

A Review on Solar Chimney Designs: Current Advances, Challenges and Future Perspectives

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Abstract: Solar chimneys, also known as solar updraft towers, have gained significant attention as a renewable energy technology for both ventilation and power generation. This paper presents a comprehensive review of the design aspects of solar chimneys, including their working principles, design parameters, performance evaluation, and recent advancements in the field. The objective is to provide a comprehensive overview of the current state of solar chimney design, identify challenges, and explore potential future directions.

Potential future research directions and emerging trends in solar chimney design are discussed. These include the development of advanced control strategies, integration with energy storage technologies, optimization algorithms for multi-objective design, and the exploration of novel materials for improved efficiency and durability. This review provides valuable insights into the current state of solar chimney design and highlights areas that require further research and development. Solar chimneys have the potential to play a significant role in sustainable energy systems, contributing to both ventilation and clean power generation. Continued advancements in design optimization and technological innovations will pave the way for the wider adoption of solar chimney systems and their integration into future energy landscapes.

1. Introduction

Solar power generating technologies harness the energy from sunlight and convert it into usable electricity. Here are some common solar powers generating technologies [1-4]:

- **Photovoltaic (PV) Cells:** PV cells, also known as solar cells, directly convert sunlight into electricity using the photovoltaic effect. When sunlight hits the cells, it excites the electrons, generating an electric current. PV cells are commonly made from silicon and are used in solar panels for residential, commercial, and utility-scale applications.
- **Concentrated Solar Power (CSP):** CSP uses mirrors or lenses to concentrate sunlight onto a receiver. The concentrated sunlight heats a working fluid, such as water or molten salt, which produces steam to drive a turbine and generate electricity. CSP systems are typically used in large-scale power plants and can store thermal energy for electricity generation during cloudy periods or at night.
- **Thin-Film Solar Cells:** Thin-film solar cells are made by depositing a thin layer of photovoltaic material onto a substrate. They are lightweight, flexible, and less expensive to produce compared to traditional silicon-based PV cells. Thin-film solar cells are used in a variety of applications, including solar panels, building-integrated photovoltaic (BIPV), and portable solar devices [1].
- **Solar Thermal Systems:** Solar thermal systems use sunlight to heat a fluid, such as water or air, for direct use or to generate electricity. These systems typically consist of solar collectors to absorb sunlight and transfer the heat to a working fluid. Solar thermal technologies can be used for water heating, space heating, and cooling applications.
- **Solar Chimneys:** A solar chimney, also known as a solar updraft tower, uses solar energy to create an updraft of air that drives turbines to generate electricity. It consists of a tall chimney-like structure with a large greenhouse-like collector area at the base. Sunlight heats the air under the collector, causing it to rise and create a pressure difference that drives the turbines [5].
- **Solar Ponds:** A solar pond is a large, shallow pool of saltwater that collects and stores solar energy. The pond has different layers with varying salt concentrations, which create a temperature gradient. Sunlight is absorbed by the lower layers and converted into heat, which can be used for various purposes, including electricity generation and water heating.
- **Floating Solar Power Plants:** Floating solar power plants are installations where solar panels are mounted on floating platforms on bodies of water, such as reservoirs, lakes, or oceans. These systems offer several advantages, such as reduced land requirements, increased efficiency due to the cooling effect of water, and the ability to utilize existing water infrastructure.

These are just a few examples of solar power generating technologies. Each technology has its own advantages, applications, and considerations depending on factors like cost, efficiency, scalability, and geographic location. The choice of technology depends on the specific requirements and conditions of a given project [8].

A solar chimney, also known as a solar updraft tower, is a renewable energy technology that utilizes solar energy to generate electricity. It consists of a tall chimney-like structure with a large greenhouse-like collector area at the base. The base of the solar chimney has a wide area covered with a transparent material, such as glass or plastic. This collector area is designed to absorb solar radiation and convert it into heat. Sunlight passes through the transparent material and heats up the air present in the collector area [9]. The air absorbs the solar energy and becomes warmer. As the air in the collector area heats up, it becomes less dense and starts to rise due to buoyancy. This creates an updraft of hot air inside the chimney. At the top of the chimney, turbines or generators are placed to capture the energy from the moving air. As the hot air rises, it flows through the turbines, causing them to rotate and generate electricity. After passing through the turbines, the air cools down and exits the chimney. The cooled air is then recirculated back into the collector area to be heated again, creating a continuous cycle. Solar chimneys are an interesting concept for harnessing solar energy and have been explored in various research and demonstration projects. While they have the potential to contribute to the renewable energy mix, further technological advancements and cost optimizations are needed for large-scale commercial viability.

Research in the design of solar chimneys is crucial for advancing the technology and unlocking its full potential as a renewable energy solution. Through ongoing research efforts, designers and engineers can optimize system performance, improve efficiency, and address the challenges associated with solar chimney design, thereby contributing to the broader adoption of this sustainable energy technology [10-14].

The aim of the literature review on solar chimney design is to provide a comprehensive overview of the existing research and knowledge in the field.

2. Previous research in the field

Many researchers around the world have introduced various projects or modifications to the conventional solar chimney to enhance its performance, expand its application, or develop or improve simulation models.

The literature review in this study is serving the purpose of identifying the main influencing factors and their effects on the performance of solar chimney when it is attached to a building. To ensure the comprehensiveness, several principles were followed during the literature review.

2.1 Influences of configuration

The term "height for wall solar chimney" refers to the vertical height of the chimney cavity. Without a doubt, height may enhance performance. There are several ways to describe this. The first is a result of an increase in ventilation rate brought on by a pressure differential that is magnified by a high chimney cavity [8]. The added heat gain is another aspect. Gan [2] observed a three-quarter increase in heat gains after increasing the wall height. The same finding has been reinforced by several studies. Test results indicate that the ventilation flow doubles when the chimney's height is doubled [9].

2.2 Cavity gap

For a roofing or wall solar chimney, the cavity gap, additionally referred to as chimney breadth or channel depth within the literature, is the depth of the roof duct or the separation between the interior wall and the exterior glass. The cavity gap has a significant impact on how well both solar chimneys work. Ong and Chow's experiments revealed that a 0.3 m cavity gap may offer 56% greater ventilation than one of 0.1 m. According to Halldorsson et al., the airflow rate increases steadily with increased cavity gap (0.1-0.6 m) while preserving all other circumstances. According to Balocco's internal model, the summertime overheating reduction improves from 7% to 27.5% as the cavity spacing climbs from 0.07 to 0.35 m.

Backward flow that occurs close to a vertical chimney cavity's outlet has a significant impact on the total mass flow rate through the cavity, and the depth of the backward flow's entry depends on the Rayleigh number [18].

Reverse flow was seen in an experimental setting with a 0.2 m cavity gap by Zhai et al. Imran et al.'s [10] numerical modelling with a 0.15 m cavity gap did not show reverse air flow circulation. According to an experiment by Ong and Chow [20], no reverse air flow circulation was seen even at a considerable separation of 0.3 m. Through a flow visualisation experiment, Chen et al. validated the reverse flow from the chimney outlet for a 0.4 m cavity gap.

2.3 Inlet and outlet areas

Air admission and escape are governed by inlet and outlet zones. The entrance and outlet sizes of earlier test rigs for roof solar chimneys are equal to the area of the cavity's horizontal cross section. This is since these test rigs are in the shape of boxes and are made up of two sets of parallel panels. In this case, the cavity gap can reflect some of the effects of the intake and outflow areas on performance.

2.4 Height/gap ratio

Height/gap ratio usually refers to the ratio between cavity height and gap for wall solar chimney, which is the ratio between cavity length and air gap for roof solar chimney. To determine the ideal height/gap ratio, previous studies have mostly been used. Both numerical models and testing led to the discovery of an optimal ratio of 10. Based on numerical modelling, Wang et al. reported that the ideal ratio is 10, which is reliant on inlet design but independent of solar radiation, in most of the simulated situations. Based on numerical modelling, Du et al. discovered that the ideal chimney length to cavity gap ratio for roof solar chimneys is 12.

Table 1. Summary of different research papers published in the field of solar chimney.

Year	Authors	Abstract summary	Intervention	Outcomes measured
2020	Leila Moosavi, Majid Zandi, Mokhtar Bidi, Ehsan Behroozizade, Iman Kazemi	The solar chimney coupled with a wind catcher and water spray system can provide reasonable thermal and airflow conditions for both floors without the need of wind force on a hot and sunny day.		Thermal Performance Ventilation Performance Cooling Potential Airflow Conditions Temperature Reduction Air Changes Per Hour (Ach) Energy Savings For Cooling Energy Savings For Ventilation
2020	Qingyuan Wang, Guomin Zhang, Wenyuan Li, Long Shi	The airflow rates through the solar chimney are largely hampered with a small cavity depth and inlet height under the external wind.	external wind	Optimum Cavity Depth Inlet Height/Area Solar Chimney Performance Airflow Rates Through The Solar Chimney Airflow Profiles
2018	Omer Khalil Ahmed, Abdullah Sabah Hussein	The total useful power produced by the system B is greater than the useful power produced from the system A.	new design of solar chimney	Thermal Gain Daily Average Of Electrical Power Kinetic Power Total Useful Power Produced
2018	Guomin Zhang, Long Shi	The performance of solar chimney can be enhanced with a high cavity, an appropriate cavity gap (usually 0.2-0.3 m), equivalent inlet and outlet area, and height/gap ratio of 10-15.		Performance Of Solar Chimney
2018	Long Shi, Guomin Zhang, Wei Yang,	A solar chimney is suggested with possible		Performance Of Solar

	Dongmei Huang, Xudong Cheng, Sujeeva Setunge	high cavity and solar radiation.		Chimney
2017	Esmail M. A. Mokheimer, Mohammad Raghieb Shakeel, Jihad Hassan Alsadah	A solar chimney formed with a 20 x 3 m south wall can be utilized to induce water evaporation of 625–1046 kg/day.	adding an external solar shield enclosing an air gap between it and the outer wall of the building to reduce the cooling load in buildings	Cooling Load Reduction Heat Gain Reduction Electrical Cooling Load Reduction Water Evaporation
2016	Somaye Asadi, Maryam Fakhari, Rima Fayaz, Akram Mahdavi Parsa	The solar chimney provides necessary ventilation rate for spaces attached to it.	different layouts of solar chimney in buildings	Ventilation Rate
2015	M. T. Esfidani, S. Raveshi, M. Shahsavari, A. Sedaghat	The performance of a solar chimney is estimated for changes in geometry and physical parameters such as chimney height, chimney diameter, radius collector and collector height.		Output Power Efficiency
2011	Xiaoqiang Zhai, Zhaopei Song, Ruzhu Wang	Solar chimney technology has been regarded as an effective and economical design method in low carbon buildings.		Heat Gain Reduction Natural Cooling Or Heating Operational Cost Reduction Energy Requirement Reduction Carbon Dioxide Emission Reduction Natural Ventilation Performance Improvement Better Indoor Thermal Comfort Cooling Effect Enhancement Ventilation Performance Enhancement
2007	S.D. Sharma, H. Kotani, Y. Kaneko, T. Yamanaka, K. Sagara	The integration of PCM storage inside the solar chimney is positive.	a solar chimney with a built in latent heat storage system using Sodium Sulfate Decahydrate as a Phase Change Material (PCM) for prolonging ventilation system operation until evening/night or even 24 hours	Airflow Rate Temperatures Of The Components Of The System
2007	D. J. Harris, N. Helwig	A south-facing chimney was optimum for the location chosen.	designing a solar chimney to induce ventilation in a building	Induced Ventilation Rate
1997	O. V. Ekechukwu, Brian Norton	The performance of the chimney was monitored extensively with and	effectiveness of a selectively absorbing surface in the solar	Performance Of The Solar Chimney

		without the selective surface in place.	chimney design	
1996	O. V. Ekechukwu, Brian Norton	A solar chimney for natural circulation solar energy dryers was monitored extensively.		Performance Of The Solar Chimney
1987	L. B. Mullett	The solar chimney is essentially a power generator of large scale.		Overall Efficiency

3. Conclusion and Future Work

Research in solar chimney design requires a multidisciplinary approach that encompasses various aspects of engineering, physics, and materials science. Based on the current review, here are some key research requirements in solar chimney design:

- **Fluid Dynamics Modelling:** Detailed computational fluid dynamics (CFD) simulations are required to understand the complex flow patterns, heat transfer mechanisms, and pressure distributions within the solar chimney system. Research should focus on improving the accuracy and reliability of CFD models to predict system performance and optimize design parameters.
- **Solar Radiation Analysis:** Accurate solar radiation analysis is crucial for designing efficient solar chimneys. Research should involve the use of advanced solar radiation models, satellite data, and ground-based measurements to assess solar resource availability, analyse shading effects, and optimize the collector's orientation and inclination angles.
- **Material Selection and Performance:** Research is needed to explore advanced materials with enhanced thermal conductivity, durability, and cost-effectiveness for solar chimney components. This includes investigating suitable materials for collectors, chimneys, heat exchangers, and insulation. Research should also focus on evaluating the long-term performance and stability of these materials under harsh environmental conditions.
- **Structural Analysis and Stability:** Thorough structural analysis is essential to ensure the stability, safety, and integrity of solar chimney designs. Research should investigate structural loads, wind effects, seismic considerations, and structural optimization techniques to develop robust and cost-effective designs that can withstand operational and environmental stresses.
- **Heat Transfer Enhancement:** Research should explore innovative techniques to enhance heat transfer efficiency within the solar chimney system. This includes investigating novel heat exchanger designs, advanced heat transfer fluids, and techniques like phase change materials or fin arrangements to maximize thermal energy capture and minimize heat losses.
- **Performance Evaluation and Validation:** Experimental studies and field measurements are necessary to validate computational models, assess system performance, and optimize design parameters. Research should involve prototype installations, data collection, and comprehensive monitoring to evaluate the efficiency, reliability, and long-term performance of solar chimney designs under real-world conditions.
- **Control and System Integration:** Research should address control strategies and automation systems to optimize the operation of solar chimneys. This includes developing intelligent control algorithms for maximizing energy conversion, managing thermal storage, and integrating solar chimney systems with energy storage technologies and grid interfaces.
- **Economic Viability and Techno-Economic Analysis:** Research should consider the economic viability and cost-effectiveness of solar chimney designs. Techno-economic analysis should be conducted to assess the levelized cost of energy (LCOE), payback period, and return on investment (ROI) for different system configurations, sizes, and applications.
- **Environmental Impact Assessment:** Research should analyze the environmental impact of solar chimney systems, including life cycle assessment (LCA) and greenhouse gas emissions analysis. This will help evaluate the sustainability and environmental benefits of solar chimneys compared to conventional energy generation technologies.

System Optimization and Design Guidelines: Research should aim to develop comprehensive guidelines, design standards, and best practices for solar chimney design. These guidelines should consider varying climatic conditions,

building types, and system sizes to enable effective and widespread implementation of solar chimneys in different regions.

By addressing these research requirements, the field of solar chimney design can advance, leading to more efficient, reliable, and cost-effective systems that contribute to sustainable energy generation.

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