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The Effect of Shading Devices and Windows Design on Energy Consumption in Tropical Buildings, Nigeria

Sanusi Sani Maimagani, Usman, Abdullahi Muhammad , Isyaku Usman Makera
Department of Architectural Technology
Waziri Umaru Federal Polytechnic Birnin Kebbi, Kebbi State, Nigeria.
Department of Architectural Technology
Waziri Umaru Federal Polytechnic Birnin Kebbi, Kebbi State, Nigeria.
Corresponding Author: Sanusi Sani Maimagani

ABSTRACT
The amount of solar heat gain in tropics particularly Nigeria which is aided by heat absorption of glass are significant due to its thermal properties are the first things to consider. Shading devices play an essential role in reflecting or admitting solar radiation into the building. This study aims at determining the ideal shading devices design in dealing with solar radiation through the windows system for energy efficiency.One of the objectives of the aim above is examining and analyzing different fenestration system design parameters of residential buildings with the help of computer simulation. Windows' system properties and shading devices performance cansignificantly affect the building's annual energy consumption, peak load of mechanical cooling system and carbon dioxide emissions. This study will, therefore,prove that about an 18% reduction in the building's annual energy consumption is possible. Furthermore, it will help the designers and stakeholders to identify simple and sufficient factors in improving buildings' energy consumption and thermal comfort.
Keywords: Glazing, Shading devices, Heat gain, Solar radiation, Windows.

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I. INTRODUCTION

Solar radiation passing through transparent surfaces such as windows or skylights, or through opaque surfaces such as walls or roofs brings about heat gain inside a building (Balcomb, 1992). In warm and sunny climates with excessive solar radiation, large amount of energy is needed to cool the building.In cold and temperate climates, winter sun entering south-facing windows contribute to passive solar heating. However, controlling and diffusing the sun rays could improve daylighting in virtually all climates (Prowler, 2014). Appropriate design and choice of shading devices are essential factors to consider in ensuring optimum energy performance and thermal comfort of a building. The rapid development in the building construction industry and the related energy and environmental concerns have triggered researchers to explore different fenestration and shading systems for proper control of solar radiation and daylighting. The overhangs and fins, when combined appropriately, would drastically help in reducing the excessive sunlight into buildings. The simulation tools also playessential role in making a decision during the early design stage that could help significantly in improving the thermal performance of buildings (Ali & Ahmed, 2012). A review by Dubois (1997) shows the importance of using computer programs to assess energy consumption and comfort in buildings with shading devices, and also in defining specific shading strategies for specific climates for different types of buildings.

II. SHADING DEVICE

According to Waheeb (2005), the most straightforward, cheapest and most effective way tocool your house is to shade it. This will curtail the sun from hitting directly into the windows, walls,and roof. Generally, where the average summer temperature is less than 800 F, shading may be all required to stay calm.

To understand shading effect on buildings one should know about the sun's movement during the day. According to Evans (1998) the sun's position for geographical location, season and time of day can be determined by geometric techniques. The sun's movement differs in azimuth and altitude angles with the seasons. These sun angles about the north-south axis can be used to predict shadows for a particular time at a specific latitude. There is a formula, d = x (tan_ / cos_), between the depth of shade and the overhang width. Sun angle geometry and sun path at 400 north latitude illustrated inthe figure 1 below.

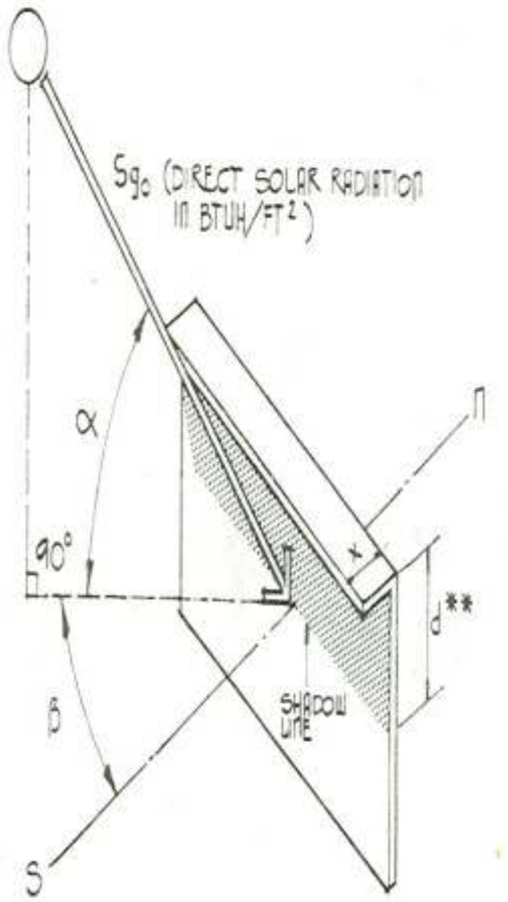

Figure 1. Sun angles. (Evans, 1998).

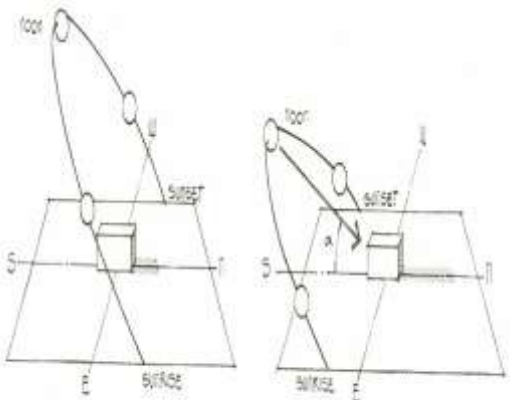

Figure 2.11. Summer and winter sun path diagrams at 400 north latitude.
(Evans, 1998).

According to Waheeb (2005), the primary purpose of shading is to reduce heat loss during cold season and also reduce heat gain during the hot season. For instance, shading poorly insulated walls is a requirement not needed for well-insulated walls. Thus, in hot climates, un-insulated walls, roofs, and also windows should be shaded. Overhangs and awnings are suitable shading devices. On the other hand, the shading provided by fixed overhangs coincides with the seasons of the sun rather than with the climate. In other words, fixed overhangs show the best performance when the sun is highest in the sky. However,the hottest days occur when the sun is lower in the sky.

Waheeb (2005) further explained that shading with vegetation depends on the prevailing climatic condition of the place. For instance, On March 21, there are dry or no leaves on most plants in the northern hemisphere that’s why sunlight easily reaches to buildings through naked branches. However, on September 21, for example, the same plants grow leaves to provide the required shading. Operable shades are meant to control solar radiation for human comfort and generally mounted on the exterior of the building. Unfortunately, these shades do not usually last very long, due to nesting animals, climbing children and wind. Interior shades are not as efficient as exterior shades. The sun rays hitting the unshaded walls and windows help in reducing the energy needed for cooling. Controlling solar radiation by using unmovable shading devices at the eastern and western sides is hard, if not impossible, because the sun at those sides is at the lower horizon during sunrise and sunset (Bhatia, 2012).The amount of sunlight at these directions, which overhangs cannot stop, is highest in summer than in winter. The method of shading such windows is to install movable vertical louvers or other vertical projections.

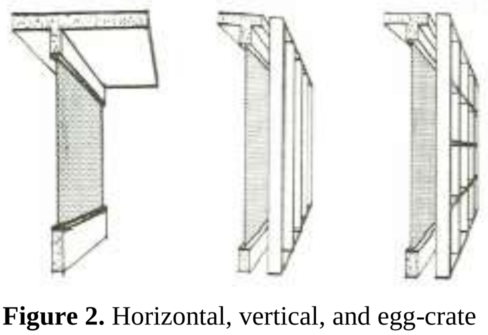

Figure 2. Horizontal, vertical, and egg-crate shading devices. (Evans, 1998).

The horizontal shading devices are more usefulfor the southernand northern elevations. East and westfacades need excessive width of overhang for effective shading. On the other handthe vertical exterior louver and egg-crate solar shading devices are preferredfor east and west facades. By acting as a windbreak, these shading elements increase the insulation resistance ofwindows in cold seasons. The egg-crate solar shading deviceis a combination of horizontal and vertical elements. These devices can aids in hot climates due to their high shading efficiency. The three types of shading devices are illustrated in figure 2 above.

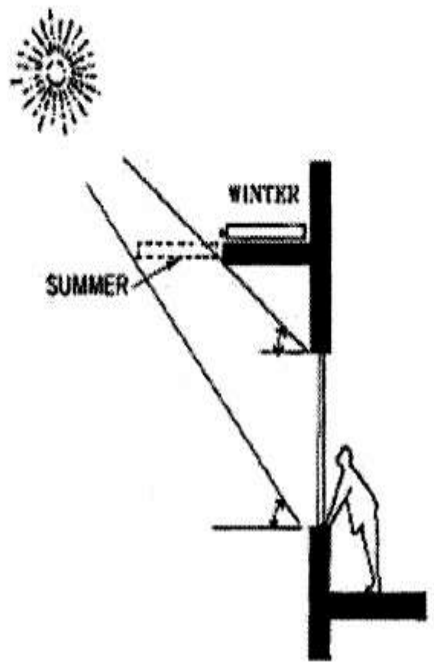

Figure 3. Adjustable overhang for solar penetration in winter. (Rassam, 2004.)

According to Rassam (2004), to design effective shading, the designer needs to know the periods when to let in the sun or to let it out. For example, two dates with similar sun angles, such as March 21 and September 21, may need different shading solutions. For instance, fixed shading devices provide shading for the glazed areas not only in hotter months but also in colder months when solar radiation may be needed. Sun angles are not entirely about air temperatures. Daily weather patterns considerably change, especially in hot and cold seasons, when too hot or too cold days might be experienced. Adjustable shading devices (Figure 3) are suitable for seasonal variations and daily weather patterns. Shading devices should not be attached to the building in order to significantly reduce the transfer of any heat absorbed by the device to the building. Another advantage of this is that it will allow unobstructed air into the building.

According to Rassam (2004),plants may be perfect shading devices when used appropriately for windows facing eastern and western directions. Leaves absorb 60-90% of incident sunlight. The shading coefficient of plants varies by 0.2-0.6 depending on the density, age, annual growth, and the angle of the incident. Vines might be useful in shading because they have a dense leaf structure growing faster than trees and provide filtered dynamic light. Vines can obstruct almost 60% of solar radiation on walls surfaces. East and west facades are suitable for the best performance of a vertical vine-covered trellis.

On the other hand, a horizontal trellis performs well on the southern façade. Notwithstanding the ability to shade the building from the sun rays, one major disadvantage of trees is that the branches themselves can block about 30-60% of the solar insolation. They can also hamper cross ventilationand block the exterior views unless they are rightly positioned (Bouchlaghem, 2013).

III. METHODOLOGY

The methodology implemented in this paper is based on an analytical literature study and comparative simulation work for research variables. The literature study was carried out to investigate and analyzethe two shading device configuration. There follows an experimental simulation study for a typical residential three-bedroom flat chosen to represent the standard type of housing in Nigeria. The floor plan and 3D view as demonstrated in the following figure 4 and figure 5.

Figure 4 Floor plan of a typical residential building in Nigeria.

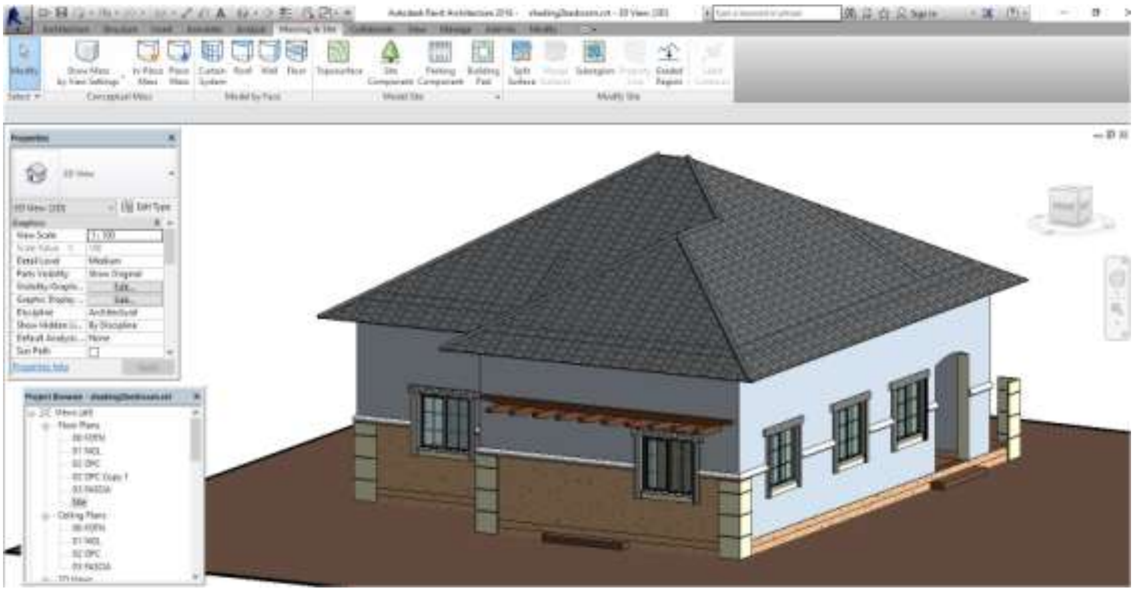

Figure 5 3D view of a typical residential building in Nigeria.

The dependent variable isEnergy consumption, which is measured in Watt-hours (Nicol, Hunphreys, & Roaf, 2012). These variables are examined as part of the process of creating a suitable base-case on which to test the performance of Dependent variables. The following figure 6 shows the dependent and independent variables.

Figure 6; Dependent and Independent Variables

The three independent variables W1,W2, and W3, as shown in figure 4, are W1 is the window without shading device, which will serve as a base case, W2 is the window with vertical shading device, W3 is the window with horizontal shading device. The material for shading device will remain the same in both cases. This will be in order to establish the difference in energy load between the vertical and horizontal shading devices.

Environment for the Experiment

Autodesk's ECOTECT is building analysis software that allows the user to quickly design and work in 3D. ECOTECT offers a wide range of analysis options from acoustics to energy efficiency tools. ECOTECT's tool related to energy efficiency can be found under thermal analysis in the interface of the ECOTECT as shown in Figure 7. For this tool to be used properly it requires the adherence to some specific principles when constructing the model that will be analyzed. The materials were appointed to the corresponding building components; afterward, an ECOTECT simulation was run to observe how these behaved altogether in regards energy consumption.

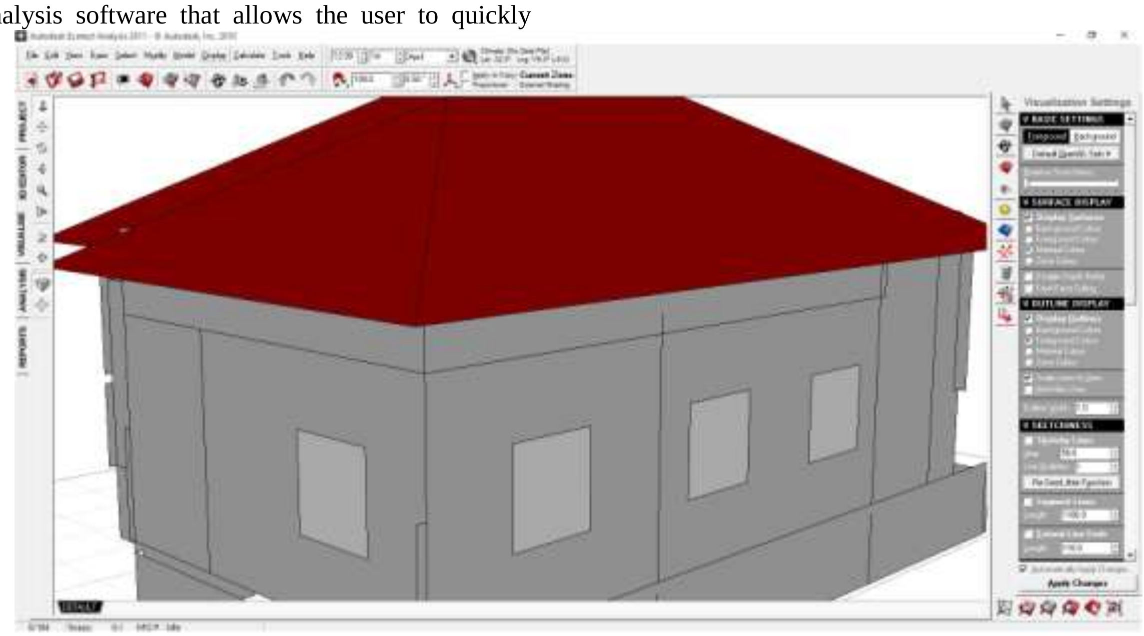

Figure 7; Interface of Autodesk ECOTECT

IV. RESULTS AND FINDINGS

Heating and Cooling Energy Load

Heating Cooling loads of air conditioning systems working with 95% efficiency and 10m² per person at a state of reading activity (55W) is considered for the calculations. The calculation would take place according to the standards ANSI/ASHRAE (2001) Standard 55-2000R) in ASHRAE (2004) applied to the Meteonorm weather data, 2010. However, due to the geographical location and climatic condition of Nigeria, the total annual energy required for heating is minimal (which can be negligible), and it has only required for few hours in the two coldest months of the year, which are January and December. Results showing the effect of various shading device configuration of the total annual energy reduction on the baseline model are presented below;

Table 1 Result of monthly energy load of the variables

MONTHLY COOLING LOADS			
	W1	W2	W3
MONTH	(kWh)	(kWh)	(kWh)
Jan	11.395	1.909	0
Feb	510.9	469.635	425.026
Mar	1437.575	1350.963	1209.258
Apr	4352.213	4011.658	3437.275
May	4029.173	3726.241	3214.803
Jun	3667.789	3395.96	2936.569
Jul	1528.181	1436.671	1298.847
Aug	359.921	338.11	349.082
Sep	800.448	717.268	668.602
Oct	1618.465	1498.795	1343.87
Nov	290.938	239.93	205.09
Dec	0	0	0
TOTAL	18607	17187.14	15088.42
PER M²	184.577	170.492	149.674

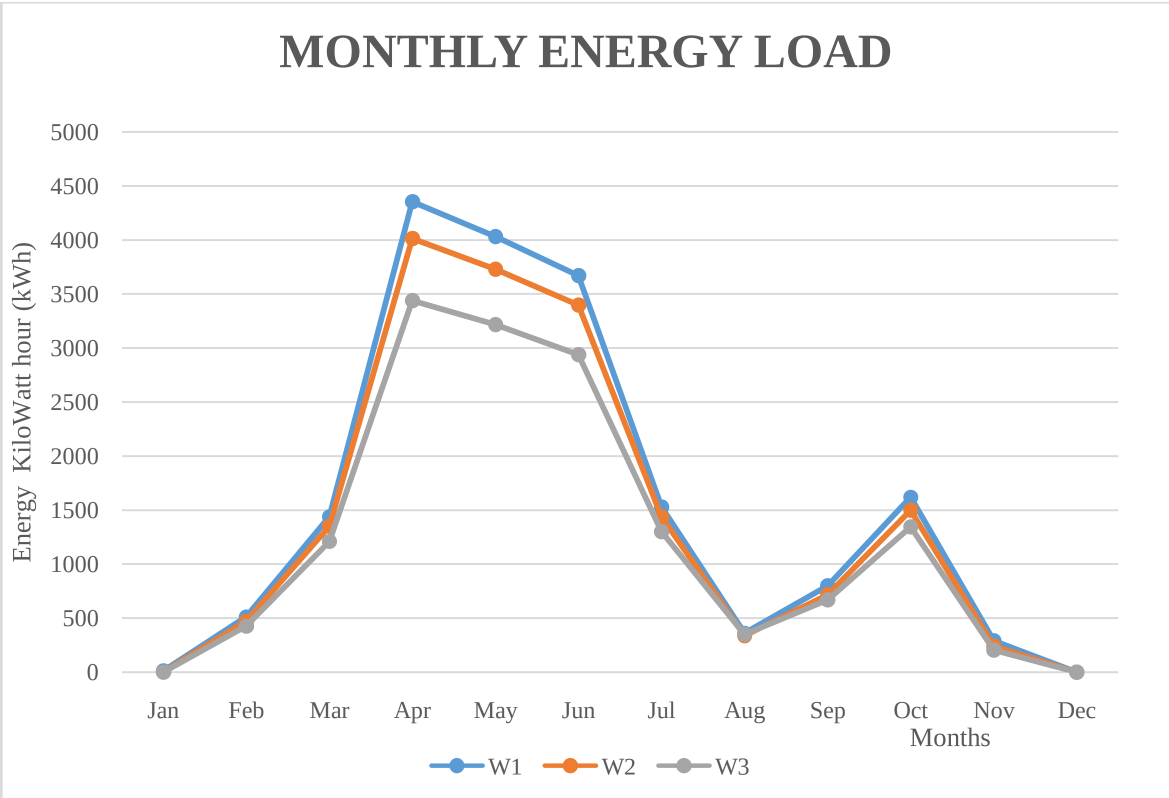

Figure 8 Result of monthly energy load of the variables

To show the effect of various walls on energy reduction in Figure 9. Various walls were displayed on axes with different tick marks. The vertical scale is in kWh (kilowatt-hours), and the horizontal axis is in months of the year. As can be seen from the simulation result in Table 7 and Figure 9, the cold season months (January& December) have the least energy demand while the hot season months (April & May) have the highest energy demand. Total values obtained from ECOTECT analysis can be referred to from Table 9.

From the figure 9 above, it can be seen that by applying vertical shading device W2, a reduction of 7.63% of total heating and cooling energy load will be achieved. By applying horizontal shading device W3, a reduction of 18.91% is achieved.

V. CONCLUSION

Energy simulations were performed on a typical residential building in Nigeria to study the impact of shading devices, which are horizontal and vertical, with no shading as the baseline. Energy simulations were performed by the Autodesk Ecotect Analysis software program. It has been observed that a judicious application of shading devices could bring about significant reductions in energy consumption.

The result from the simulation indicates that the horizontal shading device is more effective than vertical shading devices on energy load by about 11%. This is since, in Nigeria, the sun is casting overhead as Nigeria is geographically located within tropics of Cancer and Capricorn.

VI. RECOMMENDATIONS

This paper investigates the effect of shading devicesconcerning location on windows. However, it is recommended that shading devices should be horizontal for buildings under tropics of Cancer and Capricorn as the sun is casting overhead in this region.

Further research on the effect of shading device materials is also recommended in order to have strict guidelines for shading device design.

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