Examine How a Turbine Ventilator Affects Chimney Performance

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Abstract

One typical passive ventilation arrangement is solar chimney-assisted ventilation. When a solar chimney is used on its own, there is very little potential benefit. Solar chimneys are therefore always used in integrated setups. The determination of this investigation is to examine ventilation performance through the integration of a turbine ventilator and a solar chimney. To facilitate its integration with the turbine ventilator, a small solar chimney is suggested. By heating a solar chimney at a constant heat flux, its performance is investigated experimentally. Larger air gaps and higher inclination angles were shown to yield better results. However, after the ideal values of air gap depth and inclination angle, the performance begins to decline. It is advised that the input aperture area be as a minimum twice as big as the outlet aperture area, even if there is no particular relationship between the two. Through constant heat flux heating of the solar chimney and/or constant rotational speed of the turbine ventilator, we conduct experimental studies of the combined arrangement for ventilation. The findings show that the solar chimney with a revolving turbine ventilator has the optimum ventilation performance. The suggested solar chimney also demonstrates the potential to experience the flow reversal effect because it operates better without wire mesh than it does with it. All of those findings will be helpful in the construction of solar chimneys in the future, either for prediction or designation, in order to meet the ventilation demand.

Keywords

Solar Chimney, Ventilation, Passive Cooling, Renewable Energy

Introduction

As the solar system's center, the sun produces a significant quantity of energy each day. The energy that the sun emits and transfers to Earth is around two billionths of its total energy. The enormous amount of energy present on Earth might be its primary source, providing more than enough energy to meet all of the world's energy needs (Robert, 2006)[1]. Since solar energy is a viable, dependable backup energy source, it has tremendous value and a bright future (Mekhilef et al. 2012)[2]. Photovoltaic cells, solar concentrators, solar chimneys, solar air warmers, and solar dryers are a few examples of solar energy harvesting devices (Quesada et al. 2012; Zhai et al. 2011;).[3], [4]

Alternatively, result of population enhancement and changes in standards of living, energy consumption in the building industry is dramatically increasing. Furthermore, non-renewable energy resources account for the majority of energy production. Solar and passive systems have attracted a lot of interest and research due to factors such as rising costs, energy supply security, and environmental concerns (Li et al. 2014).[5]

The solar intensity and solar energy availability determine a solar chimney's efficiency. Because solar energy varies during the day, a solar chimney is an unstable arrangement. Furthermore, because solar energy is scarce or nonexistent during the day, solar chimneys cannot function in cloudy or nighttime situations (Kaneko et al. 2006)[6]. According to certain research, solar chimneys are ineffective in hot, muggy weather. The reason for this is the tiny temperature differential (less than 5°C) between the interior and external environments, which results in inadequate stack ventilation. In addition, wind or airspeed has an undesirable influence on the performance of solar chimneys (Khanal and Lei, 2011; Yusoff et al., 2010)[7], [8]. Consequently, a solar chimney alone is unlikely to induce adequate natural ventilation (Zhai et al. 2011)[9].

Resistance is another issue that solar chimneys encounter but rarely discuss. The air enters most typical solar chimneys at an angle to the right. The solar chimney inlet has considerable flow resistance as a result. These intake losses lessen the amount of entrained flow, which in turn reduces the efficiency of the solar chimney (H. Li et al. 2014; Tan and Wong, 2012).[10][11]

Integrating a solar chimney with a turbine ventilator is a viable solution to address the majority of the issues mentioned above. This is because it is fair to expect solar and/or wind energy to be available for the majority of any given day at a suitable intensity (Shun and Ahmed, 2008)[12]. Another explanation is that their advantages can compensate for each other's shortcomings. Accordingly, it is anticipated that this integration system will perform even better than their separate systems (Chan et al. 2010)[13].

Thus, the purpose of this endeavor was to validate the theory. This project's primary goal is to investigate ventilation performance through the integration of a turbine ventilator and solar chimney.

Turbine Ventilator

In 1929, Meadows obtained a patent for the idea of a turbine ventilator, which he called the "rotary ventilator." Nevertheless, Edmonds has established itself as a prominent marketer of turbine ventilators in Australia starting from 1934 (Al-Obaidi et al. 2014; Khan et al. 2008). The references are [14] and [15]. Turbine ventilators are very prevalent and have been for an extended period in most regions worldwide. It is commonly employed in rooftop areas to enhance the airflow and indoor air quality of commercial and residential structures. The source cited is Ahmed (2013). The user's text is a reference to a specific source or piece of information.

A base and a top that resemble rotors make up a typical turbine ventilator that you can buy in stores. It consists of many vertical vanes, or straight or curved blades, mounted to a frame and placed in a spherical or cylindrical array. As a result, a rotating, waterproof dome is created. A shaft and bearings, which connect the top rotating element to a base duct, are among its mechanical parts. These days, turbine ventilators are made of many different materials, sizes, and shapes. A straight vane turbine is a specific form of turbine ventilator. Empirical evidence demonstrates that it possesses a much greater amount of exhaust capacity compared to the conventional spherical vane vent design with an equivalent throat diameter. There exist two distinct categories of straight vane turbines: hurricane vents and sure draft vents, each serving a distinct function. The curved vane turbine is an alternative type of turbine ventilator. Research has shown that the robust spherical structure a curved vane turbine creates improves performance.

Research Methodology

The solar chimney variation is designed to operate at different inclination angles of 75 to 90 degrees and air gap depths of 10 to 16 mm. The input and exit aperture areas of the solar chimney range from 0.0224 m^2 to 0.6 m^2 and 0.1 m^2 to 0.14 m^2, respectively. Each model chimney keeps its stack one meter high. Each experiment starts in a frigid room with a chimney temperature that is similar to the ambient temperature. To simulate uniform sun radiation on the absorber, an electric heater running at a constant heat flux of 500 W/m^2 is heating the absorber. Temperature is measured using K-type thermocouples, which have a measuring range of 0 to 250 ^{C}. The heated absorber is outfitted with five thermocouples, whilst each air channel and air gap of the solar chimney is provided with two thermocouples positioned at both the upper and lower ends. There is only one thermocouple positioned at the midpoint of the absorber. Furthermore, a thermocouple is placed adjacent to the solar chimney to gauge the surrounding air temperature. The USB-based 8-channel data recorder module automatically collects and logs temperature values from personal PCs every 10 seconds using two units. A van anemometer is used to measure the air velocity at the inlet. Air velocity measurements are obtained at two-minute intervals.

Data is gathered continuously from the initiation of the heating process until a state of equilibrium is reached. This integration can be categorized into two distinct groups: one with a chimney equipped with a wire mesh screen, and the other lacking this feature. A turbine ventilator is used to combine with the solar chimney. A turbine ventilator can exist in either a static or dynamic condition. The technology employed in this study comprises a solar chimney, which may or may not incorporate a wire mesh screen, along with a ventilation system that can be either static or dynamic and supported by a turbine. Figure 1 illustrates the experimental setup of the integrated system.

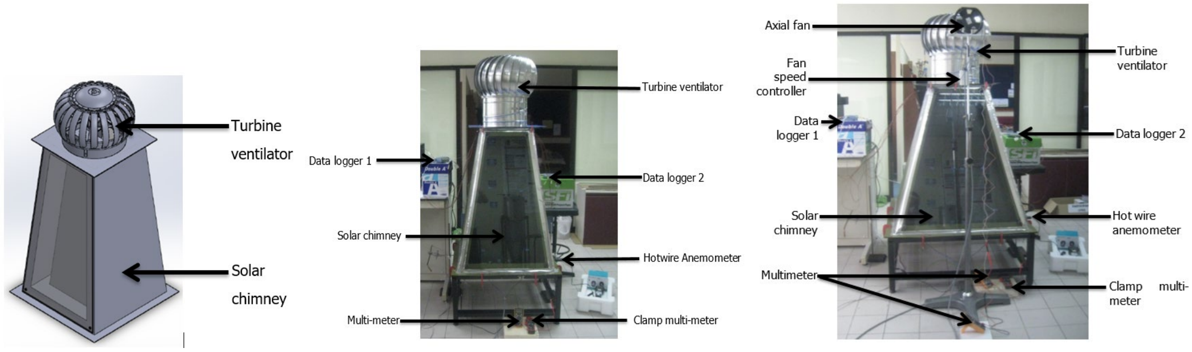

Figure 1. Experimental setup to determine the turbine ventilator effects

Measurements are conducted on the integrated system to ascertain the volumetric flow rate and air temperature. Researchers are comparing the results of the experiment to baseline data from a standard solar chimney model to see how well the integration works in both rotating and still states.

Results and Discussion

Figures 2, 3, and 4 illustrate the performance of the integrated system using six different combinations. The data provided illustrates the performance of three solar chimneys. The first chimney has a 75-degree angle and a 16-cm air gap depth, the second chimney has an 85-degree angle and a 16-cm air gap depth, and the third chimney has an 80-degree angle and a 16-cm air gap depth.

According to Figures 2–4, the solar chimney paired with a spinning turbine ventilator is exhibiting the most superior level of performance. In contrast, the combined performance of the solar chimney, wire mesh, and static turbine ventilator is below average. The subsequent solar chimney designs are anticipated to provide similar performance or rankings in relation to their respective integrated systems.

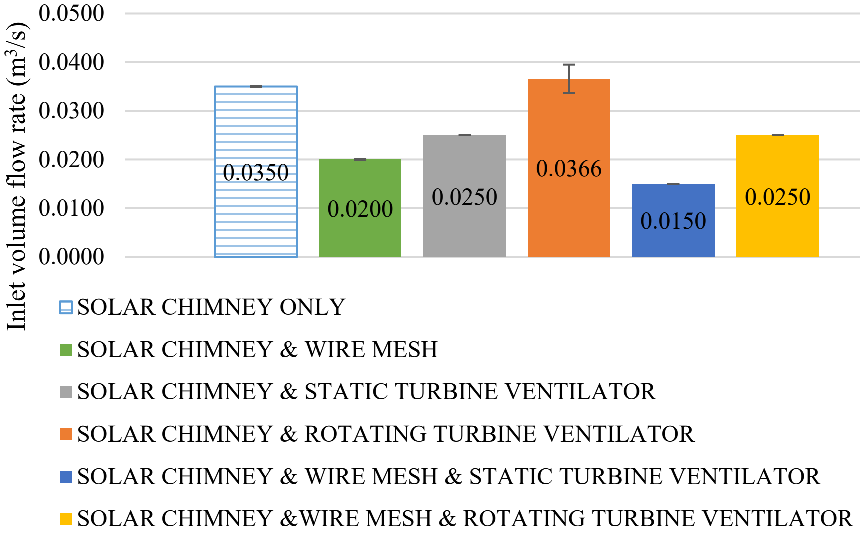

Figure 2. Volume flow rate of different integrated systems for 75° tilt angle with 16 cm gap

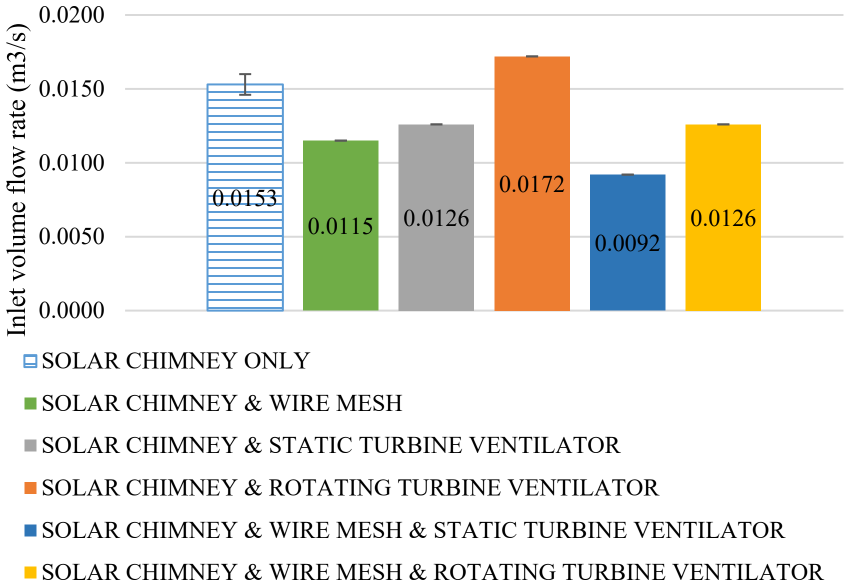

Figure 3. Volume flow rate of different integrated systems for 85° tilt angle with 16 cm gap

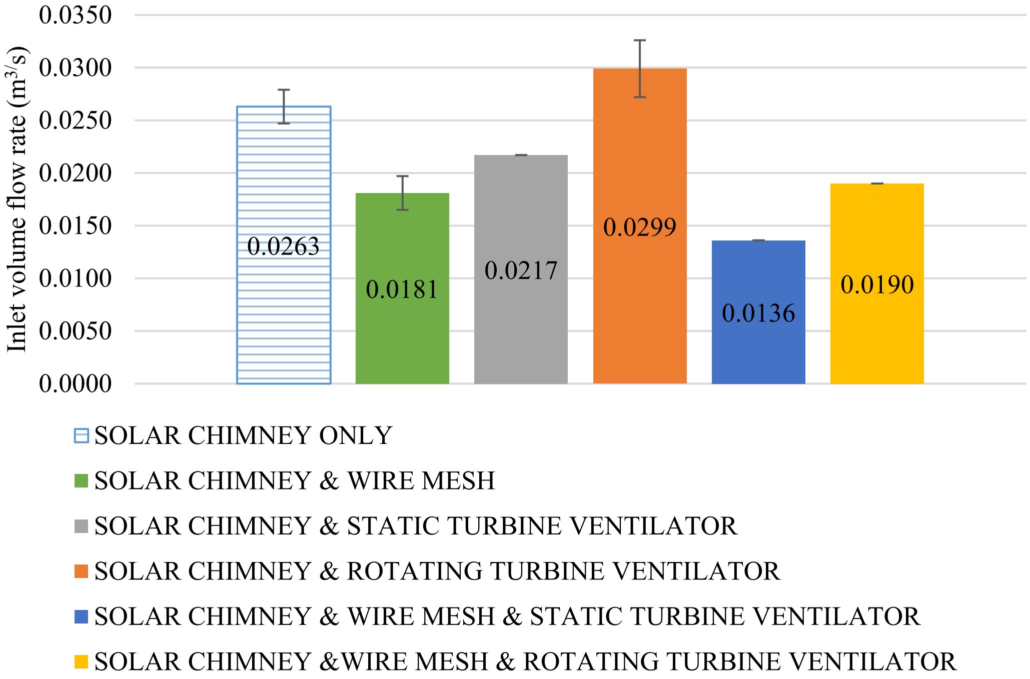

Figure 4. Volume flow rate of different integrated systems for 85° tilt angle with 16 cm gap

One of the conclusions drawn from these three data is that incorporating wire mesh into the combination consistently results in worse performance compared to the same combination without wire mesh. This demonstrates that the wire mesh cannot improve the chimney's functionality. Althoug, Chu et al. (2012)[17], and Chu et al. (2014)[17] claim that the screen mesh enhanced the solar chimney performance by reducing draft losses. This effect was not observed in this research. This is because of the shape of the chimney. Chu et al. used a circular and square-shaped chimney, whereas in the experiment, a square convergent duct was used as a chimney model. In this case, the wire mesh adds extra resistance to a flow's route since there is no flow reversal, which lowers the heat load and draft. Thus, it is demonstrated that there is a chance that the suggested solar chimney design will experience the flow reversal effect.

Despite the benefits of combining the turbine ventilator and solar chimney, there is one issue with the integration. In addition to being less effective than the identical combination with a revolving turbine ventilator, the combination with a static turbine ventilator performs worse than the combination without a turbine ventilator. This is consistent with the earlier research's discovery that the airflow is being obstructed by the static turbine ventilator (Lai, 2003)[18]. Therefore, if the turbine ventilator is included in the integrated system, a static turbine ventilator may cause issues.

Conclusion

Based on the findings obtained, there is no doubt in concluding that the combination without wire mesh and with a rotating turbine ventilator is going to perform the best. However, the enhancement of turbine ventilators from other sources is necessary to solve the problem of static turbine ventilators.

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References

Hammond, R. B., K. Pencheva, and K. J. Roberts, “A structural-kinetic approach to model face-specific solution/crystal surface energy associated with the crystallization of acetyl salicylic acid from supersaturated aqueous/ethanol solution,” *Cryst Growth Des*, vol. 6, no. 6, pp. 1324–1334, Jun. 2006, doi: 10.1021/cg0505618.

Mekhilef, S., A. Safari, W. E. S. Mustaffa, R. Saidur, R. Omar, and M. A. A. Younis, “Solar energy in Malaysia: Current state and prospects,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1. Elsevier Ltd, pp. 386–396, 2012. doi: 10.1016/j.rser.2011.08.003.

Ran, L. *et al.*, “Defect Engineering of Photocatalysts for Solar Energy Conversion,” *Solar RRL*, vol. 4, no. 4. Wiley-VCH Verlag, Apr. 01, 2020. doi: 10.1002/solr.201900487.

Quesada, G., L. Guillon, D. R. Rousse, M. Mehrtash, Y. Dutil, and P. L. Paradis, “Tracking strategy for photovoltaic solar systems in high latitudes,” *Energy Convers Manag*, vol. 103, pp. 147–156, Jul. 2015, doi: 10.1016/j.enconman.2015.06.041.

Wang, H. Li, Z., L. Chen, and X. Huang, “Research on advanced materials for Li-ion batteries,” *Advanced Materials*, vol. 21, no. 45. pp. 4593–4607, Dec. 04, 2009. doi: 10.1002/adma.200901710.

Kaneko, M., “Solar Energy Conversion by Functional Polymers.”

Khanal, R. and C. Lei, “Solar chimney-A passive strategy for natural ventilation,” *Energy and Buildings*, vol. 43, no. 8. pp. 1811–1819, Aug. 2011. doi: 10.1016/j.enbuild.2011.03.035.

Yusoff, W. F. M., E. Salleh, N. M. Adam, A. R. Sapian, and M. Yusof Sulaiman, “Enhancement of stack ventilation in hot and humid climate using a combination of roof solar collector and vertical stack,” *Build Environ*, vol. 45, no. 10, pp. 2296–2308, Oct. 2010, doi: 10.1016/j.buildenv.2010.04.018.

Zhai, X. Q., M. Qu, Y. Li, and R. Z. Wang, “A review for research and new design options of solar absorption cooling systems,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 9. pp. 4416–4423, Dec. 2011. doi: 10.1016/j.rser.2011.06.016.

H. Li, Y. Yu, F. Niu, M. Shafik, and B. Chen, “Performance of a coupled cooling system with earth-to-air heat exchanger and solar chimney,” *Renew Energy*, vol. 62, pp. 468–477, Feb. 2014, doi: 10.1016/j.renene.2013.08.008.

Wong, M. S. *et al.*, “Estimation of Hong Kong’s solar energy potential using GIS and remote sensing technologies,” *Renew Energy*, vol. 99, pp. 325–335, Dec. 2016, doi: 10.1016/j.renene.2016.07.003.

Shun, S. and N. A. Ahmed, “Utilizing wind and solar energy as power sources for a hybrid building ventilation device,” *Renew Energy*, vol. 33, no. 6, pp. 1392–1397, Jun. 2008, doi: 10.1016/j.renene.2007.07.017.

Shu, Z. R., Q. S. Li, and P. W. Chan, “Statistical analysis of wind characteristics and wind energy potential in Hong Kong,” *Energy Convers Manag*, vol. 101, pp. 644–657, Jun. 2015, doi: 10.1016/j.enconman.2015.05.070.

Al-Obaidi, K. M., M. Ismail, and A. M. Abdul Rahman, “Passive cooling techniques through reflective and radiative roofs in tropical houses in Southeast Asia: A literature review,” *Frontiers of Architectural Research*, vol. 3, no. 3. Higher Education Press Limited Company, pp. 283–297, Sep. 01, 2014. doi: 10.1016/j.foar.2014.06.002.

Rahman, M. M., “Solar Energy Potential in Bangladesh,” 2013.Available: https://www.researchgate.net/publication/303939944

Chu, S. and A. Majumdar, “Opportunities and challenges for a sustainable energy future,” *Nature*, vol. 488, no. 7411. pp. 294–303, Aug. 16, 2012. doi: 10.1038/nature11475.

Zhang, X., L. Shen, and S. Y. Chan, “The diffusion of solar energy use in HK: What are the barriers?,” *Energy Policy*, vol. 41, pp. 241–249, 2012, doi: 10.1016/j.enpol.2011.10.043.

Biographies

Md. Mizanur Rahman is currently employed as a professor at the World University of Bangladesh. In addition, he has worked on the Renewable Energy Technology in Asia (RETs in Asia) project at KUET and AIT from January 1999 to December 2004 as a research assistant, research engineer, and consultant. Following that, he went to work for an NGO called BRAC Bangladesh as a program support professional. He joined Rural Power Company Ltd. (RPCL) in February 2006 and remained there as assistant manager until July 2007. In July 2007, he began his doctoral studies at Universiti Malaysia Sabah in Natural Draft Chimney. Dr. Rahman began serving as a lecturer at the TAS Institute of Oil and Gas in July 2009 and continued to do so till August 2012. He then moved on to become a senior lecturer at Universiti Malaysia Sabah before enrolling in the World University of Bangladesh. In addition, he holds a life fellowship in the Institutes of Engineers Bangladesh and is a professional member of the IEOM.

In June 2013, **Enamul Hoq** started working at the World University of Bangladesh's Mechatronics Engineering Department. Currently, he holds the position of a senior lecturer and course coordinator in this department. He works as an active member of the WUB Department of Mechatronics Engineering's Institutional Quality Assurance Cell (IQAC). Robotics and automation are his areas of interest in research. He taught mainly CNC programming, fluid mechanics, and mechatronics courses.

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Dr. Mohammad Mashud is a research fellow at the Aerospace Center at UTEP, USA, and a professor in the mechanical engineering department at Khulna University of Engineering & Technology, Bangladesh. In 1975, he was born in Dhaka, Bangladesh. He graduated with a doctorate in aerospace engineering. In 2006, I received my degree from Nagoya University in Japan. In 2003, he graduated with a Master of Engineering from the same department and Japanese university. At Bangladesh's Khulna University of Engineering and Technology (KUET), he earned a Bachelor of Science in Engineering (Mechanical). He began working as a lecturer in the KUET Mechanical Engineering Department in 1999.