679: An Investigation to Design Strategies of Traditional Zero-Energy Water Reservoir Buildings in Iran: An Outlook to Innovative Passive Cooling System

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Abstract

Supplying potable water in hot arid regions has always been a challenge for the residents. In central and eastern deserts of Iran, where poor rainfall and seasonal rivers cause extreme conditions in supplying water, a creative traditional solution has been a unique kind of water reservoirs (cisterns) called “Ab-Anabr”. These structures typically consist of an underground cube or cylindrical reservoir with a massive covering dome and one or more wind towers for ventilation and a staircase for taking water.

As the modern life and technology dominated the region, water pipeline system replaced cisterns and only in few cases as in Naeen, they are still in use (as a complementary resource for potable water). This paper, with a critical look at the background, is to analyze the strategies used in these structures making them capable of functioning as a zero-energy building to provide the residents of a town with potable water during the hot season.

Later on the investigation is dedicated to study the considerations used in keeping water cool during hot season and providing an efficient ventilation system without any consumption of fossil energies .The focus on these strategies and considerations are in order to develop and adopt an efficient passive cooling system out of these abandoned structures which also hold historical and cultural values. This passive cooling system not only can alternate the electrical cooling systems that are now being used in the region, but also can help to reserve these buildings of historical and architectural value as an adaptive reuse approach.

Keywords: zero-energy, passive cooling, cistern

1. Introduction

Climate has always influenced people’s lifestyles. This has been particularly true in the past when the lack of abundant sources of energy made the people to take advantage of the climate’s diversity, and live with it. For example, in hot arid region of Iran, people developed highly advanced passive cooling systems and adapted a lifestyle in order to provide thermal comfort for themselves in a very harsh environment [1] In hot arid region of Iran, the lack of precipitation over 6 month of year make the rivers sources, seasonal. [2] Over this predicament, to supply potable water in summer, some contrives were performed. Cistern or Ab-Anbar (as it is called in Persian) is one of them. It was practiced extensively in Iran and some of neighbour countries before the advent of piped water and mechanical refrigeration.

Cistern typically consists of an underground cube or cylindrical storage with massive covering dome and one or more wind towers, "Ba’d-Gir", and a staircase for taking water from the bottom. Although cisterns are almost abandoned in Iran, but some of them are still in use in few cases as in Naeen - in central Iran - for supplying cold potable water for the community. In order to investigate the innovative strategies, "Masum Khani "cistern, one of the large cases in Naeen, is determined. (Fig.1)

Before piped water became popular, many houses in Iran use the river water which was stored in community cisterns in winter. These cisterns were filled during the winter nights with coldest possible water. Before entering the cistern, water flowed in open channels where it was cooled evaporatively and by radiation heat transfers to the clear sky, to temperatures only a few degrees above the freezing point. Water remained in the cistern until summer or when people need cold water for drinking. Then, people desiring cold, potable water walked to the community cistern and took the needed amount of water for their use.

Fig1. A view of " Masum Khani "cistern in Naeen

Water was removed from the bottom at a very low rate (less than 30L per min) so that there was no disturbance in the thermal stratification of water in the cistern. Furthermore, because of their very large sizes and thermal stratification, the rate of heat gain by a unit volume of water in these tanks was very small. The cisterns could then supply water at low enough temperatures for drinking. [3]

The size of the cisterns was dependant upon the size of the community they were serving. It varied between about 500 to about 5000, with 2000 m^3 designating a more common size. The height of the cisterns varied from about 5 to about 10m. "Masum Khani" cistern with the capacity of 2500 m^3 is considered an average cistern. The brick walls and floor of the cisterns were lined with an indigenous cement to prevent water leakage. [2, 3]

2. Zero-Energy Function Analysis

Measurements made by the authors during last June on Masum Khani cistern, have shown that the temperature of water supplied by this cistern was below 12°C. During this time the maximum out side air temperature was around 40°C. More interestingly, no energy is used for its function, thus the authors studied the cistern in order to investigate the passive strategies corresponding the cooling performance which have led the building to work as a zero-energy structure:

2.1 Passive Cooling Strategies

According to Lechner, five methods of passive cooling are:

1. Cooling with ventilation
2. Radiant cooling
3. Evaporative cooling
4. Earth cooling
5. Dehumidification with a desiccant: Removal of latent heat [4]

Thermal function of traditional Iranian cisterns of hot arid region is by taking the benefits the first four above mentioned methods as following:

2.1.1 Cooling with ventilation

The cistern was equipped with one or more wind towers or "Ba'd-Gir" which maintained a wind-induced airflow over the water surface. [1, 2] (Fig.2)

In urban settings and other places with little wind, wind towers are sometimes used to maximize ventilation. Wind towers were already used several thousand years ago in Middle East, and they are still found in Iran today. [1, 4]

As air hits the windward side of a wind tower, it compresses and creates a positive pressure. At the same time, air is sucked away from the leeward side, thus creating a negative pressure. In addition the velocity of air increases rapidly with height above ground.

The vent is located at the top of cistern's dome can allow the hottest air to escape with stack effect. The stack effect can exhaust air from a cistern by the action of natural convection. The advantage of the stack effect is that it does not depend on wind. [4] (Fig.3)

Briefly, vertical ventilation function of cistern is the result of low and high pressure areas and stack effect.

In hot arid region of Iran the weather at night is significantly cool in comparison to day time. [2]

Night-flush cooling works in two stages. At night, natural ventilation bring cool outdoor air in contact with the indoor mass, thereby cooling it and the next morning, the cooled mass acts as a heat sink and, thus, keeps inside temperature from raising as fast as it would otherwise.

This cooling strategy works best in hot and dry climates because of the large diurnal temperature ranges found there, above 30 F[4, 5]

Considering the high thermal mass of a cistern structure, this strategy has an efficient role in its function.

Fig2. The wind tower of " Masum Khani" cistern

2.1.2 Radiant cooling

Massive domed structures are successful in hot arid regions. Besides the thermal benefit of their mass, their form yields two different benefits. During the day, the sun sees little more than the horizontal footprint of the dome, while at night almost a full hemisphere sees the night sky. Thus, radiant heating is minimized while radiant cooling is maximized. [4]

Surface of the hemisphere is almost thrice the area it covers, therefore intensity of indicant rays of sun on a spherical surface is less than a flat one and lower part of the dome has a lower temperature. On the other hand, since the surface of the dome is exposed to huge consequently it is less affected by the radiant heat.

Considering the hot arid region of Iran which is characterized by clear sky at nights with little humidity so radiant cooling acts efficiently in cooling up the building mass. Dome shell of a cistern gives up the heat as infra red rays to the sky at night and during the day cooled mass effectively acts as a heat sink to chill up the building. [11]

Fig3. The vent of "Masum Khani" cistern

2.1.3 Evaporative Cooling

During water storage and usage in cistern, there is always a wind-induced air flow over the water surface to maintain an evaporation rate from the water surface. [2, 3]

When water evaporates, it draws a large amount of sensible heat from its surroundings and converts this type of heat into latent heat in the form of water vapour. [4]

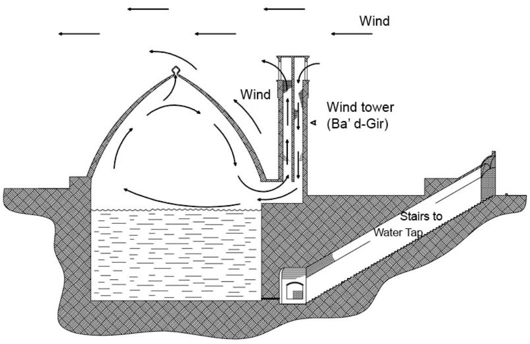

Fig5. A section of Masum-Khani cistern and its surrounding soil with wind-induced air flow over the water surface

2.1.4 Earth cooling

Temperature of soil near the surface is close to air temperature so, it fluctuates widely from summer to winter. How ever, due to the large time lag of earth, the soil temperature fluctuates less and less as the soil depth increases. At about 20 feet (6 M) in depth, the summer/winter fluctuations have almost disappeared and a steady state temperature exists year- round, which is equal to the average annual air temperature.

The graph of Fig 2 shows the earth temperatures as a function of depth. One curve represents the maximum summer temperatures, and the other represents the minimum winter temperatures of the soil.

The ground temperature is always below the maximum air temperature, and the difference increases with depth. Thus, the earth can always be used as a heat sink in summer. [4]

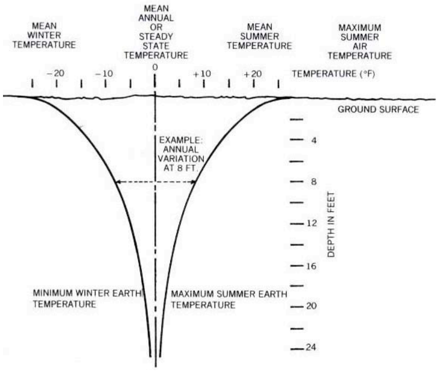

Fig4.The graph represents the overall behaviour of soil temperature as a function of depth. Soil temperature varies with time of year and depth below grade. [4]

2.2 Shading

Cistern dome, in addition to the role it has in riadant cooling, by providing shade on the water reserved, significantly reduces the direct influence of the sun. Shading is even more effective on the surrounding soil of the cistern in its thermal function

Since the sun heats the soil, shading the surface significantly reduces the maximum earth temperature. Water evaporating directly from the surface will also cool the soil. Both techniques can reduce soil surface temperatures as much as 18° F. [4] Before the new materials dominated the urban pavements, a light-colored gravel of 10 cm deep was used to effectively shade the soil while still allowing evaporation from the earth's surface below the gravel.

Therefore, it's recommended to restore the pavement surroundings the cistern with the original light-colored gravel bed to maximize the efficiency, this can also help conserving the buildings.

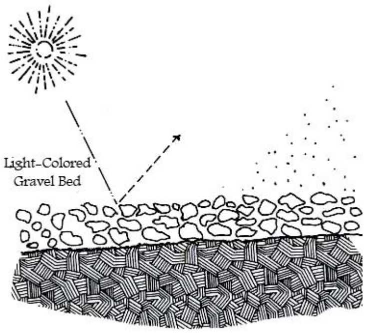

Fig6. Soil can be cooled with a gravel bed, which shades the soil while it allows evaporation to occur. [4]

2.3 Materials

Materials used in construction of cisterns are vernacular materials that are mostly comprised of the soil obtained from excavations. High thermal mass of the bricks used in cisterns cause a lag in thermal transmit which has an important role in slow absorption of heat in the dome. Eventually, this phenomenon results in high thermal efficiency of the structure. However, thermal lag in cistern body contacting the surrounding soil isn't so effective in long priod and after a definite time from the construction the materials used in the structure keep a balance with surrounding soil.

2.4 Overall Zero-Energy function

According to Bahadori and Haghighat general analysis of the typical cisterns,as presented in figure7, the temperature of water at the bottom of the cistern for 5 years of operation for the two types of soil considered in general. It is seen that at any given month of the year, the water temperature reduces greatly from first to the second year of operation, changes very little from the second year on, and does not change beyond fourth year of the operation. However the monthly warming trend of water remains the same as that of the fist year of the storage. [3]

The heat gain from the ambient air on top and from the ground surrounding the cistern was partly offset by the evaporative losses from the water surface. The high flow rates of dry ambient air over the water surface, which was created by wind action on the "Ba'd-Gir" and domed roof opening, maintained a relatively large evaporation rate from the water surface. Furthermore the high air flow rate kept the ceiling temperature of dome at about the air temperature all the time.

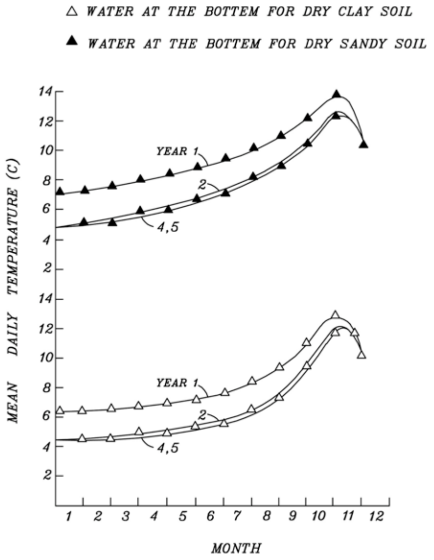

Fig7. Water temperature at the bottom of the cistern for different years of operation for dry clay and dry sandy soils. The initial water temperature is 4°C [3]

The heat gain by water was primarily near the top and was transferred to the water layers below by conduction. This created a perfectly stratified storage tank with the warmer water always staying on top. The heat gain from the bottom was generally very small, particularly after several years of operation, so that there was no appreciable mixing and disturbance of the stratification in the cistern.

According to our field investigation in "Masum Khani" cistern, without the wind tower and the circulation of ambient air over the water surface, the evaporating rate from the water surface was reduced appreciably. Furthermore, due to the solar radiation absorbed by the roof of storage, the ceiling temperature was higher than of ambient air.

This increased the thermal radiation heat exchange between the water surface and ceiling which together with reduction in evaporation rate, increased the water temperature in the cistern.

3. Conclusion

The use of cisterns in Iran has been diminishing rapidly due to the widespread use of piped water and household refrigerators. Except for a few cases still in use, most of these cisterns so-called "Ab-Anbar" have either given way to new developments or have been re-modeled as tourist attractions. These cisterns can be employed to supply cold water for applications other than drinking water. Conventional HVAC systems are dependant on a significant deal of electrical energy that is often obtained from non-renewable resources and fossil fuels, to be provided with cooled water in order to use for air-conditioning. A cistern can provide these systems with the necessary chilled water during the hot season without any use of fossil energies. More importantly, revival of thee abandoned cisterns as zero-energy functioning building in hot arid areas of Iran not only would pave the way to conserve historical and cultural values but also could sketch up a sustainable approach in establishing a more efficient environmental friendly cooling system.

4. References

1. M.N. Bahadori (1978). Passive Cooling Systems in Iranian Architecture. *Scientific American*, 238(2): p.144-154

2. V. Ghobadian (1998). Climatic Analysis of the Traditional Iranian Building. P.298-314

3. M.N. Bahadori and F. Haghighat (1988). Long-Term Storage of Chilled Water in Cisterns in Hot, Arid Regions. *Building and Environment*, 23(1): p. 29-37

4. N. Lechner (2001). Heating, Cooling, and Lighting: Design Methods for Architects. P.245-277

5. Ahmad Hamza H. Ali (2007), Passive Cooling of Water at Night in Uninsulated Open Tank in Hot Arid Areas *Energy Conversion and Management,* 48: p.93-100

6. D. Pearlmutter , E. Erell and Y. Etizon (2008). A multi-stage down-draft evaporative cool tower for semi-enclosed spaces: Experiments with a water spraying system. *Solar Energy,* 82: p.430-440

7. R. Kumar , S. Sachdeva and S.C. Kaushik (2007). Dynamic earth-contact building: A sustainable low-energy technology. *Building and environment* , 42 : p.2450-2460

8. ASHRAE Handbook, Fundamentals, Am. Society of Heat. Refrig. And Air Cond. Engineers, Atlanta, Georgia, USA(1997)

9. A.A. Dehghan (2004). An Experimental Investigation of Thermal Stratification in an Underground Water Reservoir. *Proceedings of HTFED2004: ASME Heat Transfer/Fluids Engineering Summer Conference, Charotte, NC, USA.*

10. Cunningham, W. A. And Hompson, T. L. (1986). Passive Cooling with Natural Draft Cooling Towers in Combination with Solar Chimney. *Passive and Low Energy Conference PLEA.*

11. F. Haghparast (2005) PhD thesis, Energy Conscious Design in Architecture : Optimizing the Receipt of Solar Radiation by Building Surfaces with the Aid of Enhanced Computer Simulation, Cardiff, UK. p.100