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Research article

An experimental model for predicting normal solar performance chimneys concerning the percentage of openings

Sajede Nazari[1]*, Malihe Taghipour[2], Aliakbar Heidari[3]

[1]*Department of Architect, Shiraz Branch, Islamic Azad University, Shiraz, Iran*
[2]*Associate professor, Department of Architect, Shiraz Branch, Islamic Azad University, Shiraz, Iran*
[3]*Assistant professor in architecture, faculty member of technical and engineering department, Yasouj university, Yasouj, Iran*

**s.n_nazari@yahoo.com*

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Abstract

Despite the spread of science in all fields in today's world, human beings are always seeking new knowledge. Energy is one of the issues that human beings significantly think about its control and protection. Solar chimneys can go through a very valuable process in hot and dry climates by creating air conditioning. Thus, the study of factors affecting the optimization of the solar chimney is inevitable. Since there is airflow in the solar chimney, it can be important to study the number of openings that cause air to enter the building in the wall of the building envelope. This research was done using the simulated environment method in Design Builder software and the CFD analysis. Thus, a result of 25% was obtained by examining five sample openings with different percentages in the wall, which was the most suitable option for the model in terms of economic and energy efficiencies.

Keywords: Natural ventilation; Energy efficiency; Solar chimney; Empirical model; CFD.

1- Introduction

Energy control in buildings has always been of interest to architects and engineers, and a solar chimney is one of the thousands of ways that can be used to improve natural ventilation in a building. Energy is involved in all aspects of everyday human life, including cooling and heating, and even domestic hot water production [1].

A solar chimney can provide up to 50% of the shaft fan needs in a single-story building through ventilation [2]. Ventilation is the process of removing indoor air and providing fresh air from outside the building [3].

The flow between rooms must be facilitated for the ventilation to best cool the whole house, which is achieved with vents in the interior walls, near the floor, and ceiling. These vents allow air to circulate between rooms due to temperature stratification and astute to pressure differentials caused by wind. In the case of typical single-sided ventilation, the actual airflow through windows is limited and difficult to predict even when there is significant wind [4].

The use of sustainable energy resources to meet the practical needs of buildings (for cooling, heating, ventilation, etc.) can significantly save energy and thus reduce the current problems caused by excessive energy consumption. Passive (natural) ventilation of buildings is an effective means of saving energy. One of the inactive elements used to induce airflow is the stimulus of the solar chimney [5].

This article seeks to investigate the most appropriate percentage of openings on the north side of the building. Then, the amount of solar radiation and incoming wind will be simulated and tested in a model in the two warm months of June and July.

2- Research aims

This research follows a specific path (as shown in Fig. 1), first examines the factors affecting the solar chimney efficiency and then controls and analyzes the factors in a simulation model. Then, the results are compared with each other by changing the percentage of openings, and finally, the most appropriate percentage is presented on the desired side considering both economic and solar chimney efficiencies. The purpose of this part of the project is to study the use and optimization of solar chimneys to enhance natural ventilation in a building.

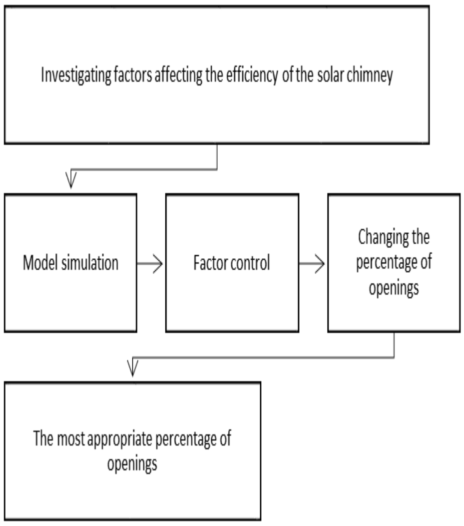

Fig. 1 Research aims

3- An overview of previous studies

Approximately 30% of CO_2 emissions in buildings are related to the service sector [1]. The use of geothermal and solar systems increases both energy production and optimal energy efficiencies [6]. The popularity of using solar chimneys is due to the increase in public awareness and environmental concerns [7].

To optimize energy consumption in solar flues, 13 effective factors are divided into four main groups [8] (Fig. 2).

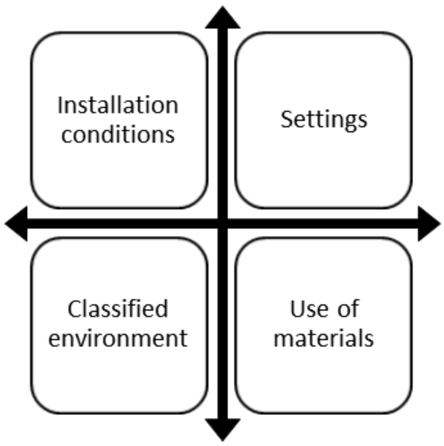

Fig. 2 Factors affecting the optimization of the solar chimney

An analysis between geometric parameters and power output in a solar chimney is one of the optimal ways to use this tool to save energy [9]. An optimal control system should be able to allow the user to respond to the situation at any time and to control the system and change the situation [10]. In their study, Ghalamchi et al. [11] examined the parameters of the solar chimney due to changes in the dimensions of the solar chimney. They concluded that there was no comprehensive formula for the geometric parameters of the chimney. Reducing the collector inlet inside the solar chimney increases the efficiency of solar energy. Toghraraie et al. [12] showed that solar chimneys has a positive relationship with the chimney height and collector radius. In contrast, it responded negatively to the collector height. It was found that the chimney radius had the greatest effect on the output power (Fig. 3).

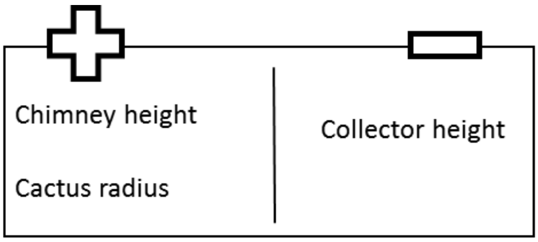

Fig. 3 The effect of factors on the output and efficiency of the solar chimney.

Solar chimneys can be an effective response to energy savings as achieved in hot summers using the right wind speed [13]. On the other hand, system performance decreases in humid weather [14]. Proposed the use of a solar pool to solve the problem of large dimensions and the low efficiency of the solar chimney, which minimized the result of the combined system [15]. The building itself has layers of air that are located between the walls, windows, and ceiling and are classified into three enclosed, the naturally ventilated, and the mechanically ventilated types [2016] (Fig. 4).

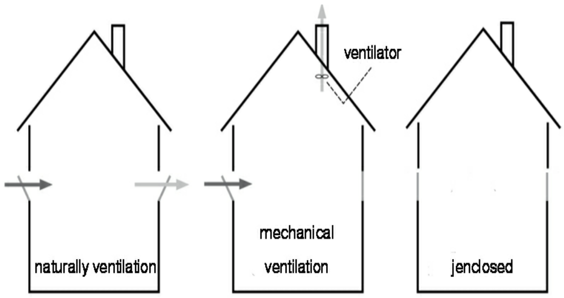

Fig. 4 Classification of building envelopes.

Shi et al. (2016) found that room size and opening space had a limited effect on the solar chimney performance.

Suggested the use of transparent materials in the construction of solar towers, which reduced energy consumption and the high efficiency of the tower [17].

3-1- History of studies

1) A review on hybrid geothermal and solar power systems, (2020).

Findings: Combining geothermal and solar systems will increase the efficiency and power generation of both energy systems [6].

2) Questions and current understanding about solar chimney power plant: A review, (2019).

Findings: Parameter influences, turbine design, flow and heat transfer characteristics, similarity analysis, and hybrid systems are presented in this work [7].

3) Determining factors influencing the performance of solar chimneys in buildings, (2018).

Findings: Although external wind shows a significant influence on the solar chimney, the solar chimney can be designed without considering the effects of wind [8].

4) A review of solar chimney integrated systems for space heating and cooling application, (2018).

Findings: A desirable control system responds to inhabitant needs unobtrusively and allows them to change a condition if it is perceived thermally uncomfortable, with prompt feedback [10].

5) An experimental study on the thermal performance of a solar chimney with different dimensional parameters, (2018)

Findings: Aluminum absorber has more heat transfer rate than iron [11].

6) Effects of geometric parameters on the performance of solar chimney power plants, (2018).

Findings: They have positive relationships with chimney height and collector radius but a negative one with collector height [12].

7) Experimental and Numerical Studies of a Solar Chimney for, Ventilation in Low Energy Buildings, (2017).

Findings: The solar chimney is an effective approach to save energy for residential buildings in transition seasons in hot summer and cold winter areas in China [13].

8) Optimization of a combined solar chimney for desalination and power generation (2017).

Findings: To resolve this, a solar desalination system has been added under the collector of a solar chimney power plant [15].

9) A review on solar chimney systems, (2017).

Findings: Including more experimental works on large-scale systems, and CFD analysis for optimization between geometrical parameters and output power [9].

10) Effect of guide wall on the potential of a solar chimney power plant, (2016).

Findings: Increase the optimization of the solar chimney [18].

11) The application of air layers in building envelopes: A review, (2016).

Findings: Operation modes of air layers used in building envelopes are roughly classified into three types: the enclosed type, the naturally ventilated type, and the mechanically ventilated type [16].

12) An empirical model to predict the performance of typical solar chimneys considering both room and cavity configurations, (2016).

Findings: It is shown that room size (length, width, and height) and opening location have limited influence on the performance [2].

13) Solar chimney integrated with passive evaporative cooler applied on glazing surfaces, (2016).

Findings: The system performance diminished when applied in locations suffering from humid weather climates [14].

14) Experimental study of geometrical and climate effects on the performance of a small solar chimney, (2015).

Findings: Reducing the inlet size has a positive effect on the solar chimney power production performance [19].

15) A new design of wind tower for passive ventilation in buildings to reduce energy consumption in windy regions, (2015).

Findings: If the desired wind speed is accessible in several directions, additional wind towers can be installed in several positions [17].

16) Experimental study of the prediction of the ventilation flow rate through the solar chimney with large gap-to-height ratios, (2015).

Findings: Experimental results show that an optimum gap-to-height ratio that maximizes the airflow rate in chimneys is around a gap-to-height ratio of 0.5 [20].

4- Case study description

The geometry of the connection of the solar chimney to the wall of the building envelope is possible in four modes: connection vertically to the roof, connection to the roof slope, connection vertically to the wall, and connection to the wall (Fig. 5).

The natural ventilation design is the control of air inlet and outlet into the building envelope. Two methods can be used regarding the entry of air into the building. The first method is to bring air in using a mechanical system, and the second method is to have natural ventilation using openings. In this research, an attempt has been made to bring the outside air in by changing the difference in the percentage of openings and to control the air temperature by entering the building envelope.

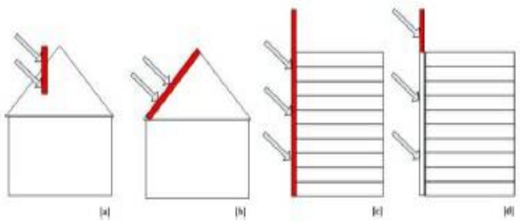

Fig. 5 Models of connecting the solar chimney to the building envelope [5].

The sample in question is model C, which is known as the Trombe wall (Fig. 6). In this model, the opening and the chimney are in the same bar. The air moves from the wall to the chimney suction and is directed upwards due to the suction created in the chimney.

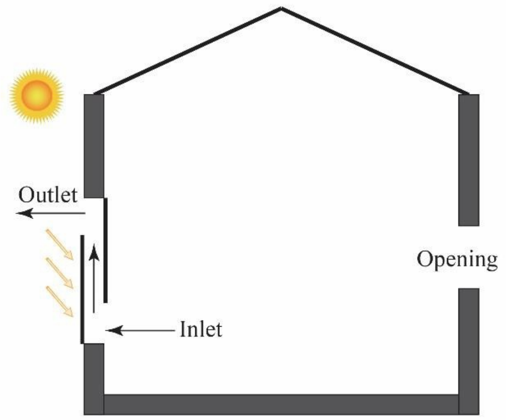

Fig. 6 Trombe wall

The heat always tends to move upwards. The presence of a solar chimney in the building and the elements in it help this movement and cause suction. The cross-sectional area of a solar chimney and its constituent elements are described in Fig. 7.

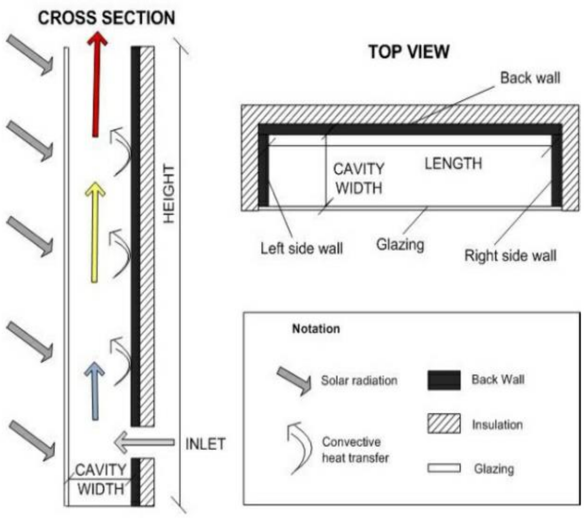

Fig. 7 Cross-section and top views [5].

4-1- Modeling

To introduce the orientation and calculation of the model, the model was divided into two zones. The first and the second zones are the solar chimney and the test environment, respectively.

Since the south side receives the most light and wind from the northwest in Shiraz, the north side and the solar chimney are located on the south side of the model for research purposes. The dimensions of the model are 3.5 m high, 4 m wide, and 6 m long, respectively (Figs. 8, 9).

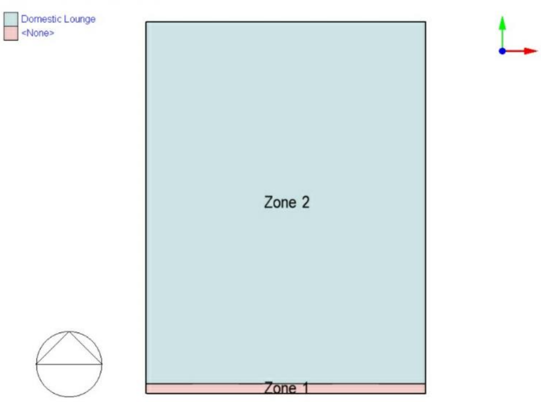

Fig. 8 Specify zones

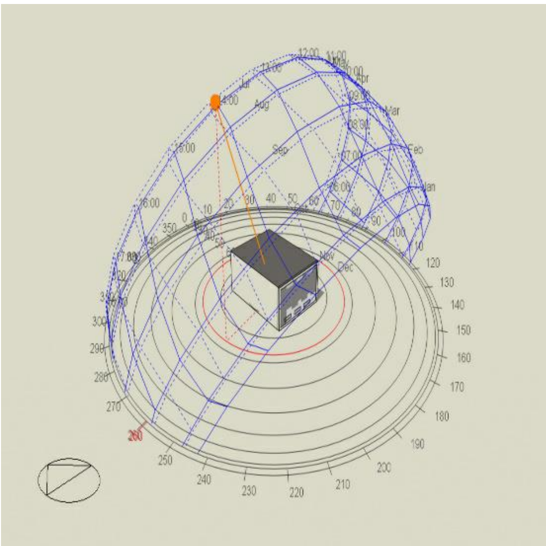

Fig. 9 The model is placed in space

4-2- Climate

The city of Shiraz is located in southwestern Iran (27° 7' 31° N and 50° 27' 55° E) [21]. The wind direction in Shiraz is from the northwest (Fig. 10).

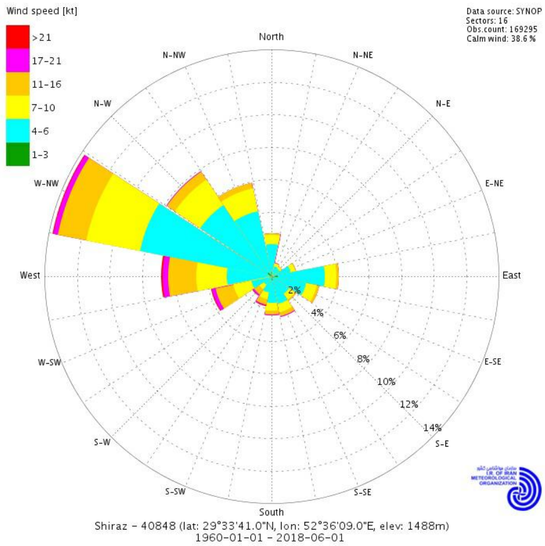

Fig. 10 The daily wind speed and wind direction in Shiraz (Fars Meteorological Bureau)

5- Methodology

This is a pilot study of a heat-simulated model. The design-builder software was used in this research. In this study, the best efficiency of the solar chimney is examined by placing the model inside the CFD software.

The steps of the research method can be as follows. First, the model is designed according to the climatic conditions as explained in the modeling section. Then, the design model is analyzed in two hot months of the year by the CFD software. Air velocity and temperature are the two important factors in this process. In the second step, the percentages of openings were calculated as 0, 25, 50, 75, and 100%, respectively, according to the next model. In the third step, the three answers will be natural ventilation, fresh air, and air temperature according to the calculation of heat from the model CFD software (Fig. 11).

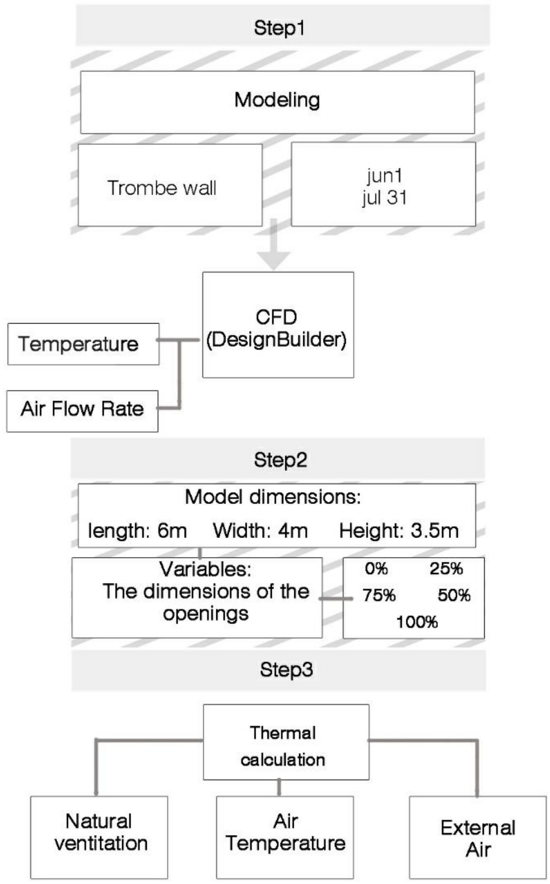

Fig. 11 Methodological scheme of research

6- Results and discussion

To calculate air movement, we need to consider three factors: air temperature, natural ventilation, and outside air. The average air temperatures in June and July in Shiraz along with the intensity of air movement are given to the software using the wind movement diagram.

Hence, these three factors were investigated by the Design Builder software using the CFD analysis. The results are accompanied by natural ventilation and fresh air.

When the model is placed in the CFD software, the airflow begins to spin in the building envelope and then is directed upwards by the suction in the chimney (Fig. 12).

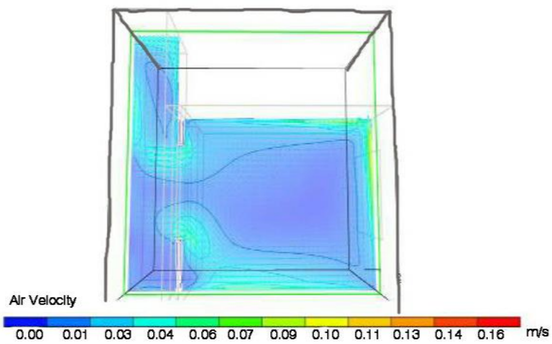

Fig. 12 Air velocity of CFD slices for the existing air well in the case study model

The model was analyzed in the software considering the fixed wall, ceiling, insulation, the number of floors, and separators. The amount of incoming air and natural ventilation changes and increases according to the expectation at each stage with an increasing percentage of openings (Fig. 13).

This change shows that airflow has a positive relationship with natural ventilation, but the trend of change is not the same. As the airflow enters the model, the amount of natural ventilation does not change as much. The effect of airflow movement inside the model has the greatest difference at some point of the opening changes compared to the previous state.

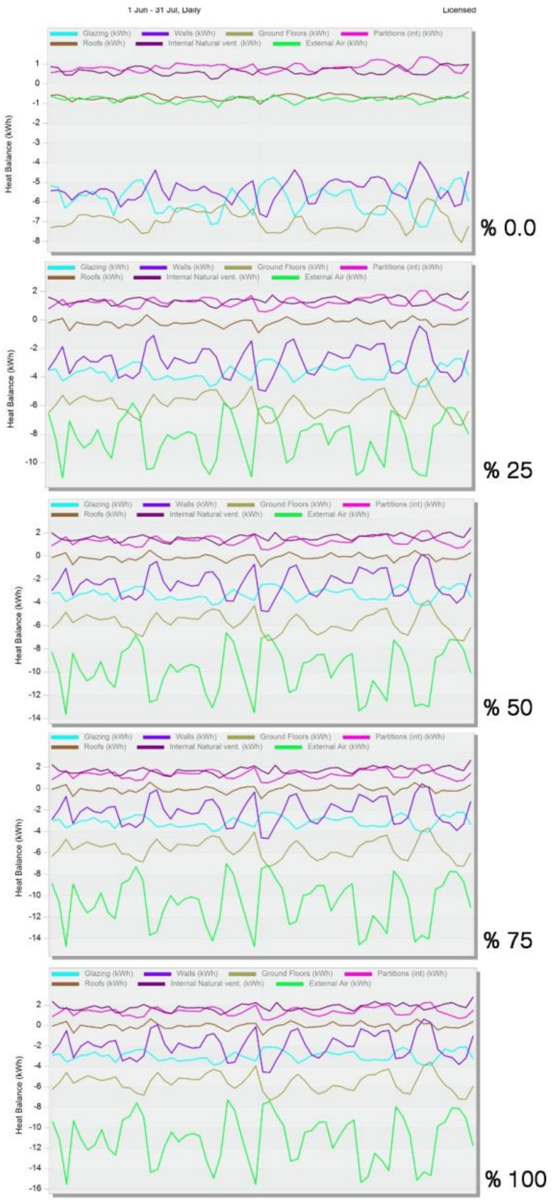

Fig. 13 Percentages of openings

The model is summarized in Table 1 in the CFD analysis. The air temperature decreased with the increasing number of openings, and the amount of natural ventilation increased with the increasing percentage of openings. The amount of external air has also been decreasing and, finally, fresh air has been on the rise.

6-1- Air Temperature

In buildings with natural ventilation, it depends on the users' perception of thermal comfort. A very hot or cold environment reduces the tolerance threshold for continuing and staying in the environment, making it unpleasant. Fig. 14 shows the average flow velocities for natural ventilation.

Table 1: Overview of factors and percentages of openings

Overview of factors and percentage of openings							
No.	Factors under study	Unit	0%	25%	50%	75%	100%
1	Air Temperature	ºC	41.23	37.26	36.54	36.18	35.96
2	Natural Ventilation	kWh	40.36	80.61	95.33	102.63	107.21
3	External Air	kWh	-48.73	-482.35	-572.48	-618.67	-647.63
4	Total fresh Air (Mech Vent+ Nat Vent + infiltration)	ac/h	0.06	1.72	2.83	3.78	4.63

The scenario is created under two warm months of the year in the model. It shows the highest air temperature in these two months (June and July) of the year in Shiraz. Air temperature is one of the most important factors in the energy sector because other factors are trying to control the temperature at the equilibrium point. As shown in Fig. 14, the temperature decreases with increasing openings, and the maximum temperature change is between 0 and 25%. After that, the temperature did not change significantly despite a change in the percentage of openings.

In Table 2, the change in temperature is compared in different percentages. In the second row, all the percentages of all the percentages are compared concerning the 25% change in the range of 25%.

It is observed that the percentage of changes with a range of 100% is almost negligible.

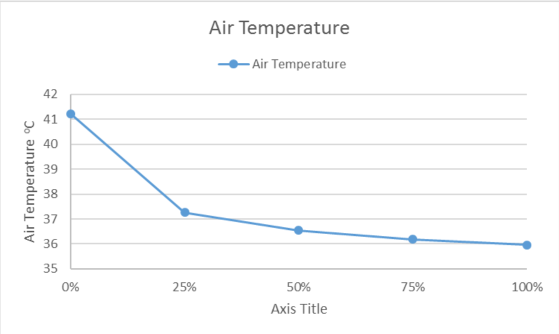

Fig. 14 Changes in the air temperature by changing the openings

Table 2: Air temperature rate change

No.	Factors under study	Unit	25%	50%	75%	100%
1	Air temperature rate change concerning previews	˚C	3.97	0.72	0.36	0.22
2	Percentage rate change concerning 25%	%	-	18.14	9.07	5.54

6-2- Natural Ventilation

When air flows using the difference in wind pressure between the two sides of the building envelope [22].

In Fig. 15, the rate of natural ventilation also increases with the opening of the openings. The maximum slope of this change is in the range of 0-25%.

Table 3 shows the rate of change in air conditioning relative to the increase in openings. In the second row, the rate of change is compared to the highest percentage of change, i.e. 25%, as a unit of percentage.

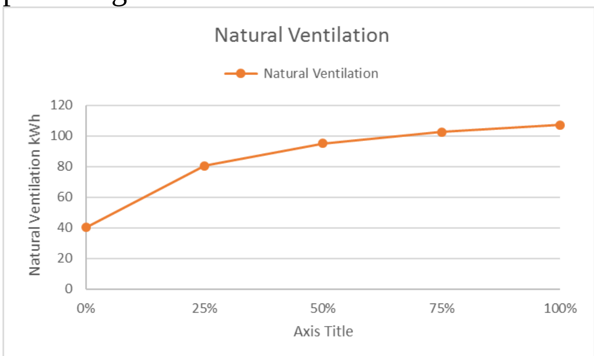

Fig. 15 Changes in the natural ventilation by changing the openings

Table 3: A natural ventilation rate change

NO.	Factors under study	Unit	25%	50%	75%	100%
1	Natural ventilation rate change concerning previews	kWh	40.25	14.72	7.3	4.58
2	Percentage rate change concerning 25%	%	-	36.57	18.14	11.38

6-3- External air

As the number of openings increases, the number of external air decreases (Fig. 16). The peak of this change is in the range of 25%. For this reason, the amount of change was calculated with the 25% range and placed in the second row (Table 4).

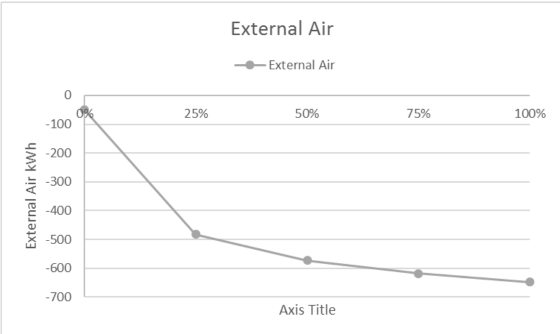

Fig. 16 Changes in the external air by changing the openings

Table 4: The external air rate change

No.	Factors under study	Unit	25%	50%	75%	100%
1	External air rate change concerning previews	kWh	-433.62	-90.13	-46.19	-28.96
2	Percentage rate change concerning 25%	%	-	20.79	10.65	6.68

6-4- Total fresh Air

As expected, as the percentage of openings increases, so does the amount of fresh air. As discussed in the previous parameters, according to Fig. 17, the highest amount of changes is observed in the range of 25%.

Table 5 shows the changes in the fresh air and in the second row, and the number of changes is 25% compared to the range.

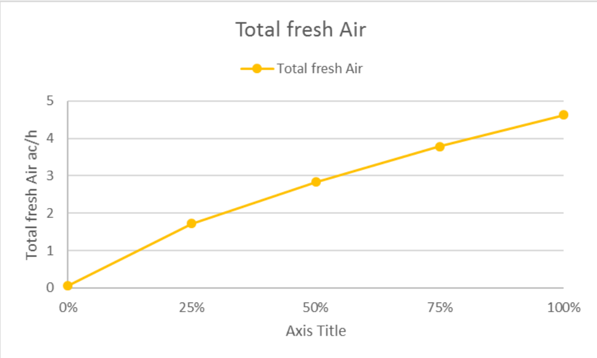

Fig. 17 Changes in the total fresh air by changing the openings

Table 5: Changes in fresh air

No.	Factors under study	Unit	25%	50%	75%	100%
1	Total fresh air rate change concerning previews	ac/h	1.66	1.11	0.95	0.85
2	Percentage rate change concerning 25%	%	-	66.87	57.23	51.20

7- Conclusion

Paying attention to the issue of energy is nowadays one of the concerns of human beings. The human need for energy and its storage is undeniable.

The solar chimney should use its suction to create fresh air in the building since openings are the air inlet path. The amount of air intake is very important in improving the solar chimney process. By examining the percentages of openings in one of the geographical directions in two warm months of the year in this study, it can be concluded that increasing the openings is ineffective in increasing the quality of solar chimney efficiency, but changes and effects are very limited after a period of 25%. Increasing the percentage of these openings may not only waste energy in the colder months of the year but can also be economically and cost-wasted. Thus, the proposal of this study is the best possible case of 25% opening for the south sidewall.

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