IJETCR
Open Access

ISSN: 2348 - 2117

International Journal of Engineering Technology and Computer Research (IJETCR)
Available Online at www.ijetcr.org
Volume 4; Issue 1; January-February-2016; Page No. 05-16

The Study on Optimum Design and Performance Analysis of Chimney for Ventilation Space

[1]Sanjay Verma, [2]Amitesh Paul

[1] M.Tech, Scholar RKDF, University, Bhopal.

[2] Associate Professor, RKDF, University, Bhopal.

Abstract

The most energy consumption is in the building industry, about 40%, and the major part of which is spent for cooling, heating and ventilation. Therefore, using suitable measures to reduce energy consumption has a great influence on energy balance of building. One of the passive design methods is using a solar chimney as a mechanical eco concept which is a simple idea to increase natural ventilation in surrounding spaces. Solar chimney can be used vertically or in the angle of horizon. The inclination angle of solar chimney influences the ventilation rate efficiency. In the present study, the effect of solar chimney on ventilation rate has been examined in four cities of Iran with different climates. Due to lack of access to the implemented samples, the computerized simulation was used as alternative method for field studies, the results of which by energy plus software in four cities of different climates show that the optimum angle of inclination is 45° so that the maximum ventilation is obtained. The vertical position of chimney provides the minimum ventilation rate in all cities except in Tabriz (cold climate)

Keywords: Solar power, Chimney, heating, ventilate, passive element, cooling.

1. Introduction

The building sector (Residential and Commercial) consumes largest energy as that the heating, ventilation and space conditioning consumed approximately 50-60% of total energy consumed by building sector.

The exploitation of sustainable energy sources to cover the functional demands of buildings (for heating, ventilation, cooling etc) can contribute to significant energy savings and thus to alleviation of the current environmental, economical and social problems related to conventional energy practices. Passive (natural) ventilation of buildings is a successful means to save energy otherwise consumed for mechanical ventilation and cooling. Solar chimneys (SC) are passive elements that make use of the solar energy to induce buoyancy-driven airflow and naturally ventilate the building

The temperature of the air inside the SC channel rises due to heat transfer from the walls and the resulting buoyancy drives the airflow through the channel. The SC pulls air from the interior of the building, which is replaced by fresh air through openings or other paths, and natural ventilation is accomplished. Performance of the SC is primarily described by the induced ventilation flow rates; in case heat harvesting is also of interest, air temperature in the channel is the other important performance indicator.

REVIEW OF WORK CARRIED OUT:

According to the Farley dictionary ventilation is defined as replacement of stale or noxious air with fresh air and ventilation is needed to provide oxygen for metabolism and dilute metabolic pollutants where carbon dioxide and odour are the main metabolic pollutants. The highest quality indoor air provides by replacing of stale. Higher quality means control of temperature; replenish oxygen, moisture, odour, dust, bacteria and carbon dioxide. The simple ventilation means fresh air is mixed with already existing air in the enclosure to dilute the pollutants or used to displace the air by means of piston flow. The air change rate affects the circulation and fresh oxygen supplied for human comfort.

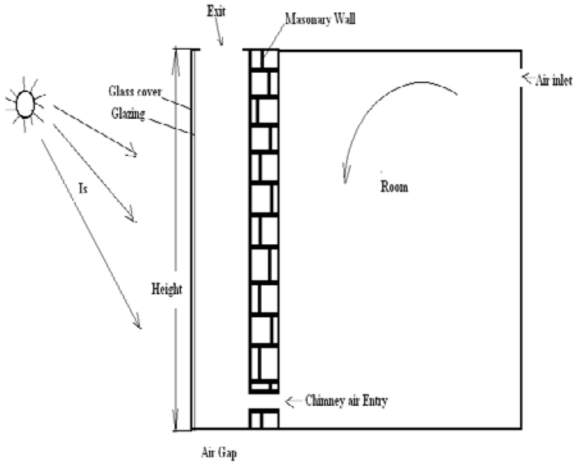


Figure 2.1: Concept of solar chimney at Trombe Wall

The air circulation can be possible by natural air flow (Through window, doors and ventilators) or by forced air flow (through fans and blowers etc.) So the ventilation process is divided into two categories as: natural ventilation and Mechanical/forced ventilation. Here authors have reviewed the natural ventilation and space conditioning methods by applications of solar chimney.

Barozzi et al. (1992) studied space conditioning in buildings is a function of temperature, relative humidity, irradiation and the method of controlling these parameters. The space conditioning is highly desirable in tropical countries like India, Africa and South America. Today's technology like passive solar applications can be used for thermal comfort of buildings (Hirunlabh, 2001). The first mathematical modelling for the solar chimney (Trombe wall) design was given by Bansal et al. (1993) and reported the concept of increasing the air flow by increasing solar irradiations. This theoretical study also reported an air change per hour with change in the coefficient of discharge. The ventilation provided by the solar chimney is not sufficient for large buildings but enhance the ventilation rate up to some extent. One important application of passive cooling for air ventilation and circulation in the form of wind tower was suggested by Bansal et al. (1994).

The solar chimney in the form of Trombe wall, roof solar chimney and roof air solar collectors are the most convenient and mature technologies used for buoyancy driven natural ventilation systems (Khedari et al., 2000; Zhai et al., 2005; Hirunlabh et al., 1997). The integrated approach like Trombe wall and roof solar collector gives improved rate of ventilation.

Awbi (1994) reported the main design considerations for naturally ventilated buildings as climatic conditions, height, building occupancy loads, and features for enhanced ventilation and classify the ventilation as single side, cross and mixed ventilation. Ong (2003) developed a heat transfer modeling of Trombe wall with considering all effect of mode of heat flow and investigated the effect of wall length on temperature, mass flow rate and instantaneous efficiency. Bassiouny et al. (2009) developed a FORTRAN programme to solve the mathematical modelling and found that the optimum flow rate could be achieved at 45˚ to 70˚ inclination angle for latitude 28.4˚ for 0.1 to 0.35m chimney width at 500W/m2 solar intensity. Bilgen and Nouanegue (2009) studied the conjugate heat transfer in the solar chimney system for ventilation of dwelling and conservation equations have been solved by finite difference control volume method and revealed that the solar radiation affects the volume flow rate, temperature field and Nusselt number. Gan (2006) used CFD for simulation of buoyancy driven ventilation system and created two domains in study where one smaller and the other larger. The investigated performance of larger domain found very sensitive for both ventilation and heat transfer.

Qirong et al. (2011) proposed an integrated approach of Trombe wall, roof solar collector and chimney and investigated the effect of total length and width of chimney on the performance of the system. They reported that the performance of integrated system found better as compared to the single solar chimney. The numerical study also carried out to evaluate the performance parameters for ventilation rate as a function of inclined angle of the second floor, length ratio of vertical to inclined, and chimney inclined angle. The optimum ratio of length to width was 12:1 and optimal inclination angle is found to be 4º by numerical study. The length of solar chimney (vertical section height) should be as large as possible within the restriction of building code to increase the flow rate of air.

Zamora and Phoenic (2009) used codes (version 3.6.1) for the numerical study of natural convection in channels or solar chimney. They used Reynolds turbulence model to simulate the turbulent case. The solar chimney was configured for a wide range othe Rayleigh numberer (varying between 105 to 1o12 for symmetrical isothermal heating), several values of wall to wall space and different heating conditions.

Gan (2011) derived the general expressions for correlation of Nusselt number, Reynolds number and Rayleigh number and these expressions can be used for calculating the heat transfer rate and air flow rate in ventilation cavity for given height and width. The heat flux and heat distribution ratio also calculated.

Ekechukwu (1997) analyzed solar chimney for ventilation and reported that the simple air heater increases ventilation up to some extent but not sufficient. Mathur et al. (2006) also experimentally analyzed window size solar chimney and found increasing summer performance of the inclined roof solar chimney. They studied the effect of various performance parameters like chimney width, height and solar radiation.

The performance of solar chimney can be improved by using glazing, increasing height, air gap, integrating Trombe wall with roof solar collector (single pass and double pass), and inclination angle.. Lee and Richard (2009) investigated the effect of these parameters along with chimney height, air gap and potential for different climatic conditions. Hirunlabh (2006) investigated the glazing effect on the performance of solar chimney and found double glazing is a suitable option as compared to single and triple glazing. Gan and Riffat (1998) were analyzed the glazed solar chimney experimentally and the data validated by simulation in CFD and found to increase the air flow rate up to 17% in the summer by using double glazing. The single pass roof solar collector (SPRSC) and double pass roof solar collector's (DPRSC) performance were compared by Wang et al. (2005) and found that DPRSC can be operated 10% more efficiently for space heating in winter and for natural ventilation in other seasons. They used roof solar collectors with damper for controlling the air flow. A FORTRAN computer program was developed to validate the experimental results.

The heat transfer analysis combined with energy analysis of solar chimney based on assumptions as wall adiabatic of constant heat flux. Vrachopoulos et al. (2007) presented a study of natural convection phenomena inside a wall solar chimney with one wall adiabatic and one under a heat flux. Their main research focused on the numerical study of buoyancy driven flow field inside the chimney and heat transfer analysis of the turbulent flow model. The k-ξ model is likely to provide superior performance for flow boundary layers under strong adverse pressure gradient that's why it was selected for simulation.

The maximum literature available for ventilation enhancement in daytime but Aboulnaga and Abdrabboh (2000) reportedthe results for improving night ventilation by use of combined wall and roof solar chimney. ACTION psychometric software was used in that study for mean cooling load calculation at corresponding induced ACH and optimized parametric configurations for maximum air flow for suitable height. For wall- roof solar chimney height of 1.95 to 3.45m the air flow rate increased up to three times (0.81 to 2.3 m3/s) as compared to single roof solar chimney and the air change per hour was achieved by 26. Zhou et al. (2011) used the shape stabilized phase change materials (SSPCM) for thermal storage in solar chimney for increasing ventilation at night. The ACH was 40 by using SSPCM and improving the thermal comfort level up to some extent. The night time Cop found 7.5 is higher than 6.5 without using SSPCM.

For thermal comfort it is more important to cool the ventilation air in the summer season by earth to air heat exchanger, air tube passed through the sanitary space, ventilation integrated by evaporative cooling, adsorption cooling etc. Wang et al. in 2004 and Santamouris et al. (2007) cooled the ventilated air by EAHE in their analysis, and Wang found experimentally 2.4kW cooling capacity with tightened envelop and spiral tube was used to increasing 25% flow rate. Sumathy et al. (2003) worked on natural ventilation in a solar house along with solid adsorption cooling and increased 20% ventilation rate at night. The new cooling method for circulating air was suggested by Macias et al. 2009. In which the circulating air cooled by using the sanitary area. The air pipe was passed through sanitary area and it cooled by low temperature of this area. The authors have used this technology in dry hot climatic conditions for low cost buildings. A solar chimney was used by passive cooling ventilation and saved more than 50% energy. It can be applied to the area where solar irradiation is high and wind speed is low.

A full scale model was built by Kishore et al. (2001) and analyzed it for whole year thermal comfort conditioning. They used solar chimney for heating in winter season and integrated evaporative cooling approach was suggested for summer. But for rainy season they also controlled the humidity up to some extent by using a dehumidifier. The 20% cost was increased by using new approach as compared to conventional room but in view of comfortness increasing cost doesn’t have matter. Miyazaki et al. (2011) predicted the evaporative cooling system experimentally and simulated M-cycle evaporative cooling channel and they found it feasible option of thermal comfort. The system used to be capable for 40-50w/m2 radiative cooling load. The chimney width optimized for maximum convective cooling capacity and air flow rate.

The solar chimney system is the most prominent technique used in building ventilation for sustainable development. There is scope to reduce energy demand, used in circulation and cooling of air up to some extent in domestic and commercial buildings. The number of factors are affecting the use of solar chimney in household buildings. More work is required to minimize the cost, improving the effectiveness and to make it in fascinating design. The aim of this paper is to review the solar chimney technology through its classification, performance variables, methodology, various designs, and integrated technology for thermal comfort and to find the scope of research in this area.

Experimental studies:

Field studies concerning the ventilation induced by SC configurations in a small-scale single-room house were performed in Thailand (Khedari et al., 2000). In a consecutive study Khedari et al. (2003) studied the performance of SC systems in an air- conditioned small-scale house. Barozzi et al. (1992) tested a 1:12 small-scale model of a building where the roof functions as a solar chimney. Hirunlabh et al. (1999) performed a similar study for a 31m3 volume house where a metallic solar wall was placed on the southern façade. Laboratory experiments on small- scale models were also performed, where temperature distribution of the air and the walls’ surfaces, the velocity profile in the chimney’s channel and the magnitude of the air flow rates were studied, in combination with parametric analysis (Chen et al. 2003, Burek and Habeb 2007). The performance of a full-scale 2m high SC that was part of a 12m3 room, was studied under laboratory conditions by Bouchair (1994), while Arce et al. (2009) studied a 4.5m high model, under real meteorological conditions in Spain.

DESCRIPTION OF SOLAR CHIMNEY

Solar chimney:

A solar chimney often referred to as a thermal chimney is a way of improving the natural ventilation of buildings by using convection of air heated by passive solar energy. A simple description of a solar chimney is that of a vertical shaft utilizing solar energy to enhance the natural stack ventilation through a building.

In its simplest form, the solar chimney consists of a black-painted chimney. During the day solar energy heats the chimney and the air within it, creating an updraft of air in the chimney. The suction created at the chimney's base can be used to ventilate and cool the building below. In most parts of the world it is easier to harness wind power for such ventilation as with a wind catcher, but on hot windless days a solar chimney can provide ventilation where otherwise there would be none.

There are however a number of solar chimney variations. The basic design elements of a solar chimney are:

The solar collector area: This can be located in the top part of the chimney or can include the entire shaft. The orientation, type of glazing, insulation and thermal properties of this element are crucial for harnessing, retaining and utilizing solar gains.

The main ventilation shaft: The location, height, cross section and the thermal properties of this structure are also very important.

The inlet and outlet air apertures: The sizes, location as well as aerodynamic aspects of these elements are also significant

PARAMETRIC ANALYSIS FINDINGS

In parametric analysis, parameters are varied one by one to determine the sensitivity of the system’s performance against each. It has been employed in the vast majority of studies and has played a substantial role in understanding the mechanisms controlling the performance of the solar chimney and their interactions. The most influential parameters can fall under the category of climatic (e.g. solar radiation, wind, effect of inclination) parameters. Some indicative results will be presented in this section, regarding the effect of these parameters on the system's performance.

Effect of inclination angle**:**

Various inclination angles ($0^o/30^o/40^o/60^o$) were studied experimentally for a constant height, cavity width. The air velocity profile across the cavity width was found to be more uniform when the SC was inclined, leading to lower pressure losses at inlet and outlet, and thus to higher airflow rates (45% higher airflow rate was found for the angle of 45^o). Harris and Helwig (2007) numerically studied the consequences of inclining the SC along the roof line of buildings (for the latitude of Edinburgh, Scotland). They argued that although the heat gains can be favored due to tilt, heat transfer between air and glazing is higher, resulting in higher heat losses that could reduce the performance. Higher flow rates by 11% were found (for the optimum angle of 67.5^o), while the performance at 45^o angle was almost the same as that of the vertical SC. It is implicit that the impact of SC inclination is highly dependent on the latitude of the location.

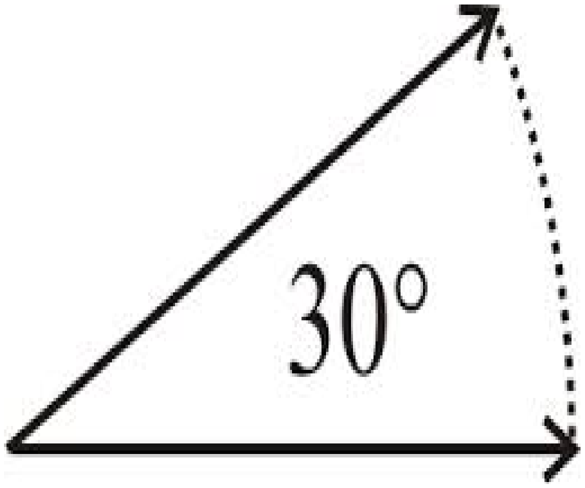


Figure 4.1: Effect of inclination angle such as 30^o

Angle of incident radiation:

The amount of solar gain transmitted through glass is also affected by the angle of the incident solar radiation. Sunlight striking glass within 20 degrees of perpendicular is mostly transmitted through the glass, whereas sunlight at more than 35 degrees from perpendicular is mostly reflected. Regional climatic conditions are often available from local weather services.

Effect of climate:

The intensity of solar heat flux is the motive force for the operation of the SC and is thus the most determinant factor for its performance. In the experimental study of Chen et al. (2003) varying values were considered for the uniform heat flux on the back wall and the airflow rate was found to rise by ~38% for a threefold increase of heat flux (from 200W/m2 to 600W/m2). Mathur et al. (2006) found that airflow rate increases linearly with solar radiation and Bansal (1993) estimated that a SC with surface area of 2.25m2, would induce 100m3/hr and 350m3/hr for solar radiation of 100W/m2 and 1000W/m2 respectively. The simulations of Ho Lee and Strand (2009) showed flow rates to vary as much as 200% between the three assumed locations of the building, as a result of the varying solar availability.

Wind is the second most influential climatic parameter, as it can create positive or negative pressures at the outlet of the SC and thus obstruct or enhance the airflow. In the outdoor experiments by Arce (2009) at a full-scale SC, the highest airflow rates coincided with the highest recorded wind velocity, while Afonso and Oliveira (2000) altered their model to include wind effects which proved significant (error between model predictions and measurements was then lower than 10%). In the analytical study of Mathur et al. (2006) the large error of 23% was attributed to wind effects, which were neglected in the model. In practice, devices canbe incorporated at the outlet of the SC so that wind of all directions creates negative pressures.

DESCRIPTION OF WORKING MODEL:

Fig 5.1Working Model of Solar Chimney concepts with Ventilation Space

Dimensions

Room-

Length= 2 feet 5 inch= 29 inch=0.7366 mtr
Breadth=1 feet 8 inch=19 inch=0.4826 mtr
Height= 3 feet=36 inch=0.9144 mtr

Solar Chimney-

Length=1feet 3 inch=15 inch=0.381 mtr
Breadth=1 feet=12 inch=0.304 mtr
Height=1.5 inch=0.038 mtr

Inlet Hole:-

Length=1feet=12 inch=0.304 mtr
Breadth=2 inch=0.050 mtr

Description

1. Temperature Indicator (Temperature Measurement)
2. Thermocouple (Thermocouple Wire)
3. Anemometre.
4. Sun path,altitude and rotation

RESULTS:

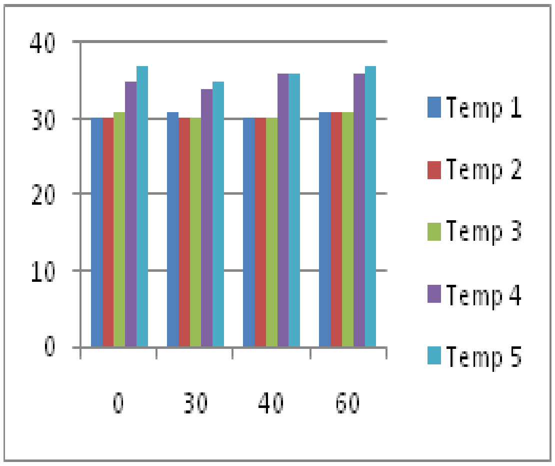
Experiments are conducted on the model for different cases. The data recorded in observation tables. On the basis of the experimental data obtained, results are plotted in the form of curves. The following are the abbreviations used for the data collection and result generation:

Temp 1- Temperature of Room at lower area.
Temp 2-Temperature of Room at Middle area.
Temp 3-Temperature of Room at upper area.
Temp 4-Temperature of Solar Chimney at lowest room side.
Temp 5-Temperature of Solar Chimney at upper exit side.

DAY 1

Time:-10:30 AM

Inlet Temp:-31	Outlet Temp:-37
Air Velocity inlet -1.5 m/s	Air Velocity Outlet:- 1 m/s
Air Velocity inlet Temp- 30	Air Velocity outlet Temp- 37

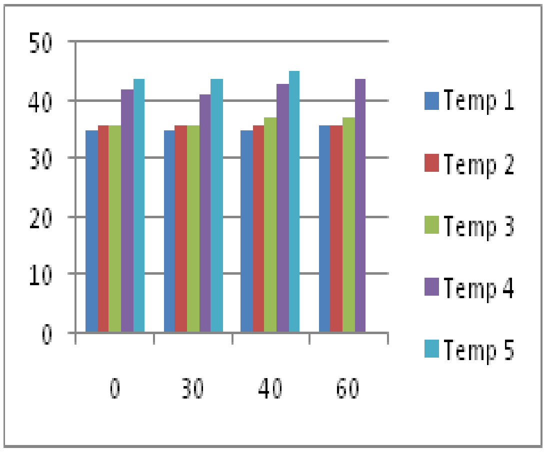


Time:-12:00 PM

Inlet Temp:-36 Outlet Temp:-44

Air Velocity inlet -2 m/s Air Velocity Outlet:- 2.5m/s

Air Velocity inlet Temp- 35 Air Velocity outlet Temp- 43

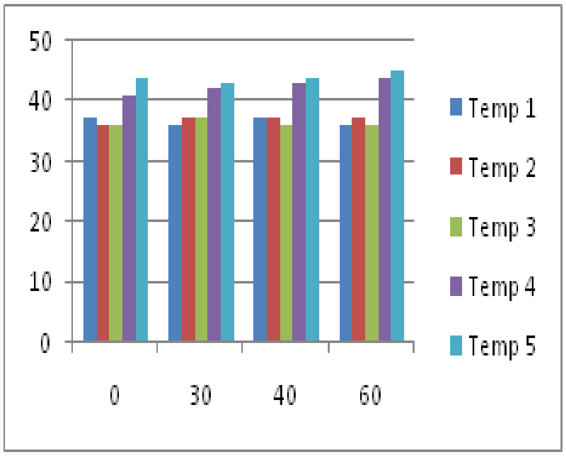


Time:-02:00 PM

Inlet Temp:-37 Outlet Temp:-44

Air Velocity inlet -3.5 m/s Air Velocity Outlet:- 3.0m/s

Air Velocity inlet Temp- 36 Air Velocity outlet Temp- 43

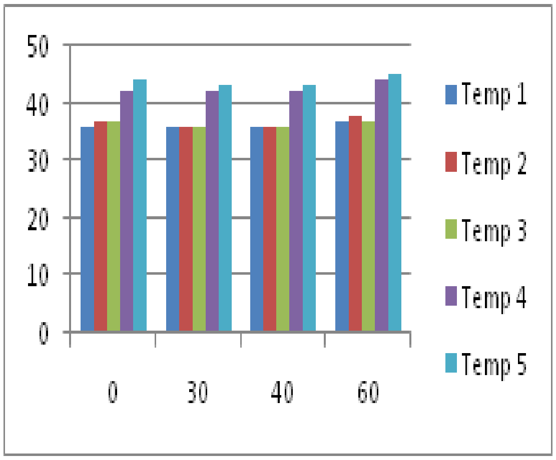


Time:-04:00 PM

Inlet Temp:-37 Outlet Temp:-43

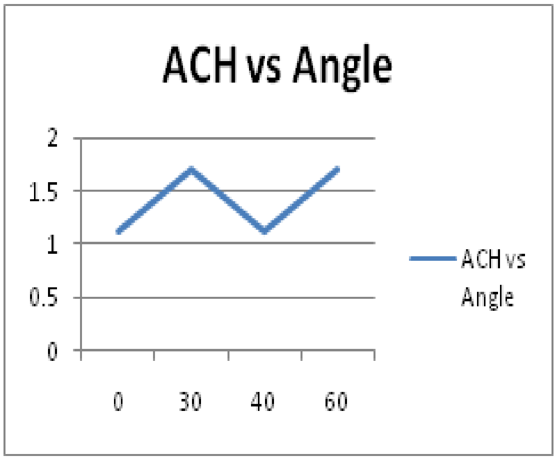
Air Velocity inlet -3.5m/s Air Velocity Outlet:- 2.8m/s

Air Velocity inlet Temp- 36 Air Velocity outlet Temp- 42

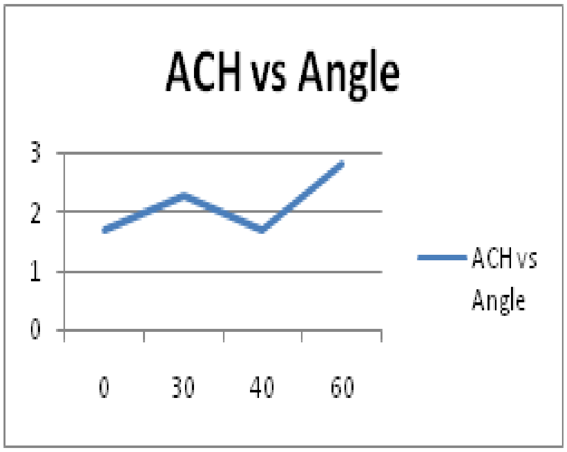


Graph b/w ACH and Angle

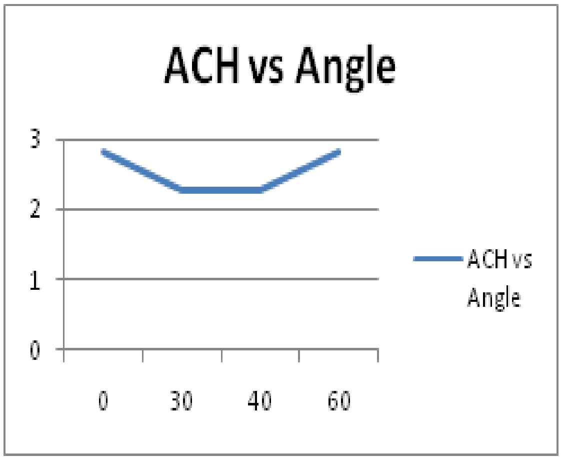
Time -10.00 AM



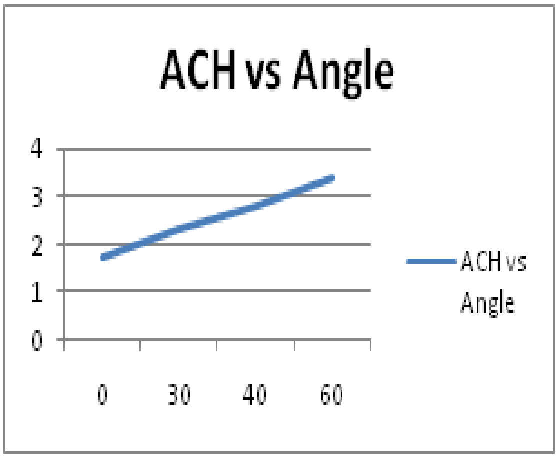
Time -12:00 PM



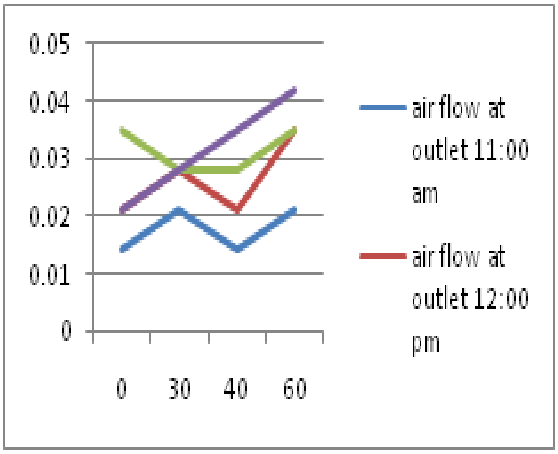
Time -02:00 PM



Time -04:00 PM

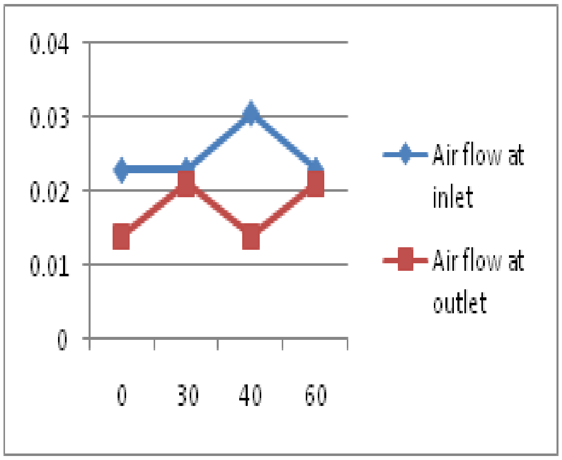


Graph b/w Air Flow rate Vs angle at diff. time

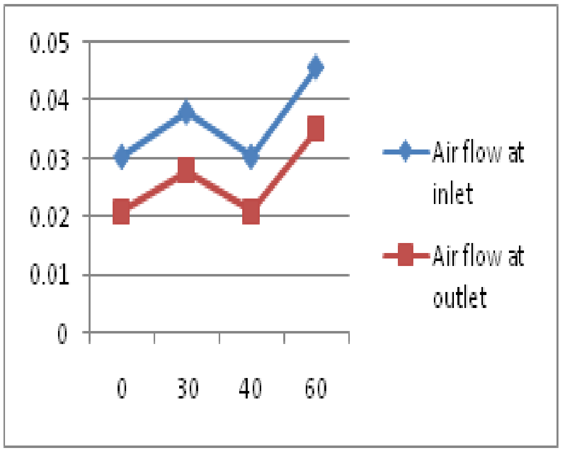


Graph b/w Air flow inlet and Air flow outlet

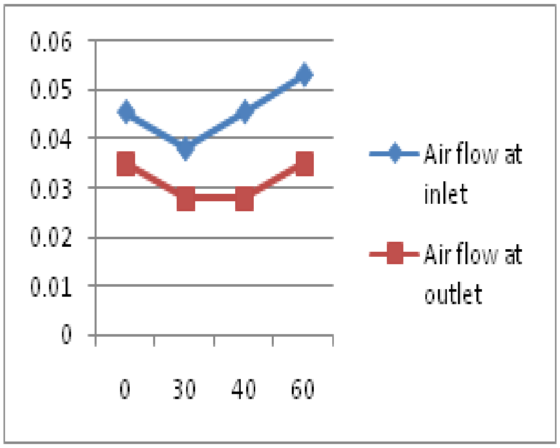
Time- 10:00AM



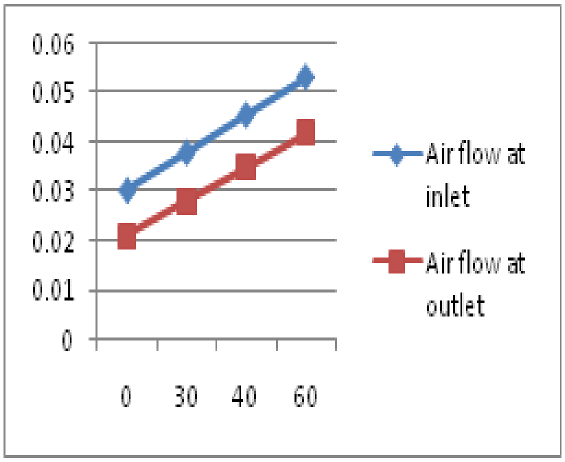
Time- 12:00 PM



Time- 02:00PM



Time- 04:00PM



CONCLUSION;

The performance mainly depends on the temperature differences. The methodology shows the simplest solution to calculate the air flow rate. Applications are depends on the type and configuration of chimney. The cooling of buildings by solar chimney aspects are clearly shown. The conventional air conditioning system can be fully replaced by adopting these integrated techniques for building space conditioning, it reduces the building energy load and sustainability will increase. The conventional construction cost is increasing slightly by use of solar chimney but in long term it will be beneficial.

Measurement data in a small-scale SC were used to calibrate and validate the SC model. A case study office building has been chosen and a sensitivity analysis (SA) of a SC design intended for this building was performed. Performing Sensitivity Analysis (SA) for a SC design and for the following parameters: Angle of incidence of solar chimney and climate parameter such as solar intensity and wind speed.. The next step is the optimization of the SC design and at the final stage a robustness analysis of the optimized design against - among others- active user behavior. At the final stage the integrated model of the SC .

REFERENCES:

1. Afonso, C. and Oliveira, A. (2000), “Solar chimneys: simulation and experiment”, Energy and Buildings, Vol. 32 No. 1, pp. 71-79.
2. Arce, J., Jimenez, M.J., Guzman, J.D., Heras, M.R., Alvarez, G. and Xaman, J. (2009), “Experimental study for natural ventilation on a solar chimney”, Renewable Energy, Vol. 34 No. 12, pp. 2928-2934.
3. Assadi, M.K., Dalir, F. and Hamidi, A.A. (2011), “Analytical model of atrium for heating and ventilating an institutional building naturally”, Energy and Buildings, Vol.43 No.10, pp. 2595-2601.

4. Bansal, N.K., Mathur, J. andBhandari, M.S. (1993),"Solar chimney for enhanced stack ventilation", Building and Environment, Vol. 28 No. 3, pp. 373-377.
5. Bansal, N.K., Mathur, R. and Bhandari, M. (1994), "A study of solar chimney assisted wind tower system for natural ventilation in buildings", Building and Environment, Vol. 29, No. 4, pp. 495-500.
6. Bansal, N.K., Mathur, J., Mathur, S. and Jain, M. (2005), "Modeling of window-sized solar chimneys for ventilation", Building and Environment, Vol. 40 No.10, pp. 1302-1308.
7. Barozzi, G., Imbabi, M., Nobile, E. and Sousa, A. (1992), "Physical and numerical modeling of a solar chimney- based ventilation system for buildings", Building and Environment, Vol. 27 No. 4, pp. 433-445.
8. Bassiouny, R. and Korah, N.S.A. (2009), "Effect of solar chimney inclination angle on space flow pattern and ventilation rate", Energy and Buildings, Vol. 41 No. 2, pp. 190-196.
9. Bassiouny, R. and Koura, N.S.A. (2008), "An analytical and numerical study of solar chimney use for room natural ventilation", Energy and Buildings, Vol. 40 No. 5, pp. 865-873
10. Bilgen, E. (1982), "Solar heating-Ventilating system using a solar chimney", Solar Energy, Vol. 28 No. 3, pp. 227-233.
11. Dai, Y.J., Sumathy, K., Wang, R.Z. and Li, Y.G. (2003), "Enhancement of natural ventilation in a solar house with a solar chimney and a solid adsorption cooling cavity", Solar Energy, Vol. 74 No. 1, pp. 65–75.
12. Ding, W., Hasemi, Y. and Yamada, T. (2005), "Natural ventilation performance of a double-skin facade with a solar chimney", Energy and Buildings, Vol. 37 No. 4, pp. 411-418.
13. Drori, U. (2004), "Induced ventilation of a one-story real-size building", Energy and Buildings, Vol. 36 No. 9, pp. 881-890.
14. Hirunlabh, J. (1999), "Study of natural ventilation of houses by a metallic solar wall under tropical climate", Renewable Energy, Vol. 18 No. 1, pp. 109-119.
15. Khedari, J. (2000), "Ventilation impact of a solar chimney on indoor temperature fluctuation and air change in a school building", Energy and Buildings, Vol. 32 No. 1, pp. 89-93.
16. Lee, K.H. and Strand, R.K. (2009), "Enhancement of natural ventilation in buildings using a thermal chimney", Energy and Buildings, Vol. 41 No. 6, pp. 615-621.
17. Liping, W. and Angui, L., (2004), "A numerical study of vertical solar chimney for enhancing stack ventilation in buildings", Plea2004 - The 21th Conference on Passive and Low Energy Architecture Eindhoven Netherlands, pp. 1-5.
18. Mathur, J. and Mathur, S. (2006), "Summer-performance of inclined roof solar chimney for natural ventilation", Energy and Buildings, Vol. 38 No. 10, pp. 1156-1163.
19. Nouanegue, H. and Bilgen, E. (2009), "Heat transfer by convection, conduction and radiation in solar chimney systems for ventilation of dwellings", International Journal of Heat and Fluid Flow, Vol. 30 No. 1, pp. 150-157.