ISSN: 2008-5079 / EISSN: 2538-2365
DOI: 10.22034/AAUD.2023.238639.2380



# The Role of Locating Solar Chimneys in Providing Comfort for an Office Building in the Hot and Dry Climate*

**Poopak Poorsistani[a]- Hossein Medi[b**]- Mostafa Mafi[c]**

[a] Ph.D. of Candidate, Architecture Department, International Kish Entity, Islamic Azad University, Kish Island, Iran.

[b] Associate Professor of Architecture, Faculty of Architecture and Urban Planning, Imam Khomeini International University, Qazvin, Iran (Corresponding Author).

[c] Associate Professor of Mechanic Engineering, Technical and Engineering Faculty, Imam Khomeini International University, Qazvin, Iran.

Received 17 December 2020; Revised 23 September 2020; Accepted 30 May 2023; Available Online 10 July 2023

## ABSTRACT

A large area of Iran is located in a hot and dry climate, so has a high amount of sunlight absorption. Systems providing indoor temperature comfort consume a major amount of energy in different parts of the building. Some passive design techniques, such as solar chimneys can be used to keep thermal comfort in buildings and reduce energy consumption. This study evaluates the thermal performance of temperature distribution through simulation Design Builder Software in a government building in Kerman City. This evaluation has been provided by doing a ventilation process with and without integrating a solar chimney in the southern front of the building during summer and winter. The formic variables of the chimney were then applied to examine temperature variations and thermal comfort in different angles to determine the effectiveness of the solar chimney within 40–90-degree angles in 10-degree steps relative to the horizon line by solving average airspeed and volumetric flow rate parameters. Finally, the computational fluid dynamics (CFD) method was used through Design Builder software to measure temperature distribution and airflow. The results implied that the integration of solar chimney could optimize around 16% of the total energy consumption with 40% angel in the best state, and the average value of the thermal comfort index in July reached from 2.97 to 2.25, while this amount reached from -2.93 to -2.24 in January. This value has approached ASHRAE standard 55 and ISO 7730. However, solar chimneys alone cannot provide considerable thermal comfort in extremely hot weather.

**Keywords**: Thermal Comfort, Energy Optimization, Solar Chimney, Design Builder, Hot and Dry Climate, Kerman.



* This paper has been derived from the Ph.D. thesis by the first author under the title of "A Method for Improving Solar Chimney Function when Applying Integrated Design in Office Buildings Located in the Hot and Dry Area of Kerman" which is conducted guided by a second author and consulted by the third author.

** E_mail: medi@arc.ikiu.ac.ir

## 1. INTRODUCTION

Energy use in buildings makes up a large share of global and regional energy demand. The heating and cooling part has a considerable diversity in the total energy demand of the building and varies between 18-73% in the whole world (Urge-Vorsatz et al. 2015). Selective heating and cooling systems of buildings affect the energy requirement and CO2 emission. Solare energy is the most substantial renewable energy source available in place (Abd Elbar and Hassan 2019). Many measures have been taken to investigate this topic. For instance, energy conservation techniques are used in construction with renewable energies like solar energy (Garcia et al. 2002). The solar chimney is one of the strategies taken to improve environmental comfort by providing access to the natural energy source of the sun. The solar chimney is one of the old strategies used for passive ventilation by Iranians in the Middle East and Romans in Europe (Lal et al. 2013) to increase ventilation effectiveness by enhancing sunlight energy absorption in the chimney (Khanal, Rakesh, and Lei 2011).

Solar chimney includes a solar collector, a transparent coating, and an inlet-outlet diaphragm. Solar thermal energy may cause a temperature difference between air temperatures inside and outside the solar chimney channel creating a ventilation flow with a buoyance effect. The hotter the day, the hotter the air collected in the solar chimney channel and the faster the air movement. This is a new design for maximizing the ventilation effect by inducing temperature rise in the chimney chamber to use sunlight radiation (Afonso, Clito, and Oliveira 2000).

## 2. BACKGROUND

It has been highly interested in introducing innovative strategies using integrated solar chimney systems in recent years. Accordingly, this study aims to contribute to current developments in the use of solar chimneys for building ventilation and enhancing energy efficiency in the case study building. Various theoretical, empirical, and numerical studies have been conducted on the integration of active and passive energy-saving systems in the building to strengthen ventilation. It is highly important to integrate active and passive solar design elements to realize energy efficiency inside the buildings (Cole, Raymond, and Fedoruk 2015). Empirical results of Afonso showed that chimney width is more effective in ventilation rather than its height, and the Mathur brothers (Mathur, Jyotirmay, and Mathur 2006) found 40°-60° as the optimum absorption inclination while this angle varies based on the geographical latitude of the location. However, Hamdy and Fikry (Hamdy, Inass, and Fikry 1998) found that the optimum inclination angle equaled 60° to provide the best ventilation performance for their experimental model. The optimum inclination angle leads to a partial increase in chimney airflow for winter consumption; however, the suitable ventilation rate is considerable for summer months. Jalil Imran (Imran et al. 2015) installed a solar chimney on the roof of a room in Iraq and suggested an optimum inclination angle of 60° to achieve the maximum airflow velocity.

In studies conducted by Gehad Mekkawi et al. (2020) conducted a study on solar chimneys for enhanced natural ventilation based on simulation through Design Builder Software in Alexandria, Egypt. Their results showed that the thermal performance of the operative air temperature was reduced by 0.81°C and air velocity was improved by 50% after introducing a solar chimney at the right angle of 90° in the hottest hours (Mekkawi, Gehad, and Elgendy 2015).

Jang Kong with Jianli Neo and Cheng Wang Lee (2020) carried out some studies using simulation-based techniques to find the optimum inclination angle of a solar chimney in three cities in Italy. The results showed that the optimum angle indicates a 45° inclination in areas with severe sunlight and hot and dry climate (Kong et al. 2020).

Mahdavunejad and Fakhari (2013) measured the solar chimney's angle in four cities: Bandar Abbas, Isfahan, Rasht, and Tabriz, and their results confirmed the effect of solar chimney's inclination angle on the air velocity efficiency and found an optimum 45° angle that resulted in maximum ventilation (Mahdavinejad et al. 2013).

Najmeh Zanganeh and Zahra Barzgar pointed to providing thermal comfort in the building and examined the thermal comfort rate of winter space and the central courtyard of the Traditional House of Toolai in Shiraz based on the thermal comfort using the PMV technique to evaluate thermal comfort and percent of dissatisfied individuals. The results indicated that the thermal comfort of the winter-stayed area of Toolai House had a considerable comfort rate, and more than 85% of users were satisfied with the winter space (Zanganeh, Najmeh, and Barzgar 2018).

Ansarimanesh and Nasrollahi conducted a study on thermal comfort and determining the thermal comfort area of residents of office buildings located in Kermanshah. They estimated the indoor ambient of the office buildings in Iran at an average level and found suitable thermal areas of office spaces in Kermanshah at the interval of 20-26°C (Ansarimanesh, Maryam, and Nasrollahi 2018).

In another study, Jan Vanand and Razaghi investigated the geometric parameters affecting airflow velocity enhancement inside the solar chimney. They implemented this study based on the numerical modeling of a solar chimney made at Tehran University based on the finite volume method and K-epsilon turbulence model through Ansys Fluent Software. The results showed that an increase in chimney height, collector height, collector radius, and chimney radius decline led to a 76% rise in inlet airflow velocity in the tower (Jan Vanand, Isa, and Razaghi 2018).

Moulai et al. examined the performance of solar chimney and data related to temperature, velocity, and pressure in different seasons of the year explaining that solar chimney has an acceptable performance as a system for ventilation and cooling the indoor space in summer. In colder seasons when more airflow is created in the environment, individual who are working lose their comfort and the weather becomes cold. Regarding the accurate performance of solar chimneys in summer, airflow can help to save fossil fuels (Moulai et al. 2019).

Fakhari and Heydari addressed the effect of applying solar chimneys on the ventilation of spaces connected to it in a hot and dry climate in Isfahan to measure the area of spaces in which, a solar chimney with optimum dimensions on each floor can ventilate its required air. This research simulated different models of solar chimneys connected to a 7-story office building using Energy Plus software through which, different models with various solar chimney sizes were compared. Their results showed that the mass flow rate of outlet air and volumetric flow rate differs on various floors. The mentioned values are higher on the upper floors. In upper floors that are close to the outlet, pressure loss is less, and the chimney (or stack) effect caused by density difference is higher in upper floors (Fakhari, Maryam, and Heydari 2012).

## 3. ANALYSIS METHOD

Regarding the developed construction industries these days, energy consumption optimization is one of the most substantial concerns in the design and operation of ventilation systems, and the distribution of flow, heat, and cold in different parts of the building. Thermal performance analysis of buildings in unstable situations requires different sophisticated computations, which this process can be done through thermal and energy consumption simulation software. Design Builder Software is one of the computer programs for energy simulation and analysis. Facilities and advantages provided by Design Builder software and Energy Plus simulation engine using specific techniques of computational fluid dynamics (CFD) allow to model airflow inside the building, airflow prediction analysis, and heat exchange.

In the present study, a revision is done to identify the most optimum place for solar chimney placement and examine the angle of its transmissive wall relative to the horizon line from 40° to 40° in 10-degree steps. Figure 1 depicts the chart of this process based on a comparative analysis of energy consumption and the Fanger index. This index is based on Asheri standard 55 and ISO 7730 and measures the predicted mean vote (PMV) of individuals based on the seven-point scale with the thermal balance of the body, which is defined between -3 and 3 as reported in Table 1. Each class expresses the average feeling of several people in the same environmental condition. This range must vary between -0.5 and +0.5 to make employees and clients feel comfortable. This index is one of the most important physiological indicators of temperature (Bahadrinejad, Mehdi, and Yagoubi 2016).

**Table 1. Thermal Comfort Range of Fanger and Asheri Standard**

| Feeling | FANGER Index | ASHERI Index |
|---|---|---|
| Cold | -3 | 1 |
| Cool | -2 | 2 |
| Slightly Cool | -1 | 3 |
| Neutral | 0 | 4 |
| Slightly Warm | 1 | 5 |
| Warm | 2 | 6 |
| Very Warm | 3 | 7 |

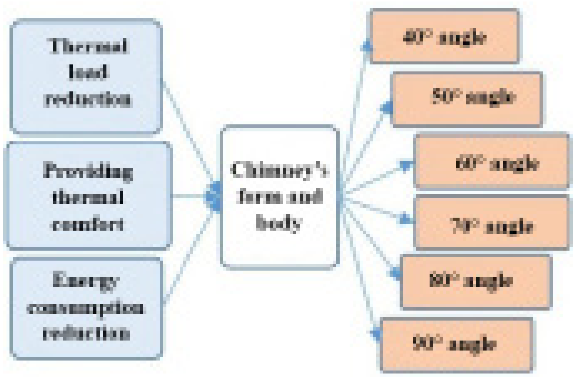



**Fig. 1. Graph of Nexus between Assessed Variables**

### 3.1. The Necessity of Choosing Kerman City and its Studies Building

According to previous studies, solar chimney outperforms in a hot and dry climate (particularly in summer) compared to other climates. The case study of the solar chimney in office buildings in Iran is not available, and only some samples have been built in the hot and dry climate of other countries.

On the other hand, a hot and dry climate is suitable for providing cool air inside the room and increasing comfort conditions by creating analytical models based on the physical algorithms with measuring absorbed radiant heat and its thermal behavior, heat and hot air control, and urban temperature changes. Therefore, Kerman was selected as the study location to examine its climatic properties and its effect on chimney function regarding the climate conditions and climatic potential of this study which is located in hot and dry climates. The Real Estate Building was then chosen based on the location, possible implementation outside the building, geometric form of the building, and considering aesthetics and integration of chimneys as much as possible into the whole building.

### 3.2. Climatic Properties of the Studied Site

Several climatic parameters (solar radiation, temperature, wind speed and direction, relative humidity, air pressure, altitude from sea level, etc.) are essential for the energy simulation process in buildings (Rahman et al. 2014). In the extant study, the climatic file of Kerman City (with geographical northern 30.29 and eastern 57.60 longitudes) is used, and its meteorological data is inserted into Design Builder Software as a climatic file. With an area of 185675 km$^2$, Kerman Province is located in the southeast of Iran (Fig. 4) and is part of a desert hot and dry climate. Most areas of this province have severe drought with extreme air temperature changes and a wide gap between air temperatures in cold and hot seasons and during days and nights.

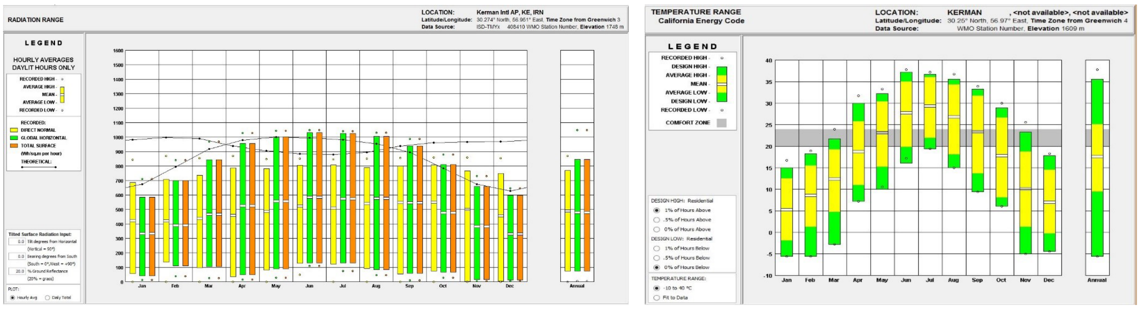



**Fig. 2. From Right to Left: Air Temperature and Radiation of Kerman during Different Months**

(Climate Consultant 6.0)

In general, the summer season with hot weather in Kerman starts in mid-November until mid-April. The weather is dry from August to November but becomes cooler from January to May. According to data obtained from the synoptic station of Kerman, the annual mean temperature of this city equals 17.8°C, with minimum and maximum temperatures of 10.9 and 25.1°C, respectively. According to statistics of climate analysis shown in Figure 2, the mean temperature difference between minimum and maximum temperature is 24.8°C (Poursistani et al. 2021).

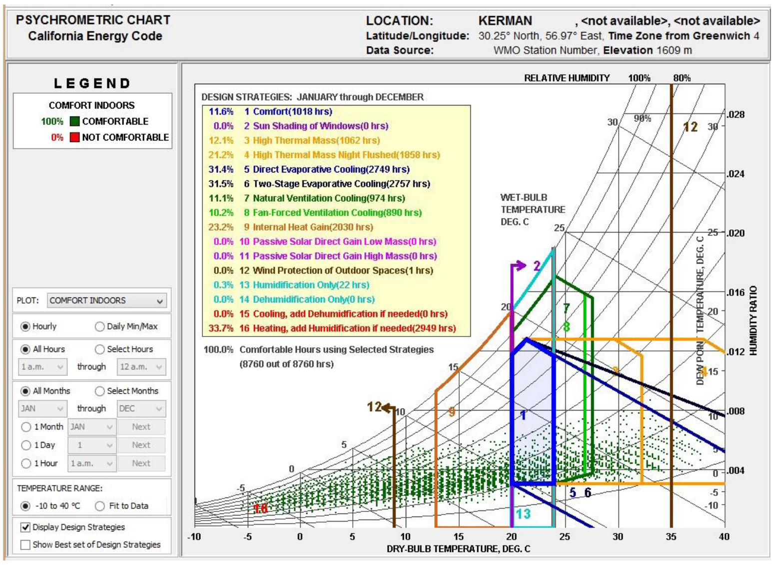
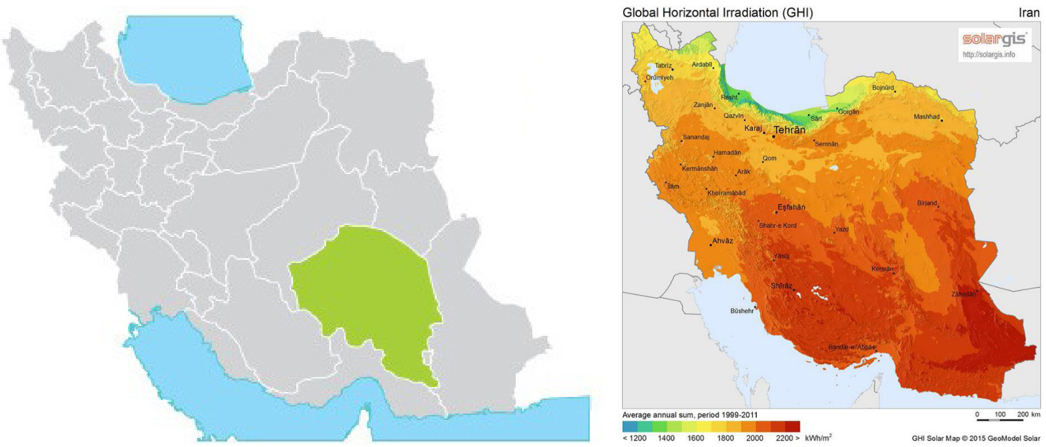



**Fig. 3. Psychrometric Chart and Thermal Area of Kerman City**

(Climate Consultant 6.0)

The psychrometric chart shows climate parameters affecting the case situation obtained from climate software and meteorological data analysis of the area. According to this chart, 11.6% of the area has thermal comfort, and 22-26°C values are considered in the temperature data of the studied building in this study. **Solar radiation:** solar radiation varies in different areas of the world. Having 300 sunny days and an average of 4.5-5.5 kWh/m$^2$ radiation at the day, Iran has been introduced as one of the countries with high solar energy potentials (Fig. 3). According to the solar radiation potential map, Kerman with 234.1 sunny days has been located in a region with an average of 4.5-5.2 kWh/m$^2$ radiation (Mojarrad, Firouz, and Moradi 2013). Average sunny hours in Iran equals 2900 hours a year. According to the data gathered from the synoptic station of Kerman during 47 years, the average annual sunny hours is 3200 hours, which is a considerable value that is even higher than the average annual radiation in Iran (Management and Planning Organization of Kerman Province 2015).




(www.Yjc.ir) (www.Solargis.info 2016)

**Fig. 4. From Right to Left: Average Annual Solar Radiation Map of Iran-Situation of Kerman at Country Scale**

## 4. THE GEOMETRY OF THE SIMULATED BUILDING

The simulated model includes a three-story Real Estate Building in Kerman Province with office use, which is located at the end of Ferdowsi Louvered-northern side of Neshat Park. The useful meterage of floors equals 3548m$^2$, and the useful height of floors equals 3.2m in length. The main entrance gate of this building is located in the southern front, and a window has been deployed on all fronts of the façade and its ceiling to achieve better lighting and ventilation of space. Figure 5 shows the modeling process of the case study through Design Builder Software.

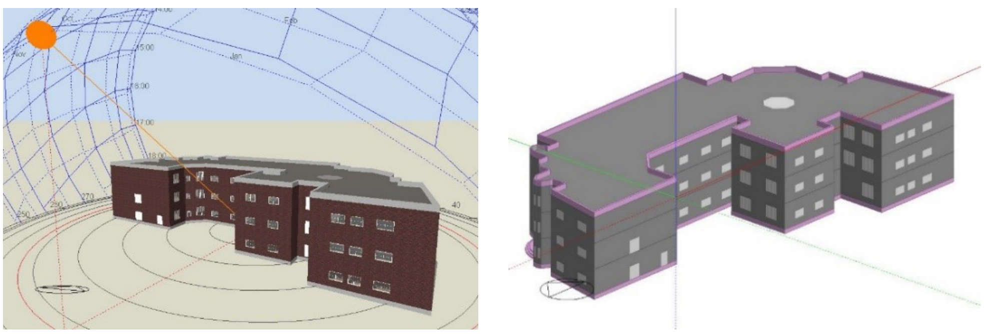


**Fig. 5. Simulated Model of Real Estate Building in Kerman City through Design Builder**

### 4.1. Base Building Analysis through Energy Optimization and Thermal Comfort Approaches

According to temperature distribution at different hours a day and higher radiation intensity, the volumetric airflow rate will rise and reaches the maximum rate in the middle of the day due to the sun's direction. The volumetric airflow rate is then reduced due to the radiation intensity decline. The average indoor air temperature of the studied building equals 34.89°C in the hottest month of the year (July), while equals 34.89°C in the coldest month (January) (Fig.s 6 & 7). The considerable point is that the temperature of office rooms is extremely high, and proper strategies must be taken to reach the optimum thermal conditions by using outdoor air to moderate the thermal conditions of office spaces and reduce the energy consumption rate in the studied building. Energy consumption equals 2337.9.13 kwh in the current situation; in other words, 66.22 kWh was extracted from the software.

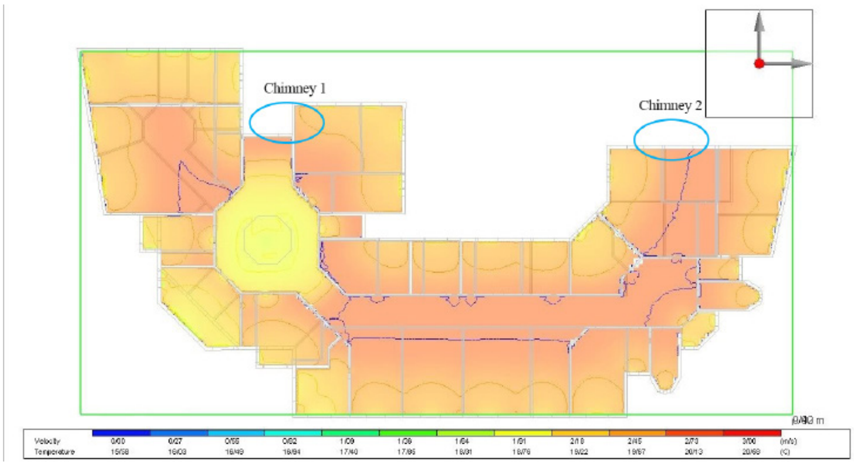



**Fig. 6. Temperature Distribution on the Third Floor of the Building based on CFD**

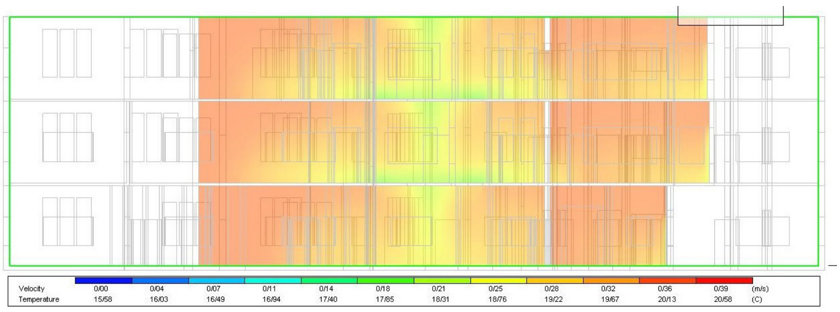


**Fig. 7. Temperature Distribution in the Floor along the Chimney based on CFD**

According to the chart shown in Figure 8, thermal comfort, indoor temperature, and radiant temperature of space, as well as the required energy of the base building are shown. Accordingly, the range of thermal comfort satisfaction varies between -2.93 and +2.97, which starts from the coldest month (January) to the hottest month (July). The results of the base office building are highly far from the comfort criteria due to the lack of thermal exchange with fresh air and suitable ventilation in different parts of the building.

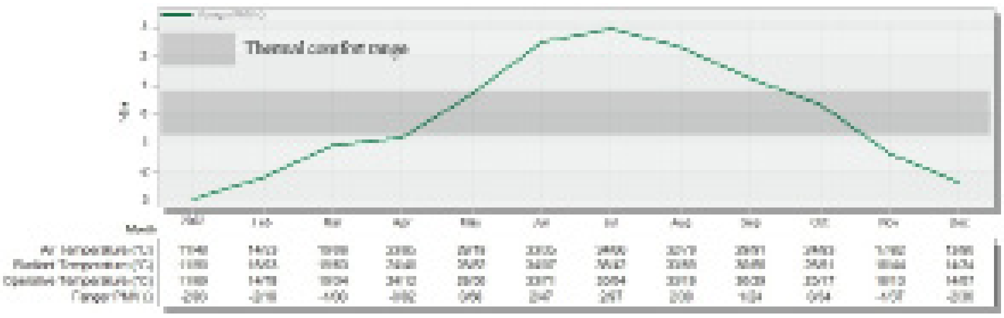



**Fig. 8. Average Thermal Comfort Index in a Sample Office Building during Different Months**

In this research, a revision was conducted to find the best location for the deployment of solar chimneys adjacent to the spaces that require higher ventilation and temperature distribution. For this purpose, the modeled process was done to find air temperature distribution in the initial mode of building and, and identify the spaces that have higher air temperature rather than the comfort extreme. The building was integrated with two southtoward solar chimneys to moderate the undesired air, which is shown in Figure 9.

The place of chimneys has specific climate properties and solar radiation angles regarding the different geographical locations and their placement front. Accordingly, solar chimneys with 1m length, 0.8 widths, and 12.8m height were installed on the southern front of the building, and some valves were created to create a temperature connection between the upper part of each floor and the chimney. The materials used in the external wall of the solar chimney comprise 10cm concrete with 5cm Polystyrene insulation (Fig. 10). The heat exchange coefficient of the window used in the chimney equals 1.96 W/ $m^2$. K, which is made of UPVC frame, transparent double-glazed glass with 6mm thickness with middle air space of 13mm in thickness.

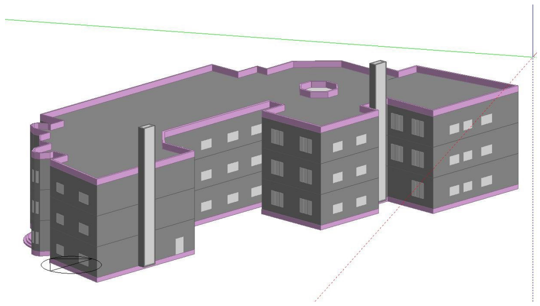


**Fig. 9. Deployment of two Chimneys in Selected Locations**

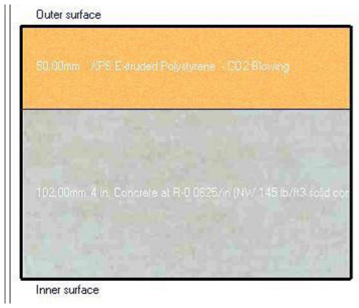



**Fig. 10. Executive Specifications Solar Chimney Wall**

## 4.2. Building Analysis by Applying Solar Chimney

Acceptable results were presented after placing two solar chimneys and doing the required dynamic analyzes. Accordingly, the high temperature of spaces was reduced due to solar chimney suction and was replaced with cooler air resulting in an energy consumption decline. According to results of Figures 11 and 12 obtained from Design Builder simulation software, the average indoor air temperature during the hottest month (July) reached from 34.29°C to 32.06°C (2.23°C reduction) assuming that mechanical facilities are turned off. The air valve is closed in cold months o the year to prevent warm air exit and heat loss on the upper part of the chimney, so the temperature of the building increased from 13.30°C to 16.42°C in January.

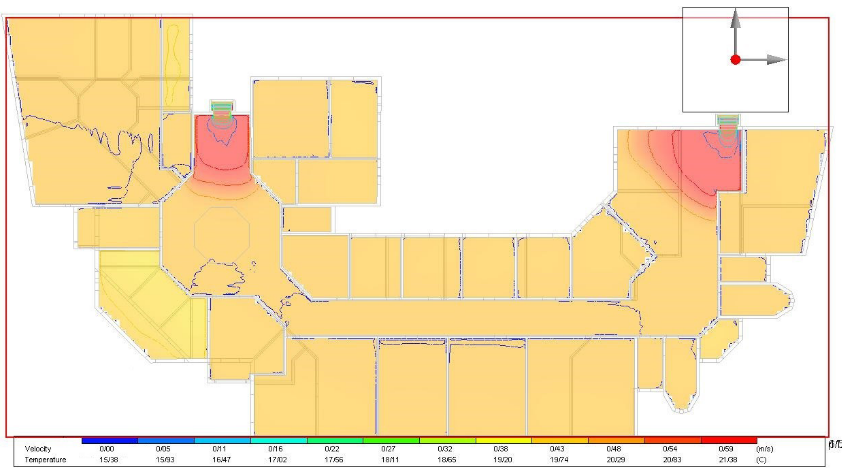



**Fig. 11. Temperature Distribution in Building Floors after Applying Solar Chimney based on CFD**

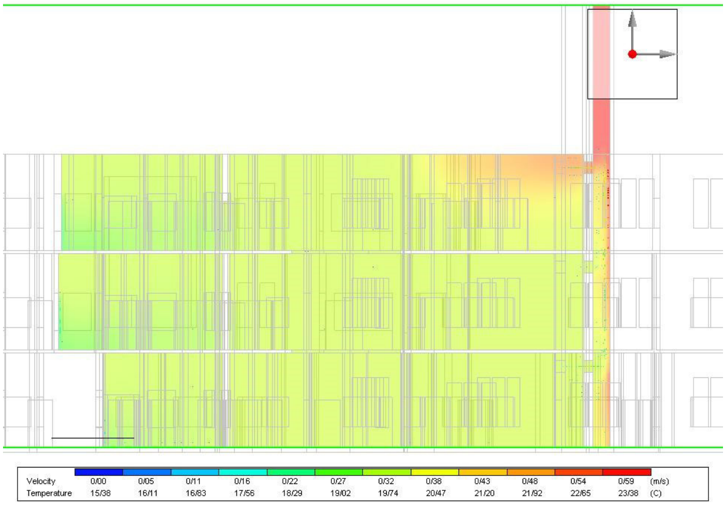



**Fig. 12. Thermal Performance and Temperature Distribution and Chimney Airflow in Sample Building of Kerman**

Energy consumption values required for a building's thermal comfort after installing solar chimneys equals 208414.61 kwh or 58.74 $kWh/m^2$, which indicates 11% energy optimization. As explained before, the thermal comfort criterion can be achieved by creating airflow. The effect of chimney on the thermal comfort can be seen in July when it reached 2.97 to 2.49 units implying improved thermal comfort and lower dissatisfaction among users. In January, this value reached from -2.93 in the base building to -2.47 in the building where the solar chimney was installed by closing the end valve of the chimney and transferring the produced warm air into the case building.

### 4.3. Analysis of Form Variable on the Chimney of the Studied Building in Kerman City

The ratio of the transmissive wall inclination angle of the solar chimney to its horizontal surface is one of the most important factors affecting the volumetric airflow rate. The assumed models have been simulated in six states to achieve the optimum depth. In simulated models, all specifications are considered similar (like the initial model) except for the transmissive wall inclination of the solar chimney. The air volume inside the chimney chamber moves by gaining solar radiation and an internal load of the building, and air layering take different complicated shapes based on the size and form of the chimney and specifications of the transmissive wall's shells. To determine airflow and its speed in the case study, software analysis was done in determined points at entrances leading to air transfer valves from inside to outside it. Seven points were selected from the indoor space (points A, B, C) and its outlet from the chamber to outside (selected points D, E, F, G), as shown in Figure 13. Despite the difference between indoor temperatures of chimneys caused by different heights of place and the microclimate of buildings, temperature values of this space must be measured. The equations ruling chimneys include equations 1-4, which are the protection of mass, velocity, and energy which are three underlying principles for thermal flow through the solar chimney.

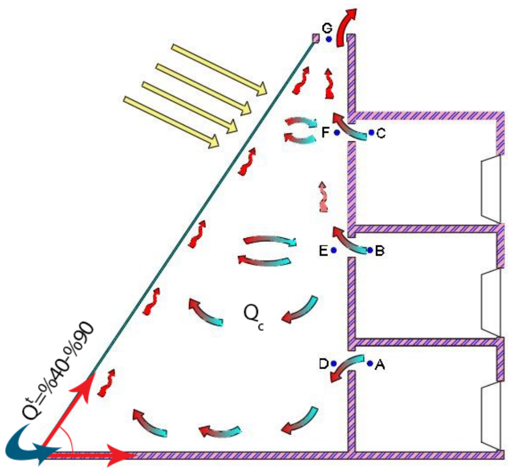



**Fig. 13. Airflow Path and Heat Exchange, and Analyzed Points in a Studied Building in Kerman**

(1) $$\frac{\partial}{\partial t}(\rho v^{\rightarrow}) + \nabla \cdot (\rho v^{\rightarrow} v^{\rightarrow}) = -\nabla P + \nabla \cdot (t^{=}) + pg^{\rightarrow}$$

(2) $$\dot{Q}_{conv} = hA_h \Delta T,$$

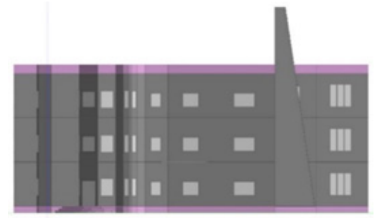
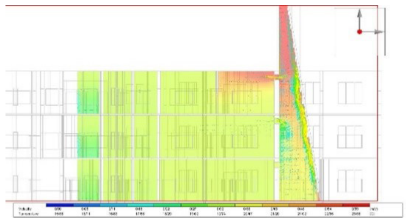
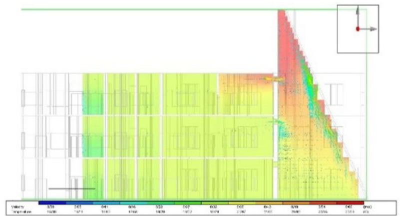
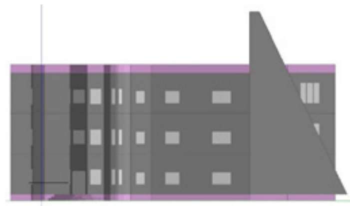
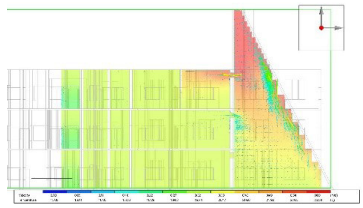
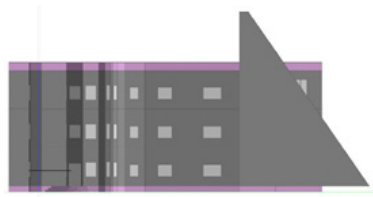
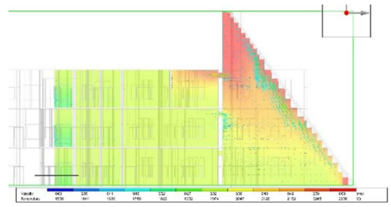
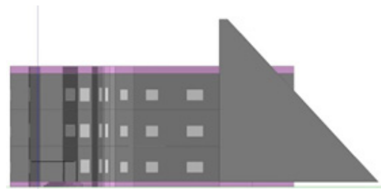
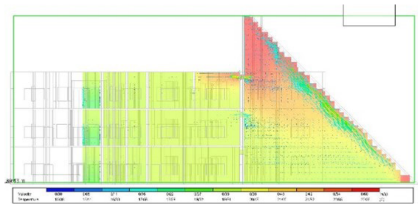
(3) $$M = \frac{m}{\rho \alpha}$$

(4) $$ACH = \frac{q \times 3600}{V\,vol}$$

In these equations, Q represents volumetric flow speed and Vvol expresses the room volume to which, the solar chimney is connected. ACH depends on the room-to-chimney area ratio. M (normal mass flow)

(Khanal and Lei 2011), ACH (air change in hour), and Qconv (convective heat exchange speed) are operative indicators of the present study. When Equation 4 is applied on some floors, air change repetitions through the solar chimney will exceed the required value. According to Asheri ventilation standard (62.1), air change must be done 6-8 times per hour in an office building (ASHRAE Standard 62.1). Moreover, it is worth noting that the temperature of floors will be increased as reported in Table 2 when the sun height rises or when the bottom floor of the solar chimney chamber is decreased.

**Table 2. Airflow Path and Heat Exchange in a Studied Building in Kerman-Author**

| Row | Rotation | Schematic Façade | Airflow |
|---|---|---|---|
| 1 | 80% |  |  |
| 2 | 70% |  |  |
| 3 | 60% |  |  |
| 4 | 50% |  |  |
| 5 | 40% |  |  |

The outputs of Design Builder software indicated good direct and indirect solar heat gain on the upper floor of the building, so great static heating energy is created for warming the building in cold seasons. When valves are closed in winter, lower floors obtain thermal comfort easily without using any installation. Therefore, chimneys have the potential to increase direct and indirect radiative energy gain but also provide higher thermal ventilation and discharge. Temperature stability reduces the cooling load for the next day. All floors face temperature disturbance during hot months of the year when the cooling system works; therefore, space temperature will be reduced due to airflow between openings of the building's floors. Stable thermal layering indicates the indoor chimney's potential for creating thermal distribution balance and convective flows. Accordingly, temperature changes on each floor have minimum and maximum rates that are occurred in different intervals due to thermal capacity and lag and temperature differences with the space. Equation 5 contributes to a suitable index for displaying temperature change and thermal layering in solar chimneys:

(5) Temperature change index = $(T_{max} - T_{min})/n$

where Tmax and Tmin indicate maximum and minimum temperatures, and n shows the number of records within the time interval between maximum and minimum temperatures in the considered floor. Figure 14 has shown and compared temperature change indicators in different points determined under various physical conditions (90%, 80%, 70%, 60%, 50%, and 40%).

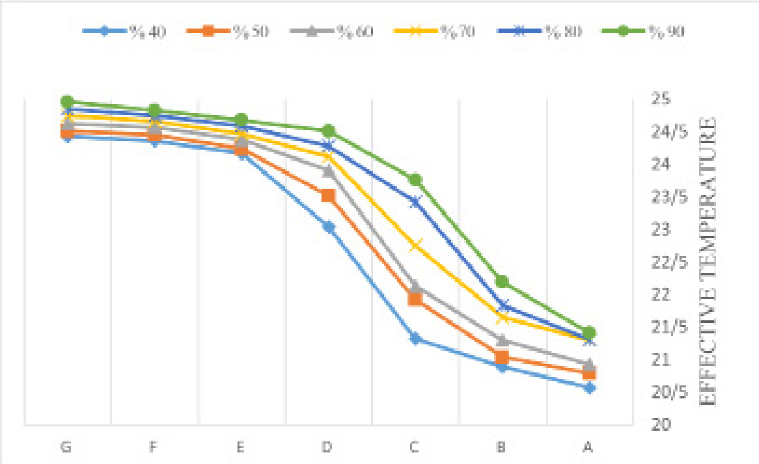



**Fig. 14. Temperature Change Index in Determined Points of Building under Different Physical Conditions: 90%, 80%, 70%, 60%, 50%, and 40%**

The critical point of temperature changes is seen in the area close to the chimney's transmissive wall, so a temperature movement cycle is created when temperature is directed towards the upper valve of the chimney. Therefore, the results of chart 4 indicate that the studied chimney shows considerable 3.86-degree temperature changes in terms of thermal change index in the chimney with a 40-degree angle relative to the horizon angle. Accordingly, temperature equals 23.04°C in point D at 3m height from the chimney's surface, 24.17°C in E point at 6m height, 24.36°C in point F at 9m height, and 24.43°C in point G at 12.4m height. However, this temperature difference reaches 3.55° in vertical solar chimneys, while temperature equals 21.41, 22.19, and 23.76°C in points A, B, and C, respectively. The temperature of points D, E, F, and G equals 24.51, 24.68, 24.83, and 24.96°C, respectively.

According to assessments done in Figure 14, the indoor space of the building would have changed for temperature reduction by increasing the bottom floor surface and chamber volume in terms of static function. Chimneys with smaller chamber volumes have higher temperature velocities rather than chimneys with larger chambers. The larger the size of the chamber, the more the temperature changes will be. The chamber size affects the heat exchange due to direct and indirect solar radiation gain and its better connection with the surrounding environment. The thermal discharge will be terminated after exiting the upper valve of the chimney.

On the other hand, Figure 15 depicts the effect of the increased depth of the chimney on volumetric airflow on upper floors. As seen in the charts, solar chimney function depends on its depth. On all floors, the highest volumetric airflow during office hours is seen in the chimney, which has a better bottom distance of the chimney chamber and transmissive wall angle rather than solar radiation angle. According to the presented models in this research, the chimney with 40% inclination has the highest airflow volume, and its highest amount occurs during hours when solar radiation is maximum. The outlet air speed of the chimney during office hours has more airspeed changes in the model of 40% with 16.47m depth. This speed reaches 0.3m/s in point D, 0.47m/s in point E, 0.53m/s in point F, and 0.58m/s in the peak point of the chimney (G), while the lowest air speed is seen in the vertical chimney with 1m depth. This speed reaches 0.29m/s in point A, 0.31m/s in point B, 0.48m/s in point C, 0.42m/s in point D, and 0.5m/s in point E. The points F and G exit the chamber with 0.55 and 0.6m/s speeds, respectively. Therefore, the optimum depth of a solar chimney in a three-story office building equals 40%. Hence, solar chimney functions have been compared on different floors. Figure 15 depicts the volumetric airflow speed on different floors indicating less airflow rate on lower floors. Because air passes a longer path from lower floors to reach the air exit in the upper part of the solar chimney, pressure loss is higher on these floors due to the friction between air and the solar chimney's wall. (Therefore, flow speed and rate are higher on upper floors). Moreover, the chimney effect phenomenon caused by density difference is higher in upper floors.

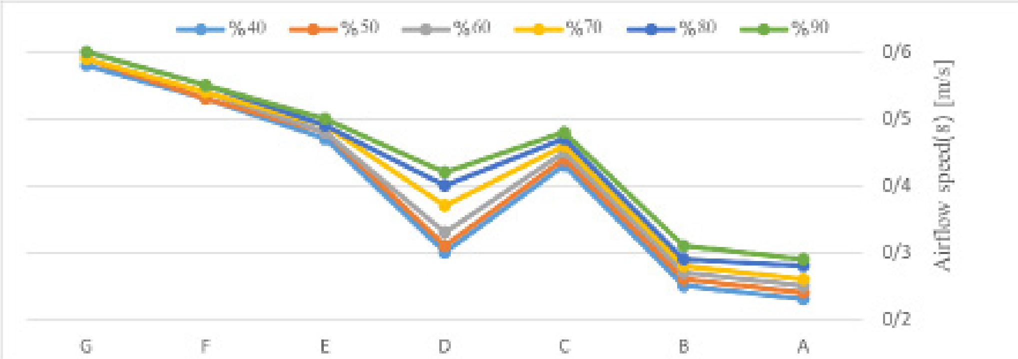



**Fig. 15. Airspeed Change in Certain Points of the Studied Building at Different Angles: 90%, 80%, 70%, 60%, 50%, and 40%**

According to the simulation results of this study, this system helps to achieve lower PMV indicators reducing its rate from 2.97 to 2.25 in July as shown in Figure 16. However, average thermal comfort reached from -2.93 to -2.24 in January.

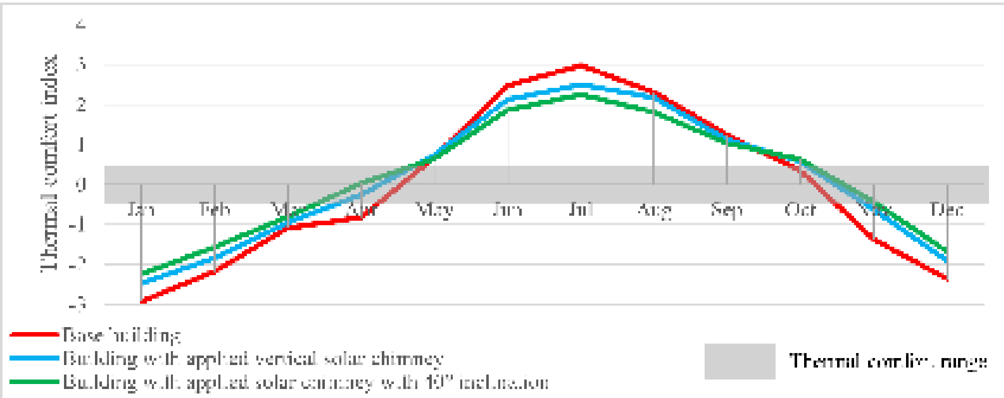



**Fig. 16. Thermal Comfort in Different Months of the Year within Various Modes**

The 40% solar chimney can be used to provide a part of the building ventilation standard. This chimney has improved the average operating temperature from 34.89 to 30.41°C in July, and increased air temperature from 13.30 to 17.13°C in January. Therefore, this chimney provides climate conditions during the hot and cold months of the year. The energy consumption rate in each mode was determined as reported in Table 3. In the most optimum model, the energy consumption of the base building was reduced from 233709.13 kWh to 196058.59 kWh after applying the chimney with a 40% angle, while energy reduction in the most optimum model equals 16.11%.

**Table 11. Energy Consumption Rate in Real Estate Buildings when using Chimneys in Different Angles**

| Specifications of Shell | Energy Consumption Rate | | | | Optimum Percent Relative to base Building |
|---|---|---|---|---|---|
| | Total (kwh/m²) | Total (kwh) | Heating (kwh) | Cooling (kwh) | |
| Base Building (without Chimney) | 66.22 | 233709.13 | 97953.41 | 135755.72 | ----- |
| Regular Chimney (90°) | 58.74 | 208414.61 | 88157.71 | 120257.14 | 10.82 |
| Regular Chimney (80°) | 58.32 | 205827.63 | 87888.40 | 117939.23 | 11.93 |
| Regular Chimney (70°) | 57.56 | 203139.98 | 85521.93 | 117618.05 | 13.08 |

| Specifications of Shell | Energy Consumption Rate | | | | Optimum Percent Relative to base Building |
|---|---|---|---|---|---|
| | Total (kwh/m²) | Total (kwh) | Heating (kwh) | Cooling (kwh) | |
| Regular Chimney (60°) | 56.83 | 200569.18 | 83236.21 | 117332.97 | 14.18 |
| Regular Chimney (50°) | 56.09 | 197951.63 | 80962.22 | 116989.41 | 15.30 |
| Regular Chimney (40°) | 55.55 | 196058.59 | 79403.73 | 116654.86 | 16.11 |

## 5. VALIDATION

According to the subject of this study that examined design models of solar chimneys from different angles, the software simulation results of this novel subject must be validated. Since an inclined sample of solar chimneys is not available in Iran, the design strategies obtained from conducted studies and simulation results of the model were implemented on a lower scale. The results were then projected in real space to achieve actual volumetric airflow and ventilation speed inside the solar chimney's chamber. Figure 17 depicts the sample of solar chimneys at different angles. According to the data obtained from the temperature data recorder, solar chimneys with 40% inclination had higher thermal rates rather than other models, so it could enhance ventilation level.

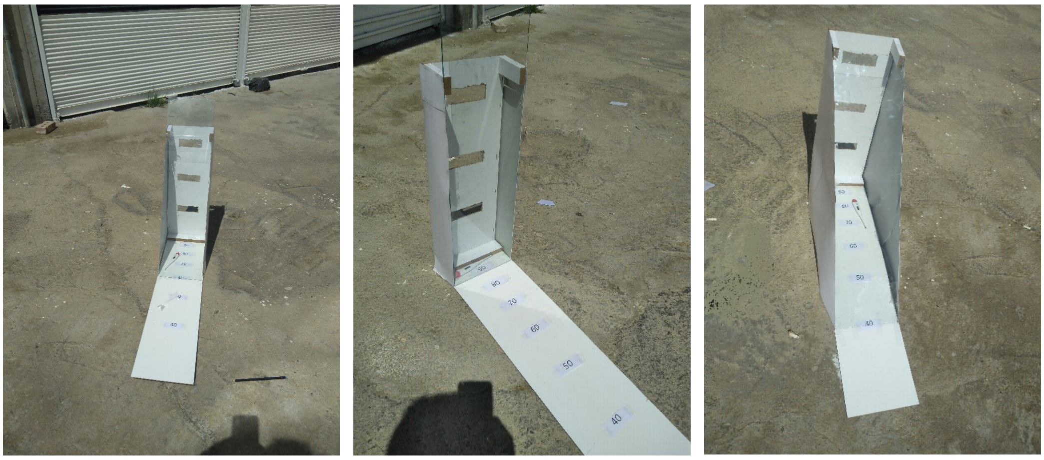


**Fig. 17. Sample of the Inclined Solar Chimney on a Smaller Scale and Different Angles**

## 6. CONCLUSIONS

Many incentives direct us toward the development of green buildings. Natural ventilation provided by solar chimneys is considered a novel strategy for reducing energy consumption, so it can be used in areas with proper solar radiation to create natural cooling or heating. Regarding the better performance of chimneys in Kerman City, this study compared the average temperature of rooms, air inlet speed in the rooms, and air outlet pressure in formic models.

In the conducted assessments, the body and form of studied chimneys were changed and it was found that the inclined transmissive wall of the solar chimney towards the sun angle led to more air volume in the chamber. This case, in turn, increased the volume of exchanged air, so that the increased volume of the chamber in the chimney with 40% inclination experienced some changes regarding temperature reduction, and more temperature fluctuations occurred in its chamber due to direct and indirect solar radiation gain and better connection with the surrounding environment. The mentioned changes affect the heat exchange, so more heat discharge occurs exiting from the upper valve of the chimney. On the other hand, this case results in more acceptable thermal comfort and more optimum energy consumption. It should be mentioned that the environmental temperature on the floors resulting from solar radiation entering the chimney would change the volumetric airflow rate and speed on each floor. The higher temperature is felt on the upper floors. In all floors, the highest volumetric airflow during office hours occurs in 40% of chimneys in which, a bottom distance of the chimney chamber has a better ratio to solar radiation providing the highest volumetric rate and average airflow speed rather than other samples. Moreover, the high heat of space and radiative properties of sunlight due to the location of the studied building in the hot and dry climate of Kerman enhance the performance of the solar chimney in increasing temperature exchange speed inside the chamber.

Increased depth of chimney (40% sample) in floors plays a better role rather than other samples leading to higher volumetric airflow speed in a horizontal line of that floor due to the higher volume of air chamber of the chimney. This higher volume in upper floors lead to increased volumetric airflow speed in lower floors, which caused more rapid exchange speed in upper floors. It is worth noting that pressure loss caused by friction between air and the wall of the solar chimney is higher because the air passes a longer path from lower floors to reach the air outlet point in the upper part of the solar chimney. However, the increased temperature trapped in the chimney and chimney effect phenomenon caused by density difference is higher than the imposed pressure loss, which leads to outperformance and higher efficiency of inclined solar chimneys compared to vertical chimneys without inclination in the transmissive wall.

## REFERENCES

- Abd Elbar, Ayman Refat, and Hamdy Hassan. 2019. Experimental investigation on the impact of thermal energy storage on the solar still performance coupled with PV module via new integration. *Sol. Energy:* 584-593. https://doi.org/10.1016/j.solener.2019.04.042 [in Persian]
- Afonso, Clito, and Oliveira Armando. 2000. Solar chimneys: simulation and experiment. *Energy Build* 32: 71-9. https://doi.org/10.1016/S0378-7788(99)00038-9
- Ansarimanesh, Maryam and Nazanin Nasrollahi. 2018. Proper Range of Carbon Dioxide to Optimize Indoor Environmental Quality in Office Buildings of Kermanshah. *Naqshejahan- Basic studies and New Technologies of Architecture and Planning*, 8(1): 9-15. http://magiran.com/p1816300 [in Persian]
- ANSI/ASHRAE Standard 62.1. 2010 Supersedes ANSI/ASHRAE Standard62.1-2007- American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle NE, Atlanta, GA 30329. https://upgreengrade.ir/admin_panel/assets/images/books/25223276727.pdf
- Bahadrinejad, Mehdi, and Mahmoud Yagoubi. 2016, *"Natural ventilation and cooling in traditional Iranian buildings"*. Tehran University Publishing Center, first edition. http://www.lib.ir/book/60184757/ [in Persian]
- Cole, Raymond J., and Laura Fedoruk. 2015. Shifting from net-zero to net-positive energy buildings. *Build. Res. Inf.* 43: 111-120. https://doi.org/10.1080/09613218.2014.950452
- Fakhari, Maryam, and Shahin Heydari. 2012. Optimizing the solar chimney and investigating its effect on building ventilation. *Architecture and urban planning (fine arts)* 18(2): 83-88. https://sid.ir/paper/154382/fa [in Persian]
- Garcia-Hansen, Veronica, Esteves Alfredo, and Pattini Andrea Elvira. 2002, Passive solar systems for heating, daylighting and ventilation for rooms without an equator-facing facade. *Renew Energy* 26: 91-111. https://doi.org/10.1016/S0960-1481(01)00089-1
- Mekkawi, Gehad, and Rana Elgendy. 2016, Solar Chimney for Enhanced Natural Ventilation Based on CFD-Simulation for a Housing Prototype in Alexandria, Egypt. In *the 63rd International Conference on Civil and Architectural Engineering (ICCAE)*, At Berlin, Germany, July. https://www.worldresearchlibrary.org/up_proc/pdf/363-146959948407-12.pdf
- Hamdy, Inass, and, Fikry Mohamed Anwar. 1998. Passive solar ventilation. *Renew Energy* 14: 3816. https://ideas.repec.org/a/eee/renene/v14y1998i1p381-386.html
- Imran, Ahmed Abduinabi, Jalil Jalal M., and Ahmed Sabah T. 2015. Induced flow for ventilation and cooling by a solar chimney. *Renew Energy* 78: 236-44. https://ideas.repec.org/a/eee/renene/v78y2015icp236-244.html
- Jan Vanand, Isa, and, Reza Razaghi. 2018. Numerical investigation of parameters affecting air speed in solar chimney. *Energy Management Engineering (Energy Management)* 9(4):74-81. https://sid.ir/paper/376786/fa [in Persian]
- Jing Kong, Jianlei Niu, and Chengwang Lei. 2020. A CFD based approach for determining the optimum inclination angle of a roof-top solar chimney for building ventilation. *Solar Energy* 198: 555-569. https://doi.org/10.1016/j.solener.2020.01.017
- Khanal, Rakesh, and Lei Chengwang. 2011. Solar chimney, a passive strategy for natural ventilation. *Energy, Build* 43:1811-1809.http://dx.doi.org/10.1016/j.enbuild.2011.03.035
- Lal Shiv, Kaushik S., and Bhargav P. 2013. Solar chimney: a sustainable approach for ventilation and building space conditioning. *Int J Dev Sustain* 2: 277-97. https://isdsnet.com/ijds-v2n1-20.pdf
- Mahdavinejad, Mohammadjavad, Maryam Fakhari, and Fateme Alipoor. 2013. The Study on Optimum Tilt Angle in Solar Chimney as a Mechanical Eco Concept. *Frontiers of Engineering Mechanics Research* 2: 71-80. https://www.researchgate.net/publication/256198688
- Management and Planning Organization of Kerman Province. 2015. Kerman Province Planning Studies. [in Persian]
- Mathur, Jyotirmay, and Sanjay Mathur. 2006, Experimental investigation on four different types of solar chimneys. *Adv Energy Res* 12:151-156. http://www.sciepub.com/reference/37569
- Mojarrad, Firouz, and Kamran Moradi. 2013. An attitude on the inconsistencies and trends of sunny hours in Iran. *Geography and Development* 12(series 34): 153-165. https://sid.ir/paper/77093/fa [in Persian]
- Moulai, Mohammad Mahdi. 2019. Pilleh Chiha Peyman, Zarin Mehr Zahra, Shaari Jalil. Investigating the combination of open and closed urban space on the efficiency of solar chimney, case study: office building in the hot and dry climate of Shiraz. *Utopia architecture and urban planning* 13(31): 157-167. https://sid.ir/paper/378695/fa [in Persian]
- Poursistani, Poopak, Hosein Medi, and Mostafa Mafi. 2021. Evaluation of thermal performance of a solar chimney with two independent modes and air injection from the floor - Case study: Office building in Kerman. *Geography (Regional Planning)* 11(44): 702-721. magiran.com/p2346444 [in Persian]
- Rahman, MdMizanur, Chu Chi-Ming, Kumaresen Sivakumar, Yan Farm, Kim Phang, Mashud M., Shahidur, Rah-

man. 2014. Evaluation of the modified chimney performance to replace mechanical ventilation system for livestock housing. *Procedia Eng* 90: 245-8. https://doi.org/10.1016/J.PROENG.2014.11.844

- Urge-Vorsatz, Diana, Luisa F. Cabeza, Susana Serrano, Camila Barreneche, and Ksenia Petrichenko. 2015. Heating and cooling energy trends and drivers in buildings. *Renew Sustain Energy Rev* 41: 85-98. https://doi.org/10.1016/j.rser.2014.08.039
- Zanganeh, Najmeh, and Zahra Barzgar. 2017. The Comparison of Internal and External Thermal Comfort of winter stayed and Central Yard in Traditional House by PMV and PPD Methods (Case Study: Tavallaee House in Shiraz). *Haft Hesar J Environ Stud* 6(24): 55-68. http://hafthesar.iauh.ac.ir/article-1-570-fa.html [in Persian]
- https://www.Solargis.info
- https://www.yjc.ir/fa/news/5608745
- https://climate-consultant.informer.com/6.0/
- http://kerman-met.ir/

**HOW TO CITE THIS ARTICLE**

Poorsistani, Poopak, Hossein Medi, and Mostafa Mafi. 2023. The Role of Locating Solar Chimneys in Providing Comfort for an Office Building in the Hot and Dry Climate. *Armanshahr Architecture & Urban Development Journal* 16(43): 1-15.

DOI: 10.22034/AAUD.2023.238639.2380
URL: https://www.armanshahrjournal.com/article_174386.html

**COPYRIGHTS**

Copyright for this article is retained by the author(s), with publication rights granted to the Armanshahr Architecture & Urban Development Journal. This is an open- access article distributed under the terms and conditions of the Creative Commons Attribution License.

http://creativecommons.org/licenses/by/4.0/