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# Iranian vernacular architecture: notable example of a thermal mass

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***Abstract***

*In some climates, massive buildings made of stone, masonry, concrete, earth and … can be utilized as one of the simplest and most effective ways of reducing building heating and cooling loads. Very often such savings could be achieved in the design stage of the building and with a relatively low-cost. Such declines in building envelope heat losses combined with optimized material configuration and proper amount of thermal insulation in the building envelope could help to decrease the building's cooling and heating energy demands and building related co2 emission into environment. This paper presents a typical study of thermal mass buildings, especially, a kind of masonry building called YAKHCHAL, where most of the buildings are constructed out of mud or sun-dried bricks. They behave like a thermal mass building types. In this climate, there are great many buildings which have been adapted to their climatic conditions. Such traditional solutions may help to overcome the energy crisis which the mankind faces today and may face in the future.*

*Keywords: Yakhchal, Ice-house, Thermal mass, Earth-sheltered building, Iranian vernacular building*

## 1. Introduction

Thermal capacity is the ability of a material to store heat, and is roughly proportional to the material's mass or its weight. A large quantity of dense material will hold large quantity of heat. Light, fluffy and small pieces of material can hold small quantities of heat.Thermal capacity is measured as the amount of heat required to raise the temperature of a unit (by volume or weight) of the material by one degree Celsius. Water has a higher thermal capacity than any other common material at normal air temperatures. Consequently, the heat from the sun retained by a large body of water during the day will only gradually be given off into the air during the cooler night. This is why, once a lake or an ocean warms up, it will stay warm even after the air cools off [1].

In small cities located on edges of deserts, where the historical textures are not yet lost among the new parts of city , one is often confronted with huge cone-like structures called Yakh-chal (the ice-house). These structures resemble mountains rising above the surface of the desert. Existence of the ice-house as a response to the need for ice in these cities (where temperature can rise up to 50 degrees Celsius in summer) is a sign of climatic conformity of the historical cities to the hot and arid climate of the desert. These cities have succeeded in using the great temperature fluctuation round the clock and throughout the year as a source of energy. In residential buildings, materials with high heat transmission delay time have been utilized. Nighttime coolness is used during the day and day time heat is utilized over the night.

Thus, prior to analyzing Yakh-chals, and because of their climatic behavior, "thermal mass" and "earth-sheltered structures" will be shortly introduced. Therefore, this article will include three main topics: Thermal mass, Earth-sheltered structures and Yakh-chals.

## 2. Thermal mass

Thermal mass is the ability of a material to absorb heat energy for extended periods. The temperature of the material changes slowly during the warm-up or cool-down periods. It stores and re-radiates heat, and by doing so, it acts as a thermal battery.

Thermal mass is effective in improving building's comfort in any environment that experiences daily temperature swings—both in winter as well as in summer (Fig. 1 and Tab.1).

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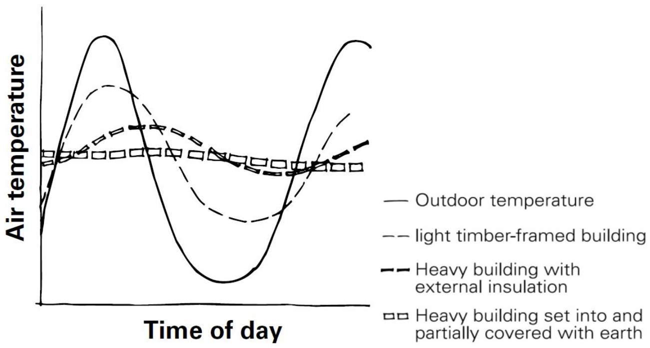



**Fig. 1.** Outdoor temperature swipe, compare with three kind of thermal mass [2]

**Tab. 1.** Thermal mass act during a day

| | | |
|---|---|---|
| | Daytime | Reducing cooling load: absorb heat gains |
| | Night | Reducing heat load: release the heat |

In winter, thermal mass absorbs the heat during the day from direct sunlight or from radiant heaters.It will re-radiate this thermal energy back into the home throughout the night.

During the summer, cool night breezes and/or convection currents pass over the thermal mass, drawing out all the stored energy. During the day, protect the thermal mass from excess summer sun by shading and insulating if required [2] (Fig. 2).

Thermal mass is particularly beneficial where there is a big difference between day and night outdoor temperatures. Heavy mud or stone buildings with high thermal mass work well in hot desert climates where extreme changes in temperature exists between the day and the nighttime temperature.

Passive TES [Thermal Energy Storage] systems utilize pre-cooling strategies of the building's thermal mass during the nighttime to shift and reduce peak cooling loads. Simulation analysis of various pre-cooling strategies have shown that energy cost savings of 10% to 50% and peak demand reductions of 10% to 35% are possible by utilizing a pre-conditioning control strategy. Experimental studies have also shown comparable levels of cost savings and peak demand reduction. Control optimization geared toward specific outcomes can generally increase cost savings or peak demand reduction [3].

To be effective, the thermal mass must be integrated with sound passive design techniques. This means having appropriate areas of glazing which face appropriate directions with appropriate levels of shading, insulation and thermal mass.

## 3. Types of thermal mass

There are two types of thermal mass:

1. Traditional
2. Phase change materials (PCMs)

Traditional thermal mass includes common materials such as brick, concrete, stone, adobe and earth. Meanwhile, PCMs act differently. Heat is absorbed or released when the material changes from solid to liquid and vice versa. This type of thermal mass stores and releases large amounts of energy. As it can be seen in the chart below, PCM's heat capacity is more than 4 times bigger than water's and is considered as the material with the highest amount of heat capacity among the traditional materials (Fig. 3).

One form this technology uses thousands of plastic capsules filled with kind of wax that absorbs and releases energy as it melts and solidifies within the temperature range of human comfort. This increases the effective thermal capacity of the material which contains the capsules and dampens the temperature fluctuations, acting like a thermal mass. At least, one company manufactures building products that integrate phase-change microcapsules into their structures, including plasterboard and aerated concrete (AAC) blocks. Gypsum plasters, paints and floor screeds have the potential to contain phase change materials. Many such applications are likely to appear on the market over the next few years as the technology offers the prospect of lightweight buildings that can behave with characteristics associated with 'traditional' thermal mass – for instance, the thermal capacity of a 13mm thick plaster layer with 30 percent microcapsule content is claimed to be equivalent to that of a six-inch thick brick wall [2].

Yakh-chals are mostly made of adobe or brick. Therefore,

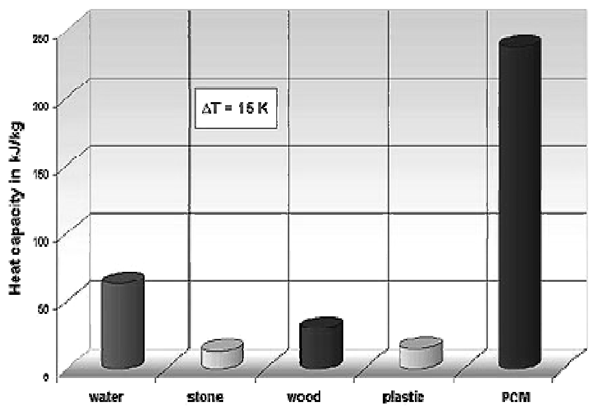



**Fig. 3.** Heat capacity in traditional materials and PCMs [12]

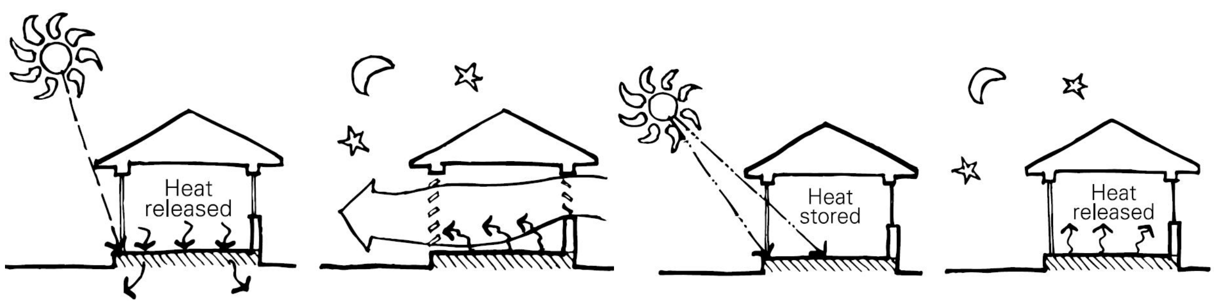



**Fig. 2.** Thermal mass performanceduring winter and summer [1].

brick's performance is analyzed here (Fig.4-6):

On a hot day, brickwork can slow the passage of heat from the outside for up to eight hours by storing it in its mass. Before the heat reaches the interior, the heat-peak of the day has passed, the outside is cooler and the stored heat starts to flow back out (heat flows from the hot medium to cold one). In winter, internal mass absorbs stores and slowly releases any heat generated internally or gained throughout the day [13].

For a mass to be considered a good thermal mass three basic properties are required:

1. Density (p),
2. Specific heat (cm),
3. Conductivity (k).

Water has the highest specific heat among the common materials. However, its density is much lower than heavy materials such as stone and concrete. These properties can be compared between a wide range of materials, (tab. [2]).

Insulating materials have low thermal capacity since they are not designed to hold heat; they prevent heat from passing through them by incorporating lots of air spaces between their thin fibers [1].

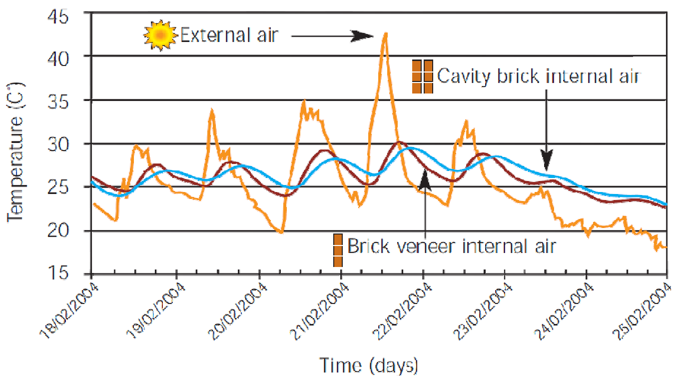



**Fig. 4.** Thermal behavior of brick walls, compare with lightweight walls [13]

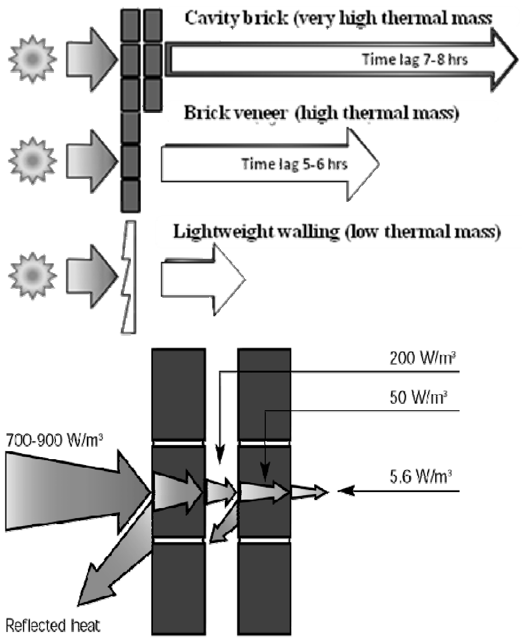



**Fig. 5, 6.** Brick walls are more able to moderate temperatures than lightweight walls [13]

**Tab. 2.** Density, specific heat and thermal mass of a range of materials [15]

| Material | Density (kg/m3) | Specific heat (KJ/kg.K) | Volumetric heat capacity Thermal mass (KJ/m3.K) |
|---|---|---|---|
| Water | 1000 | 4.186 | 4186 |
| Concrete | 2240 | 0.920 | 2060 |
| AAC | 500 | 1.100 | 550 |
| Brick | 1700 | .0920 | 1360 |
| Stone (Sandstone) | 2000 | 0.900 | 1800 |
| FC Sheet (compressed) | 1700 | 0.900 | 1530 |
| Earth Wall (Adobe) | 1550 | 0.837 | 1300 |
| Rammed Earth | 2000 | 0.837 | 1673 |
| Compressed Earth Blocks | 2080 | 0.837 | 1740 |

High thermal mass materials can be an integral part of the building envelope. They may, also, be incorporated into the furnishings of the space. For maximum benefit, they must be within the insulated part of the building. The building's envelope will store heat if it has a large amount of mass (Fig. 7). This will delay the transmission of heat to the interior, resulting in a thermal lag that can last for several hours or even for days; the greater the mass, the longer the delay. Where thermal mass is used inappropriately, excessively high temperatures or coolingloads may result on sunny days, or insufficient storage may occur overnight. Low thermal mass is a better choice when the outside temperature remains consistently above or below the comfort temperature. Heavy mud or stone buildings with high thermal mass work well in hot desert climates where extreme fluctuation in temperature exists.

In a cold climate, a building that is occupied occasionally (like a ski lodge) should have a low thermal capacity and a high thermal resistance. This will help the building to warm up quickly and cool quickly after the occupancy, with no stored heat wasted on an empty interior.

## 4. Massive walls

For massive walls, four basic material configurations are considered:

- Exterior thermal insulation, interior mass (Int.mass)
- Exterior mass, interior thermal insulation (Ext.mass)
- Exterior mass, core thermal insulation, interior mass, and (CIC)

**Fig. 7.** High thermal mass works well in hot desert climate [14]

• Exterior thermal insulation, core mass, interior thermal insulation (ICI). Liquorish

The four types of massive walls, which are mentioned above, comprise most of the currently used multilayer massive wall configurations. For example, the first two wall configurations may represent any masonry block wall insulated with rigid foam sheathing. The last wall configuration may represent Insulated Concrete Forms (ICF) walls. Therefore, results presented in this work can be used for estimating energy calculations of most of the massive wall systems [4].

## 5. Earth-sheltered structure

The high thermal capacity of soil ensures that basement walls and walls banked with earth stay fairly onstant in temperature, usually around 13°C to 15°C (mid-fifties in degrees Fahrenheit) year-round. Earth-bound walls are not exposed to extreme air temperatures in cold weather [1].

The large thermal inertia of the soil cover causes the temperature in the surrounding soil to be higher/lower than the outdoor air temperature during the winter/summer. This way, the temperature differences between the interior and exterior are reduced. In other words, the heat transmission is lower compared to the conventional above the ground houses. The application of soil cover, thus, potentially cuts down on the required heating and cooling loads [3].

For a better understanding, the performance of the earth-sheltered structures, a recent research from Maja and Henryk is shown here [5].The authors have undertaken the analysis of the influence of soil cover thickness, thermal insulation thickness, glazing area of exposed elevations and type of the soil on heating and cooling loads of the earth-sheltered buildings with one or two elevations exposed. The results were then compared to the respective above the ground buildings as shown in Fig.8.s

Conditions and hypothesis of this research are as shown below:

• Simulations were focused on the influence of soil cover and

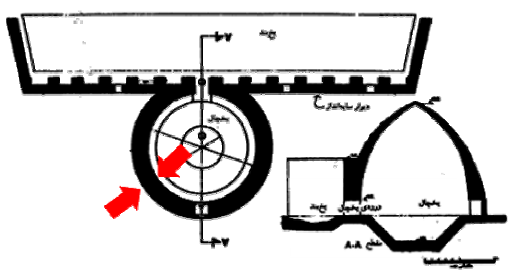


**Fig. 8.** Plan and Section of a Yakh-Chal, Meibod, Iran – Ground Floor plan: massive wall [11]

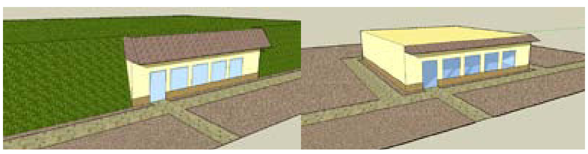


**Fig. 9.** The analyzed schemes of earth-sheltered and above-ground buildings [5]

**Table 3.** Climate conditions of the example research [5]

| | |
|---|---|
| Latitude (N): | 52º25’ |
| Longitude (E): | 16º49’ |
| Maximum air temperature: | + 35,6°C |
| Annual air temperature: | + 9,8°C |
| Minimum air temperature: | - 16,0°C |
| Annual direct sun radiation: | 1 865 [Wh/m$^2$] |
| Annual diffusive sun radiation: | 1 679 [Wh/m$^2$] |
| Annual total sun radiation: | 2 692 [Wh/m$^2$] |
| Annual air humidity: | 78 % |
| Annual wind speed: | 3,3 [m/s] |
| Annual clouds cover: | 0,61 [-] |

the thermal insulation of the building envelope's thickness

• Earth-sheltered building, with one (southern) elevation exposed

• Simulations were done for “Poznan, Poland” climate conditions.

• Floor area: 12x12 m (144 m2).

• Glazed with 60 % of the wall area.

• Both buildings have a concrete construction

• Climate conditions (Tab: 3).

## 6. Simulation results

Figure 10 shows heat losses/gains from the analyzed earth-sheltered and above the ground buildings for annual values and separately for the heating and cooling seasons. Because of the linear dependence of the heat losses to the ground from the buildings, they are presented for 0.5m, 1.5 m and 2.5 m of soil cover thicknesses. Results are presented for 5 cm, 10 cm and 20 cm of thermal insulation. Analyzing annual values of the heat losses/gains of the earth-sheltered and above the ground buildings may show the insignificance of the differences between them. A clear difference is seen when the values are separately analyzed for the heating and cooling seasons (Fig. 10 and Tab. 4). This is caused by the fact that the heat losses from the earth-sheltered buildings are smaller than that of the above the ground ones but only during winter (heating season) [5].

During the heating season, heat losses from earth-sheltered buildings are about 14%, 8% and 5% smaller for: 5cm, 10cm and 20cm of thermal insulation thicknesses respectively. Increasing soil cover thickness over 0,5m decreases heat losses about 20-25%, 10-15% and 5% for 5cm, 10cm and 20cm of thermal insulation compared to the buildings with 0.5m of thermal insulation. IN above the ground houses heat gains are 3% of the heat losses, while, in the earth-sheltered houses heat gains are up to about 15% of the heat losses. Heat gains during the heating season are about 40% higher in earth-sheltered houses than in above the ground ones. IN above the ground buildings, thickness of the thermal insulation does not have a significant influence on the heat gains. However, in the earth-sheltered houses heat gains are greater with increasing thermal insulation thickness. Each 5 cm of thermal insulation increases the heat gains by about 40%.

During the cooling season, heat losses from the earth-sheltered buildings are about 20-35% greater than that of the above the ground buildings, while, the heat gains are nearly 80% lower. In the summertime, each 5cm of thermal insulation lowers the heat losses by about 20% in the earth-sheltered houses. If the heat losses are 100 %, then the heat gains are only 5 %, which is why the earth sheltered buildings need less cooling energy. As it will be explained, Yakh-chals use this property to prevent ices from melting.

When analyzing the monthly values (Fig. 11) it can be noticed that the earth-sheltered buildings require longer heating periods than the conventional above the ground ones, while the total heating loads are still smaller. This is due to the lower temperature of the soil surrounding the earth-sheltered houses. The cooling period is nearly the same [5].

It can be easily noticed that the heating and cooling consumption of the analyzed earth-sheltered buildings is definitively smaller than that of the above the ground ones. The difference between them gets smaller with the increase of the thermal insulation thickness (Fig. 11).Because the interpretation of the results of the monthly values presented would be very complicated, the annual values are discussed;

The earth-sheltered buildings with exposed southern elevations, which are covered with a soil cover of 0.5 m have heating energy consumption reduced by about 25 % compared to the respective thicknesses of above the ground buildings.

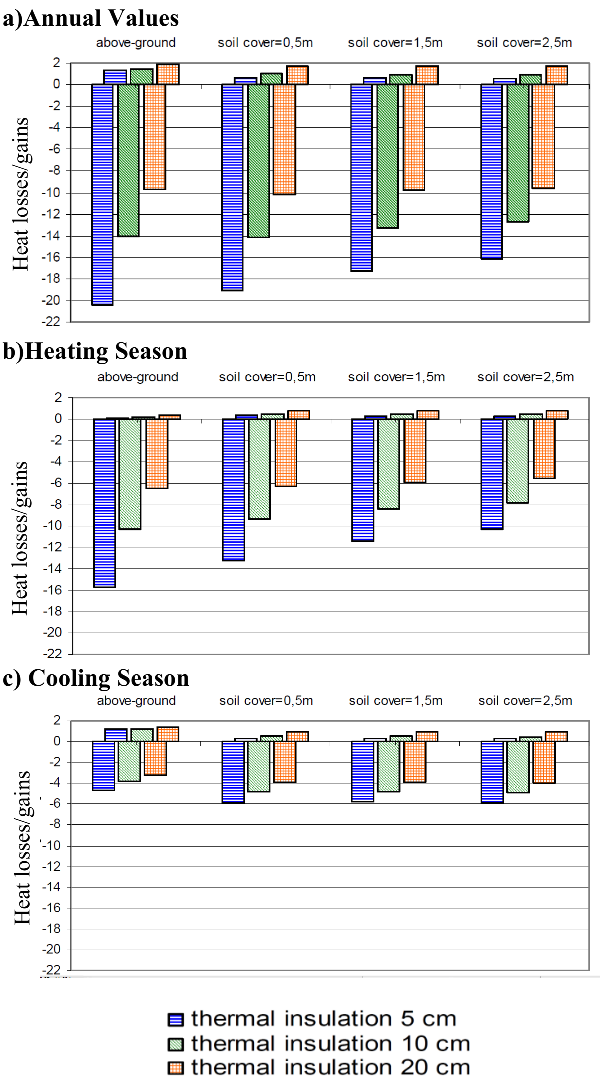



**Fig. 10.** Heat losses/gains from the analyzed earth-sheltered and above the ground buildings [5]

**Table 3.** Climate conditions of the example research [5]

| Summer (Cooling Season) | Winter (Heating Season) |
|---|---|
| The temperature of soil is higher that of external air | The temperature of soil is lower that of external airwhich naturally cools downa building |
| Heat losses from earth sheltered buildings are smaller than from aboveground ones | Heat losses from earth-sheltered buildings are higher |
| Causes lower heating loads for earth-sheltered buildings. | Earth-sheltered buildings require less cooling energy than aboveground ones. |

Each next 0.5 m soil cover thickness reduces the heating loads by about:

- 8 % for 5 cm of thermal insulation,
- 7 % for 10 cm of thermal insulation,
- 5 % for 20 cm of thermal insulation,
- 4 % for 30 cm of thermal insulation.

The earth-sheltered buildings with southern elevation exposed, which are covered with a soil cover of 0.5 m have the cooling energy consumption reduced by about:

- 52 % for 5 cm of thermal insulation,
- 36 % for 10 cm of thermal insulation,
- 20 % for 20 cm of thermal insulation,
- 15 % for 30 cm of thermal insulation.

During the heating season (winter), the thicker soil cover and insulation are both above the ground and the earth-sheltered buildings naturally consume less heating energy. With increasing thermal insulation thickness the influence of soil gets smaller, which causes insignificant differences between above the ground and the earth-sheltered buildings for large insulation thickness. Meanwhile, during the cooling season (summer), for cooling loads, the soil cover thickness does not have a significant impact. Both types of buildings consume more cooling energy with increasing thermal insulation thickness. Thus, the thinner the thermal insulation is the greater the cooling energy savings are, compared to the above the ground ones. This is due to the fact that thermal insulation acts like a coat, and during wintertime protects a building from the colder outside soil temperatures. However, during the summertime it does not allow the soil to naturally cool a building down.

*Yakh-chal definition*

Ice houses, originally invented in Persia, were buildings used to store ice throughout the year, prior to the invention of the refrigerator. The most common designs involved underground chambers, usually man-made, which were built close to the natural sources of winter ice such as freshwater lakes.

During the winter, ice and snow would be taken into the ice house and packed with insulation, often straw or sawdust. It would remain frozen for many months, often until the following winter, and could be used as a source of ice during the summer months. The main application of the ice was the storage of

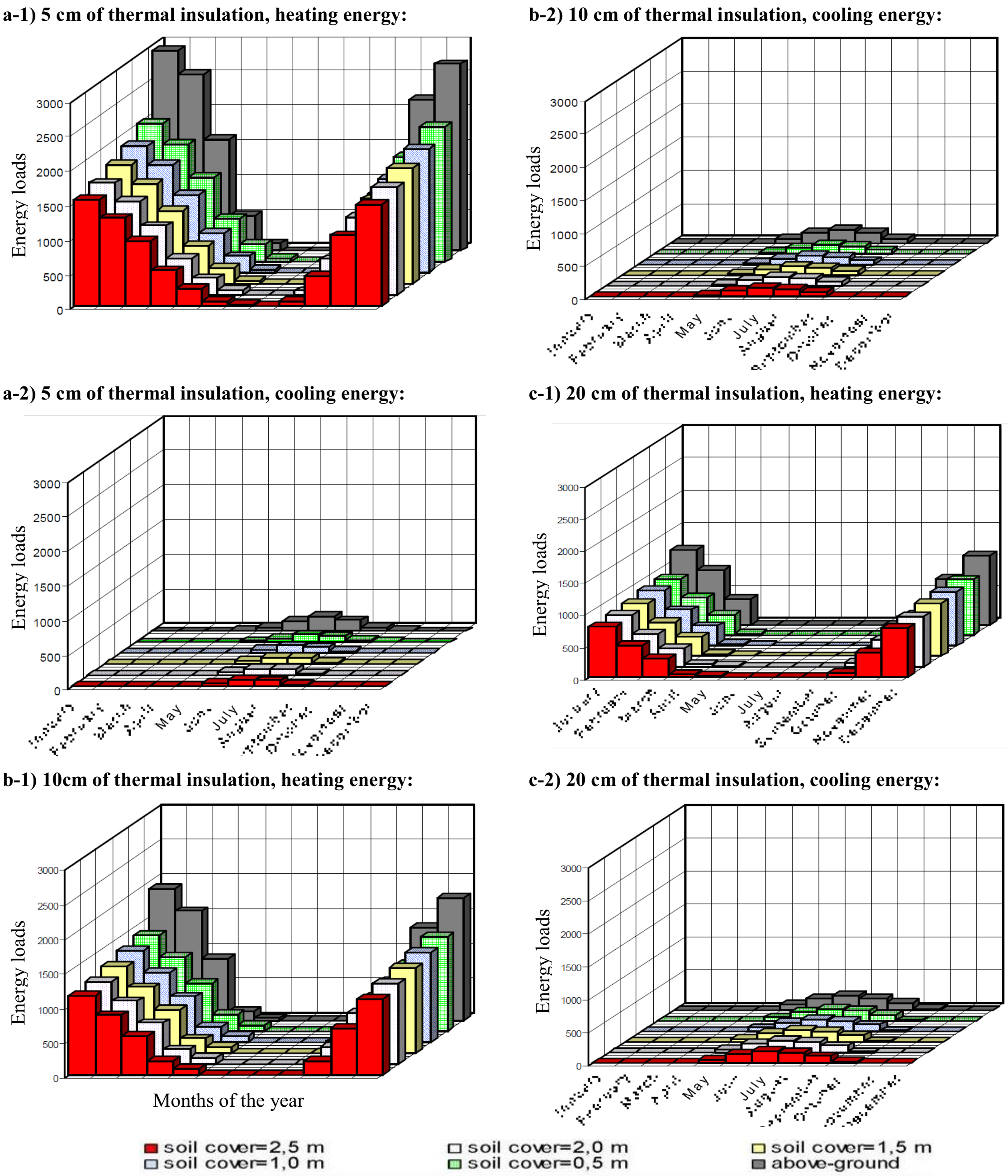



**Fig. 11.** Monthly values of heating and cooling loads of earth-sheltered and above-ground buildings, with 5, 10 and 20 cm of thermal insulation[5]

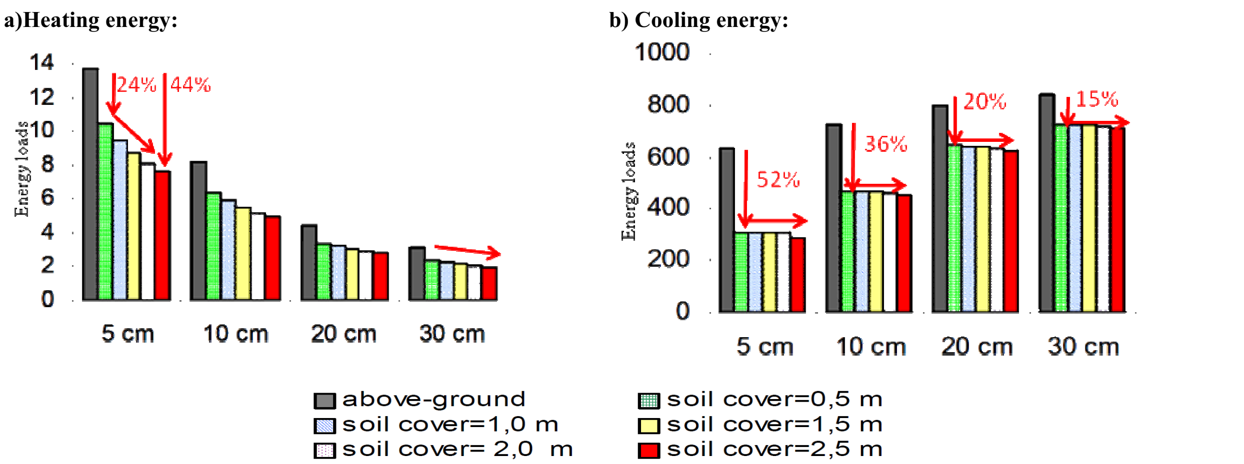



**Fig. 12.** Annual heating and cooling energy loads of earth-sheltered and above-ground buildings, with 5, 10 and 20 cm of thermal insulation

perishable foods, but it could also be used simply to cool drinks, or allow ice-cream and sorbet desserts to be prepared.

*Yakh-chal history*

An inscription from 1700 BC in the northwest of Iran records the construction of an icehouse, "which never before had any king had built." In China, archaeologists have found remains of ice pits from the seventh century BC, and references suggest they were in use before 1100 BC. Alexander the Great around 300 BC, stored snow in pits for that purpose. In Rome, in the third century AD, snow was imported from the mountains, stored in straw-covered pits, and sold from the snow shops. The ice formed in the bottom of the pits sold at a higher price than the snow on top.

*Yakh-chal functions*

1. Producing and Storing Ice: The main purpose of Yakh-chal was keeping ice from winter to be used in the summer. In the cold season, at night, when the temperature dropped, they produced ice and stored it. During the hot season, when they needed ice, they extracted ice from the Yakh-chal for ice-cream and fruit juices.
2. As a Fruits' Fresh-keeper: Some Yakh-chal-owners poured pomegranate's seeds into the ice and, in the summer, they had fresh pomegranate.
3. As an Urban Element: Yakh-chal are huge buildings , so they play an iconic role for the cities, a role which they have still preserved.

**Fig. 14.** a) An ancient ice house, called a Yakh-chal, built in Kerman, Iran b) Boboli Gardens, Florence: domed icehouse (ghiacciaia) half-sunk into a shaded slope.

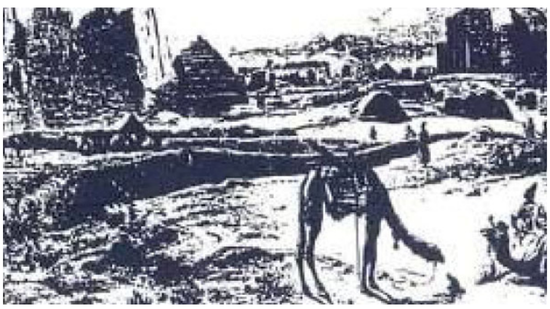
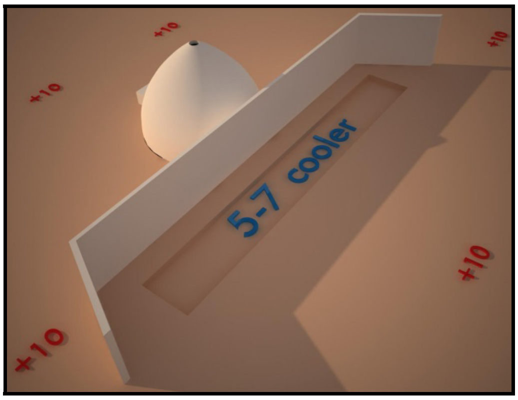


**Fig. 15.** Ice-house and Carvan-sera(designed by Jules Lawrence) Ice Principle Producing

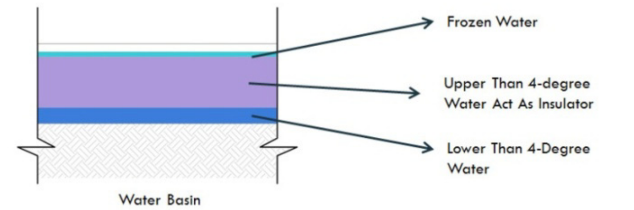
*Ice principle producing*

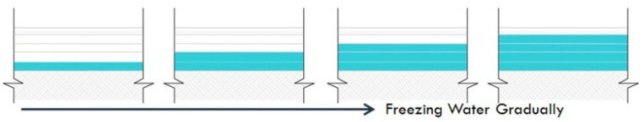
The principle governing the function of the ice-houses is to make use of below-zero winter temperatures by constructing tall wall casting shadow on the ground and thus achieving freezing condition. At night ,especially, when the sky is clear, the ground temperature drops quickly due to radiation. In areas where the Earth is cooler due to having been in the shade, the temperature drops more quickly and reaches the freezing point.




*Ice principle producing*

In order to produce ice, shallow basins were constructed. Since water's density is highest at 4 degree Celsius and drops above or below that point, so only a thin layer on the surface of the basin freezes and a comparatively warmer layer of water acts as a thermal barrier between that layers and much of the 4-degree water sinking. To solve this, they used shovels to pour water on the thin frozen water to make it thicker, and the act was continued until dawn.

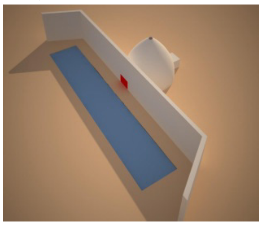


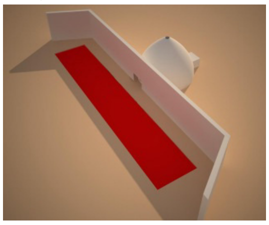

*Ice-house components*

1.Water basin: ice was produced here. The needed water was procured from the brooks near the water sources like qanat , pond or river 2. Ice transfer closure :They moved ice from the basin through this window to store it. 3.Tall wall: The height of this wall was at least 12 meters. It, usually, stretched from east to west preventing south sun light. Furthermore, two shorter walls were built next to the main walls. These two walls had 2 roles: first to thwart the west and the east sun light. The second and a structural role was to support the main wall, because it was too tall, so there was the danger of its collapse. 4.Yakh-chal's Dome: To prevent hot air penetration, and push the warm air out. 5.Yakh-chal as a Storage: for ice storage, a large container 6 meters in depth was required. As a result of the Earth's seasonal heat delay effect, the depth would help contribute to keeping the temperature low. (The Earth doesn't play the role of a thermal barrier only) the standard dimensions of the ice house (8-14 meters in width and 6 meters in depth) are among its inseparable idiosyncrasies. 6.Yakh-chal;s stairs: There are two kinds of Yakh-chal stairs, one straight and the other spiral. 7. Yakh-chal's sewage: There is a small hole at the bottom of the storage which works as a drain for the melted ice.

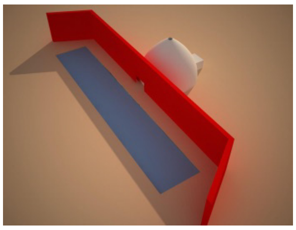
**a)Yakh-chal Closure**



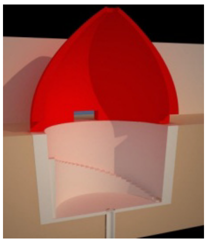
**b) Ice Transfer Basin**



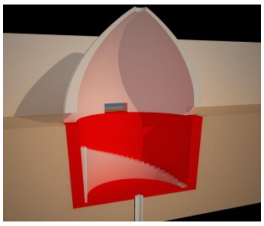
**c)Tall Wall**



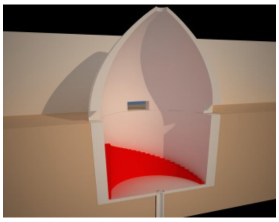
**d) Yakh-chal Dome**



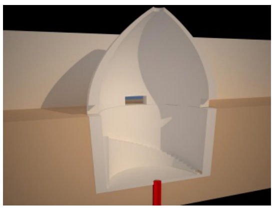
**e) Yakh chal Store**



**f) Yakh-chal Stair**



**e) Yakh-chal Sewage**



## Ice-house temperature:

To prevent the solar heat from entering the ice-house, a substantial dome is required. On top of the dome, a large hole lets the warm air out while allowing the cool air to penetrate the storage area from the bottom. Such a shape is the ideal from for an ice-house.

## Temperature during the Day

The soil at the bottom of the pond does not absorb much heat.2) Cold and fresh air goes down, So warm air goes up and exits from a hole on the top of the dome. 3) "Great thickness of the container's dome", "using masonry (with low coefficient of heat transfer) ", and" its external thatched coverage "play the role of thermal insulation to prevent thermal conductivity.4) As a result of "Earth's Seasonal Heat Delay Effect", the container keeps it's winter's condition during the hot seasons.

## Temperature during the night

1. Water in the pond loses heat.2. Cold air goes down the ice-house and covers the upper layer of the stored ice.3. A staircase connect the door of the ice-house to its lower level, to store the ice pieces in a deeper layers of the earth.

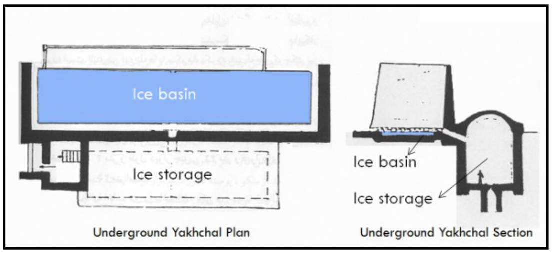
*Yakh-chal types*

There are 3 common types of Yakh-chal in Iran

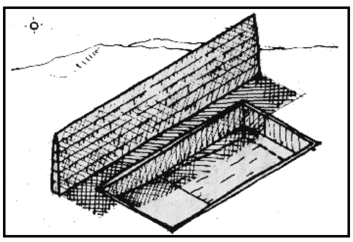
1. Domical Yakh-chal: these kinds of Yakh-chals have domes on the storage part. They are more usual in periphery of the central Kavir and districts on northwest of Iran. 2. Underground Yakh-chals :Another type of Yakh-chal was common in central-north districts of Iran like Tehran, Zanjan, Saveh and … its function was like domical Yakh-chals, but its body-shape was different. Its main part was underground. 3.Vaultless Yakh-chal: The third type of Yakh-chal which was without vault was popular in Isfahan. Like other Yakh-chals, it was used 40-50 years ago. This type of Yakh-chal had tall-wall 4-5 meters in height and 12 meters in length. on the north side of the wall there was a pool 5-6 meters deep and 12 meters in length and width.

*Domical Yakh-chal:*

*Underground Yakh- chal:*




*Vault-less Yakh-chal:*



## 7. Conclusion

Yakh-chals are the great Iranian tradition. They are not very well known in the West, and there is much to be learnt, both from it and the building techniques which are integral to it. It is the fate of the vernacular buildings throughout the world to be neglected until they are nearly extinct. The Folk Museum and the Museum of Buildings are relatively new ideas in Europe, where they are thought of primarily in terms of conservation and education in history and the arts. In Iran, their value could be even greater since these functions could be combined with those of an institute of intermediate technology. Not only is the building tradition itself is still alive, but there is much to be gained from knowledge of a highly developed technology that makes such an ingenious use of the natural resources without the consumption of additional power. The Persian ice-house with its great shade wall could hardly be described as small, but the technology it represents is certainly beautiful in its simplicity. However, unless a positive action is taken, most Iranian cultural heritage buildings will turn into ruins and rubbles.

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