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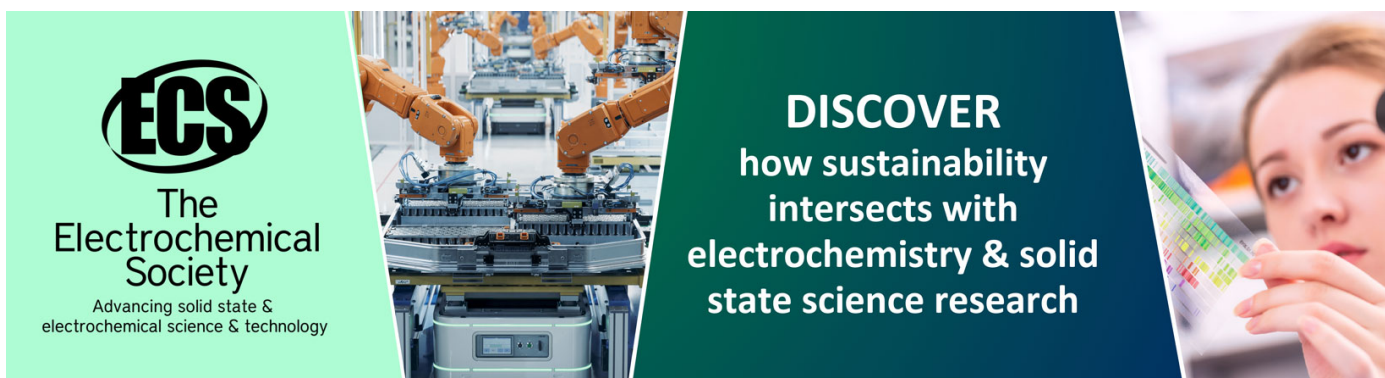
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Assessment of Solar Power Tower System for Closed Space Ventilation: Numerical Investigation

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Abstract. The small closed space demand increase as a secondary station for commercial production. It leads to the need to improve these stations by enhancing proper self-ventilation and daylighting. The natural air ventilation system significantly works in small closed stations; this system can be improved using different thermal storage materials in the solar collector and integrated approaches in closed space for heating, ventilation, and space conditioning. Three models were simulated; the first model is the normal model (single-pass roof solar collector). The second and third models are solar tower systems; chimney height is 6 m, with external collectors using water and wax containers. Results demonstrated that increasing thermal absorbance (wax container) of the thermal storage unit in the solar collector system enhances system performance. The mean percentage of increasing air velocity between the numerical results of Model-A and Model-B from the standard model is 18.9 % and 11.4%, respectively. Also, the mean percentage of increasing the collector's efficiency between Model-A and Model-B's numerical results from the normal model is 8.4 % and 5.3%, respectively.

Keywords. Solar Power, Ventilation, Numerical Investigation.

1. Introduction

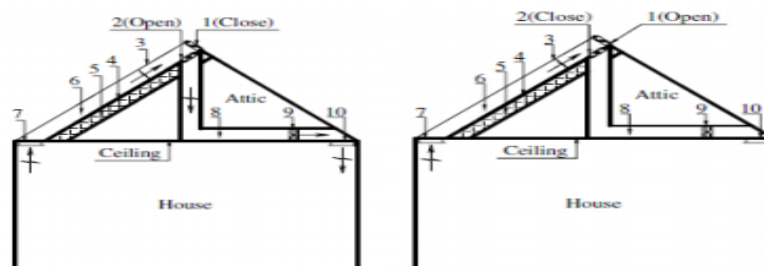
A natural air updraft method for the building rooms by converting thermal energy into kinetic energy of air movement was one way for cooling processes [1]. Generally, a solar tower utilizes solar radiation energy to build up stack pressure. This strategy saves from cooling systems' costs due to the non-use of the mechanical intervention [2, 3]. Lee and Strand [4] reported the influences of the solar tower height, heat absorption for the tower wall, effect for transmittance of the glass cover, and the air gap, under various conditions. Subsequently, Burek and Habeb [5] investigated experimental tests to heat transfer and mass flow in thermo systems for air heaters, such as solar chimneys. Wei et al. [6] created new integrated ideas of solar roof collector, Trombe wall, and chimney and concluded the effect of total length and width of the chimney on the ventilation efficiency system. They also proved that the integrated solar system's efficiency was better than the single solar chimney. Several numerical studies were also carried out to assess the performance parameters for ventilation rate as a function of the solar collector's inclined angle and tower inclined angle [7-9]. Gan [10] proved that the length of a solar tower (vertical height) should be considered within the building style conditions to increase the airflow rate. Wang et al. [11] studied single and double pass roof solar collectors in two models as space natural ventilation models. They used several dampers to control the application state. The heat transfer studied with solar chimney energy analytic based on assumptions as wall adiabatic of constant heat flux [12]. Jomehzadeh et al. [13] reported a study of natural heat transfer phenomena inside a solar wall chimney. Their primary research focused on the numerical study of the buoyancy-



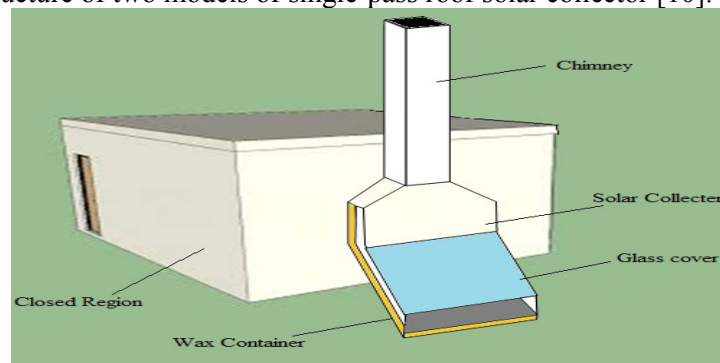
driven flow field inside the chimney and heat transfer analysis of the turbulent flow model; these conclusions are also confirmed by [14]. The above literature review presented that improving solar chimney efficiency depends mainly on design dimensions such as height, width, inclination angle, and spacing into the tower. However, the development of solar ventilation systems needs many studies that improve the ability to store heat energy to continue working these systems during the end of the solar radiation effect (at night). Moreover, for the numerical simulation, the k- ϵ model is best to provide superior performance for flow boundary layers under a strong adverse pressure gradient; that is why it was selected for simulation [15]. In the current research, three models were simulated; the first model is normal design presented by [10] (single-pass roof solar collector), second and third models (Model-A and Model-B) are solar tower system; chimney height is 6 m, with external collector using water and wax containers, respectively.

2. Guidelines of the solar power tower system

In designing a collector for solar power tower system to closed space ventilation, additional key solar chimney system design considerations include; collector dimensions (collector height at inlet air and collector height at the base of chimney) and thermal storage material type (wax container). The solar chimney is also the main part of the ventilation system, which works on the buoyancy principle. When the air is heated in the collector through the greenhouse effect generated by solar heat energy, the solar chimney can be used in several locations; roof level or inside wall. The solar chimneys are solar self-ventilation systems, so it does not need mechanical power sources. The cooling principle adopted by the heat dissipation. The solar tower's design is based on the idea that heated air rises upward; it reduces high heat during the day and exchanges warm air in the closed space for cool exterior air. So, the inner surface of the solar tower is mainly coated with black thermal mass. In this work, three models were simulated. The first model is the normal design presented by [10] (two models of single-pass roof solar collector), Figure 1(a). The second model (Model-A) is a solar tower system with an external collector using a water container, and chimney height is 6 m, Figure 1(b). The third model (Model-B) is a solar tower system with an external collector using wax containers, and the chimney height is 6 m.



(a) Structure of two models of single-pass roof solar collector [10].



(b) Solar tower system (Model-A and Model-B).

Figure 1. Schematic of the solar ventilation systems: (a) Structure of two models of single pass roof solar collector [10], (b) Model-A and Model-B.

3. Numerical investigation

The finite volume models of the computational domain are built using the finite volume method (Fluent, ANSYS Workbench 17.2, Inc.), a 3D geometrical modeling on the solar tower system based on the prototype's parameters was support with a pre-processing tool - GAMBIT 2.4.6. Computational Fluid Dynamics (CFD) simulation techniques were applied to simulate physical phenomena and predict the dynamic behavior and thermo-properties of air within 3-D Cartesian coordinates. Finite Volume Method (FVM) was used to discretized continuity equation, Navier-Stokes equations, and energy equation.

3.1. Computational Method

The 3D K-epsilon (k-ε) model of the energy system was used. The values of the turbulence kinetic energy and the turbulent dispersion rate are defined [11]. The turbulence kinetic energy can be estimated from the turbulence level, which can be described as:

- The Discrete Ordinates (DO) method calculates the direct and diffuse intensity from the solar beam depending on the system's location related to the solar beam at a specified time and location limited by the user, so there is a solar calculator to specified the directions and solar values.
- The extreme distortion of the fluid domain can cause grid error. Therefore, the dynamic mesh simulates the fluid domain's transient flow behavior and the aeroelastic deformation. The re-meshing is adopted, which is suitable for large deformation and large displacement. It is done by relocating the nodes based on the smoothing techniques.

3.2. Governing equations

The airflow into the solar power tower system and out of the system can be considered in batches because the inflow of air to the system varies with temperature within the collector and some other environmental factors like wind and humidity. The buoyant air at the collector exit/chimney base of the solar power plant can be determined using [16, 17]:

$$\frac{\partial}{\partial r} (\rho_{air} V_{coll} r_{coll} H_{g-c}) = 0 \quad (1)$$

Considering Equ.1, the air density and air velocity are dependent on the temperature of in collector area, while the height of the collector canopy above the ground determines the volume of potential air in the system. Similarly, the airflow continuity at the chimney can be described with Equation 2. Thus, considering mass balance and continuity.

$$\frac{\partial}{\partial h} (2\pi r_{air-ch} V_{air-ch} r_{ch} H_{ch}) = \frac{\partial}{\partial h} (\rho_{air-ch} \dot{V}_{air-ch}) = 0 \quad (2)$$

The collector's airflow momentum describes the buoyant air's strength that reaches the turbine, which can be determined using Equation 3 [18, 19]. The airflow momentum experienced at the chimney is described using Equation 4.

$$\rho_{air-coll} V_{coll-exit} H_{g-c} \frac{\partial V_{coll-exit}}{\partial r_{coll}} = -H_{g-c} \frac{\partial p_{air-coll}}{\partial r_{coll}} - \tau_{air-coll} \quad (3)$$

$$\rho_{air-ch} \dot{V}_{air-ch} \frac{\partial \dot{V}_{air-ch}}{\partial h} = -\frac{\partial p_{air-ch}}{\partial h} - \frac{2\tau_{air-ch}}{r_{ch}} - \rho_{air-ch} g \quad (4)$$

The basic simulation equation considered in this investigation is the energy equation, as shown in Equation 5.

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{\lambda}{\rho c_p} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (5)$$

3.3. Boundary conditions and simulation parameter cases

This simulation employed a radiation model that helps determine the various velocities and temperatures of the solar power tower system from simulation results following the thermo-physical properties of three models. The boundary conditions used in the simulation are presented in Table 1.

Table 1. Boundary conditions for the simulation of heat storage media selection.

Component	Boundary type	Value
Thermal storage unit; Normal wall in [10], Water container in Model-A, Wax container in Model-B.	Wall	Adiabatic system ($q=0$), no-slip, temperature values depending on solar intensity while the storage materials depend on thermo properties.
The glass cover of the collector in models A and B	Wall	Adipatic system ($q=0$), temperature values depending on solar intensity, no-slip
Chimney walls	Wall	Adipatic system ($q=0$), temperature values depending on solar intensity, no-slip
Collector inlet	Velocity inlet	Inlet parameters depending on ambient condition.
Chimney	Pressure outlet	Pressure difference ($\Delta p=0$)

Figure 2 shows the geometrical model and mesh for the solar power tower system for closed space ventilation. The fluid domain and the solid domain are solved separately. Then, the interaction information between the fluid and solid is exchanged periodically. This approach can save computation time and has enough accuracy in dealing with many complex non-linear problems. The pressure-based type solver was used. Nodes and elements of fine mesh for all models are represented in Table 2.

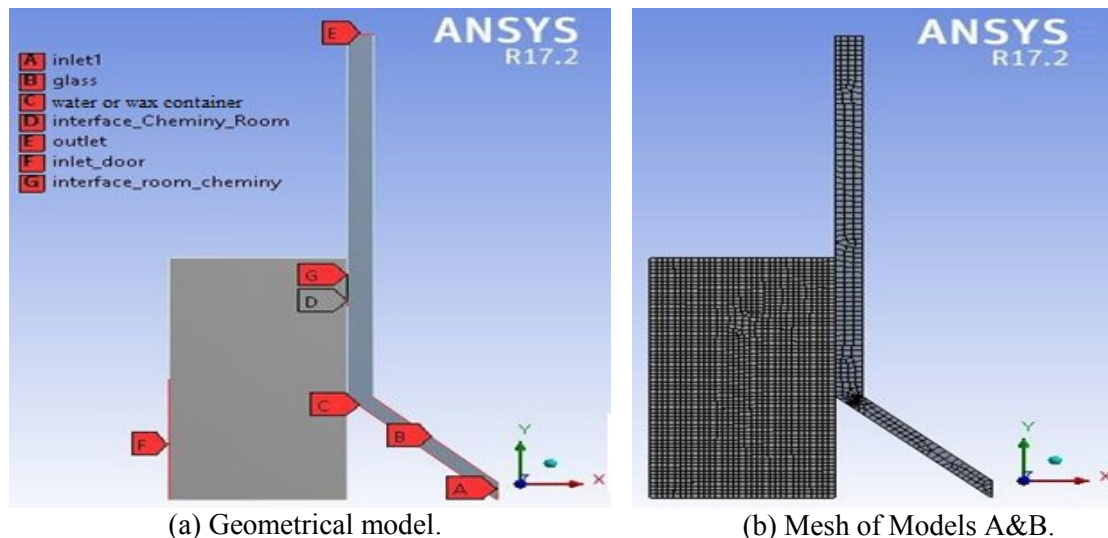


Figure 2. Computational domain and geometrical mesh for the solar power tower system for closed space ventilation.

Table 2. Nodes and elements for solar power tower system.

Sutpp	Dimensions	Nodes	Elements
Model- normal	Chimney in-room wall with dimensions, $0.5 \times 1 \times 6$ m and height at inlet 0.05 m.	1818341	1389433
Model-A	Collector dimensions, 1.5×2 m with water container, Chimney wall dimensions, $0.5 \times 1 \times 6$ m.	1907893	1671994
Model-B	Collector dimensions, 1.5×2 m with a wax container, Chimney wall dimensions, $0.5 \times 1 \times 6$ m.	1907893	1671994

4. Results and discussion

The numerical study was conducted on three different operational models as previously discussed; this analysis was presented in Table 2. This section has been identified and explained numerical results for the proposed solar power tower system in three different cases. Case 1 is a normal design presented by [10] (chimney in-room wall with dimensions). Case 2 is a solar tower system with an external collector using a water container. Case 3 is a solar tower system with an external collector using a wax container, and all cases were operating at a solar source during the daytime. The velocity results were predicted numerically and presented for solar intensity ranges from 50 to 1050 W/m² with increasing 100 W/m². The maximum velocity values identified of three cases: normal, Model-A, and Model-B were 3.32, 3.8, and 4.2 m/s, respectively, at solar radiation of 1050 W/m², as shown in Figure 3. These outcomes occur in the ventilation hatch between the closed space and the chimney. The mean percentage of increasing air velocity between the numerical results of Model-A and Model-B from the normal model is 18.9 % and 11.4%, respectively.

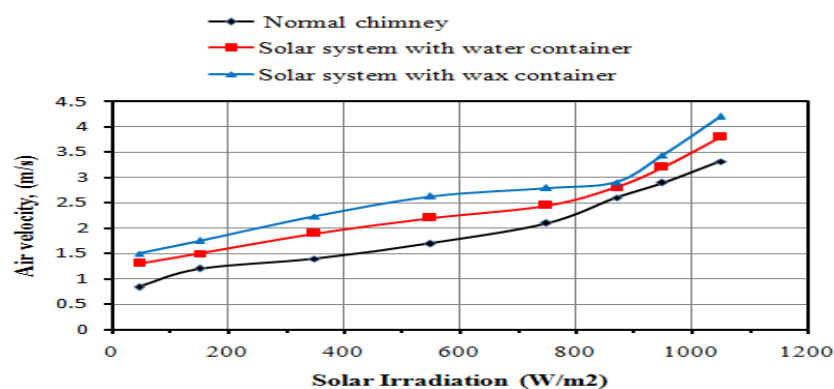


Figure 3. Air velocity at the ventilation hatch, for normal chimney [10], solar system with water and wax containers.

The results showed that the contour maps for air velocity at maximum solar irradiation varied collector design with different thermal storage units; water container (Model-A) and wax container (Model-B), as shown in Figure 4. The air velocity at the ventilation hatch (Model-B) was the maximum value compared with other models. This is because the air in a solar collector with a wax container (Model-B) will have higher internal energy as it gains more thermal energy, which stimulates the buoyancy forces.

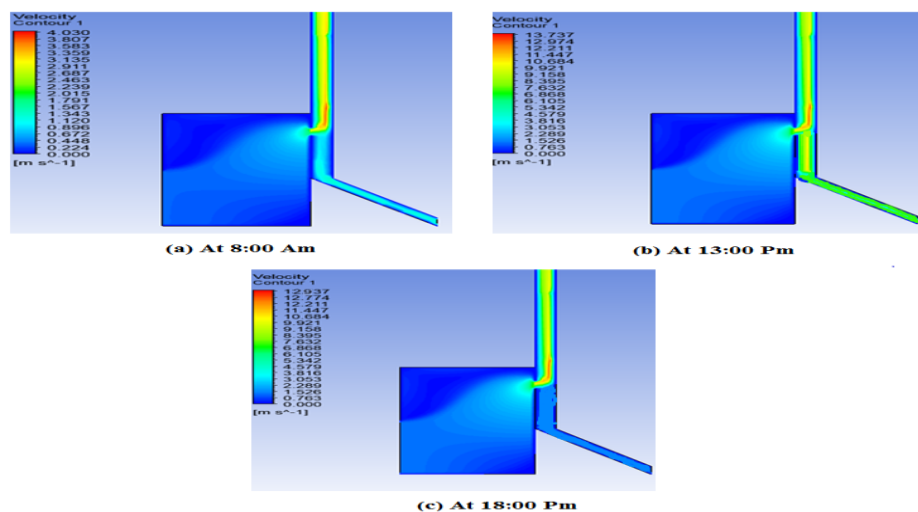


Figure 4. Velocity contours for the solar power tower system for models A and B at daytime with: (a) at 8:00 Am, (b) at 13:00 Pm, and (c) at 18:00 Pm.

The solar ventilation system's efficiency is presented by the overall thermal behavior in terms of indicator (air mass flow rate $\times$ air temperature rise [kg/s.K]). Figure 5 explained that the solar ventilation system's thermal performance with a wax container is better in the daytime hours. This model's improvement is due to an increase in the storage energy gained from solar radiation during daylight hours, during which solar radiation continues to increase. Therefore, the wax container has been improved compared to the normal chimney model [10] and the water container system, especially in the afternoons. The mean percentage of increasing collector's efficiency between the numerical results of Model-A and Model-B from the normal model is 8.4 % and 5.3%, respectively.

Figure 6 illustrate the temperature contours as identified by the computational simulation for varied collector design with different thermal storage units; water container (Model-A) and wax container (Model-B); the simulation indicates that the temperatures are around 51°C for normal chimney [10], 54°C, and 52.4°C for thermal storage units; water and wax containers, respectively. The air temperature rises, at 1 pm, were 17°C, 19.3°C, and 21.4°C. Increasing the thermal absorbent of the thermal storage unit in the solar collector system increases the range of heating for the airflow inside the collector, contributing to the increase in kinetic energy with increasing the air temperature.

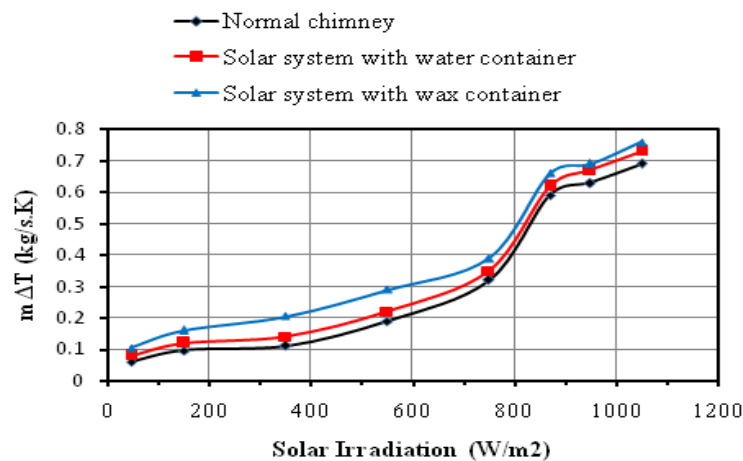


Figure 5. The performance of Solar power tower system for the different models.

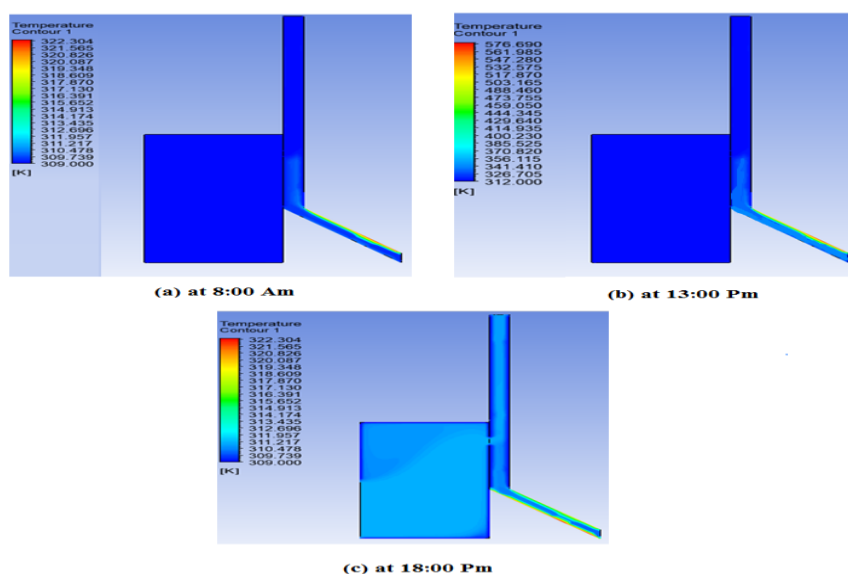


Figure 6. Temperature contours for the solar power tower system for models A and B at daytime with: (a) at 8:00 am, (b) at 13:00 pm, and (c) at 18:00 pm.

5. Conclusions

Numerical modeling for a solar power tower system to closed space ventilation is studied in this paper. The analytic has been conducted with two solar collectors with different thermal storage units; water and wax containers. The trend of simulation results is consistent with that of literature data. Results demonstrate that increasing thermal absorbance (wax container) of the solar collector system's thermal storage unit enhances system performance. For increases, the range of heating for the air flows inside the collector, which contributes to the increase in kinetic energy with increasing the air temperature. The air velocity in the ventilation hatch between closed space and chimney increases with increasing thermal absorbance of the solar collector's thermal storage unit. The temperatures are around 51°C for normal chimney [10], 54°C, and 52.4°C for thermal storage units; water and wax containers, respectively. The air temperature rises, at 1 Pm, were 17°C, 19.3°C, and 21.4°C. The mean percentage of increasing collector's efficiency between the numerical results of Model-A and Model-B from the normal model is 8.4 % and 5.3%, respectively. It is strongly recommended to envisage the turbulent flow within a solar collector with the different heat storage materials. Further studies could continue elucidating the exact physical basis for the observed correction of the heat transfer process. All of the tests presented in this work were for ventilation.

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