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Evaluation of Air Thermodynamic Performance Indicator of Different Designs of Solar Vortex Chimney

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ABSTRACT

This research focused on integrating two modern updraft system technologies, namely solar vortex technology and solar chimney technology, in order to test a simulation system for three proposed models and compare their speed and thermal energy performance, using the ANSYS 2022 R1 program. At the same time, the proposal of these three models is regarded as a system development, with previous research serving as a foundation. Choosing the optimal angle for the guide blades and the number of blades. Three speeds were tested using the ANSYS 2022 R1 program (0.6, 0.9, 1.2) m/s. Simulations of the three proposed models were compared, and it was discovered that the shape of the air vortex in the first model, which consists of a vortex motor and a perforated glass casing, is more regular than in the second and third models, The results showed that the speeds and resulting energy for the suggested models were close, but the initial model had the highest speed (2.418) m/s and energy (2.340 J), When selecting the entry speed (0.9) m/s followed by the second and third models, respectively.

1. Introduction

Renewable energy [1] is energy that cannot be depleted while in use [2]. Energy is the primary driver of any country's development. The availability of energy raises the standard of living. Access to energy is essential for the long-term survival and well-being of individuals and societies [3]. Furthermore, renewable energy is both environmentally friendly and durable [4,5]. Conserving energy is an essential way to safeguard the environment. Many studies have been carried out to reach the goal of reducing energy use [6] There are numerous renewable energy sources such as solar, biomass, wind, hydropower, and ocean energy [7,8]. Renewable energy applications are very important around the world today in order to reduce the consumption of traditional fossil fuels [9]. However, among renewables, solar is the most appropriate resource [10] solar energy is the most sustainable and cost-effective renewable energy source. Solar power is increasingly popular due to its safety and accessibility [11,12]. Due to its numerous advantages, including abundant resources, cleanliness, safety, and economic efficiency [13]. Many technologies use solar energy to generate

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electricity. Solar energy can be converted directly using photovoltaic cells or indirectly via solar thermal systems. Solar modules affect the temperature of PV panels and ensure compliance with standard specifications [14-16]. In order to lower the solar cell's temperature and prevent the PV panels from overheating [17,18] However, installing the panels in hot areas and overexposing them to increased solar radiation over extended periods of time raises the working temperature of the PV panel, which lowers its performance [19,20]. increasing the solar panel's efficiency by highlighting and addressing the impact of environmental factors [21]. Solar thermal systems fall into two categories: concentrated solar power systems and updraft solar power systems. However, concentrated solar systems have Updraft systems that have higher energy conversion efficiencies, are easier to use, and operate at significantly lower temperatures. Unlike concentrating systems, these systems can use both direct and diffuse solar radiation [22]. The solar updraft tower (SUT) technique, is a low-temperature solar thermal system that generates electricity using both the buoyancy effect of hot air generated inside a greenhouse by solar radiation and the chimney effect while emitting no greenhouse gases or hazardous waste [23,24]. The greenhouse effect heats the air below the glass collector. The hot air, which is less dense than the surrounding air, rises. The chimney in the collector's center. The rising air powers an electricity-generating turbine at the bottom of the chimney [25][26]. Solar chimneys have been extensively used and proven to be an effective solution in a variety of fields, including building physics and civil engineering [27]. The ability of a solar chimney to produce flow and raise temperature through the chimney [28]. By creating a hybrid system, the authors attempt to address the issue of uneven power generation using renewable energy [29]. Prior research has demonstrated that one of the most crucial elements influencing the efficiency of solar chimneys is the size of the opening [30]. In 1982, it became known as the Spanish model for calculating energy production. This model has a collector radius tower chimney (122 meters) and length (194.6 meters), a single turbine system, and a collector diameter (5.08 meters) with four rotating blades [31]. According to studies conducted by Omar *et al.*, [32], Hassan, *et al.*, [33], and Siamak *et al.*, [34] most studies also show that solar chimney technology influences energy production along the length of the chimney, so its efficiency is limited by the length of the chimney. Michaud [35] proposed another approach to generating solar updraft power. This technology is similar to the SCPP but uses an air vortex column instead of a chimney. This concept lowers plant costs and increases power output without relying on chimney height. However, the technology remains It is still in its initial stages, with only a few studies on its development available [36]. There are two ways to generate a vortex updraft flow: (i) by creating an updraft tower with a unique design that creates a vertical pressure gradient along the axis of a vortex. Because of the tall tower, these systems are expensive to install, or (ii) using an external heat source to cause a large temperature rise in ambient air and boost buoyant forces [37]. The solar vortex engine (SVE) consists of a solar air collector (SAC) and a vortex generation engine (VGE). Solar vortex generation (SVG) is a technique that has piqued the curiosity of renewable energy researchers. The SVE utilizes solar energy to heat the airflow in the SAC, which is then spun by the VGE to generate a vortex [38]. Michaud [39] proposed an atmospheric vortex engine to generate solar power. Multiple inlets around the perimeter allow for the installation of horizontal-axis wind turbines. The researcher provided Ali A. Ismaeel [40]. The proposed SVPG contains a numerical simulation of a swirl air generator. The swirl air generator configuration was modeled and simulated using eight air inflows, each with an open slot for airflow and a guide vane. In a study by Hussain H. Al-Kayiem *et al.*, [41], a modern design model of (SVE) was presented. The model involved transporting air from the collector to the apron of the vortex-generating engine through eight air entry holes equipped with guide vanes that rotate the air stream. As the researcher presented Hussein A. Jaffar *et al.*, [42] propose a new system model that solves the challenges encountered in the Hybrid Solar Chimney PV system by combining a Solar

Vortex Engine and an Updraft system the optimal angle for the guiding blades was tested and determined to be (20). This design was based on the optimal number of guide blades (8). Ali M. Tukkee *et al*., [43] This study simulates the entire SVE system with CFD to determine the best location for the turbine unit and to demonstrate the vortex generator's ability to replace the chimney. However, this technology is still in its early stages, with little research into its development.

2. Description of the Models

This technology is still in its early stages, with little research into its development. The research aims to complete the ideas presented on employing or producing updrafts in the solar vortex system. In the ANSYS 2022 R1 program, three new and improved models were proposed that combine solar vortex engine technology (SVE) and solar chimney technology in one structure, known as the solar vortex chimney (SVC), in order to increase and improve the updraft system and thus produce more energy. These proposed designs address many of the issues raised by previous designs, including the length of the chimney, which affects the efficiency of solar chimney technology. It also addressed the issue of area collectors for the solar energy complex. The most important aspect of the proposed models is the integration of the chimney and the solar vortex engine (SVE). Three velocities (0.6, 0.9, 1.2) m/s were also tested in the ANSYS 2022 R1 program within the proposed models, and the outside air velocity is assumed to be (0.9) m/s. The angle of 20° was chosen for the vortex structure based on previous studies and research by Ali A. Ismaeel *et al*., [44], Hussein A. Jaffar *et al*., [45], as well as the number of guide vanes which is (8). The first model consists of a solar vortex engine (SVE) with eight guide vanes at an angle of 20°. In addition, a perforated glass cover along the guide vanes serves as the model's heating surface, with the holes used to enter the ambient air. This design improves the updraft process (six circular holes on each side of the model). The model also includes two intake tubes at the bottom and top of the model (the bottom for air entry and the top for air exit) with a diameter (of 0.2) meters and length (of 0.25) meters, as shown in Figure (1).

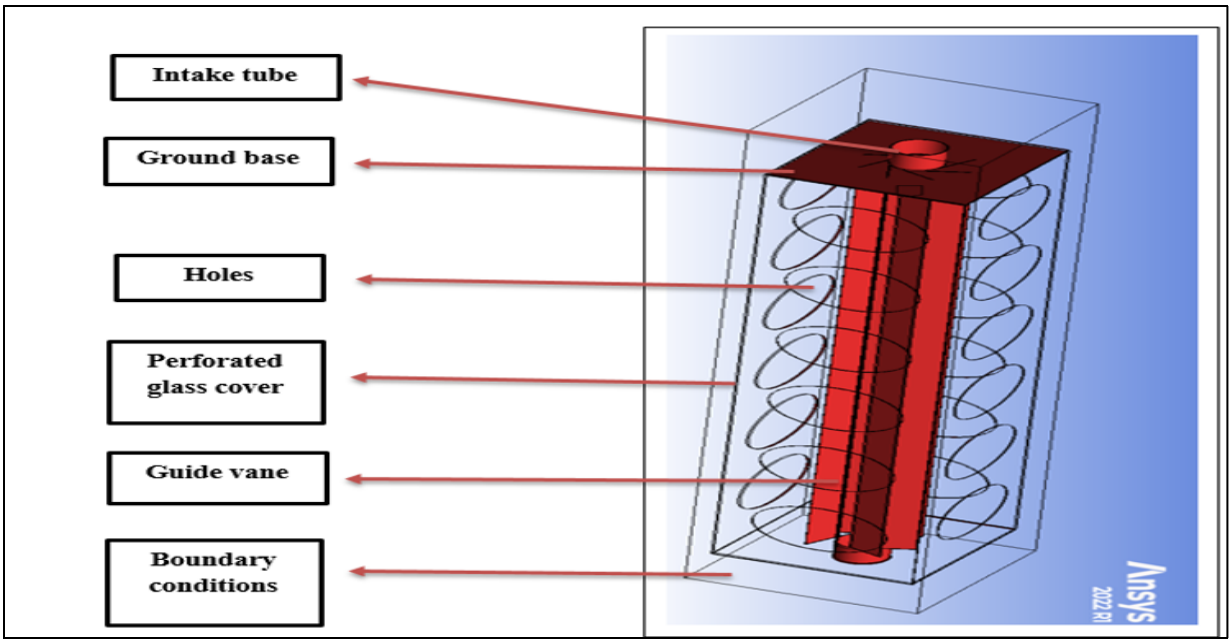


Fig. 1. Description of the first model

Based on previous studies and research, the second model also includes a solar vortex engine with eight guide vanes at a 20° angle, as well as a perforated glass cover along the guide vanes. The proposed model now includes a metal cover perforated with longitudinal holes, as shown in Figure (2). It is also considered a heating source for the model, with two intake tubes at the bottom and top, as shown in Figure (3). The proposed third model now includes longitudinal holes in the metal casing to increase the entry of ambient air into the proposed model, as shown in Figure (4). In this research, the velocities and resulting kinetic energy are used to compare the three models. To determine which design improves the updraft process the most, resulting in the highest energy
Production.

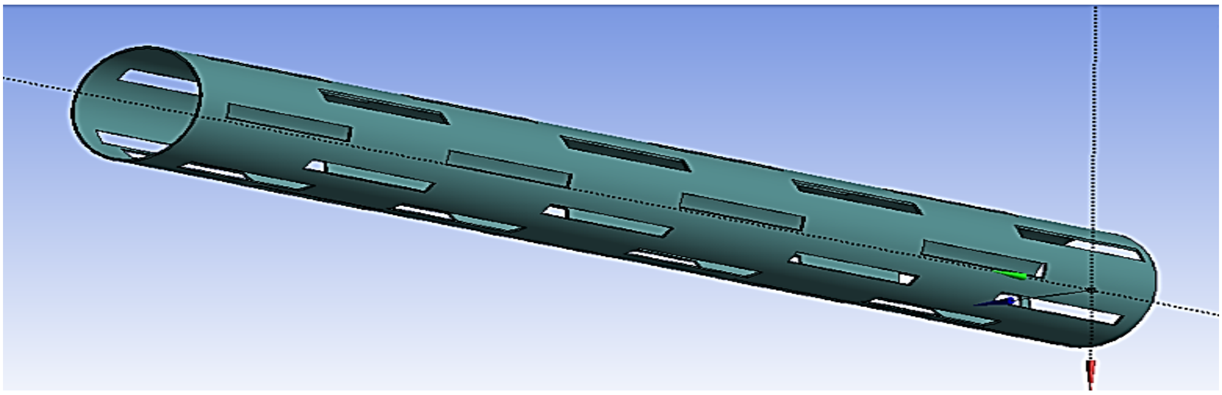


Fig. 2. The perforated metal glass casing of the second proposed model

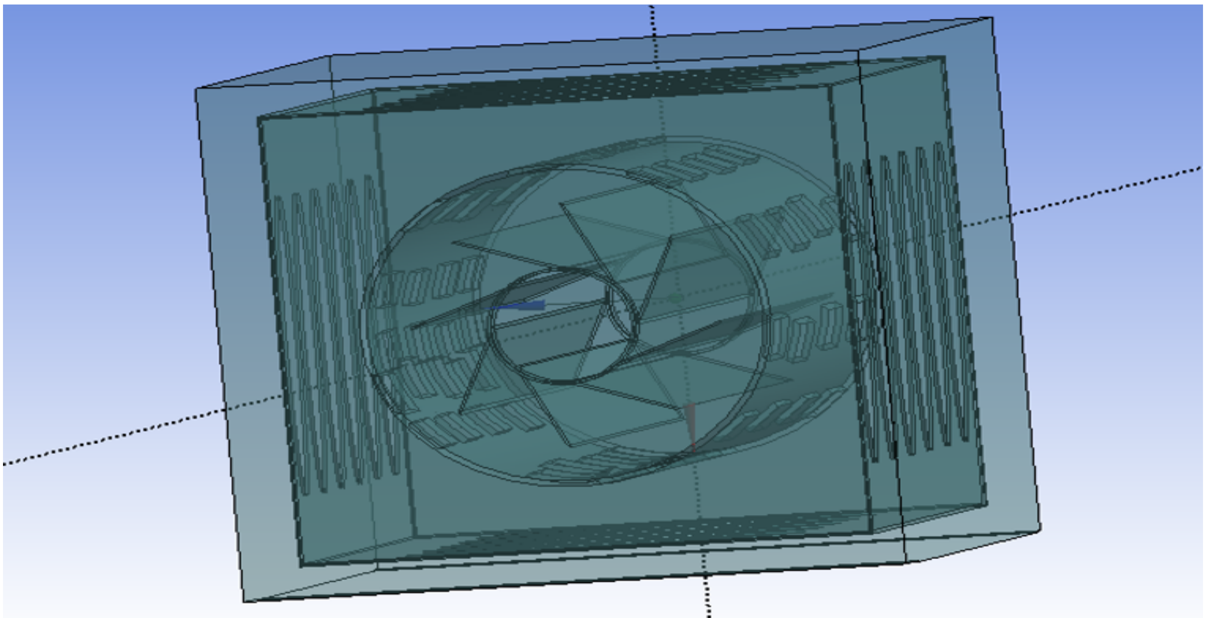


Fig. 3. The description of the Second Model

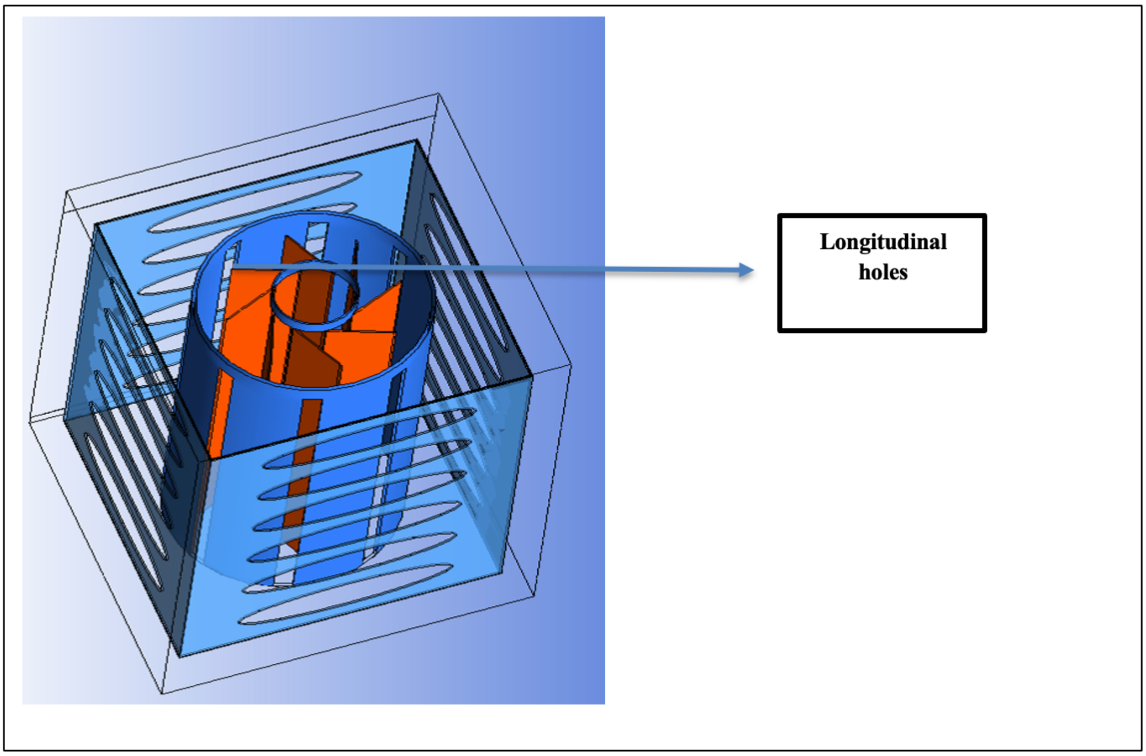


Fig. 4. Description of the third model

Table 1
Sizes of the proposed models for (SVC)

Dimensional Parameter	First model	Second model	Third model
Vortex generator	L=2.5meter, W=0.4meter	L=2.5meter, W=0.4meter	L=2.5meter, W=0.4meter
Intake tube	D=0.2meter, L=0.25meter	D=0.2mrter, L=0.25meter	D=0.2meter, L=0.25meter
Guide Vane	L=2.5meter, angle (20), W=0.095meter	L=2.5meter, angle (20), W=0.095meter	L=2.5meter, angle (20), W=0.095meter
Ground Base	(0.4*0.4) meter	(0.4*0.4) meter	(0.4*0.4) meter
Holes	D= 0.3 meter	D=0.27 meter	L=0.030472-meter, W=0.31995 meter
Perforated glass cover	L= 2.5meter, W=0.4meter	-----------	----------
perforated metal glass	------------	L=2.5meter, W= 0.3 meter	L=2.5meter, W=0.3 meter

3. Mathematical Modeling

The three proposed models' flow fields were analysed using the conservation of continuity, momentum, and energy balance equations.

$$\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)=0$$

Momentum equation:

$$\rho\nabla.(uv) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_x$$

$$\rho\nabla.(vV) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + S_y$$

$$\rho\nabla.(wV) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + S_z$$

Turbulence Model:

$$\rho\frac{\partial}{\partial x_i}(Ku_i) = \frac{\partial}{\partial x_j}\left(\alpha_k\mu_{eff}\frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\varepsilon - Y_M$$

$$\rho\frac{\partial}{\partial x_i}(\varepsilon u_i) = \frac{\partial}{\partial x_j}\left(\alpha_\varepsilon\mu_{eff}\frac{\partial \varepsilon}{\partial x_j}\right) + G_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}C_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R_\varepsilon$$

Energy Equation:

$$\rho C_p\left(\frac{\partial(uT)}{\partial x} + \frac{\partial(vT)}{\partial y} + \frac{\partial(wT)}{\partial z}\right) = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + S_E$$

The radiation equation solved by the software can be written as follows:

$$\nabla.(I_\lambda(\vec{r}\ ,\ \vec{s})\,\vec{s}) + (\alpha_\lambda + \alpha_s)I_\lambda(\vec{r},\vec{s}) = \alpha_\lambda\ n^2\ I_{b\lambda} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I_\lambda\ (\vec{r},\vec{s})\varphi(\vec{s},\vec{s})d\ \Omega'$$

The solar intensity in every direction $\vec{s}$ and position $\vec{r}$ may be written as follows [46]:

$$I_\lambda(\vec{r},\vec{s}) = \sum_k I_\lambda\ (\vec{r},\vec{s})\Delta\,\lambda_k$$

Table 2
Describes the symbols in the Navier-Stoke equations

Symbols	Definition
(α)	absorption coefficient
(n)	refractive index
(σ_s)	scattering coefficient
$(\vec{r})$	scattering coefficient
$(\vec{s})$	direction vector
$(\vec{s}')$	scattering direction vector
(σ)	Stefan-Boltzmann constant (5.669×10^{-8}W/m^2. K^4)
(I)	radiation intensity
(T)	temperature
(Φ)	face function
(Ω')	solid angle
(λ)	wavelength
(α_λ)	spectral absorption coefficient
$(I_{b\lambda})$	black body intensity
(S_h)	Heat source
(G_k)	Production of turbulent kinetic energy
(G_b)	Generation of turbulence kinetic energy
$(C_{3\varepsilon})$	constant to calculate the degree of ε affected by buoyancy

4. CFD Procedures
4.1 ANSYS-Geometry

To begin any project in the ANSYS 2022 R1 program, the first step is to draw or create the models that were proposed in one of the design programs (such as AutoCAD, Solid Work) or any other program, and then insert them into the ANSYS program's geometrics. Program folder, where the dimensions of the proposed models have been determined. The proposed models are distinguished by the fact that they combine two technologies, the solar vortex engine and the solar chimney, in a single structure to address the modelling problems identified in previous studies. The length and width of the proposed first model are (2.5 m) and (0.4 m), respectively. It was based on previous research by Ali A. Ismaeel et al [44], and Hussein A. Jaffar *et al.*, [45] with the number of guide vanes (8) and an angle of (20) being the optimal angle for producing the updraft. The second proposed model has a length (2.5 m) and a width (0.4 m), but it includes a perforated metal casing between the solar vortex engine and the perforated glass casing. The holes have a diameter of (0.27) m. This casing is considered a slot for heating the system, and the holes are designed to allow ambient air to enter and increase the updraft. The third proposed model includes longitudinal holes with a length (0.30472) m and width (0.31995) m that run the length of the metal casing between the solar vortex engine and the perforated glass casing. These holes were made longer than in the second model to allow more ambient air to enter the proposed model (SVC) and thus increase the updraft process. As shown in Table 1.

4.2 ANSYS-Mesh

In ANSYS, use the mesh tool to convert a volumetric figure from solid parts (Sloid Model) to finite elements. Instead of solid building blocks, the software makes use of finite elements and Nodes. Division measures, such as Size Element Edge Length, are frequently used to ensure accurate outcomes. Where (0.01m) was used as the size of all finite elements in the model. The most suitable division is selected, resulting in accurate results and a reasonable computer time when solving the model. It is well known that the smaller the partition, the more accurate the results; however, this requires more computer time to analyse and consumes more storage space. Furthermore, the order Mesh identifies the main components. To allow the program (ANSYS) to enter physical properties via the Setup command. This section describes the process of creating a mesh, including material properties and standard conditions for improving and developing the model, as well as determining boundary conditions.

Table 3
Types of boundary conditions for the proposed (SVC) models

Components	Boundary Type	Boundary Conditions
Perforated glass cover	Solid	Material = Glass
Air enters through holes	Velocity-Inlet	Constant Velocity = (0.6, 0.9, 1.2) m/s Temperature = 300 K
The air enters the Intake Tube	Velocity-Inlet	Normal Velocity = 0.5 m/s Temperature = 300 K
Perforated metal casing	Wall	Material = Aluminium
Out air	Pressure-outlet	Pressure = 0 Pa Temperature K = 300
Chimney, Intake Tube, Ground base, Top base, and Guide Vane.	Wall	Material = Aluminum

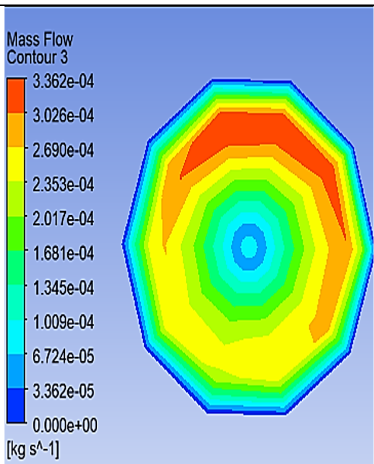
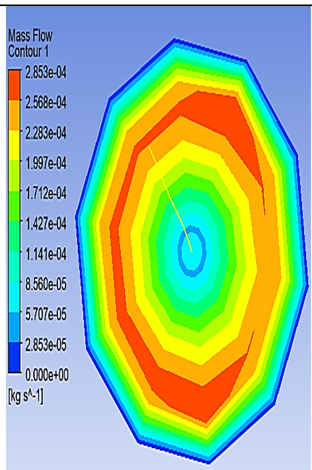
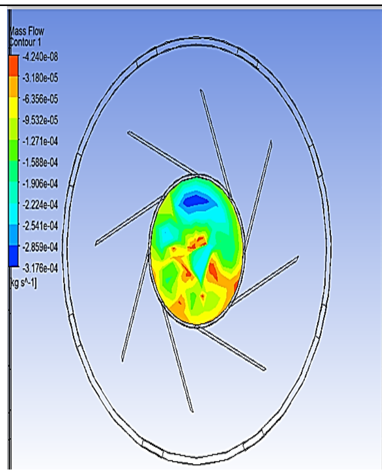
Table 4
The properties of air, aluminium, and glass have been used

Material	Density (kg/m^3)	Thermal conductivity (W/m· K)	Specific heat (J/kg· K)	Properties
Aluminium	2719	202.4	871	Solid
Glass	2500	1.4	750	Solid
Air	Ideal gas (Incompressible)	0.0242	1006.43	Fluid

5. Result and Discussion
5.1 Implementing The Solution and Validation

The main objective of this research is to broaden the design ideas for employing and producing updrafts in the solar vortex system, with three designs proposed as shown in Fig (1), (3), and (4) and compared to determine which model produces the greatest amount of energy. The primary goal of this technology is to convert thermal energy into kinetic energy in the air by increasing its velocity. Previous studies were used to determine the angle of the vanes, which is 20°, and the number of vanes is eight, Hussein *et al*., [45] Ali *et al*., [44] The turbine's location on top of the chimney was also adopted. Three velocities (0.6, 0.9, and 1.2 meters per second) within the solar vortex chimney (SVC) were assessed by comparing the computational method (simulation) to the typical behavior of previous experiments. The results are close, The ANSYS 2022 R1 program indicates the solution's accuracy. After monitoring the simulation of air velocity and temperature, we discovered that the higher the velocity of air entering the (SVC), the faster the external wind, the mass air, and thus the outgoing air velocity from (SVC). It was confirmed that the general behavior of the (SVC) model is similar to the study of Hussein *et al.,* [45], and Ali *et al.*, [44], which confirms the validity of the results presented in this research.

Table 5
The three suggested models are displayed in an analysis of the ANSYS 2022 R1 program's air movement and velocity

<table>
<tr><th></th><th>The first proposed model</th><th>The second proposed model</th><th>The third proposed model</th></tr>
<tr><td>Mass flow</td><td>
</td><td>
</td><td>
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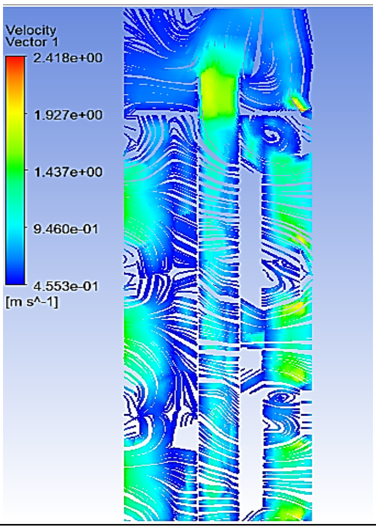
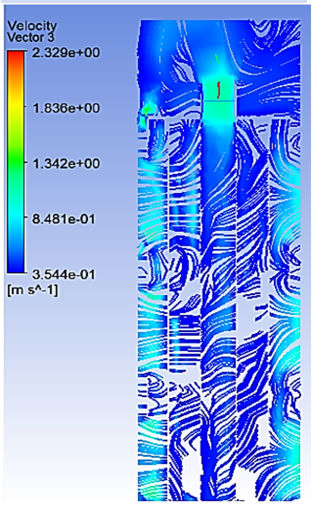
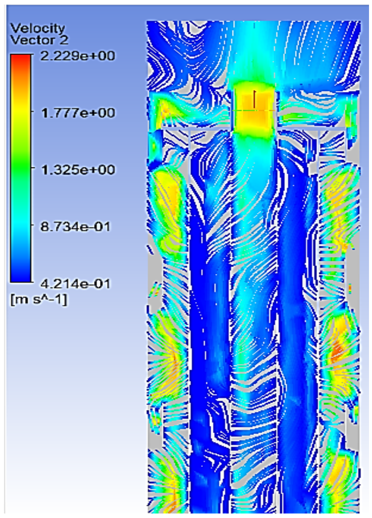
<tr><td>The velocity</td><td>
</td><td>
</td><td>
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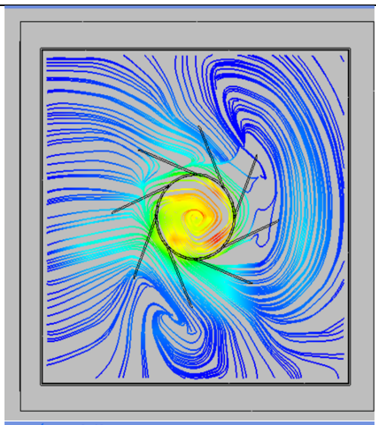
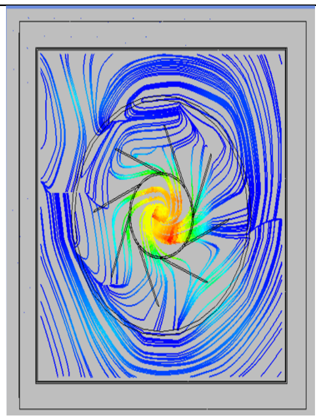
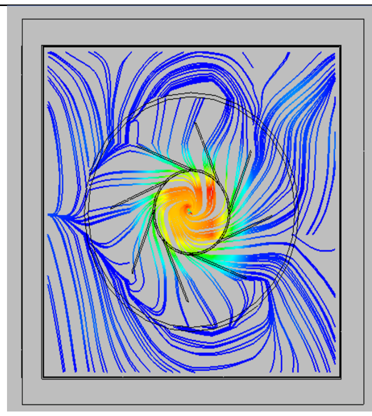
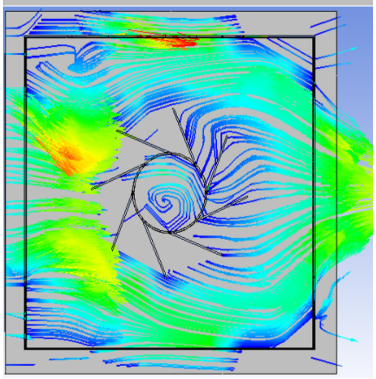
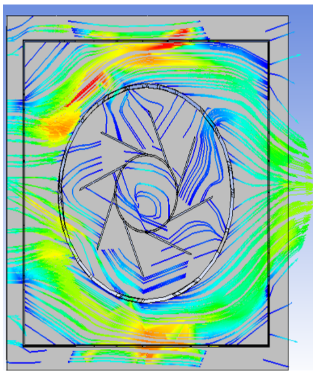
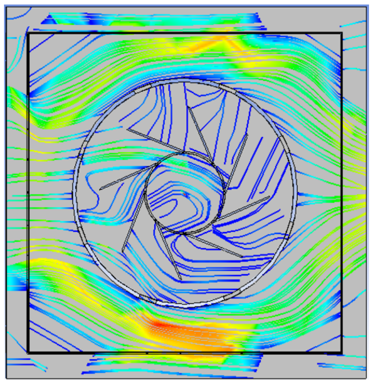
Velocity clip from above, at height (2.48 m)			
Velocity clip from above, at height (1 m)			

It appears in Table (5) that the highest air exit velocity was obtained in the first proposed model, where it reached (2.418 m/s), followed by the second model, where the velocity was about (2.329 m/s), and then the third (2.225 m/s), When the inlet air velocity (0.9 m/s), believing that the reason is the presence of the perforated metal cover, which, while considered a heating surface for the system, prevents the entry of the greatest amount of air into the design. It has been shown that the shape of the vortex in the first model at a distance of (2.28 m) is more regular than in the other proposed models, as the amount of air entering from the bottom and from the holes in the perforated glass cover that have a diameter of (0.3) increases, the density of the air decreases, and as a result, it rises to the top, but the second proposed models The third model addressed the problem of air dispersion through the vortex more than the first by placing a perforated metal casing, which reduces air dispersion by a smaller amount. Table (6) displays the goods obtained through the ANSYS 2022 R1 program for the three proposed models.

Table 6
Displays the goods obtained through the ANSYS 2022 R1 program for the three proposed models

Model	**Air entry velocity (m/s)**	**The air exit velocity at the end of the design (meters per second)**
The first proposed model	0.6	1.631
	0.9	2.418
	1.2	3.224
The second proposed model	0.6	1.555
	0.9	2.329
	1.2	3.103
The third proposed model	0.9	2.225

5.2 Comparing The Improvement in Velocity and Kinetic Energy

Table (7) displays the temperature differences between metal and glass for the proposed models. We find that metal has higher temperatures than glass because it absorbs temperatures faster, indicating the validity of the data and the behavior. We also observed in all of the proposed models that the faster the entry velocity The temperature of the metal and glass decreases. This is because the density of the air decreases as its velocity increases, causing the air to rise upward and thus lower the temperature of the metal and glass. Table (8) compares the kinetic energy of the proposed models, revealing that the first model has more kinetic energy due to the model's higher air velocity. We observe that the perforated metal cover influences the amount of air entering, but this metal cover addresses the issue of air dispersion through the vortex. Number of Iterations with (epsilon, energy, (x, y, z)-velocity, K) for solar vortex chimney (SVC) As shown in the form (5) for the first model, (6) for the second, and the form (7) for the third model This figure represents the correctness of the data solution that was completed in the ANSYS 2022 R1 program.

Table 7
Shows a comparison of metal and glass temperatures for the proposed models

Model	Air entry velocity (m/s)	Metal Temperatures (K)	Glass Temperatures (K)
The first proposed model	0.6	346	338
	0.9	344	337
	1.2	343	335
The second proposed model	0.6	346	338
	0.9	344	337
	1.2	343	335
The third proposed model	0.9	344	337

Table 8
It shows the differences in kinetic energy between the three proposed models

Model	Air entry velocity (m/s)	The air exit velocity at the end of the design (meters per second)	The kinetic energy of the proposed models
The first proposed model	0.6	1.631	1.064 J
	0.9	2.418	2.340 J
	1.2	3.224	4.160 J
The second proposed model	0.6	1.555	0.967 J
	0.9	2.329	2.170 J
	1.2	3.103	3.853 J
The third proposed model	0.9	2.225	1.981 J

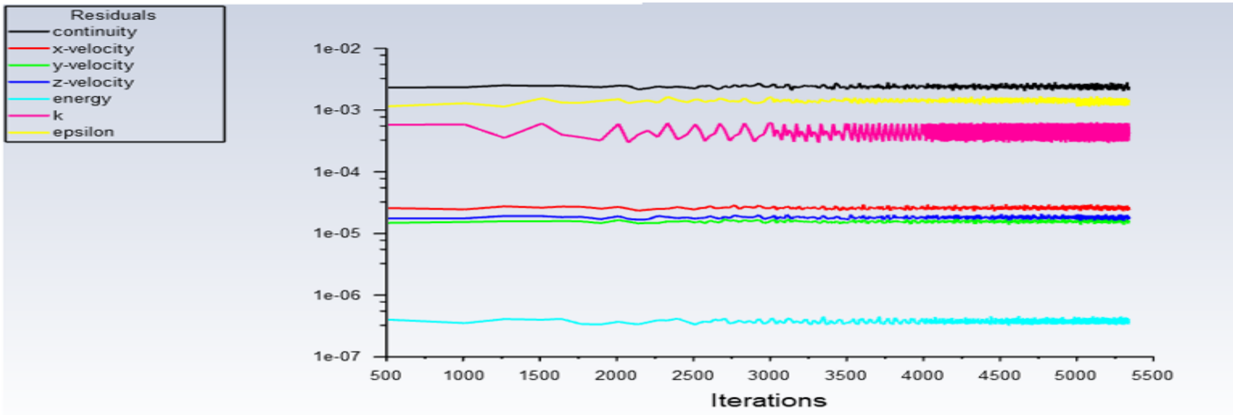


Fig. 5. Number of Iterations with (epsilon, energy, (x, y, z)-velocity, K) for the first model

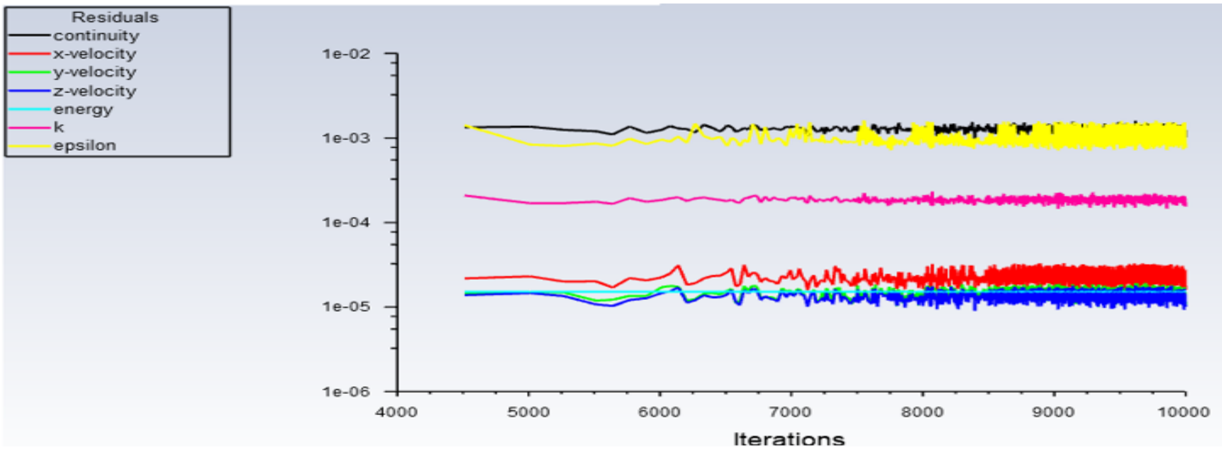


Fig. 6. Number of Iterations with (epsilon, energy, (x, y, z)-velocity, K) for the second model

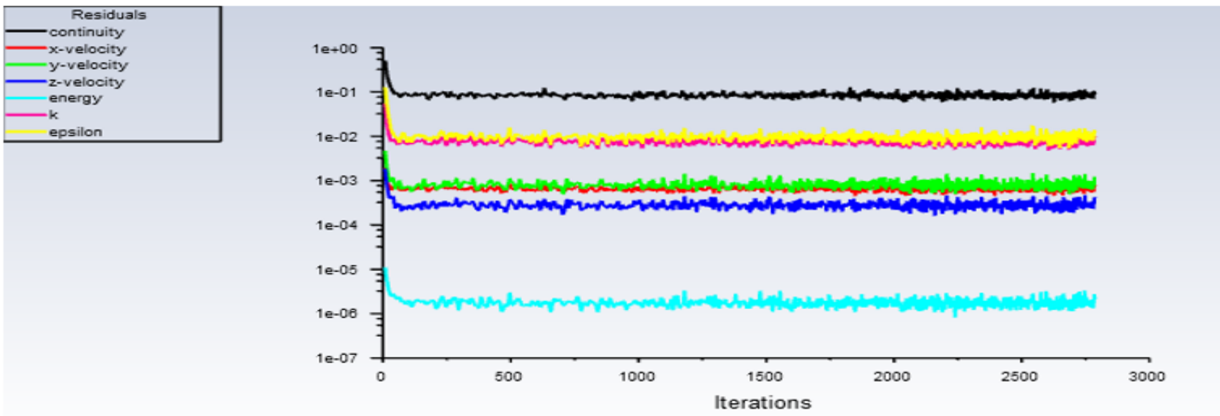


Fig. 7. Number of Iterations with (epsilon, energy, (x, y, z)-velocity, K) for the third model

6. Conclusions

This research presented a simulation system using the ANSYS 2022 R1 program for three proposed models. These models combine the technology of the solar vortex and the solar chimney. We used some previous studies to determine the best angle for the Guide Vanes, which is 20°, and the best number of Guide Vanes, which is (8). Three velocities were tested using the ANSYS 2022 R1 program (0.6, 0.9, and 1.2) m/s. The first model had the highest speed (2.418) m/s and energy (2.340 J) when choosing the entry speed (0.9) m/s, followed by the second and third models, respectively. Simulations of the three proposed models were compared, and it was discovered that the shape of the air vortex in the first model, which consists of a vortex engine and a perforated glass casing, is more regular than in the second and third models, because the amount of air entering the first model is greater, and thus the airspeed increases when there is solar radiation. Higher, and thus the updraft process is better, leading to higher energy production. As for the second and third models, which consist of a vortex engine, a perforated glass cover, and a perforated metal cover with different diameters between the two models, it turns out that the added perforated metal cover obstructs the incoming air, as the amount of air becomes less and the shape of the air vortex for the two models is less regular than the first model, but this cover treats the problem of air dispersion through the holes is greater than in the first model.

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