NATURAL VENTILATION IN HOSPITAL WARDS OF SEMI-ARID CLIMATES: A CASE FOR ACCEPTABLE INDOOR AIR QUALITY AND PATIENTS' HEALTH

Mohammed Alhaji Mohammed[*1], Steve JM Dudek[1], and Neveen Hamza[1],

[1] *School of Architecture, Planning and Landscape, Newcastle University, NE1 7RU, Newcastle Upon Tyne, UK*
**Corresponding author's e-mail address: a.m.mohammed@ncl.ac.uk*

ABSTRACT

Owing to the growing concern about indoor air quality (IAQ) globally in hospitals, especially after the recent outbreak of diseases like severe acute respiratory syndrome (SARS), Swine Flu (H1N1) and other airborne infections such as Tuberculosis, the quest for energy efficient ventilation system is growing. To provide acceptable indoor air quality that is capable of removing indoor air contaminants in hospital wards, sustainable ventilation strategy is required. Therefore, this paper tends to exploit the possibilities of using natural ventilation strategies in providing acceptable indoor air quality in hospital wards of semi-arid climates. The study established that, Mosquito insects, Harmattan dust, and high temperatures are the three major factors militating against the achievement of natural ventilation in semi-arid climates of Nigeria. Mosquito insects remain the only source of Malaria parasites that kills thousands of people in the tropics, while the inhalation of Harmattan dust causes cardiovascular and respiratory diseases.

To achieve the objectives of this study, a comprehensive literature review, full-scale measurement and field survey have been conducted. The results obtained from the field measurement shows that none of the hospitals measured achieved the required ventilation rates of 6 ACH as enshrined by AHSREA. Moreover, the survey results for the five hospitals studied shows that more than 80% and 90% of the respondents have admitted the presence of Harmattan dust and mosquitoes respectively in the hospital multi-bed wards. Therefore, the design of sustainable natural ventilation that can remove indoor contaminants while excluding outdoor pollutants in the hospital wards of semi-arid climates without compromising occupants comfort is essential.

KEYWORDS

Natural Ventilation, indoor air quality, Mosquito, Harmattan dust, semi-arid

1 INTRODUCTION

Nowadays, the quest for energy efficient natural ventilation system design is growing due to the increasing concern about carbon emission, indoor air quality and health, especially in hospital multi-bed wards. Moreover, this concern has instigated the professionals in building system design to intensify efforts in proposing different ventilation strategies to achieve healthy and acceptable indoor air quality.

The adoption of natural ventilation system was informed by the prevalent energy shortage in the study area. Despite the abundant resources to generate energy in Nigeria, due to the poor planning, maintenance and management of the energy sector, it has been difficult to fulfil the electricity generation and supply demands of its population. The electricity demand extremely exceeds the supply, and even the supply remains unreliable (Sambo, 2008). The total grid installed capacity produced by Nigerian power stations was 8,876 MW with only 3,653 MW available as at December 2009, hence, the available power supply is less than 41% of the total installed capacity (Emovon, et al. 2011). Moreover, the 2009 International Energy Agency (IEA) records shows that the electrification rate for the whole country was about 45% to 50%, thus, depriving approximately 76 million people access to electricity.

According to a World Bank report, the yearly (2007–2008) average power outages experienced in Nigeria was 46 days, and an outage last for about 6 hours on average. In addition to problems such as insufficient maintenance, inadequate feedstock and insufficient transmission network, high population growth combined with underinvestment in the electricity sector have also resulted in increased power demand without any substantial growth in production (IEA, 2012).

Nigeria's location on the southern fringe of the Sahara makes it more vulnerable to numerous climatic problems including Harmattan dust, mosquitoes and high temperatures. The mosquito insect and Harmattan dust usually seize the advantage of the openings provided for natural ventilation to find their way into the building indoor spaces. Moreover, the consequences of these Harmattan dust and mosquitoes are more destructive in hospital environment compared to any other type of facility. This is because, hospital wards accommodates immunosuppressed and immunocompromised group of people due certain ailments. These group of people are easy to be infected by diseases especially Malaria, which solely caused by mosquitoes. Furthermore, Harmattan dust will help in deteriorating patients' sickness especially those with respiratory diseases.

2 CHARACTERISTICS OF SEMI-ARID CLIMATES

The environmental parameters for building design for tropical countries such as Nigeria are quite contrary with temperate regions due to the difference in climate and weather conditions. Climate references are required for the design of buildings in semi-arid climates to achieve acceptable indoor air quality and thermal comfort. Therefore, to accomplish indoor air quality and thermal comfort requirements with the presence of mosquitoes and Harmattan dust in hospital wards, the climatic parameters have to be considered right from the design stage. Three major parameters should be considered when designing for natural ventilation in semi-arid climates including Harmattan dust, Mosquitoes and high ambient temperatures.

Harmattan is a fugitive dust transported by dry North-East trade wind that usually blows across Nigeria between November and March annually and diminishing southwards. The consequences of this dust are higher in the Nigerian semi-arid climatic zone being situated in the Northern boarders of the country. The relationship between dust particles concentration and its effect on human health is established in literature, particularly linking cardiovascular and respiratory diseases to Dust outbreaks (Kwon et al. 2002, Chen et al. 2004, Meng and Lu, 2007). The dust particles size varies with location, depending on the proximity of the collection center from the dust origin in the Sahara desert. The mean sizes of dust samples collected in Nigeria for two Harmattan seasons are 2.7μm and 4.4 μm, respectively (Chineke and Chiemeka 2009). However, the elemental composition of Harmattan dust in Nigeria was measured using neutron activation analysis to determine the concentrations of 29 elements, with iron (Fe), aluminum (Al), and potassium (k) being among the highest at 61 mg g-1, 431 mg g-1, and 15 mg g-1, respectively (Adepetu et al. 1988).

Mosquitoes are cold-blooded insects that have the same body temperature as the surrounding environment. There are only three species out of more than 3,000 species of mosquitoes that are largely responsible for the spread of human infections including; Anopheles, Culex and Aedes. The Anopheles mosquitoes are found in the study area (Maiduguri, Nigeria), and are the only species known for transmitting the malaria parasite (National Geographic, 2013). The average lifespan of a Mosquito is from 2 weeks to 6 months and its average size is 0.3 to 2 cm, with average weight of 2.5 mg) (National Geographic, 2013).

The consideration of high outdoor air temperatures that exceed human comfort thresholds creates a challenge in designing natural ventilation strategies for acceptable thermal comfort in semi-arid climates. In the dry season the temperature in Maiduguri (Study area) peaks with

wide diurnal and annual ranges of dry bulb temperatures, with the hottest months of April, May and June. Dry bulb temperatures can exceed 43^{o}C but falls to a mean of 24^{o}C or 29^{o}C with the start of the rainfall (Maxlock Group Nigeria, 1976).
Since, the thermal comfort and human preferences are related to acclimatisation to local conditions the neutrality temperature of the study area (Maiduguri) has been estimated using the outdoor average ambience temperature using the formula Tn = 17.8 + 0.31Toav (Szokolay, 2008). The thermal neutrality temperature of Maiduguri is found to be 26.7^{o}C, and considering a temperature band of ±2.5 as recommended in Szokolay, S. V. (2008), the thermal comfort zone will fall between 24.2^{o}C and 29.2^{o}C. Figure 1 illustrates the annual ambient temperature in the study area in relation to the neutrality temperature range. The ambient average temperatures that are within the comfort zone includes February, August and November, while the remaining nine months are out of the comfort temperature zone.

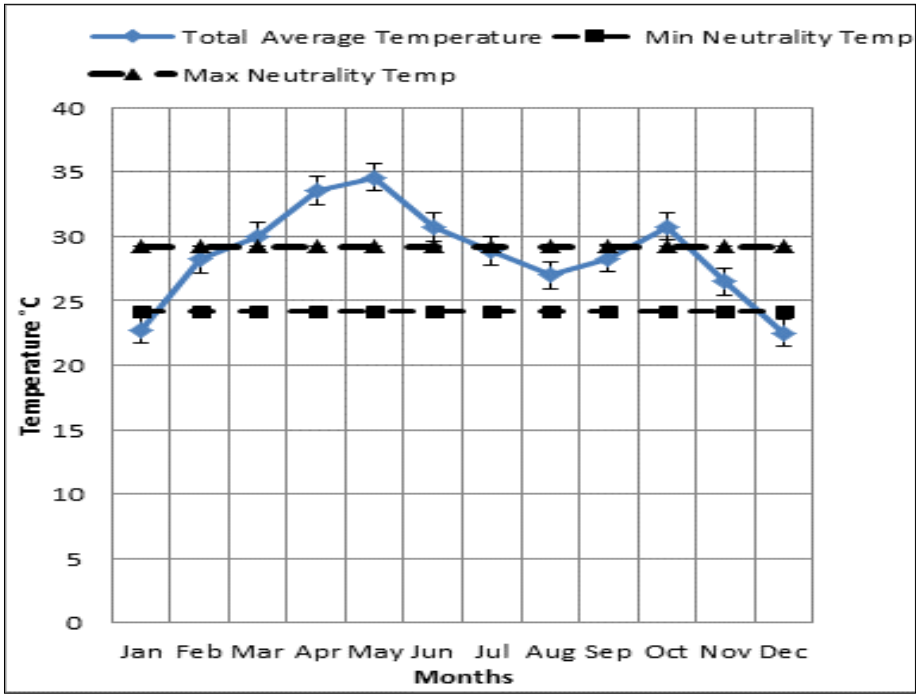

Figure 1: Total Average Ambience Temperature of the Study Area in Relation to Neutrality Temperature Zone

3 INDOOR AIR QUALITY AND NATURAL VENTILATIONS IN HOSPITAL MULTI-BED WARDS

The quality of indoor air dictates the health status of an environment and its occupants. As clean indoor air quality is critical for healthy indoor environment. Poor indoor environmental qualities are responsible for many health problems including allergies, eye irritations, and respiratory problems (Yau, et al, 2011). Various indoor air contaminants exist in hospital multi-bed wards. These contaminants are very difficult to predict as they generate from both indoor and outdoor sources, and contain different types of substances (Hobday, R. 2011). Indoor air contaminants especially those with outdoor sources are largely dependent on climatic condition of the environment, whereas contaminants with indoor sources are largely originates from furniture, building materials, chemicals and human body.
The achievement of acceptable indoor air quality and thermal comfort passively, while excluding unwanted parameters such as mosquitoes and Harmattan dust in the semi-arid climates is a difficult task that requires a holistic approach. The exclusion of these unwanted

parameters are easy to realize when using mechanical means for ventilation, as the need for opening large ventilators to the outside is not required. Regrettably, there is insufficient energy in the study area to cater for such demands. Therefore, there is a salient need to explore the possibility of using natural ventilation for achieving acceptable indoor air quality and thermal comfort.

Natural ventilation is usually driven by natural forces such as wind, thermal buoyancy force owing to variations in indoor and outdoor air density, which force in fresh air from outside through custom-made building envelope openings (Atkinson, 2009). It relies on the pressure differences caused by either wind or the buoyancy effect created by temperature or humidity difference to move fresh air through buildings. The use of natural ventilation in buildings becomes an increasingly attractive means of cutting energy cost and achieving acceptable quality of indoor environment, due to the improvement on the cost and environmental consequences of energy utilization (Walker, 2010). However, the performance and condition of ventilation in hospitals have great impact on the perceived indoor air quality (Hellagren, U. et al, 2011).

4 HEALTH CONSEQUENCES OF OUTDOOR POLLUTANTS IN HOPSITAL MULTI-BED WARDS IN SEMI-ARID CLIMATES

The two major outdoor pollutants in the hospitals of semi-arid climates are Harmattan dust and Mosquitoes.

4.1 Health consequences of Harmattan Dust

The respiration of airborne dust particles in form particulate matter of less than 2.5 micrometres in size is known as a health hazard, particularly at ambient concentrations as reported for many West African countries (Ogunseitan, 2007). These airborne dust particles usually affect human health, as a result of their impact on local and regional air qualities (Anuforom, 2007). The relationship between dust particles concentration and its effect on human health has already been established in the literature, particularly linking cardiovascular and respiratory diseases to Dust outbreaks (Kwon et al. 2002, Chen et al. 2004, Meng and Lu, 2007). Likewise, study by Yoo, et al. (2008), established that children with mild asthma reported more respiratory symptoms during dust days, often requiring the use of bronchodilator compared to clean days. Furthermore, Harmattan winds and more humid conditions usually experienced during dry season in North Eastern Nigeria are believed to be responsible for an increase in positive ions and other gases in the air triggering migraine head pain. When an interview was conducted among margarine sufferers in this region, 46% and 38% of the respondents mostly experienced migraine attack during warmest months and Harmattan season respectively (Timothy, et al. 2011)

Environmental Protection Agency (EPA) in Unites State of America issued final guidelines on 29th March, 2007 for regions to clean up their air that, the presence of Fine particles or "PM2.5" in the air can ignite heart and lung diseases and have been connected to premature death and a range of severe health complications including heart attacks, chronic bronchitis and asthma attacks (Ogunseitan, 2007).

4.2 Health consequences of Mosquitoes

Malaria is the most parasitic infectious disease in the world, is transmitted by mosquitoes which breed in fresh or rarely salty water. It symptoms include fever, headache, chills, muscle aches, tiredness, nausea and vomiting, diarrhoea, and jaundice. It could also lead to

convulsions, coma, severe anaemia and kidney failure. The severity and range of symptoms is determined by the specific type of malaria. In the absence of prompt and effective treatment, malaria can evolve into a severe cerebral form leading to death. Moreover, malaria is among the five leading causes of death in children under the age of 5 in Africa (WHO, 2001). Figure 2 shows the control of Malaria in Africa.

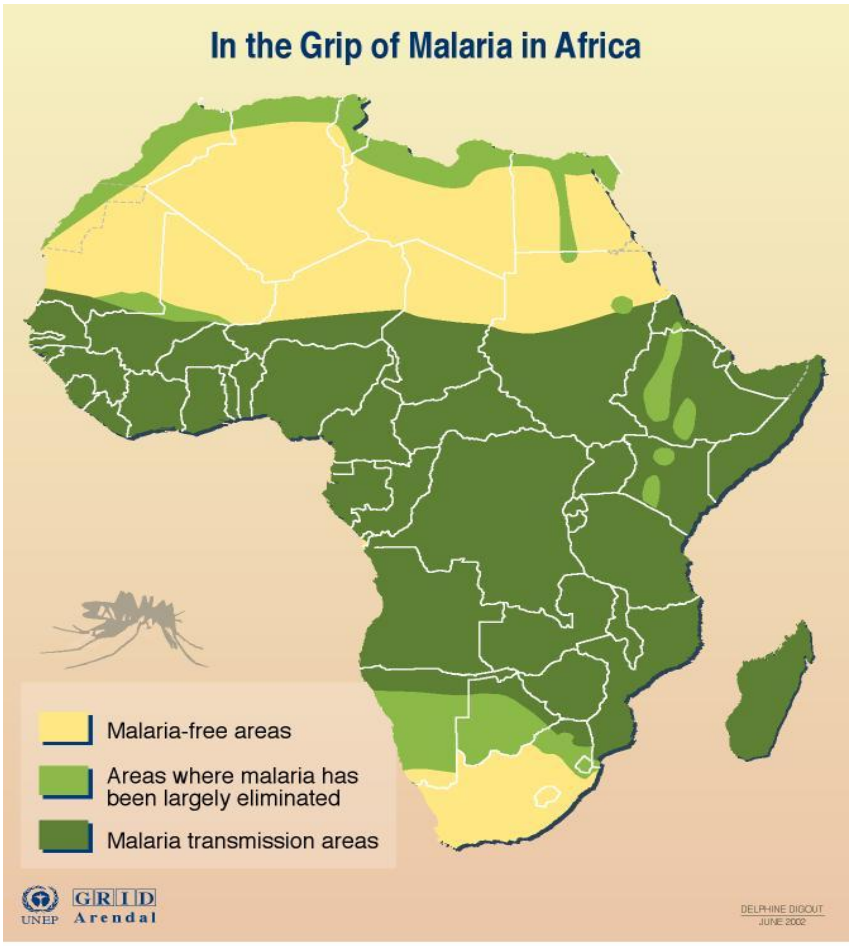

Figure 2: The Control of Malaria in Africa

5 CASE STUDY

5.1 Physical Measurement

Four hospital wards were selected in the study area Maiduguri and the Air Change Rates (ACR) in these hospital wards was measured using tracer gas (Concentration decay) techniques with CO_2 as the tracer gas. The concentration decay method is usually done by releasing a small amount of gas initially, after which there is no injection of gas throughout the measurement period (Etheridge and Sandberg 1996). Once the injected tracer gas is mixed with the space air, the concentration is measured at a regular time interval (Laussman and Helm 2011). Concentration decay is the most commonly used method in practice, which provides a direct measurement of the nominal time constant or the air change rate and gives unbiased estimate of the mean airflow rate. Typical procedure that has been used for conducting concentration decay tracer gas measurement is illustrated in Figure 3.
The results obtained from these measurements were used to estimate the air change rates in the selected hospitals multi-bed wards using the mathematical expression in equation 1. The

result shows that the air change rates (ACR) in all the measured hospital wards are below the standard ACR of 6 ACH set aside by AHSRAE (Ninomura and Bartley, 2001). The ACR measurement result is illustrated in Figure 4.

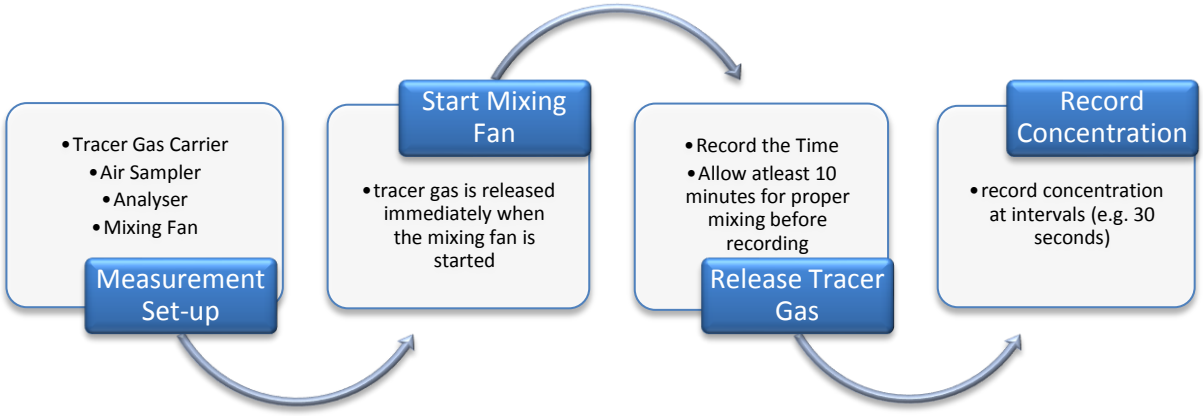

Figure 3: Procedures for conducting concentration decay tracer gas measurement

$$N = \frac{\ln C(0) - \ln C(\tau 1)}{\tau 1} \quad (1)$$

Where
N = Air Change Rate
C = Tracer Gas Concentration in Rooms
τ = Time (h)

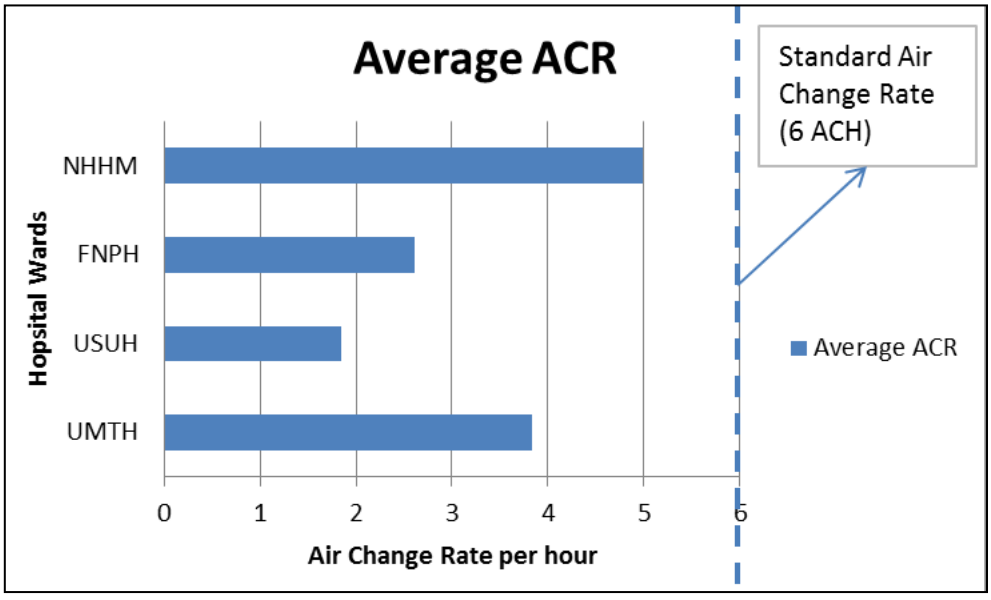

Figure 4: Air change rates in four hospitals in the study area compared to the standard

5.2 Psychosocial Perception

Questionnaire survey has been conducted among the immediate occupants of the hospital multi-bed wards including medical doctors, nurses and other healthcare workers. The respondents were asked about their perception on Harmattan dust and mosquitoes in the

hospital wards. Both Harmattan dust and mosquitoes usually penetrates through windows, doors and air-conditions openings.

The availability of dust particles within hospital wards has great consequences on the patients' health condition. According to the result of the survey conducted to ascertain the level of dust within the hospital wards, by asking the respondents "Do you normally experience dust problem in the wards?" about 97% have agreed they experience dust problems in the wards and the remaining 3% don't experience any dust problem as illustrated in Figure 5.

Moreover, when the respondent to the survey to ascertain the level of mosquito problem in the hospital wards were asked "Do you usually experience Mosquito problem in the wards?" 99% of the respondents said they are facing mosquito problems in the multi bed wards, while the remaining 1% said they are not as shown in Figure 6.

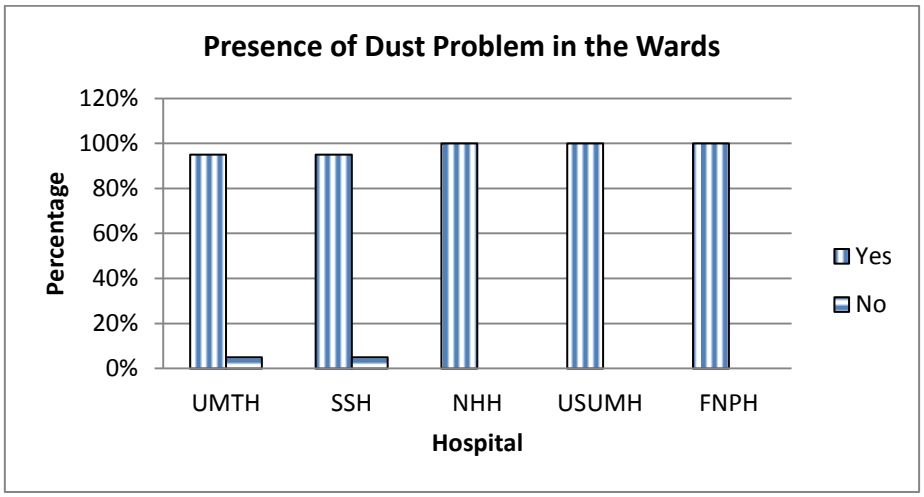

Figure 5: Dust problems in the hospital wards

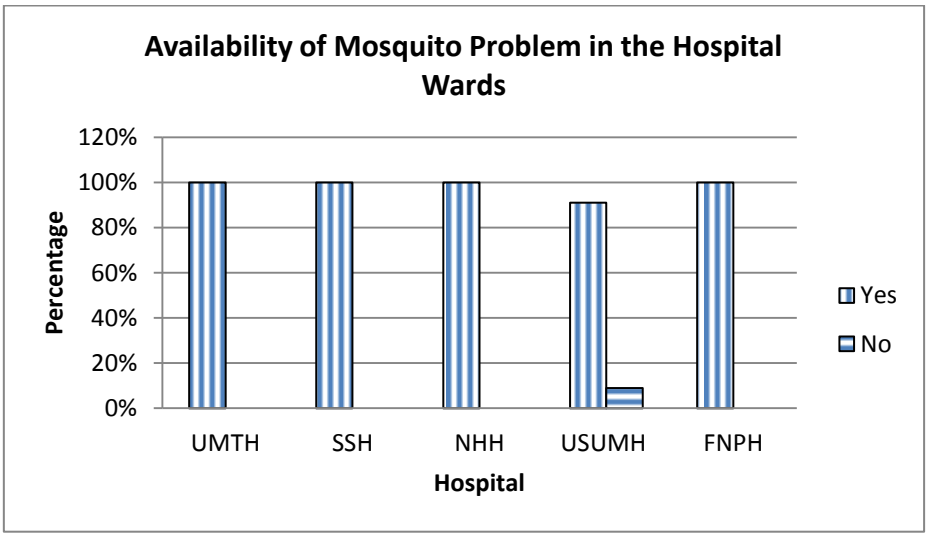

Figure 6: Mosquito problems in the hospital wards

6 DISCUSSION AND CONCLUSION

This paper examined the status of acceptable indoor air quality in the hospital multi-bed wards of semi-arid climates. It tends to exploit the possibilities of using natural ventilation strategies in providing acceptable indoor air quality in hospital wards of semi-arid climates. The study established that, Mosquito insects, Harmattan dust, and high temperatures are the

three major factors militating against the achievement of natural ventilation in semi-arid climates of Nigeria. The mosquito insect and Harmattan dust usually seize the advantage of the openings provided for natural ventilation to find their way into the building indoor spaces. Mosquito insects remain the only source of Malaria parasites that kills thousands of people in the tropics, while the inhalation of Harmattan dust causes cardiovascular and respiratory diseases.

To achieve the objectives of this study, a comprehensive literature review, full-scale measurement, and field survey have been conducted. The consequences of Harmattan dust and mosquitoes are more destructive in hospital environment compared to any other type of facility. This is because, hospital wards accommodates immunosuppressed and immunocompromised group of people due certain ailments. These group of people are easy to be infected by diseases especially Malaria. Moreover, Harmattan dust will help in deteriorating patients' sickness especially those with respiratory diseases.

The results obtained from the field measurement shows that none of the hospitals measured achieved the required ventilation rates of 6 ACH as enshrined by AHSREA. Moreover, the survey results for the five hospitals studied shows that more than 80% and 90% of the respondents have admitted the presence of Harmattan dust and mosquitoes respectively in the hospital multi-bed wards.

Therefore, the design of sustainable natural ventilation that can remove indoor contaminants while excluding outdoor pollutants in the hospital wards of semi-arid climates without compromising occupants comfort is essential.

7 REFERENCES

Adepetu J. A., Asubiojo O. I. Iskander F. Y., and Bauer T. L. (1988). Elemental Composition of Nigerian Harmattan Dust. *Journal of Radioanalytical and Nuclear Chemistry,* Articles, Vol. 121, No. I, 141-147

Anuforom A. C. (2007) "Spatial distribution and temporal variability of Harmattan dust haze in sub-Sahel West Africa" *Atmospheric Environment,* Vol. 41, Page 9079–9090.

Atkinson, J (2009). *Natural Ventilation for Infection Control in Health-care Settings.* World Health Organization publication/guidelines, WHO press, http://www.who.int/water_sanitation_health/publications/natural_ventilation/en/index.html

Awadzi T. W. and Breuning-Madsen H. (2007). Harmattan Dust Deposited in Ghana within 2000–2005. *West Africa Journal of Applied Ecology,* Vol. 11 (2007), pp. 173–188

Chen Y. S., Sheen P. C., Chen E. R., Liu Y. K., Wu T. N., and Yang C. Y. (2004). Effects of Asian dust storm events on daily mortality in Taipei, Taiwan. *Environmental Research,* Vol. 95, Page 151–155.

Chineke T. C. and Chiemeka I. U. (2009). Harmattan Particulate Concentration and Health Impacts in Sub-Saharan Africa. *African Physical Review,* Vol. 3: 0018

EIA (2012). *Nigeria: Independent Statistics and Analysis of Energy Sector.* A report of the Energy Information Administration (EIA), United State Department of Energy, Washington ULR: http://www.eia.gov/countries/cab.cfm?fips=NI accessed on 10th January, 2013

Emovon, I., Adeyeri, M.K. and Kareem, B. (2011). Power generation in Nigeria; Problems and solution. *presented at the 2011 International Conference of Nigerian Association for Energy Economics*, Abuja, Nigeria

EPA (2010). *An Introduction to Indoor Air Quality (IAQ).* United States Environmental protection Agency (EPA), Indoor Environments Division Administrative Office, http://www.epa.gov/iaq/ia-intro.html Accessed on 19th January, 2010

Etheridge, D. W., and Sandberg, M. (1996) *Building Ventilation: Theory and Measurement.* John Wiley and Sons Ltd. West Sussex, Engand

Hellagren U., Hyvarinen M., Holopainen R., and Reijula K. (2011). Perceived Indoor Air Quality, Air-Rated Symptoms and Ventilation in Finnish Hospitals. *International Journal of Occupational Medicine and Environmental Health*, Vol. 24, No 1, Page 48-56.

Hobday, R. (2011). Indoor environmental quality in refurbishment. *Historic Scotland Technical Paper 12*, www.historic- scotland.gov.uk/technical papers, research report

Kwon H. J., Cho S. H., Chun Y., Lagarde F., and Pershagen G. (2002). Effects of the Asian dust events on daily mortality in Seoul, Korea. Environmental Research, Vol. 90, Page 1–5.

Laussmann, D., and Helm, D., (2011). *Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality: Air Change Measurements Using Tracer Gases.* Edited by Mazzeo N. A. InTech publishers, Janeza, Croatia

Maxlock Group Nigeria (1976). *surveys and planning reports for Borno state government*. Warministers press Ltd, U.K.

Meng Z. Q., and Lu B. (2007). Dust events as a risk factor for daily hospitalization for respiratory and cardiovascular diseases in Minqin, China. *Atmospheric Environment,* Vol. 41, Page 7048-7058.

National Geographic (2013). *Animals: Mosquito Culicidae.* National Geographic Society, USA. http://animals.nationalgeographic.com/animals/bugs/mosquito/ Accessed on 8th January, 2013.

Ninomura, P.P.E., and Bartley, J. (2001). New Ventilation Guidelines for Health-Care Facilities. *ASHRAE Journal*, w.w.w.ashraejournal.org

Ogunseitan O. A. (2007). Harmattan Haze and Environmental Health. *African Journal of Environmental Science and Technology* Vol. 1 (4)

Sambo A. S. (2008). Matching Electricity Supply with Demand in Nigeria. *Publication of the International Association for Energy Economics*, Fourth Quarter 2008.

Szokolay, S. V. (2008). *Introduction to Architectural Science: The Basis of Sustainable Development.* Architectural Press, Elsevier. Oxford, UK

Timothy S. Y., Kwanashie H. O., Nyandaiti Y. W., Watila M., Mava Y., Sadiq G. U., Maspalma D. I., Bwala A. Y., Abdussalam B. (2011). Impact of Weather Conditions on Migraine Headache in North-Eastern Nigeria. *International Journal of Pharmacy and Pharmaceutical Sciences,* Vol 3, Suppl 3, Page 133-136

Walker, A. (2010). *Natural Ventilations.* Whole Building Design Guide, National Institute of Building Sciences, Washington, http://www.wbdg.org/resources/naturalventilation.php, accessed on 14th November, 2011

WHO (2001). *Water Sanitation and Health (WSH): Water-related diseas.* Prepared for World Water Day 2001. Reviewed by staff and experts from the cluster on Communicable Diseases (CDS), and the Water, Sanitation and Health Unit (WSH), World Health Organization (WHO), Geneva, http://www.who.int/water_sanitation_health/diseases/malaria/en/# accessed on 2nd February, 2012

Yau, H. Y., Chandrasegaranm, D., and Badarudin, A. (2011). The Ventilation of Multiple-Bed Hospitals in the Tropics: A Review. *Building and Environment,* Vol. 46, Page 1125-1132

Yoo Y., Choung J. T., Yu J. H., Kim D. K, and Koh Y. Y. (2008). Acute effects of Asian dust events on respiratory symptoms and peak expiratory flow in children with mild asthma. *Journal of Korean Medical Science,* Vol. 23, Page 66–71.