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PARAMETRIC ANALYSIS OF ENERGY EFFICIENCY IN DOUBLE SKIN FAÇADES FOR HOT AND DRY CLIMATES: A CASE STUDY OF KEBBI STATE, NIGERIA

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ABSTRACT

This research evaluates the energy and concepts of Double Skin Façades, which were established through computational simulations integrated with some relevant examples. DSF is regarded as one of the best solutions in realizing the interface between the interior and the exterior building spaces. It also allows provides architectural flexibility in the design. Recently, the double-skin façade has received much attention as opposed to the more typically glazed curtain wall. This is for its ability to effectively reduce the thermal transmission (U-value) and solar heat gain (G-value). DSF design comprises assessments of building geometric factors, glazing type, ventilation procedures, shading devices, daylighting aesthetics, and maintenance expenses. However, the concept of DSF is sometimes complicated, and its use and function influence different parameters of the building, but if the approach is overall and the aims to be realized are distinct, then the stated method is flexible enough to reach climatic variations for the greatest types of building use. Besides the fact that large number of researches carried out on the performance of this facade configuration in moderate climates, it is very vital to recognize its performance and viable formations in hot and dry climates. It is therefore a chance to learn about this facade arrangement earlier the technology is transmitted into construction in hot arid areas. Results of the analysis revealed that variation in value by certain degrees and alteration of some parameters has a direct effect in the energy use intensity as well as the illuminance values of an office building in Birnin Kebbi.

Keywords: Double skin, Energy, Performance, Simulations, Analysis

INTRODUCTION

Typical building façades, including DSF, face several challenges in terms of natural ventilation, and thermal comfort, especially in buildings with a high ratio of glass in the facade, and arid and hot climate regions. These problems cause architects and other building industry professionals to develop techniques for solving these problems through the utilization of new techniques such as shading devices, and color glass among others (Shameri M.A. et al, 2011). The adoption of these techniques has shown a reduction in natural lighting, and the increase in the use of artificial light; which inevitably led to the increase in the interior heat gain. To battle this situation, artificial cooling is used to cool down the heat effect. This results in the increase of energy consumption which leads to an increase the cost (Faggembau D. et al, Solar Energy 75 (2003) 229–239).

Double skin façade is mainly used to boost the building's thermal efficiency with great glazing facade formations. DSF is mainly adopted for architectural reasons and its transparency properties because it allows close contact with the surroundings of the building, to the point that it allows a great amount of daylight to pass in to the building deprived of intense glare. Finally, it has an attractive aesthetic value which is much desired by architects, developers, and owners (Elizabeth G., et al, EIA, 2004, 2011). Though, there are numerous tasks of using DFS; one of them is the construction expenditures that is vividly much higher compared to a conventional glazed facade. Moreover, the possibility of overheating during days with relatively high temperatures is obvious which may lead to an excessive need for cooling the interior spaces.

Unfortunately, few buildings currently utilize DSF, especially in hot, arid climates. Thus it is said that it is somehow difficult to find any objective data on the actual performance of buildings with DSF specifically in hot arid climates. Key innovation in GF skills has equipped the architects and experts a chance to integrate the Components of the building envelope within sustainability philosophies but preserving a great level of capability. That is the reason why it is vital that GF construction systems and materials should be planned and fixed appropriately to deliver an exciting living environment, while maintaining a sustainable system for the environment and the society (Elkadi, H. et al, 1999). This research will focus primarily on some of the configuration issues in designing a DSF in hot and dry climate specifically in north-western Nigeria "Kebbi state"), to comprehend its performance and arrangements in the region.

The task anticipated from buildings with DSF is to attain harmony between the visual aesthetic, acoustics insulation, and performance in terms of energy efficiency. The elementary structure of DSF consists of the inner skin, an air cavity, and the outer skin (Oesterle P. et al., 2001). The inner skin and the outer skin can be of a single or double pane glass. The DSF can also be combined with shading elements such as louvers to moderate solar gains and consequently, the cooling mandate of the building is reduced. Nevertheless, heat is fascinating in the air cavity of the DSF when the weather is hot, due to solar gains and thermal transfer of the exterior skin. Depending on the design, the gap of the DSF is commonly ventilated naturally or mechanically to drive out the excess heat gained (Kim B. et al, 2007).

Key innovation in GF skills has equipped the architects and experts a chance to integrate the Components of the building envelope within sustainability philosophies but preserving a great level of capability. That is the reason why Double Skin Façade construction systems and materials must be planned and fixed appropriately to deliver an exciting living environment while maintaining a sustainable system for the environment and society (Blocken, S. et al., 2005)

Since the late 1970s, reliance on artificial cooling systems in buildings has been growing, continuously which in consequence increases the maintenance cost of these buildings. The formations of some commercial building facades in hot and dry regions have an excessive impact on dwindling/growing the building's maintenance demand. In hot arid climates, about 45% of the cooling loads emanate from the facade's configuration (Uuttu, J. N. et al, 2001)
space is attached to the outdoor atmosphere so that the windows of the inner façade can be operable, even in high-rise buildings pending wind pressures; this system permits cooling at night time and natural ventilation of the building (Zimmermann Michael, 2008).
When solar radiation is high, the air space has to be efficiently ventilated, to surpass overheating. In this regard, the basic criteria are the cavity depth and the size of the openings in the outer skin. Depending on the wind pressure and the prevailing climatic conditions, the air changes within the cavity of the building façade (Saelens' Peter Son, 2002).
There are numerous merits in addition to the energy performance benefits behind using Double Skin Facades over the conventional Facades portrayed in the sequence below:

Lower Construction Cost
In comparison to various solutions that can be furnished via employing specially treated glasses like thermochromic, photochromic, electrochromic among other panes (their qualities transform according to environmental and the climatic conditions of the region). Although these panes can be very promising, they are very expensive. Inversely, Double Skin facades can attain a quality of variability thru a coordinated combination of components which are both known and available.

Acoustic Insulations
Based on some authors' perception, the acoustic insulation can be one of the highly important rationales to use a Double Skin Façade. Degree of the interior nuisance can be minimizing inside an office building decreasing both the room to room sound transmission (interior nuisance) and the transmission from exterior sources (external nuisance). The acoustic insulation concerning the internal and the external nuisance can be attained by adopting this Double Skin Façade especially if incorporated with the quantity of openings which can be indeed very vital.
Jager, (2003) stated that for an acoustic insulation, 100 mm has to be proposed as minimum value. Faist, (1998) indicated in a report written about calculating acoustic aspects of Double Skin Facades. Both calculations and real measurements are presented in this report. Finally, acoustic performance was thoroughly reported in Oesterle et al., (2001).

Thermal Insulation
Many authors cited that the DSF System can produce with optimum thermal insulation for the presence of its outer skin both in winter and in summer periods.
During the winter, the exterior supplemental skin provides improvement; during the heating period the results will improve if the intermediate space (cavity) is closed (partially or completely). The reduced speed of the air flow and the increased temperature of the air inside the corridor drop the degree of heat transference on the surface of the glass which results in heat losses reduction. Has the effect of maintaining higher temperatures on the inside part of the interior pane. Oesterle et al., (2001) depict how the thermal performance can be enhancing by portraying how the best proportion of the opening area should be.

Twin Face Double Skin Façade System
This is composed of ordinary curtain wall system within a single glazed building skin. The exterior skin may be made with specially treated glass to blend with the intended function. Sun shading elements are incorporated and the synthesis should have an intermediate air space of at least 500mm-600mm to allow for cleansing. Natural ventilation is allowed in the twin faced DSF due to the presence of an opening which distinct it from the buffer and extract air DSF system. The internal skin gives insulation for minimizing loss of heat from the interior, whereas the external skin functions as a guard to the air cavity contents (shading elements) and consequently mitigate energy consumption.

Study Area
Figure 1 below illustrates the location Map of the case study building which is located in Birnin Kebbi, Kebbi state in the northwest part of Nigeria bordering Sokoto, Zamfara, and Niger states. It also shares international borders with Benin and Niger Republic.

Figure 1: Showing the study area location

Climatic Data of the Study Area
All buildings' fundamental operation is to fit the predominant climate and furnish an internal and external environment that is comfortable and conducive to the dwellers. Nevertheless, in this era of global warming and drastic climate change, comfort provision for the occupants of a building is quite

challenging and very fundamental. This is a consequence of the growing series of challenges confronting professionals who are presently producing buildings that will be fit and comfortable for the 21st century. This chapter presents climatic condition of hot arid climate within the study area, as well as its effect on the building facades. This study looks into the climate condition of Nigeria in relation to climatic zones for architectural design. Nigeria is a tropical climate West African country located between longitude 30oE and 15oE of the Greenwich Meridian, and latitude 4oN and 14oN of the equator. Due to the location of the country near the equator, the temperature is high throughout the year, though with regional variations (Yahaya O. M., et al., 2024). As in most West African countries, Nigeria's climate is identified by strong latitudinal zones, becoming drastically drier as one moves north from the coast (Lee, E. et al., 2002).

The wet season customarily starts in February or March as humid Atlantic air, famous as the southwest monsoon, occupies the country in the coastal and southeastern portions of Nigeria. The commencement of the rains is often manifested by the prevalence of high winds and dense but scattered squalls. The dispersed quality of this rainstorm is exclusively manifest in the northern regions, though there may be plentiful rain in some minor regions while some other places remain dry. Toward the end of April to the first week of May in most occasions, the rainy season begins through the southern part of the Niger and Benue river basins. Habitually in the far north of Nigeria, it is mostly toward May end or early June when rains indeed commence. The uttermost of the rainy period befalls over utmost of the northern part of Nigeria in August, as soon as air from the Atlantic shields the whole country. In southern districts, this era indicates the August dip in rainfall. Even though hardly dry, this dip in precipitation, which is particularly marked in the southwest, can be beneficial agriculturally, for it allows a momentary dry period for grain harvesting (Soberg, H. et al, 2008).

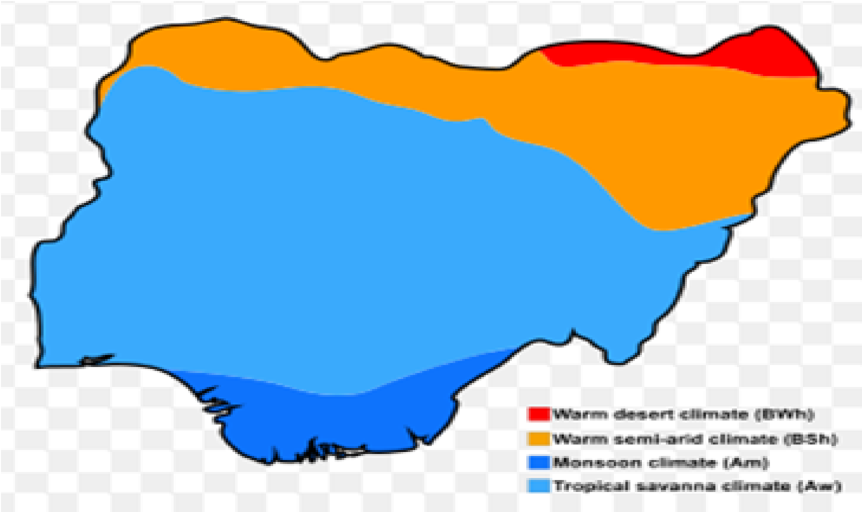

Figure 2: Nigeria Climatic Zones

In Nigeria, temperatures all through are mostly high; daily variations are more definite than periodic ones. Maximum temperatures befall thru the dry season; rains adequately afternoon highs through the wet season. Middling lows and highs for Kano are 27° C and 33° C respectively in January and 33° C and 28° C in June respectively. Even though average temperatures differ slightly from coastal to inland regions, inland regions, specifically in the northeast, have larger excesses. There, temperatures extent as high as 44° C before the onset of the rainfalls or descent as low as 6° C during an invasion of cool air from the northern part from December to February (Charron, R., et al, 2006).

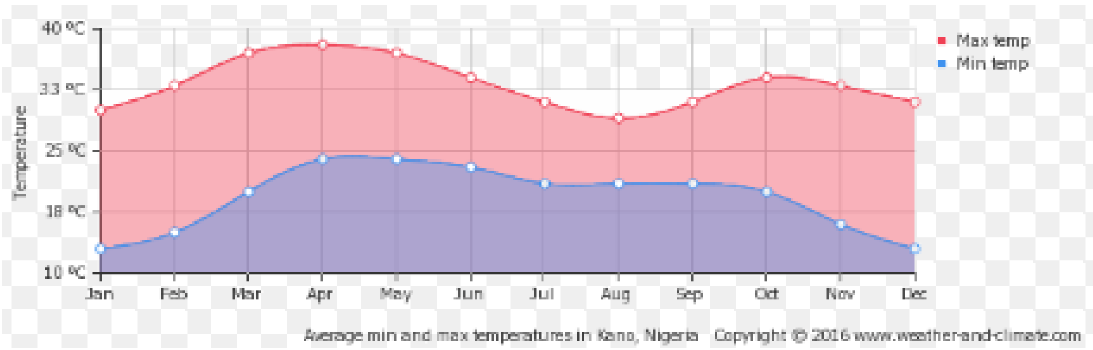

Figure 3: Average temperature of Birnin Kebbi, Nigeria.

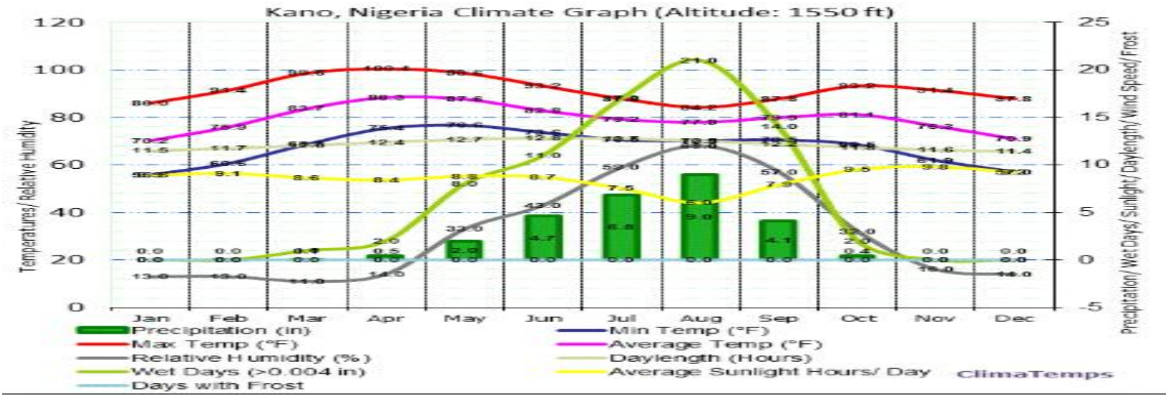

Figure 4: Climate Graph of Birnin Kebbi, Nigeria.

MATERIALS AND METHODS

Design Strategies in Hot and Arid Climate

Climatic factors greatly influence on the building performance specifically daylight as well as its energy consumption. Reduce energy consumption, leveraging natural resources and producing healthier, comfortable, and sustainable living functions are the aims of a climatic-responsive sustainable building design (European Standard EN 832, 1998). Viable design and construction approaches are of pronounced importance these days. One may say that sustainability was previously a motivating potency, revealing its rationality through the various forms and procedures used. Consequently, from those days till today, there have been no sufficient transformations in difficulties and necessities encountered in the design and construction environment; however several developments have been realized in terms of innovative technologies and modernization of materials. Consequently, all-inclusive deliberation on the building process should be ensured. Moreover, the choice of climate-responsive materials and building performance should be assessed together and the final product should accomplish well during its lifespan.

Data Acquisition

Data acquisition was based on the following categorization of the research design:

i. Descriptive (case studies)
ii. Experimental (simulation)

Data concerning building location, and materials configuration were gathered through the earlier mentioned mechanism.

Case Study Building

The building is a prototype to all Zenith bank branches across the nation. Zenith Bank is headquarters is located in Lagos, Nigeria; Zenith Bank has more than 500 branches and financial offices nationwide, it exists in all state capitals including Abuja (FCT). United Kingdom Financial Service Authority befitted Zenith Bank as the first Nigerian bank to be certified by the (FSA) In April 2007, resulting in Zenith Bank (United Kingdom) Limited. The building is located Along Presidential Lodge Road, Birnin Kebbi, Kebbi State as a financial institution that many people patronize and visit daily during the five working days (Mondays to Fridays, 7 ‘o clock in the morning to 6 ‘o clock in the evening (Loveday, D.L. and Taki, A.H., 2016).

To achieve the targeted results, the workflow indicated in the figure below should be adhered to while conducting the simulation experiment.

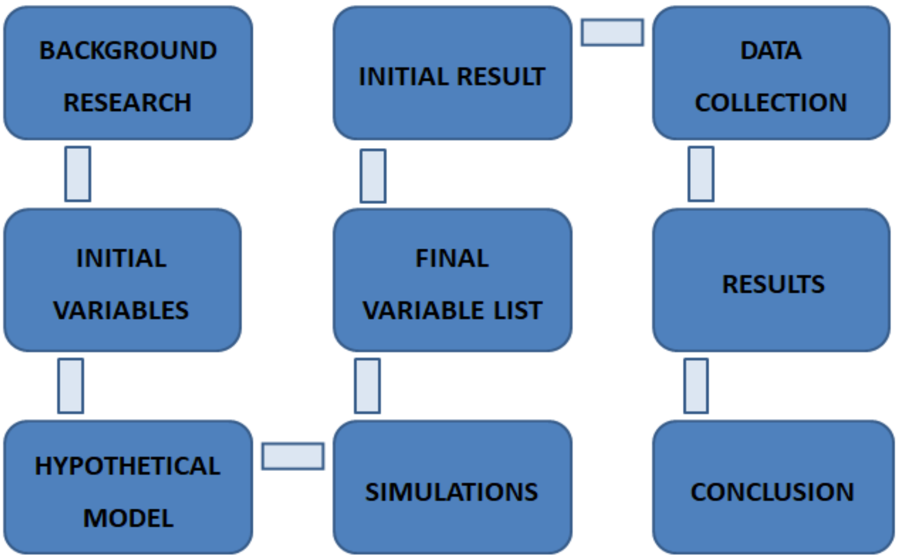

Figure 5: Methodology Workflow

Instruments for data collection

The instruments include a physical survey, drawings, and computational tools (simulations):

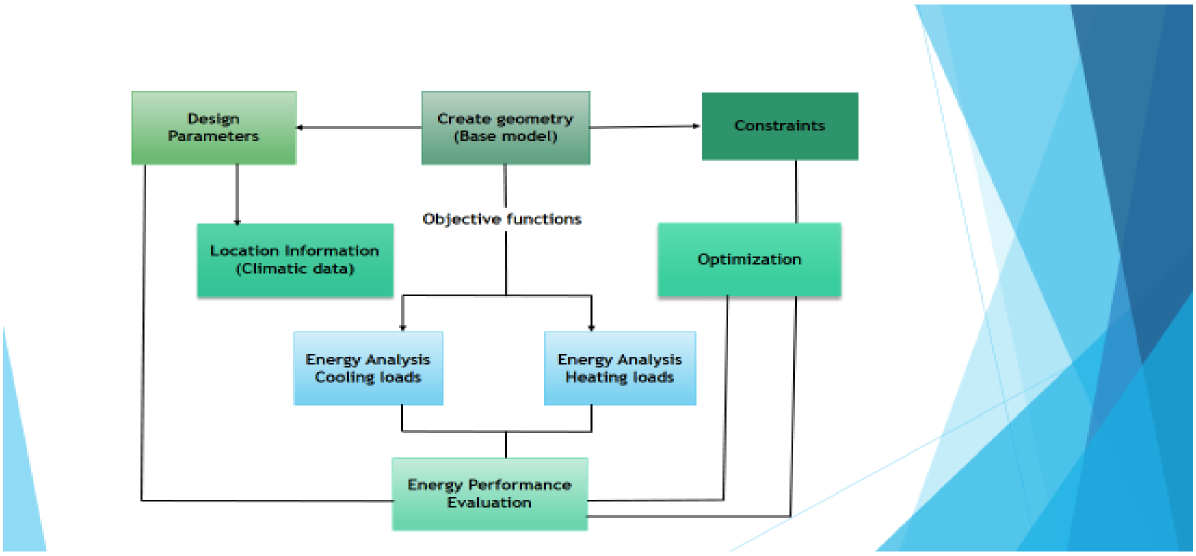

Figure 6: Ladybug + Honeybee Energy/Daylight Genetic Algorithm flowchart

Description of parametric model and decision variables

The methodology embraced in this investigation aimed to show the efficiency of employing the parametric approach in generating diverse alternatives, assessing and donating their performance. This method could overlay the way to the generation of inventive and exceptional design ideas. The workflow established in this research began with the generation of 3D model of the office building by means of a three dimensional parametric modeler tool called "Grasshopper", which is plug-in for Rhinoceros. Other environmental analysis plugins adopted are Ladybug + Honeybee. Ladybug Apparatuses is an association of free computer applications that upkeep environmental design and application of all existing environmental design software parcels. Ladybug tools help in connecting 3D Computer-Aided Design (CAD) interfaces to the prior stated simulation engines. Ladybug Tools uses weather data analysis to aid the parametric workflow of innovative simulation process and is very vital in analyzing the energy performance of a building. The Parametric model developed for an office building comprised Double-skin glazed facades with aluminium mullions with an air cavity between them. The parametric model allows for changing the glazing configuration (glazing type and ratio), and the change of different times that produce different values based on the predominant weather. All the decision variables are changeable using some intervals and were fixed with minimum and maximum value limits as shown in (Table 1) below:

Table 1: Parametric decision variables and extent of their values

Variables	Minimum Values	Maximum Values
Glazing type	1	3
Glazing depth	500cm	2m
Month	January	December
Day	1	Last day of the month
Time	8:00am	6:00pm

Honeybee Energy Simulations

The workflow established in this research began with the generation of a 3D model of the office building by means of a three dimensional parametric modeler tool called "Grasshopper", which is a plug-in for Rhinoceros. Other environmental analysis plugins adopted are Ladybug + Honeybee. Ladybug Apparatuses is an association of free computer applications that upkeep environmental design and application of all existing environmental design software parcels. Ladybug tools help in connecting 3D Computer-Aided Design (CAD) interfaces to the prior stated simulation engines. Ladybug Tools uses weather data analysis to aid the parametric workflow of innovative simulation processes and is very vital in analyzing the energy performance of a building. However, weather files for most African countries are not available, consequently you have to use the weather files for countries of the same climatic zone with the country where the research is carried out.

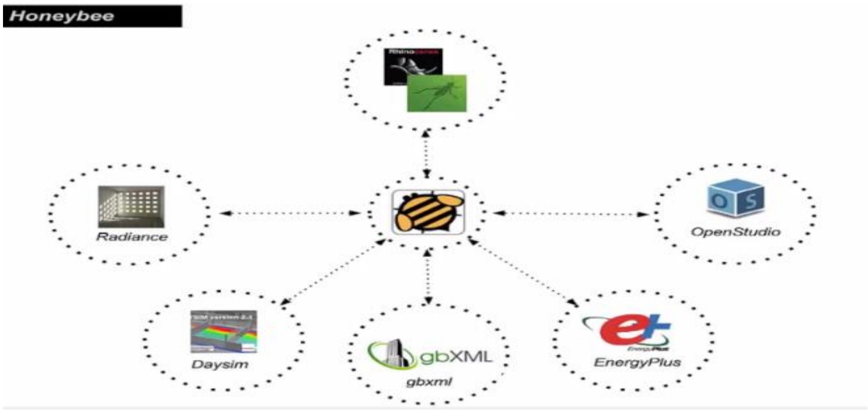

Figure 7: Ladybug + Honeybee connectivity to Energy and Daylight Simulation Engines. Source: www.mebd-penndesign.info/honey

Simulation Base Model

As earlier mentioned, the selected building is a two-storey building, with a double skin glazed facade. Each floor area is 672 m2 excluding the cavity depth. The cavity depth is 500mm. It has a length of 28 m a width of 24 m and a height of 11 m storey

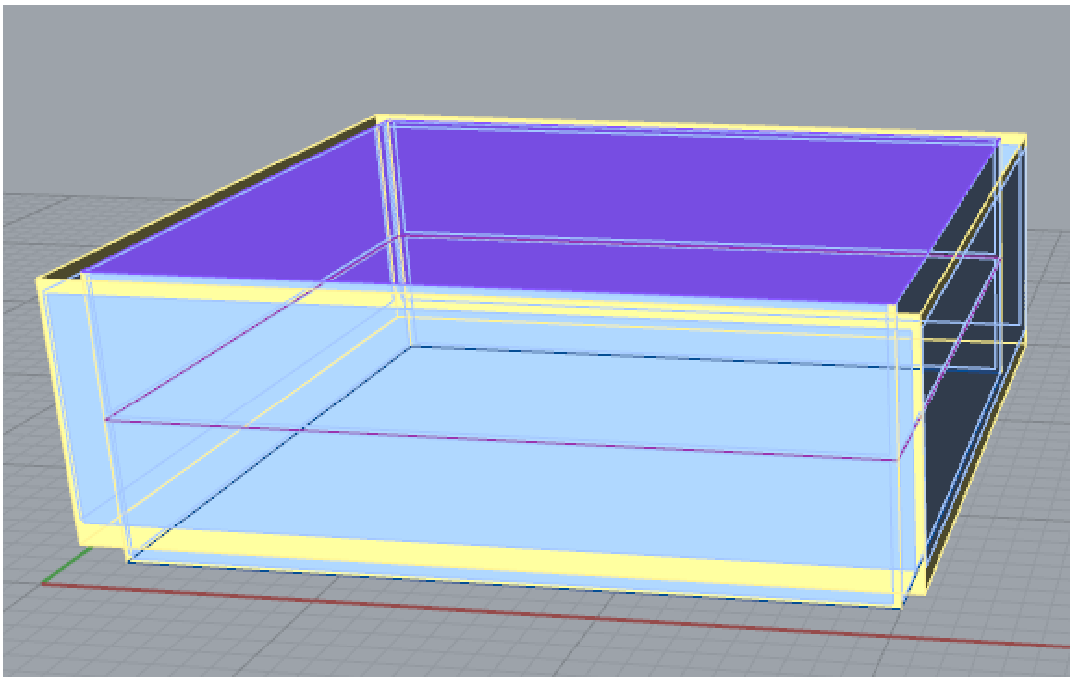

Figure 8: Simulation base model

Ladybug + Honeybee Energy Simulation

The method to be adopted for evaluating the energy performance and natural daylight within the office building under study is Honeybee and Ladybug which also would allow for the visualization of Energy and daylight Simulations results as well as some visual information about the study location in terms of Temperature, Sun paths Relative humidity among others (Gliner, H., Morgan R., & Leech, P., 2000).

RESULTS AND DISCUSSION

Table 4 below shows some energy simulation values for Cooling and Heating loads as well as the artificial lighting requirements of the selected hypothetical model with different glazing configurations at different times. The depth of the air cavity between the interior and exterior skin also serves as a decision variable.

Table 2: Energy Consumption Simulation Results

S/No	Inner glazing	Cavity Depth	Inner glazing	U-Value W/m2K	SHGC W/m2	VT (W/m2)	Thick-ness (Cm)	Month	Cooling Loads Kwh/m2	Heating Loads Kwh/m2	Lighting Loads Lumen/Watt
1	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	January	107.04	16.28	448.59
2	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	February	196.98	22.88	843.25
3	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	March	325.77	26.16	129.19
4	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	April	1949.21	26.22	169.53
5	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	May	1741.98	26.25	214.39
6	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	June	1494.79	26.25	257.45
7	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	July	1081.19	46.25	299.59
8	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	August	473.72	27.11	344.45
9	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	September	890.76	46.25	386.39
10	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	October	894.96	26.25	429.65
11	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	November	973.75	26.25	472.71
12	Single P.	50cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	December	819.19	26.25	514.85
13	Low_ E A.	50cm	Double P.	0.64/0.83	0.38/0.65	0.56/0.63	0.25	April	1350.82	33.11	169.53
14	Low_ E A.	50cm	Double P.	0.64/0.83	0.38/0.65	0.56/0.63	0.25	May	1205.03	32.58	214.39
15	Low_ E A.	50cm	Double P.	0.64/0.83	0.38/0.65	0.56/0.63	0.25	August	269.44	33.29	344.45
16	Low_ E A.	50cm	Double P.	0.64/0.83	0.38/0.65	0.56/0.63	0.25	September	820.98	32.58	386.39
17	Low_ E A.	50cm	Double P.	0.64/0.83	0.38/0.65	0.56/0.63	0.25	September	820.98	32.58	386.39
18	Low_ E A.	50cm	Double P.	0.64/0.83	0.38/0.65	0.56/0.63	0.25	December	605.71	32.58	514.85
19	Single P.	100cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	April	1734.36	30.34	132.67
20	Single P.	100cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	May	1237.38	28.15	193.25
21	Single P.	150cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	August	400.34	29.71	323.68
22	Single P.	150cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	September	534.22	54.79	295.79
23	Single P.	200cm	Double P.	0.85/0.83	0.73/0.65	0.69/0.63	0.25	December	624.81	34.38	457.81

In the Table 2 above, about 23 scenarios were analyzed thereby assigning various configurations of the glazing type: (Single Pane, Double Pane, and Low E Argon) in the interior and exterior façade, Cavity depth: (50 cm, 100 cm, 150 cm, and 200 cm) at different time throughout the year. The base model was analyzed based on each month of the year (January to December) having the same glazing configuration and the cavity depth and the results were obtained and recorded as in the table above. The results revealed that glazing configuration has a greater influence on the energy consumption of the building as well as the depth of the cavity. It is also observed that due lack of shading elements within the cavity increases the cooling loads of the building, therefore some shading elements should be mounted amidst the air cavity.

The analysis also revealed that the wider the cavity the less cooling load is required; therefore one should be cautioned enough in designing the air cavity. Hottest and coolest period is also very vital in the provision of the shading elements that may be adjustable or removable when required. Comparatively, from the above table, three different configurations were compared to evaluate the best formation in terms of energy performance at the same time (August) and the best formation was found to be; Low E Argon in the interior skin, double pane in the exterior skin with an air cavity of 50 cm. The second best option was that with a Single pane in the inner skin, a double pane in the outer skin with an air cavity of 150 cm. Then the third one was that with a façade configuration of single and double pane in the inner and outer skins respectively and the air cavity of 50 cm.

Ladybug Data Visualization

As stated in the previous chapter, Ladybug offers a diversity of 3D communicative climate graphics that back the decision-making progression during the initial design stages. Ladybug was used for the visualization of some basic climatic data which very vital in ascertaining the energy consumption of a building as well as the daylighting. The figures below visualize different climate-based information including the Sun path, Relative humidity, Outdoor temperature, cooling and heating loads among others (Van Paassen, D.K., 2003).

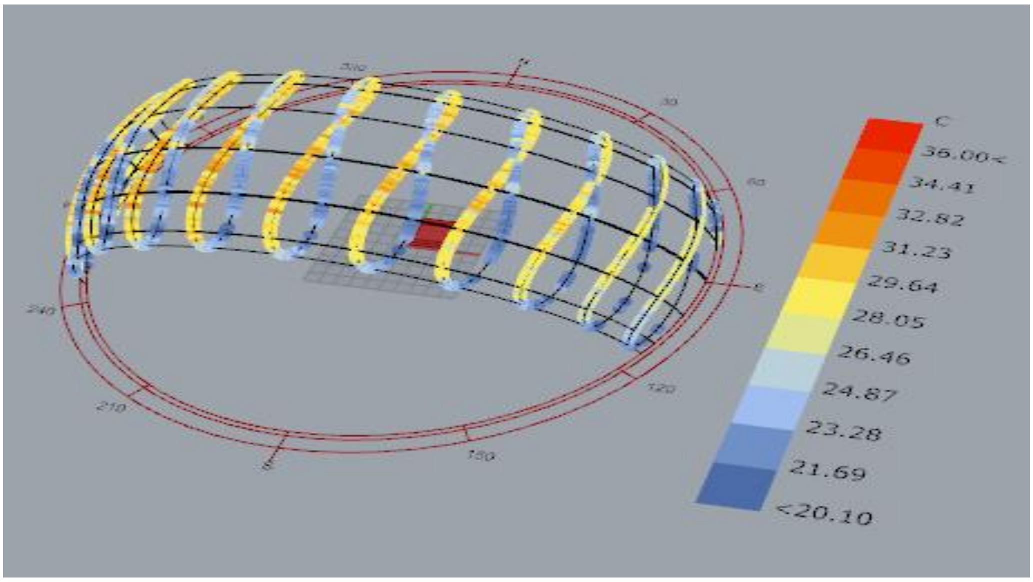

Figure 9: Showing the Sun Path in relation to Temperature as well as Relative Humidity respectively

Figure 9 above illustrates the sun's path, it shows the position of the sun as it rose and moved along the meridian at different times of the year its relationship to the building, how it affects the building in terms of solar radiation, and from there, we can evaluate the suitable shading elements and its best position on the façade.

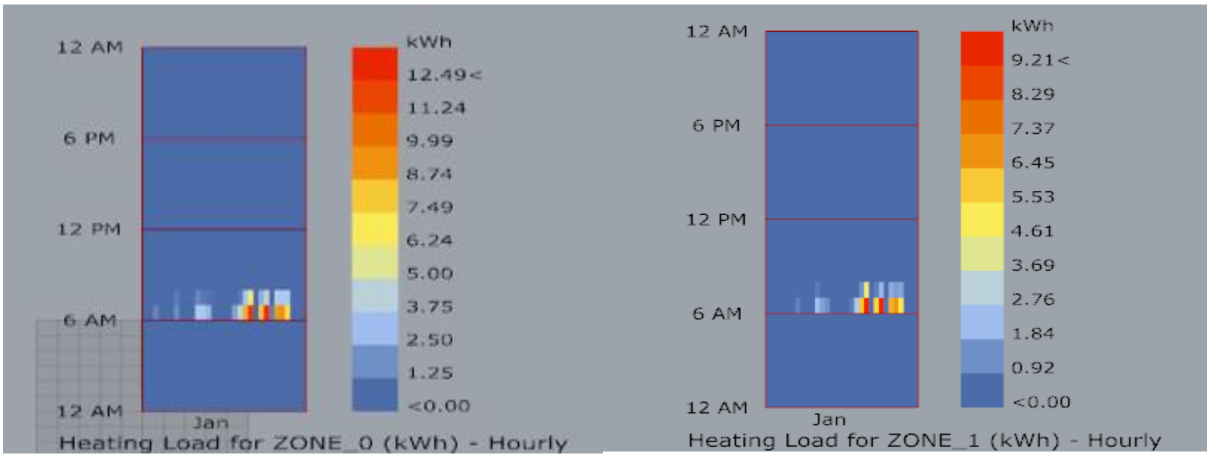

Figure 10: Showing the Heating Loads for Zone_0 and Zone_1 respectively

Figure 10 above illustrates the energy required for the heating of the interior of the building under study in January to maintain the indoor temperature in an acceptable range. And from the figure, it is observed that the heating load is manageable since it is relatively low. The heating is just required from around 6:00 up to 10:00 in the morning in the month of January.

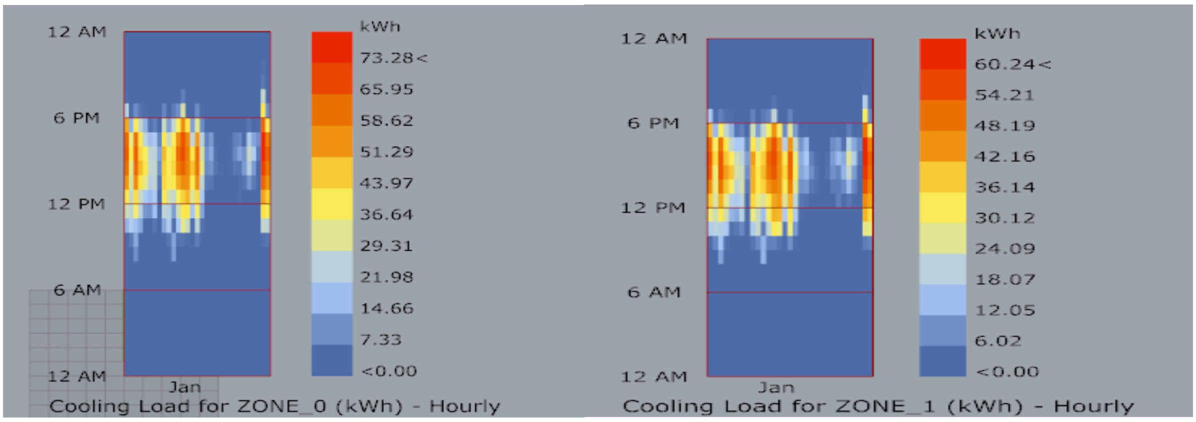

Figure 11: Showing the Cooling Loads for Zone_0 and Zone_1 respectively

Figure 11 above illustrates the energy required for cooling the interior of the building under study in January to maintain the indoor temperature in an acceptable range as well as thermal comfort. From the figure it is observed that a cooling load is required the 12:00 pm to 4:00 pm daily especially in April, through June.

CONCLUSION

The current research initially introduced the aim to predict the energy consumption of an office building in Kebbi, Nigeria. These goals were achieved by investigating the energy consumption of the building by consideration of different sets of parameters. These variables were established as the main responsive aspect for the energy use intensity. Adopting the parametric model, several simulations were conducted computationally. In these tests, we calculated different solutions with altered values of independent variables under study. The computer parametric approach performed most of the process in an automated fashion. The investigation of the energy performance for the office building remains constant between 8 to 18 hours of the five working days (Mondays to Fridays).

Attentive to energy use in buildings necessitates substantial amounts of data opinions. These data are needed to evaluate the possible effects of energy efficiency and improvements. Much less detailed information is available on energy consumption in office buildings, which includes different types of working hours and variants of activity within buildings. Buildings want energy space for heating, water heating, lighting, refrigeration, ventilation, and auxiliary facilities. These are used collectively with restrained utilization and office equipment, interpretation for about half of the total request for energy, and a comparable ratio of all energy-related CO2 releases. Enhancements to the effectiveness with which energy is used in buildings could offer substantial chances for reducing emissions.

It can be seen clearly that the change in value by certain degrees and alteration of some parameters has a change in the effect of energy as well as the illuminance values. Within the research scope, we examined around 22 different options having different glazing types and cavity depths. However, further research can easily apply the method to several other options, especially by incorporating the air cavity with some suitable shading elements. In this way, the energy performance of the building can effectively be achieved. It is very vital to study further but deeply about the most suitable shading devices that can efficiently be incorporated in the double skin facade air cavity especially those that can be movable or changeable according to the prevailing weather. Finally, Double Skin Façade has an added advantage compared to Electrochromic, Thermochromic, and Photochromic panes. These include: thermal insulation during summer, Night time ventilation, minimizing wind pressure effect, low thermal transmission (U-value) and solar heat gain (G-value). Consequently; reducing the construction and maintenance cost.

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