

Application of a Genetic Algorithm to Determine the Optimal Location and Cross-Sectional Area of the Derizeh in a Shavadoon for Reducing Temperature and Increasing Ventilation Velocity During Summer

Delaram Izadpanah¹ , Mehdi Tavakoli Kazerouni² , Ali Mehboudi³ 

1. Department of Architecture, Yas.C., Islamic Azad University, Yasuj, Iran. E-mail: Delaram.izadpanah@iau.ac.ir

2. Corresponding author, Department of Architecture and Urban Development, Shi.C., Islamic Azad University, Shiraz, Iran. E-mail: me.tavakoli1356@iau.ac.ir

3. Department of Civil Engineering, Yas.C., Islamic Azad University, Yasuj, Iran. E-mail: ali.mehboudi@iau.ac.ir

Article Info

Article type:

Research Article

Article history:

Received July 25, 2026

Accepted September 19, 2026

Published online September 30, 2026

Keywords:

Shevadan,
Underground spaces,
Natural ventilation,
Thermal performance
CFD,
Genetic algorithm.

ABSTRACT

Shawadans are a type of underground dwellings in the southwestern regions of Iran that are used by people at different times, especially during the hot seasons of the year. This type of architecture has three main components, including the entrance staircase, the courtyard and the window, so that fresh air enters the courtyard through staircase and exits through the window. The main goal of this research is to determine the best position of the window relative to the entrance staircase and the most optimal dimensions of its cross-sectional area in order to increase the ventilation speed and reduce the temperature inside the shawadan during the hot seasons of the year. Accordingly in the first step, the 45 case samples determined in this study were simulated in the CFD environment and the average temperature and velocity inside the courtyard were extracted for each sample. In the next step, using the genetic algorithm the best location of the vent and the most optimal cross-sectional area were determined to improve thermal performance and ventilation inside the barn during the summer. The research results showed that the most optimal condition for creating comfortable conditions inside the greenhouse in the summer is when the cross-sectional area of the air outlet duct is reduced by increasing the distance between the air inlet duct (sill) and the air outlet duct (window).

Cite this article: Izadpanah, D., Tavakoli Kazeroni, M., & Mehboudi, A. (2026). Application of a Genetic Algorithm to Determine the Optimal Location and Cross-Sectional Area of the Derizeh in a Shavadoon for Reducing Temperature and Increasing Ventilation Velocity During Summer. *International Journal of Applied Arts Studies*, 11(3), 85-104.



© The Author(s).

Publisher: Islamic Azad University, Yazd Branch.

Introduction

Today, humanity is facing numerous crises, including limited and expensive energy resources pollution caused by the use of various fossil fuels, global warming, and so on. With the increase in energy demand in recent years, this crisis has become more widespread, with it estimated that global energy demand will increase by about 50 %between 2018 and 2050 (Mattoni et al, 2018). However, the use of fossil fuels to provide heating and cooling of buildings is one of the most important factors in this regard, and according to existing reports, about 40 % of the energy produced in the world is consumed in the building sector (Singh et al, 2018). However, in local architecture in different regions of the world, sometimes smart solutions are used that reduce dependence on fossil fuels in buildings and try to provide comfortable conditions inside the building by using renewable energy sources. Among these solutions, we can mention the use of the thermal capacity of the earth, which is used in underground spaces in different parts of the world. These spaces, which are considered the oldest type of human shelter, date back more than 3000 BC years (Mohammadifar and Hemati, 2017).Iran is one of the countries that use underground spaces as a residence humanity has been prevalent in it for a long time. The construction of these spaces, which is more prevalent in the southwestern regions of Iran, and especially in the cities of Dezful and Shushtar, is known as shavadan. Shavadans are usually built at a depth of 8 to 12meters from the ground surface, and their most important function is to use them as living spaces in the hot and cold seasons of the year (Bina, 2008). Due to their location deep in the ground, these spaces use the heat capacity of the earth and have warmer air in winter and cooler air in summer than their outside environment (Sadooghi et al, 2019).

An underground space such as a cellar, in order to have suitable conditions for people to live in, must be at the optimum level of human comfort from two perspectives: "thermal characteristics and ventilation conditions". On the one hand, cellars have various components whose physical and geometric characteristics can play a significant role in this matter. Accordingly, in this research emphasizing the physical characteristics of the vent as an air outlet channel, its position and dimensions are examined to improve the thermal performance and ventilation of the space inside the cellar . Given that finding an optimal pattern in relation to the position and dimensions of the cross-sectional area of the air outlet channel in the cellar is considered, the genetic optimization algorithm will be used for this purpose. With this explanation, the most important research question can be posed as follows:

What is the most optimal location and dimensions of the cross-sectional area of a window in a vault (with a cross-shaped shape) in order to improve the thermal performance and ventilation of the space inside it?

Research Background

The construction of underground spaces has been used in architecture in different parts of the world since the past, but few studies have been conducted in relation to the analysis of ventilation methods and comfort conditions inside this type of building. One of the first studies conducted in this regard is the study of Golany and Ojima. In their study, they divided underground spaces into five categories and, after examining ten different ways of using these spaces, examined the different effects of their use on the natural environment and thermal comfort (Golany and Ojima, 1996). Gabriel also studied natural ventilation in underground tombs in ancient Egypt. The results of this study showed that when the temperature drops rapidly in the desert with sunset, a cool air-flow flows into the underground tombs, replacing stale air and dust (Gribble, 2009). In another study conducted by Lee and Shon on ancient underground shelters in Korea, it was concluded that the average daily relative humidity and temperature in these spaces were significantly lower than in typical buildings on the ground surface (Lee and Shon, 1988).

Iran is one of the countries that uses underground spaces as residences. Human habitation has been prevalent in it for a long time. The construction of these spaces, which is more common in the southwestern regions of Iran, and especially in the cities of Dezful and Shushtar, is known as shavadan. Shavadans are usually built at a depth of 8 to 12 meters from the ground surface, and their most important function is to use them as living spaces in the hot and cold seasons of the year (Bina, 2008). Due to their location deep in the ground, these spaces use the heat capacity of the earth and have warmer air in winter and cooler air in summer than their outside environment (Sadooghi et al, 2019). Among the first studies that analyzed the thermal performance of shavadans is Bina 's research. In this study, while introducing the different components of the greenhouse, by measuring the temperature inside the greenhouse in the hot and cold months of the year and comparing it with the outside temperature, it was concluded that the temperature inside the greenhouse in the hot and cold seasons has a difference of 15 to 25 degrees with the outside temperature (Bina, 2008). In another study conducted by Moradi and Eskandari (2012), the cooling and heating conditions inside the greenhouse were measured during different months of the year using two experimental and numerical methods and then the results of these two methods were compared. The results of their study showed that the temperature inside the greenhouse fluctuates between 17 and 23 degrees Celsius throughout the year (Moradi and Eskandari, 2012). In another study in Hazibi and his colleagues 2015, conducted a numerical analysis of the temperature in a greenhouse in Dezful. Their research results showed that with a 10 % error, the numerical and experimental analysis results are similar to each other, and therefore, the use of the svadan in the cold and hot seasons of the year can provide the possibility of creating thermal comfort conditions for its residents (Hazbei et al, 2015). In the same regard, in another study, Mohammadshahi et al. analyzed ventilation and heat transfer in the svadan

using numerical simulation, in which the characteristics of the form of the svadan entrance staircase on the thermal comfort inside it were examined. The results of their research showed that the use of an S-shaped form in the staircase can have a better effect on the entry of air flow and, as a result, thermal comfort inside the svadan (Mohammadshahi et al, 2016). In another study, they analyzed some additional elements to the architecture of the svadan, including the footrest, the coat, and the nightstand, and their effect on ventilation inside the svadan. Their research results showed that adding a coat reduces the ventilation rate inside the courtyard, and adding a rest foot and a nightstand to the shavada increases the air flow rate entering the shavada and the ventilation rate inside it (Mohammadshahi et al, 2019). In another study, the thermal behavior of the shavada located in a historic house in the city of Dezful was investigated using two experimental and numerical methods. The results of this study showed that the internal temperature of the shavada decreases compared to the outside, and in the winter, the temperature increases compared to the outside (Tahbaz and Mofidi Shemirani, 2018). In another study, Sadooghi et al. 2019 experimentally measured and compared the thermal behavior of five different shavadas in the city of Dezful between June and December. Their results showed that using these spaces in hot and dry areas as a passive strategy can play a significant role in reducing household energy consumption (Sadooghi et al, 2019).

Theoretical foundations of the research

Before entering the body of the research, it is necessary to introduce the different components of the research:

Entrance: The entrance to the shed is located on the ground level, usually in the yard of a house some sheds have an entrance door and others do not. The presence of a door can help direct more air flow into the shed

Entrance staircase: All sheds have this section. These staircases provide a connection between the ground level and the main space of the shed, and in addition to providing physical access for people to the space inside the shed, they also provide the ability to direct air flow from the ground level to the main space of the shed. Accordingly, in this article, the entrance staircase is also referred to as the air inlet duct.

Main space: This space is a residential space that is used for human use and food storage. This space is generally built at a depth of 6-12 meters from the ground and has a flat or arched roof. In this article, the main space of the pavilion is introduced as the courtyard.

Air outlet channel: This channel is built on the main courtyard and connects the courtyard space vertically to the ground. During the construction of the shed, this channel was used to transfer soil to the ground surface, and when in use, this channel serves as a conduit for

transferring air from inside the shed to the outside. In this article, this element is introduced as a slit.

Cat: This space includes rooms that are enclosed by the main space on one side and by soil on the other three sides, and has a surface difference of 20 to 50centimeters with the main space of the tomb.

Tal: The main space of some of the shwadans , whose owners were related by family, were connected to each other through horizontal channels known in the local dialect as tal (Sadooghi et al, 2019; Hazbei et al, 2015).

Research Method

Based on what was mentioned earlier, the main goal of this research is to find the most optimal window pattern to improve the thermal and ventilation performance of the windows in the summer season in Dezful city. Accordingly, the research process is carried out in two steps as follows:

Step 1 Numerical analysis of the fan in - CFD: In this section, after determining the research case samples, the average values of temperature and air velocity inside the fan are extracted for each sample by simulation in CFD. In this regard, Autodesk CFD 2018 software is used to simulate the case samples.

Step 2 Using the Genetic Optimization Algorithm: In order to determine the most optimal location and dimensions of the cross-section of the culvert in Shevadan, the genetic optimization algorithm will be used. In this section, numerical data from the CFD section will be used.

CFD simulation is of great importance (Chen and Srebric, 2002). In this study, a uniform flow pattern i at the inlet of the boundary($U_{\infty} = 4.2$ m/s) and turbulence intensityii (I) equivalent to3%. The value of the turbulence kinetic energy (K) was used in the input range iii which is derived from the values of U_{∞} and It can be calculated it is obtained through equation 1. Also, the amount of turbulence lossiv (ε) via the equation 2 can be derived that in this relation C_{μ} is a constant value(0.09) and (I) is the turbulence length scalevwhich is obtained from the equation $I = 0.07D/H$. Also, D/H is the hydraulic diameter of the domain which is equal to(=0.46m).

$$K = (U_{\infty} I)^2 \quad (1)$$

$$\varepsilon = C_{\mu}^{3/4} \frac{K^{3/2}}{I} \quad (2)$$

The walls of the computational domain are considered to be non-slip and have zero roughness height ($K_s = 0$). (Launder and Spalding, 1983; Cebeci & Bradshaw, 1977). At the outlet wall of the domain, zero static pressure is assumed. The case studies in this study were simulated based on the climatic conditions of Dezful city. Based on the data of Dezful city meteorological station, The average daily temperature in July and the average wind speed in 10 year period from 2012 to 2022 in this city are 36.3 degrees and 4.2 meters per second respectively (Khuzestan Province Meteorological Organization 1401). In all simulations, the wind angle is considered to be zero degrees ($\theta = 0^\circ$).

Choosing the right turbulence model among other settings, it is used to accurately solve simulations in CFD. The purpose of this is to verify the ability of the selected turbulence model to accurately predict the flow. In this study, the standard k- ϵ will be used as a turbulence model for numerical simulation of case studies.

The computational domain in the analysis of the research case studies consists of a cross shaped fan that is installed in a wind tunnel with dimensions of 5H WT and 10H WT upstream and downstream 5H WT. On the sides and 5H WT in height, considering the dimensions of 9 x 24 m² for the courtyard of the pavilions in the case studies and their placement at a depth of 10 meters in the ground ($H=10$ m) the dimensions of the computational domain in this study, are $3 W \times D \times H = 109 \times 174 \times 50$ is considered (Figure 9). Calculations are performed through CFD simulations in both open and closed spaces, which directly calculate the volumetric flow rate through the openings. This method can create a dynamic interaction between the internal and external environment at the openings (Ramponi and Blocken, 2012; Tan & Glicksman, 2005). In constructing the mesh network in the computational domain, a hexagonal mesh was used, with the number of cells in the case studies ranging from 1,625,412 to 1,798,125 in Nostan. Figure 10, shows the mesh pattern of one of the case study buildings.

Software validation

Autodesk CFD software will be used to simulate case studies. In order to assess the validity and accuracy of the outputs of this software, a validation analysis will be performed. In order to validate the temperature inside the shack, the results of the experimental study of Moradi and Eskandari (2012) will be used. The sample studied in their study includes a shack in Dezful city, which has dimensions of 5*12*2.70 m³ and is located 10 meters below ground level. This vault has no entrance and is accessed through a horizontal duct measuring 1.2 x 1.8 m² at ground level. After entering through an L-shaped staircase, it is possible to enter the main space of the vault. The air outlet is also via a vertical cylindrical duct located in the central part of the main space of the vault. The height of this duct from the vault ceiling to the ground level is 7.80 m Figure 1.

The CFD validation sample analysis is based on the guidelines of (Franke et al., 2011) and (Tominaga et al., 2008). According to this guideline, the upstream and downstream dimensions of the domain v_i are equivalent to 5H WT and 10H WT and on the sides 5H WT. Accordingly, the dimensions of the computational domain are based on the size of the constructed model, equivalent to 3m. $W \times D \times H = 55 \times 192 \times 60$ has been calculated. The validation results regarding the comparison of the internal temperature of the swashplates in the experimental study of Moradi and Eskandari 2012, and the CFD results are shown in Figure 2.

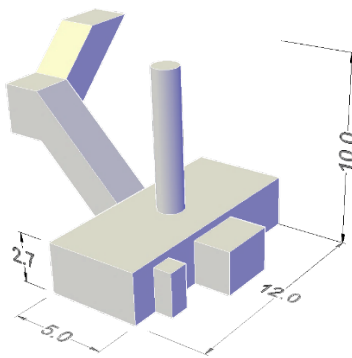


Figure 1. Shavadan model in the experimental research of Moradi and Eskandari (2012).

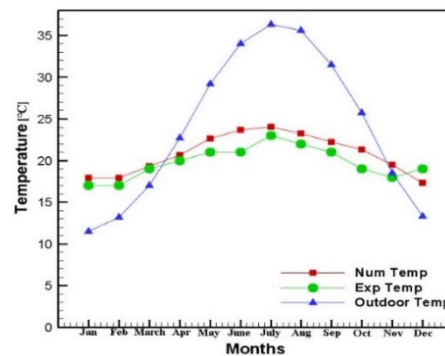


Figure 2. Comparison of CFD results with the experimental research results of Moradi and Eskandari (2012).

As can be seen in Figure 2, the results of CFD numerical simulation have been compared with the experimental results of Moradi and Eskandari (2012) regarding the temperature inside the greenhouse during 12 months. Examination of these figures shows that the simulation results are consistent with the experimental results of Moradi and Eskandari (2012), with an error of less than 50 percent. Therefore, while confirming the validity of the simulation results in relation to the calculation of the two parameters of temperature and air velocity inside the greenhouse, the use of the RANS model is reliable for analyzing research samples.

Case examples

As mentioned earlier, the main goal of this study is to determine the most optimal location and cross-sectional area of the air outlet channel in the shack. Accordingly, one of the most common types of shacks in Dezful city with a cross-shaped spatial pattern was selected as the base building and different positions and cross-sectional areas of the windows were installed on it. The base building plan pattern, different positions of the windows and different cross-sectional areas of the windows are shown in Figure 3.

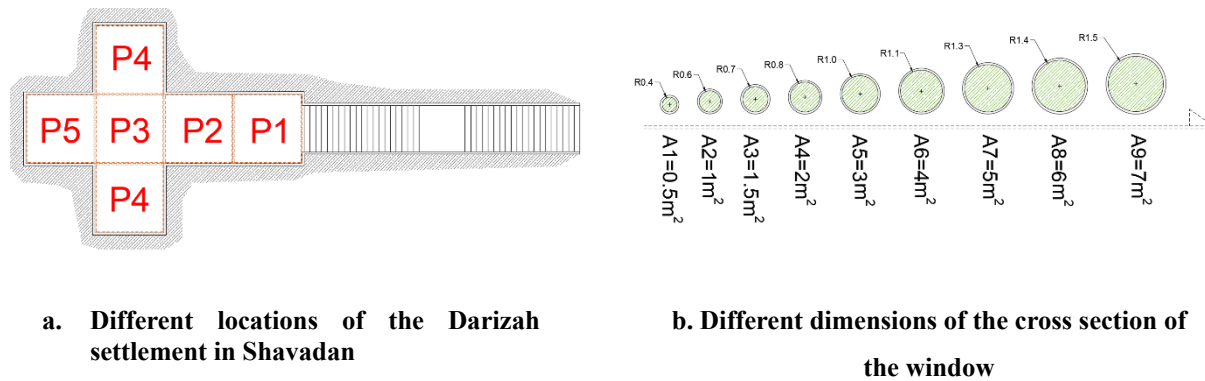
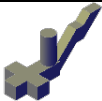
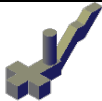


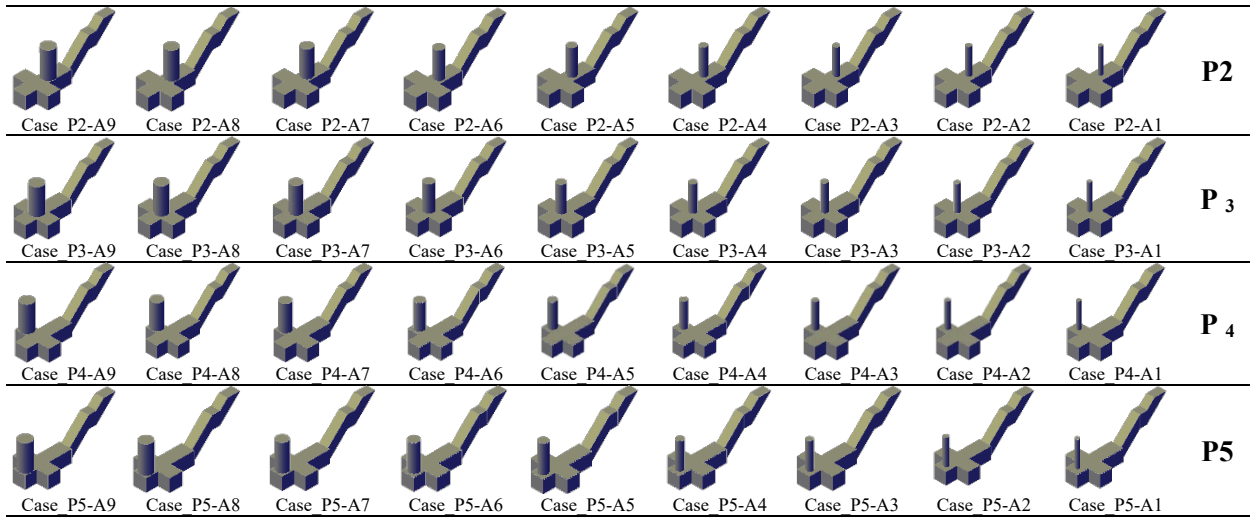
Figure 3. Plan of the location and dimensions of the cross-sectional area of the window in the case examples.

This building includes a pavilion with courtyard dimensions of 9x3 meters, located 10meters below ground level, and accessed via a direct staircase. It has a width of 2meters (with a footbridge) and leads to the ground level. Also, at the end of the courtyard, there are three 3x3 meter-wide chambers with a height of 50centimeters from the floor of the courtyard. The courtyard is 3 meters high and the courtyard space is connected to the ground level through a cylindrical window located at different positions and cross-sections. Outside air enters the courtyard through the entrance cloister and , after passing through the courtyard, is transferred to the ground level through the window.

Figure 3-A shows the different positions of the windows in the slats and Figure 3-B shows the different cross-sectional areas of the windows. As shown in Figure 3A, in the model under - study window positions can be considered, with 5P1 being the closest and P5 the furthest position from the slat entrance. Also, Figure 3 B shows 9 window cross-sectional areas from ($A1 = 0.5m^2$ to $A9 = 7m^2$), with A1 being the smallest cross-sectional area and A9 being the largest. The maximum cross-sectional area that can be installed at each position is (P) each P consists of a square with dimensions $3 \times 3m^2$. With this description in each P different cross-sections can be examined resulting in a total of 45 case studies in this study (Table 1).

Table 1. Research case studies based on location and cross-sectional area of the window.

A9 = 7	A8 = 6	A7 = 5	A6 = 4	A5 = 3	A4 = 2	A3 = 1.5	A2 = 1	A1 = 0.5	Area Posit ion
									P1
Case_P1-A ₉	Case_P1-A ₈	Case_P1-A ₇	Case_P1-A ₆	Case_P1-A ₅	Case_P1-A ₄	Case_P1-A ₃	Case_P1-A ₂	Case_P1-A ₁	



Data analysis and discussion

As previously mentioned, the findings of this research are divided into two parts, including numerical analysis of the shafts in the CFD environment and the use of a genetic optimization algorithm to find the best option among the case studies. In the numerical analysis section the average temperature and average air velocity inside the building were extracted using CFD simulation, and in the optimization section, the most optimal position and cross-section of the shaft will be extracted using a genetic algorithm.

First step: Numerical analysis of case studies iCFD

As mentioned, in this section, after simulating case studies in the CFD environment results , regarding the average temperature and average air velocity inside the courtyard will be presented.

Average temperature inside the courtyard

According to the simulation results , the average temperature inside the Shavadan courtyard at a depth of 10 meters from the ground surface in July fluctuates between 21 and 25degrees; the lowest temperature in Case_ P 1 _A 1 at 21.22 C° and the highest value corresponding to Case_ P 3 _A 9 at 24.89 C° It has been obtained. Also, with the increase in the cross-sectional area of the window in different positions, the average temperature inside the courtyard has also increased relatively. This increase is clearly visible in positions P 3 , P 4 and P 5 while this rhythm is not ; observed in position P 2 and P 1 is somewhat different from the others (Figure 4).

Figure 5 Average temperature of all samples examined in different positions (P i) shows the ratio of input. Based on this image, it can be seen that the average temperature in all samples in P 1 is the lowest and with increasing distance from the inlet, the average temperature of the samples under study increases at each position, so that this value at P 5 is the highest value. In other

words, with increasing distance from the entrance, the average temperature inside the courtyard has increased relatively overall.

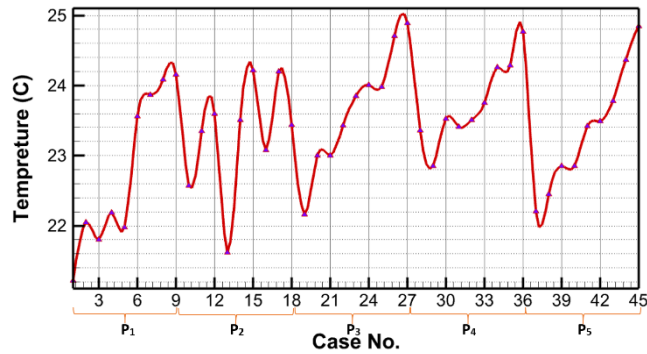


Figure 4. Average indoor temperature in case samples in July

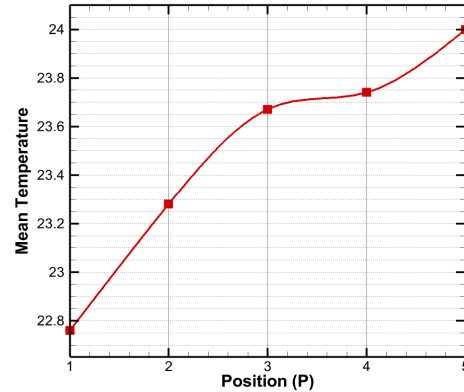
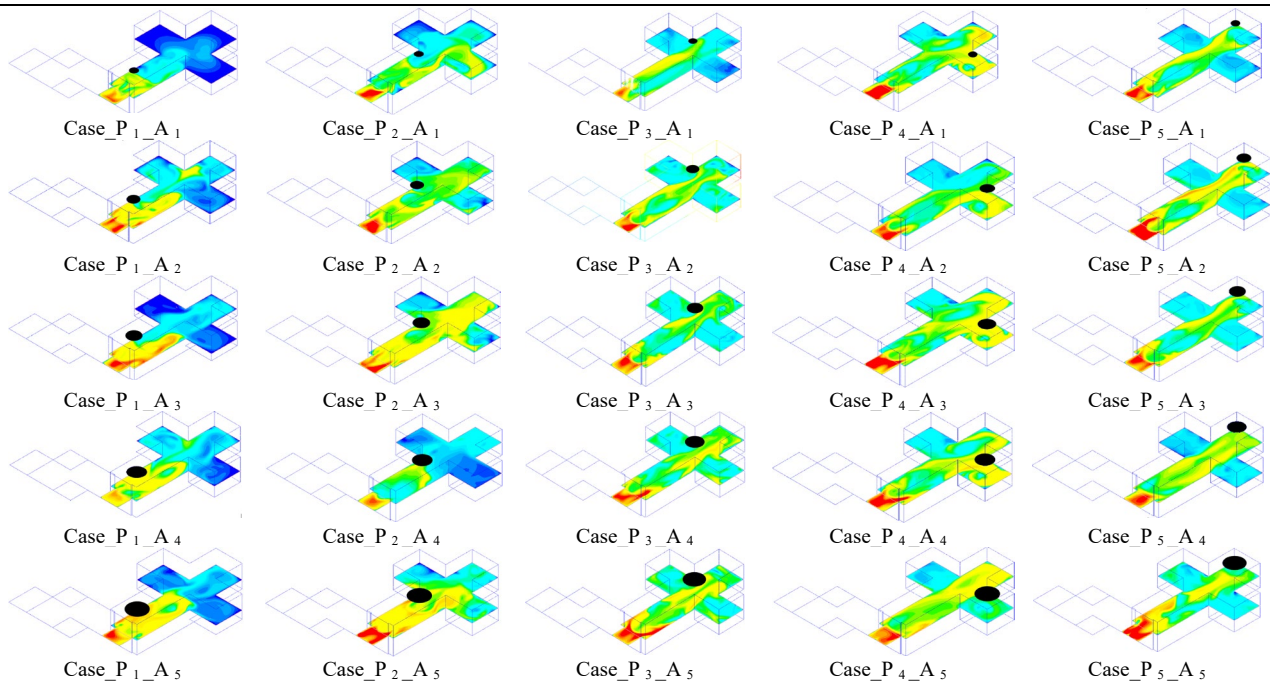


Figure 5. Average temperature of the total surface calculated for the vent at different positions relative to the inlet.

Figure 6 shows the different temperature contours associated with the case samples at a height of 90 cm above the ground. As can be seen in these contours, with the increase in the cross-sectional area of the window in the samples under study, the average temperature inside the courtyard has increased.



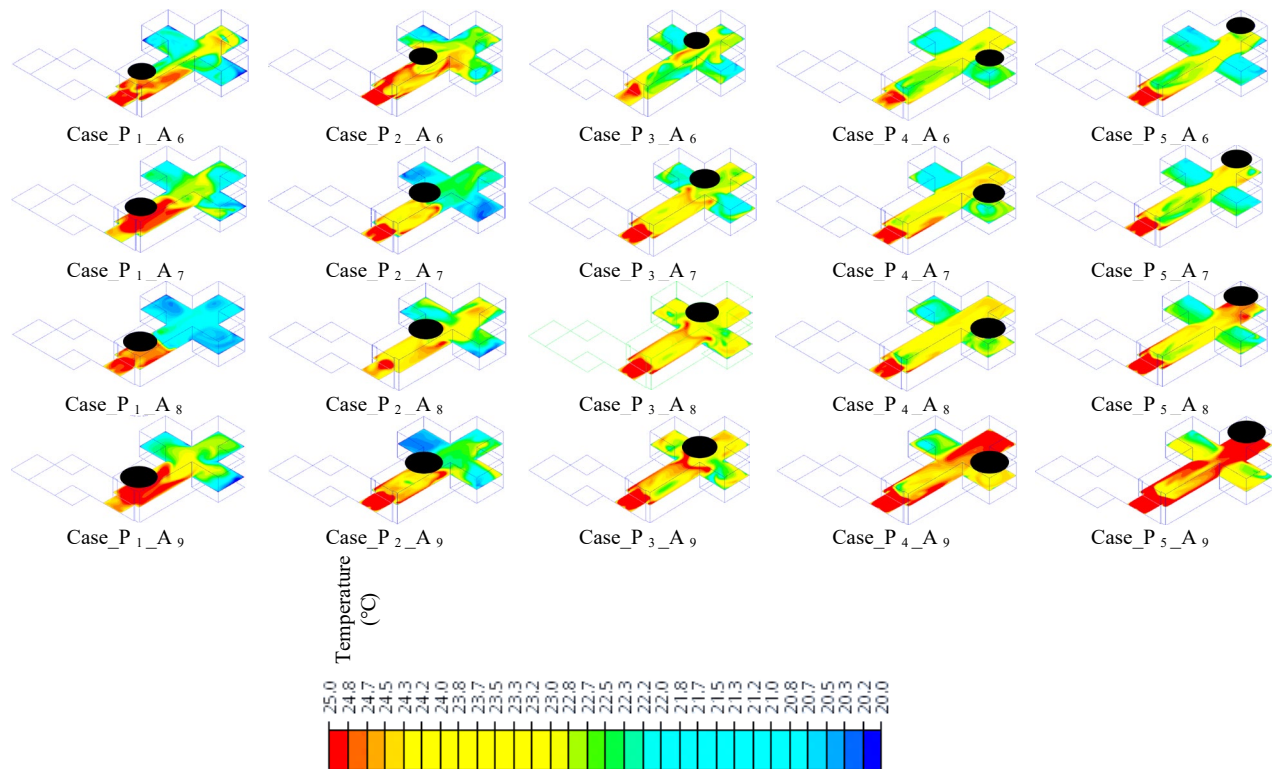


Figure 6. Heat contours in the interior of the Shavadan courtyard in July.

Average air speed inside the courtyard

Airflow velocity is the rate of movement of air molecules in space (Tian et al, 2017). The data obtained from the average velocity inside the courtyard in different samples show a linear trend with increasing cross-sectional area of the vent (Figure 7). The highest velocity value in Case_P 4 _A 9 with a value of 0.1 m/s and the lowest value in Case_P 1 _A 1 with a value of 0.004 m/s. Also ,with increasing the distance of the vent to the inlet, the speed difference between A 9 and A 1 In each Pi it has increased significantly .

Figure 8, Average speed of all samples examined at each PiAs can be seen, the average speed in all the samples studied is the lowest in P 1 and increases with increasing distance from the input in a way that this value is the same in P5. It is the highest value compared to other positions.

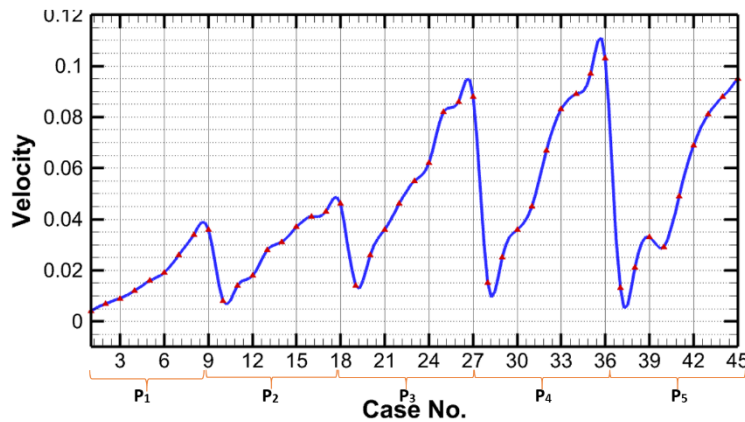


Figure 7. Average air speed inside the Shavadan courtyard in Dezful in July

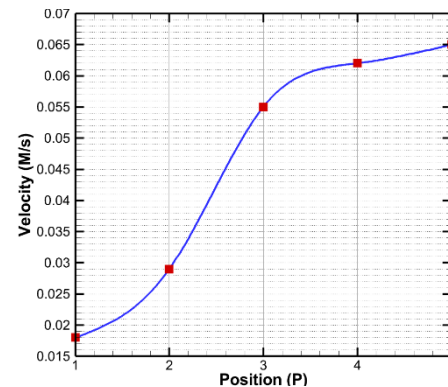


Figure 8. Average velocity of different positions relative to the top for the total surface calculated for the window

Second step: Finding the best option among the case examples using the genetic algorithm

Genetic algorithm is an evolutionary algorithm used to find optimal formulas or values for various problems ((Schmitt , 2001). In genetic algorithm, several solutions to the problem are first are generated randomly (Vose, 1999). This set of solutions is called the initial population and each solution is called a chromosome. After selecting the best chromosomes, Using the genetic algorithm operators, chromosomes are combined and a mutation is created in them. Finally, the current population is combined with the new population resulting from the combination and mutation in the chromosome (Schmitt, 2004). In short, the process of using genetic algorithms can be summarized as follow (Whitley, 1994):

- A) Introducing the answers to the problem as chromosomes
- B) Introduction to the fitness function
- C) Gathering the first population
- d) Introducing selection operators
- e) Introduction to operators Reproduction

To solve each problem, it is necessary to map each of the above steps to the problem space and then solve it.

Based on what was stated earlier, the main goal of this research is to find the most optimal - location and cross-sectional area of the air outlet channel in the courtyard in a way that increases the speed and reduces the temperature inside the courtyard in summer. Accordingly, the research problem is to optimize A_i for each P_i and finding the most optimal A_i ingeneral, it is a building. In order to find these points, which are the so-called extrema of the functions related to speed and temperature.Genetic algorithm was used as one of the most basic algorithms in solving

optimization problems for this purpose. The Python implementation environment and the dataset used are the same data obtained from the CFD process.

After creating the initial population, the set of operators related to the boundary conditions is checked, and if the condition is met, a new population is created and the data related to the area and position are loaded to calculate the fitting function corresponding to each of the positions as well as the overall fitting function. Next, the obtained fitting value is compared with the previous value. If the conditions related to optimizing the desired parameters (minimum temperature and maximum speed) are met, the algorithm ends; otherwise, the gene is increased and the initial operators are applied, and the same process is repeated.

In each P_i , speed and temperature are two parameters that are to be measured relative to A_i and corresponding to each, the minimum temperature and maximum speed are determined. For this purpose, in the first step, the equations related to each of these parameters are calculated in terms of A_i proportional to P_i according to Algorithm 1 and their graphs are drawn. The results obtained from the equations related to these parameters and the desired graphs with them are as shown in Table 2.

Algorithm 1: Determination of Equation of Velocity/Temperature

1-Start

2-Initialization:

-Set array of Velocity/Temperature and A based on CFD data

- Standardize Velocity/Temperature data based on the concept of standardization: $S_value = X - \mu / \sigma$

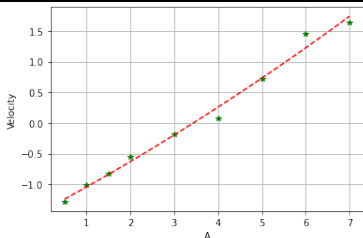
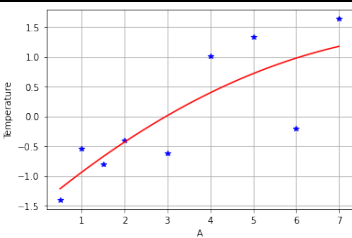
3- Calculation of coefficient of trend line of best equation

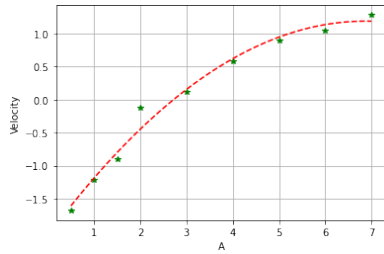
4-Calculation of r -squared

5-Plot figure of equation based on dataset

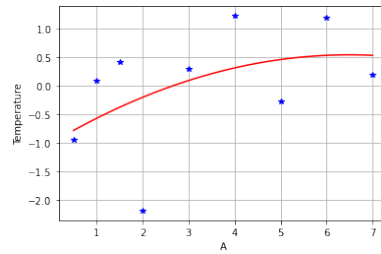
6-End

Table 2. Equations related to the values of velocity and temperature inside the courtyard based on - different positions of the window(P_i) and the area of the window cross-section(A_i)

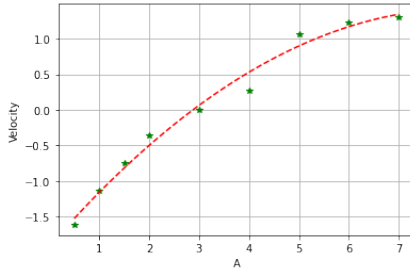
P_i	Velocity (V)	Temperature (T)
P1		
	$V = 0.01005387 * A^2 + 0.38333079 * A - 1.4369555$	$T = -0.03093943 * A^2 + 0.59994891 * A - 1.50995541$

P₂

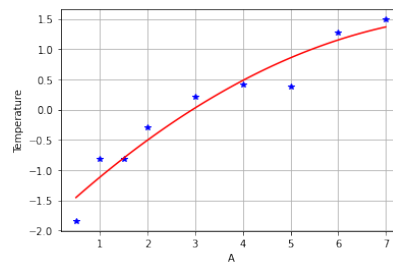
$$V = -0.06887397 * A^2 + 0.94707209 * A - 2.06640244$$



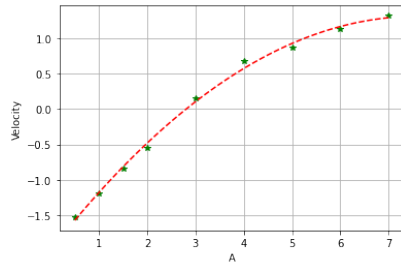
$$T = -0.03683648 * A^2 + 0.47893614 * A - 1.01320951$$

P₃

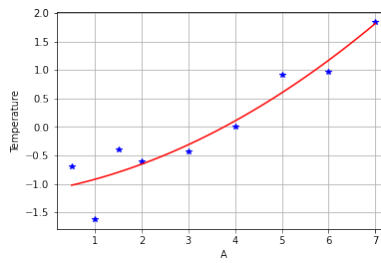
$$V = -0.04864497 * A^2 + 0.8065979 * A - 1.91844759$$



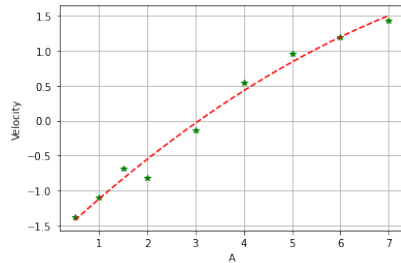
$$T = -0.03965922 * A^2 + 0.73128287 * A - 1.80967187$$

P₄

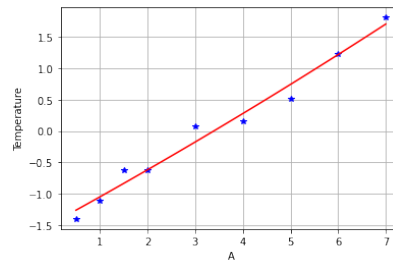
$$V = -0.05745659 * A^2 + 0.8710665 * A - 1.99382563$$



$$T = 0.03800932 * A^2 + 0.15147657 * A - 1.1067362$$

P₅

$$V = -0.02648332 * A^2 + 0.64898339 * A - 1.7439588$$



$$T = 0.00545593 * A^2 + 0.41459126 * A - 1.46835646$$

After determining the equations related to each of the velocity and temperature parameters, the next step is to determine the minimum temperature and maximum air velocity in the case samples which is done according to Algorithm 2. In brief to determine the corresponding points, A_i for each of the P_i where the temperature is the lowest value and the velocity is the highest value. The gradient-based optimization scheme is used. The details of determining these points are as viiper Algorithm 2.

Algorithm 2: Details of optimized point of Temperature and Velocity based on optimization scheme**1-start****2-initialize variables***2-1-initialization: initialize population of chromosomes $p(g)$* *2-2-Set generation: iter=1000,**2-3-Calculation: initial cost of temperature and initial cost of velocity as fitness measure***3-Define Requirement class for problem****3-1- class Problem: problem.py****3-1-1: set argument of problem.py****3-1-1-1-objective functions** : minimize temperature and maximize velocity**3-1-1-2- num_of_variables** : set with 2 (based on P and A)**3-1-1-3- range variables:** set (a with [0.5,7]) and (p with [1,5])**3-1-1-4- same_range:** A Boolean argument, default = False. If true, the range of all variables are the same.**3-1-1-5 - expand** : A Boolean argument, default = True. in our expand set with false and functions are treated as a vector of $f([A, P])$ **4-Define Requirement class for Evaluate class evolution : evolution .py this class has two phases****4-1-Phase 1: set argument****4-1-1-1-num_of_generations** : number of generations, set with 1000**4-1-1-2- num_of_individuals** : set with value 100**4-1-1-3- num_of_tour_particips:** set with default value(2)**4-1-1-4- tournament_prob:** set with default value(0.9)**4-1-1-5 - crossover_param** : set with default value(2)**4-1-1-6 - mutation_param** : set with default value(2)**4-2- Phase 2: define methods: this method returns list of best temperature and velocity in the last generation****4-2-1** - if Cost satisfies conditions $\rightarrow$ store results**4-2-2** - Else while termination criteria not met**4-2-2-1** $g \rightarrow g+1$ **4-2-2-1-1-** Select $P(g+1)$ from $P(g)$ **4-2-3** -Crossover $P(g+1)$ **4-2-4** - Mutate $P(g+1)$ **4-2-4-1** -Evaluate $P(g+1)$ **5-increment of iteration step****5-1** - $i=i+1$ **6-Calculate new cost and checking***Checked the optimally satisfied condition and iter check? ($i>iter$)***5-1** - If yes $\rightarrow$ stop algorithm and generate results**5-2** - If No $\rightarrow$ optimizer and go to Evaluate of Function step**7-End**

After implementing Algorithm 2 in the Python environment, the optimal values of the cross-sectional area of the vent for each P are presented in Table 3.

Table 3. Optimal values of A with the lowest temperature and highest speed in each of the P_i

Row	Window position in the courtyard(P _i)	Window cross-sectional area(M ²)
1	P1	5.42
2	P2	4.36
3	P3	3.14
4	P4	2.29
5	P5	1.61

As can be seen from the table above, the optimal values of the cross-sectional area of the window have been introduced in different positions of the courtyard. The values obtained in this table mean that in each position(P_i) if the value mentioned in the table is considered as the cross-sectional area of the window, the lowest temperature and the highest air velocity are created inside the courtyard. In other words, in these conditions, thermal comfort inside the courtyard in the hot season of the year (which comes with a decrease in temperature and an increase in ventilation speed) is created.

Discussion

The findings obtained in this study can be divided into two parts: The first is the findings related to the numerical part, which is derived from the outputs of the CFD was obtained and the second is the data related to the optimization that was used by the genetic algorithm. In the numerical findings section, the average speed and average temperature inside the space of the shaft were extracted for each case sample, the results of which are shown in Figures 4 and 7. By examining these graphs, it can be seen that Case_P1_A1, Case_P2_A1, Case_P3_A1, Case_P4_A1 and Case_P5_A1 has the lowest values and Case_P1_A9, Case_P2_A9, Case_P3_A9, Case_P4_A9 and Case_P5_A9 have the highest velocity and temperature values. This means that with the increase in the cross-sectional area of the vent at each P_i the temperature and velocity values also increase relatively. However, considering that the analyses conducted on the case studies were conducted in the summer season, the simultaneous increase in temperature and velocity cannot lead to thermal comfort for the occupants. In such conditions, thermal comfort is created when the temperature is the lowest and the velocity is the highest possible. Accordingly, in order to extract the best vent cross-sectional area for each P_i, optimization methods were used.

As mentioned above, the genetic algorithm was used in the optimization analysis. This method was used to predict the most optimal cross-sectional area (A) at each P_i and in the entire building. The results of this section are presented in Table 3. In addition to the optimal values of the window cross-sectional area for each position (P_i) this table also shows that by increasing the distance between the window as the air outlet channel and the plenum as the air inlet duct, in order to create comfort conditions in summer, the dimensions of the window cross-sectional area should be reduced; so that according to the results of the genetic algorithm, the most optimal

window cross-sectional area was obtained at position P 1 as the minimum distance between the window and the(inlet plenum), while at position P 5as the maximum distance between the window and the(entrance door), the most optimal window cross-section area was obtained as 1.61 square meters (Table 3).

Conclusion

The present study investigated the thermal performance and ventilation of the space inside the Shevadan as a type of underground space in traditional Iranian architecture using numerical modeling. The main goal of this study is to find the most optimal location and the most suitable cross-sectional area for the air outlet channel in the Shevadan in order to improve the thermal performance and ventilation of its internal space in the summer season in a hot and dry climate. The independent variable in this study is the location of the air outlet channel relative to the courtyard and its cross-sectional area, and the dependent variable is the thermal performance and ventilation of the internal space of the Shevadan (courtyard). In this study, one of the most common types of Shevadan in terms of space in the city of Darful in southwestern Iran (with a hot and semi-arid climate) was selected as the base sample and 45case samples were extracted based on the independent variables of the study. The diversity of case samples is formed based on changes in the position of the air outlet channel and its cross-sectional area. The Shevadan courtyard is located with a cruciform geometry at a depth of 10meters from the ground surface and is accessed via a direct staircase. Air enters the courtyard through this staircase and air exits through a vertical cylinder (window). It is carried out on the roof of the courtyard. The results of this research are presented at two levels, including numerical results from CFD analysis of the samples and the results of the optimization section extracted from the genetic algorithm, as follows:

- Numerical analysis results derived fromCFD outputs
 - As the cross-sectional area of the slat increases, the average temperature inside the slat increases: in different positions(P_i), the lowest temperature was observed at $A=0.5 \text{ m}^2$ and the highest temperature was observed at $A=7 \text{ m}^2$.
 - As the cross-sectional area of the vent increases, the average air velocity inside the vent increases: in a way that at different positions(P_i), the lowest average velocity was observed at $A=0.5 \text{ m}^2$ and the highest at $A=7 \text{ m}^2$.
 - the window and the entrance staircase (as an air inlet channel) increases, the average temperature inside the shed increases: in different positions (P_i), the lowest temperature was observed at $A=0.5 \text{ m}^2$ and the highest temperature was observed at $A=7 \text{ m}^2$.
 - the window and the entrance staircase increases, the average air velocity inside the shed increases in different positions (P_i), the lowest velocity was observed at $A=0.5 \text{ m}^2$ and the highest at $A=7 \text{ m}^2$.

- Optimization results based on the output of the genetic algorithm

- Thermal comfort inside a shed as an underground structure in summer is created when the temperature reaches the lowest possible value and the speed reaches the highest possible value. Therefore, the most optimal state for creating comfort conditions inside a shed is created when , by increasing the distance between the air inlet and air outlet channels, the cross-sectional area of the air outlet channel also decreases.

In this study, finding the optimal conditions was carried out in conditions where the location and cross-sectional area of the air outlet duct were considered as independent variables of the research. However, the study of other form features of the air outlet duct such as height from the ground, angle, geometric form, etc. can be considered by researchers in future research. Also, the analysis of the thermal and ventilation performance of the sheds in other seasons, including winter can be introduced as a field of future research in this field.

Author Contributions

The authors have done the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Data available on request from the authors.

Ethical considerations

The authors avoided data fabrication, falsification, plagiarism, and misconduct.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare no conflict of interest.

References

- Bina, M., 2008. Climatological Invest. Shavadoon. *Journal of Fine Arts (Honarhaye Ziba)*, 33, 37–46.
- Cebeci, T., & Bradshaw, P. (1977). *Momentum transfer in boundary layers*. Hemisphere Publ. Corp., Washington, 194.
- Chen, Q., & Srebric, J. (2002). A procedure for verification, validation, and reporting of indoor environment CFD analyses. *HVAC&R Research*, 8(2), 201-216.
- Franke, J., Hellsten, A., Schlunzen, KH., & Carissimo, B. (2011). The COST 732 Best Practice Guideline for CFD simulation of flows in the urban environment: a summary. *International Journal of Environment and Pollution*, 44(1-4), 419-427.
- Golany, G. S., & Ojima, T. (1996). *Geo-space urban design*. John Wiley & Sons.
- Gribble, D. (2009). Natural ventilation, harnessed by New Kingdom Egyptian tomb builders, may explain the changed floor levels in the Valley of the Kings tomb KV5. *Tunneling and underground space technology*, 24(1), 62-65.
- Hazbei, M., Nematollahi, O., Behnia, M., & Adib, Z. (2015). Reduction of energy consumption using passive architecture in hot and humid climates. *Tunneling and Underground Space Technology*, 47, 16-27.
- Launder, B. E., & Spalding, D. B. (1983). The numerical computation of turbulent flows. In *Numerical prediction of flow, heat transfer, turbulence and combustion* (pp. 116-96). Pergamon.
- Lee, S. W., & Shon, J. Y. (1988). The thermal environment in an earth-sheltered home in Korea. *Tunneling and underground space technology*, 3(4), 409-416.
- Mattoni, B., Guattari, C., Evangelisti, L., Bisegna, F., Gori, P., & Asdrubali, F. (2018). Critical review and methodological approach to evaluate the differences among international green building rating tools. *Renewable and Sustainable Energy Reviews*, 82, 950-960
- Mohammadifar, Y., & Hemati, E. (2017). A study and analysis of the handmade troglodytic architecture of Iran. *Journal of Housing and Rural Environment*, 156, 97-110.
- Mohammadshahi, S., Nili-Ahmadabadi, M., & Nematollahi, O. (2016). Improvement of ventilation and heat transfer in Shavadoon via numerical simulation: A traditional HVAC system. *Renewable Energy*, 96, 295-304.
- Mohammadshahi, S., Tavakoli, MR, Samsam-Khayani, H., Nili-Ahmadabadi, M., & Kim, K. C. (2019). Investigation of naturally ventilated shavadoons component: Architectural underground pattern on ventilation. *Tunneling and Underground Space Technology*, 91, 102990.
- Moradi, H., & Eskandari, H. (2012). An experimental and numerical investigation of Shovadan heating and cooling operation. *Renewable Energy*, 48, 364–368.
- Ramponi, R., & Blocken, B. (2012). CFD simulation of cross-ventilation flow for different isolated building configurations: validation with wind tunnel measurements and analysis of physical and

- numerical diffusion effects. *Journal of Wind Engineering and Industrial Aerodynamics*, 104, 408-418.
- Sadooghi, A., Kibert, C., Sadeghi, F. M., & Jafari, S. (2019). Thermal performance analysis of a traditional passive cooling system in Dezful, Iran. *Tunneling and Underground Space Technology*, 83, 291-302.
- Schmitt, L. M. (2001). Theory of Genetic Algorithms. *Theoretical Computer Science*, (259), 1–61.
- Schmitt, L. M. (2004). Theory of Genetic Algorithms II: models for genetic operators over the string-tensor representation of populations and convergence to global optima for arbitrary fitness function under scaling. *Theoretical Computer Science*, (310), 181–231.
- Singh, R., Sawhney, R. L., Lazarus, I. J., & Kishore, V. V. N. (2018). Recent advancements in earth air tunnel heat exchanger (EATHE) system for indoor thermal comfort application: A review. *Renewable and Sustainable Energy Reviews*, 82, 2162-2185.
- Tahbaz, M., & Mofidi Shemirani, S. M. (2018). The Study of the Thermal Performance of Shavadoons, Case Study: The Souzangar House in Dezful, Iran. *Journal of Iranian Architecture Studies*, 7(13), 49-70.
- Tan, G., & Glicksman, L. R. (2005). Application of integrating multi-zone model with CFD simulation to natural ventilation prediction. *Energy and Buildings*, 37(10), 1049-1057.
- Tian, T., Liu, Y., Yan, H., You, Q., Yi, X., Du, Z., ... & Su, Z. (2017). agriGO v2. 0: a GO analysis toolkit for the agricultural community, 2017 update. *Nucleic acids research*, 45(W1), W122-W129.
- Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M., & Shirasawa, T. (2008). AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. *Journal of wind engineering and industrial aerodynamics*, 96(10-11), 1749-1761.
- Vose, M. D. (1999). *The Simple Genetic Algorithm: Foundations and Theory*. MIT Press, Cambridge, MA.
- Whitley, D. (1994). A genetic algorithm tutorial. *Statistics and Computing*, 4, 65–85.

-
- i - A uniform mean wind speed profile
 - ii - turbulence intensity
 - iii - The turbulent kinetic energy
 - iv - turbulence dissipation rate
 - v - The turbulence length scale
 - vi - upstream and downstream
 - vii - Gradient based optimization scheme