Enhancement of Natural Ventilation Using Solar Chimney in Hospital Buildings

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Abstract
The study assesses the impact of solar chimneys on natural ventilation in hospitals of hot dry climate region in Nigeria. It takes a quantitative approach using computer simulation software, CFD Ansys Fluent. Input/control data for the software is recorded through a case study of the general hospital, Katsina. A comparison of indoor air velocity and air temperature is made between a base model with and without solar chimneys as indicators of natural ventilation in a selected ward. Result predicts that the application of vertical solar chimney can increase the air velocity up to 0.86 m/s. This shows that, irrespective of the wind velocity outside, the solar chimneys can induce air flow in the building thereby enhancing natural ventilation, which removes unpleasant smells and excessive moisture, introduces fresh air from outside so as to keep interior building air constantly circulated while preventing stagnation.

Keywords: *Air Temperature, Air Velocity, Natural Ventilation, Solar Chimney, Thermal Comfort.*

Introduction

Natural ventilation is clearly a valuable tool for sustainable development as it relies on air movement, and can save significant amount of fossil fuel based energy by reducing the need for mechanical ventilation and air conditioning (Tukur, 2013). Reducing electrical energy used for cooling contribute to reduction of greenhouse gas emissions from electrical generating plant providing the energy (Health and Safety Executives, 2014). Natural ventilation relies on moving air in buildings under natural forces caused by outside wind pressure and the buoyancy effect of difference in temperature.

As opined by Abdullahi (2015), the function of ventilation can be categorized into two, which are for health and thermal comfort whereas the function for structural cooling included as part of a function of thermal comfort. Health requirement is achieved through the exchange of internal air and fresh outdoor air with the unpleasant odour removed. For thermal comfort, air movement cools the body and removes excessive heat (Tukur, 2013).

Although it is difficult to satisfy everyone in a space due to physiological and psychological variation from person to person, thermal comfort is still one of the most significant factors affecting environmental satisfaction (Nazanin, Jones, & Knight, 2008). The excessive heat generated from the suns radiation in the tropics is the major cause of thermal discomfort. This problem emphasized by the fact that it is important to understand the solar radiation, temperature and wind profile within and outside buildings.

Katsina is located in hot dry climate which is characterized by excessive solar radiation; high daily temperature for a greater part of the year which result in very poor indoor thermal comfort as much hospital designs in the region are not climate conscious. Hospital buildings especially in low rise development are subject to significant cooling requirements due to high intensity of solar radiation received by the roof. Single sided window or opening could not provide good passive ventilation strategy. Alternatively, passive cooling by solar induced ventilation can substantially increase air velocity in the rooms and large energy savings can be achieved.

Air temperature is the most important environmental factor, measured by the dry bulb temperature (DBT). Air temperature is a measure of the heat or air temperature surrounding a body, and it is usually measured in degree Celsius (°C) or degree Fahrenheit (°F) (HSE, 2014). Most thermometers are measuring ambient air heat. However, radiant heat loss or gain is also important. Radiant heat may not be reflected in the air temperature, but is the impact of cold or hot objects in the area. The temperature in a building is based on the outside temperature and sun loading plus whatever heating or cooling is added by the HVAC or other heating and cooling sources. Room occupants also add heat to the room since the normal body temperature is much higher than the room temperature.

The significant question concerning how temperature affects thermal comfort is, is the air temperature less or greater than the skin temperature? The difference between these two temperatures determines in which direction heat transfer will occur. Additionally, if the temperature of the air is less than the temperature of the gases exhaled from the lungs, then heat from respiration will be exchanged to the air. Generally, whenever the air temperature exceeds the temperature of the skin and the respired gases, it is difficult to maintain thermal comfort, (Deen, 2004).

Bouchlaghem (2013) opines there are two types of parameters affecting a building's thermal performance. The first type relates to unsteady climatic conditions such as solar radiation, relative humidity, air temperature and wind direction. The second types are design variables which can be controlled by architects.

Bouchlaghem (2013) Also claims that these variables do not affect the thermal performance of buildings in the same way or at the same rate; some are more effectiveness than others. Changing window area, for example, has more effect on the building thermal performance than changing the thickness of a wall. Whereas some variables including orientation are independent, others are interrelated such as floor to ceiling height and the volume of a room.

Abdullahi (2015) discusses that, in the northern part of the Europe, most of the glazing is placed on the south façade so as to have more solar gain. On the other hand, smaller windows are located on the other facades. Use of glazing materials having good insulation can prevent draughts resulting from cold north air flow to glazed south façade. The challenge is to allow efficient conduction of solar energy and to reduce heat loss. The authors claim that some installations may improve thermal and solar capabilities of the glazing in the following manner.

Awbi (2003) reported that the main design considerations for naturally ventilated buildings as climatic conditions, height, building occupancy loads, and features for enhanced ventilation 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.

Barozzi, Imbabi, Nobile, & Sousa (1992), studied space conditioning in buildings as 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 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. One of the more promising passive cooling methods for tropical climatic regions is the stack ventilation strategies.

Stack ventilation is caused by stack pressure at an opening due to variation in air density as a result of difference in temperature across the opening. The same principle can be applied for openings at different heights, the difference in pressure between them is due to the vertical gradient (Awbi, 2003). It utilizes solar radiation, which is abundant in these regions, to generate the buoyant flow. However, as currently applied, the induced air movement is insufficient to create physiological cooling. More studies are needed to improve the ventilation performance of this cooling method. Velocities associated with natural convection are relatively small, and usually not more than 2 m/s (Mills, 1992).

Stack induced ventilation can be improved by solar induced ventilation. In this cases however, where the wind effect is not well captured, solar–induced ventilation may then be a viable alternative. This strategy relies on heating of the building fabric by solar radiation resulting in a greater temperature difference. There are three building elements commonly used for this purpose: tromble wall, solar chimney, and solar roof (Awbi, 2003).

A stack chimney is usually designed in combination with a wind tower in hot arid climatic regions. In many types of ventilated building, winds are considered to be more important than buoyancy. This is because wind induced ventilation flow is commonly stronger than stack induced flow, particularly in low rise buildings. The other method is used in areas with large solar altitude. In this case, a large sloping roof is used effectively to collect the solar energy (Awbi, 2003).

The first mathematical modelling for the solar chimney (Trombe wall) design was given by Bansal, Mathur and Bhandari (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, Mathur and Bhandari (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, 2000). The integrated approach like Trombe wall and roof solar collector gives improved rate of ventilation.

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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. Chantawong, Hirunlabh, Zeghmati, Khedari, Teekasap, and Win, (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) 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.

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. Liping and Angui in 2004 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, Dai, Wang, and Li, (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, Gaona, Luxan and Gomez. 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.

The solar chimney is one of the technologies which works on the buoyancy principle. Here, the air is heated through greenhouse effect which is generated by solar radiation (heat energy). The expenditure involved is not so high. So many techniques can be used in cooling or heating of buildings. The solar chimney can be used in roof level or inside wall as well. The solar chimneys are solar passive ventilation systems thus, they are non-mechanical. The heat is carried out through convective cooling principle.

The solar chimney is designed based on the fact that hot air rises upward; they reduce unwanted heat during the day and exchange interior (warm) air for exterior (cool) air. The solar chimney is mainly made of a black hollow thermal mass with opening at the top of chimney for exit the hot air. The air passes through the room and exits from the top of chimney. Two purposes are solved; one is better ventilation and secondly it reduces the temperature inside the room. It can be worked in reverse for heating the room all well. Thus, merits of solar chimney include but not limited to:

a. There is no mechanical part, thus has low maintenance
b. No electrical consumption.
c. No contributions to greenhouse gasses and thus no aiding of global warming.
d. No emission of pollutants, and
e. It can be used for both heating and cooling

The only identified demerit is that it increases the initial cost of construction of the building.

The solar chimney system is the most prominent technique used in building ventilation for sustainable development (Lal, Kaushik, and Bhargav, (2013). There are many improvements done to the use of solar chimney in enhancing natural ventilation and cooling as well as improving thermal comfort (including integrated techniques).

The solar chimney system is the most prominent technique used in building ventilation for sustainable development. The use of solar chimneys incur high initial cost during construction, as such more work is required to minimize the cost, thereby improving the effectiveness and to making it a more fascinating design. The aim of this study is to assess the impact of such solar chimneys on natural ventilation in hospitals in hot dry climate.

Methodology

This study takes the quantitative approach using computer simulation software, CFD Ansys Fluent®. Input data for the software is recorded through a case study of General Hospital Katsina and weather data was obtained from the Nigerian Meteorological Agency. A comparison is made of the indoor air velocity and air temperature between a base case model with and without solar chimneys as indicators of natural ventilation in a chosen ward.

The dependent variables are the predicted indoor air temperature, indoor air speed and thermal comfort. Thermal comfort is measured in terms of indoor dry bulb air temperature and operative temperature, both measured in degree Celsius (°C) and air speed is measured in metre per second (m/s). Dry bulb temperature is the most common index for the specification of comfort (Nicol, Hunphreys, & Roaf, 2012).

However operative indoor air temperature combines the effect of surface temperature of the wall surface as well as air temperature which is considered more accurate.

Several tools were used to obtain weather data i.e. temperature, wind velocity, wind direction, and solar radiation in the area of the study. The existing hospital ward was modeled and also solar chimney modeled but in Ansys Fluent® as seen in Figure 1. The solar chimney was placed at the middle of the ward. Different orientation was used as well as some selected solar times of a selected day. Ansys Fluent® is a widely used software for modeling engineering fluid flows due to its robustness, accuracy, and user friendliness.

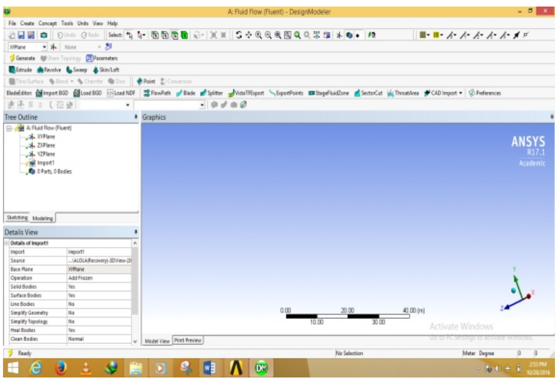

Figure 1: Ansys Fluent interface

In general, for simulation analysis and assessment, these research principles apply: qualitative analysis, quantitative analysis, comparison with previous studies, comparison with real world conditions and statistical data analysis (Satwiko, 1994).

Firstly, the qualitative analysis for secondary problems is made. These include issues what should be accounted for, but should not be the major consideration. Some research is full of philosophy and not be easily linked to building science scenarios. To determine the relevance of a philosophical thought to building science, a logical qualitative analysis is conducted. This usually precedes a quantitative analysis.

Secondly, the quantitative analysis for simple problems is conducted. People demand different indoor air conditions to keep comfortable, depending on their activities. In many cases, recreation and behaviour are culturally determined.

Thirdly, comparison with previous studies is sourced in research reports for complicated numerical problems. Computational fluid dynamics codes involve complex mathematics. Since this research focuses on the application of computational fluid dynamics codes, any issues raised by the numerical are referred to the relevant experts or, if appropriate, compared to results found in other research reports.

Fourthly, the comparison with real world conditions is made. Rather than simply adjusting the computer simulation to imitate real conditions, it quickly identifies suspicious or *strange* results that may indicate the existence of flaws. These flaws can be caused by various problems from false data input to improper computer programming configuration. Last, Statistical analysis is used particularly for interpreting weather data. In this research Excel software is used.

Hospital Ward Model

The ward is selected from prototype wards of the General Hospital Katsina. They consist of a nurses' station, main ward, nurse in charge room, staff common room, patient's waiting area, dressing room and toilets for patients and staff. The ward has single sided and high level windows. The purpose of the simulation is to make evaluation of the room's parametric study as shown in Figure 2.

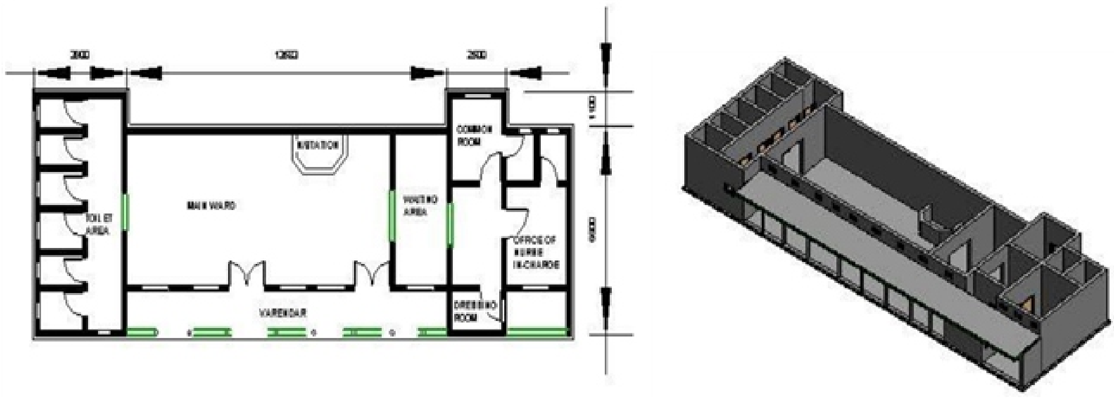

Figure 2: Hospital ward plan and 3D section

Solar Chimney Model

The vertical solar chimney model has the following configuration; length 3000mm, height 3000mm, width 500mm, thickness 150mm and made of glass material as shown in Figure 3.

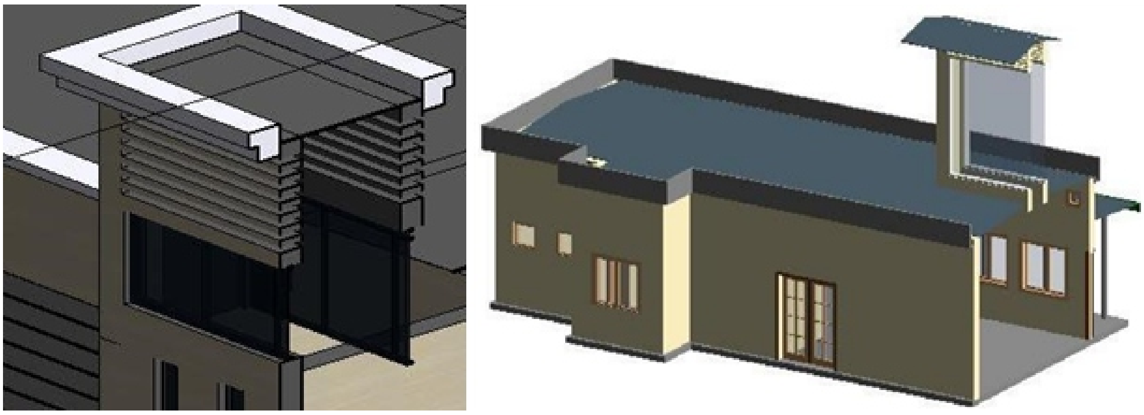

Figure 3: Solar chimney model

Discussion from simulation

A simulation of the ward was conducted with and without solar chimney model and a comparison of air temperature and air velocity was done with and without the solar chimney. Maximum and minimum values were obtained for solar times 10:00, 11:00, 12:00, 13:00, 14:00, 15:00, 16:00 and 17:00 hours as these are the solar times that the sun tends to be hottest.

North-South Orientation

Orientation as stated above plays an important role in aiding cooling and heating of buildings. The sun path when facing the solar chimney provides more heat and induces air flow. The temperature differences between simulations done with and without solar chimney on the base case model at different solar times are shown in Figure 4.

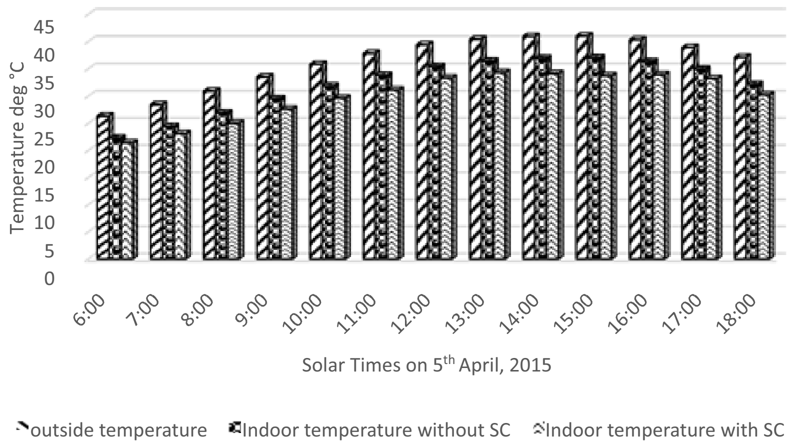

Figure 4: Temperature difference with and without solar chimney

Generally, 5th April happens to be hottest day of the year in 2015 with the highest temperature at 41°C at 15:00 hours. Even at 10:00 hours, the temperature is still high at 35.8°C which gives thermal discomfort and by the 18:00 hours, the temperature is still above the thermal comfort range of 37.1 °C.

Greater temperature difference was seen by the introduction of solar chimney induced cooling. A maximum temperature difference $\Delta T = 3.3°C$ was achieved in the north-south direction. The minimum temperature difference $\Delta T = 0.9°C$ recorded while the average recorded temperature difference $\Delta T = 2.1°C$.

The application of solar chimneys in the North-South direction gives some percentages of comfort as recorded. The maximum percentage of comfort recorded is 9.8% for the respective solar times. The minimum comfort percentage recorded is 4.2% and the average comfort percentage recorded for the respective solar times is 9.3%.

The results for the simulation done to the base case model with and without solar chimney to check its effect on the indoor air velocity is presented in Figure 5. Great increase in indoor air velocity was recorded on the 5 of April, 2015. The different solar times have different increase in the indoor velocity. The minimum recorded velocity difference $\Delta V = 0.26$ m/s and the maximum velocity difference $\Delta V = 0.72$ m/s whilst the average recorded velocity difference $\Delta V = 0.36$ m/s.

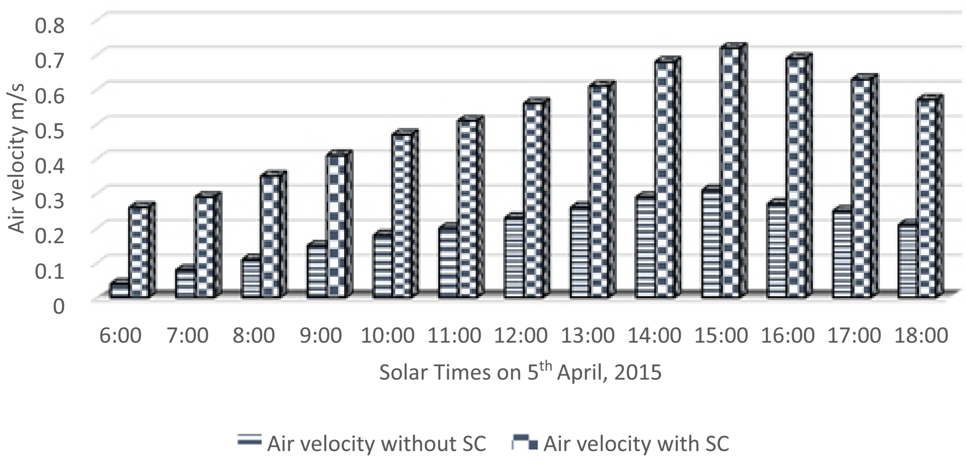

Figure 5: Indoor Air velocity with and without solar chimney

The application of a solar chimney gives an improvement to the indoor air velocity at the respective solar times of the chosen day 5 April, 2015. The minimum percentage of improvement recorded for it is 15.4% and the maximum percentage of improvement recorded is 43% whilst the average percentage of improvement recorded is 36%.

East-West Orientation

The chart indicated in Figure 6 shows the simulation result for the temperature difference and air velocity for the base case model with and without solar chimney facing the East-West orientation

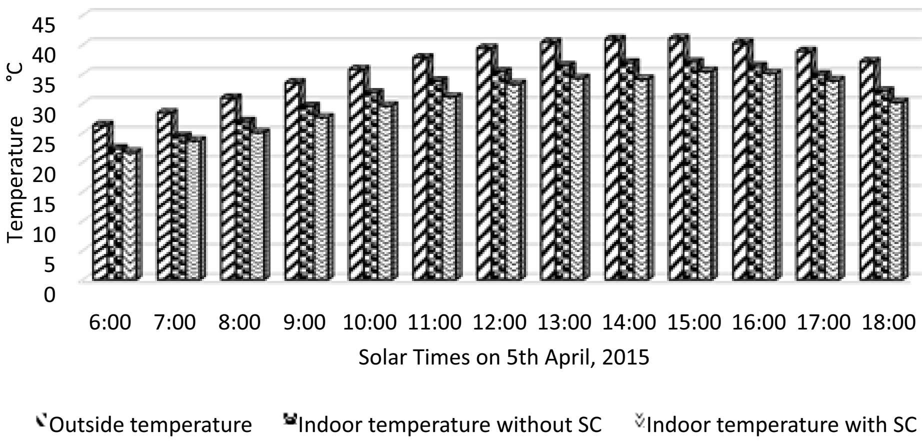

Figure 6: Indoor Temperature with and without solar chimney

By the introduction of solar chimney, a considerable reduction in temperature was recorded at the respective solar times. The maximum temperature difference Δ T 1.5°C was recorded and the minimum temperature difference Δ T = 0.6°C was also recorded. The average temperature difference Δ T recorded is 1.05°C.

From the simulations done, results show that significant percentage of improvements indoor temperature were obtained, the maximum percentage of improvement in indoor temperature obtained is 4% and the minimum percentage of improvement in indoor temperature recorded is 2.7% while the average improvement in indoor temperature recorded is 3.5%

The difference in velocity ΔV recorded for the simulation conducted in the East- West orientation shows that the maximum velocity difference $\Delta V = 0.48$ m/s and the minimum velocity difference $\Delta V = 0.19$ m/s while the average difference in velocity $\Delta V = 0.34$ m/s as recorded and shown in Figure 7.

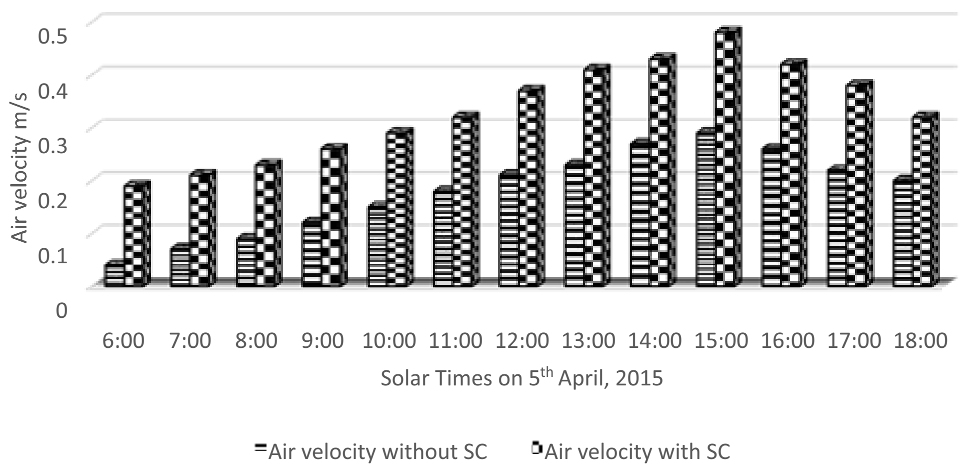

Figure 7: Air Velocity with and without Solar Chimney

The application of solar chimney gives some percentages of improvement on the indoor air velocity on the respective solar times. The percentage of improvement recorded for the indoor air velocity as a result of the effect of solar chimney shows the maximum improvement of 30% and the minimum percentage of improvement recorded is 21% whilst the average percentage of improvement recorded is 26%.

Conclusion

The ability of solar induced ventilation is viable as seen in this study. The application of solar chimney shows a considerable increase in air velocity up to 0.86 m/s which is sufficient to provide natural air movement without the need of active means thereby providing considerable thermal comfort (50% increase) to the occupants of the building. The maximum psychological cooling was obtained on the north-south orientation that showed the maximum temperature reduction and air velocity induction. This indicates when considering only the indoor air movement and temperature, the north south orientation can improve thermal comfort ventilation. All orientations illustrated provide natural ventilation requirement under Katsina conditions compared to the ward without vertical solar chimney.

This also shows that irrespective of the wind velocity outside, solar chimney can induce air flow in the building interior due to the high solar radiation in hot dry climate region. The North-south orientation gives the best result when considering orientation. This study thus concludes that an application of solar chimney induced ventilation can efficiently replace active means in inducing air flow and preventing stagnation of air in the hospital ward interior of hot dry climate region of Nigeria.

References

Abdullahi, M.U (2015). Application of Energy Efficiency Strategies in the Design of National Library, Katsina. Unpublished M.sc thesis. Department of Architecture, Ahmadu Bello University Zaria.

Abdul, M. I. (1996). Wind Driven Natural Ventilation in High-Rise Office Building with Special

Reference to the Hot-Humid Climate of Malaysia, University of Wales College of Cardiff, PhD, Thesis,

Alfonso, C. (2000). Solar Chimneys: Simulation and Experiment, Energy and Buildings, Vol. 32, Pergamon Press.

ASHRAE (2010), Thermal Environmental Conditions for Human Occupancy, ANSIASHRAE Standard 55-2010

Awbi, H. B. (2003). Ventilation of Building, Spon Press, London

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

Bansal, N.K., Mathur, J. and Bhandari, M.S. (1993), solar chimney for enhanced stack ventilation, Building and Environment, Vol. 28 No. 3.

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.

Biket, A. (2006). Architectural Design Based On Climatic Data, 1st International CIB Endorsed METU Postgraduate Conference, Built Environment & Information Technologies, Ankara.

Bouchlaghem, N. (2013). Optimising the Design of Building Envelopes for Thermal Performance. Automation in Construction, Vol. 10,

Chandra, S., Kaushik, S.C. and Bansal, P.K. (1985), Thermal performance of a non-air-conditioned building for passive solar air-conditioned: Evaluation of roof cooling system, *Energy and buildings*, Vol. 8.

Chantawong, P., Hirunlabh, J., Zeghmati, B., Khedari, J., Teekasap, S. and Win, M. (2006), "Investigation on thermal performance of glazed solar chimney walls", *Solar Energy*, Vol. 80 No. 3, pp. 288-297.

Deepti, C. (2015). Numerical Study of the Thermal Performance of Solar Chimneys for Ventilation in

Buildings. Energy Research Centre Department of Mechanical Engineering. M.Sc. Thesis.

Deen, H. (2004), Passive and Active Environmental Controls. The McGraw-Hills Companies, New York.

Salata, F., Alipi, C., Tarsitano, A., Golasi, I. and Coppi, M. (2015). A First Approach to Natural Thermoventilation of Residential Buildings through Ventilation Chimneys Supplied by Solar Ponds. ISSN 2071-1050, www.mdpi.com/journal/sustainability.

Gan, G. (1998), a parametric study of Trombe wall for passive cooling of buildings, Energy and Buildings, Vol. 27.

Gan, G, A. & Riffat, S. B. (1998). Numerical Study of Solar Chimney for Natural Ventilation of Buildings with Heat Recovery, Applied Thermal Engineering, Vol. 18, Oxford: Pergamon Press.

Awbi, H. (2010). BASIC CONCEPTS FOR NATURAL VENTILATION OF BUILDINGS. Technologies for Sustainable Built Environments Centre University of Reading, UK. http://www.reading.ac.uk/tsbe

Hamdan, M. and Nugroho, A.M. (2005). Towards Development of Tropical Solar Architecture: The Use of Solar Chimney as Stack Induced Ventilation Strategy, Proceeding World Renewable Energy Regional Congress and Exhibition, Jakarta

Health and Safety Executives (2014). A publication on of health and safety executives, retrieved on 15 August 2014 from www.hse.gov/temperature/thermal.

Hirunlabh, J. (2001), new configurations of a roof solar collector maximizing natural ventilation, Building and Environment, Vol. 36 No. 3.

Lu J., Gao, X., Li, Q. and Li, Y. (2017). Thermal Storage Capacity and Night Ventilation Performance of a Solar Chimney Combined with Different PCMs. International Journal of Photoenergy, Hindawi. https://doi.org/10.1155/2017/8363190

Khedari J. (2000). Field Measurements of Performance of Roof Solar Collector, Energy and Buildings, Elsevier Science Ltd. ,Vol 31, pp 171–178.

Lal, S., Kaushik, S.C. and Bhargav, P.K. (2013), solar chimney: A sustainable approach for ventilation and building space conditioning, *International Journal of Development and Sustainability,* Vol. 2 No. 1

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

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.

Macias, M., Gaona, J.A., Luxan, J.M. and Gomez, G. (2009), Low cost passive cooling system for social housing in dry hot climate, *Energy and Buildings*, Vol. 41 No. 9

Mohd. Hamdan bin Ahmad, MD Rajeh Bin Saleh and Hong Lim Foo (2006), towards development of tropical solar Architecture: the use of solar chimney as stack induced ventilation strategy. Faculty of built environment universiti teknologi Malaysia

Nazanin, N., Jones, P., and Knight, I. (2008). Workplace satisfaction and thermal comfort in air conditioned office buildings: Findings from a summer survey and field survey in Iran. Indoor Built Environt

Nicol, J., Hunphreys, A., & Roaf, S. (2012). Adaptive thermal comfort: Principles and practice. Oxon, UK Routlege.

Nugroho, A. M. and Hamdan, M. (2005). Possibility to use Solar Induced Ventilation Strategies in Tropical Conditions by Computational Fluid Dynamic Simulation, Proceeding International Seminar Sustainable Environmental Architecture 6, Bandung Indonesia.

Ong, K.S. (2003), a mathematical model of a solar chimney, Renewable Energy, Vol. 28, No. 7

Satwiko, P. (1994) The Development and Modelling of a Natural Ventilation System for Indonesian Conditions, Thesis Master of Building Science, Victoria University of Wellington.

Sapian, A. (2004). Possibilities of using Void to Improve Natural Cross Ventilation in High-rise Low Cost Residential Building, Thesis.

Straaten, J. (1967). Thermal Performance of Buildings, Elsevier Publishing. Amsterdam London Newyork.

Sumathy, K., Dai, Y.J., 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.

Tukur, R. B. (2013). Harnessing daylight potentials as a tool for thermal comfort in residential buildings. Unpublished PhD Thesis University of Nottingham

UNDP. (2001). Human Development Report Nigeria. Oxford: Oxford University Press.