

## Energy Efficient Building Design in Nigeria: An Assessment of the Effect of the Sun on Energy Consumption in Residential Buildings

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### Abstract

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The effect of the sun and its path on thermal comfort and energy consumption in residential buildings in tropical climates constitutes serious concern for designers, building owners and users. Passive design approaches based on the sun and its path have been identified as a means of reducing energy consumption, as well as enhancing thermal comfort in buildings worldwide. Hence, a thorough understanding regarding the sun path is key to achieving this. This is necessary due to energy need, poor energy supply and distribution, energy poverty and over-dependence on electric generators for power supply in Nigeria. These challenges call for a change in the approach to energy related issues, especially in terms of buildings. The aim of this study is to explore the influence of building orientation, glazing and the use of shading devices on residential buildings in Nigeria. This is intended to provide data that will guide designers in the design of energy efficient residential buildings. The paper used EnergyPlus software to analyze a typical semi-detached residential building in Lokoja, Nigeria, using hourly weather data for a period of 10 years. Building performance was studied as well as possible improvement regarding different orientations, glazing types and shading devices. The simulation results showed reductions in energy consumption in response to changes in building orientation, types of glazing and the use of shading devices. The results indicate a 29.45% reduction in solar gains and 1.90% in annual operative temperature using natural ventilation only. This shows a huge potential to reduce energy consumption and improve people's wellbeing using proper building orientation, glazing and appropriate shading devices on building envelope. The study concludes that for a significant reduction in total energy consumption by residential buildings, design should focus on multiple design options rather than concentrating on one or few building elements. Moreover, the investigation confirms that energy performance modelling can be used by building designers to take advantage of the sun and to evaluate various design options.

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**Keywords:** Energy consumption, energy efficient buildings, glazing, thermal comfort, shading devices, solar gains.

### Introduction

Buildings consume nearly 40% of the total energy use worldwide and are responsible for one-third of global greenhouse gas (GHG) emissions (IEA, 1995; Pearce and Ahn, 2013). Ghiaus (2006) posited that buildings consume 40%, 16% and 25% of the world's energy, fresh water and forest timber respectively. Perez-Lombard et al. (2008) stated that buildings account for the largest share of global energy consumption compared with other economic subsectors. These statistics have negative impacts on the environment and communities through the effect of climate change. The adverse effects include an increase in temperature, flash flooding and rising sea levels. These have led to increased thermal discomfort, displacement of communities and loss of valuable assets. Hence, it has generated global interest on how to downsize the level of energy consumption by the building sector.

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A study by Nielsen et al. (2016) noted that the high level of energy consumption by buildings demands definite efforts towards the adoption of energy efficiency measures. This shows the relevance of research efforts towards reducing the buildings share of global carbon emissions through the adoption of energy efficiency and conservation measures (Harish and Kumar, 2016).

There are several factors that can affect energy demand in buildings. These factors include the climatic zones, the building envelope, building materials, building occupants' characteristics and behaviours, ventilation systems, artificial lighting and appliances and building design. The energy demand and consumption of buildings are determined by these factors, especially the building external envelopes and its components. Despite the significant effects these factors could have on thermal comfort and energy consumption in buildings, they can be managed through the adoption of energy efficiency measures. Although some buildings may require more energy, Nigeria faces a challenge in energy supply. Only about 40% of the entire population have access to electricity (GIZ, 2015). A large percentage of households and businesses depend majorly on electric generators. This can be very expensive and a huge source of environmental pollution. This also contributes to the effects of climate change, which are also experienced in Nigeria. To improve energy supply, enhance thermal comfort in buildings and mitigate the effect of climate change in Nigeria, it is important to key into energy efficiency measures. Akinbami and Lawal (2009) posited that the increase in energy demand in all sectors in Nigeria calls for efficient use of available energy resources as a viable option towards achieving sustainable development. In buildings, a good understanding of the effect of solar radiation is crucial to energy efficiency measures as solar gain is a major source of thermal discomfort for building occupants.

Despite the challenges with energy supply and distribution in Nigeria, we are yet to key into available opportunities, especially energy efficient design approaches to significantly reduce energy demand and consumption by buildings. Intelligent building design can significantly reduce buildings energy consumption, operational cost and ultimately lower GHG emissions. Designers are yet to properly adopt design approaches that takes full advantage of the sun. Hence, this paper focuses on the effect of the sun on energy consumption in buildings considering building orientation, types of glazing and shading devices based on passive design strategies. Previous research has shown that these strategies which are low cost and mainly passive can decrease primary energy consumption by 40 – 60% (Moore et al., 2013).

## **The sun and energy efficient building design**

### **Sun and its path**

The sun path refers to the apparent seasonal and hourly positional changes of the sun and duration of daylight as the earth rotates around the sun. The sun path and the intensity of solar radiation at different geographical locations pose a challenge to the design of energy efficient buildings. It determines the level of heat gain and comfort in buildings. Hence, studies have shown that the sun is a significant factor in the design of energy efficient buildings (Stemmers, 1991; Witmer, 2014).

The pattern of the sun's intensity, angles and path at different locations are predictable with little variation over the year. For instance, in Nigeria, times for sunrise and sunset and the path of the sun at different seasons vary slightly due to its proximity to the equator. FMPWH (2016) stated that the little variation in the sun path in Nigeria presents design professionals with good opportunity to optimize building orientation and shading devices. It helps in the design of shading devices towards enhancing thermal comfort in buildings. The sun paths for different locations in the world can be determined using solar charts or building simulation tools. The sun path for the case study building in this paper would be determined using building simulation software, Design Builder.

Energy efficiency in buildings is closely related to climate and the sun's energy. In tropical climates a major challenge with the design of energy efficient buildings centres on the control solar radiation. Passive design approaches based on the sun and its path have been identified as a means of reducing energy consumption as well as enhancing thermal comfort in buildings worldwide (Yuichiro et al., 1991; Givoni, 1994; Joelsson and Gustavsson 2009; Moore et al., 2013; Latha et al., 2015)

### **Energy efficient buildings**

Interest in environmentally responsible buildings commenced around the middle of the last century owing to the ambition of several communities that advocated green buildings consequent to the need for an ecological world (Charles, 2008).

After few years, embargo by OPEC resulted in energy crisis. This led to the promotion of regulations to minimize energy consumption by buildings (Berardi, 2013) and the use of energy consumption as a yardstick for measuring building sustainability. Up until now, energy performance is mostly used to assess the sustainability of buildings (Cole, 2004; Berardi, 2012). Ball et al. (2011) argued that energy reduction is a major focus of mitigating the effect of climate change.

Energy efficiency refers to using less amounts of energy to achieve results that have been achieved with a certain quantity of energy. It means using energy in a way that reduces the quantity of energy required to provide building services (Etiosa, 2009; Chung et al, 2006). Energy efficient buildings has been defined as those buildings that strives towards the lowest possible energy requirements with reasonable utilisation of resources using energy efficient measures (Radhi, 2008). Energy efficiency can be regarded as the first step toward achieving sustainability in buildings. It helps to minimise rising energy costs, enhance the value and competitiveness of buildings and reduce greenhouse gas (GHG) emission.

### **Factors that affects energy demand of buildings**

Energy consumption in buildings can be influenced by several factors. While some of these factors are climate related, others depend on the building envelope, the materials used for construction, the technologies involved, and the building space usage. According to Cowan et al. (2014), the factors that affect energy and cooling demand of buildings include building orientation, building occupancy profile, internal heat gains, external environment, comfort levels and temperature set points. This paper centres on building orientation, glazing types and shading devices based on the effects of the sun.

### **Building orientation**

An appropriate building orientation will support energy reduction through passive solar heating and cooling, day lighting and natural ventilation. To achieve energy efficiency, building orientation should take good advantage of solar radiation and the prevailing wind. A good understanding of building site by designers is necessary to achieve proper orientation (Ochedi et al, 2016).

In hot and humid climates, buildings should be designed so that the short side face East and West (FMPWH, 2016). Design should avoid or minimize placement of windows on the East and West façades of buildings (Al-Tamini, 2011; Mirrahimi et al., 2016). This will reduce heat gain and cooling demand. No single orientation is suitable for all buildings. Hence, it is important for every design to be tested for the most suitable orientation. For Malaysia with a tropical climate like Nigeria, Mirrahimi et al. (2016) revealed that north orientation is the best practice for residential buildings. The result of a study conducted by Shaviv (1981) revealed that for maximum energy saving in buildings, the major glazing facades should face south, especially in hot humid climates. Where this is not possible, the study maintained that buildings should face southeast to reduce heat gain and improve indoor thermal comfort.

There are situations where it may not be possible for buildings to take advantage of the best orientation. For instance, there are locations where buildings must be made to face the access road. This may be due to challenges with land allocation processes. Where this is the case, designers can employ the concept of zoning. Functional spaces should be placed based on when and how long they are used with respect to climatic factors and sun paths. Gut and Ackerknecht (1993) maintained that the arrangement of spaces in buildings should be based on their functions and when they are used during the day. Moreover, functional spaces like bedrooms should be located on the eastern side of the building, which is coolest in the evening. Living room(s) and other rooms, which can be used almost throughout the day, should be situated on the north side. Auxiliary spaces like kitchen and store can be located on the western side. Buildings can be made more energy efficient if they are planned to take advantage of solar radiation and the prevailing wind direction (Watson and Labs, 1983).

This discussion points to the need for proper building orientation and zoning of functional spaces which are key to achieving energy efficiency in buildings.

### **Glazing**

The relevance of window glazing ratio to comfort and energy consumption in buildings have been properly documented in previous studies (Roos and Karlsson, 1994; Chaiyapinunt et al., 2005; Yang et al., 2006; Sadineni et al., 2011; Pacheco et al., 2012; Mirrahimi et al., 2016).

An appropriate window glazing selection bearing in mind the microclimate can greatly reduce energy consumption and improve comfort in buildings.

Roos and Karlsson (1994) revealed that 10-20% of the total heat loss in standard family residence occurs through the window glazing. An intelligent glazing selection based on the local climate can greatly reduce energy consumption in buildings. This can be realised through good understanding of the performance rating of windows. For proper glazing design, it is important to take into consideration the level of heat transfer, light transmission, thermal comfort and appearance (Chaiyapinunt et al., 2005).

Glazing technologies have advanced with focus on controlling solar heat gain, providing daylighting solution and high-performance insulation. Some of these include aerogel glazing, vacuum glazing, holographic optical elements (HOE), suspended particle device (SPD) and switchable reflective glazing (Sadineni et al., 2011). Yang et al. (2006) classified energy saving glazing types into heat-reflecting glass, heat-absorbing glass and low radiation glass. Building designers should take advantage of these technologies to reduce energy consumption by buildings.

Krarti et al. (2005) maintained that tinted windows would enhance energy saving in buildings. Gijon-Rivera et al. (2011) argued that double-glazing is an effective method of optimizing window performance for both hot and cold climates. While they advocated double-glazing with film coating for cold climates, they recommended double-glazing with clear glass for hot climates. A study by Chandel and Sarkar (2015) recommended single-glazing, clear glass for southern and eastern windows and double-glazing for northern and western windows. The reason for this was to reduce heat loss in winter and heat gain in summer. For climates where heating demand is not an issue, a different approach for window glazing may apply.

Key factors to consider in the design of window glazing include thermal comfort, heat transfer, light transmission and appearance (Chaiyapinunt et al., 2005). Building design approaches that enhance interior daylighting through windows have possible risk of overheating and increase in cooling load during hot seasons (Pereira and Sharples, 1991; Pacheco et al., 2012). An appropriate selection of window glazing should strive towards striking a balance between daylighting and comfort demands in buildings.

## Shading

Several studies have discussed the importance of shading devices on cooling load and thermal comfort in buildings (Olson, 1997; Datta, 2001; Tzempelikos and Athientis, 2007; Gratia and Herde, 2007; Wong, 2008; Bessoudo et al., 2010; Ralegaonkar and Gupta, 2010). The importance of appropriate shading devices on buildings include reduction of cooling loads, means of avoiding overheating, control of the visual environment and protection of openings from the elements (Corrado et al., 2004; Gugliermetti and Bisegna, 2006). Buildings, especially in hot humid climates require appropriate external window shading devices for proper control of solar radiation.

Ralegaonkar and Gupta (2010) recommended static sun shading devices as the most effective radiation control as their geometry can be designed based on the sun paths to minimize solar insolation. A study of Wong and Li (2007) recorded 2.62-3.24% savings using 300mm deep horizontal shading on windows. Shading depth of 600mm led to 5.85-7.06% reduction of cooling load. An increase of shading device depth to nearly 900mm lowered the cooling demand by 8.27-10.13% (Wong, 2008; Al-Tamini and Fadzil, 2011).

Chandel and Sarkar (2015) recommended 450mm horizontal shading for windows on the southern and northern walls and 600mm horizontal shading for windows on the east and west facades in hilly terrain of India. The reason for this was to enhance heat gain on the southern side in winter and reduce gains on the eastern and western facades during summer. The Building Energy Efficiency Code (BEEC) for Nigeria recommended 500mm wide horizontal shading for buildings (FMPWH, 2017).

Considering shading as passive design strategy for hot and humid climates, McGee and Reardon (2013) recommended the following:

- Provide shading on all external openings and walls.
- Employ the use of deep balconies and verandas to shade and enhance cooling of incoming air.
- Use shaded skylights to overcome in adequate natural daylighting in building interiors.
- Use landscape elements to provide enough shading without blocking cool breezes.
- Use plantings, which help to reduce ground temperature and reflected heat instead of paving.
- Use 'fly roof' to protect buildings from radiant heat and enhance cool breezes.



**Figure 2. 3D view of the case study**

### Building elements

The external and internal walls of the building were constructed with 9 inches hollow sandcrete block. Both the external and internal walls were plastered using sand/cement plaster. The external walls were painted with cream colour emulsion paint. The following are other relevant information on the building elements.

- The windows were fixed with aluminium burglar-proof to enhance the security of the building and discourage the activities of burglars and thieves. Mosquito blinds were also fixed on the windows to prevent mosquitoes and other insects from entering the building.
- The building does not have shading devices on the external windows
- The ceiling height from the floor surface measured during survey was 2.762m.
- The approximate size of the eave was 500mm.
- The wooden fascia board was painted with black oil paint.

### Key observations from the case study

This section presents the main lessons learnt from the case study in terms of design, energy efficiency and thermal comfort.

- The building was not designed to be energy efficient. Building users complained about poor ventilation and lighting. This can be seen in the approach to the design especially in the placement of windows and the choice of window type. This is complicated using mosquito blinds and burglar-proof that reduce the size of openings and the amount of daylight coming into the building.
- The building has no shading devices that could reduce the effect of direct sunlight on the building elements. This can lead to thermal discomfort in the building.
- The dark colour roof may not be the best option for the roof cover and it can increase heat gain into the building. Studies have shown that light colour materials for the building envelope are useful in reducing heat gain and storage, thereby enhancing thermal comfort in buildings (Cheung et al., 2005; Muselli, 2010; Ochedi et al., 2016).

### Modeling and simulation of the case study

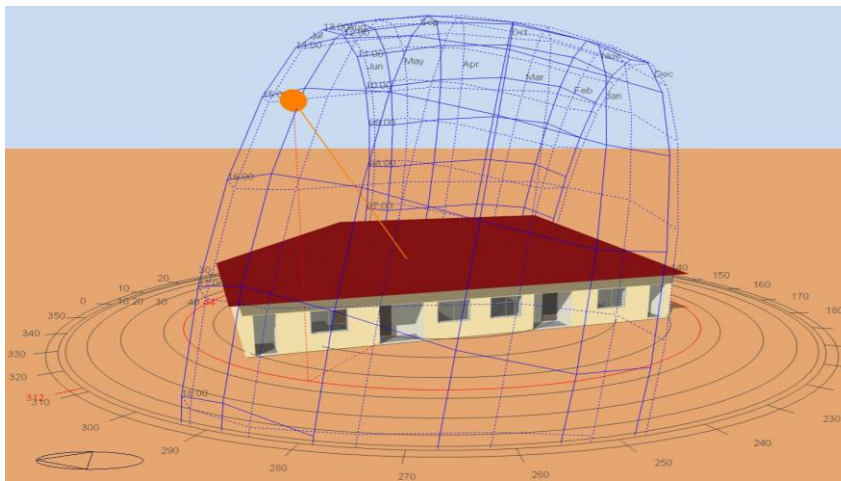
The construction materials which were identified during measurement and observational survey of the case study building were selected from Design Builder template for modelling and simulation. Where the actual construction materials were not found in DesignBuilder templates, modifications were made to achieve similar properties. Natural ventilation (no heating/cooling) was selected as the HVAC template for modelling and simulation of the case building. Air changes per hour (ac/h) of 2.5 was assumed instead of the default value of 5.

This was because of the use of insects' net, drapes and aluminium burglary proof on windows in the study area, which limits airflow. Outside air definition method was by zone and operation was based on the default schedule for residential spaces.

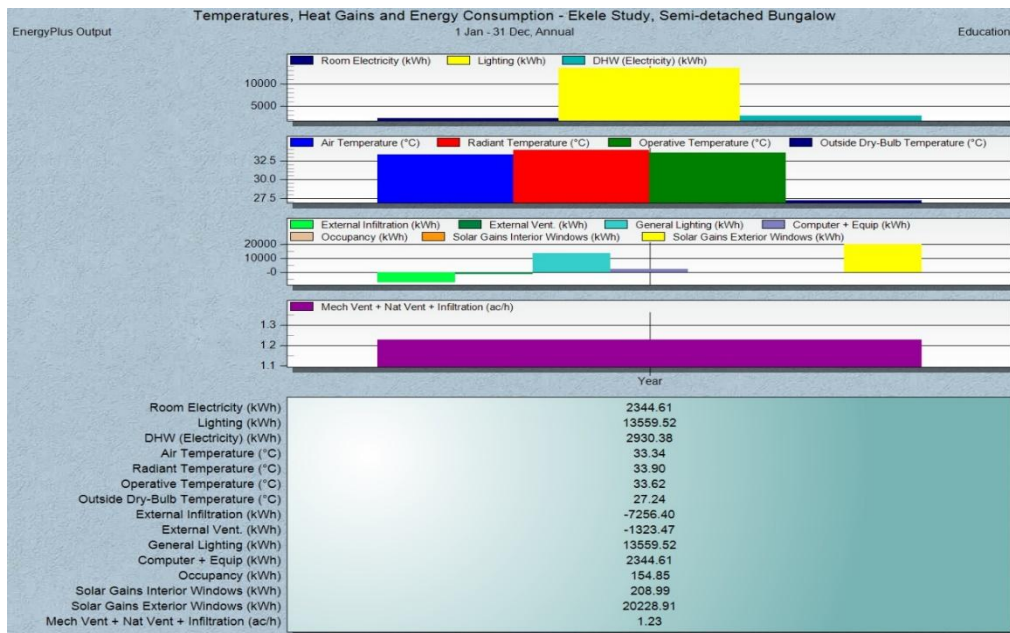
The floor of the existing building was modelled using 150mm thick concrete slab finished with glazed ceramic floor tiles having a U-Value of 2.602 W/m<sup>2</sup>K. The external and internal walls were modelled using 225mm thick hollow lightweight concrete block finished on both sides with 25mm thick cement plaster and having a U-Value of 1.867 W/m<sup>2</sup>K.

Aluminium metal doors made up of three layers were used for all external doors while hardwood solid doors with conductivity of 0.05W/m-K, specific heat 2100J/Kg-K and density 90Kg/m<sup>3</sup> were assumed for all internal doors. All windows were modelled with ‘single glazing, clear, no shading’ template and single clear 6mm glazing type. The roof was modelled using uninsulated lightweight aluminium pitch roof having U-Value of 3.447W/m<sup>2</sup>-K. Figure 3 shows a 3D model of the case study building while figure 4 shows the annual simulation results in relation to temperature, heat gains and energy consumption.

**Figure 3. Design Builder 3D model of case study**



**Figure 4. Annual simulation result for temperatures, heat gains and energy consumption**



**Simulation results**

**Orientation**

The orientation of the existing building as measured during the site visit was 247° SW. In addition to the existing building orientation, four other options were considered for their energy implications. The various inputs, in terms of the annual operative temperature and the total solar gains are shown in table 1.

**Table 1. Different orientations and their implications**

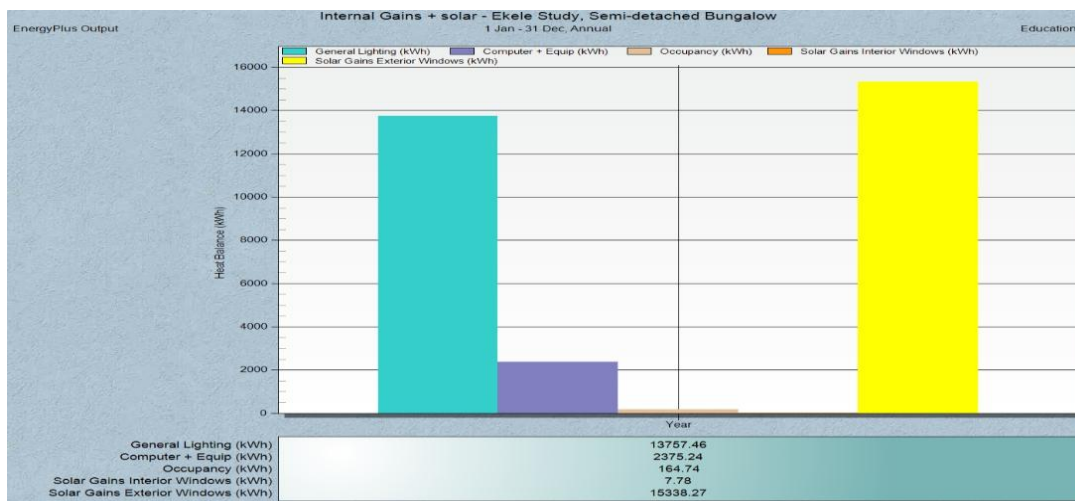
Orientation (°)	Operative Temperature (°C)	Solar Gains (kWh)
247	33.62	20,437.90
0	33.91	26,111.40
90	33.57	19,559.15
180	33.91	26,103.18
270	33.58	19,769.90

Table 1 show the operative temperatures and solar gains of the case building based on the existing orientation of 240° and four other selections. Operative temperature and solar gains were investigated to understand the relevance of different orientations on cooling demand and indoor thermal comfort. The simulation results showed that there is a relationship between building orientation thermal comfort in buildings. The relationship is for significant in terms of solar gains than operative temperature. The difference between the lowest and the highest solar gains in terms of orientation is 6,552.25kWh (26,111.40 - 19,559.15), which correspond with 25.09% reduction. The difference between the existing orientation and the orientation in terms of solar gain is 878.75kWh which corresponds with 4.29% reduction in solar gains. The result indicated a decrease in operative temperature compared with the existing orientation. The decrease in annual operative temperature was about 0.15%. Hence, the various results confirmed that different orientation can have different energy and comfort implications in buildings. This result showed that the choice of a good building orientation by design professionals can help to reduce solar gains thereby improving thermal comfort and energy efficiency.

▪ **Glazing**

By using single leaf, no shading as glazing template and Single Ref-A-L Tint 6mm as glazing type, the annual solar gains reduced by 5,091.93kWh (20,437.90 – 15,345.97) representing 24.91%. The annual operative temperature reduced by 0.20°C (33.62 – 33.42), which corresponds with 0.59% compared with that of the existing building. Figure 5 shows the simulation result for internal gains and solar.

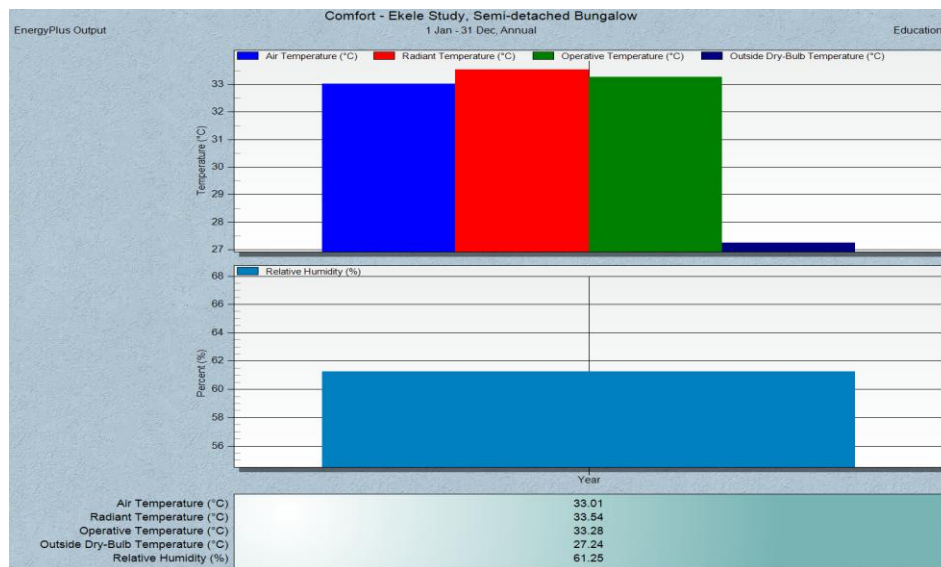
**Figure 5. Annual simulation result for internal gains and solar**



▪ **Shading**

Testing different glazing devices on windows showed significant changes in solar gain and thermal comfort in the existing building. By using both overhang and side fins of 600mm projection, the annual solar gains decreased by 697.33kWh (15,345.97 – 14,648.64) representing 4.54%. The annual operative temperature reduced by 0.14°C (33.42 – 33.28) which corresponds with 0.42% improvement in indoor comfort. Figure 6 shows the annual simulation result for comfort.



**Figure 6. Annual simulation result for comfort**

## Findings

This paper aims to explore the influence of building orientation, glazing and the use of shading devices on residential buildings in Nigeria considering the effect solar radiation. The study confirmed the relevance of building orientation, glazing types and external shading devices in reducing solar gains and improving thermal comfort in buildings.

The simulation results of the case study model showed that different orientation can have significant effect on building energy demand. Although there was no significant difference between the orientation of the existing building and the best orientation, there was significant difference between other orientations as shown in the simulation results in Table 1. This table showed that there can be up to 25% reduction in solar gains by adopting appropriate orientation. For the base case model, the most significant reduction in solar gains occurred when the longer side of the building faced north or south façade. This confirmed that north orientation is the best for buildings in hot humid climates (see Mirrahimi et al., 2016). Moreover, the simulation results confirmed suggestions in previous studies that to reduce energy demand in hot humid climates, the shorter side of buildings should face east-west axis and that energy efficient building should minimize placement of windows on the east and west facades (Al-Tamini, 2011; Mirahimi et al., 2016; FMPWH, 2016).

Changing the glazing types produced significant effect in terms of solar gain. Single-leaf tinted glass proved more effective in reducing solar gains. This confirmed previous studies on the suitability of tint glass for buildings in tropical climates (Kradi et al., 2005; FMPWH, 2016). Nevertheless, building designers should be careful with the adoption of tint glass as the test simulation of the base case model confirmed significant reduction in daylighting. The simulation results showed no significant reduction in solar gains using double-glazing, clear glass, which was advocated by Gijon-Rivera et al (2011) for hot climates. The simulation results for different sizes and types of external shading devices showed reduction in solar gains.

The results revealed that a combination of overhang and side fins is more suitable compared with only overhang. Increasing the width of shading devices by 100mm from 500mm default in DesignBuilder showed corresponding reductions in solar gains. Noticeable savings in terms of solar gains were observed by increasing the width of shading devices from 500mm to 1000mm. However, care should be taken in choice of the width of shading devices in terms aesthetics, moderateness and cost effectiveness. A width of 600mm seems to be more suitable.

## Conclusion

This study has shown that the sun and its path have significant effect on energy demand in buildings in terms of orientation, glazing types and shading devices, especially in tropical climates. The simulation results (using natural ventilation only) showed that intelligent building design can reduce solar gain by nearly 30%.

Energy savings from the adoption of appropriate building orientation, glazing types and external shading devices will no doubt help to improve people's wellbeing, quality of life and productivity. Reduction of solar gains through these measures will go along way to reduce CO<sub>2</sub> emissions, and environmental pollutions due to excessive use of cooling devices. The results indicated that to enhance energy efficiency in buildings, especially in tropical climates, designers should focus on downsizing heat gain through the building envelope considering the sun path, glazing types and external shading devices.

This study confirmed that appropriate design of buildings based on excellent understanding of the sun and its path could help to reduce high energy need, poor energy supply and distribution, energy poverty and over dependence on electric generators for power supply in Nigeria. Hence, there is enormous opportunity for design professionals, homeowners and other stakeholders in the building industry to reduce energy demand by buildings thereby improving thermal comfort.

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