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Review on Solar Chimney Design and Challenges

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Abstract- The growing global demand for sustainable and renewable energy sources has fueled research and development in the field of solar technologies. Among these, the solar chimney stands out as a promising and innovative approach to harnessing solar energy for power generation. This paper provides a comprehensive review of the current state of solar chimney technology, encompassing its historical evolution, key components, operational principles, and applications. The review begins with an overview of the fundamental concepts underlying solar chimneys, emphasizing their capacity to convert solar radiation into electricity through a combination of solar collectors, a vertical chimney, and a turbine system. Various design configurations and structural considerations are explored, highlighting the impact of geographical and climatic factors on performance.

Index Terms- Solar Chimney, Ventilation, Power

I. INTRODUCTION

Ventilation can be defined as the supply and removal of air, to and from any space, in order to control the level of air contaminants, humidity or temperature within that space. Air may or may not undergo conditioning during the process of ventilation. Since ventilation in buildings plays a major role on the health, comfort and productivity of their occupants, ventilation standards have been issued in many countries around the world. It is estimated that the minimum volume of fresh air needed for the purpose of breathing is approximately 1.2 liters per second per person but for comfort purposes, it is essential to supply more than this minimum amount in order to meet the occupants' oxygen requirements, for dilution of odors, dilution of carbon dioxide concentration and to minimize the increase in air temperature in case there are extreme sensible heat gains.

A ventilation system in a building is an important design criterion as it helps to improve thermal comfort and the indoor air quality. The latter is dependent on the following factors:

- Climatic parameters including humidity, velocity of air, temperature and levels of air contaminants.
- Parameters related to the occupants such as moisture, carbon dioxide, odours and tobacco smoke.
- Parameters related to the building and outdoor sources such as formaldehydes, volatile organic compounds, radon, biological agents and airborne particulates.

The ventilation process in buildings can either take place naturally or mechanically. Natural ventilation is dependent on wind or thermal buoyancy for the movement of air while an external power input is required for mechanical ventilation.

II. LITERATURE REVIEW

During the last two decades, increasing awareness of greenhouse gas emissions and the need for effective, efficient and ecologically sound building ventilation has led to renewed interest in solar chimneys. In recent years, a number of experimental, numerical and theoretical investigations have contributed to the current understanding of solar chimneys. The effects of solar chimney height, solar absorptance of the absorber wall, solar transmittance of the glass cover and the air gap width are investigated by Lee and Strand [1] under various conditions. The effects of chimney inclination angle on number of air changes per hour and indoor flow pattern, and also chimney inlet size and width were numerically and analytically investigated by Bassiouny and Korah [2, 3]. An experimental investigation was done by Burek and Habeb [4] to investigate heat transfer and mass flow in thermo-syphoning air heaters, such as solar chimneys and trombe walls. Experiments were carried out by Chen et al [5] using an experimental solar chimney model with uniform heat flux on one chimney wall with a variable chimney gap to height ratio. A simple and useful tool to study energy performance of different ventilated facades typology was done by Balocco [6]. Several modeling tests were carried out by Coussirat et al. [7] on a well documented experimental test case taken from open literature in order to obtain a suitable model for the double glazed facades. A commercial CFD package was used by Guohui Gan [8] to predict buoyant air flow and flow rates in the cavities. Thermal performance of a solar chimney for natural ventilation was experimentally investigated by Arce et al. [9]. The experimental model was implemented on full scale and real meteorological conditions. A parametric analytical study of roof solar chimney coupled with wind cooled cavity using spread sheet computer program has been presented by Aboulnaga [10]. A low energy consumption technique to enhance passive cooling and natural ventilation in a solar house, using a system consisting of a solar chimney and an evaporative cooling cavity has been proposed by Maerefat and Haghighi [11]. A numerical study is presented by Giabaklou, and Ballinger [12] to demonstrate the passive evaporative cooling system efficiency and air flow rate through building. There have been relatively few reports of detailed measurements using multi solar chimneys. So, the present research was directed to study the effect of multi solar chimneys at different directions on natural ventilation. In this work, experiments were carried out using a solar chimney experimental rig under actual outside operating conditions (hot and dry) of Aswan city at South Egypt. Air temperature and velocity for different chimney parameters (height, gap, orientation, and numbers) were measured to provide further understanding of the ventilation performance of solar chimney. Solar chimneys are often painted black to improve the absorption of solar radiations. When the solar radiations are absorbed by the absorber the heat so obtained is utilised in heating of air. The hot air then provides the suction of cold air and flow of this air in the upward direction and thus enabling the ventilation. Studies on solar chimney technology have been carried out by the researchers globally. These studies include theoretical, experimental and numerical studies. These studies are based on the design concepts of solar chimney, operational parameters, performance and economic aspects of solar chimney. A set up of solar chimney was built in Florid in 1997 [13]. The chimney was 7.92 m high of diameter 2.44 m at inlet and gradually decreasing to 0.61 m at the top with Laxan roof which was covered collector of 9.15 m diameter. The study was performed on three types of collectors as Type I, Type II and Type III for different material of the collector and arrangement and size of collector. The temperature rise found by them in different cases was 15 °C, 25 °C and 28 °C in Type I, Type II and Type III respectively. Solar chimney power plant as an option of power generation with the use of renewable energy source has also been developed. The power generation through this technology involves green house, solar energy collector and wind turbine. It has severable potential advantages over conventional technologies involving fissile fuels. The solar radiations in both the forms of direct and diffused can be utilised, no cooling water requirement are the key advantages of this technology of power generation [14]. A small prototype was built in the campus of RMIT University, Bundoora, Australia in 2002. This prototype was having a experimental solar pond of approximate diameter of 4.2 m with depth of 1.85 m. The solar chimney was 8 m high and 0.35 m in diameter [15] & [16]. The results of measurements showed the temperature rise of entering air from 17 C to 28 C at exit. The velocity of air flow measured was 1 m/s.

Fasel et al. [17] carried out CFD simulations to study the effect of distance of the collector from the ground on power input. They carried out extensive simulation work to understand the effect of scale (with reference to Manzanares pilot plant) on temperature distributions between ground and temperature cover, on the collector near to the chimney and on the ground. The scales ranged from scaling down 250 times the Manzanares plant to scaling up 5 times the Manzanares plant. They found that power varied very differently in case of smaller and larger scales and hence an optimum height for optimum power generated could not be obtained. They used 2D axisymmetric simulations using unsteady Reynolds Averaged Navier-Stokes Equations (RANS) to solve the turbulence. They also compared three different turbulence models like k-ε, kω, and RANS and found that RANS gave the best predictions. Deviations in the prediction of power output were attributed to the fluid dynamics in between the collector and ground.

Filkoski et al. [18] performed 3D CFD simulations for a solar chimney of collector radius of 100m and height of 100m, with the chimney radius increasing along its height the base being 6.25 to 10.5m. The realizable k-ε model was chosen for turbulence formulation, while discrete ordinates (DO) model was considered for accounting for thermal radiations. Authors showed predictions of velocity and temperature patterns and recommended CFD as a powerful tool for analysis of solar chimney studies. They also stressed on a need to include heat accumulation methods, like, water pipes, water bags etc., on the ground so that considerable heat can be stored in the ground to enhance the temperature gradients at night. Authors, however, did not study the effect of diurnal variations on power generated.

Gholamalizadeh and Kim [19] performed CFD simulations for the Manzaranes prototype using the realizable k-ε model for turbulence parameters and DO model for radiation heat transfer. They captured the temperature profile of the ground, thermal efficiency of the collector and power generated and validated their model with experimental results of Manzaranes prototype. They also performed detailed analysis of the green-house effect causing depth of heat penetration in the ground and increase in mean ground temperature. This increase in mean ground temperature influenced the predicted heat storage of the ground. Authors were able to provide better predictions for temperature distributions than previous researchers and could also match the Manzanares experimental data very well.

Hassan et al. [20] performed 3D CFD simulations with energy storage layer of the ground. Authors varied the chimney diverging angle from 1 to 3◦ and collector slope 4 to 10◦. They found that the diverging angle of 1◦ raises the velocity from 9.1 m/s to a remarkable value of 11.6 m/s, which is good for improving the performance of the chimney.

III. CONCLUSION

This comprehensive review underscores the remarkable strides made in solar chimney technology, showcasing its potential as a viable renewable energy solution. The evolution of solar chimneys from their conceptual origins to contemporary advancements demonstrates a maturation of the technology, with innovations in materials, collector designs, and computational models driving increased efficiency. While challenges related to technical complexities, economic viability, and environmental impact persist, ongoing research endeavors indicate a concerted effort to overcome these hurdles. The integration of energy storage solutions and hybridization strategies, along with continued optimization efforts, signifies a commitment to addressing the intermittent nature of solar power. By examining case studies and real-world applications, the socio-economic and environmental implications of solar chimneys become evident, portraying them as a promising contributor to the global transition towards sustainable energy. As we navigate the complex landscape of renewable energy solutions, the insights provided in this review contribute valuable perspectives on the current state of solar chimney technology. Looking ahead, the momentum generated by recent advancements and the ongoing commitment to research and development position solar chimneys as an integral component in the broader framework of renewable energy systems. As the world strives for a greener and more resilient future, the potential scalability and adaptability of solar chimneys underscore their significance in shaping the trajectory of sustainable energy technologies.

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