

Energy Efficient Buildings in Tropical Climate Through Passive Techniques- An Overview

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Abstract
The geometric increase in energy consumption in buildings due to high living standards, display of wealth and affluence and increase in population has resulted in energy crises and series of environmental problems such as sudden rise in temperature in urban areas, risk of global warming, climate change and co_2 emissions. Architects and builders hence have a role in mitigating these effects through the reduction of energy consumption in buildings. This has informed various studies on climate responsive designs or what is referred to as passive cooling of buildings. Passive cooling (designs) refers to design features or technology used in heating or cooling buildings naturally without energy consumption; it takes full advantage of the micro climate by using climate responsive design parameters. Passive cooling of buildings if properly imbibed is a significant way by which energy efficiency can be ensured in buildings.This paper therefore critically reviews and analyses the various passive cooling techniques that could be adopted in the tropical climate to achieve desirable thermal comfort in buildings and factors affecting their choice of selection; with a view to contributing to the development of guidelines on how to mitigate the effect of climate change especially in Nigeria, as well as in the tropical regions.
Keywords: passive cooling, techniques, climate responsive designs, energy consumption, energy efficiency, Thermal comforts.

1. Introduction

Before the invention of mechanical heating and cooling devices, passive heating and cooling methods were exclusively adopted to achieve desirable thermal comforts in residential homes. Today, mechanically driven active devices ensure interior comforts but depend heavily on energy inputs. Total energy consumption distributed according to economic sectors indicated that residential buildings consume about 78% while industrial and other buildings consume the remaining 22% (Ezema, Olotuah & Fagbenle, 2016).

Similarly, with respect to electricity consumption, residential buildings in Nigeria are noted to consume between 50.4% (Akinbami & Lawal, 2010) and 65% (UNDP, 2010) which are clearly above the world average which was put at 31% in 2007 by Saidur, Masjuki & Jamaliddin. The reason for this on one hand according to Nwofe (2014), can be ascribed to the Nigeria housing sector concentrating on provision of enough homes for the teeming populace without much consideration on the impact of non-energy efficient homes on the environment, economy, health and on the society in general and on the other hand building designers concentrating attention on aesthetic with little or no consideration for energy efficiency. This was also noted by Ogunsote, Prucnal-Ogunsote& Adegbie (2011). The effect of this is the sudden rise in temperature in urban areas, increase in risk of global warming and climate change (Nwofe, 2014), increase in heat radiation from the sun which consequently penetrates the indoor space of buildings through openings in walls, roofs, and fabrics thereby leading to overheated indoor space and discomfort (Lawal, 2008). This according to Ogunsote et al (2011) has caused a prevalent and abusive use of active driven mechanical devices such as Fans, Heaters and air conditioning systems to achieve comfort in buildings which has not only constituted series of environmental problems as a result of severe energy consumption and co2 emissions but has also led to energy crisis as a result of low generation, high cost and epileptic supply.

Mohammad (2012), noted that the growing trend of energy depletion and environmental problems can only be corrected by the adoption of passive (natural) cooling techniques of achieving comfort in buildings (climate responsive designs). This was backed by Lawal (2008) who indicated that effect of extreme climate condition which is discomfort could be best reduced through introduction of climate responsive design parameters. Similarly, Ajibola (2001) also stressed that buildings in Nigeria should respond to passive energy and have minimal use of active energy for economic viability and reduced environmental depletion. According to Ogunsote et al (2011), passive cooling designs (climate responsive designs) refers to technologies or design features used to cool buildings naturally without power consumption i.e. without the use of active driven mechanical devices. They are based on the way a building form and structure is designed to moderate the climate for human good and wellbeing. Ways of achieving climate responsive designs according to Mohammad (2012), Lawal (2008), Jackson& Jackson (1997) and SKAT (1993) include solar shading, orientation, sitting of buildings, appropriate greeneries (vegetation), shape and size of buildings, choice of appropriate materials, ventilation, use of biogas etc. to minimize or prevent heat gain in buildings. Hence, this paper gives a succinct study of passive cooling techniques with a special focus on factors to be considered in choice of appropriate selection. It is hoped that this will guide designers of buildings in Nigeria in the choice of passive techniques selection.

2. Study Area.

According to Wikipedia (2013), Nigeria is a country in West Africa sharing land boarders with Republic of Benin in the west, Cameroon and Chad in the east, Niger republic in the north, and its coast lies in the gulf of Guinea in the south. Nigeria is located in the tropical region with latitude 4^0 N and 14^0 N and longitude 2^0 E and 15^0E (Menakaya& Floyd, 1980). The climate in Nigeria is seasonally damp and very humid, with a mean total solar radiation of 500W/m2 (DanShehu, Asere& Sambo, 2006). The climate has been subdivided into different zones by various research scholars according to geographical peculiarities, but like the rest of West African countries and other Tropical lands, it can generally be subdivided into two: The wet (rainy season) and the dry season- the dry season is accompanied by the dust laden air-mass originating from the Sahara desert called the harmattan while the raining season is influenced by an air-mass originating from the south Atlantic ocean, locally known as the south west trade winds (Wikipedia, 2012).

There are various sources of energy in Nigeria which include the renewable and the non-renewable sources (ECN, 2003). According to the U.S. Environmental Protection Agency (2012), 30-40% of the global energy use comes from the housing sector. There is no exception in the case of Nigeria as Nwofe (2014) submitted that the housing sector in the country accounts for a reasonable quota of materials and energy that lead to greenhouse gases. This implies that use of energy efficient buildings will offset the greenhouse gases (CO_2, CO, CH_4) by 30-40% which could have emanated from the housing sector thereby saving the climate from the negative effect of these gases.

3. Passive Cooling of Buildings (Climate responsive designs).

The process by which building heats up or cools down itself naturally without the use of mechanical driven devices is called passive cooling. Unlike active cooling which ensures the use of energy to maintain a balanced interior condition, Passive cooling takes full advantage of the micro climate, using climate responsive design parameters such as Orientation, shape, fenestration, landscape etc. (SKAT, 1993). Wikipedia (2010) refers passive cooling techniques (Climate responsive designs) to design technologies or features used to cool buildings without power consumption i.e., without the use of mechanical and electrical driven devices. Climate responsive design according to Nwofe (2014) is relatively unknown in Nigeria due to factors which include poverty, lack of awareness, Illiteracy and poor governmental policies.

A. Poverty

According to the report released by the National Bureau of statistics (NBS) reported by Vanguard Newspaper (2016), approximately 67.1% (112 million) of Nigeria's total population of 167 million live below the poverty line. This means that the Nigeria poverty rate is becoming very high compared to the 54% reported by the same body in 2010. Poverty is a strong limiting factor to energy efficient buildings as money is needed to procure the materials and human resources needed to execute such Climate responsive buildings. (Nwofe, 2014).

B. Lack of awareness.

Ogunsote et al (2011) noted that buildings in Nigeria rather than being designed to take full advantage of its bioclimatic factors are becoming a show of owners profligacy i.e., attention of building designers is concentrated on aesthetic values which in turn calls for an abusive use of mechanical driven devices to achieve desirable thermal comfort by users without knowledge of the severe negative implications of the devices. The need for awareness both by designers and owners of buildings on the influence of climate responsive design is essential.

C. Illiteracy.

With the adult illiteracy rate standing at 56.9% in 2010 (National Bureau of Statistics, 2010) and reported to reach 59.6% by 2017, Nwofe (2014) opined that the level of knowledge the illiterates have as regards passive designs and energy efficient buildings is very low hence, they need to be educated on the merits of passive designs (climate responsive designs).

D. Poor governmental policies

The government rather than concentrating attention on making policies that will ensure that energy efficiency is achieved in buildings has concentrated attention on how to generate more non-renewable energy sources which will subsequently increase global warming and climate change. KPMG (2013) reported that 82% of energy use in Nigeria come from non-renewable energy sources and Nigeria has further plan to increase energy generation by 2020 (Nnaji, 2012).

In their opinion, Ogunsote et al (2011) blamed the rising increase in energy use to maintain indoor comfort (Active cooling) as against passive techniques in Nigeria on the rising standard of living, the proliferation of new work profiles and equipment that requires air conditioning, 'peer' pressure from other modern cities and unfaithfulness on the part of the political elites and scientists who condemn voracious energy use (Active cooling) from the comfort of their fully fitted air conditioned offices.

According to Mohammad (2012), Maintaining a comfortable environment within a building in the tropics depend on how well heat gain into the building can be minimized and dissipating excess heat from the building, i.e. to prevent ingress of heat and swift removal of excess heat once it has entered is the basic technique for accomplishing thermal comfort in passive cooling concepts. These techniques are further stressed below.

3.1 Passive cooling through prevention of heat gains in buildings.

The climate of the warm humid zone (Tropics) is characterized by high rainfall, high humidity and relatively high temperature which was put at between 300c -350c and is fairly even throughout the day and throughout the year, the solar radiation is intense and hence should be prevented from entering into the building SKAT (1993). Ogunsote et al (2011) further stressed that preventing heat from entering the building should be the first concern and not how to cool down the building i.e., if excessive heat can be minimized, then the problem of cooling down the building will be half solved. The important methods of reducing heat gains in buildings such as shading, vegetation (landscape), building orientation, use of high thermal mass to reduce heat absorption, insulation etc. are further discussed.

3.1.1 Shading.

Among all other solar passive cooling techniques in the tropical region, shading is considered to be the most effective and should be the first line of defense if ingress of solar gain is to be minimized in buildings. Kumar, Garg& Kaushik (2005) in their studies revealed that shading reduces the indoor temperature by about 2.50c to 6.80c more than other passive cooling techniques. Mohammad (2012) also posited that shading of buildings is cheaper, effective and easy to implement than every other passive cooling techniques. Shading can be achieved through the following:

3.1.1.1 Shading using trees and shrubs

Trees and vegetation are most useful as a mitigating strategy when planted in strategic locations around buildings in the tropical regions; they lower surface and air temperatures by providing shade and through evapotranspiration (Akbari& Kurn, 1997). Evapotranspiration alone can help reduce peak summer temperatures by 2-90f (1-50c) (Huang, Akbari& Taha, 1990). Trees with wide shading crowns protects roofs, walls and windows from direct solar gains and can reduce surrounding air temperature significantly (SKAT, 1993).

3.1.1.2 Shading by overhangs and fins.

Fins and overhangs act like caps and help in blocking direct sun rays. Fins and overhangs if properly designed can effectively reduce solar ingress and heat gain in buildings. Effective design of fins and overhangs depends on the solar orientation of building façade (Mohammad, 2012). Types of fins include horizontal, vertical and egg-crate fins.

3.1.1.3 Shading by textured surfaces.

According to Mohammad (2010), surface shading should be adopted especially on walls if passive cooling of building is to be achieved in the tropics. Textured walls have parts of their surface in shade which helps in insulating the interior from solar heat gain.

3.1.2 Proper landscaping

Incorporating shade through proper landscaping can reduce solar heat gain. Ogunsote et al (2011) affirmed that proper landscaping is an effective means of protecting buildings from direct solar radiation, helps in minimizing heat gains and redirecting wind flow to enter the house for natural ventilation design. Proper landscape and vegetation create more physically comfortable and energy conscious buildings in the tropics (SKAT, 1993).

3.1.3 Building orientation.

Orientation is the way a building is positioned on a site. Buildings orientated for passive designs provide good natural (passive) thermal and visual comfort. Proper building orientation in the tropics can be best achieved by positioning the longer side of the building on East-West axis; it helps minimize the radiation received by building walls and hence reduces energy use in buildings (Lawal (2008).

3.1.4 Wind orientation

Wind flow is the movement of air in and around buildings. To achieve passive cooling and energy efficient buildings, wind orientation should be incorporated at the early state of settlement planning and building design. (SKAT 1993) suggested an open settlement pattern in the tropics to avoid wind flow from being impeded. Interior rooms should be crossly ventilated and windows should be designed along the windward sides of the site and not the leeward sides

3.1.5 Thermal insulation, reflective roofs and wall colours.

According to SKAT (1993), thermal insulation has little effect if wind orientation is properly incorporated in designs; but has a great effect in places where sun radiation is received. Reflective ceiling and roof coatings are easy ways of reducing roof overheating and heat transmission into the building through the roof. This goes a long way in reducing the need to cool down the building (House-Energy, 2010). Wall and surface colours also play an important role in absorbing and reflecting heat. Ogunsote et all (2004) stressed that walls should be in light colours to reflect heat, boundary walls and hard landscapes should be in dark colours to absorb heat and avoid reflecting heat and glare. This will mitigate against heat build-up in buildings in the tropics.

3.1.6 Heat storage and time lag.

In the tropical climate, construction with materials characterised by high thermal storage capacity and long time lag should be avoided because it would cause undesirable re-radiation of heat at night thereby causing hot discomfort in buildings (Lawal, 2008).

3.2 Passive cooling through solar cooling systems (Induced ventilation techniques)

Once heat has been built up in building, the next point of action is to find means of removing excess heat. This according to Tiwari (2006) can be achieved naturally through direct cooling techniques which include ventilation, infiltration, courtyard, wind tower, air vents etc.

3.2.1 Ventilation.

Ventilation is the replacement of used air in buildings with fresh ones from outside (Ogunsote, 1991). According to Walker (2010), the amount of ventilation in buildings will depend on the size and positions of windows. To achieve good and effective exchange of air in buildings in the tropical region, Lawal (2008) stressed that windows should be located along north and south walls i.e. window positioning along east and west walls should be reduced or better still avoided. Adequate ventilation is best achieved according to Wikipedia (2010) by:

i. Cross ventilation- a situation where openings are created on two sides of the building called the inlets and outlets in order to optimize the path of air flow through the building. The sizing and placements of the openings will determine the velocity and direction of air through the building.

ii. Stack ventilation- stack effect is a situation where openings are located at ceiling and floor heights; it relies on the buoyancy of hot air to rise and exit through openings located at ceiling heights. Cooler air from outside moves to replace used warm air in buildings through inlets placed near the floor. Stack ventilation is effective in cases where cross ventilation is ineffective as a result of the unreliable movement of the wind.

3.2.2 Infiltration

Infiltration refers to uncontrolled air movement in and out of the building. Air is introduced in to the building accidentally or unintentionally. These often arise as a result of cracks in building envelope, gaps in openings, poor weatherization etc. Wikipedia (2010) indicated that infiltration can contribute about 40% of heat loss in buildings in the tropics but should not be encouraged because it is also capable of bringing in uncontrolled dust, pollen and microorganisms in unfiltered air.

3.2.3 Wind Tower

Wind towers or wind catchers are small towers installed on top of buildings; they serve as natural ventilation systems by directing the outside air into the building. They have been used for ventilation of buildings in the tropics and arid regions for centuries (Bahadori& Dehghani-Sanij, 2014).

3.2.4 Air vents

Air vents are used for passive cooling and dehumidification in the tropical regions in areas where dusty wind is severe. Air vents are protected holes provided in the apex of a dome or a tower which helps in introducing ambient air free of pollutants into the space. The introduction of ambient air will help to improve indoor comfort by providing ventilation and dissipating hot air collected at the top.

Other natural means of dissipating heat from buildings include: courtyards Solar chimney, Radiative coolin, Diode roof, roof pond, rain water recycling, use of biogas etc.

4. Conclusion and recommendations

Energy efficient buildings are designed in a way that ensures that energy usage in buildings is reduced to the barest minimum; this will help reduce the capital cost incurred on purchase of mechanical equipment, recurrent cost incurred on equipment maintenance and energy consumed. Several studies have shown that the best possible way by which energy efficiency can be achieved in buildings is by adopting passive design techniques (climate responsive design) - passive designs techniques refers to design features or technology used in heating or cooling buildings naturally without power consumption, this will not only ensure less energy consumption but will also reduce the amount of emitted co2 waste causing environmental degradation and climate change.

This paper has reviewed and discussed several passive cooling techniques that can be imbibed in designs in Nigeria, if these techniques are properly used they will significantly reduce building cooling loads and correspondingly reduce the prevalent use of air conditioning and other energy dependent systems. We are strongly suggesting that:

1. Designers of buildings in Nigeria should make achieving passive solar energy efficient design their top aim while designing rather than aesthetics, and passive design strategies should be incorporated from the outset.
2. Nigerian government should create awareness on the benefit of energy efficient buildings over non energy efficient ones, they should also subsidize energy efficient materials and create enforceable legislation banishing abusive use of energy as this is the only way environmental problems due to excessive energy use can be avoided.

3. If possible, research in this area should be encouraged through grants and conferences.

Conflict of interests
The authors have not declared any conflict of interests.

References
Ajibola K. (2001): "Design for Comfort in Nigeria – a Bioclimatic Approach". *Journal of Renewable Energy*. Oxford, U.K.Pergamon, 23, 57 – 76.

Akbari, H. and Kurn, D. (1997)." Peak Power and Cooling Energy Savings of Shade and Trees". *Energy and Buildings* 2:139-148.

Akinbami, J. and Lawal, A. (2010). "Opportunities and Challenges to Electrical Energy Conservation and C02 Emissions Reduction in Nigeria's Building Sector". *Proceedings Cities and Climate Change Workshop,* Midrand, South Africa, pp.345-365.

Bahadori, M. N., Dehghani-Sanij, A., and Sayigh, A. (2014): "Wind Towers: Architecture, Climate and Sustainability". *Energy Renewal and Green Architecture*. Mehdi.

DanShehu, B.G., Asere, A.A., and Sambo, A.S. (2006). "Development of Community-based Solar Water Heating System. Nigeria" *Journal of Solar Energy*. 16, 106.

Energy Commission of Nigeria (ECN). (2003). "National Energy Policy". Federal Republic of Nigeria, Abuja.

Ezema, I., C., Olotuah, A., O. and Fagbenle, I., O. (2016). "Evaluation of Energy Use in Public Housing in Lagos, Nigeria: Prospects for Renewable Energy Sources".

House-Energy. (2010). "Roof and Ceiling Insulation". Retrieved from http://www.houseenergy. com/Insulation/Roof-Insulation.htm.

Huang, J., Akbari, H., and Taha, H. (1990). "The Wind –Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements". *ASHRAE Winter Meeting*, *American Society of Heating, Refrigerating and Air-Conditioning Engineers.* Atlanta, Georgia.

Jackson, A.R.W., and Jackson, J. M., (1997). "Environmental Science – The National Environment and Human Impact", *Addison Wesley, Edinburgh*, Longman (Publisher) Ltd, First Edition, pp. 89-132.

KPMG. (2013). "A Guide to the Nigerian Power Sector". *KPMG Advisory Services,* KPMG, Nigeria.

Kumar, R., Garg, S. N. and Kaushik, S. C. (2005). "Performance Evaluation of Multi-passive Solar Applications of a non-Air-conditioned Building." *International Journal of Environmental Technology and Management,* Vol. 5, No.1, pp. 60-75.

Lawal, A. F. (2008). "Assessment of Public Building Designs for Energy Conservation in Southwestern Nigeria." *Unpublished Ph. D. Thesis, Technology Planning and Development Unit*, Faculty of Technology, ObafemiAwolowo University, Ile-Ife. Nigeria.

Menakaya, J.C. and Floyd, A. (1980). "Junior Atlas for Nigerian Secondary Schools", *Nigeria, Macmillan Publishers.*

Mohammad, A. K. (2010)." A Study on Shading of Buildings as a Preventive Cooling and Energy Conservation in Buildings." *International Journal of Civil& Environment Engineering IJCEE-IJENS* Vol: 10 No:06.

Mohammad, A. K. (2012). "An Overview of Passive Cooling Techniques in Buildings: Design
Concepts and Architectural Interventions," *Acta technical Napocensis: Civil Engineering and Architecture*, Vol. 55, No 1.

National Bureau of Statistics, NBS (2010). "Annual Abstracts of Statistics", Federal Republic of Nigeria. 1 - 611.

Nnaji, B. (2012)." Investment Opportunities in the Nigerian Power Sector. Nigeria Business and Investment Summit", London. July 30, 2012. Retrieved from http://www.newworldnigeria.com/pdf/HMPPowerSectorReformsPresentationBoINOCLondon30JULY2012 .ppt. Accessed July 16, 2014.

Nwofe, P. A. (2014). "Need for Energy Efficient Buildings in Nigeria." *International Journal of Energy and Environmental Research.* Vol. 2, No. 3, pp. 1-9.

Ogunsote, O. O. (1991). "An Introduction to Building Climatology - A Basic Course for Architecture Students". Zaria: *Ahmadu Bello University Press*.

Ogunsote, O. O. and Prucnal-Ogunsote, B. (2004). "Reducing Urban Heat Islands: Sustainable Design through Landscaping and Renewable Technologies. In*: Scientific and Environmental Issues in Population, Environment and Sustainable Development in Nigeria*. Edited by Ibitoye, O. A. Department of Geography and Planning Science,University of Ado Ekiti, Ado Ekiti. Pp. 127-139.

Ogunsote, O. O., Prucnal-Ogunsote, B. and Adegbie M. (2011). "Optimizing Passive Cooling Systems in Residential Buildings: A Case Study of Akure, Nigeria". Retrieved from www.sdngnet.com

Saidur, R., Masjuki, H.H., and jamaluddin, M.Y. (2007). "An Application of Energy and Energy Analysis in Residential Sector of Malaysia," Energy Policy, 35(2), 1053-1063

SKAT (1993): "Climate Responsive Building- Appropriate Building Construction in Tropical and Subtropical

Regions."

Tiwari, G.N. (2006). "Solar Energy Fundamentals, Design, Modelling and Applications." *New Delhi, Narosa Publishing.*

U.S. Environmental Protection Agency (2012): http://www.epa.gov/greenhomes/ReduceEnergy.html. Accessed July 16, 2014. "Nigeria Country Programme document", 2014-2017, Unicef http://www.unicef.org/about/execboard/files/2013-PL7-Nigeria_CPD-final_approved-English.pdf. Accessed July 16, 2014.

United Nations Development program (UNDP). (2010): "UNDP in Nigeria." Retrieved from www.ng.undp.org.

Vanguard. (2016): "Poverty: 112m Nigerians live below poverty line." Retrieved from www.vanguardngr.com/2016/10/poverty-112m-nigerians-live-poverty-line/.

Walker, A. (2010). "Natural Ventilation: National Renewable Energy Laboratory." Retrieved from: http://www.house-energy.com/cooling.

Wikipedia. (2010). "Passive Cooling." Retrieved from http://en.wikipedia.org/wiki/Passive_cooling.

Wikipedia (2012). "Geography of Nigeria." Retrieved from http://en.wikipedia.org/wiki/Geography_of_Nigeria.

Wikipedia. (2013). "Nigeria." Retrieved from http://en.wikipedia.org/wiki/Nigeria.

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