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Improvement of ventilation and heat transfer in Shavadoon via numerical simulation: A traditional HVAC system

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ABSTRACT

In the past, at several areas of Iran, different efficient methods are used for improving the life quality. Environmental conditions in hot and semi-humid climate of southwest of Iran persuade native architects to construct buildings under the ground. These buildings in depth of 5–15 m create comfort mean temperature by using soil thermal properties in various seasons of year. In the north of Khuzestan particularly in Dezful and Shushtar, these spaces are called Shavadoon. The aim of this paper is to recognize and introduce some ways to use Shavadoon in green houses. In this research, Shavadoon components are first explained. Then, natural ventilation and heat transfer in Ghasri's Shavadoon during August is numerically studied by a viscous flow solver. The results show that when the ambient temperature is 45 °C, the temperature of Shavadoon becomes about 28 °C. For this case, the mean temperature is suitable in terms of comfort conditions not ventilation. Thus, some different geometrical parameters like form of stairs, valve at the canal outlet, place and diameter of canal for better living are perused. The numerical results show that using the S-shaped intake with exit controlling valve improves the ventilation without deteriorating the thermal comfort conditions inside the Shavadoon. Therefore, it can effectively decrease energy consumption and help to enrich the nature.

1. Introduction

Wind catchers, Ab-Anbars (underground water houses), and Yakhchals (ice houses) are examples of architectural innovations to overcome undesirable weather conditions in different parts of Iran. Shavadoons are another illustration of these innovations caused by the climatic conditions in the southwest parts of Iran. High strength of natural substrates of the ground has provided the possibility of excavating Shavadoons.

In fact, native people had a complete understanding of the ground's material and used it as a shield against heat. It should be noted that the ground of Dezful's suburb is mainly composed of limestone conglomerate and very hard fine or course sandstones. Therefore, given the soil characteristics in these areas, Shavadoons are typically used as underground spaces without any construction materials.

Along with typical living of people in the area, another form of lifestyle existed in Shavadoons. They were mostly used in hot and overwhelming days of summer. Besides daily rest, Shavadoons were also used for food storage.

There are few studies on the unique characteristics of these constructions. Bina [1] introduced and analyzed Dezful's Shavadoons [2]. Result of this study showed that Shavadoon's temperature at the hottest days was still lower than the minimum temperature of the ground's surface. Stability of Shavadoon's temperature is another finding of this study. Moradi and Eskandari [3] used numerical and experimental solutions to evaluate heating and cooling performance of Shavadoons. Their results showed a 36% temperature error in August through their numerical analysis. Rahaei [4] also studied the cultural identity and its effects on local methods of natural ventilation in Dezful's old Bazaar, craftsmen's line. Simulation scenario in this study was based on Fluent and Gambit model.

Golani and Ojima [5] divided underground spaces into five groups, which were used in ten different ways. The effect of using the underground spaces on the natural environment and mental comfort of the humans is studied. According to this research, using the underground spaces has a desirable effect on both of them.

Gribble [6] studied the natural ventilation in Egyptian underground tombs. He indicated that in the desert, when the outside air

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temperature drops dramatically in the evening, a cool air flows into the excavations which flushes out the stale air and dust, and replaces it with the fresh air, enabling the residents to continue working day after day.

In the present study, the heat and air flow inside Shavadoons is first numerically simulated using a viscous flow solver. The obtained results show a modeling error of less than 5%. In this Shavadoon, the mean temperature is suitable in terms of comfort conditions not ventilation. Thus, by changing the intake shape, an almost uniform air flow is formed through the canal that causes the recirculating flow at the canal outlet to be removed. On the other hand, it causes the mean temperature to increase that is undesirable. In order to compensate the mean temperature increment, a controlling valve at the canal outlet is used. Finally, an optimal mode for these basements is presented.

2. Dezful

Dezful (also Romanized as Dezfūl and Dezfool) is a city in and the capital of Dezful County, Khuzestan Province, Iran. This city was built on a type of Conglomerate at an elevation higher than that of Dezz river surface. Dezful has a hot semi-arid climate (Köppen climate classification) with extremely hot summers and mild winters. Table 1 shows the climatic data for Dezful in the period of 1961–1990. Location of this city is showed in Fig. 1.

3. Shavadoon's structure

Shavadoons are composed of different elements including entrance, stairway (Pella), foot rests (pellapam), main hall (Sahn), Kat, Darizeh, and Tal which are explained in the following:

3.1. Entrance

Shavadoons are provided with a rather wide door-less entrance which is usually located at a part of courtyard or at a patio adjacent to the yard.

3.2. Stairway

Stairs connect the building to the end of underground space which starts from the entrance and ends to the Sahn of Shavadoon. In most cases, the slope of these stairs is steeper than modern stairs.

3.3. Foot rests

After each 12 successive stairs there is usually a wider step as a landing with a size and applicability beyond modern foot rests. For example, when the number of residents exceeds what Shavadoon could accommodate, these foot rest spaces were used. In most of the large buildings, there are 2 or 3 foot rests.

3.4. Sahn

Sahn is the main element of the construction with a square plan which is the main center of activity and living in Shavadoons.

3.5. Kat

With the exception of the first side of Sahn which is connected to the stairs, there are 3 other sides which are connected to some small rooms called Kat. In fact, Kats are more personal spaces of Shavadoon with a difference in level which separates them from Sahn.

3.6. Darizeh (vertical canals)

A vertical cylindrical channel to provide lighting and ventilation of Shavadoon which is also called “Si Sara” in Shushtar. In some of the cases, Darizehes are connected to the inner space of house to transfer cool air from Shavadoon to the building. Most Shavadoons are provided with only one Darizeh.

3.7. Tal

Shavadoon's Kats are connected to the neighboring Shavadoons through a horizontal tunnel called Tal. This tunnel also facilitates air circulation. A sample of Shavadoon plan is shown in Fig. 2.

4. Temperature conditions in Shavadoons

The minimum and maximum temperature of the first days of summer along with the temperature conditions of Shavadoon are presented in Table 2. As seen, when the maximum temperature of summer is 19 $^{\circ}C$ higher than the human comfort temperature, Shavadoon's indoor temperature is lower than the minimum outdoor temperature.

The reason behind using such constructions in the past was due to the lower temperature of Earth substrates compared to the surface and their natural ventilation.

4.1. Temperature in various layers of the Earth

Kasuda [8] presented a sinusoidal Eq. (1) for the annual variation in ground temperature based on the ground depth in terms of air temperature:

$$T(z,t) = T_{mean} - T_{amp} e^{-z\sqrt{\pi/365\alpha}} \times \cos\left(\frac{2\pi}{365}\left(t - t_0 - \frac{z}{2}\sqrt{\frac{365}{\pi\alpha}}\right)\right) \tag{1}$$

where T(z, t) is the undisturbed ground temperature at time t (day) and depth z (m), T_{mean} is the mean surface temperature (average air temperature) which is the ground temperature at an infinite depth, T_{amp} is the amplitude of surface temperature (The maximum surface temperature will be $T_{mean} + T_{amp}$ and the minimum value will be $T_{mean} - T_{amp}$), α is the thermal diffusivity of the soil (m^2/day) and t_0 (day) is the day of the year with the minimum surface temperature.

Fig. 3 shows the temperature changes at various depths during a year based on Eq. (1) and properties of region's conditions [3]. As Fig. 3 shows, with increasing the depth, temperature changes are

Table 1
Climatic data for Dezful [7].

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Average high (°C)	17.2	19.6	24.1	30	37.5	43.7	46	44.9	41.7	34.8	26.2	19.3	32.08
Daily mean (°C)	10.8	13.2	17.3	22.8	29.9	35.1	37	35.8	32	25.6	17.9	12.5	24.16
Average low (°C)	5.3	6.8	10	14.7	20.5	23.8	26.2	25.5	21.1	16.2	10.8	6.8	15.64