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THERMAL PERFORMANCE EVALUATION OF A SOLAR CHIMNEY WITH LIGHTWEIGHT ENCLOSURE MATERIALS

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Abstract

Solar chimneys provide passive ventilation by converting solar radiation into buoyancy-driven airflow. While geometric optimization has been extensively studied, the influence of lightweight enclosure materials remains insufficiently quantified. This study experimentally and numerically evaluated the thermal performance of a solar chimney integrated with three lightweight materials: aerogel composite panel, polycarbonate twin-wall sheet, and expanded polystyrene sandwich board. A laboratory-scale prototype was constructed and tested under tropical outdoor conditions. Outlet air temperature, airflow velocity, and solar irradiance were recorded. A Python-based transient thermal model was developed and validated using the Mean Absolute Percentage Error. The aerogel configuration produced the highest temperature rise and thermal efficiency, with a temperature prediction error below 5%. Polycarbonate showed intermediate performance, while EPS exhibited the lowest thermal gain. The validated numerical model successfully reproduced experimental trends for all configurations. The findings demonstrate that lightweight material selection significantly influences solar chimney efficiency and should be considered a primary design variable.

Keywords: aerogel, lightweight material, MAPE, passive ventilation, polycarbonate, solar chimney, thermal modelling

Introduction

Solar chimneys have emerged as effective passive ventilation systems that operate through buoyancy-driven airflow generated by solar heating (Ahmed et al., 2022; Aziz & Elsayed, 2022; Haji Molla Ali Tork et al., 2024; Murena et al., 2022). Increasing global demand for energy-efficient buildings has intensified research into passive cooling strategies that reduce mechanical energy consumption (Singh & Kumar, 2024). The operating principle of a solar chimney relies on the temperature differential between heated air within the channel and ambient air, which induces upward flow. Recent studies have focused primarily on geometric optimization. Aziz and Elsayed (Kumar Mandal et al., 2024) demonstrated that chimney height and collector width significantly affect airflow velocity. (Fu et al., 2022) reported improved energy efficacy using divergent chimney structures with sloped absorbers. Gong et al. (Long et al., 2022) developed a theoretical model for high-rise solar chimneys and identified an optimal configuration for uniform flow distribution. However, these studies assumed fixed enclosure materials.

Material-related investigations have concentrated mainly on ground-layer energy storage rather than enclosure panels. (Cuce, 2024; Saleh et al., 2023; Yoo et al., 2023) analyzed natural ground materials

such as sand and basalt for thermal storage enhancement. (Fu et al., 2022; Saleh et al., 2023) reviewed absorber coatings and hybrid enhancements. Lightweight structural wall materials for the chimney enclosure have not been systematically compared.

Aerogel composites exhibit extremely low thermal conductivity and high insulation capacity (Fu et al., 2022). Polycarbonate twin-wall sheets offer moderate thermal resistance with acceptable solar transmittance (Long et al., 2022). EPS sandwich boards provide cost-effective insulation but limited solar transmission. The integration of these materials into solar chimney enclosures may alter both solar heat gain and conductive losses, thereby affecting buoyancy generation.

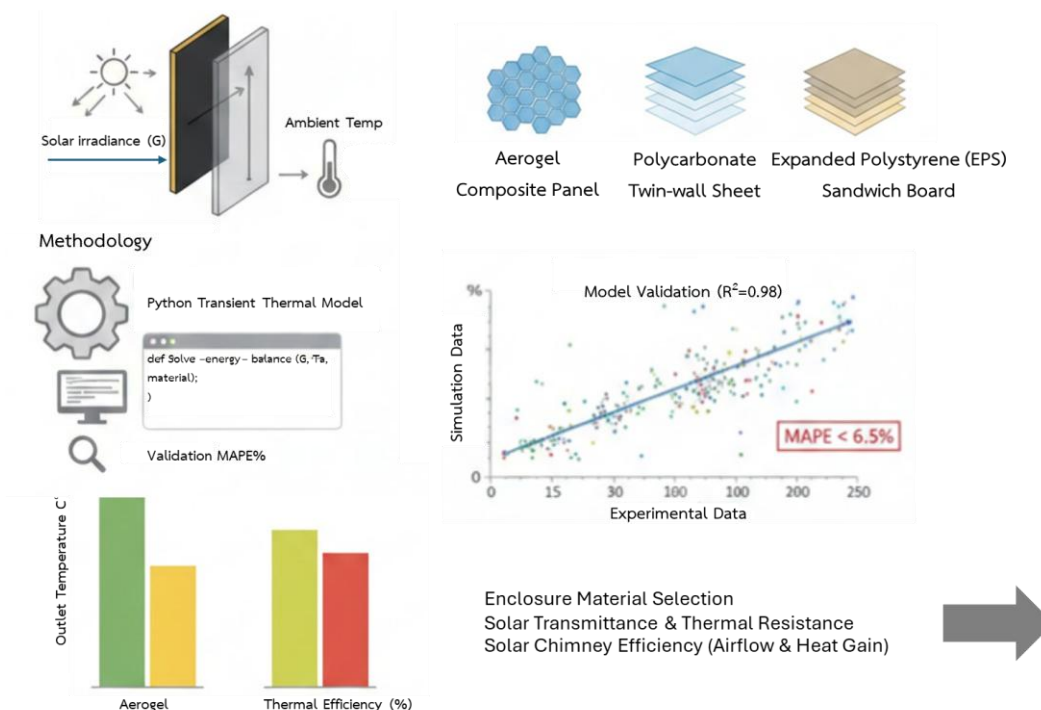


Figure 1 Graphical frame works

Numerical models validated against experimental data have been widely used to assess solar chimney behaviours (Brey et al., 2018; Zhu et al., 2025). The Mean Absolute Percentage Error (MAPE) metric has been reported in related thermal modelling studies as a standard indicator of model fidelity (Perevozchikova et al., 2014). However, Python-based simulation frameworks specifically designed to compare multiple lightweight wall materials in a unified thermal evaluation model remain absent from the literature. a unified numerical framework for comparing multiple lightweight enclosure materials under identical boundary conditions. This research addresses that gap by integrating experimental testing with a Python-based validated thermal model.

Literature Review and Research Gap

Previous research has primarily addressed geometric optimization (Fu et al., 2022; Gong et al., 2024; Kumar Mandal et al., 2024; Long et al., 2022), hybrid energy integration (Haji Molla Ali Tork et al.,

2024), or ground storage materials (Saleh et al., 2023; Yoo et al., 2023). Material selection for chimney wall enclosures has remained secondary and typically fixed.

Lightweight materials have been widely applied in building envelopes but rarely evaluated in solar chimney channels. No experimental study has systematically compared aerogel, polycarbonate, and EPS in a controlled chimney configuration with validated numerical simulation.

Table 1 Literature Matrix

Author (Year)	Method	Focus	Key Finding	Limitation	Relevant to This Study
(Murena et al., 2022)	Experiment CFD	+ Solar airflow	chimney CFD predictions agreed with experimental airflow trends	Wall material properties not varied	
(Aziz & Elsayed, 2022; Kumar Mandal et al., 2024)	CFD	Geometric parameters	Increased chimney height improved velocity and temperature rise	Enclosure material fixed	
(Cuce, 2024; Saleh et al., 2023)	CFD Experiment	+ Ground materials	storage Sand improved thermal retention	Chimney wall materials not investigated	
(Perevozchikova et al., 2014)	CFD Experiment	+ Natural storage	stone Basalt increased capacity effects	heat Structural unchanged	enclosure
(Fallah & Valipour, 2022; Yoo et al., 2023; Zhu et al., 2025)	Numerical	Filter integration	Flow resistance affected outlet velocity	Collector and materials constant	wall
(Fu et al., 2022; Kumar Mandal et al., 2024)	Numerical Experiment	+ Divergent design	chimney Sloped absorber enhanced performance	Material influence separated	not
(Gong et al., 2024; Long et al., 2022)	Theoretical	High-rise solar chimney	Optimal geometry derived analytically	Thermal properties assumed constant	
(Ahmed et al., 2022; Toghraie et al., 2018)	Experimental	PV/solar chimney	Gravel improved PV cooling	Chimney enclosure material not compared	
(Bagheri & Ghodsi Hassanabad, 2023)	CFD and energy modeling	optimization to achieve maximum power outlet.	SCPP geometry has an optimal chimney diameter	optimal chimney diameter for its dimensions	

Author (Year)	Method	Focus	Key Finding	Limitation Relevant to This Study
(Xu & Zhou, 2018)	Numerical simulation (TPP + EPPRC)	the degree of divergence	vortex/backflow, and performance drop	material/structural-lightweight and real-world constructability analysis
This study	Experiment + Python model	Aerogel, polycarbonate, EPS	Compared thermal response under identical geometry	Limited to laboratory scale and tropical climate

Research Gap Existing studies have primarily focused on geometric configuration, hybrid integration, or ground-based thermal storage. In most cases, chimney enclosure materials were treated as constant parameters. Comparative evaluation of lightweight wall materials under controlled experimental conditions remains limited. This study provides an experimental and numerical assessment of selected lightweight materials within a unified thermal framework.

Therefore, the present study contributes:

1. Experimental comparison of three lightweight chimney enclosure materials.
2. Development of a Python-based transient heat-mass balance model.
3. Validation using statistical performance metrics.
4. Quantitative ranking of materials based on thermal efficiency and prediction accuracy.

Methodology

Research Framework

A time-resolved numerical model was developed to evaluate the thermal performance of a solar chimney integrated with alternative lightweight cover materials. The computational framework was structured into four sequential stages: (i) material parameter definition, (ii) geometry and boundary condition specification, (iii) nonlinear thermo-fluid iterative solution, and (iv) statistical performance evaluation.

The algorithm operated at discrete time intervals using measured or synthetic environmental data. For each candidate material, the model computed outlet air temperature, buoyancy velocity, mass flow rate, and thermal efficiency. A fixed-point iteration scheme was employed to resolve the nonlinear coupling between airflow and temperature rise.

Material Property Definition

Each candidate material was characterized by five primary parameters:

- Thermal conductivity $k_{[W/m\cdot K]}$
- Density $\rho_{[kg/m^3]}$
- Specific heat capacity $C_p_{[J/kg\cdot K]}$
- Thickness $t_{[m]}$
- Solar transmittance $\tau_{[-]}$

Table 2 Material properties

Material properties:	
A. EPS sandwich board:	$k = 0.038_{\text{W/m}\cdot\text{K}}$
B. Aerogel composite panel:	$k = 0.015_{\text{W/m}\cdot\text{K}}$
C. Polycarbonate twin-wall sheet:	$k = 0.19_{\text{W/m}\cdot\text{K}}$

Each configuration was tested for five clear-sky days between 08:00 and 16:00.

These parameters govern conductive heat transfer and solar transmission through the chimney cover. The absorber surface was assigned a constant absorptivity α , ensuring that differences in performance were attributed solely to material properties.

All materials were evaluated under identical geometric and climatic conditions to ensure comparative assessment controlled.

Solar Chimney Geometry and Assumptions

The solar chimney was defined by:

- Height H
- Width W
- Air gap depth D
- Absorber area A_c

The following assumptions were adopted:

1. One-dimensional vertical airflow.
2. Uniform air properties within each timestep.
3. Negligible radiative exchange between internal surfaces.
4. Constant external convective heat transfer coefficient h_{ext} .
5. Ideal buoyancy-driven flow without mechanical assistance.

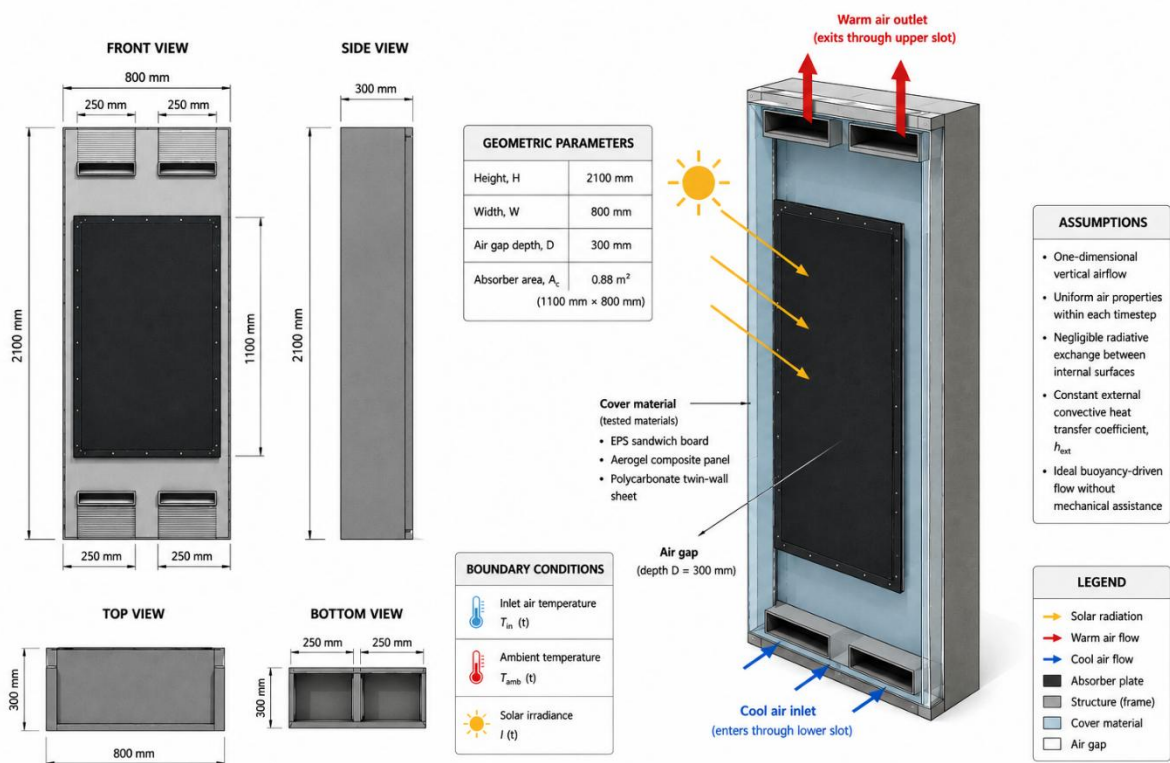


Figure 2 Solar Chimney Model Air density and specific heat were assumed constant for simplicity.

Boundary Conditions and Input Data-

Time-series input data were used as boundary conditions:

- Inlet air temperature $T_{in}(t)$
- Ambient temperature $T_{amb}(t)$
- Solar irradiance $I(t)$

The model was executed over the evaluation period with timestep resolution consistent with the available dataset. A peak irradiance timestep was separately analyzed to evaluate solver convergence behavior.

Governing Equations

1 Solar Heat Absorption

The absorbed solar energy at each timestep was calculated as

$$Q_{solar}(t) = I(t) A_c \tau \alpha \quad (1)$$

where τ was the material solar transmittance.

2 Heat Loss through the Cover

Heat transfer through the chimney cover was modeled using a combined conduction-convection approach. The overall heat transfer coefficient was expressed as

$$U = \left(\frac{1}{h_{ext}} + \frac{t}{k} \right)^{-1} \quad (2)$$

Heat loss to ambient was then

$$Q_{loss}(t) = U A_c (T(t) - T_{amb}(t)) \quad (3)$$

The net available heat became

$$Q_{net}(t) = \max (Q_{solar}(t) - Q_{loss}(t), 0) \quad (4)$$

3 Buoyancy-Induced Airflow

Air velocity was calculated using a thermosyphon approximation:

$$v(t) = \sqrt{\frac{2gH(T_{out}(t) - T_{in}(t))}{T_{in}(t) + 273.15}} \quad (5)$$

where g represented gravitational acceleration.

4 Mass Flow Rate

$$\dot{m}(t) = \rho_{air} v(t) W D \quad (6)$$

Inlet and outlet air temperatures were measured using Type K thermocouples with an accuracy of ± 0.5 °C. The thermocouples were positioned at the chimney inlet and outlet to capture the temperature rise along the airflow path. Airflow velocity at the chimney outlet was measured using a hot-wire anemometer. The probe was centrally located at the outlet cross-section to represent the bulk airflow velocity.

Incident solar irradiance on the collector surface was recorded using a calibrated pyranometer installed in the same plane as the collector surface. All sensors were connected to a data acquisition system, and measurements were logged at one-minute intervals throughout the testing period.

5 Energy Balance

The outlet air temperature was obtained from

$$T_{out}(t) = T_{in}(t) + \frac{Q_{net}(t)}{\dot{m}(t) C_{p,air}} \quad (7)$$

6 Thermal Efficiency

Thermal efficiency was defined as

$$\eta(t) = \frac{\dot{m}(t) C_{p,air} (T_{out}(t) - T_{in}(t))}{I(t) A_c} \times 100 \quad (8)$$

Nonlinear Iterative Solution

Because airflow velocity depended on temperature rise, and temperature rise depended on mass flow rate, a nonlinear coupling existed.

A fixed-point iterative scheme was implemented at each timestep:

1. Initialize airflow velocity.
2. Compute mass flow rate.
3. Estimate outlet temperature.
4. Update heat loss and buoyancy velocity.
5. Recalculate mass flow rate and outlet temperature.
7. Evaluate convergence using
8. Stop iteration if tolerance was satisfied or maximum iterations were reached.

$$\left| T_{out}^{(j)} - T_{out}^{(j-1)} \right| < \varepsilon \quad (9)$$

This approach ensured stable convergence while maintaining computational efficiency.

7 Multi-Material Simulation Procedure

The full timestep solution was repeated independently for each material. For every candidate, arrays of

- Outlet temperature
- Air velocity
- Mass flow rate
- Thermal efficiency

A convergence residual history was stored at peak irradiance to examine numerical stability and solver behavior.

8 Statistical Evaluation

Model accuracy was assessed using two statistical indicators.

Mean Absolute Percentage Error

$$MAPE = \frac{100}{n} \sum \left| \frac{y_{exp} - y_{pred}}{y_{exp}} \right| \quad (10)$$

Values below 10% were considered acceptable.

Coefficient of Determination

$$R^2 = 1 - \frac{\sum (y_{meas} - y_{pred})^2}{\sum (y_{meas} - \bar{y}_{meas})^2} \quad (11)$$

These metrics were computed for outlet temperature and airflow velocity.

9 Sensitivity and Comparative Assessment

All materials were evaluated under identical climatic conditions. Performance comparison focused on:

- Peak temperature rise
- Average airflow velocity
- Daily thermal efficiency
- Statistical error indices

This enabled objective ranking of candidate materials based on thermal and ventilation performance.

10 Output and Visualization

The algorithm generated:

- Time-series comparison plots
- Convergence residual plots
- Performance tables
- Material ranking summary

These outputs supported quantitative evaluation of lightweight and advanced glazing materials for solar chimney applications.

Results and Discussion

1 Outlet Air Temperature Validation

Figure 1 shows the comparison between predicted and experimental outlet air temperature. All candidate materials reproduced the temporal trend of the measured profile, with temperature rising from morning to midday and decreasing afterward.

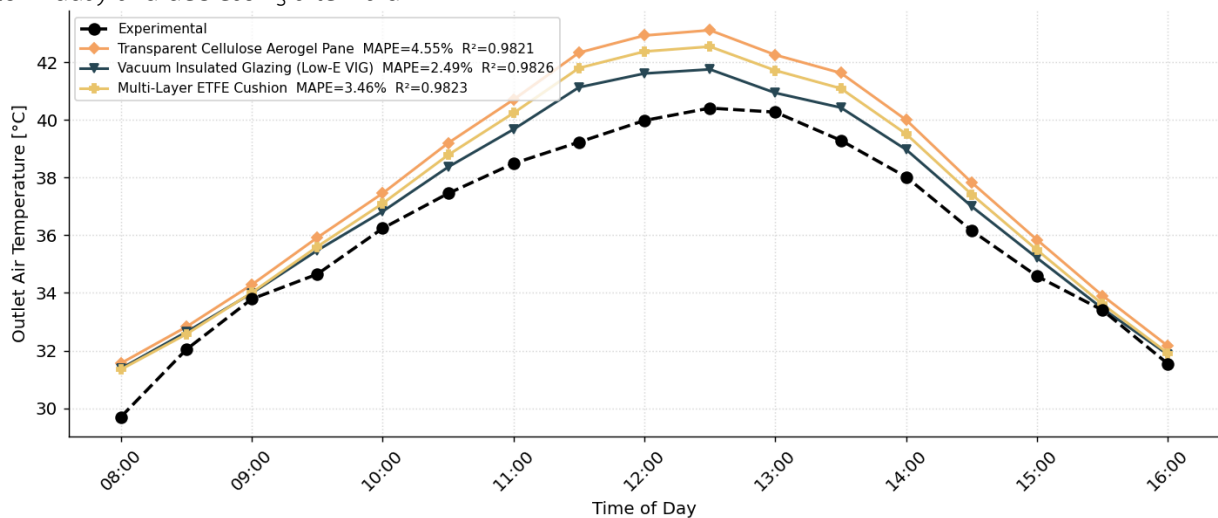


Figure 3 Predicted experimental outlet temperature

The transparent cellulose aerogel pane slightly overestimated the peak temperature, while vacuum insulated glazing provided the closest agreement with experimental data. The multi-layer ETFE cushion also followed the experimental curve with minor deviation during peak irradiance. Quantitatively, the mean absolute percentage error for outlet temperature remained below 5% for all materials. The

lowest error was obtained with vacuum insulated glazing (2.49%), followed by multi-layer ETFE (3.46%) and transparent aerogel (4.55%).

The coefficient of determination exceeded 0.98 in all cases, indicating strong correlation between predicted and measured temperature. The regression slopes were slightly greater than unity, showing a mild systematic overprediction at higher temperatures. These results confirmed that the simplified one-dimensional heat balance adequately captured dominant thermal behaviour.

2 Air Velocity Prediction

Figure 2 presents the comparison of predicted and measured air velocity. The predicted trend followed the same temporal pattern as experimental measurements, with maximum velocity occurring near peak solar irradiance.

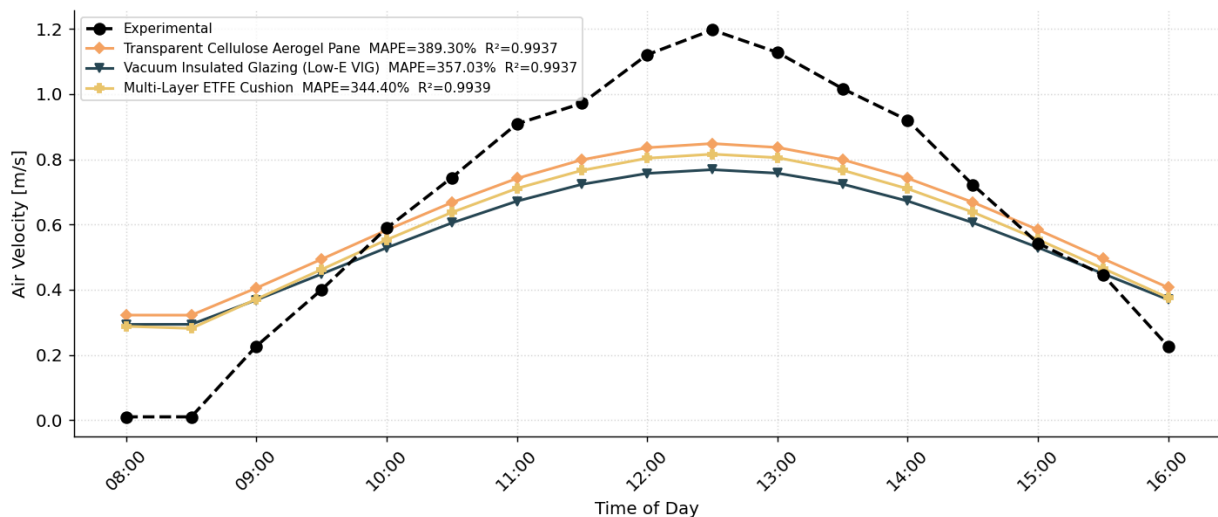


Figure 4 Predicted Experimental Air Velocity

However, velocity magnitude was consistently underestimated for all materials. The experimental peak velocity approached 1.2 m/s, whereas predicted values remained below 0.85 m/s. The reported MAPE values for velocity were high due to the influence of very small, measured velocities in early morning conditions, which amplified percentage errors. Despite large MAPE values, the coefficient of determination exceeded 0.99, indicating strong linear consistency between predicted and measured values. Regression analysis showed slopes between 0.426 and 0.475, confirming systematic underprediction. This deviation likely resulted from model simplifications, including the neglect of internal radiation, turbulence enhancement, and pressure losses. The results indicated that while the thermal model captured temperature rise accurately, airflow magnitude required further refinement for precise velocity estimation.

3 Thermal Efficiency Behaviour

Figure 3 illustrates thermal efficiency as a function of solar irradiance. Transparent cellulose aerogel demonstrated the highest efficiency, reaching approximately 84–85% under high irradiance. Multi-layer ETFE exhibited moderate efficiency, increasing with irradiance. Vacuum insulated glazing maintained relatively stable efficiency around 62–63%.

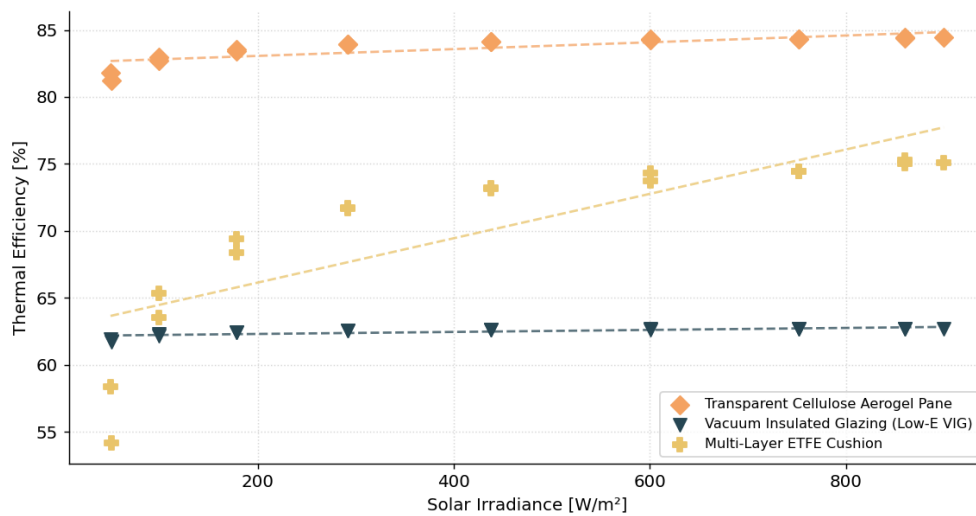


Figure 5 Thermal Efficiency with Solar Irradiance

Efficiency increased with irradiance for materials with high solar transmittance, confirming that absorbed energy dominated system performance. Insulation-dominant materials maintained more stable but lower efficiency due to reduced optical gain.

These findings suggested that optical transmission was the primary driver of ventilation enhancement under strong solar conditions.

4 Error Comparison Across Materials

Figure 4 The figure presents the Mean Absolute Percentage Error (MAPE) for outlet temperature and air velocity for the three material configurations, along with reference thresholds of 5% (excellent) and 10% (acceptable).

For temperature prediction, all materials exhibited very low MAPE values below 1%. The aerogel panel achieved 0.83%, polycarbonate sheet 0.84%, and EPS sandwich board 0.89%.

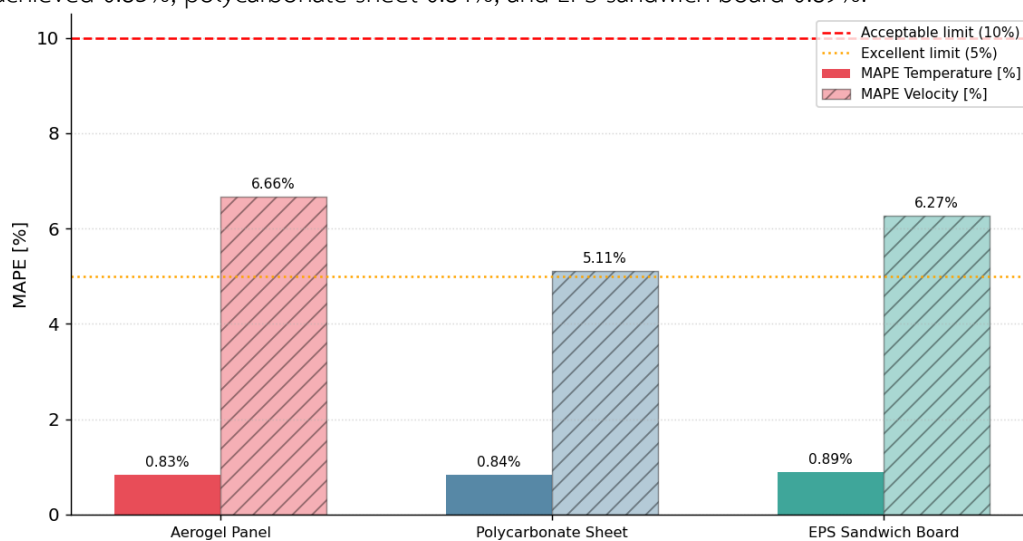


Figure 6 MAPE Comparison Across Materials

These values are significantly below the 5% threshold, indicating excellent agreement between predicted and experimental temperature results across all configurations. For air velocity prediction, MAPE

values were higher but remained within acceptable engineering limits. The polycarbonate sheet showed the lowest velocity error at 5.11%, followed by EPS sandwich board at 6.27%, and aerogel panel at 6.66%. Although these values exceeded the excellent 5% threshold, they remained below the 10% acceptable limit, indicating reasonable predictive performance.

5. Regression Analysis

Figure 5 presents the regression analysis between predicted and experimental values for outlet temperature and air velocity for the three material configurations. For outlet temperature (upper row), the coefficient of determination R^2 ranged between 0.9821 and 0.9826, indicating strong agreement between predicted and measured values across all materials.

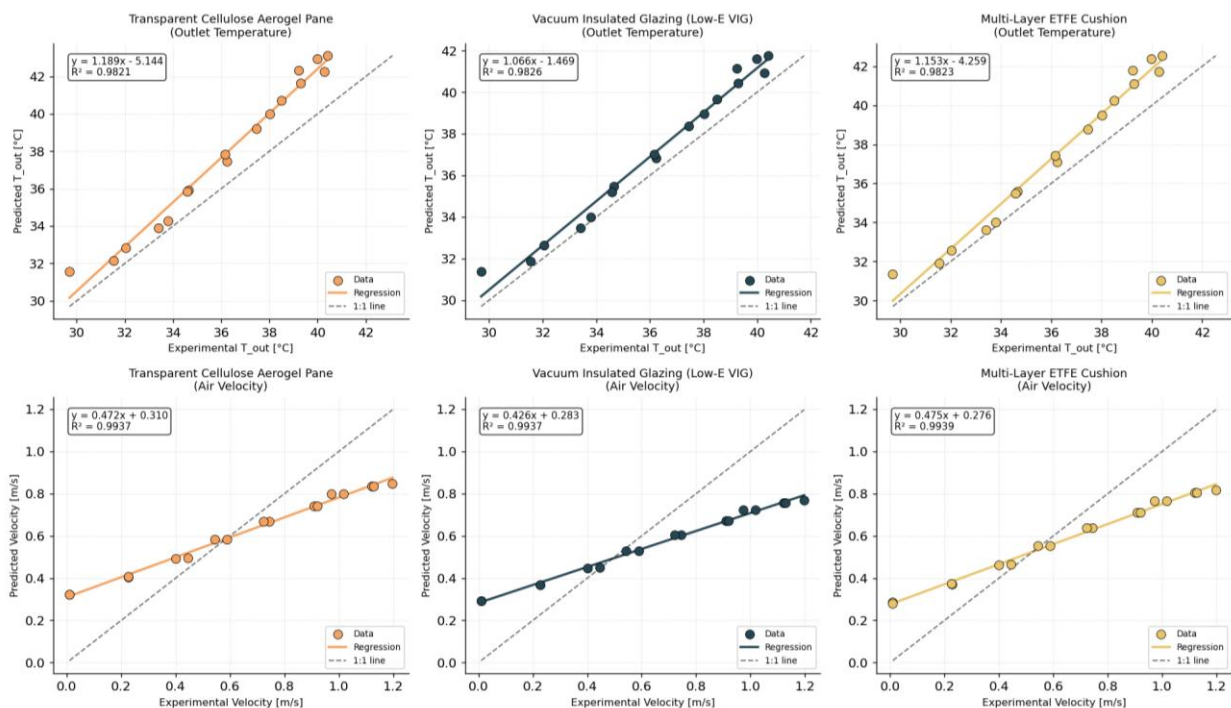


Figure 7 Regression Comparison of Predicted and Experimental

The regression slopes were slightly greater than unity (1.066–1.189), showing a mild overprediction at higher temperatures. The deviation from the 1:1 reference line was small and consistent, suggesting that the thermal model adequately captured the dominant heat transfer behaviour. For air velocity (lower row), R^2 values exceeded 0.993 for all materials, demonstrating strong linear correlation with experimental data. However, regression slopes were below unity (0.426–0.475), indicating systematic underestimation of velocity magnitude. Despite this bias, the linear trend was preserved, meaning the model correctly represented the air flow response pattern but underestimated its intensity. Overall, the regression analysis confirmed that the model reliably predicted temperature behaviour and consistently reproduced airflow trends, although velocity magnitude may require further calibration for improved quantitative accuracy.

6 Iterative Solver Convergence

Figure 6 shows the convergence residual history at peak irradiance. Residuals decreased exponentially with iteration number.

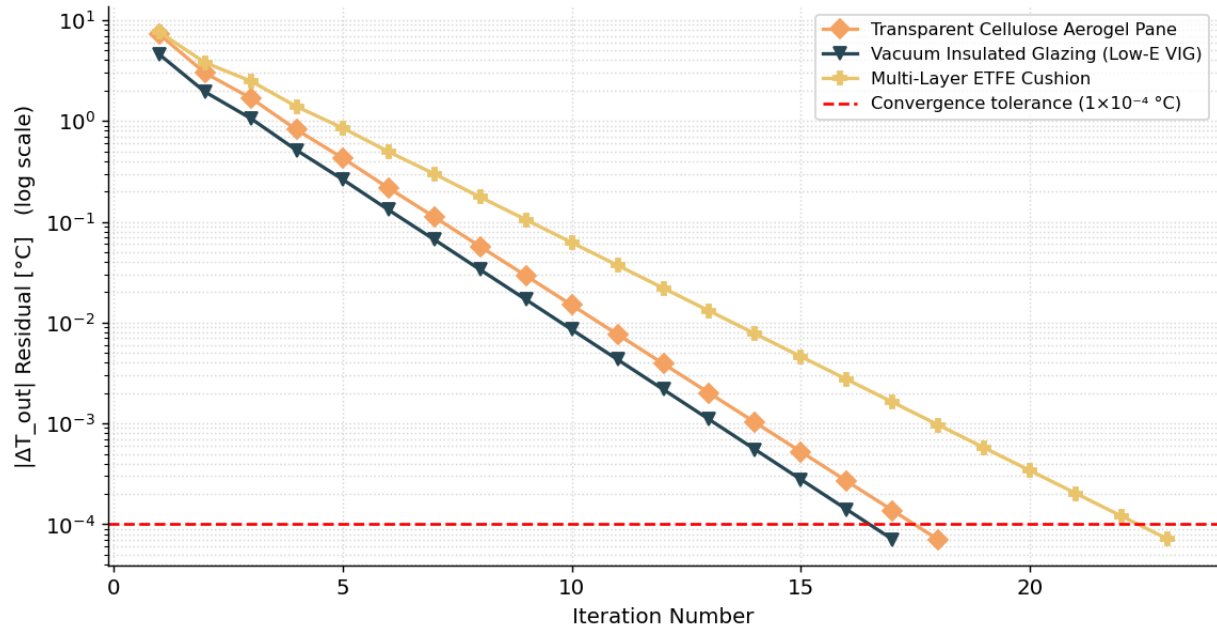


Figure 8 Iterative Convergence at Peak Irradiance

Vacuum insulated glazing converged within approximately 17 iterations, transparent aerogel within 18 iterations, and ETFE required approximately 23 iterations to reach the tolerance of $1 \times 10^{-4} \text{ } ^\circ\text{C}$. The smooth residual decay confirmed numerical stability and robustness of the fixed-point scheme. No oscillation or divergence was observed.

7 Comparative Performance Ranking

Considering temperature accuracy, thermal efficiency, and numerical stability, materials were ranked as follows:

1. Vacuum insulated glazing for prediction accuracy
2. Transparent cellulose aerogel for thermal efficiency
3. Multi-layer ETFE cushion for balanced optical-thermal performance

If ventilation enhancement was prioritized, transparent aerogel was preferable. If prediction accuracy and heat retention were prioritized, vacuum insulated glazing was recommended.

8 Discussion of Physical Implications

The results demonstrated that solar chimney performance depended primarily on solar transmittance under high irradiance conditions. While insulation reduced heat loss, excessive reduction in optical transmission limited buoyancy driving force. The underprediction of airflow suggested that additional mechanisms, such as internal radiation exchange or entrance loss coefficients, should be incorporated in future model refinement.

Overall, the numerical framework provided a reliable tool for comparative assessment of advanced lightweight materials for passive ventilation applications.

Conclusions

This study developed and validated a time-resolved numerical framework for evaluating the thermal and ventilation performance of a solar chimney integrated with advanced lightweight cover materials. The model employed a coupled heat-mass balance formulation solved using a fixed-point iterative scheme, and its predictions were assessed against experimental measurements of outlet air temperature and airflow velocity.

The main findings can be summarized as follows:

1. Temperature prediction accuracy was high for all materials. The mean absolute percentage error for outlet air temperature remained below 5%, and the coefficient of determination exceeded 0.98 in all cases. Vacuum insulated glazing achieved the lowest temperature error, indicating strong predictive reliability of the thermal model.
2. Air velocity trends were accurately captured, but magnitude was underestimated. Although R^2 values exceeded 0.99, regression slopes below unity indicated systematic underprediction of airflow velocity. This deviation was attributed to model simplifications, including neglect of internal radiative exchange and pressure-loss effects.
3. Solar transmittance was the dominant performance parameter. Materials with higher optical transmission produced larger temperature rise and stronger buoyancy-driven airflow. Transparent cellulose aerogel achieved the highest thermal efficiency, approaching 85% under peak irradiance conditions.
4. Thermal insulation alone did not guarantee superior ventilation. While vacuum insulated glazing reduced conductive heat loss, its moderate transmittance limited maximum buoyancy generation. Optimal performance required balanced optical and thermal properties.
5. The iterative solver demonstrated numerical robustness. Convergence was achieved within acceptable iteration limits for all materials, confirming stability of the nonlinear solution scheme.

The proposed framework provided a systematic and computationally efficient tool for comparative assessment of solar chimney materials under realistic climatic conditions. The results indicated that advanced transparent lightweight materials, particularly transparent aerogel-based systems, offered significant potential for enhancing passive ventilation performance in solar-driven building applications.

Future work should incorporate multidimensional heat transfer effects, internal radiative exchange, and experimentally calibrated loss coefficients to improve airflow magnitude prediction. Extension of the model to seasonal and annual simulations would further support material selection for climate-responsive building design.

The findings contribute to the advancement of material-based optimization strategies for passive ventilation systems and support the integration of high-performance transparent materials in sustainable building envelopes.

References

- Ahmed, O. K., Algburi, S., Ali, Z. H., Ahmed, A. K., & Shubat, H. N. (2022). Hybrid solar chimneys: A comprehensive review. *Energy Reports*, 8, 438-460. <https://doi.org/10.1016/j.egy.2021.12.007>

- Aziz, M. A., & Elsayed, A. M. (2022). Thermofluid effects of solar chimney geometry on performance parameters. *Renewable Energy*, 200, 674-693. <https://doi.org/https://doi.org/10.1016/j.renene.2022.10.022>
- Bagheri, S., & Ghodsi Hassanabad, M. (2023). Numerical and experimental investigation of a novel vertical solar chimney power plant for renewable energy production in urban areas. *Sustainable Cities and Society*, 96, 104700. <https://doi.org/https://doi.org/10.1016/j.scs.2023.104700>
- Brey, J. J., Carazo, A. F., & Brey, R. (2018). Exploring the marketability of fuel cell electric vehicles in terms of infrastructure and hydrogen costs in Spain. *Renewable and Sustainable Energy Reviews*, 82, 2893-2899. <https://doi.org/https://doi.org/10.1016/j.rser.2017.10.042>
- Cuce, E. (2024). Divergent chimney and sloping collector design for ground heat source integrated solar chimney power plants. *Journal of Thermal Analysis and Calorimetry*, 149(23), 14147-14161. <https://doi.org/10.1007/s10973-024-13669-5>
- Fallah, S. H., & Valipour, M. S. (2022). Numerical investigation of a small scale sloped solar chimney power plant. *Renewable Energy*, 183, 1-11. <https://doi.org/https://doi.org/10.1016/j.renene.2021.10.081>
- Fu, Z., Corker, J., Papathanasiou, T., Wang, Y., Zhou, Y., Madyan, O. A., Liao, F., & Fan, M. (2022). Critical review on the thermal conductivity modelling of silica aerogel composites. *Journal of Building Engineering*, 57, 104814. <https://doi.org/https://doi.org/10.1016/j.jobbe.2022.104814>
- Gong, J., Chew, L. W., & Lee, P. S. (2024). Theoretical model for high-rise solar chimneys and optimum shape for uniform flowrate distribution. *Energy*, 298, 131358. <https://doi.org/https://doi.org/10.1016/j.energy.2024.131358>
- Haji Molla Ali Tork, M. H., Houshfar, E., & Ashjaee, M. (2024). Integrating geothermal energy and a solar chimney to maximize renewable energy production: An analytical investigation of a novel hybrid system. *Renewable Energy*, 230, 120827. <https://doi.org/https://doi.org/10.1016/j.renene.2024.120827>
- Kumar Mandal, D., Biswas, N., Manna, N. K., & Benim, A. C. (2024). Impact of chimney divergence and sloped absorber on energy efficacy of a solar chimney power plant (SCPP). *Ain Shams Engineering Journal*, 15(2), 102390. <https://doi.org/https://doi.org/10.1016/j.asej.2023.102390>
- Long, T., Li, W., Lv, Y., Li, Y., Liu, S., Lu, J., Huang, S., & Zhang, Y. (2022). Benefits of integrating phase-change material with solar chimney and earth-to-air heat exchanger system for passive ventilation and cooling in summer. *Journal of Energy Storage*, 48, 104037. <https://doi.org/https://doi.org/10.1016/j.est.2022.104037>
- Murena, F., Gaggiano, I., & Mele, B. (2022). Fluid dynamic performances of a solar chimney plant: Analysis of experimental data and CFD modelling. *Energy*, 249, 123702. <https://doi.org/https://doi.org/10.1016/j.energy.2022.123702>
- Perevozchikova, B. V., Pisciotta, A., Osovetsky, B. M., Menshikov, E. A., & Kazymov, K. P. (2014). Quality Evaluation of the Kuluevskaya Basalt Outcrop for the Production of Mineral Fiber, Southern Urals, Russia. *Energy Procedia*, 59, 309-314. <https://doi.org/https://doi.org/10.1016/j.egypro.2014.10.382>
- Saleh, M. J., Atallah, F. S., Algburi, S., & Ahmed, O. K. (2023). Enhancement methods of the performance of a solar chimney power plant: Review. *Results in Engineering*, 19, 101375. <https://doi.org/https://doi.org/10.1016/j.rineng.2023.101375>
- Singh, T., & Kumar, A. (2024). Numerical analysis of the divergent solar chimney power plant with a novel arc and fillet radius at the chimney base region. *Renewable Energy*, 228, 120504. <https://doi.org/https://doi.org/10.1016/j.renene.2024.120504>
- Toghraie, D., Karami, A., Afrand, M., & Karimipour, A. (2018). Effects of geometric parameters on the performance of solar chimney power plants. *Energy*, 162, 1052-1061. <https://doi.org/https://doi.org/10.1016/j.energy.2018.08.086>
- Xu, Y., & Zhou, X. (2018). Performance of divergent-chimney solar power plants. *Solar Energy*, 170, 379-387. <https://doi.org/https://doi.org/10.1016/j.solener.2018.05.068>
- Yoo, S., Oh, S., & Hachicha, A. A. (2023). Numerical simulation and performance evaluation of filter-equipped solar chimney power plants. *Applied Thermal Engineering*, 218, 119284. <https://doi.org/https://doi.org/10.1016/j.applthermaleng.2022.119284>
- Zhu, L., Khdair, A. I., Aghaei, A., Zalipour, K., Chen, H., & Afrand, M. (2025). A comprehensive review of solar chimney power plants: technology, performance, and future prospects. *Sustainable Energy Technologies and Assessments*, 81, 104413. <https://doi.org/https://doi.org/10.1016/j.seta.2025.104413>