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# Automatic ventilation and cooling of the building using the combination of wind deflector and solar chimney (state 3D with differential perspective)

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**Abstract.** Using new sources of energy and inventing new methods for energy consumption has always been the focus of researchers. The building sector is known to contribute largely in total energy consumption and $CO_2$. Expanding the availability of energy storage technology and materials is considered as crucial as discovering new energy sources. The International Energy Outlook by the EIA (Energy Information Administration of the outlook) examines and predicts future trends in building energy usage. It anticipates a 34% growth in energy consumption within the built environment over the next two decades, with an average annual increase of 1.5%. By 2030, it is projected that approximately 67% of this consumption will be attributed to dwellings, while the non-domestic sectors will account for about 33%. This study endeavors to combine one of these ventilation techniques from ancient Persian architecture, known as the windcatcher in the form of an innovative roof radiative cooling (Windcatcher) with a solar chimney. In order to save energy consumption and reduce environmental problems by presenting the idea of using solar energy to exhaust the air inside the building through the chimney and using the latent heat of water evaporation to create cooling that is carried out in the direction of the wind by the windcatcher. Hence, fuel consumption can be created in hot and dry areas, in a comfortable environment with suitable humidity conditions. The purpose of this research is to introduce computational areas (3D) and determine the governing values and methods calculated by Ansys Fluent software, which has enabled the use of suction and the creation of moisture balance and heat reduction without fuel consumption, which plays an important role in It implements energy efficiency in the building. This system is also able to save 60% cooling energy and 80% of the ventilation energy during peak hours in a warm and arid climate. Furthermore, the effects of a wall opening on ventilation and thermal efficiency were examined.

**Keywords.** Natural ventilation, radiative cooling, windcatcher, solar chimney.

## 1. Introduction

The prospect of depleting fossil fuel reserves in the coming decades, along with globalization and the consequent increase in competition among nations, has led to the optimization of energy consumption emerging as a strategic policy advocated by economists and statesmen worldwide. This has resulted in annual allocations of budgets towards research and development in the field of alternative energy sources to replace fossil fuels, paving the way for new energy optimization methods to be proposed each year. In recent years, the discussion surrounding the use of renewable energy sources for building heating and cooling has captured the attention of engineers and architects. Given that a substantial portion of the world is situated in warm climatic regions, implementing appropriate methods to reduce building cooling costs is of significant interest Considering the desert climate of cities like Yazd, characterized by long, hot, and dry summers, the application of energy optimization principles in buildings is essential. This paper focuses on the design of a building with a natural cooling system (utilizing wind and solar energy) in desert cities [1, 2]. The interesting results obtained suggest that the initial investment cost for implementing energy optimization principles in buildings can be offset in the subsequent years through reductions in fuel or electricity consumption costs. With a calculated perspective, it can be deemed economically feasible to construct buildings reliant on energy consumption optimization principles. The intense summer heat in desert regions of Iran and the limited access to energy resources derived from fossil fuels in the past have prompted humans to consider natural ventilation and self-sufficiency in buildings without relying on fossil fuels. In this regard, tower-like structures such as the narrow and tall four-sided, six-sided, or eight-sided buildings known as “wind catchers” [2] have been constructed.

Today, due to the uncontrolled consumption of fossil fuels and the significant increase in environmental pollution, it seems reasonable and logical to consider renovating and revitalizing traditional wind catchers to address their drawbacks. Moreover, in these regions where there are many hours of sunshine throughout the year, solar radiation can be utilized as a clean energy source. By constructing Trombe walls or solar chimneys, automatic airflow can be established inside the building. Inside the wind catcher, negative buoyancy (cool and heavy air) creates airflow downwards, while inside the Trombe wall (solar chimney), positive buoyancy is created as the air warms up, causing the air to move upwards. By placing suitable evaporative systems at the inlet of the wind catcher, as shown in Figure 1, we can create a comfortable and well-conditioned interior space in terms of temperature and humidity. These structures are built above rooftops, serving not only to beautify the building but also to provide natural ventilation to the interior space. Reference [3] in order to give the most ventilation possible through a solar chimney. The performance of solar chimneys is also impacted by wind direction and speed [4], and even at moderate velocities, an opposing wind direction can decrease the volumetric airflow of the chimney [5]. According to Rabani and Kalantar’s experimental study [6], a water spraying system can increase a solar chimney’s thermal efficiency by 30% and even 80% when installed in an underground channel [7].

Nevertheless, the technique works best in compact building areas [8]. Another method that can effectively ventilate a 54 $m^3$ classroom in a warm and humid area is the use of an absorber-partitioned air channel solar chimney [9]. Using a control system can lower the annual ventilation energy by 77.8%, according to modeling results of a two-story detached home with a solar chimney in China [10]. However, more research into creating control systems is advised in order to improve the ventilation [11]. The ventilation powered by the sun can be improved using a windcatcher.

This article aims to study the cooling performance of buildings by employing numerical methods and utilizing the equations governing fluid motion in two-dimensional and steady-state conditions. The effects of wind speed and direction, air temperature, wind catcher height, material composition, and the role of moisture resulting from water spraying in the airflow path will be investigated. Additionally, the impact of the solar chimney and air volume on the circulation created by it will be evaluated. Ultimately, by providing appropriate solutions, the groundwork for the reuse of these structures in modern architecture will be established. It is worth mentioning that significant energy savings can be achieved in this regard.

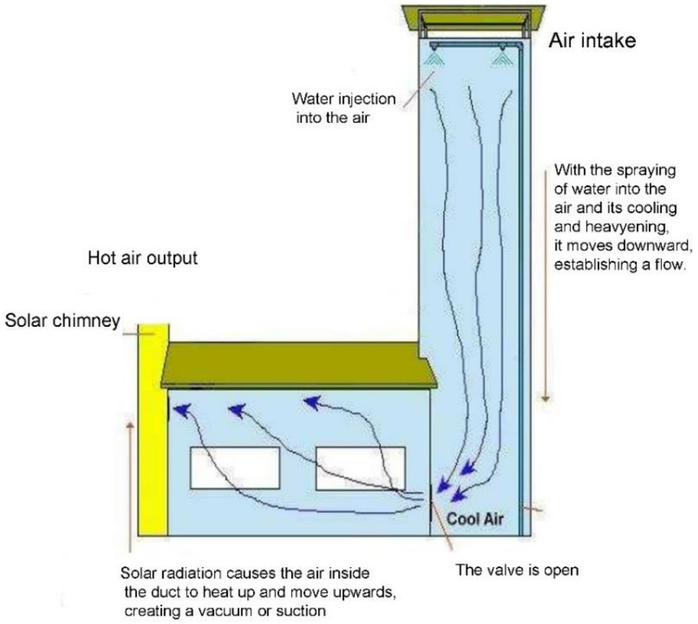

**Figure 1.** An initial natural ventilation design without the use of mechanical force with a wind catcher.

The governing equations for fluid flow inside a building, considered as a control volume or computational domain, are as follows:

## 2. Governing equations of the flow

### 2.1 The equation of mass conservation

$$\frac{\partial(\rho u_i)}{\partial x_i} = S_m \tag{1}$$

$S_m$ The term source refers to a quantity that is added or removed from the main flow, and is associated with phenomena such as water evaporation or condensation.

### 2.2 Momentum equations

The time-averaged Navier-Stokes equation governs the flow.

$$\frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) + f_i \tag{2}$$

The term $\rho\overline{u_i' u_j'}$ represents the Reynolds stresses, which are associated with velocity fluctuations around the mean value and are obtained using the Boussinesq assumption.

### 2.3 Energy equation

To calculate the temperature distribution inside the building, the energy equation is required, which is as follows:

$$\frac{\partial}{\partial x_j}[u_i(\rho E+P)]=\frac{\partial}{\partial x_j}\left[\left(\lambda+\frac{c_p\mu_t}{pr_t}\right)\frac{\partial T}{\partial x_j}-\sum_j h_j J_j\right]+S_h \quad (3)$$

It is: $E$ in this equation:

$$E=\sum h_j Y_j+\frac{u^2}{2} \quad (4)$$

$\lambda$ is the thermal conductivity coefficient, and $J_j$ is the partial flux of component $j$, while $S_h$ refers to any energy source.

$$\frac{\partial}{\partial x_j}(\rho Y_{H2o}u_i)=\frac{\partial}{\partial x_j}\left[\left(\rho D_{H2o}+\frac{\mu_t}{sc_t}\right)\frac{\partial Y_{Ho_0}}{\partial x_j}\right]+S_{H2o} \quad (5)$$

$S_{h2o}$ is related to the amount of water added (resulting from evaporation) or subtracted (resulting from condensation) from the main stream. $D_{H2o}$ is the water vapor diffusion coefficient into the air, taken as $2.88\times10^{-5}$ square meters per second. Sct is the dimensionless Schmidt number for vapor, which is assumed to have a limit of 0.7.

The chosen numerical method for solving the turbulent flow within the control volume is based on the k-ε model with the simple algorithm. The computational grid and boundary conditions were implemented using FLUENT 6.3 software. The selected boundary conditions and computational grid are illustrated in Figures 2 and 3.

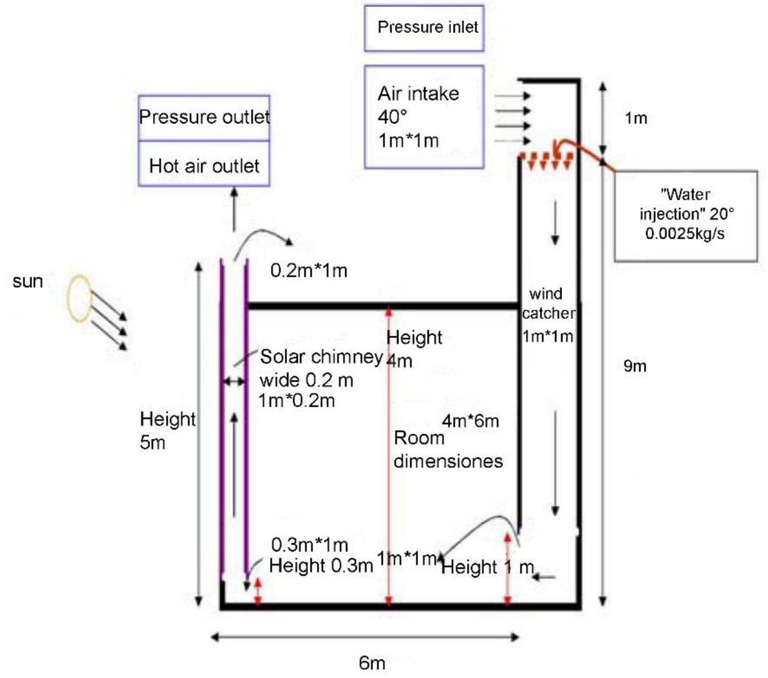

**Figure 2.** Representation of the geometry and general problem statement.

According to Figure 2, the entire wall is chosen as an insulator, and inside the solar chimney, the right wall has a temperature of 120 degrees Celsius, while the left wall (made of glass) has a temperature of 35 degrees Celsius. The computational grid has been selected in such a way that the size and number of nodes ensure independent convergence and accuracy. The execution time for calculations up to 0.000001 has been lengthy due to the fine mesh (as shown in Figure 3) and the small dimensions, requiring approximately eighteen hours for each run on a regular computer.

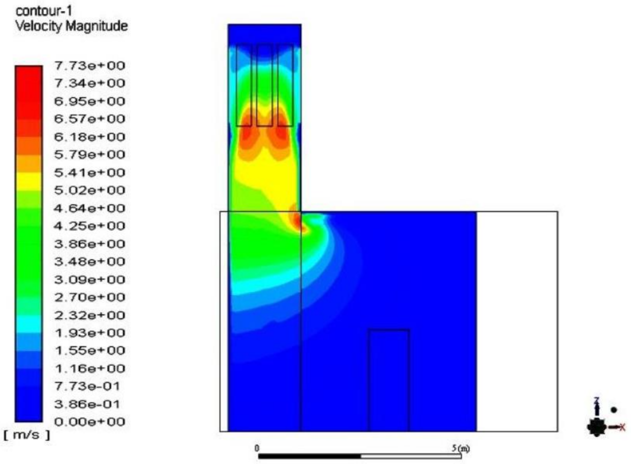

**Figure 3.** Selected grid for numerical solution.

## 3. Finding

According to the results obtained from running the program under various conditions, it is observed that adding water to the airflow path significantly affects various quantities such as temperature, relative humidity, fluid velocity, volume mass, etc. For example, the temperature value (as shown in Figure 4) decreases considerably, while the relative humidity or fluid mass (as shown in Figure 5) increases. Both of these are suitable for warm and dry climates like Yazd. Assuming the walls of the windcatchers are insulators, the air temperature at the outlet decreases significantly according to Fluent. The results obtained from the software match those obtained from experimental testing [5]. According to the standard for air conditioning, which recommends a temperature of 25 degrees Celsius and a relative humidity of 50% inside buildings, the results show that with a reasonable consumption of water (33 liters per hour) and considering a temperature of 100 degrees Celsius for the hot plate of the solar chimney, which can easily be achieved, the volumetric flow rate of the air passing through the chimney within an hour is 2000 cubic meters, which is sufficient for ventilation and providing cooling for a building with an area of 120 square meters without the consumption of electricity, fuel, or motive power. (Providing a small amount of electricity for the water circulation pump through solar energy is feasible). In Figure 6, the air temperature near the floor of the room is plotted, which is relatively low. This indicates the efficiency of the method; we can reduce the amount of water injected into the air so that the relative humidity inside the room is below 50%. According to Figure 7, obtained from running the program under various conditions, it is concluded that as the amount of injected water increases, the water temperature decreases further until saturation is reached. In this case, adding water will have no effect, and it will accumulate around the walls and bottom of the windcatcher as a liquid. Therefore, it is easy to provide sufficient temperature and humidity according to the standard air conditioning conditions [6] inside the building. If the walls of the windcatcher are insulating, the water consumption will decrease significantly. The taller the windcatcher, the higher the wind speed at the inlet, increasing its performance. Additionally, the negative buoyancy effect due to the heavy air also increases, resulting in a stronger flow of the air-water mixture downwards in Figure 8. The material of the windcatcher is important for storing energy inside it. During the day, the walls store heat and release it at night, creating a natural convection inside, which is favorable in the summer, and ventilation also takes place simultaneously. Inside the solar chimney, due to the sunlight entering and passing through the glass (left wall), the air heats up and moves upwards, effectively performing the fan's function. The distribution of temperature and velocity between the two walls on the middle plane is observed in Figures 9 and 10.

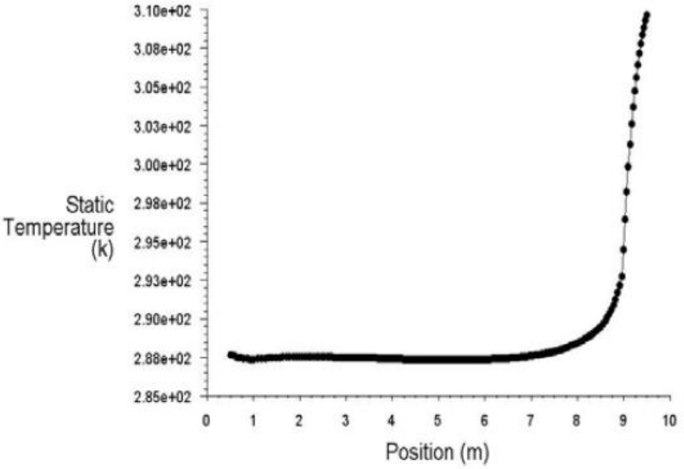

**Figure 4.** Changes in air temperature inside the windcatcher from top (9 meters above ground level) to bottom (0.5 meters above floor) immediately after water injection.

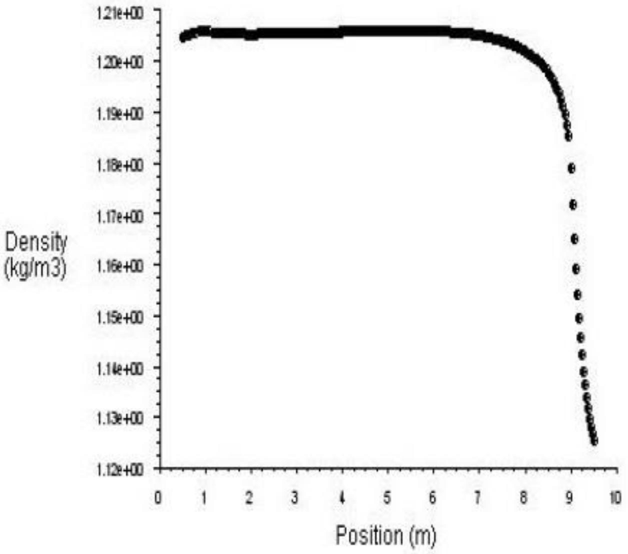

**Figure 5.** Changes in air volume mass inside the windcatcher.

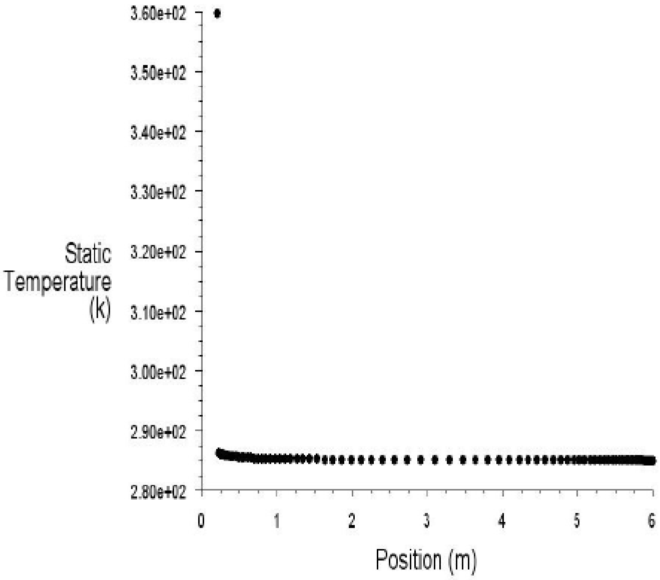

**Figure 6.** Temperature distribution inside the room near the floor.

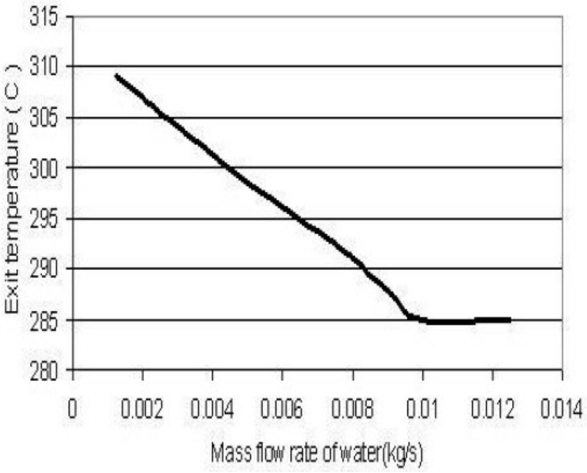

**Figure 7.** Relationship between the outlet temperature from the windcatcher and the amount of injected water.

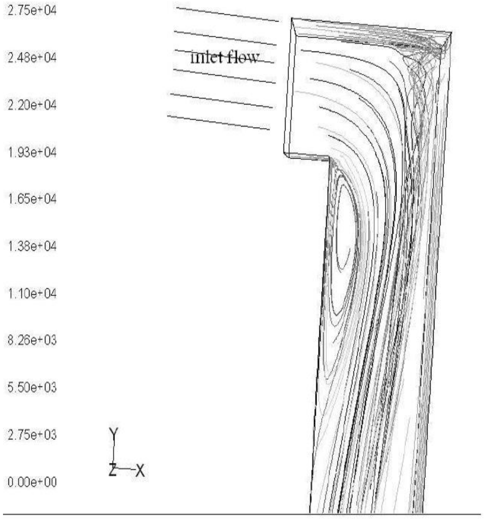

**Figure 8.** Streamlines inside the windcatcher (middle plane).

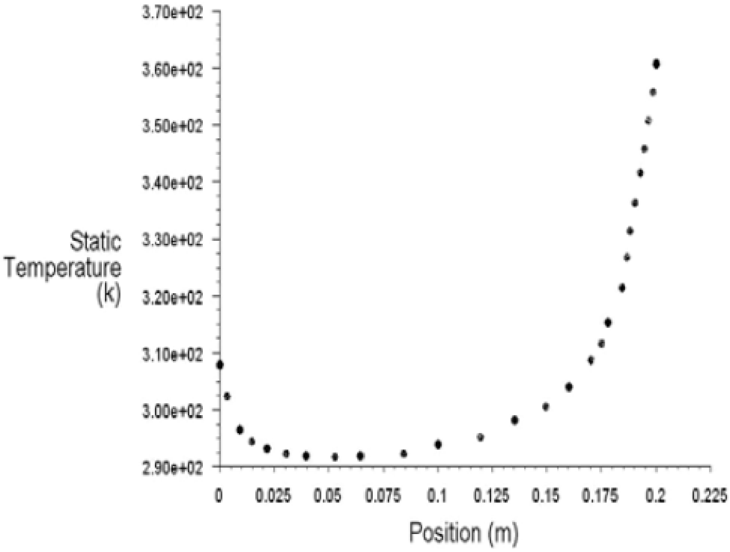

**Figure 9.** Temperature distribution between the two walls of the solar chimney.

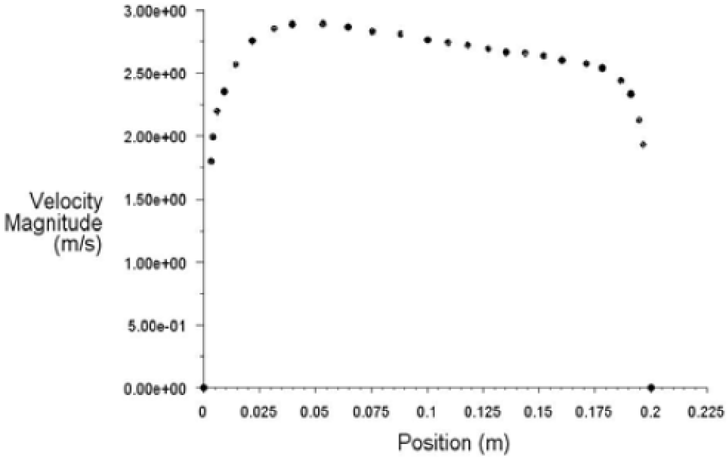

**Figure 10.** Velocity distribution between the two walls of the solar chimney.

## 4. Conclusions

The study demonstrates that adding water to the airflow path significantly affects temperature, humidity, and fluid velocity, particularly beneficial for hot, dry climates like Yazd. Insulated windcatcher walls decrease air outlet temperature, aligning with experimental data. The findings indicate that moderate water usage and solar chimney heating can effectively ventilate and cool buildings without electricity. Reduced water injection maintains indoor humidity, while increasing water reduces temperature until saturation. Taller windcatchers enhance performance, and wall material choice impacts energy storage. Natural convection during the day and ventilation at night contribute to cooling efficiency. In the solar chimney, sunlight heating the air aids ventilation. Figures illustrate temperature and velocity distribution between walls, highlighting method fectiveneses. The main achievements are as follows: A solar chimney integrated with a windcatcher system can reduce the average temperature by 5.2°C and generate about 9 ACH during peak daylight hours for the occupied space. Additionally, it can save 75% of cooling energy and 90% of ventilation energy in a sample building during working hours in the peak cooling season of a hot and dry climate.

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