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Optimizing Ventilation Performance of Rooftop Solar Chimneys: A Study on Design Parameters in Erbil City, Iraq

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ABSTRACT

The implementation of a solar chimney in buildings can enhance ventilation and create a comfortable indoor environment using renewable energy. A research study conducted in Erbil City, Iraq, utilized numerical modelling with MATLAB to investigate the impact of design parameters on the ventilation performance of rooftop solar chimneys throughout the year. The study focused on the relationship between solar energy availability and its conversion within the chimney, particularly considering inclination angles. Results demonstrated that the highest solar radiation occurred in June, while the lowest was observed in December. The angle at which the solar incident struck the chimney had a significant impact on the amount of solar energy captured at different times of day and in different seasons. During the summer, a 30-degree inclination angle maximized solar energy capture, whereas a 60-degree angle was best for the spring and fall. Interestingly, with a chimney angled vertically, wintertime energy conversion efficiency is at its maximum. The conversion of solar energy to thermal energy within the chimney was also impacted by the angle of inclination. A 60-degree inclination angle was found to be ideal for a 2 m^2 solar chimney arrangement in Erbil City. The amount of solar energy captured is greatly influenced by the angle at which sunlight strikes the chimney, which varies depending on the season and time of day. In the summer, a 30-degree tilt is ideal for capturing the most energy; in the spring and fall, a 60-degree slant works best. It's interesting to note that in the winter, a vertical chimney achieves the best energy conversion efficiency. The process by which solar energy is converted into thermal energy inside the chimney is also greatly influenced by this inclination angle. For example, a 60-degree angle was found to be the most efficient in a 2 m^2 solar chimney arrangement in Erbil City, producing a ventilation rate exceeding 3.75 air changes per hour (ACH) for a 27 m^3 space. The study finds that these design factors can greatly improve the ventilation effectiveness of solar chimneys.

1.Introduction

An integral aspect of building design is the incorporation of a ventilation system, which plays a significant role in enhancing thermal relaxation and maintaining good indoor air (ASHRAE, 2017).The increasing demand for energy-efficient and sustainable building designs has led to the exploration of innovative technologies for natural ventilation (Charvat et al., 2004). The rooftop solar chimney is one such technology that uses solar energy to drive the airflow, it operates on the principle of creating a density change in air to drive the movement of air and enhance ventilation within buildings (Shi et al., 2018).

Buildings in hot and arid climates, such as in Iraq, present significant challenges in maintaining thermal comfort while reducing energy consumption. Selecting the top roof of the building for installation of the solar ventilating system working based on solar chimney effect had significant contribution to energy saving in Erbil City in Iraq as it can work and cater to the good ventilating effect that satisfies the international standards and consequently this process has a great positive effect on the environment protection (Qasim et al., 2024, Charitar, 2015). Many types of research have been performed to determine the economic viability in case of using kitchen or space ventilation based on the solar chimney effect. The main aim of the researchers is to study the factors affecting the system to cater for the optimum operation of the natural circulation of the ventilator, and study the effect of geographical location on its operation (Zhang et al., 2021). This study will open the opportunity for Iraqi building designers to think about buildings and houses integrated with rooftop solar chimneys for ventilation purposes.

The researches were performed in different parts of the world, and their studies were in different parameters, such as area, and various types of materials, including phase change materials(Kassaei et al., 2022).

(Harris and Helwig, 2007) utilized the computer program ANSYS-Fluent to determine the effect of parameters such as tilt angle of the collector, the glazing of the collector and using single and double glazing in Edinburgh city in Scotland at the latitude of 52° North of the equator. The results show that the collector tilt angle of 67.5° gives better results than that collector in the vertical case, and the results improved by 11%. On the other hand, using the materials for the collector design with low emissivity increased the efficiency by 10%.

Sreejaya et al studied the solar chimney for space ventilation that has an area of 15 m^2 and a velocity of flow of 0.17 m/s at the solar noon time and they concluded that the solar intensity and area of the chimney are important factors in getting the optimum operation of the system (Sreejaya et al., 2011).

Amori and Mohammed studied the benefits of phase change materials (PCM) in solar chimney design for ventilation applications. They used the CFD program to determine the best operation of the system. They concluded that the PCM caters for the ability to operate the system even after the sun sets in periods more than in cases where no PCM materials are used (Amori and Mohammed, 2012).

Ahmad, Badshah and Chohan in Pakistan used CFD software ANSYS to study the flow between two plates to get the ventilation for the space to be ventilated. The two parallel plates were used, and the lower plate acts as the absorber, and the upper plate is a transparent material. The different parameters studied included the air gap between the plates, and the tilt angle of the collector has a great effect on the performance of the solar chimney operation (Ahmad et al., 2014).

Lal. Kaushic and Bhargava studied the solar chimney for the ventilation process in Kota, India. The solar chimney has with 9.76 m2 absorber area and a height of the chimney of 4.6 m. This system is used to ventilate a room with a ground area of 167.3 m2 and a roof height of 3.05 m and take the air change per hour as the main goal to obtain the optimum airflow through the system. They observed that the maximum rate of air change flow of 5.7 to 7.7 was obtained, and this value is suitable and convenient to cater for the required ventilation process in the summer season. The result emphasizes the benefit of solar chimney ventilating systems are suitable to be use in residential buildings (Lal et al., 2013). Zha, Zhang and Qin studied the solar chimney working under the effect of the Boussinesq phenomena in a true building located in eastern China. The collector had dimensions of 6.2 m in length, 2.8 m in width an air gap of 0.35 m. The results show that the volume flow rate was in the range of 70.6 m^3/h to 1887.6 m^3/h were obtained daytime period. The numerical simulation values were compared with those of the theoretical calculations, with the coefficient Cd= 0.51 taken into account. based on the results obtained, the outcome of the system could be effective in the transition seasons (from April to December), with an expected energy saving and a range of 14.5% in Shanga (Zha et al., 2017).

Ma'bdeh et al in Jordon studied the top roof solar chimney for space ventilation. They take into consideration many factors for the numerical simulation of the case and compare it with that of experimental work. They dedicated that using this system led to a reduction of CO2 production and better conditions related to temperature and humidity ratio inside the ventilated space, furthermore, they got an energy saving of 38.9% as compared with conventional split units (Ma'bdeh et al., 2020).

(Mahdi and Mawlood, 2020) studied the implementation of building information modelling has been a crucial aspect in recent years to apply the suitable new design approaches to add rooftop solar chimneys in buildings.

Agonafer in Bahir Dar city, Ethiopia, applied mathematical and CFD models to study the benefit of top-roof solar chimneys for ventilation purposes. They created a thermal model using MATLAB to determine the optimal factors such as the tilt angle of the chimney collector, the dimensions of the collector and the air gap between the collector's upper and lower plates. The collector placed with 45^o inclined from the horizontal and facing south. The results showed that the system can push 560 kg/hr. of air with a temperature of 44.5 ^oC (Agonafer, 2020).

Optimization of the ratio between height and base length in a trapezoidal prism-shaped solar chimney for the best performance of the solar chimney is investigated to give more flexibility to the architectural design in buildings. Two correlations are proposed based on experimental work of three different ratios of height to base length. The correlations used to predict solar chimney exit air velocity and efficiency. Results show that the flow rate increases by increasing (h/l) in a logarithmic manner. The optimum thermal efficiency is given where h/l = 1.65. Using the RETScreen4 software, the design configuration was simulated, and the results indicated that a 1 m² solar chimney can provide ventilation coverage for an area of 37 m². In the context of a 120 m² house, implementing a solar chimney system leads to annual savings equivalent to 23.9 litres of gasoline (Belhadj et al., 2020).

(Mohammed, 2024) studied the evaluation of the safety management system of the building construction projects, adding of the rooftop solar chimneys should be a suitable case to protect the residents in the buildings from exhaust gases inside the building.

(Othman and Aula, 2023) studied the effect of the dual axis tracking system for solar collectors and they emphasize that the dual tracking will lead to higher flow rate and temperature from the collector.

A study by Qasim et. al explored the use of solar chimneys with phase change materials (PCM) to improve natural ventilation using solar energy in Basrah theoretically and experimentally on September 30, 2023. The research tested different chimney tilt angles, air gap widths, and PCM thicknesses. Results showed that the best ventilation performance occurred with a 30° tilt angle, 15 cm air gap (Qasim et al., 2024).

This research article aims to investigate the factors that affect the performance of rooftop solar chimneys for ventilation as shown in Figure 1. Through a comprehensive review of existing literature, this study identifies and analyzes key parameters, including chimney collectors’ slope and solar radiation intensity, which significantly influence the effectiveness of rooftop solar chimneys under Erbil city local weather. The results of this study help to consider all factors in designing and optimizing rooftop solar chimneys for building ventilation purposes in the region.

2.METHODOLOGY

This study develops a mathematical model for the rooftop ventilation system, then examines the system's output with parameters, a mathematical model solution by MATLAB Coding based on a flowchart as shown in Figure 2. The simulation takes part by representing the system with a set of equations, such as heat transfer mechanisms, airflow patterns, and temperature distributions throughout the system. The meteorological data were taken from the NASA database (NASA, 2023). The geographical location and systems dimension data used for the simulation are presented in Table 1.

In addition, the study tends to study significant parameters that determine the optimum operation ventilation output with the rooftop chimney system to obtain the required air changes per hour based on international standards. MATLAB program coding has been used with the specified mathematical model of the system to ensure the optimum condition for the system operation and to get the required mass flow through the system. Figure 2 demonstrates the step-by-step operation of the coding to find the best results of the system operation.

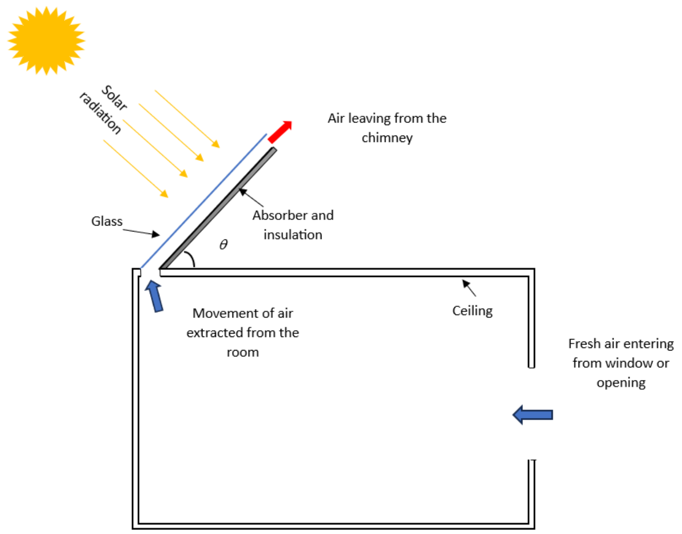


Figure 1. Roof Top Solar Chimney

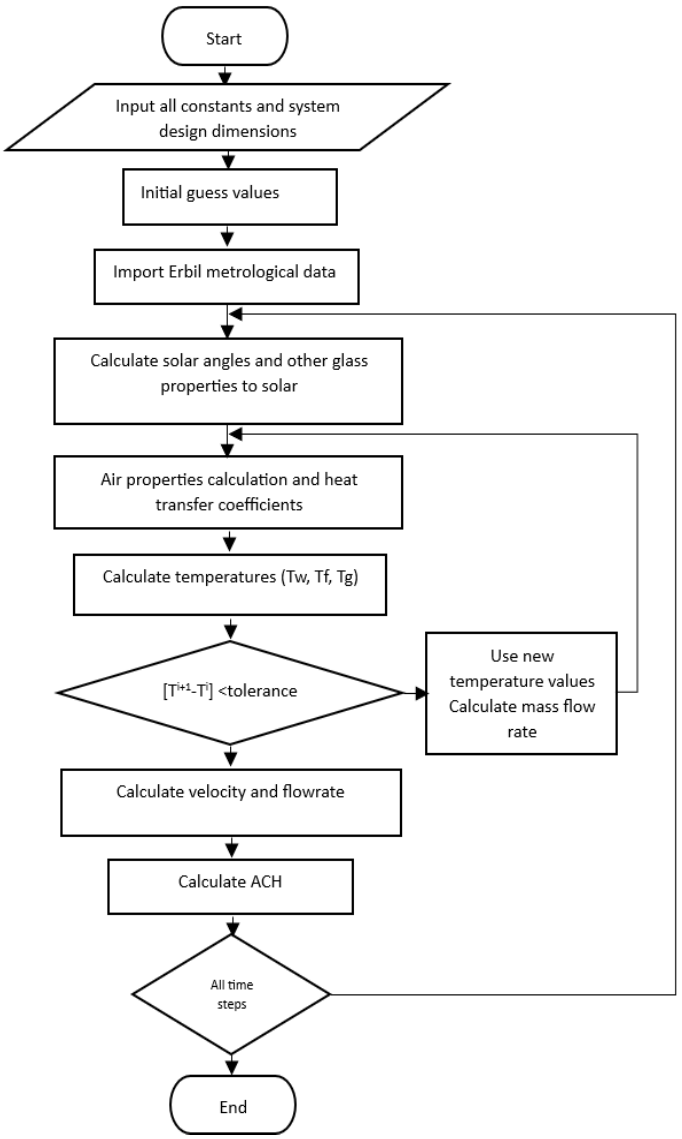


Figure 2. Simulation Algorithm flowchart

Table 1: Data and dimensions used in the simulation.

No.	Description	Dimensions and units
1	The geographical location of Erbil City	longitude =44.0193 latitude =36.1 degree
2	solar chimney dimensions.	Air gap (d)=0.25 m Width (w)=1 m and Length (Labs) =2 m
3	Room dimensions	Length=3 m , Width =3 m and Height=3m
4	Glass dimensions	Length = 2m , Width =1 m
5	Absorber plate (thickness)	0.5 mm
6	Insulation thickness and thermal conductivity	2 cm, 0.029 w/m K
7	Solar chimney orientation due to south (γ)	$\gamma = 0$

3. Mathematical model

A mathematical model is used to optimize the system's performance. The model consists of a set of algebraic equations to determine and describe the thermal characteristics of the chimney system. The iteration method was the most effective method to achieve the convergence of the solution and enable the researcher to get the required outcomes from the simulation process.

The quantity of heat transferred to the system is directly proportional to the solar intensity and area of the solar collector. Providing the chimney to the collector has a great effect on better operation of the system and getting the required ventilation that is within the standards relating to the residual building ventilation requirements (Charitar, 2015).

The system's performance is evaluated based on the following assumptions:

1-Ideal gas flow: The behaviour of the gas inside the system is assumed to follow ideal gas laws.

2- Steady State flow: the flow parameters through the system are considered to be constant with time.

3- One-dimensional flow: the flow is considered in one of the Cartesian directions, such as the x-direction, y or z-direction.

4- The temperature of the entry air is considered to be equal to the temperature of the room under test and, in return, equal to ambient temperature. $T_{f,i} = T_r = T_a$.

The assumptions made for the mathematical model simplify the model solution, in addition to understanding the operation mechanism of the model, which also leads to effective analysis and estimation of the system's performance.

The output performance of the system (rooftop solar ventilation) highly depends on the energy solar energy conversion, the energy conversion is transferred through a heat transfer mechanism inside the system elements, including covering glass, absorption plate, and insulation in facilitating heat transfer.

Energy and mass conservation equations are used to assess the interactions of thermal energy and mass throughout the system. Energy transfer equations such as conduction, convection, and radiation, occurring within the system are taken into model consideration.

The heat flow from and to the glass cover can be modelled in equation (3.1), The flows of heat to the glass cover are heat from solar radiation and radiative heat from the absorber wall while heat flows from glass include the heat loss to the surroundings and the convective heat loss to the air inside the channel of the solar chimney (Charitar, 2015).

$$S1 * Ag + hrwg * Aw * (Tw - Tg) = hg * Ag * (Tg - Tf) + Ut * Ag * (Tg - Ta) \qquad (3.1)$$

The heat flow to the collector absorber wall is solar radiation from the glass cover. On the other hand, the heat flow from the absorber wall comprises convective heat to the airflow, radiative heat to the glass cover and conductive heat to the room (Charitar, 2015).

$$S2 * Aw = hw * Aw * (Tw - Tf) + hrwg * Aw * (Tw - Tg) + Ub * Aw(Tw - Tr) \qquad (3.2)$$

the heat absorbed (q) by the airflow inside the solar chimney, as depicted in Figure 3, is the addition of the convective heat from the upper transparent cover and the convective heat from the absorber wall (Khidhir and Atrooshi, 2020).

$$q = hw * A_w * (T_w - T_f) + hg * Ag * (T_g - T_f) \qquad (3.3)$$

The total heat transmission to the airflow is given as:

$$q = m * C_{f1} * (T_{f,o} - T_{f,i}) \qquad (3.4)$$

The temperature inside the system needs to be corrected and the equation below should be used to perform this action related to experimental considerations (Hirunlabh et al., 2001).

$$T_f = 0.75 * T_{f,o} + 0.25 * T_{f,i} \qquad (3.5)$$

And assumed that $T_{fi}=T_r$

After rearranging equations:

$$h_g * A_g * (T_g - T_f) - [h_g * A_g + h_w * A_w + \frac{mcf1}{0.75}] Tf + h_w * A_w * T_w = -(\frac{mcf1}{0.75}) Tr \qquad (3.6)$$

the empirical formula reported by Mathur should be used to determine the circulating mass flow ($\dot{m}$) through the system (Mathur et al., 2006):

$$\dot{m} = Cd * \rho_{f1} * A_{out}\sqrt{\frac{2\,g\,L\sin\beta(Tf - Tr)}{(1+{A_r}^2)T_r}} \qquad (3.7)$$

Where:

$$A_r = \frac{A_{out}}{A_{in}} \qquad (3.8)$$

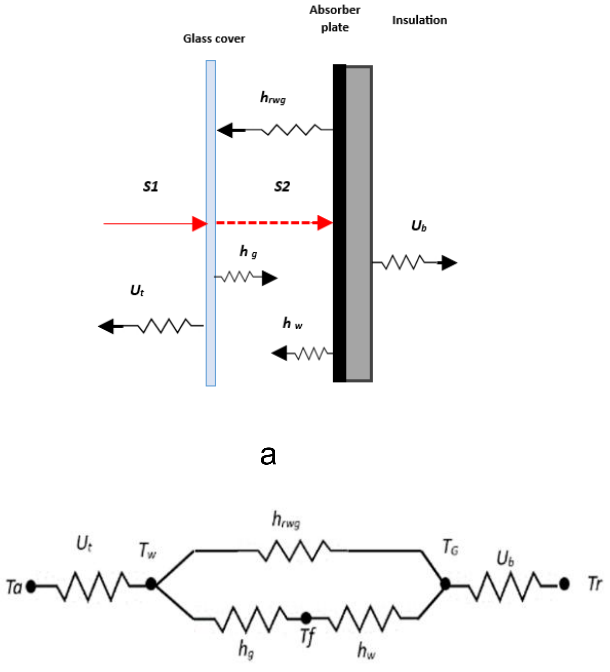
the volumetric circulating air flow rate is given by

$$\dot{V} = \frac{\dot{m}}{\rho} \qquad (3.9)$$

The number of air changes per hour is determined using the equation below (Mathur et al., 2006):

$$ACH = \frac{\dot{V} * 3600}{V_R} \qquad (3.10)$$

Where V_R is the ventilated room volume.



a

b

Figure 3. (a) components and thermal system of roof solar chimney (b) Thermal resistance diagram

3.1 Earth – Sun angles

These Earth-Sun angles are essential for determining solar insolation (the quantity of solar intensity received at a specified location and certain area), The angles are explained below:

the hour angle (ω) is defined as the sun's position over the head at specific time and it is zero at the solar noon and changes by 15 degrees per hour (Duffie and Beckman, 2013).

$$\omega = 15(ST - 12) \qquad (3.11)$$

Where ST is Solar time and expressed in the following equation;

$$ST = Standard\ time + E_{\ time} + 4(L_{st} - L_{lo}) \qquad (3.12)$$

Where: L_{ST} is standard time meridian longitude

L_{lo} local longitude.

E_{time} indicates the Equation of time and is given in most textbooks as (Duffie and Beckman, 2013)

$$E_{time} = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B \qquad (3.13)$$

The declination angle of the Earth (δ) is the angle between the equatorial plane and the orbital plane of the can be calculated as follows (Goswami, 2015):

$$\delta = 23.45 \sin(360\ \frac{284+n}{365}) \qquad (3.14)$$

Where n = has a range 1 ≤ n ≥ 365 and changes during the days of the year.

Solar zenith angle (θ_z) is the angular displacement from south to the projection of beam radiation on the horizontal plane

$$\cos \theta z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega \qquad (3.15)$$

The angle of incidence (θ) is the angle between the beam radiation on a surface and the normal to that surface (Duffie and Beckman, 2013).

$$\cos \theta = \cos \theta_z \cos \beta + \sin \theta_z \sin \beta \cos(\gamma_z - \gamma) \qquad (3.16)$$

The solar intensity outside of the atmosphere in space, where there is no air, Io, is defined as the amount of solar energy on the horizontal surface in space can be determined in the following equation (Duffie and Beckman, 2013):

$$I_o = I_{sc}(1 + 0.033 \cos(\frac{360\ n}{365.25})) \qquad (3.17)$$

Where: I_{SC} is Solar Constant 1362 Wm^{-2}

(R_b) is defined as a monthly average daily ratio of beam insolation on a tilted surface to that on a horizontal surface, is given as (Duffie and Beckman, 2013):

$$R_b = \frac{I_{b,t}}{I_b} = \frac{\cos \theta}{\cos \theta_z} \qquad (3.18)$$

($I_{b,}$) can be found by multiplying the beam radiation component on a horizontal surface with the geometric factor.

$$Ib, = Ib * Rb \qquad (3.19)$$

The equation, known as the reflectance-absorptance-transmittance equation, expresses the relationship between the reflectance (ρ), absorptance (α), and transmittance (τ) of radiation incident on a surface. The equation is as follows (Goswami, 2015):

$$\rho + \alpha + \tau = 1 \qquad (3.20)$$

The researchers determined the quantity of solar intensity that was absorbed by the upper transparent cover (referred to as *S1*) and the lower collector absorbing wall (referred to as *S2*) using the procedure below (Mathur et al., 2006):

$$S1 = \alpha * I_t \qquad (3.21)$$

$$S2 = \alpha_{wall} * \tau * I_t \qquad (3.22)$$

3.2 heat transfer by convection correlations

The calculation of convection heat transfer depends on many dimensionless equations (Hirunlabh et al., 1999):

Prandtl number

$$P_r = \frac{\mu_f * C_f}{k_f} \qquad (3.23)$$

Grashoff number

$$G_r = \frac{g\beta\Delta T L^3{}_{stack}}{\upsilon_f^2} \qquad (3.24)$$

$$\beta = \frac{1}{Tm} \qquad (3.25)$$

Rayleigh *number*

$$Ra = Gr * Pr \qquad (3.26)$$

Chimney elevation

$$L_{stack} = L \ \sin\theta \qquad (3.27)$$

For Ra<10^9

Nusselt number

$$Nuf = \frac{h*L}{k} = 0.68 + \frac{0.67*Ra^{0.25}}{\left[1+\left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right]^{4/9}} \qquad (3.28)$$

For 10^{-1}<Ra<10^{12}

$$Nuf = \left[0.825 + \frac{0.387*Ra^{\frac{1}{6}}}{\left[1+\left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right]^2 \qquad (3.29)$$

$$h_{rwg} = \frac{[\sigma(Tg^2+Tw^2)(Tg+Tw)]}{(\frac{1}{\varepsilon g}+\frac{1}{\varepsilon w}-1)} \qquad (3.30)$$

Heat transfer by Convection from transparent upper surface due to wind velocity (V_w) (Charitar, 2015) :

for $V_w \le 5$ m/s

$$h_{wind} = 5.7 + 3.8\, V_w \qquad (3.31)$$

for V_w >5 m/s

$$h_{wind} = 6.15\, V_w{}^{0.8} \qquad (3.32)$$

3.3 Instantaneous efficiency:

The calculation involves determining the immediate efficiency of heat collection through a solar chimney (Agonafer, 2020).

$$\eta = \frac{mC_{f(}T_{f,o}-T_{f,i)}}{I_t \ Aw} * 100 \qquad (3.33)$$

4. Model validation:

Validation of the numerical code used in this study, calculations was conducted for a solar chimney (SC) using the same conditions as the experimental research carried out by (Mathur et al., 2006) and the numerical research conducted by (Haghighi and Maerefat, 2014) and (Charitar, 2015). The aim was to confirm the accuracy of the developed mathematical structural processing and the computations. The obtained simulation results, shown in Figure 4, were compared with the numerical results from Haghighi and Maerefat, 2014 for air temperature in the system under various solar radiation conditions. Also, Figure 5 shows the comparison of air velocity magnitude and percentage discrepancy to experimental work for previous works. The quantitative analysis indicates that the simulation results of the present study are near and in the same trend as those of Mathur et al., 2006 and Charitar, 2015, with a minor discrepancy between the two. This difference may be returned to the presentation of the current model's results alongside the experimental results of Mathur et al., 2006 and the simulation results of Haghighi and Maerefat, 2014 and Charitar, 2015 for different combinations of solar radiation, solar chimney height, and chimney inlet dimensions. The quantified similarity demonstrates that the results of the present study are moving closer to the experimental results compared to the simulation results of previous numerical studies, yielding errors of less than 8% at the compared velocity value points.

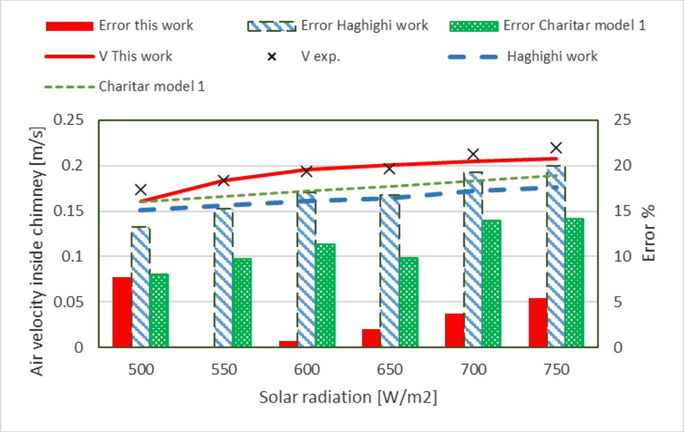


Figure 4. Air velocity inside the chimney and solar radiation for this work and other works.

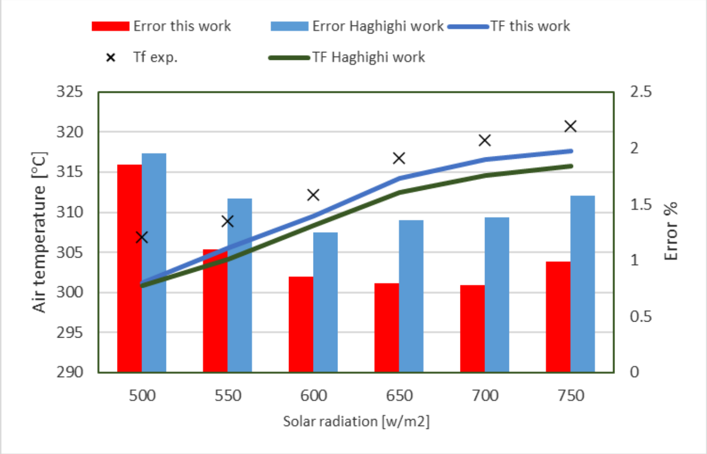


Figure 5. Air temperature leaving the chimney and solar radiation for this work and other works

5. Results and Discussions

The solar chimney utilizes solar energy to create a buoyancy force that drives air flow through a chimney channel, effectively ventilating the building. The constriction parameters of the rooftop ventilating system using solar chimneys significantly impact its ventilation attainment.

Understanding factors and their influence on the conversion of solar energy into useful energy for building ventilation enables the improvement of more adequate and dependable solar chimney systems. Further research and experimentation can lead to improved designs and strategies for maximizing energy conversion and optimizing building ventilation.

Solar thermal systems are highly dependent on the magnitude of solar energy received at a specific location and conversion efficiency. The solar energy received directly affects the amount of heat that can be harvested or utilized for ventilation purposes. Figure 6 depicts the monthly average solar insolation on horizontal surfaces for Erbil City in the year 2021. The figure demonstrates that the highest level of solar radiation, known as insolation, occurs in June. Conversely, the lowest value is observed in December. This disparity can be attributed to two factors: the minimum day length during that period and the increased cloudiness of the weather. Both these factors contribute to a reduction in the magnitude of solar intensity embracing the surface during December, resulting in the recorded minimum value.

The angle of incidence is connected to the angles between the sun and the Earth and determines the quantity of energy that falls on a tilted surface at any given location on Earth.

By considering the solar earth angles and their relationship to the angle of incidence, designers can optimize the orientation and tilt of sloped surfaces (such as solar chimneys) to maximize the capture of solar energy throughout the day and across different seasons. This is crucial for efficient solar energy utilization and the design of solar-powered systems.

Figure 7 illustrates the relationship between the inclination angle of a chimney and the daily average solar energy it receives throughout the year. The figure shows that the tilt angle of the collector has a significant effect on the solar intensity of the solar chimney collector. In the winter season, the day length is short, the energy obtained in this season remains almost constant, which leads to the insignificance of the tilt angle on the solar collector due to the reduced daytime hours. On the other hand, in the summer season, the tilt angle has a great effect on energy gain by the solar collector and the maximum energy earned in this season when the tilt angle is 30°. The 30-degree tilt angle in hot months is the most efficient for gaining solar intensity in the summer season, as the solar intensity is at its optimum point.

Additionally, the figure reveals that the minimum energy is received at an inclination angle of 90 degrees, which corresponds to a vertical orientation. This minimum energy occurs during the long days of the year when solar energy availability is relatively high. This suggests that a vertically oriented chimney receives the least amount of solar energy under these conditions.

Figure 8 represents the daily average transformation of solar energy to thermal energy in the air inside the chimney for three disparate angles of the chimney's inclination. The conversion is influenced by factors such as the mass circulation of air and the temperature disparate between the heated air and the outside temperature and they change with the chimney inclination angle.The bar chart in Figure 8 demonstrates that the maximum transformation of solar energy to thermal energy occurs during the spring and fall seasons when the tilt angle is set to 60 degrees. This suggests that a 60-degree angle provides optimal conditions due to the active conversion of solar power to heat during these seasons. On the other hand, the least conversion takes place when the angle of inclination is 90 degrees, particularly during the summer seasons. This implies that a vertical chimney orientation (90-degree inclination) is less effective in converting solar energy to thermal energy, resulting in lower overall efficiency during the summer months.

The solar energy transfer in the system is defined as the ratio between the energy absorbed by working fluid to the available solar energy at the chimney surface. Figure 9 represents the monthly average energy conversion efficiency of the chimney for different tilting angles. The figure reveals the highest energy conversion is in winter with a 90-degree chimney angle, resulting in vertical solar collectors ideal for winter seasons. While in summer, a 60-degree angle is best for efficiently converting solar energy into thermal energy.The solar energy received by the solar chimney system, the heat generated inside the system used to induce air movement inside the building for ventilation. Amount of the air ventilated inside the building is measured by air changes per hour. The rate of air changes per hour over the year for different chimney tilt angles is shown in Figure 10. According to the figure highest value of ACH typically occurs in the spring and summer at the chimney's inclination angle of 60 degrees, which means the chimney's inclination of 60- degrees works well for creating airflow and obtaining a high number of air changes (ACH), Moreover, the chart depicts the lowest ACH values are related to a 30-degree inclination angle during winter seasons. This suggests that a 30-degree angle results in a smaller amount of air changes during shorter daylight hours.Furthermore, the bar chart demonstrates that the chimney's inclination of 90 degrees makes minimum ACH ventilation during long daylight hours; this is due to a reduction in solar energy incident on the chimney plane at vertical orientation during periods of extended daylight hours.The optimization of the chimney's slope for producing the maximum amount of ventilation throughout the year is measured by ACH. Figure 11 shows the daily average Air Changes per Hour (ACH) for five chimney slopes. The figure confirms that 60 degrees is the optimal angle for Erbil City. At this angle, the solar chimney produces over 3.75 ACH per day, which shows effective ventilation and air exchange within the building.

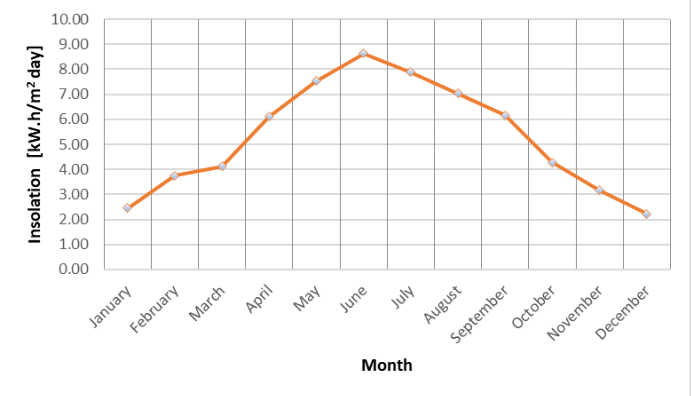


Figure 6. The monthly average solar insolation on horizontal surfaces for Erbil City in the year 2021.

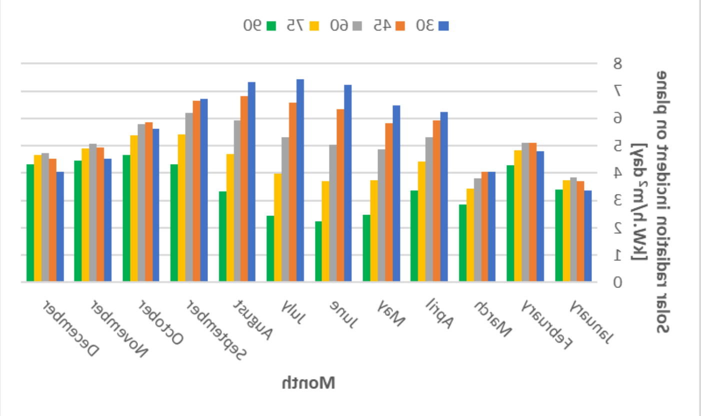


Figure 7. Average monthly hourly incident insolation on inclined and vertical surfaces (It) at Erbil City

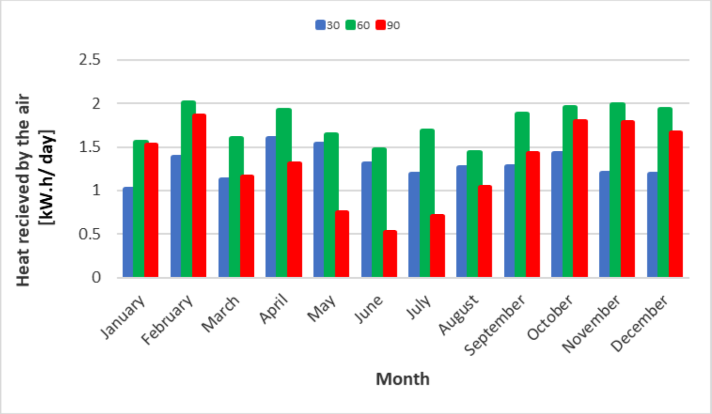


Figure 8. Heat gain by the air inside the collector of the solar chimney

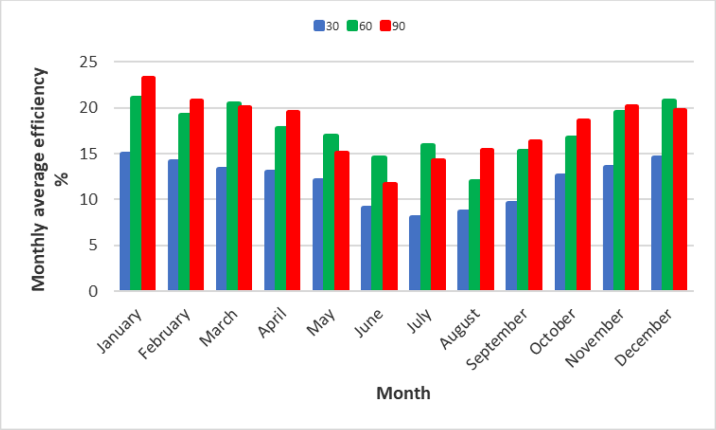


Figure 9. Monthly average efficiency of the system

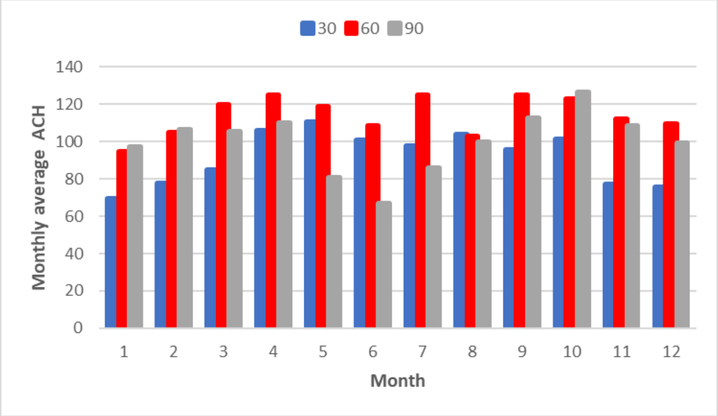


Figure 10. Reaction of tilt angle on mean monthly hourly for tilted and vertical chimney plane for Erbil city.

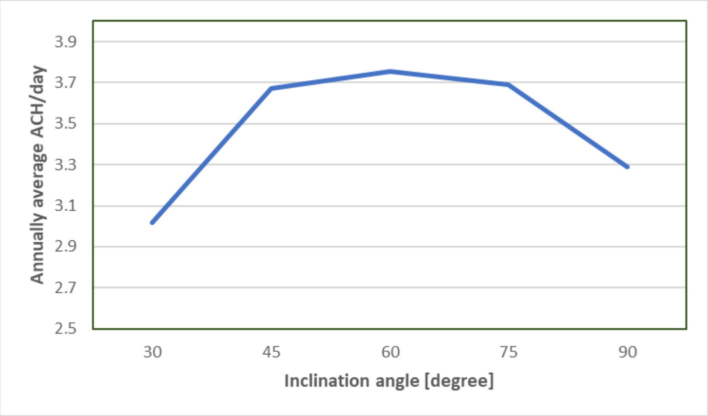


Figure 11. The reaction of tilt angle on the mean annual ACH in for tilted and vertical solar chimneys in Erbil City.

6. Conclusions and Recommendations

6.1 Conclusions

In conclusion, a mathematical model is employed for evaluating the reliability of using solar chimneys for ventilation purposes. The system uses renewable energy and can be a solution for building ventilation. Simulations were conducted using MATLAB code with an algorithm. The simulation is carried out based on 2021 data from Erbil City, and the results show that the relationship between solar intensity and the chimney tilt angle is a key parameter. Solar intensity peaks in June and drops in December due to shorter daylight hours and increased cloudiness. The chimney tilt angle selection has a significant effect on optimizing solar energy capture during different seasons.

It found that maximum solar energy capture by the chimney surface during the summer is at a 30-degree inclination angle, while vertical orientation (90-degree inclination) is the least effective. Converting solar energy to thermal energy inside the chimney is influenced by the angle of inclination; setting with a 60-degree angle provides optimal conditions during the spring and fall seasons. Winter achieves the highest energy conversion efficiency with a vertically oriented chimney, while a 60-degree inclination angle is most efficient during summer.

Furthermore, the research indicates that a 60-degree inclination angle results in the highest ventilation rate during spring and summer, contributing to improved ventilation. However, a

30-degree angle shows reduced ACH during periods of short daylight. The study identifies the best tilt angle for the solar chimney configuration in Erbil City as 60 degrees, leading to a ventilation rate of over 3.75 ACH per day. This optimized configuration facilitates effective air circulation and exchange within the building, ultimately enhancing overall ventilation performance.

6.2 Recommendations for Future Works

To enhance the implementation of solar chimneys in building ventilation systems, forthcoming research should take the focal point on optimizing the shape of the model and reducing costs. Investigating various chimney shapes is essential to determine the most efficient design for airflow and thermal performance. Additionally, it is crucial to assess the economic viability of these optimized chimney shapes in various building types, including an evaluation of payback periods and return on investment. By addressing these areas, future studies can contribute to the advancement of more efficient and cost-effective solar chimney systems.

Abbreviations and symbols

ACH	Air Changes per Hour
Ag	Area of glass m^2
A_{out}	outlet of air flow air flow channel
A_r	The ratio of cross-sectional area of inlet to outlet of air flow air flow channel
Aw	Area of absorber wall m^2
Cd	Coefficient of discharge of air channel inlet Dimensionless is 0.57
cf1	Specific heat capacity of air $J\ kg^{-1}K^{-1}$
d	Air gap (between glass cover and absorber wall) m
Fw-g	View factor between absorber wall and glass cover Dimensionless
g	Gravitational acceleration ms^{-2}
hc	Conductive heat transfer coefficient for glass $Wm^{-2}\ K^{-1}$
hg	Convective heat transfer coefficient between glass cover and air $Wm^{-2}\ K^{-1}$
hrs	Radiative heat transfer coefficient from the top of glass cover to the sky $Wm^{-2}\ K^{-1}$
hrwg	Radiative heat transfer between absorber wall and glass cover $Wm^{-2}\ K^{-1}$
hw	Convective heat transfer coefficient between absorber wall and air
$I_{b,t}$	Beam radiation on a tilted plane
I_{bt}	Beam radiation on a horizontal plane
ISC	Solar Constant Wm^{-2}
k_f	Air thermal conductivity $Wm^{-2}\ K^{-1}$
L	Solar chimney height
Q	Heat transfer to air stream Wm^{-2}
Rb	Ratio of beam radiation on tilted surface to that on horizontal surface Dimensionless
S1	Solar radiation absorbed by glass cover Wm^{-2}
S2	Solar radiation absorbed by absorber wall Wm^{-2}
Ta	Temperature of ambient air K
Tf	Mean temperature of air in flow channel of chimney K
Tf,i	Temperature of air at inlet of chimney K
Tf,o	Temperature of air at outlet of chimney K
Tg	Mean temperature of glass cover K
T_m	Air mean temperature K
Tr	Room temperature (inside building) K
Tw	Mean temperature of absorber wall K
Ub	Overall heat transfer coefficient between absorber and room $Wm^{-2}K^{-1}$
Ut	Overall heat transfer coefficient from top of glass cover $Wm^{-2}K^{-1}$
V_R	Volume of room to be ventilated m3
V_w	Wind speed ms^{-1}
α	Absorptance of glass cover Dimensionless
$\alpha wall$	Absorptivity of absorber wall Dimensionless
γ	Surface azimuth angle °
γ_z	Collector angle due to the South °
δ	Declination angle °
η	Efficiency Dimensionless
μf	Dynamic viscosity of air Pa.s
vf	Kinematic viscosity of air m^2s^{-1}
τ	Transmittance of glass cover Dimensionless
θ	Angle of inclination of solar chimney with the horizontal °
θz	Solar Zenith °
ρ	Reflectance of glass cover Dimensionless
$\rho f1$	Density of air kg/m^3
σ	Stefan-Boltzmann constant $Wm^{-2}K^{-4}$

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Conflict of Interest

We confirm that we have no conflicts of interest to disclose related to the publication of this work.

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