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Effects of Climate on Building Elements: A Case Study of Federal University, Kebbi, Kebbi State

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Abstract

Elements of climate have posed a challenge to the design and construction of buildings that could provide comfort for the occupants. Buildings now have to moderate the outdoor climate and provide comfortable conditions for its occupants without excess use of energy. In order to achieve this, buildings should be designed in a way that they are responsive to the climatic conditions of its environment. This paper seeks to investigate the effectiveness of faculty buildings in Federal University Birnin Kebbi, Nigeria, with respect to the climate. Ecotect simulation software is used to simulate building performance of three (3) faculty buildings that were selected by random. These were modelled and further analysed using the existing climatic data of the study area. Building simulations were carried out from February to June, during the solar radiation peak period, and a temperature of 45°C that was recorded April 10th, 2021. Results from the study showed that on the East-West axis of the buildings a performance was observed that was not as great when compared to the North-South axis, which experienced a much better performance. The research therefore concludes that these faculty buildings did not take into account the micro climate and were generally not climate responsive in their design.

Keywords: Climate, building form, building orientation, building materials, simulation

INTRODUCTION

One of the major challenges facing designers now is the problem of climate change fuelled by greenhouse gas emissions [1, 2]. This climate change which brings about global warming occurs when fossil fuels are burned. This then causes concentrated heat which traps greenhouse gases that are in large amounts and released greatly into the atmosphere. This is a serious environmental effect, and it is as a result of the adoption of a uniform style of architecture irrespective of the climatic conditions thus consuming high energy in buildings. [3] asserted how adoption of international styles of architecture in the 20th century eradicated traditional concepts to the local climate making it difficult to achieve comfort without the use of mechanical systems. This has adverse effects on the environmental [4]. Architects using these concepts of design are endangering the eco-system contributing to the effect of climate change [5], as such buildings should adapt to both its macro and micro climate [6]. [7, 8] state that before necessary design decisions are made, it is important to understand and control the effects of climate where the building is located. Furthermore, there is a

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growing trend towards achieving low energy building designs with the aid of simulation [9]. This paper seeks to investigate the effectiveness of faculty buildings in Federal University Birnin Kebbi, Nigeria, in respect to the climate. It focuses on temperature and building orientation, and further makes an analysis of the building elements responsible for the heat temperature consumptions in the buildings.

LITERATURE REVIEW

Climate and the Built Environment

Building climatology helps in achieving an efficient and effective building climate together with a design that is structurally sound and energy-saving. The main aim here is to prevent users of a building from being adversely affected by external climatic factors by providing adequate passive building construction measures. The use of natural resources, such as natural light, natural ventilation, solar heating and geothermal heat also plays an important role in buildings that are responsive to their climate [10]. In clearly applying climate-responsive principles to buildings, it is necessary to understand the basics elements of climate. In any building construction, there are different climatic factors that should be considered in order to achieve a climate responsive building. According to [11], humidity, rainfall, sunlight, temperature (weather), temperature (soil), and wind are considered the most important.

Temperature (as it pertains to weather), is probably considered the most important of climatic factors affecting building construction. This factor in turn determines choice of material, dimensions/size, building form and building orientation. Furthermore, the quantity and quality for constructing a building differs from one geographical location to another, depending on the weather [12]. In any locale, the amount of sunshine received is determined by latitude, the amount of cloud, and sunshine hours. When the degree of the latitude is less, it brings about a lessened angle of stretch of sunshine, and where sunshine received is high, then temperature is also said to be high [11].

Studies by [12] and [8] explain that radiation from the sun determines the amount of heat gain or loss on the earth surface; the relationship between the sun and the site has to be taken into consideration right from the design process in order to design efficient buildings. Generally, the amount of solar access radiation on a building mostly depends on the position of the sun in relation to the building. The sun is dynamic and mostly moves in the direction of east to west (sunrise and sunset); the lower the angle of the sun in relation to the building the lesser the heat radiation. Therefore, proper orientation of the building to the sun can control the overall heat gain or loss on the building elements (walls, roof and openings). Consequently, the decision on the choice of material type, shape and composition are determined by the effect of climate on the building site. The thermal property of the said material is dependent on how much heat is transferred through it; this will determine its effectiveness. The higher the insulation and mass of the material the more the storage of heat through the material and the less the heats transfer. So, the ability of the material to store heat during the day and effectively dissipate it at night is determined by its thermal performance.

Climate Responsiveness in Buildings

For a building to respond to climate, it means that the building reduces adverse effect or impact of the environment on its elements [13]. What this means is that this concept aims to achieve comfort of its users through the efficient use of elements of its micro-climate Climate responsive design utilizes climatic elements in formulating design strategies such that buildings are able to create a suitable atmosphere for human comfort. The architect is therefore able to control choice of form, layout, openings, space and materials. Building elements (floor, roof, wall) are thereby able to store and transport air, light, heat and moisture [14] maintaining a comfortable environment. [15] therefore postulates that for indoor environment quality to improve, building designs should incorporate climate responsive principles. This will in turn improve occupant wellbeing in the building.

Zoning of Floor Plan and Orientation of Building

In the design of buildings in relation to its site/environment, it is advised that the building orientation should be that the shorter axis of the building be along the north-south direction; this is so that solar heat gained by the building envelope is reduced to its barest minimum. Another factor to consider is zoning of the floor plan in relation to its functions. The manner in which rooms are spatially organized depends on the activities carried out therein. As suggested by [15], it might become difficult to achieve efficient building orientation on certain sites where the longer sides are the opposite and as such where the sun sets on the west becomes the hottest. Therefore, zoning should be such that the spaces provided on this side of the building are usually being used frequently in the morning and afternoon and activities that are majorly carried out in the evenings, should be along the east axis of the building.

Shading and Building Materials

One factor that contributes to heat gain in the interiors of buildings is increase in surface temperature of the building envelope through windows, doors, and opaque walling fabrics [16]. Studies by [15] suggest that the provision of sun shading devices on building exteriors will significantly reduce heat gain. These sun shading devices can either be in the form of vegetation or neighbouring structures. However, the most effective are considered to be external shading devices, which significantly bring about a reduction in the amount of solar radiation that passes through the building and into its interior. [16] further suggests that through a properly oriented high-pitched roof, it affords a rather simple but effective self-shading technique.

In modern building construction there are materials that restrict air flow within the building, which in turn necessitates the use of mechanical ventilation. In Nigeria, cement blocks constitute the major material in building construction envelope. Studies however show that cement blocks tend to absorb and retain a lot of heat during the day and at night, dissipates this stored heat. This creates an environment that is not thermally conducive. Consequently, in recent times, traditional materials have come to light and its usage become more acceptable and a common practice. These traditional building materials are considered to be efficient in attaining a sustainable design in achieving a great indoor climate [17, 18]. In Nigeria however, there is a claim that previously, traditional buildings especially in the North-East have been influenced by environmental elements such as climate, construction materials and the culture of the people [19]. According to [20] choosing to build with contemporary over natural construction materials results in the ignorance of the advantages natural materials have.

Vegetation

Landscaping according to [21] is an element of architecture that is underutilised in the Nigerian construction industry despite its affordability and effectiveness in improving comfort and energy efficiency all through the year. Research has revealed that when walls are shaded with certain types and layout of plants, an average temperature of 5°C to 15°C less can be achieved than with walls that have no form of shading form vegetation. Furthermore, roof gardens can also be said to contribute immensely to a conducive climate as these can attain temperatures that can go 10°C to 30°C below that of roofs without vegetation. This is however dependent on the type of roof construction. Nigeria is a country with an abundance of vegetation that should be harnessed in order to achieve a passive design both vertically and horizontally as in patios, pergolas, screens, atriums, flower pots, etc. The use of vegetation can therefore be used to create cooling microclimates [16]. Other methods where passive cooling can be achieved, is through the use of enclosed courtyards, wind catchers and stack ventilation.

Building Simulation

When it comes to developing buildings that are climate responsive, an important tool to be considered is building simulation. With building simulation, it is a design tool used to make

predictions on how elements of climate interact with and influence the buildings. This prediction is then used in order to create solutions that are essential to the wellbeing of its users in creating an optimal environment. The use of building simulation has become necessary in that it allows potential solutions to be evaluated, which can then be compared and analysed for their cost effectiveness in terms of its design. In addition to the effectiveness of building simulation, it goes further in investigating solutions that are innovative and the application of energy sources that are regenerative. This is in terms of building functionality and cost effectiveness that may be affected by general conditions or constraints [10].

THE STUDY AREA

Federal University Birnin Kebbi (Figure 1) is located in Birnin Kebbi, capital of Kebbi State. The school was established on 23th February 2013 with the aim to increase access to education for the people of this region. The region falls under the hot and dry climatic conditions of the north-western Nigeria. The State is characterised with high temperature that can rise up to 45°C, with low precipitation, low humidity and intense sunlight in most of the periods. Three (3) faculty buildings have been constructed on the permanent site of the university, most of which are facing the same direction (East-west) where the sun rises and sets. Designing for this kind of climate requires careful examination of the dynamic movement of the sun in relation to the buildings on site. As high sun intensity can affect the performance of the buildings on site which results to heat discomfort to the occupants of these buildings.

METHODOLOGY

The methodologies used for this research are the case study method and software simulation of the buildings [9]; this is to examine the manifested design intentions of the architect and actual performance of the buildings when compared with the extreme climate. Three buildings were selected randomly: faculty lecture hall, school of environmental and school of art and science. The buildings were modelled with Revit in their existing forms, materials and orientations, and then imported to Ecotect software using Sokoto climatic modules gotten from the Nigerian meteorological agency. This simulation subjected the buildings to peak period of solar radiation so as to identify the elements of the buildings that are exposed to the climate and further simulated on hottest recorded temperature of the day (45°C; April 10th, 2011) to examine the moderation level of the buildings when compared to the microclimate.

BUILDING CLIMATOLOGY AND FACULTY BUILDINGS

School of Environmental

This is a faculty building located on the temporary site of the Federal University Birnin Kebbi having coordinates 12°19′53″N, and 4°09′16″E, housing three departments of the environmental studies namely Architecture, Building and Quantity Survey. The structure comprises of partitioned offices as separate wing departments with studio rooms separated from the offices forming a ring like structure. The offices are located along the north eastern direction and studio rooms at the south west direction as shown in Figure 2. Table 1 shows the features of the building elements that were applied in Revit architecture in modelling the structure.

Effect of Orientation on Building Elements

The building was simulated based on the peak solar access radiation. The sun path direction was maintained East-West facing the structure as the orientation of the building could determine the elements of the building that are exposed to solar radiation. The colour bar located on the top right corner of Figure 3 shows the amount of heat gain from yellow to deep blue. The roof which is the component of the buildings mostly exposed to solar radiation has yellow colour, followed by the windows and walls facing the sun direction with different shades of brown colour while the shaded walls areas have the least effect of sun radiation from the colour brown to blue.

Figure 1. Google earth of the study area 18/09/2021 (Google earth.com, 2021)

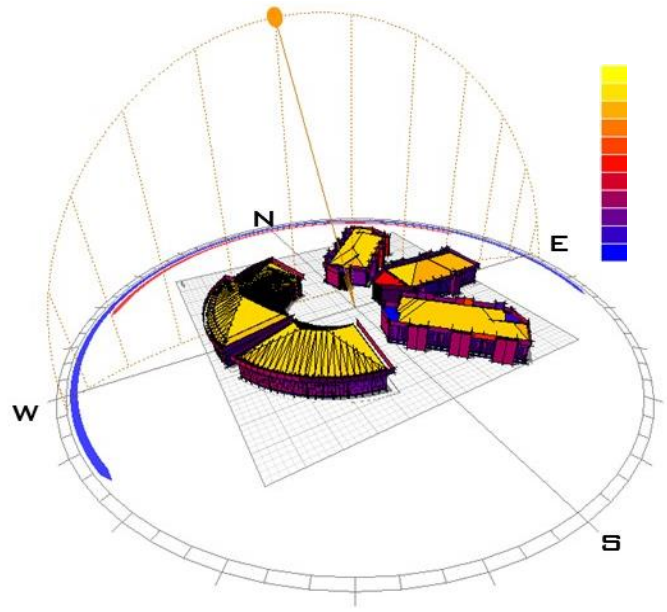

Figure 2. Revit model of school of environmental (Author, 2021)

Table 1. Physical properties of simulated building materials.

Building elements	Type	Thickness	Colour	Texture
Wall	Hollow Sandcrete block	230 mm (Density 2002.21 kg/m^3)	Light	Rough
Window	Single glazed	8 mm	Reflective blue	Reflective
Ceiling	P.V.C. panels	5 mm	Light	Smooth
Roof	Long span Aluminium	0.55 mm	Light	Smooth

(Author, 2021)

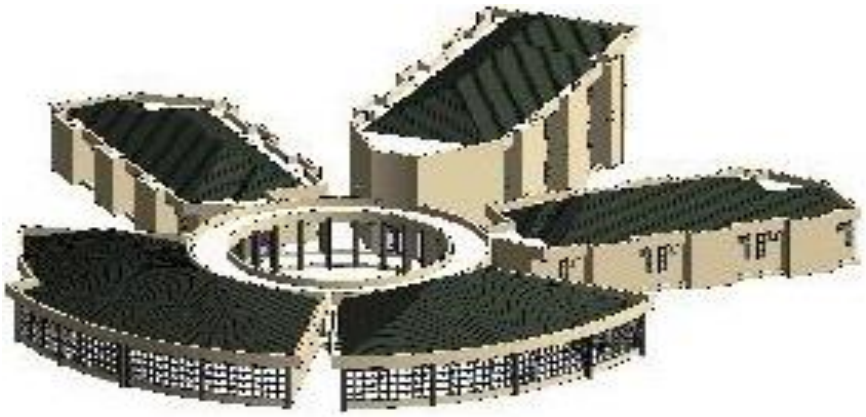

Figure 3. Showing a rendered image of the simulation model (Author, 2021)

Effect of Temperature on Building Elements

Table 2 shows the differential moderation temperature level of the building indoor spaces and the general outdoor temperature of 45°C. On the ground floor, the north Eastern rooms alongside the east room and east south rooms have the highest differential temperature as shown in Figure 4. However, the west south and west north rooms have the joint lowest moderation.

Table 2. Showing deferential temperature at average temperature of 45°C.

	North East Rooms	East Rooms	East South Rooms	West South Rooms	West North rooms
Ground Floor	3	3	3	1	1

(Author, 2021)

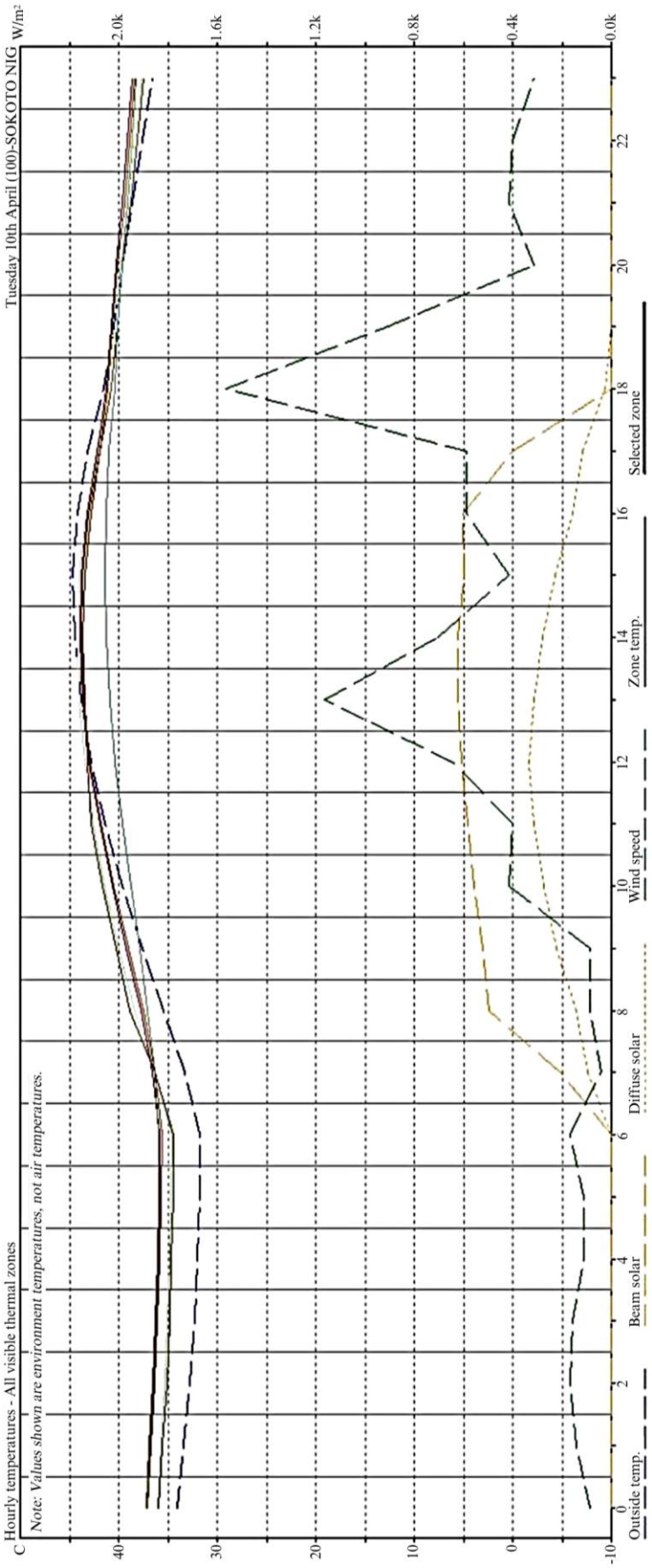

Figure 4. Simulated indoor temperatures for the hottest day (10th April) (Author, 2021)

Faculty of Art and Social Science

The Faculty of Art and Social Science building of Federal University Birnin Kebbi is located on coordinates 12°19′53″ N, 4°09′16″ E, it houses staff offices for school of art and social science. Table 3 shows features of the building that were applied in Revit architecture in modelling the structure.

The building is cross-like shaped with the head form which is the main entrance is oriented to face the east direction and the tail end facing the west direction. As shown in Figure 5, the use of vertical and horizontal sun shading devices were not employed in the building's exterior walls except for the roof eaves overhang.

Effect of Orientation on Building Elements

Building was modelled to mimic existing as-built orientation with regards to the sun and its component materials from the roof, wall and windows. Results from the simulations showed that the roof has the highest exposure to radiation from the sun as indicated on the high to low meter bar in Figure 6, this represents the radiation level of the roof in yellow. The windows and walls with the colour red are directly facing the sun direction while elements that are shaded away from the sun having colour meter brown to blue.

Effect of Temperature on Building Elements

From the chart in Figure 7, there is an appreciable variation in temperature moderation along the North, East West and Southern ends of the building at 45°C outdoor temperature. On the ground floor, the south room has the highest moderation followed by the north and west rooms on the first floor. Subsequently the east rooms on the ground floor and first floor are with the least moderation. Table 4, shows the deferential temperature of both floor levels at an average temperature of 45°C.

Faculty Lecture Hall

The faculty lecture hall is located in the school of Federal University Birnin Kebbi (12°19′49″N, 4°09′02″E). The building houses classrooms, offices and conveniences for the faculty building of art and social sciences. Table 5 shows features of the building that were applied in Revit architecture in modelling the structure.

The building form comprises of a combination of rectangular and square shape with open courtyard forming the central area as depicted in Figure 8. It is oriented with the shorter side facing east-west and longer side facing north-south.

Simulation Result: Effect of Orientation on Building Elements

From Figure 9, the building was simulated based on peak period of solar radiation in which the sun path direction along the East-west axis facing the structure. As consistent with the other two buildings simulated the roof with colour yellow is the most exposed component, followed by the windows and walls in the sun direction with colour yellow to red while the shaded walls are least exposed with the colour ranging from brown to blue.

Effect of Temperature on Building Elements

Figure 10 shows the differential moderation temperature level of the building functions. At outdoor temperature 45°C, the north and south rooms on the ground and first floor have the highest temperature moderation in the building while the east and west rooms have a lower moderation compared to the others. There is also a slight difference in the result between the ground and first floor as shown in Table 6.

Table 3. Physical properties of simulated building materials.

Building elements	Type	Thickness	Colour	Texture
Wall	Hollow sandcrete block	230 mm (Density 2002.21 kg/m^3)	Light	Rough
Window	Single glazed	8 mm	Reflective blue	Reflective
Ceiling	Hardboard ceiling	3 mm	Light	Smooth
Roof	Long span aluminium	0.55 mm	Light	Smooth

(Author, 2021)

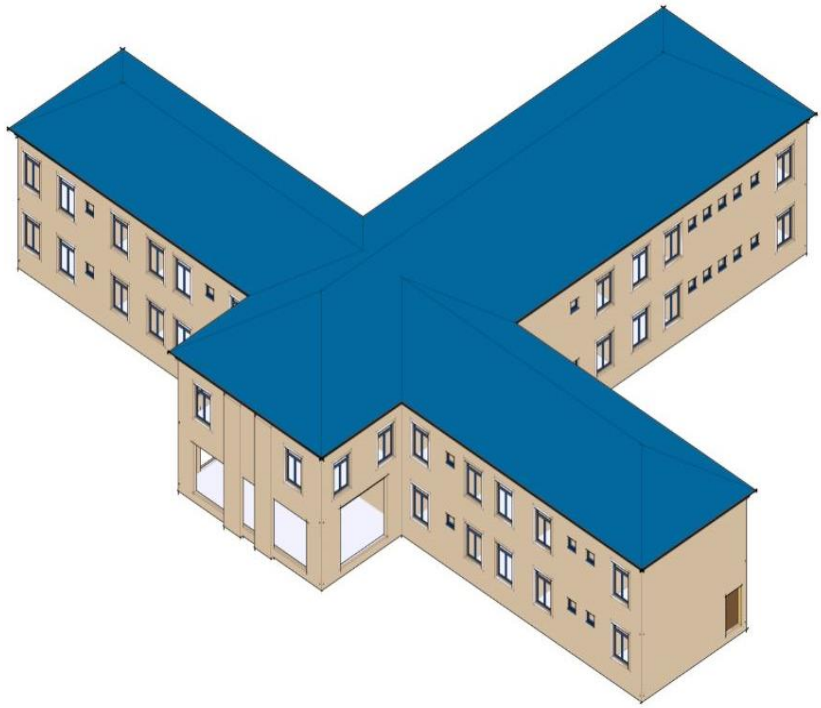

Figure 5. Revit model of school of art and social science (Author, 2021)

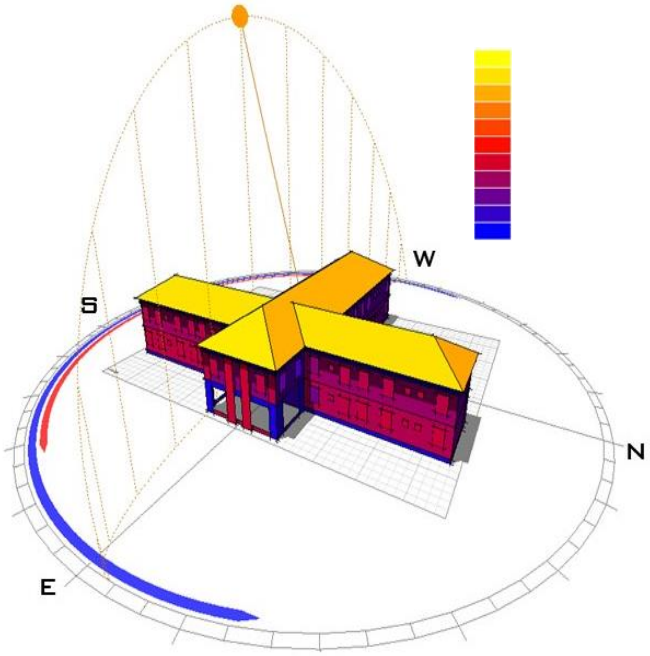

Figure 6. Rendering of the simulation model (Author, 2021)

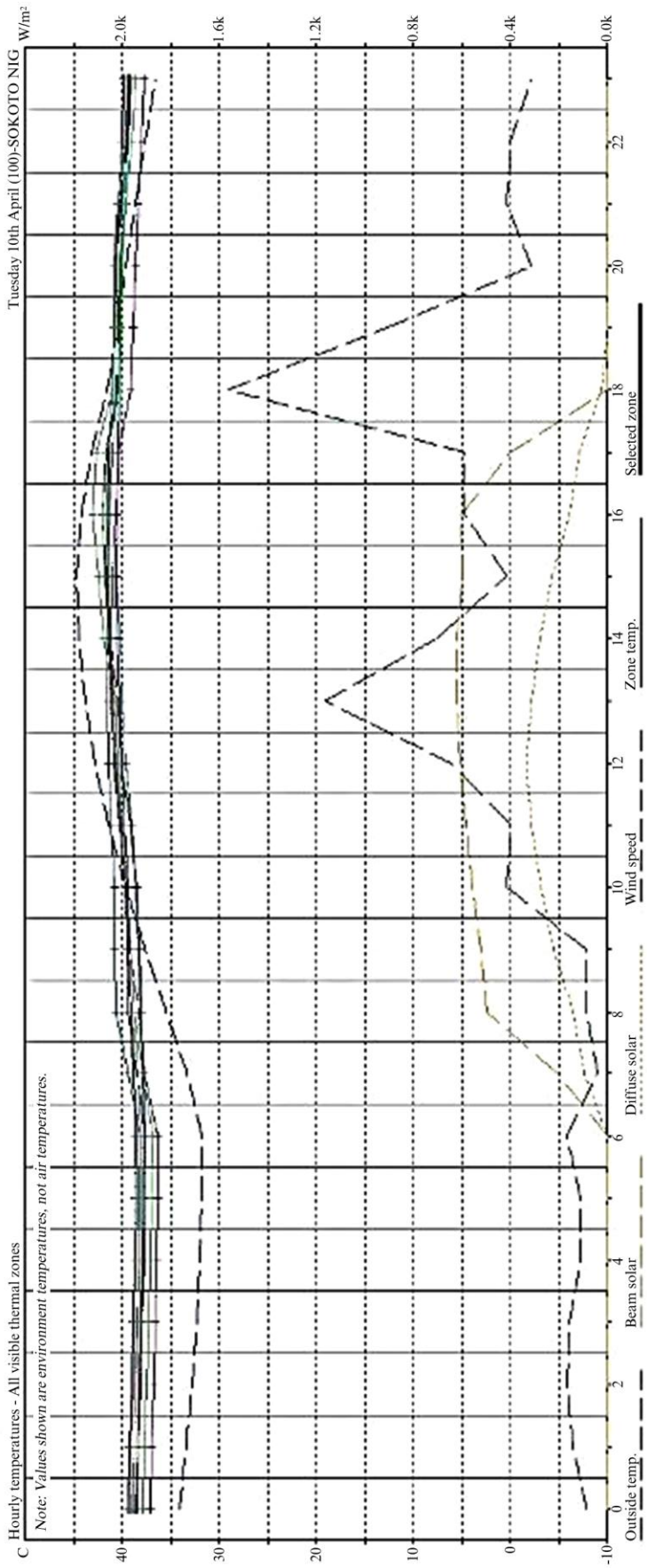

Figure 7. Simulated indoor temperatures for the hottest day (10th April) (Author, 2021)

Table 4. Showing Deferential Temperature at Average Temperature of 45°C.

	North Rooms	South Rooms	East Rooms	West Rooms
Ground Floor	3	4.5	2	3
First Floor	3.5	4	2.5	3.5

(Author, 2021)

Table 5. Physical properties of simulated building materials.

Building elements	Type	Thickness	Colour	Texture
Wall	Hollow sandcrete block	230 mm (Density 2002.21 kg/m^3)	Light	Rough
Window	Single glazed	8 mm	Reflective blue	Reflective
Ceiling	Hardboard ceiling	3 mm	Light	Smooth
Roof	Long span aluminium	0.55 mm	Light	Smooth

(Author, 2021)

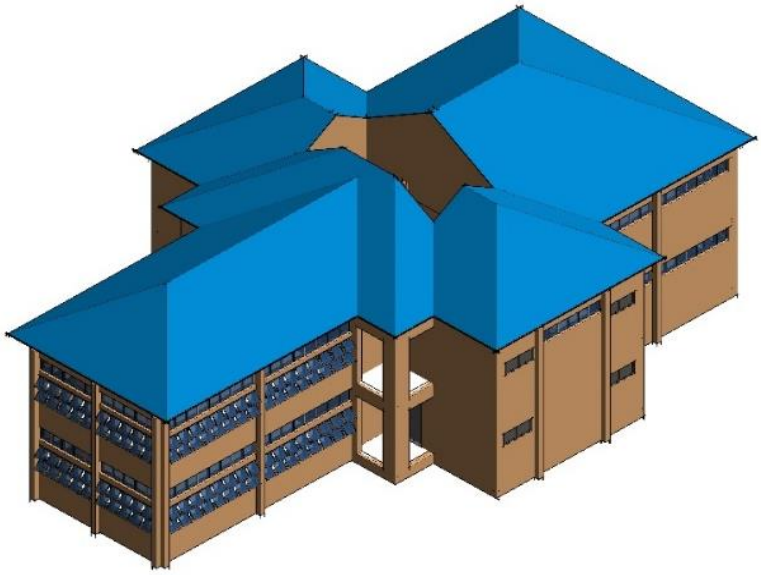

Figure 8. Revit model of faculty lecture hall (Author, 2021)

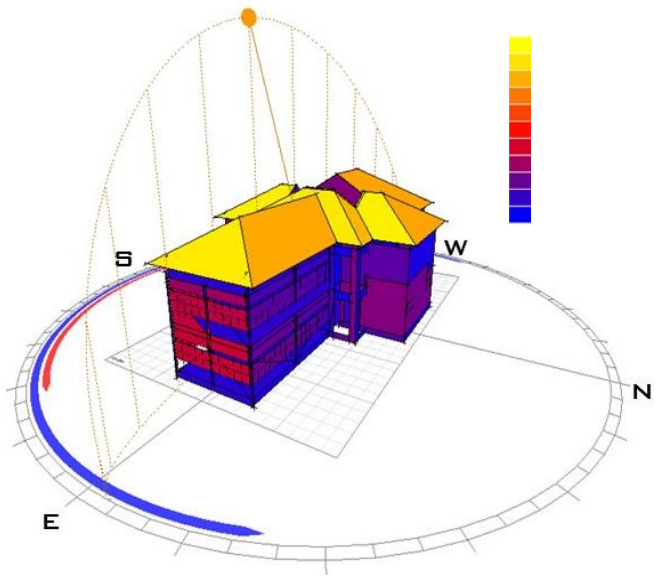

Figure 9. Rendering of the simulation model (Author, 2021)

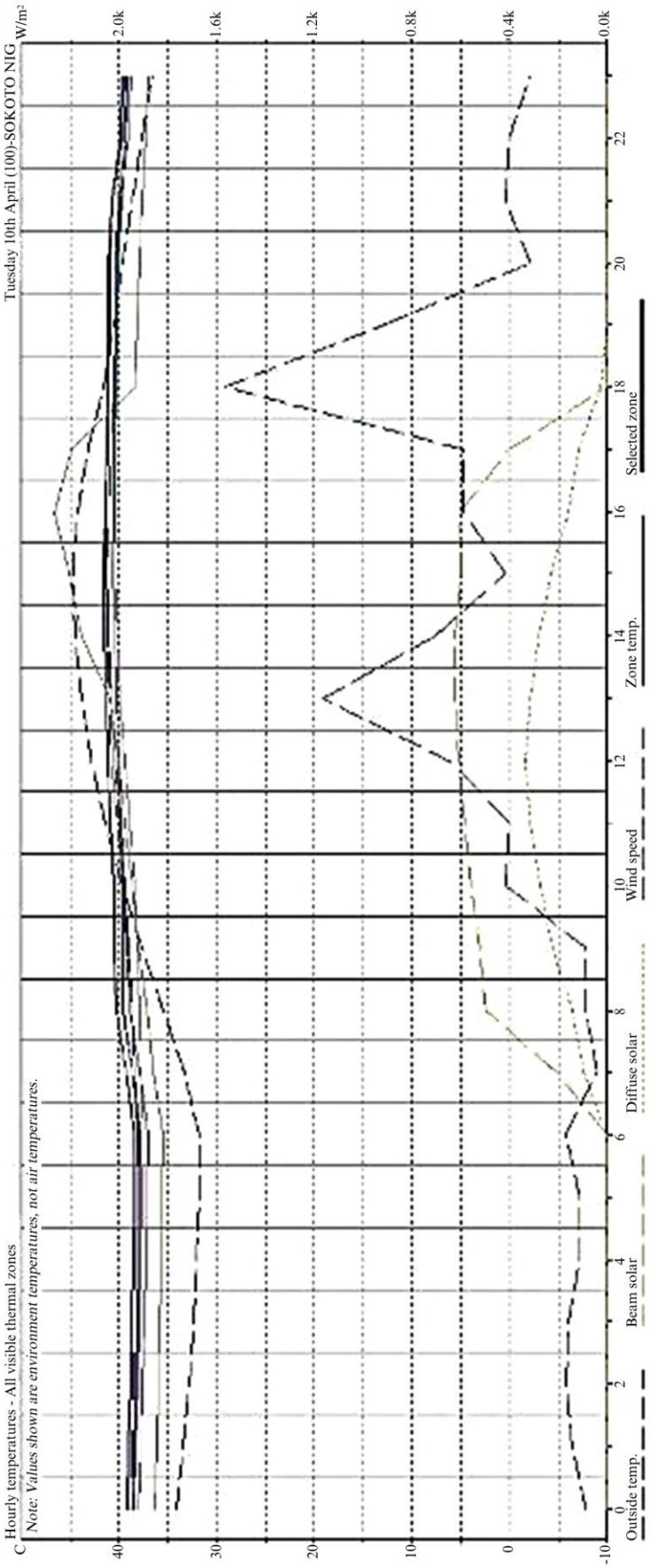

Figure 10. Simulated indoor temperatures for the hottest day (10th April) (Author, 2021)

Table 6. Shows the differential Temperature of the building functions at average temperature of 45°C.

	North Rooms	South Rooms	East Rooms	West Rooms
Ground Floor	6	5	3	1
First Floor	6	5	4	1

(Author, 2021)

FINDINGS AND DISCUSSION

The findings from the study reveals that the designers of the building did not put orientation with regards to the direction of the sun into consideration during the design of the buildings as shown with building orientation in Figures 3, 6 and 9. From this perspective the buildings proved to be climatically ineffective as the major functions of the building are facing the east-west direction. Furthermore, a larger number of the windows in Figures 3, 6 and 9 are located along the east-west axis of the sunrise and sunset causing the slight moderation in temperature of these spaces as revealed in Tables 2, 4 and 6. The exposure of the roof to solar radiation is responsible for difference in temperature between the ground floor and the first floor as shown in Table 4. Besides orientation, the application of sun shading devices in Figure 3 was among the reason behind the appreciable moderation temperature of the building's wing; north east, east and east south wing axis as shown in Table 2. The functions of the building on those axes are entirely masked from sun penetration when compared to west south and west north rooms. Furthermore, courtyard and veranda application have significant impact on the north and south rooms of the building in Figure 9, as remarkable temperature moderation is achieved in Table 6.

CONCLUSION AND RECOMMENDATION

Challenges faced by architects are numerous and cannot disregard the environmental effects of buildings. In order to achieve buildings that are more sustainable, adopting the concept of climate responsive design is paramount. Findings revealed that it can therefore be concluded that the application of building elements that respond to its micro-climate were not efficiently and effectively applied. Faculty buildings of the study area were not designed to suit the climate as shown with the lack of proper building orientation. It can be said that the designers did not fully take into consideration the extreme micro climate of the site as the major functions face the East-West direction and functions with lesser importance face the North-South direction. Consequently, the buildings did not harness the solar radiation directions. More so, the lack of sun shading devices in two of the three faculties simulated proved to be a major factor in the heat gain within these buildings. There is therefore, the need to adopt climate responsive building functions such as courtyards, verandas and sun shading devices during conceptual design and integrated in construction stage in order to suit the climate of the region. In developing buildings that are responsive to climate, adjusting the form and orientation of the subsequent buildings yet to be constructed on the existing master plan would have a positive impact on the existing performance moderation level of the buildings within the microclimate. Preferably, the enclosure of the major functions of the buildings should be taken completely away from sun direction; openings of the buildings also should be positioned in a place where sun is not penetrating. Trees can as well be planted around exposed building elements as they serve as a shield to cool down effect of the climate, providing buildings that positively respond to climate.

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