santa Fe, New Mexico, USA, June 7–10, 2022 (pp. 149–153). Getty Conservation Institute. https://doi.org/10.2307/jj.32155379.26

[49] Cancino, C., Cardenas Fuentes, R., Macchioni, E., Mellado, J. C., Miranda, C., & Paliza Flores, V. S. (2025). *La importancia de ser el senor Cardenas: El rol de la comunidad en la conservacion y mantenimiento del templo de Kunotambo, Peru.* In L. Rainer, L. F. Guerrero Baca, F. Matero, & L. Meyer (Eds.), Terra 2022: Proceedings of the 13th World Congress on Earthen Architectural Heritage, Santa Fe, New Mexico, USA, June 7–10, 2022 (pp. 154–159). Getty Conservation Institute. https://doi.org/10.2307/jj.32155379.27

[50] Tenze, A., Cardoso Martinez, F. A., Abad, C., & Allaico, C. (2025). *La Casa-Hacienda de Susudel: Un proyecto de cocreacion y beneficio comunitario.* In L. Rainer, L. F. Guerrero Baca, F. Matero, & L. Meyer (Eds.), Terra 2022: Proceedings of the 13th World Congress on Earthen Architectural Heritage, Santa Fe, New Mexico, USA, June 7–10, 2022 (pp. 167–172). Getty Conservation Institute. https://doi.org/10.2307/jj.32155379.29

[51] Mileto, C., Vegas Lopez-Manzanares, F., Cristini, V., & Garcia-Soriano, L. (2021). *Earthen architecture in the Iberian Peninsula: A portrait of vulnerability, sustainability and conservation.* Built Heritage, 5, Article 24. https://doi.org/10.1186/s43238-021-00043-9

[52] Mileto, C., Vegas, F., Cristini, V., & Garcia-Soriano, L. (2020). The research project *"Earthen architecture in the Iberian Peninsula: Study of natural, social and anthropic risks and strategies to improve resilience (RISK-Terra)."* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIV-M-1-2020, 871–876. https://doi.org/10.5194/isprs-archives-XLIV-M-1-2020-871-2020

[53] Mileto, C., & Vegas Lopez-Manzanares, F. (2022). *Earthen architectural heritage in the international context: Values, threats, conservation principles and strategies.* Journal of Cultural Heritage Management and Sustainable Development, 12(2), 192–205. https://doi.org/10.1108/JCHMSD-06-2021-0115

[54] Mileto, C., & Vegas, F. (2023). *Heritage for people: A project for connecting people with their tangible and intangible heritage.* In L. Dipasquale, S. Mecca, & L. Montoni (Eds.), Heritage for people: Sharing vernacular knowledge to build the future (pp. 16–29). DIDA Press.

[55] Heinsen, C., & Pereira, M. (2025). *Conservacion sostenible en comunidad: Aprendizajes tecnicos y adaptativos de la conservacion de templos andinos en Arica y Parinacota, Chile.* In L. Rainer, L. F. Guerrero Baca, F. Matero, & L. Meyer (Eds.), Terra 2022: Proceedings of the 13th World Congress on Earthen Architectural Heritage, Santa Fe, New Mexico, USA, June 7–10, 2022 (pp. 180–186). Getty Conservation Institute. https://doi.org/10.2307/jj.32155379.31

[56] Mazirh, K., Ibnoussina, M., & Kasimi, R. (2025). *Participatory planning and management: A tool for the conservation and enhancement of Douar Azrou in Morocco.* In L. Rainer, L. F. Guerrero Baca, F. Matero, & L. Meyer (Eds.), Terra 2022: Proceedings of the 13th World Congress on Earthen Architectural Heritage, Santa Fe, New Mexico, USA, June 7–10, 2022 (pp. 173–179). Getty Conservation Institute. https://doi.org/10.2307/jj.32155379.30

[57] Ragab, A., Marchi, L., Mazzoni, E., Silvani, P., & Damiano, S. (2025). *Drought-proof communities: Learning from vernacular architecture and adopting contemporary solutions to tackle desertification.* In M. Balzani, F. Maietti, & F. Raco (Eds.), Heritage at risk: Improving resilience and awareness towards preservation, risk mitigation and governance strategies (pp. 424–437). CRC Press. https://doi.org/10.1201/9781003530787-49

Chapter 5 — Bioclimatic Performance of Yakhchals
[58] Passe, U., & Battaglia, F. (2015). *Designing spaces for natural ventilation: An architect's guide.* Routledge.

[59] Kruger, E. L., Gonzalez-Cruz, E. M., & Givoni, B. (2010). *Effectiveness of indirect evaporative cooling and thermal mass in a hot arid climate.* Building and Environment, 45(6), 1422–1433. https://doi.org/10.1016/j.buildenv.2009.12.005

[60] Hago, A. W., & Al-Rawas, A. A. (1997). *Properties of the Omani Sarooj*. Engineering Journal of the University of Qatar, 10, 81–91.

[61] Polidori, G., Aras-Gaudry, A., Beaumont, F., Bogard, F., Murer, S., Lachi, M., Maalouf, C., Moussa, T., Bliard, C., Fronteau, G., & Hamard, E. (2024). *Adobe bricks of the Champagne Region (France): Characterization of a chalky raw earth construction material.* Materials, 17(10), 2307. https://doi.org/10.3390/ma17102307

[62] Lawrie, L. K., & Crawley, D. B. (2026). *Development of global typical meteorological years (TMYx)* [Weather database]. Climate.OneBuilding.Org.

[63] Meddah, M. S., Benkari, N., Al-Saadi, S. N., & Al Maktoumi, Y. (2020). *Sarooj mortar: From a traditional building material to an engineered pozzolan – mechanical and thermal properties study.* Journal of Building Engineering, 32, 101754. https://doi.org/10.1016/j.jobe.2020.101754

LIST OF FIGURES

Chapter 1— Introduction

Figure 1. Aerial photograph of Qanat and ice-house of Aqa, 1963 — p. 2

Figure 2. Aerial view of a traditional Persian qanat in Iran, with a linear sequence of vertical access shafts — p. 4

Figure 3. Badgir (windcatcher) — p. 6

Figure 4. Vertical section illustrating ab-anbar architectural components — p. 7

Figure 5. Section-perspective of ab-anbar — p. 9

Figure 6. Yakhchal-e Heg (Icehouse of Heg) — p. 10

Figure 7. Abarkuh city center — p. 16

Chapter 2— Context and Analysis

Figure 8. Historic photograph of a yakhchal near Ashgabat, present-day Turkmenistan, c. 1910 — p. 18

Figure 9. Sketches of the Iranian yakhchal — p. 21

Figure 10. Three domed yakhchals with different types of shading walls in Yazd Province — p. 22

Figure 11. Ice-house in Qom (1703), depicting a stepped conical dome and shading wall of a traditional yakhchal — p. 23

Figure 12. A Safavid-period icehouse and caravanserai, drawing by Jules Laurens — p. 24

Figure 13. Schematic diagram of a traditional Iranian ice-house (yakhchal), showing the shading walls, freezing pool, and domed storage chamber — p. 25

Figure 14. Ice Houses in Yazd Province — p. 34

Figure 15. Ice Houses in Kerman Province — p. 36

Figure 16. Ice Houses in Semnan Province — p. 38

Figure 17. Ice Houses in Isfahan Province — p. 40

Figure 18. Ice Houses in East Azerbaijan Province — p. 42

Figure 19. Ice Houses in West Azerbaijan Province — p. 44

Figure 20. Ice Houses in Markazi Province — p. 46

Figure 21. Ice Houses in Razavi Khorasan Province — p. 48

Figure 22. Ice Houses in South Khorasan Province — p. 50

Figure 23. Ice Houses in Alborz Province — p. 52

Chapter 3— Case Study: Yakhchals of Abarkuh

Figure 24. Yakhchal-e Heg (Icehouse of Heg) — p. 54

Figure 25. Aerial photograph of the agricultural landscape and ice-making structures associated with the yakhchal system, 1963 — p. 58

Figure 26. Aerial photograph of the agricultural landscape and ice-making structures associated with the yakhchal system, 1994 — p. 59

Figure 27. Aerial photograph of Abarkuh City, 2026 — p. 60

Figure 28. Shading wall of Yakhchal-e Aqa (Icehouse of Aqa) — p. 63

Figure 29. Shading wall of Yakhchal-e Aqa (Icehouse of Aqa) — p. 64

Figure 30. Yakhchal-e Barzan (Icehouse of Barzan) — p. 65

Figure 31. Yakhchal-e Heg (Icehouse of Heg) — p. 66

Figure 32. Robat Castle — p. 67

Figure 33. Abarkuh Sarv (Cypress of Abarkuh) — p. 68

Figure 34. Nezamieh Minarets of Abarkuh — p. 69

Figure 35. Aqazadeh Boutique Hotel, Abarkuh — p. 70

Figure 36. Solat House (Khaneh-ye Solat), Abarkuh, Yazd Province, Iran — p. 71

Figure 37. Solat House (Khaneh-ye Solat), Abarkuh, Yazd Province, Iran: a Qajar-period courtyard house now functioning as the Abarkuh Anthropology Museum — p. 72

Figure 38. Gonbad-e Ali — p. 73

Figure 39. Gonbad-e Ali — p. 74

Figure 40. Field survey of Yakhchal-e Heg (Icehouse of Heg) — p. 76

Figure 41. Field survey photographs of the Aqa and Heg Ice Houses, taken in April 2025 — p. 78

Figure 42. Icehouse of Aqa: Plan and Section — p. 79

Figure 43. Interior of Yakhchal-e Barzan dome — p. 81

Figure 44. Exterior of Yakhchal-e Barzan dome / Stratigraphy diagram of the yakhchals — p. 82

Figure 45. Interior of Yakhchal-e Barzan — p. 84

Figure 46. Yakhchal-e Barzan — p. 85

Figure 47. The Dome of Yakhchal-e Barzan — p. 90

Figure 48. Decay representation on the western facade of Yakhchal-e Barzan — p. 91

Chapter 4 — Community and Social Practices

Figure 49. Yakhchal in a village landscape near the Turkish border, Iran, 1955 — p. 94

Figure 50. The Faro Convention methodology for cooperative heritage governance — p. 96

Figure 51. Participants in a mud plastering workshop at Ohkay Owingeh, New Mexico (2012), as part of the Owe’neh Bupingeh Restoration Project — p. 97

Figure 52. Meeting with village elders in Shey, Ladakh (2002), to discuss the proposed conservation of wall paintings at the Temple of Dorje Chenmo — p. 98

Figure 53. Workers of the Direccion Desconcentrada de Cultura and residents of Kunotambo transporting adobe prepared on-site using local materials and traditional techniques — p. 99

Figure 54. Community members of Susudel engaged in hands-on training for traditional adobe brick production — p. 100

Figure 55. Children participating in hands-on earthen architecture activities at the UPV Children's and Summer Schools, Universitat Politecnica de Valencia — p. 102

Figure 56. Community gathering during Festival Arica Barroca 2018 in Pachama, Chile — p. 104

Figure 57. Workers preparing ice in shallow freezing ponds at the yakhchal complex of Jolfa, Isfahan — p. 106

Figure 58. Workers preparing ice in shallow freezing ponds at the yakhchal complex of Jolfa, Isfahan — p. 107

Figure 59. Transport of harvested ice blocks by mule from a yakhchal in Iran — p. 108

Figure 60. WHO Diagram — p. 111

Figure 61. HOW Diagram — p. 112

Figure 62. WHAT Diagram — p. 112

Chapter 5 — Bioclimatic Performance of Yakhchals

Figure 63. The model of Yakhchal in DesignBuilder software — p. 120

Figure 64. Monthly mean, maximum, and minimum air temperature (°C) — p. 135

Figure 65. Monthly mean daily diurnal range (°C), relative humidity (%), and wind speed (m/s) — p. 136

Figure 66. Annual wind rose of Abarkuh showing the frequency (%) of wind occurrence by direction — p. 138

Figure 67. Monthly average daily global horizontal radiation — p. 139

Figure 68. A connected thermal zone comprising the domed chamber and underground ice pit — p. 142

Figure 69. Daily Mean Temperature – Year Analysis — p. 143

Figure 70. Monthly Mean Temperature — p. 143

Figure 71. EPW Summer Extreme Week (6–12 July) — p. 144

Figure 72. Monthly Mean Outdoor-Air Exchange — p. 144

Figure 73. Thermal Section of Yakhchal Illustrating Passive Cooling Mechanisms — p. 146

Chapter 6 — Adaptive Reuse Proposal: Yakhchals as Cultural Cooling Hubs

Figure 74. Illustration of Cultural Cooling Hub in Abarkuh — p. 147

Figure 75. Illustration of Cultural Cooling Hub in Abarkuh — p. 151

Figure 76. Plan of Proposed Design for Yakhchal-e-Barzan as Community Cooling Hub — p. 154

Figure 77. Illustration of Cultural Cooling Hub in Abarkuh — p. 156

Figure 78. Adobe and gypsum face sculptures made by a local artist — p. 157

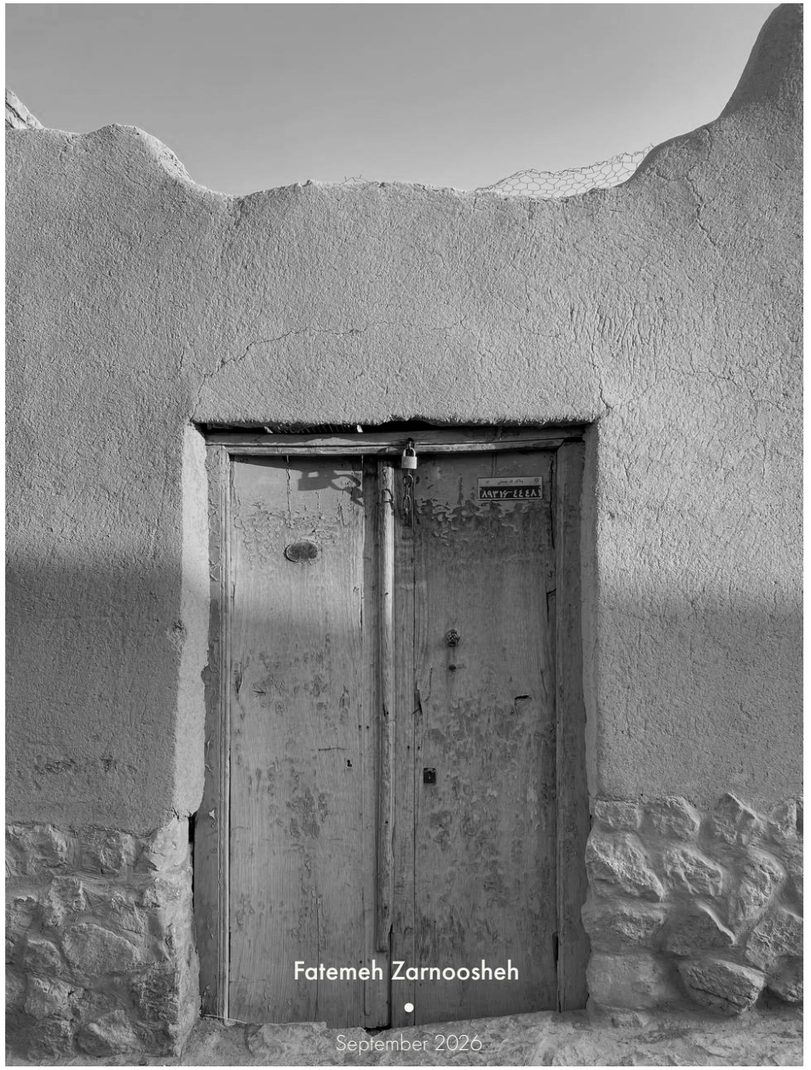
Figure 79. Adobe and gypsum handmade figures of passive cooling infrastructures in Abarkuh made by a local artist — p. 158

Chapter 7 — Appendix

Figure 80. A Local Construction Worker While Doing Adobe Plastering Near Yakhchal-e-Heg — p. 160

The earth is the only answer.

Nader Khalili, Architect.



The yakhchal was a monumental earthen infrastructure that enabled the production and preservation of ice in hot desert climates.

The Thesis investigates:

How did Iranian vernacular infrastructures, especially yakhchals, respond to the environmental challenges of hot-arid climates?

To what extent do the thermal inertia of the massive adobe envelope and the earth-sheltered configuration of the the yakhchals of Abarkuh reduce, delay, and stabilize indoor operative temperatures during hot periods?

How can local residents, workers, heritage experts, and tourism actors collaborate and participate in the conservation, management, and reuse of the yakhchal?

How can conservation diagnosis, environmental simulation, and community participation be translated into a reversible adaptive reuse strategy for a cultural and cooling hub?

The core subject of the research is to reimagine the yakhchal as living infrastructure: a place where conservation, cultural memory, passive cooling, and community life come together to strengthen resilience in a warming climate.

SEPTEMBER 2026