Review on Thermal Analysis of Solar Chimney

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Abstract— With increase in energy demand due to increase in population the need for passive cooling for building ventilation has become important. Passive cooling is used as low energy driven technique to remove undesired heat from the building to bring the comfort condition of occupant. This paper is based on application of experimental and CFD techniques on solar chimney analysis using various optimization parameters of design.

Key words: Passive Cooling, Solar Chimneys, Design Optimization

I. Introduction

The employment of natural ventilation is almost as old as vernacular architecture. Examples include the wind assisted badgir or wind tower commonly used in the Middle East since 900 AD and the stack assisted chimneys developed since the Roman period. In the industrialized 19th and 20th centuries, solar stack ventilation was developed further with the introduction of the Trombe-Michel wall, modified Trombe wall and solar roof collector. Increasing energy demand in recent year because of fast economic growth of the thickly populated nations increases the utilization of sustainable energy sources and energy conservation methods. Shortage of conventional energy sources and high energy cost has caused the alternate methods for cooling and heating purpose of buildings. Power usage in buildings accounts 30% to 40% of global energy consumption. Passive cooling method is one of the many alternative methods of energy sources. Present study discusses performance of solar chimney as passive ventilation and cooling systems as well as performance of some integrated passive cooling systems. The principle of the solar chimney effect is a combination of solar stack-assisted and wind-driven ventilation. Air in the chimney expands due to solar heating and being relatively lighter, rises out of the chimney outlets, drawing the cooler air into the interior through the fenestrations.

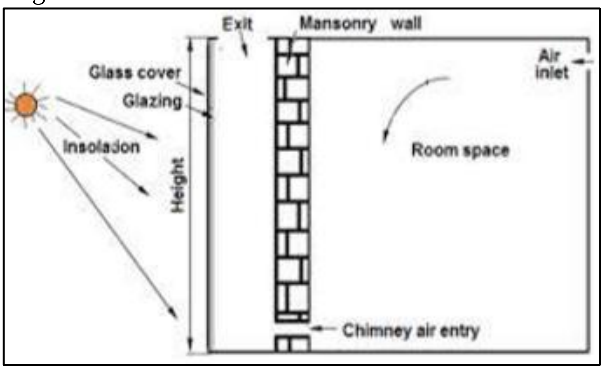

Fig 1: Schematic of Solar Chimney

This pull effect is further complemented by the push effect from the ambient wind. The stack pressure difference driving the air movement is a combination of the different densities between the interior and ambient environment as well as the stack height where the greater the stack height and temperature difference, the stronger the pressure difference. In solar assisted stack ventilation, the temperature difference is achieved from heat gained due to solar irradiance

Cooling systems based on thermal energy generally have solar energy as the most widely available heat source for solar thermal driven cooling applications where a low temperature (below 200°C) and/or cost-efficient heat source is available. Industrial processes also produce waste heat that can be an alternative to the solar energy. On the market, four major solar thermal driven cooling systems are available with absorption, desiccant, ejector, and adsorption cooling systems. Furthermore, the Rankine power cycle for refrigeration can be driven by solar thermal energy to produce work output.

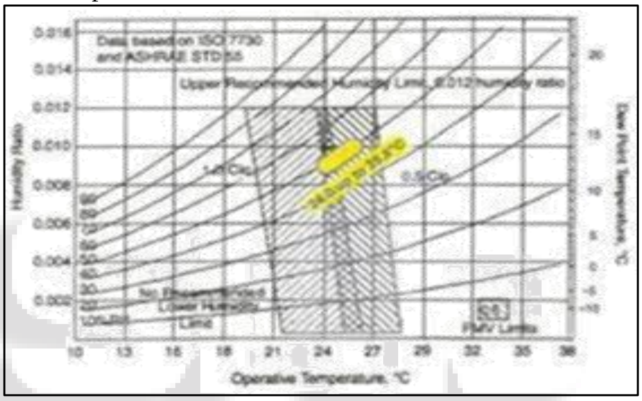

Fig 2: Human Comfort Range

Figure 2 above shows the human comfort range of temperature and humidity as per ASHRAE standards.

II. Literature review

Chung et al. [1] has studied solar chimney cross ventilation performance in Malaysia terraced house where climate was tropical with high humidity using techniques of Computational Fluid Dynamics. The design optimization parameters were 1. Air width gap2. Chimney Length 3. Air Velocity. Air speed variation was .04m/s to .223m/s.

Tongbai et al. [2] has worked on enhancement of roof solar chimney using CFD technique. The optimization parameters were angle of channel, air gap, and angle of inclination and height of chimney. At 6°channel expansion flow rate increases by 24%. Air flow rate increases up to 250% when air gap increased from 10 to 60cm. At air gap 10cm when the angle increases from 15 to 45 deg. The ventilation increases by 90%. Flow rate increases as height of the vertical. The climatic conditions were tropical climate with high temperature and humidity

Alzaed et al. [3] has conducted Experimental study of solar chimney for ventilation in hot arid region experimentally studies were based on air gap. It was found that air gap of 5cm achieves better ventilation compared with 10cm air gap.

Ahmad et al. [4] has studied solar chimney using CFD simulation technique. The parameters of optimization were air width gap, chimney height. It was found that optimum gap width of .4m and height 2m gave the best results. The analysis was conducted in hot and dry conditions.

Tan et al. [5] has conducted parametric studies of solar chimney in tropical climate with high temperature and humidity. The optimization variables were stack height, chimney depth, chimney width. It was found that with increase of stack height solar chimney outlet air temperature increases, optimized solar chimney depth is .05m and outlet temperature decreases with increasing width.

Wei et al [6] studied about the performance of ventilation when the solar chimney are connected in series and integrated with building. Both the physical and mathematical model were set up, and the effects of sizes on ventilation performance were analysed by RNG k-e model and enhanced wall unction method using a CFD software and concluded that performance of ventilation of solar chimney which are connected in consisting of an inclined section on roof and vertical section, the velocity decreased after the first increase with chimney channel width. The optimal ratio of length to width was found to be 12:1. The improvement of fluid flow as well as increase in flow rate can be achieved by decreasing the inclined angle of second floor chimney inlet. They found that the optimum angle of inclination was 4^0. The ventilation rate is decreased inside the chimney increases with length ratio of the inclined section to vertical section. These are indicating that the vertical section height should be maximum to increase the flow rate inside the chimney as well as to optimize the chimney ventilation performance. The ventilation performance was enhanced with the increase of total chimney length.

Christine Walker et.al [7] examined on a building model of reduced scale in which air is used as working fluid for natural ventilation through buoyancy effect analyzed and it is experimentally found using the scaled model for common natural ventilation building, which is connected to central atrium of open office floor plans. The parameters of the scaled building model's experiments thus were used as inputs into CFD (computational Fluid Dynamics) simulation model to compare predicted and measured airflow patterns, temperatures and velocity distribution in scale building model.

Shiv Lal et.al. [8] Studied about solar chimney performance which are used in Power generation in warm and steppe climate of Kota, Rajasthan. The study was based on Computational Fluid Dynamics (CFD) and mathematical formulas. The specific parameters energetic and exegetic efficiencies are calculated by CFD modelling. They concluded that the high-rise chimney and a lot of collector area required for MW power generation and it is feasible solution for sustainable development. They observed that the velocity of air is 12.2m/s and the temperature of air is 42.4^0C at 12:00h and recorded maximum solar radiation of 820W/m2 at 1400h. They found that the temperature of absorber plate is 40^0C to 60^0C higher than the atmospheric temperature of air. At 12:00h the high energy is calculated by 3.5% and it is reduced in morning and evening time. The exergy efficiency is also observed about low of 8%. The aim of this study was based on the power generation so the turbine is installed at the point where maximum velocity is obtained by the simulation software. The performance of the chimney was based on the parameters height of chimney, inlet temperature and solar radiations. The diameter of the opening of chimney is taken very low as 0.20 m and generated low velocity so it produced small power and it can be used as small power plant.

Mathur et al [9] conducted an experiment to investigate the increment in ventilation rate increased with the ratio of absorber height to gap between glass and absorber. They setup a small size solar chimney to conduct the experiment and their calculations are based on mathematical approach. The parameters are taken of nine different combination of air gap between glass and absorber plate and the height of the absorber. It was found that the highest rate of ventilation of 5.6 Air Changes per hour in the room of 27 m^3 at solar radiation of 700 W/m^2 with the ratio between absorber height and air gap of 2.83 for a 1 m chimney height. So on the basis of experiment they finally concluded that in hot climatic conditions, when windows are kept closed /covered for preventing direct entry of solar heat, concept of solar chimney can be utilized by making minor modification to existing windows. Rakesh

Khanal et al. [10] performed an experiment with an inclined solar chimney model of passive wall with constant heat flux on absorber plate. The performance of the design has been evaluated for the range of 100 W/m^2 to 500 W/m^2 of heat flux with a constant air gap of 10 cm and the inclination angle of the passive wall was varying between 0 to 6 degrees. They found that the angle of inclination is not provide an influenced effect on the distribution of temperature across the gap width and along the height of chimney. The experimental results show that the inclined passive wall solar chimney provide the sufficient ventilation for a room of $27m^3$ volume with absorber height of 70 cm and 10 cm air gap at an angle of 60^0 at an input heat flux of 500 W/m^2 based on ASHREA standard. The present design of inclined passive wall solar chimney has influenced improvement to achieve the maximum ventilation rate in comparison with other conventional chimney design.

Somaye Asadi et al [11] studied on a solar chimney to investigate the performance of solar chimney which are based on its layout in southern, west-southern and east southern part of the building. The performance of seven models are examined by simulated models which are performed on energy plus simulation software. These seven models are installed in different part of a seven-story building. Their results are based on the only two parameters which are building layout and the materials of the walls and glasses. They found that the chimney which was installed in east southern part has maximum ventilation rate with compare to others and every solar chimney provides the necessary ventilation for space which are attached to it. The results was based on the 24 hours model and solar radiation through simulation.

De Carli et.al [12] context a numerical model able to perform the detailed simulation of the dynamic behaviour of water-based surface embedded heating and cooling systems developed by authors is presented. To perform validation the test room was subjected to heating/cooling load profiles aimed to simulate different climatic conditions. The conclusion made was when comfort conditions are achieved, the indoor parameters are close to each other and therefore small differences between the surface temperatures and air and operative temperatures are present. This explains why the calculations based on fixed or variable heat exchange coefficients do not differ in terms of calculated operative temperatures compared to the measured values.

III. Conclusion

It was noticed that, numerous work has been done on solar chimney using vertical and inclined configuration. The use of solar chimney for passive ventilation can substantially reduce power consumption by 15%. Various design and material optimization parameters such as chimney height, gap, stack height and inclination angle has been studied using CFD techniques. The use of computational fluid techniques can reduce time and cost required for analysis.

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