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A Critical Review of the Application of Passive Cooling Combined Methods in Traditional Underground Buildings in Iran

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Abstract

Nowadays, a high amount of energy is used for ventilation, cooling, and heating of buildings. Using clean and natural energy is one of the best ways to reduce energy consumption in buildings. Using the passive approach as a non-mechanical method is an effective technique to deal with high energy consumption. Also, underground and semi-underground buildings are some of the most productive Iranian traditional structures that include the category of passive cooling and are very useful in hot and dry and hot and humid areas. The range of temperature fluctuations in the depths of the earth is much lower than that in its surface layers, so the temperature is almost stable and equal to the annual mean temperature of the earth's surface at depths below 6 meters. Thus, the purpose of this study is to review the studies conducted in this field, specifically those that have investigated the types of underground structures and their cooling potentials. Also, it aims at finding the gaps in these studies and determining the underground structure that needs more detailed studies. The research method in this study is descriptive and analytical. The results revealed that passive cooling strategies and related techniques can be classified based on the performance of underground structures. These strategies are sometimes used in combination. The results also revealed that it is possible to provide the conditions for modernization for some of these structures. However, these elements such as aqueducts and Yakhchals have been further studied and developed.

Keywords: Passive cooling, Underground spaces, Heating dissipation technique, Heating prevention technique

1. Introduction

The construction of underground buildings has been popular since the old days in Iran. The construction of rock tombs and underground water transfer channels (aqueducts) are among the underground structures built and used by Iranians in the past (Bahadori, 1978). Some of these buildings have Public functions and some others have private functions, including aqueducts, Sardab, garden pits, Shawadan, house ponds, Yakhchals, and cisterns (Kasmaei, 2003). Most of these buildings were built in a hot and dry climate. The purpose of their construction was to use the cooling capacity of the earth (Saeli & Saeli, 2015). Each of these buildings uses different passive techniques to cool its interior pace. This issue has been addressed in various studies (Foruzanmehr, 2018; Soflaee and Shokouhian, 2005; Beladi & Karaman, 2022; Subramanian & et al, 2017: Mohammadi & Daraio, 2020). The purpose of creating cooling in this underground space has not been mentioned so far. However, the use of combined methods to create cooling in this underground space has not been addressed so far. Thus, this study deals with a comprehensive investigation in the field of the application of passive combined cooling systems in indigenous underground buildings in Iran. In this regard, types of passive cooling strategies will first be introduced under the two sub-sets of "heating dissipation" and "heating prevention”. Then, the cooling techniques related to the mentioned strategies will be explained. Finally, it examines how the strategies and techniques related to passive cooling have been used in combination with traditional underground structures in Iran.

2. Materials and Methods

The present review research addresses the application of passive combined cooling systems in indigenous underground buildings in Iran. Accordingly, it is first necessary to develop the theoretical framework of the study. This framework is defined in three levels including strategies, techniques, and elements.

In the strategy section, the two concepts of heating dissipation and heating prevention are introduced as different models of passive cooling in underground buildings. In the techniques section, some cooling techniques are defined for each of the above strategies. Some of them include natural ventilation, radiative cooling, evaporative cooling, and ground cooling. Solar control and microclimate are some of the techniques used for heating dissipation. Finally, the elements in which these strategies and techniques are supposed to be analyzed will be mentioned. These buildings are six underground buildings in Iran's traditional architecture, which include an aqueduct, cistern, Yakhchal, garden pit, Sardab, and Shawadan. Considering the review nature of

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the research, the present research has collected articles in its subject area. The main research keywords include: passive cooling, traditional basement buildings and natural ventilation. According to the keywords of the research, the search was done on the sites of "*sciencedirect", Elsevier, "wiley", "googlescolar*" and "*springer*". Also, books (chapter books) written in connection with the research topic were used as other sources. Scientific and research conferences and journals were also examined at the next level to obtain a complete set of seven selected traditional underground elements that are inactive in the field of cooling.

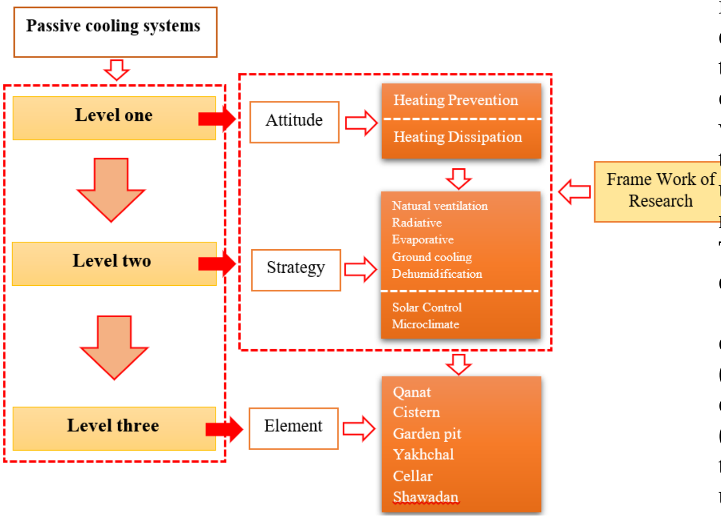

Fig. 1. Conceptual model of the research.

3. Conceptual Framework

This section is developed in two levels, which first deals with the general introduction of passive cooling strategies used in traditional buildings (heating dissipation and heating prevention strategies). In the second level, the
(A) Ground cooling based on the use of soil properties (thermal capacity)
(B) Convection cooling or ventilation based on the use of a heat transfer process through the roof.
(C) Using evaporative cooling (installing a pond or using underground water, etc.) using water as an internal heat sink (Santamouris & Kolokotsa, 2013).
However, heating dissipation strategies primarily work with the installation of devices that provide the conditions to prevent heating dissipation before it enters. These strategies for passive cooling in underground buildings can be used according to the structure of elements and the desired space. For example, the construction of awnings and windows (in semi-underground and underground structures) and creating shade as well as insulation, which is related to the heat capacity of the soil. Each of these techniques can help heat dissipation in some cases. The excessive and unwanted heat is removed by heating dissipation strategies so a space with pleasant heat is available to people for the desired element. Generally, a few studies have been conducted regarding heating prevention, while more studies have been conducted regarding heating dissipation (Santamouris & Kolokotsa,

techniques related to each of the two strategies will be introduced.

3.1. First level: introducing strategies related to passive cooling in underground buildings

The studies conducted in the field of passive cooling in buildings can be categorized into two strategies: "heating dissipation" and "heating prevention" (Santamouris & Kolokotsa, 2013; Idayu Ahmad & et al, 2019). The strategy of heating prevention primarily by solar radiation control and avoiding the entry of heat from the outdoor environment into the inside of the building causes cooling inside. In the heating dissipation strategy by using different techniques, the goal is to transfer the heat outside the building (Prieto & et al, 2017). Based on the conducted studies, heating dissipation techniques deal with the dissipation of excessive heat. In this technique, the heat of the building can be dissipated by undergrounding. This strategy is done using techniques related to lowering the temperature using passive cooling. This effective dissipation of excess heat (heating dissipation) depends on two primary preconditions:
(a) Availability of a suitable environmental heat sink by creating a temperature difference for heat transfer (creating a temperature difference in the environment causes heat transfer or airflow)
(b) Efficient thermal connection between the building and the ground (selecting the appropriate depth for undergrounding to create a constant mean temperature in the underground compared to the outdoor environment and also connecting with the outdoor space through an opening (window) or wind catcher to proper ventilation and airflow)
Also, the three primary processes of heat loss (heating dissipation) that have been studied by researchers include:

2013; Idayu Ahmad & et al, 2019). Based on the conducted studies (specifically, review articles) in this field, some strategies have received more and some less attention from researchers. The "shadow" and "orientation" strategies separately have had a high number of results in these studies (Ralegaonkar & Gupta, 2010; Prieto & et al, 2017). Figure 2 shows the types of passive strategies used in buildings.

3.2. The second level: introducing passive cooling techniques in underground buildings

After introducing two strategies of heating prevention and heating dissipation regarding passive cooling in underground buildings, in this section, we introduce the techniques related to each of these strategies in traditional underground buildings in Iran.
-Techniques related to the "heating dissipation" strategy

- **Natural ventilation**

The natural ventilation is based on the pressure difference between the inside and outside of the building. However, its cooling potential depends on the speed of the airflow, the thermal capacity of the building, and its thermal mass (Givoni, 1991; Givoni, 1992).

The use of this technique to cool the air in hot and dry areas alone is not effective and depends on macroclimatic weather conditions including outdoor temperature, relative air humidity, and wind speed (Santamouris & et al, 1996). However, night ventilation is one of the efficient methods for heating dissipation and creating cooling inside the building in these areas (Monghasemi & Vadiee, 2018, Valizadeh & et al, 2019). In night ventilation, cold air outside the building replaces the hot air absorbed by the building during the day by creating convective cooling. This causes the indoor air of the building to cool down during the night and shorten the heating period during the day.

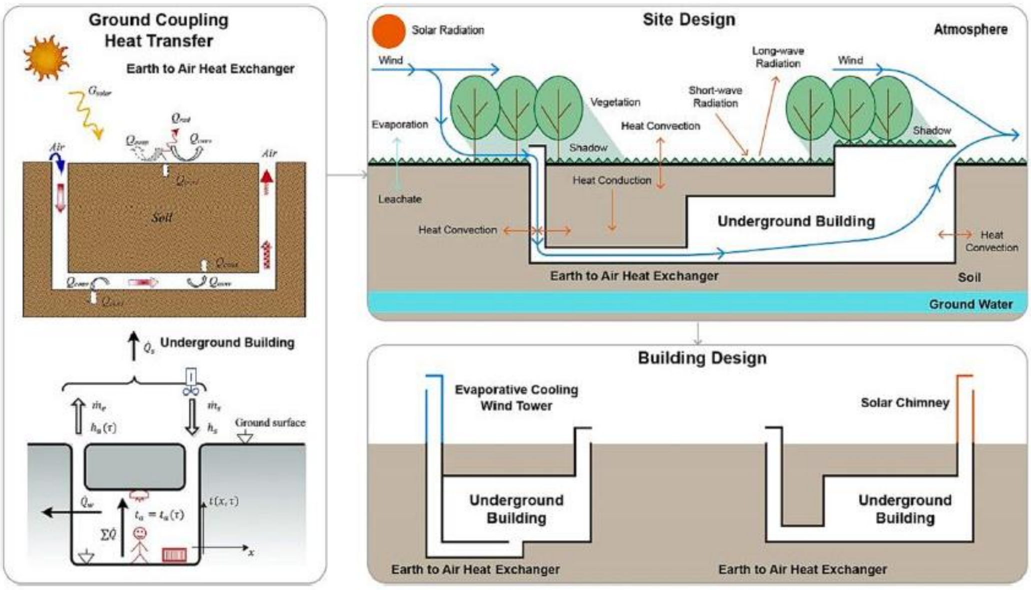

Fig. 2. Thermal strategies used in the underground (Wen & et al, 2023)

- **Evaporative cooling**

Cooling by water evaporation is one of the conventional methods used in areas where the air has low relative humidity (Prieto & et al., 2017). Thus, this technique is mostly used in hot and dry areas. Using this technique along with natural ventilation can have a significant cooling effect in different parts of the building (Bongs & et al, 2003; Vitte & et al, 2008).

The humidity resulting from the evaporation of water can help to increase surface evaporation and thus dissipate the heat inside the building by replacing the airflow (Santamouris & Kolokotsa, 2013). Thus, the efficiency of this cooling system is based on easy access to water. Water can be used both in the form of a surface (such as a water basin) and in the form of a spray in space (Taleb, 2014).

- **Ground cooling**

The soil temperature is different at different depths of the earth. However, its fluctuations throughout the year are less than on Earth and almost equal to the mean annual temperature of the ambient air. This phenomenon makes it possible to use soil as a heat or cold absorber (Alam et al, 2015). Ground cooling is generally done in two ways: earth-to-air exchange and earth-to-water exchange (Florides & Kalogirou, 2007). In through-earth-to-air exchange cooling, the air passing through the underground space due to contact with the soil loses its temperature and reaches the soil temperature at the desired depth (Kumar Agrawal & et al, 2018). In the earth-to-water exchange method, the desired cooling is created through the surface evaporation of the water in the underground space. This issue is clearly observed in spaces such as the sardab.

- **Radiative cooling**

The effects of radiative cooling can be observed in the natural environment, such as the formation of ice during the cold season or the formation of dew during the warm season. The significant parameters required to calculate the radiant cooling power are the dew point temperature and the ambient temperature (Singh & et al, 2015). This parameter can be related to the thermal conductivity (due to the heat transfer property) and convection (due to the connection with the ambient temperature and airflow) factors due to the radiation cooling property. This process helps to heat dissipation from the environment.

-Techniques related to the strategy of "heating prevention"

- **Microclimate**

Microclimate is a small scale of the climate of an area affected by vegetation, landform, and environmental texture. The presence of elements such as vegetation or water in an environment can decrease the temperature of that environment by increasing the relative humidity (Mohammad Alinezhad, 2020).

The establishment of a part of the building or all of it inside the ground or using shading elements in the environment around the building are among other solutions to change the microclimate in an environment.

The set of these factors can cause passive cooling by reducing the sun's radiation, increasing the relative humidity in the environment, or changing the ventilation pattern (Geetha & Velraj, 2012).

-Solar control

Solar control is one of the crucial strategies in heating prevention from entering and creating natural cooling in an environment. The appropriate orientation of the building, the use of shade in different directions of the building, the use of shading elements in the surrounding environment of the building, or the transfer of part or all of the building to underground are among the solar control solutions for temperature control (Santamouris & Assimakopoulos, 1996, Santamouris & Goswami, 2005, Santamouris, 2007).

Given what was stated above, Figure 3 shows the passive cooling techniques related to each of the strategies for heating prevention and heating dissipation.

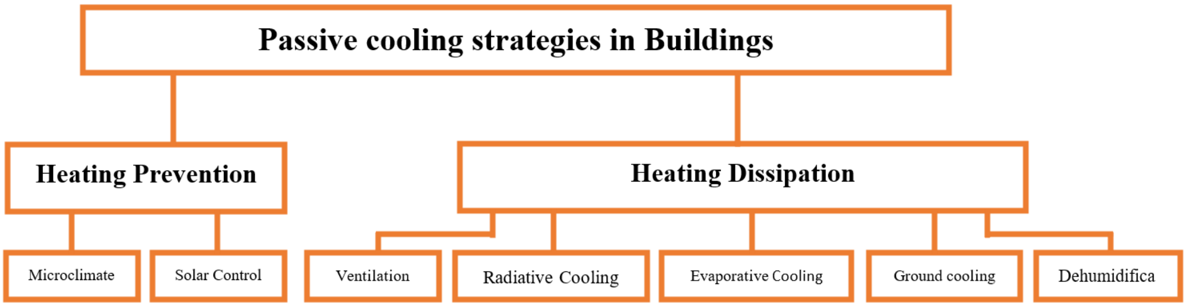

Fig. 3. Techniques related to passive cooling strategies

3.3. The third level: introducing underground buildings and their relationship with various passive cooling techniques and strategies.

The construction of underground spaces has been popular from the old days in Iran. Since a large part of Iran's area has a hot and dry climate, the use of the earth's thermal capacity, especially its cooling capability in the hot seasons, created the idea of building such spaces in the minds of Iranians (Staniec & Nowak, 2011). Despite the problems of such buildings, such as lack of access to daylight or difficulty in ventilation, the use of these buildings is a suitable solution to deal with the extreme heat of the air in the hot months of the year (Yap & et al, 2021: Dehvari & Mofidi Shemirani: 2023). In one classification, underground buildings in traditional architecture can be spatially divided into three categories: sloped buildings, semi-sheltered buildings, and buried buildings (Figure 4). Also, functionally, they are divided into two categories: biological and installation (Wen & et al, 2023). Each of these buildings is introduced below.

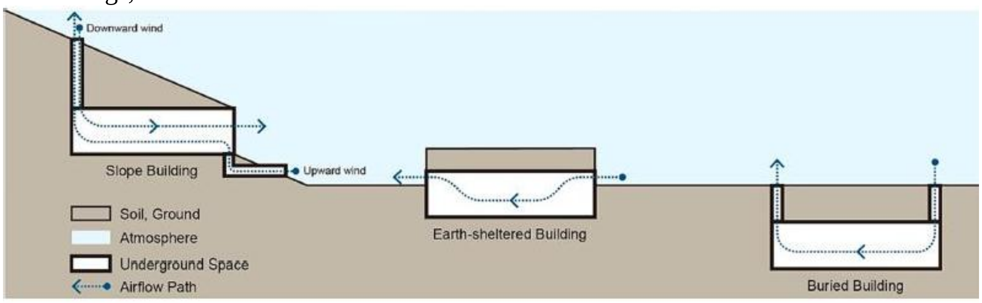

Fig. 4. Different types of underground buildings (Wen & et al, 2023)

As stated before, the primary purpose of this study is to investigate the types of passive cooling strategies and techniques used in underground buildings in traditional Iranian architecture. After explaining the types of strategies and techniques of passive cooling in the form of the theoretical framework of the study and introducing the types of underground buildings in the traditional architecture of Iran, in this section, we examine how each building uses the types of strategies and techniques of passive cooling .

- **Shawadan**

Using the thermal capacity of the earth is the most significant factor in creating cooling in Shawadan since the temperature of the earth in the hot months of the year is lower than its surface temperature and equal to the annual mean temperature in that area (Moradi & Eskandari, 2012; Sadooghi et al, 2019). Natural ventilation is another factor involved in creating passive cooling in the architecture of Shawadans (Hosseini & Vatankhah, 2014). Fresh air is transferred through the main staircase to the Shawadan in the underground and it is transferred to the outside through the air outlet channel (Masoodi Nejad et al., 2022). In this two-way ventilation, the incoming air collides with the body of the staircase and loses its temperature. This causes the indoor air to be closer to the temperature of the ground and causes cold air to enter the main space of the Shawadan in the hot months of the year (Naghibi & et al, 2021; Shirin Jani & et al, 2015). The placement of Shawadan living space in the depth of the earth prevents direct sunlight to it and thus solar control. Therefore, the two techniques of ground cooling and natural ventilation are connected with the heating dissipation strategy and it leads to creating passive cooling in people's living space through radiation control with the strategy of heating prevention.

- **Sardab**

The placement of Shawadan underground and using the thermal capacity of the ground is one of the most crucial factors in creating passive cooling in this space (Mukhtar & et al, 2019). Also, the presence of water in this space increases air humidity due to surface evaporation and as a result creates passive cooling in this space (Fethi & Roaf, 1986). Also, the presence of the opening to the central courtyard and the connection of the Shawadan with the wind catcher led to the formation of ventilation in this space. The airflow entering this space, after hitting the water surface in the Shawadan, increases the evaporation of water. As a result, it increases the humidity in the space.

This issue, along with the ventilation resulting from air movement leads to passive cooling in this space (Moosavi & Vakilinezhad, 2011). Thus, it can be stated that Sardabs are related to the strategy of heating dissipation through the techniques of ground cooling, natural ventilation, and surface evaporation, and are related to the strategy of heating prevention through the control of radiation and the creation of microclimate.

- **Garden pit**

The high walls around the garden pit control the radiation and create shadows in the yard. The presence of a water pond and the planting of trees in the space inside the pit cause the evaporative cooling in the pit and the surrounding spaces in addition to creating humidity (Nazem, 2015; Karimi & Ghazanfari, 2016). The set of these factors causes the creation of a microclimate in the central space of the house in the hot and dry climate of Iran (Jahanara & et al 2014). Given what was stated, it can be concluded that garden pits are related to the strategy of heating dissipation through the techniques of using the thermal capacity of the earth and surface evaporation and natural ventilation and the strategy of heating prevention through radiation control techniques and the creation of microclimate.

- **Aqueduct**

Since the water was in the underground (aqueduct) all along the path and never entered the surface of the ground, it was constantly exposed to the heat capacity of the ground and it had a low temperature for drinking in the hot months of the year. Also, in addition to the movement of the water flow inside the aqueduct, the air in the canal also moves along the water path. This issue led to the creation of a kind of suction in the sardabs, which were located in the vicinity of the aqueduct in some cases and supplied their water from the aqueduct (Mostafaeipour, 2010; Alemohammad & Gharari, 2017). Given what was stated, it can be concluded that it is related to the heating dissipation strategy through the ground cooling technique and the heating prevention strategy through the natural ventilation technique.

- **Cistern**

Using the "cooling capacity of the earth" to reduce the water temperature in the cistern in the hot months of the year was considered one of the cistern techniques in creating cooling. Also, the presence of several wind catchers around the water tanks leads to ventilation in the space inside the tank. The contact of the air with the surface of the water in the tank leads to the surface evaporation of the water and thus the cooling of the air inside the tank, which finally helps to keep the water cool (Memarian, 2008). Given what was stated, it can be concluded that the cistern is related to the heating dissipation strategy by using the thermal capacity of the ground and natural ventilation, and it causes passive cooling and the cooling of water inside the tank.

- **Yakhchal**

In addition to the ice storage tank, the Yakhchals also had a space for producing ice. This space included ponds that were located along a long clay wall. Rainwater was collected in these ponds in the cold seasons of the year and turned into ice during the night. Then, the collected ice was transferred to the underground tank for storage and use in the hot months of the year (Hosseini & Namazian, 2012). Thus, one of the most crucial cooling techniques used in Yakhchals can be controlled to produce ice and use the thermal capacity of the earth to store ice. Therefore, Yakhchals are related to the strategy of heating dissipation through radiation control and the strategy of heating prevention through ground cooling. Table 1 summarizes the passive cooling techniques and strategies used in the underground spaces of traditional Iranian architecture.

Table 1
Summary of the relationship between thermal strategies and passive cooling systems in traditional basements (source: authors)

Attitude	Thermal strategy	Element / PCP	Qanat	Cistern	Garden pit	Yakhchal	Cellar	Shawadan
Heating prevention	Microclimate	Air temperature	✓	✓	✓	✓	✓	✓
		relative humidity	✓	✓	✓	✓	✓	
		wind speed	✓	✓	✓		✓	
		Natural cooling	✓			✓		
		Soil-water properties	✓	✓	✓	✓	✓	✓
		Absolute humidity	✓	✓			✓	✓
	Solar Control	Orientation			✓	✓		
		aperture	✓	✓	✓	✓	✓	✓

		shading			✓	✓		✓
		insulation			✓	✓	✓	
Heating dissipation	Natural Ventilation	Night ventilation		✓		✓		
		Cross ventilation	✓		✓			✓
		Single sided ventilation				✓		
		Air flow	✓		✓		✓	
		buoyancy ventilation	✓	✓			✓	✓
	Radiative	heat transfer		✓				✓
		convection		✓				
	Evaporative	evaporation		✓	✓	✓	✓	
		evaporative cooling	✓	✓				
	Ground cooling	Geothermal			✓		✓	✓
		Indirect Cooling					✓	
		Direct Cooling	✓	✓	✓	✓		

4. Research background

Several studies have been conducted so far regarding the introduction of underground buildings in the traditional architecture of Iran and how they use the heat capacity of the earth for passive cooling. The studies conducted in this regard were first categorized since one of the goals of the study was to introduce the process and method of these studies. In the selection of articles, the studies conducted in English publications and books were considered. A few studies in this field are available in the Persian language and the methods used in the studies are presented in the English language in more diverse ways, and there are several other reliable sources from the latest achievements in this field. Therefore, in the selection of the studies, those articles were used that have used a variety of methods and analyses. Also, those studies were selected that had the most references to other articles. This problem helped to gain more confidence in the findings and method of the article. This issue increases our confidence in the findings and method of the article. The keywords selected for searching in scientific and reliable sites such as Springer, ScienceDirect, and Google Scholar &... were taken from the keywords mentioned in the research strategy section (heating dissipation and heating prevention) and the passive cooling techniques (natural ventilation, ground cooling, etc.). Also, one search was conducted through traditional underground elements (aqueduct, sardab, etc.). Finally, due to the necessity of dealing with the issue of new energies, one of the important goals in this table is specifically to extract the existing gaps in the studies conducted in this field. These gaps were investigated with emphasis on the field of elements or passive cooling strategies. Table 2 presents a summary of the studies found in this regard.

Table 2
A review of the studies conducted in the area of passive cooling systems in underground buildings (Compilation: Authors)

element	Author (s)	Frame work (principles)	Data Analysis	Solver & Software	Measured Parameters: Dependent variable	Measured Parameters: Independent variable	Measured Parameters: Other setting	Critical Findings
Qanat	Bahadori (1978)	Description of the function of the aqueduct: floating underground water systems that work by using water vapor and the evaporation process during the day and storing cold at night.	Description of the work of the components of the aqueduct, such as the path, building, walls, dome, etc.	-	Passive cooling systems	Qanat	-	The basis of the operation of passive cooling systems such as aqueducts is to adjust the cooling reception at night and its consumption during the day so that clean and cool water flows.
	Wen &et al (2023)	"Space- airflow" coupling "wind pressure"-thermal pressure synergy Passive fresh air preconditioning	form of spaces, effectively enhances the natural ventilation that investigated in four multiscale spaces: 1) urban scale; 2) site scale; 3) building scale; and 4) room scale	field measurements, scaled models and CFD simulations	Passive ventilation	traditional underground buildings (scal of space)	Space–airflow thermal pressure Passive fresh air	- Optimizing underground passive ventilation by creating microclimate and site design. - Presenting contemporary examples inspired by traditional underground buildings -Designing a framework for connecting airflow paths (such as solar chimneys) to the building at the building scale.
	Hughes & et al (2012)	Natural ventilation Thermal comfort Evaporative cooling	Aqueduct in combination with wind deflector	(review)	Natural ventilation	Qanat	-	Underground buildings are a key element in the architectural design of traditional structures The design of the wind tower is based on natural cooling systems in traditional Iranian architecture. Almost all historical buildings were naturally ventilated

	Moossavi. (2011)	- passive cooling, - heating, - ventilation - natural cooling - passive building design	A general survey of the aqueduct from the point of view of passive ventilation (cooling).	Descriptive and qualitative	Passive cooling	Qanat	-	Considering the problems of global warming and the clean possibilities of passive cooling, it is necessary to bring them back to the architectural design by contemporizing them, which needs special studies.
	Boustani (2008)	- no evaporation - natural cooling -passive cooling,	A general review of the aqueduct from the perspective of passive ventilation (cooling) and its history	Descriptive and qualitative	Passive cooling	Qanat	-	Since the aqueducts are often buried under hard soil and if necessary covered with relatively impermeable clay rings, there is little leakage, the water level does not rise, there is no water input, and no evaporation during transfer. The water flow rate in an aqueduct is controlled by the underground water table
	Salih (2006)	-	A general review of the aqueduct from the perspective of passive ventilation (cooling) and its history	Descriptive and qualitative	derground water Manageme nt	Qanat	-	The aqueduct system provides a great display of human ingenuity to deal with water shortage. A long-term plan can only be formulated by considering the interaction between underground water and other environmental components.
	Ghanbarpour. &et al (2007)	-	A general review of the aqueduct from the perspective of passive ventilation (cooling) and its history	Descriptive and qualitative	derground water Manageme nt	Qanat	-	- Small water management systems such as Khooshab or Bandsar have been proposed as the most appropriate technology for the development of basins in rural and rainfed and agricultural areas in dry areas. -Traditional knowledge has been integrated with economy, environment, and society.
	200- Aghazadeh. (2013)	central watershed basin, the rate of the rainfall and the water reserves in the highlands, the depth of the underground water resources, the slope	A general survey of the aqueduct from the perspective of passive (cooling) use management	Descriptive and qualitative	sustainable developme nt and Manageme nt of undergroun d waters	Qanat	-	- Some villages and cities should remain constant in terms of size due to the limitation of water supply. -Organizing and planning separate canals for rural, urban, and industrial sewage to protect the aqueducts from water pollution.
	Moghadam. & et al (2020)	- chemo-isotopic and general hydrochemical characteristics - dissolution of evaporate	chemo-isotopic characteristics and geological of Qanat water	Laboratory analysis of aqueduct water samples. PHREEQC software	chemo-isotopic characteristic s and origin of the groundwater -water quality	groundwater	- dissolution of evaporate - interlayers in Neogene	- The isotope ratio of the underground water of the aqueducts is heavier in the dry period than in the wet period. - The isotopic composition of groundwater can be changed by factors such as evaporation and/or water-rock interaction. -Evaporation is greatly reduced at low temperatures due to the higher amount of rainfall and the amount of surface floods in the wet season.
	Maghrebi. & et al (2023)	- hydraulic and geologic characteristics -Qanat discharge	A general survey of the aqueduct from the perspective of the depth of the aqueduct and the chemical characteristics of the earth and its waterand its water	-GIS -Google Earth -Regional Water Authority records	groundwater depth - Qanat discharge -water quality	Groundwater Aqueduct bed	bedrock thickness	- The depth of the aqueduct is higher upstream and decreases toward the aqueduct (where the water reaches the surface), indicating the depth of the water table. -The destruction of the aqueduct due to the growth of agriculture is a counterfactual since the aqueducts have been fed by agricultural irrigation in this area for thousands of years.
	Martinez- & Martinez (2012)	-Hydrogeological factors -water quality	General examination of the aqueduct from the perspective of the depth of the aqueduct and geological features	data from Trol and Braun (geological and climatic data)	groundwater depth -water quality	Water Quality	permeable deposits	- The water of the aqueducts penetrates into the sediments and creates a path that eventually drains at a lower level. - The storage potential of the aqueducts is high and their response to recharging events is relatively fast.
	Bahadori (1978)	Description of Cistern function: Stationary underground water storage systems, which work by using water vapor and the evaporation process during the day and cold storage at night. These systems work	Description of the work of the components of the water Cistern, such as chimneys (wind catcher) of the building, walls, dome and its valves..	-	Passive cooling systems	Qanat	-	The base of the operation of cool passive water systems is to regulate the cooling at night and its consumption during the day so clean and cool water is available in the lower part of the ground.

		with a chimney (wind catcher) that performs the action of traction and suction						
Cistern	Najafi & Yaghoubi (2015)	hermal behavior of an active cistern is investigated experimentally and Temperature distributions on the outer surface of the dome and wind catchers of cistern	evaluate dome surface temperature distribution and also its variation during the day (Study of components)	CFD simulation And thermography device (to obtain temperature distribution on the dome)	natural convection is called "no wind" and forced convection	Cistern's Dome	-	- In "non-windy" conditions, the heated dome causes air to enter through wind catchers and exit through an opening at the top of the dome. - For "windy" conditions, the convection coefficient increases significantly. -The temperature distribution on the surface of the dome depends on the angle of the sun and the time of day
	Memarian (2009)	-	Materials for the construction of the Cistern (Materials: wood, stone, mortars, coatings) Archery, Grave digging and its methods, hardening (Study of components)	Observation, Interview with water storage masters	Different implementation methods	Construction features	-	- High-quality construction has given it a life of hundreds of years -Cisterns are one of the symbols of efforts of Iranian architects in the field of a solid and usable building for the public.
	Haghparast. (2008)	- Earth cooling - Evaporative Cooling - Shading - Radiant cooling - Cooling with ventilation	- Materials - Overall Zero-Energy function -Reservoirs (Study of components)	Qualitative description	Zero-Energy Function Analysis	Construction features	-	Conventional mechanical ventilation systems depend on a significant amount of electrical energy, often obtained from non-renewable sources and fossil fuels, to supply cooled water for use in natural ventilation. This issue can be replaced nowadays by using passive systems.
	Razavi & et al (2015)	-Thermal stratification - Thermal performance - Meshless local - Artificial neural networks - conduction heat - heat transfer	-bottom and top layers of the cistern and general inspection of the reservoir (general study)	-MLPG method -ANN modeling	-thermal performance -time	-bottom and top layers of the cistern -withdrawal cycles	-	The results show a stable thermal classification in the cistern during the water withdrawal cycle. The thermal classification is linear in the lower regions and exponential in the upper regions. The upward trend of the upper region is due to several factors including heat exchange between the upper layers of water and the dome roof, heat transfer, and evaporation caused by incoming air through wind towers.
	Rabani (2019)	-Passive cooling system -Water spraying system (wss) -Temperature effectiveness -Outdoor air temperature -Heat flux - evaporation -temperature variation	-Water mass - floors -room (Study of components)	-CFD -Navier-Stokes - Continuity equation -Momentum equation -Energy equation -Species transport equation	-thermal performance -temperature variation -time -Water spraying system	rooms	-	In the absence of the water spraying system, the temperature in the entire room was uniform and almost the same as the inlet temperature. The use of this system, in the air inlets to the room, reduced the temperature of the room by about 8 to 14 °C compared to the outdoor temperature.
	Ameri Siahoui & et al (2011)	-Passive cooling system -Thermal stratification -Natural convection -heat conduction -evaporation -heat transfer -air flow -humidity	- cylindrical reservoir - room - water reservoir - storage reservoir - domed roof (Study of components)	-MLPG method - ANN modeling - Calibration parameters of MLP	- temperature - temperature distribution -time	- storage reservoir - domed roof	-	-During the research process, a stable thermal classification was maintained in the tank throughout the harvesting cycle. - Two different areas inside the tank with different thermal classifications were observed during the discharge cycle. -The lower part of the tank has a linear temperature distribution and the upper part has an almost exponential thermal classification.
	Najafi & et al (2014)	-Air flow - heat transfer -Thermal performance -evaporating water	-doom hale diameter -inlet and outlet of wind catcher -wind speed -cistern geometry (Study of components)	-CFD modelling -FLUENT software	air flow	cistern geometry	-doom hale diameter -inlet and outlet of wind catcher -wind speed	-The air inlet flow rate increases with the increase in wind speed, but after reaching a certain value, a significant increase in the air inlet flow rate to the wind catcher is not observed with a further increase in wind speed. This happens due to geometric constraints.
	Bahadori & Haghighati (1988)	- heat flow - airflow - evaporation	-soil properties -walls and floor -ground -ceiling	-Thermometer (average daily temperature of water and soil)	Tank water temperature changes	underground reservoir	airflow evaporation	- The thermal classification of the water in the tank is maintained. -Cold water comes out while creating

		- thermal stratification -air conditioning - natural convection	(Study of components)	-Mathematical relations				small flows from the bottom without disturbing the thermal slope of the graph (linear lower and exponential upper).
	Almodovar & La Roche (2019)	-water-to-air heat -passive cooling -evaporative cooling -thermal energy storage	-pond configuration (wall and floor)	-floating insulation -spray system. -air gap -(WAHE) system (Water-to-air heat exchanger)	-water-to-air heat	-The floor of the cells -insulation	-	- It is very effective to cool the pond water in the roof area. -At nighttime, the water temperature is close to the minimum ambient temperature, usually below 20°C. However, in daytime, the water temperature increases by about 2 °C above the nighttime value
	Najafi & Yaghoubi (2017)	-Passive cooling -Ventilation -Outdoor and indoor air temperature -Humidity -Water temperature - Convection heat transfer	-Water reservoir of cistern - dome - Geometry of cistern	- Pyranometer - Data logger - Air Temperature and humidity Sensor - Temperature sensor - Transmitter module - CFD -Weather data	-Outdoor and indoor air temperature -Humidity -Water temperature - Time	Underground`s depth -dome	-	The minimum water temperature is at the bottom of the tank where the water removal valve is located The mean humidity inside the tank is almost constant in different seasons, and the daily humidity changes follow the changes in the air temperature inside
	Beladi & Karaman (2022)	-air temperature	and general inspection of the reservoir (general study)	Descriptive	air temperature	Cistern	-	The use of materials with high capacity against heat, the maximum use of solar energy, and elements such as wind catchers for the use of renewable energy such as wind, saving water consumption, and sardabs to supply the water needed by the building were discussed.
	Vaezizadeh & Kazemzade (2013)	-shade in the yard brought desired -cool air-decreased-heat exchange -between outside and inside	Description of the function of the garden pit, such as the depth of shading and walls and the creation of a cool space in the depth of the ground (general study)	Sketch drawing and comparative table	Earth cooling	Garden pit	-	In Earth-sheltered buildings, due to constant internal conditions, air temperature is favorable, but improper one-way light and ventilation do not ideally meet the needs of residents. It is recommended to combine sheltered buildings with central courtyards in which part of the spaces around the courtyard are underground (semi-underground buildings)
Garden pit	Mohammad Alinezhad (2020)	-Conservation of Energy -Natural Passive Cooling -Evaporative cooling -Radiative cooling -Dehumidification - Microclimate -Thermal fluctuation - shading air circulates -	garden components such as the depth of the garden (shadow effect) plants Water -Soi	Draw a diagram and table of measurements	Three passive strategies	Iranian garden components (garden pit)	-	This study showed that three passive strategies occur in garden pits: - Heating prevention - Heating dissipation -Thermal fluctuations
	Moossavi (2011)	-Passive cooling, -Heating, -Ventilation -Natural cooling -Passive building design	A general survey of the Iranian garden from the point of view of passive ventilation	Qualitative description	Passive cooling systems	garden pit	-	Given the problems of global warming and the clean possibilities of passive cooling, it is necessary to bring them back to the architectural design by contemporizing them, which needs special studies.
	Yaran & Jafari (2022)	Passive energy- -Evaporative cooling -Cross ventilation -Natural ventilation -Geothermal ventilation -Night ventilation -Soil moisture -Coolness	-Canopy -Outer shell - Yard -Walls -Opening -Solar room -Soil	Questionnaire from experts Descriptive	Passive cooling systems	garden pit	-	The garden pit makes use of geothermal energy. By going deep into the ground, it has good thermal comfort in desert areas. Also, the space can be cooled by using natural elements such as water.

	Poorang (2014)	-sustainable heating and cooling -subterranean geothermal - moisture	-Solar room -Soil General survey of garden pit	Thermometers	temperature	garden pit Yard	-	In the garden pit, although the slight difference in outdoor and indoor temperatures in winter is not enough to create a pleasant atmosphere, the use of passive heating techniques can also help thermal comfort along with other methods. Although this comfort may not be provided pleasantly and completely in cold nights.
	Ayatollahi (2012)	- Passive Heating - Passive cooling - Evaporative cooling - Natural ventilation - Relative humidity	- garden pit courtyard - Air outlet General survey of garden pit	Thermometers -Sensor	-Water temperature	- garden pit courtyard	-	Increasing humidity in dry temperature increases thermal comfort. The garden pit and the water pond in the yard are mostly a source of thermal comfort, and the family enjoys the cool airflowing underground.
	Kordhaghi & et al (2022)	- shaded - ventilation -Airflow -Thermal comfort -climatic comfort	- garden pit courtyard General survey of garden pit	-Thermometer	-Climatic comfort	- garden pit courtyard	-	Texture form, geographical orientation of houses, materials, surfaces of houses relative to the ground, size of windows, and roof form are among the most significant construction techniques that affect climate efficiency and create passive cooling.
	Al-Mumin (2001)	- modify the harsh climate - Thermal benefits - cooling load - shaded - soil temperature	- Earth-sheltered buildings -Soil -geometrical shape -walls	-SUNCORT software -Weather data	- Heat conduction - Shaded	-Geometries -Soil cover -Insulation lengths and locations -walls	-	- Annual savings in energy costs, protection of building components against rapid wear, and having a cozy environment with additional "free" spaces for any possible future needs make the use of a garden pit an excellent sustainable design concept. Finally, with this type of design, the negative feelings related to being underground can be removed.
Yakhchal	Pochee & et al (2017)	-passive cooling, -heat transfer model -space cooling -passive ice making	- Space geometry - Dome-Ice Storage Modelling (Study of components)	- Weather data - The Ashton Ice Model - Virtual Environment (software)	-heat transfer model -space cooling	Ice Storage Modelling	Hours of work, Light factor	-Harvesting ice every morning is more useful than storing it. This was because even with the presence of shading walls, the amount of heat received due to scattered solar radiation caused excessive heat generation. The shape of the dome helps to transfer heat and create a convective process
	Hosseini & Namazian (2012)	-temperature difference between the sun-lit and the shaded -shadow	-The Shading Wall -The Provision Pool -The Ice Reservoir -Water pond (Study of components)	Qualitative description	The process of ice formation in the refrigerator	Different forms and components of Yakhchal	-	The considerable point regarding these ice tanks is that they did not need the energy to maintain the space and the process formed in them. In other words, a stable cycle was created in all stages of manufacturing, storage, and ice using a variety of passive cooling techniques. Thus, they were quite technically beneficial. However, nowadays, it is not possible to use them in the same way as before.
	Bahadori (1978)	Description of the cistern opration: creating cooling through conduction and convection (ground by conduction and from the air by convection) In ponds with a depth of 10-20 meters that are used to store ice.	Description of components : maker ice storage, adobe wall, shallow pond and ..	-	Passive cooling systems	Ice pit	-	The base of the operation of passive cooling systems such as Yakhchals is to regulate the reception of cooling at night and its consumption during the day so a cool space is available in the lower part of the earth.
	Mahdavinejad & Javanrudi (2012)	-insulating	-Shade wall -Ice bound -Water rill -Dome roof	Qualitative	dimensions of pits	Types of refrigerators include: - dome -A pond -underground	-	The architecture of the Yakhchals shows that smart methods of using passive cooling techniques have been used to insulate and prepare enough cold to store ice. Thud, this survey has created a basis for valuing these buildings.

	Zandieh & et al (2012)	-Thermal mass -Outdoor temperature -Thermal behavior -thermal insulation	-Massive walls -Water basin -Dome -Storage (Study of components)	Weather data Descriptive	-thermal mass	Massive walls	-Cooling energy -heating energy	Iranian Yakhchals help to create thermal stability in the inner part by shading the wall in the outer part of the space. Also, the Earth-sheltered buildings also helps to create a balanced and almost constant thermal behavior during the day.
	Hensel & et al (2012)	-Heat Transfer -winter wind -prevailing wind	-Dome -Chamber -walls (Study of components)	Qualitative CFD Weather data	Heat Transfer	storage of ice walls	-	The walls in the glacier structure had to be high enough to protect the ice pool, but not so high as to completely cover the water surface from the open space. In other words, this complete lack of coverage helped to create the heat transfer process.
	Mahdavinejad. M & et al (2013)	-Temperature - humidity - Air flow - Cooling	-Water storage	Qualitative	-Temperature -humidity	Water storage	-	The mechanism of Yakhchals can be used in contemporary design, including cool sidewalks in hot and humid areas since these spaces are considered to be the most economical way to cool down due to the use of passive cooling techniques.
	Niroumand & et al (2012)	- Energy conservation - Air flow	-Underground -Mud structures	Qualitative	Temperature	-Underground space -Mud structures	-	The tallest or one of the tallest buildings in the city or village was Yakhchals, which transferred heat to the highest point through the process of convection on hot summer days with their pyramidal structure. In this case, the lower part remains in a stable and cool condition.
	Eiraji & Akbari Namdar (2011)	-Natural Energies -Convection -Evaporation	General description of the operation of the refrigerator	Qualitative	Natural Energies	Yakhchal	-	The structure of the Yakhchal is designed in such a way that it helps to keep the space cool by relying on the convective process and prevents heating by reducing the surfaces.
	- Bahadori (1983)	-Soil freezing -Passive and low-energy -Water evaporation -thermal radiation -Wind -Heat Pipes	-Pond -Heat exchanger pipe - insulation (Study of components)	Descriptive and modeling	-Snow -thermal radiation	ice ponds	-	-Ice ponds can be easily built under existing commercial, industrial, institutional, residential parking lots, shopping centers, etc., or underground. This method is suitable for cooling the space with a high percentage of efficiency due to the use of thermal radiation and heat transfer techniques (due to the spatial structure).
Sardab	Wen, et al (2023)	-Space- airflow coupling -wind pressure -thermal pressure synergy -Passive fresh air -preconditioning	form of spaces, effectively enhances the natural ventilation that investigated in four multiscale spaces: 1) urban scale; 2) site scale; 3) building scale; and 4) room scale	field measurements, scaled models and CFD simulations	Passive ventilation	traditional underground buildings (scal of space)	Space–airflow thermal pressure Passive fresh air	Recommendations: - Optimizing underground passive ventilation by creating microclimate and site design. - Building structures where the underground is connected to the open space through the design of a chimney. -Designing paths to connect the airflows in the whole building.
	Fernando (2009)	Thermal performance	Checking the depth of different basements to get the best storage depth (basement components are not considered)	Record the temperature with a thermometer in different months of the year	cellar	Earth depth	-	- When the outdoor air temperature is higher than the indoor air temperature, more suitable conditions are created for food storage (fermentation). -Excellent thermal behavior of warehouses is created in spring and summer in the period when the temperature is higher and provides optimal temperature conditions for preparation and storage.
	Foruzanmehr & Fergus (2008)	Thermal comfort indoor temperatures ventilation type, current functionality	Installing thermometers in 12 different points of the house and obtaining their temperatures (checking components)	Questionnaire and interview Meteorological organization report and temperature recording with thermometer	temperature changes	cellar	-	Acceptability of underground temperature in summer and winter due to low-temperature fluctuations; The relationship between variables affecting the acceptability/application of traditional Iranian architectural technologies in the modern context, and their effectiveness in reducing energy consumption and CO2

								emissions
	Sadooghi & et al (2019)	Thermal behavior Energy efficiency indoor temperature Outdoor temperature	Entrance and stairs Main space (Sahn) Sub-space (Kat) Vertical Shaft Darizeh) Horizontal channel (Taal) Study on the effects of temperature according to the characteristics of components (study of components)	Record the temperature of different parts (including the Sardab) inside and outside with a thermometer	temperature changes	cellar	-	- The significant difference between the indoor and outdoor air temperature is not only due to the location of the buildings in the ground but also due to the passive ventilation made possible by the warehouse. -The stability of the air temperature inside the underground warehouses during the study is one of the experimental results of this study.
	Alwetaishi (2021)	indoor temperature relative humidity natural ventilation daylight evaporative cooling Thermal comfort	A basement with fixed dimensions, by designing details (such as windows, ceiling and walls)	-Thermal Imaging Camera -TAS EDSL (software) - Professional high-temperature thermometer laser pointer -Temperature and humidity data logger	Temperature and humidity changes	cellar	-	The UGC room (a room designed by researchers) had up to 70% less heat transfer than the room above ground. This issue had a significant effect on fluctuations in the built indoor environment, especially temperature, which was related to thermal comfort.
	Ocan˜a & Can˜as (2006)	indoor temperature Thermal behavior soil temperature soil thermal diffusivity	The temperature of the underground part in summer and winter (general temperature)	-Labs equation (which provides the soil temperature at depth z in the time) thermometer	predict the temperature inside the wine cellars	Soil type	-	The mean temperature difference in the two winter seasons is close to the ideal thermal comfort temperature.
	Foruzanmehr (2015)	temperature variations thermal comfort comfort temperature	General study of the cellar and its temperature changes	sociocultural questionnaire survey, interviews and personal observations thermometer	temperature changes	cellar	-	- 97% of the respondents stated that their house has an underground. - Mean temperature in underground continuously and significantly lower than the mean outdoor temperature.
	Izadpanahiet & al (-2021)	-convective air -thermally comfort -night purge ventilation -natural ventilation -Evaporative cooling	General study of the cellar and its temperature changes	Annual temperature thermometer	temperature changes	cellars	-	The constant annual temperature of these underground spaces helped keep them cooler than the courtyards and above-ground spaces. Thus, it provides a thermally pleasant place for the residents on hot summer days.
	Foruzanmehr & Vellinga (2011)	-thermal comfort -mean indoor temperature Dampness -natural ventilation	General study of the cellar and its temperature changes	questionnaires, interviews and observation thermometer	temperature changes	cellars	-	- The mean temperature in the underground was significantly lower than the mean temperature of outdoor space. - The diversity of temperature in indigenous houses provides the possibility of adaptation to the residents. The results of the questionnaire showed that people are aware of the potential of the underground for passive cooling, but they consider its use to require updating.
	Khalili & Amindeldar (2014)	-Energy efficiency -Behavioral adaptation	General study of the cellar and its temperature changes	Annual temperature Thermometer (taken from previous research) Comparative table	-Behavioral adaptations	cellars	-Using time -Activity	-Reducing the use of the underground and the tendency to eliminate the use of passive heating and cooling energy can be seen in modern houses.
	Saljoughinejad & Rashidi Sharifabad (2015)	-Air temperature levels -trapping temperature -natural ventilation	General study of the cellar and its temperature changes	Comparative table	temperature changes	cellars	-	Climate strategies are used similarly in the three temperatures. Levels: - Roof and roof level - The distance between the roof and the floor -Ground level and underground

	Passe & Battaglia (2015)	-natural ventilation -temperature differences (convection) -pressure -wind directions and speeds -Thermal Comfort -Operative Temperature -Humidity -Temperature and air velocity distributions	Studying the components of space, including the underground	CFD Energy Plus Annual temperature thermometer	Spatial Strategies / Space-Induced Air Movement	Building components including the basement	-	The air exchange rate for comfort, energy, and indoor air quality purposes is a function of the geometry, scale, and size of the openings. Smaller openings increase and larger openings decrease air velocity. The basic assumptions are based on the law of conservation of mass: what goes in one way should come out the other. However, what happens between input and output is important to know.
	Soltanzadeh & Bideli (2015)	-air ventilation -air influence -Cooling -evaporation	-Basement dimensions -depth (basement) -height (basement)	-Thermal thermometer -Digital meter -Descriptive	temperature changes	-depth (basement) - height (basement)	-	Several factors such as the depth, height, and dimensions of the Sardab have had an effect on reducing the amount of energy consumption and the extent of their effect has been different
Shawadan	Beigli (2016)	pressure or -temperature differences wind driven-ventilation -buoyancy driven ventilation	-Stairway Vertical Canal -Si-Sara -Kat -Underground passage (Investigation of the relationship between the depth of the snow in the ground and the amount of temperature reduction in different seasons)	Record the temperature with a thermometer in different months of the year	Passive cooling principles	The components of Shavadan	-	The strategies of this element will be a suitable alternative for contemporary modern buildings. It also results in saving the occupation of the land surface
Shawadan	Sadooghi & et al (2019)	-Thermal behavior -Energy efficiency -indoor temperature -Outdoor temperature	Entrance and stairs Main space (Sahn) Sub-space (Kat) Vertical Shaft Darizeh) Horizontal channel (Taal) A study on the effects of temperature according to the characteristics of components (Study of components)	Record the temperature of different parts of Shawadan (inside and outside) with a thermometer	temperature changes	cellar	-	- The significant difference between the indoor and outdoor air temperatures is not only due to the depth of the buildings but also due to the passive ventilation made possible by the structure of the Shawadans. -The stability of indoor air temperature in Shawadan.
Shawadan	Heidari & et al (2023)	- Natural ventilation -Thermal performance -Effective Draft Temperature - Multi objective optimization - air velocity - Thermal load	role of various components of Shovadan on the thermal performance and the quality of ventilation inside it: Air outlet shaft Kat Tall	-EDT (Effective Draft Temperature) - Genetic algorithm (GA) -CFD simulations	-thermal performance -Natural ventilation	-location of the AOSh and its cross sectional	-	By increasing the vertical cross-sectional area, the air velocity inside the Shawadan increases - By increasing the distance between the entrance and the entrance staircase, the mean speed inside the Shawadan increases. -Thermal comfort is created in Shawadan as an underground space in summer when the temperature and speed are close to the lowest and highest possible values, respectively.
Shawadan	Moradi & Eskandari (2012)	-Temperature -Cooling -Heating - Natural Ventilation - ventilation effectiveness	A study on the effects and changes of temperature (in cold and cold seasons) according to the depth of the lower part of Shawadan (Study of components)	-Navier-Stokes -thermometer-meteorological data	Temperature	underground depth	-	- At shallow depths, temperature changes are large throughout the year. As the depth increases, the temperature changes are negligible since the temperature remains almost constant. - An entrance and the valves of Shawadan are necessary since they are effective in night ventilation. -If the valve is not installed, even if the holes are open, ventilation is not done except in cases where the wind flow leads to ventilation.
Shawadan	Mohammadshahi. & et al (2016)	Natural ventilation-comfort mean -temperature -heat transfer -comfort conditions - “changing” or replacing air - air flow	-effect of canal location on natural ventilation -stairs shape on the comfort conditions - Kat (Study of components)	Annual temperature thermometer-viscous flow solver - Naiver-Stokes	Distribution of ground temperature	-two geometries with different canal locations -canal location -stairs shape	canal area and diameter	- The use of an S-shaped inlet with an outlet control valve improves the ventilation inside Shawadan. -Displacement of the channel does not significantly affect the mean temperature of Shawadan. -Wind flow, underground heat capacity, thermal conductivity, and natural convection airflow can provide cooling and ventilation.

	Mohammadshahi & et al (2019)	-Natural ventilation -temperature - Air conditioning - temperature distribution	foot rest cross-sectional area of the shavadoon Sardab (Study of components)	-Naiver Stokes - ANSYS CFX (software) - SST model -Annual temperature -thermometer	- wide foot rest - cross-sectional area of the shavadoon Sardab	underground depth	temperature of the earth's crust	- Although the addition of coats adjacent to the scene (which changes the cross-section of the Shawadan from simple to cruciform) can increase the stored cold air during the nighttime, the backflow in the staircase increases and the ventilation rate decreases. -The Shabestan on the upper floor increases the inlet flow and improves the ventilation.
	Mas'oudi-nejad (2022)	-temperature -humidity -Spherical temperature -wind speed -Average radiant temperature Wet bulb Temp- relative humidity- Average minimum - temperature Average maximum temperature	-Stairway Vertical Canal -Si-Sara -Kat -Underground passage -Sahn (Study of components)	-CFD analysis -Design Builder software -thermometer -Anemometer -Device for measuring climatic indicators -Psychometric chart -Annual temperature	temperature changes Changes in -relative humidity -Airflow speed changes	Shawadan and its spaces	-	The existence of thermal comfort conditions in different seasons in Shawadan and the stability of the mean radiant temperature are affected by the thermal capacity of the walls, especially in the hot summer season. Also, the speed of air movement is very low and close to zero, removing humidity from the entrance part of Shawadan.
	Poorang. (2014)	-sustainable heating and cooling -subterranean geothermal - moisture	Shabestan General Study of Shawadan	thermometer	temperature	Sardab	-	Although a slight temperature difference in winter is not enough to create a pleasant atmosphere, there is potential to use other techniques for passive heating.
	Mohammad Alinezhad (2019)	Evaporative Cooling - Ground Cooling - Passive Cooling - cooling through - ventilation - Thermal comfort	Entrance- Stairway- foot rest- Sahn- Kat- Tal- General Study of Shawadan	Annual temperature	-Ground Cooling -Passive Cooling cooling - through ventilation	Shawadan and its spaces	-	-The structure of Shawadan is such that it cools it through three types of cooling, including ground cooling, ventilation cooling, and evaporative cooling.

5. Analysis of Findings

In this section, the data extracted from the articles will be explained first. In the next section, the primary findings related to the articles are discussed. In other words, the primary topics are classified in the body of passive cooling studies. In the next section, considering the "research methods" of the desired studies, the details related to the research methods and tools will be discussed. Finally, the parameters measured in the research are introduced and explained based on the independent and dependent variables in the research. Finally, the purpose of this section is to introduce the articles in the field of passive cooling, and the details addressed in these articles are presented. Such solutions are primarily used to solve the primary research problem and the issues that have not been mentioned in these studies, as they have been shown in the table.

5.1. Table data analysis

The purpose of articles in the field of "traditional earth buildings with emphasis on passive cooling" is to analyze one or more thermal strategies. Depending on the type of attitude, methods, and the primary research problem, the process of reaching the answer in these articles is different. The element selected for analysis in these articles is examined in two ways, generally and without considering the components (Khalili & Amindeldar, 2014; Aghazadeh, 2013; Ocan˜a & Can˜as, 2006; Foruzanmehr, 2015; Foruzanmehr & Vellinga, 2011; Khalili & Amindeldar, 2014; Saljoughinejad & Rashidi Sharifabad, 2015; Eiraji & Akbari Namdar, 2011; Poorang, 2014, Moosavi & Vakilinezhhad, 2021) or by considering the element components (Bahadori. M, 1978; Fernando, 2009; Mohammad Alinezhad, 2020; Haghparast, 2008; Rabani, 2019; Ameri Siahoui & et al, 2011; Najafi & et al, 2014; Najafi & Yaghoubi, 2017; Yaran & Jafari, 2022; Bahadori, 1983).

Regarding the aqueduct, studies are divided into two general categories. Concerning the problem of water shortage, land subsidence, and illegal withdrawals from underground water, a part of the articles has addressed the issue of "groundwater management" (Salih, 2006; Ghanbarpour et al, 2007; Aghazadeh, 2013). Some others have described the general function of the aqueduct (Boustani, 2008; Moossavi, 2011; Bahadori, 1978) and some have also analyzed the components of the aqueduct (Wen & et al. al, 2023; Moghadam & et al, 2020; Maghrebi & et al, 2023; Martínez & Martínez, 2012). Studies in the passive cooling sector in this element have been neglected to some extent and still need studies.

In the area of cistern, articles are placed in several categories. Some articles have addressed water quality and soil characteristics (creating microclimate) (Bahadori & Haghighati, 1988; Almodovar & La Roche, 2019; Najafi & Yaghoubi, 2017) to create passive cooling (Wen & et al, 2023; Najafi & Yaghoubi, 2015; Memarian, 2009; Rabani, 2019; Ameri Siahoui & et al, 2011; Najafi & et al, 2014) and some articles have referred to cisterns as a space that provides an environment for cistern without using fossil energy and described its process (Razavi & et al, 2015; Beladi & Karaman, 2022).

Regarding garden pit, given the direct connection of garden pit with the atmosphere (unlike other underground spaces), the articles, have dealt more with microclimate and thermal control and their subsets. Factors such as wind speed and soil characteristics regarding microclimate have been addressed in articles (Moossavi, 2011; Yaran & Jafari, 2022; Poorang, 2014). These articles have examined garden pit components. Also, in the field of thermal control, orientation, insulation, and shading have been examined in the articles (Vaezizadeh & Kazemzade, 2013; Mohammad Alinezhad, 2020; Kordhaghi & et al, 2022). Regarding the Yakhchal, articles have examined the components of the Yakhchal. The structure of the Yakhchal, the orientation of the wall (for proper shading), and the geometry of the dome and isolation have been addressed by researchers (Pochee & et al, 2017; Hosseini & Namazian, 2012; Hensel & et al, 2012; Mahdavinejad & Javanrudi, 2012; Bahadori, 1983). Additionally, some articles have described and qualitatively examined the Yakhchal and its operation from the passive cooling viewpoint (Mahdavinejad & et al, 2013; Niroumand & et al, 2012; Eiraji & Akbari Namdar, 2011).

Some articles on Sardabs have investigated the temperature changes in different depths of the Sardab and other factors affecting the thermal regulation of the space (Fernando, 2009; Foruzanmehr & Fergus, 2008; Sadooghi & et al, 2019; Alwetaishi, 2021; Ocan˜a & Can˜as, 2006; Izadpanahiet & al, ¬2021; Foruzanmehr, 2015; Khalili & Amindeldar, 2014; Saljoughinejad & Rashidi Sharifabad, 2015) and some articles have addressed the geometry of space and Sardab components (Passe & Battaglia, 2015; Soltanzadeh & Bideli, 2015). Regarding the Shawadan, most articles are technical and have investigated the components of Shawadan and their impact on air quality and natural ventilation (Sadooghi & et al, 2019; Heidari & et al, 2023; Mohammadshahi & et al, 2019, Masudi Negad & et al, 2019). Some articles have also investigated the impact of the depth of the staircase on the optimal performance of the Shawadan (Beigli, 2016; Moradi & Eskandari, 2012; Mohammadshahi & et al, 2016). Some articles have also generally evaluated (qualitatively) the components and structure of Shawadan (Poorang, 2014; Mohammad Alinezhad, 2019).

Critical Findings

Based on the conducted studies, the findings of the studies are divided into two categories. A part of the findings is the field of the "structural" summary of the studies and another part of them is related to the "content" and technical topics of the articles. Both categories help researchers to have a general and appropriate view of research in the field of underground spaces and passive cooling. The next studies in this area should be summarized considering the studies reviewed in this study.

Structural summary

- Some articles worked only on the desired element and some other elements were also examined (Hughes & et al, 2012).
- The articles were generally descriptive-analytical, experimental, and numerical analyses and reports.
- The survey scale was multiple, from hypothetical samples to single samples and global scale: hypothetical sample: 10 cases: 15%; numerical (from one sample to 20 samples): 32 cases: 47%, at a scale of a neighborhood: 1 case: 1%; at the scale of the city: 4 items: 6%; Climate area: 20 items: 30%; global scale: 1 case: 1%.
- The number of references was about 65 on mean: the number of descriptive articles: 33 cases: 49%, the number of numerical articles: 15 cases: 22%, the number of combined articles (numerical-descriptive): 20 cases: 29%.
- The house pond has been mostly examined as a mixed space with a Shawadan wind catcher and sometimes as a part of the Sardab (as a room).
- Articles in general, hot and dry: 54 cases: 79%; Semi-hot and dry: 5 cases: 7%; Hot and humid: 7 cases: 10%; Semi-hot and humid: 6 cases: 9%; Mediterranean (temperate and humid): 2 cases: 2%; Cold and mountainous: case 1: 1%; Different areas: 1 case: 1%.
- The articles related to cistern and Yakhchal were somewhat similar in terms of the research method because they are similar regarding structure and shape in some cases.
- Articles related to Sardab and Shawadans are more technical and have been investigated using experimental and simulation methods.
- The articles related to garden pits are more descriptive.
- The articles related to the garden pit have been investigated more in combination with other elements of the house (such as the central courtyard at ground level, Shawadan, etc.).
- In some cases, such as the articles related to Shawadan and the Yakhchal (Bahadori, 1983), by studying historical and traditional samples, "hypothetical" samples have been used for the case study and spatial analysis.
- Reputable magazines mostly had articles in the field of Sardab and Shawadan.
- It seems that a Sardab with a pond and a garden pit needs more studies in future articles.
- In some articles (especially the combined experimental and simulation articles), researchers are trying to introduce a "process" in reaching the research question. This means that the researchers are looking for a method to prove the validity of the simulation findings so valid results can be obtained in less time in the future. They are also trying to introduce the method or methods that can be used to examine an underground environment from different aspects so they can be used in the contemporary design of spaces with optimal function in real conditions. In this study, the role of the research "process" is more highlighted than its "results".

Content Summary

Based on the general research strategies (heating dissipation and heating prevention) and the results obtained from the framework in passive cooling developments (Table 2), the results of the relevant articles are reviewed.

- The basis of operation of passive cooling systems such as aqueducts, cisterns, and Yakhchals is to adjust the intake of cooling at night and its consumption during the day so there is clean and cool water in them. Heating dissipation strategies such as night ventilation, cross ventilation, buoyancy ventilation, and evaporative cooling are used (Bahadori, 1978).
- Some underground buildings are completely inside the ground, such as aqueducts and Shawadans, and some Yakhchals, and cisterns
- Some are a little outside and a little inside the ground; such as the garden pit, some examples of Shawadans, and some Yakhchals.
- Those that are completely inside the ground have fewer temperature changes and work using convection and evaporative cooling systems (heating dissipation strategies).
- Semi-undergrounds are more affected by the sun and temperature increase (temperature changes) and heating (heating prevention).
- The soil properties and the quality of water in underground structures that use the combination of these two properties to create cooling use microclimate to prevent heat penetration (Wen & et al., 2023 & Boustani, 2008).
- Airflow has a great impact on the quality of water consumed in cisterns that are connected to wind catchers (Najafi & Yaghoubi, 2015).
- Evaporative cooling helps heat exchange and create thermal stratification in the water in traditional undergrounds (Razavi & et al, 2015)
- The water spraying system (WSS) lowers the room temperature significantly. In other words, the combination of two passive techniques of evaporative cooling and heat exchange helps with heating prevention in undergrounds that use this system (Rabani, 2019).
- The inlet flow rate of the airflow increases with the wind speed, but after reaching a certain value, a significant increase in the inlet flow rate to the wind catcher is not observed with a further increase in the wind speed. This occurs due to the geometric limitations of space (Najafi & et al, 2014).
- The base of the operation of underground structures related to water is night cooling and night ventilation (Almodovar & La Roche, 2019; Najafi & Yaghoubi, 2017).
- Geographical orientation and the use of geothermal energy are significant issues in the formation of airflow in open undergrounds (garden pits). This means that strategies used for heating prevention provide thermal control of the conditions (Poorang, 2014; Soltanzadeh & Bideli, 2015).
-Insulation (heat capacity of soil) and shading as heating dissipation strategies in Yakhchals have turned them into an efficient space for harvesting ice (Mahdavinejad & Javanrudi, 2012).
- Measuring the water temperature in the upper and lower part of the water in the cisterns and drawing a diagram to record the temperature changes in this element has been done in previous articles. These articles have investigated the performance of cisterns by considering various variables as intervening factors in different conditions.

Research tools and methods (Solver & Software)

The articles are generally reviewed in three ways: qualitative (descriptive) articles, quantitative research, and mixed types. Articles related to passive cooling in traditional buildings include all three types. Descriptive articles include those related to garden pits. These articles, considering the ambient temperature in a period and the annual outdoor temperature using meteorological data, justify the annual temperature difference according to the determining factors of the environment such as water and soil heat capacity, and underground depth (Mohammad Alinezhad, 2020; Khalili & Amindeldar, 2014; Saljoughinejad & Rashidi Sharifabad, 2015; Poorang, 2014; Ayatollahi, 2012; Kordhaghi & et al, 2022). Therefore, different types of thermometers such as the thermometer laser pointer and temperature sensor play a crucial role (Alwetaishi, 2021). Using their results, the performance of the desired space was described. Comparative diagrams (tables), questionnaires, observations, and interviews are among the most crucial tools to reach the primary research question in these studies. Quantitative articles reviewed in this study have more diversity regarding the research tools and various solutions have been used to solve the research problem. In this regard, to quantify the research findings, several types of software have been used. Autodesk CFD and Fluent CFD are the most used software in articles (Wen & et al, 2023; Najafi & Yaghoubi, 2015; Heidari & et al, 2023; Passe & Battaglia, 2015; Masudi Negad & et al, 2019; Rabani, 2019; Najafi & et al, 2014; Najafi & Yaghoubi, 2017; Hensel & et al, 2012).
The primary task of this software is the simulation and analysis of fluid dynamics and the simulation of heat transfer flow. Other energy software such as Ansys (Najafi & et al, 2014), SUNCORT Software (Al-Mumin, 2001), Virtual Environment (Pochee & et al, 2017), EDSL TAS Software (Alwetaishi, 2021), Energy Plus (Passe & Battaglia, 2015), Ansys-CFX (Mohammadshahi & et al, 2019), and Design-Builder (Masudi Negad & et al, 2019) are among the most crucial software used in the articles. The most significant task of this software is data analysis for optimization and proper efficiency of the studied subject. Also, extracting data from the desired element or element components using simulation is one of their other tasks. In addition to software, mathematical equations, algorithms, and flowcharts are among the widely used tools in these articles. For example, Navier-Stokes (Mohammadshahi & et al, 2016; Mohammadshahi & et al, 2019; Masudi Negad & et al, 2019), algorithm genetics (Heidari & et al, 2023), and MLPG and ANN (Razavi & et al, 2015; Ameri Siahoui & et al, 2011) have been used in some experimental models (Almodovar & La Roche, 2019; Najafi & Yaghoubi, 2017).

In the reviewed articles, the Navier-Stokes mathematical equation is the most widely-used mathematical equation to solve all types of relations between fluid movement (relationship between velocity and stress), temperature changes, and other atmospheric factors. Some articles have also used a combination of the above two models (Ocan˜a & Can˜as, 2006; Bahadori, 1983). While describing the desired element, these studies have investigated quantitatively and experimentally using the software and numerical relations (equations, etc.). In some cases, simulation has been done practically (Moghadam & et al, 2020; Bahadori & Haghighati, 1988).

Measured parameters

The most significant factor or parameter measured in studies is "temperature changes" related to air, water, soil, and humidity level (Foruzanmehr & Fergus, 2008; Sadooghi & et al, 2019; Alwetaishi, 2021; Izadpanahiet & al, 2021; Foruzanmehr & Vellinga, 2011; Saljoughinejad & Rashidi Sharifabad, 2015; Bahadori & Haghighati, 1988; Soltanzadeh & Bideli, 2015). Both of them are related to heating dissipation strategies. Thus, it seems that in the reviewed passive cooling articles, this strategy is seen more in traditional underground buildings. Based on the researchers' findings, these two factors determine air quality and thermal comfort in the desired element whether in elements such as Yakhchals, aqueducts, and cisterns that do not have human inhabitants or in human laments such as Sardab, garden pits, and Shawadan.

After these two factors, the structure of the components of some elements has also been addressed. For example, the structure of the dome in the cistern (Najafi & Yaghoubi, 2015; Ameri Siahoui & et al, 2011; Najafi & Yaghoubi, 2017), Yakhchal (Pochee & et al, 2017; Zandieh & et al, 2012; Hensel & et al, 2012; Mahdavinejad & Javanrudi, 2012); Shade wall in the Yakhchal (Hosseini & Namazian, 2012; Hensel & et al, 2012; Mahdavinejad & Javanrudi, 2012), the dimensions of the building and the geometry of the components in the Sardab, Shawadan, and the garden pit (Alwetaishi, 2021; Mohammad

- Thermal comfort in underground structures is created in summer when the temperature and wind speed are close to the lowest and highest possible values, respectively
- It seems that a few studies have been conducted in the field of "Aqueducts" and "cisterns" in passive cooling systems, and the studies have been conducted in other related fields. However, in the case of Sardabs and Shawadans, more extensive scientific studies (in method) have been conducted in connection with passive cooling systems and strategies.
- Some of the early articles conducted in the field of passive systems (the 1970s and 1980s) did not follow the principles of article writing properly in terms of structure, although they have been referenced a lot in subsequent articles (such as the Bahadri's article) due to being the "first". For this reason, it is necessary to introduce them in this article.
- The articles mentioned above are mostly introduction and descriptive and less analytical.

Alinezhad, 2020; Pochee & et al, 2017; Mohammadshahi & et al, 2016; Najafi & et al, 2014; Najafi & Yaghoubi, 2017; Soltanzadeh & Bideli, 2015), and the water pool is in Yakhchal have been investigated (Mahdavinejad & et al, 2013; Ayatollahi, 2012).

In all elements, components that play the most significant role in creating appropriate temperature and humidity using passive cooling parameters have been investigated. Other components that play a less significant role have been investigated in fewer articles. Both "element and its components" and "passive strategies" have been used as independent and dependent variables in different studies, depending on the primary problem of the study. However, the examination of changes in temperature and humidity (strategies) has been generally considered as a dependent variable in the studies, and the element or implementation has been considered as an independent variable.

6. Conclusion and Recommendations

In the conducted studies, underground buildings are generally divided into two categories:
- Undergrounds
- Semi-undergrounds
- One of the challenges of such spaces (undergrounds), if human beings are supposed to live inside them, is the issue of "light supply". The basis of using such spaces is the use of clean energy. Thus, the use of electronic and mechanical facilities in them needs to be minimized. In this regard, if these spaces are to be used in contemporary architecture, this problem should be solved somehow.

The garden pit is the only example that has a complete connection with the outdoor space and at the same time is placed inside the ground. Having "shade" and the benefits of the Earth-sheltered buildings, the problem of daylight has been solved in it.

- The depth of the underground has a great impact on the quality of the indoor air. This means that at shallow depths, the impact of ventilation and generally underground conditions is negligible.
- Some passive cooling factors have been investigated as a case, such as soil temperature, daylight, dehumidification, and heat load.
- Element components have not been investigated in many articles such as the geometry of the space, height, type, and thickness of materials, etc., which can be intervening and influential variables in the results.
- The negative aspects of passive strategies have been mentioned in articles such as dust, humidity, high construction, maintenance costs, and low space efficiency. These aspects can be categorized under more general headings including "unfavorable", "unhealthy", "uneconomic" and "impractical".
- An article mentioned that the underground space has lost its past function as a space with a passive strategy. This result indicates that sometimes cultural considerations can be more effective than environmental factors.
- Some articles have emphasized the necessity of using and modernizing passive cooling in buildings based on its characteristics.

- Examining the interrelation between thermal behavior and human behavior, for example, midday sleep, was a local and regional response to the thermal problem.
- Concerning the aqueduct, articles in the field of "Evaluation of traditional water management" have also been defined due to the necessity of preserving and using underground water resources. For this reason, it seems that the aqueduct structure can be used in contemporary conditions due to its optimal function and high efficiency.
-The diversity of studies in the field of aqueducts included geological, chemical, environmental sciences, and protection against pollution, which includes a broader set of studies.

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