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Achieving Energy Efficient Building through Energy Performance Analysis of Building Envelope in Student Housing

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Abstract-

Protecting the built environment through reasonable incorporation of sustainable principles into the design of buildings is a vital role of architects and other built environment professionals. By so doing, the increase observed in energy demand of buildings constitutes a major challenge to the protection of and reduction of greenhouse gases produced by buildings. This constitutes a critical element in the movement towards a more sustainable future. This study examines the indispensable relevance of carrying-out energy performance analysis on a building design blueprints prior to construction. The study employs the use of Autodesk Revit 2014 as a Building Information Modeling (BIM) tool and Autodesk Green Building Studio (GBS) for energy performance analysis of an existing student housing at Federal University of Technology Akure, Ondo state, Nigeria in order to recommend energy efficient strategies that could be implemented at the design phase of the student housing. The energy-saving effects of the different building envelope were investigated and results were analyzed. The annual energy use revealed approximately 60 percent of electricity consumed from the national grid with the left-over 40 percent expelled on fuel. This result was, however, based on an assumption of a 20 hours minimum daily power supply from the national grid. The monthly heating load chart shows that heat is lost from the walls of the building. The walling material has a considerable impact on energy consumption. The simulation results of the existing student housing were compared with eight alternative designs that alter the building envelope and incorporate shading devices to reduce the carbon footprint and energy use. The best alternative design runs reduced the energy consumed yearly from 402,168 kWh/year to 385,318 kWh/year.

Key words: Building Envelope, BIM, Energy consumption, Energy Efficiency, Sustainability

1. Introduction

The concept of sustainability in building design stage is geared towards minimizing the adverse effect buildings has on the environment. This encompasses building energy efficiency, moderate use of available materials and space development [1, 2]. In the quest to safeguard the environment, the building sector has been a major target as it accounts for about 40% of global energy consumption and 33% CO₂ emissions basically through the use of fossil fuel during their operational phase [3]. Energy demand in buildings, however, is constantly increasing over years due to upsurge demand for comfort attributed to technological advancement, population



growth and time spent inside buildings [4]. In recent years in Nigeria, for instance, buildings were constructed having negligible consideration for energy efficiency due mainly to lack of awareness and poorly conceived policies by the government and other regulators [5]. This accounts for the tremendous increase in energy consumption in the various sector over the years. However, 'the residential sector accounts for about 65% of the energy use in Nigeria' [6]. Energy demand savings is one of the sustainable energy development strategies which can be improved through the integration of locally-sourced materials for construction of buildings. In achieving this, it is important that the architect be able to assess the impacts the materials specified for building envelope will have on energy use.

In view of this, the designers' ability to predict design consequences and operation decisions is a pathway to achieving sustainable buildings. Hauge, Thomsen [7] revealed that 'the use of Building Information Modelling (BIM) tools provides necessary and substantiated information regarding the energy in-use of building, thermal comfort, visual comfort, acoustic comfort, and the life cycle assessment of the building'. The aspect of energy performance simulation also investigates the consequences of design specifications and provide quantifiable predictions to help out in identifying strategies to improve building energy efficiency and the overall building performance [8]. BIM models are often linked to an energy analysis tool to obtain a more accurate and comprehensive result in order to achieve energy efficient buildings [9].

Studies explicitly devoted to BIM for building energy simulation are available in the literature and the reliability of using BIM to predict energy consumption has been proved by various studies. A simulation study conducted by Stec, Van Paassen [10] on the thermal performance of double skin façade covered with plants revealed that plants improve the indoor environmental climate and save energy used in the building. Abanda and Byers [11] conducted a simulation to emphasize 'the impact of building orientation on energy use within a building'. Also, Hu, Zhang [12] simulated the energy consumption of an office building and compared the results with the actual monthly power consumption.

However, much study has not been done on the impact the building envelope has on energy consumption using BIM. This study partly tries to close this gap. This study provides detailed energy performance of different building envelope and its components (wall, roof and shading device) available in Nigeria to emphasis the relevance of carrying out building energy analysis at the design phase. This research also seeks to exhibit the benefits of using BIM to achieve energy-efficient buildings. This provides better and more comprehensive choices for concerned stakeholders.

2. Energy Demand

2.1 Building Energy Consumption and Demand

The energy use in developing nations such as countries in the Sub-Sahara Africa is growing tremendously at about 3.2% annually which is higher than the annual population growth [4]. Therefore, the concept of energy efficiency in buildings encompass measures to improve the ability of buildings to absorb and retain heat during different seasons and use of appliances for lighting, heating, ventilation, and air conditioning. A large amount of energy is consumed 'to

make the indoor environment conducive and habitable' [13]. The assessment of energy consumption in various sectors of the economy is based on the various fuels used. Building energy consumption is influenced by several factors such as climatic conditions, building structure, building envelope, operations of 'lighting and HVAC systems, occupancy and their behaviour' [4, 14]. Steemers and Yun [15] grouped these factors into direct and indirect factors. Nwofe [5] revealed that 'the climatic and physical housing variables, occupant choices and behaviour' were grouped as direct factors while indirect factors relate to household disposable income. However, these factors can be managed to improve building energy efficiency.

Several studies have shown the importance of these factors in building energy consumption and demand. According to Santin, Itard [16], the energy use in residential housing stock is significantly affected by the characteristics of the occupants and their behaviour. This was also corroborated by Abanda and Cabeza [17] using BIM. However, 'building characteristics still determine a large part of the energy use in dwellings' [7]. The energy performance of the building envelope and its components (external walls, roofs, windows etc.) are important in determining the energy use within the building [18, 19]. Insulation materials and the use of more energy efficient building elements can be used to lower energy consumption [20]. The building structure in terms of shape and size also have an impact on energy consumption. According to a study conducted by Catalina, Virgone [20], revealed that heat loss can be minimized through the use of compact shape. Building orientation has also been observed to influence energy consumption as it determines the heating and lighting systems [21, 22].

2.2 Energy Performance Analysis and BIM

BIM refers to a methodology for building design and documentation that enables users to create and manage information about building projects. BIM can be linked to energy analysis software such as Green Building Studio (GBS) and ECOTECT to enhance the energy performance of a building. According to Samuel and Joseph-Akwara [9], integrating BIM and energy analysis tool assists the project team to deliver a building that is energy efficient in the sense that the energy consumption profile and cost can be predicted and improvements can be made during the design phase [23]. Kurul, Abanda [2] stated that 'building performance analysis is typically performed after the architectural design and construction documents have been produced'. According to Tantisevi and Sornsuriya [24], BIM has multi-disciplinary data repository which enables the integration of energy performance into design production.

The use of BIM in the conceptual design phase helps the design team to make better decisions concerning the building plan, its massing and orientation [7]. Energy performance analysis is carried out on building designs to evaluate alternative designs, systems, subsystems, components, annual and life-cycle energy cost, and compliance with energy standard [25]. Simulation cloud-based analysis tools help to quickly compare energy consumption and life-cycle cost of design alternatives in order to achieve a more sustainable design. These tools are used to evaluate energy flows in buildings. Autodesk Building Performance Analysis (BPA) uses GBS database to run analyses on the whole building based on several assumptions such as building construction, schedules and equipment [22, 26]. BIM also assists in achieving efficient design through energy modelling, building orientation [11, 25] and building mass [1]. Building

massing deals with the analyses of the building form and optimizes its envelope ‘assessing the heat transfer through the building envelope in order to manage heating and cooling loads’ [27].

Several studies such as Garcia and Zhu [25], Pérez-Lombard, Ortiz [4] and Wong and Fan [21] explored the use of BIM to investigate the impact of the building envelope on energy consumption. The components of the building envelope have substantial effects on energy use during its operational phase. The size of windows has a significant influence on the winter thermal loads and summer cooling loads of buildings [15]. Also, improving the thermal performance of windows can reduce the energy use and greenhouse gas emission as revealed by Nikoofard, Ugursal [28] using energy simulation. The use of exterior shading devices also effectively reduce the energy use for air conditioning in a building [29]. Furthermore, the external building walls have a predominant influence on building energy consumption compared to other parameters [13].

3. Research Methodology

3.1 Case Selection

The study focused on assessment of energy efficiency level of student housing. Various studies employed case study approach to determine the energy performance of different building typologies: Ward, Schutzman [30] focused on student attitudes and behaviours, Cascone and Sciuto [31] examine abandoned student housing and Cauvain and Bouzarovski [32] studied multiple occupancy housing. This study, therefore, assessed student housing in the Federal University of Technology Akure (see Figure 1). The building was constructed in the year 2011 without any energy conservation and sustainability considerations during the design phase. The student housing is a single-story with a floor area of is 851m² while the external wall area is 2,911m² (see Figure 2-4). The building contains twenty-seven rooms on each floor, common room, porter’s lodge, laundry, kitchenette and lavatory. It is expected to accommodate 432 students. The building is constructed with cement sandcrete block, finished with cement rendering and painting. Roofed with long-span aluminium roofing sheet.

3.2 BIM Tool

The Autodesk Revit architecture, one of the commonly used BIM authoring tools was employed to prepare digital model an existing building with detailed background information. The model was linked to Autodesk Green Building Studio via green building Extensible Markup Language gbXML. The Green Building Studio is a web-based energy analysis service used for evaluating the environmental impacts of the building components during the design stage. The energy and thermal analysis, lighting and shading analysis, and cost analyses can be obtained using this software.

The simulation base run for the existing building was carried out using the Green Building Studio. In addition, the original design was replaced with different components for the building envelope to investigate their effects. Two elements of different u-values for each of the wall (W), roof (R) and shading (S) options i.e $\frac{1}{3}$ of the window height and $\frac{1}{4}$ of the window height (see Table 1) were used to form Alternative Design (AD) schemes for improving energy

consumption. These building elements were alternated resulting in eight alternative runs. The computed results from the alternative design options are compared with the energy consumption of the base run simulation results.

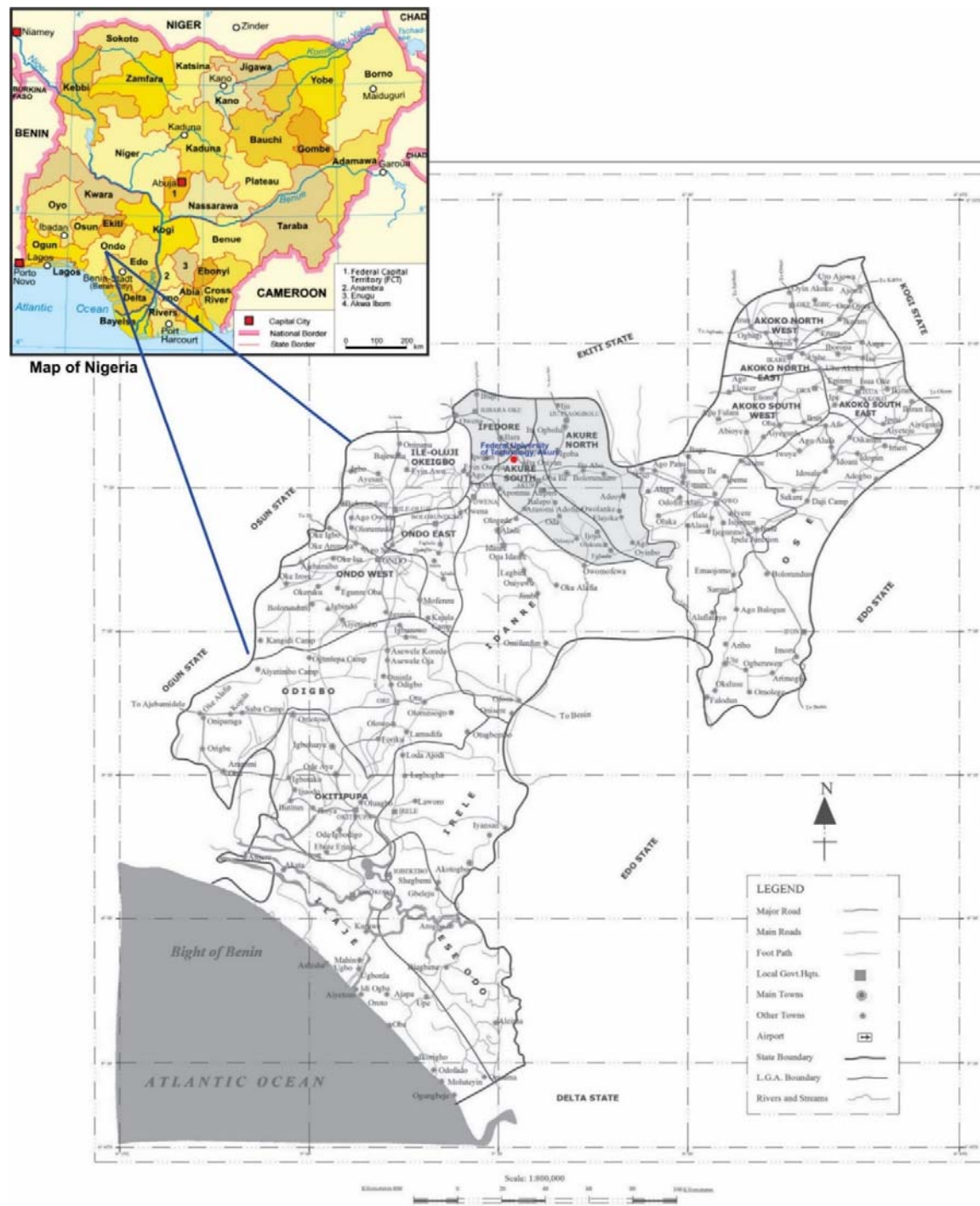


Figure 1: Map of Ondo state, Nigeria showing the location of Federal University of Technology, Akure adapted from Olamiji and Olujimi [33]

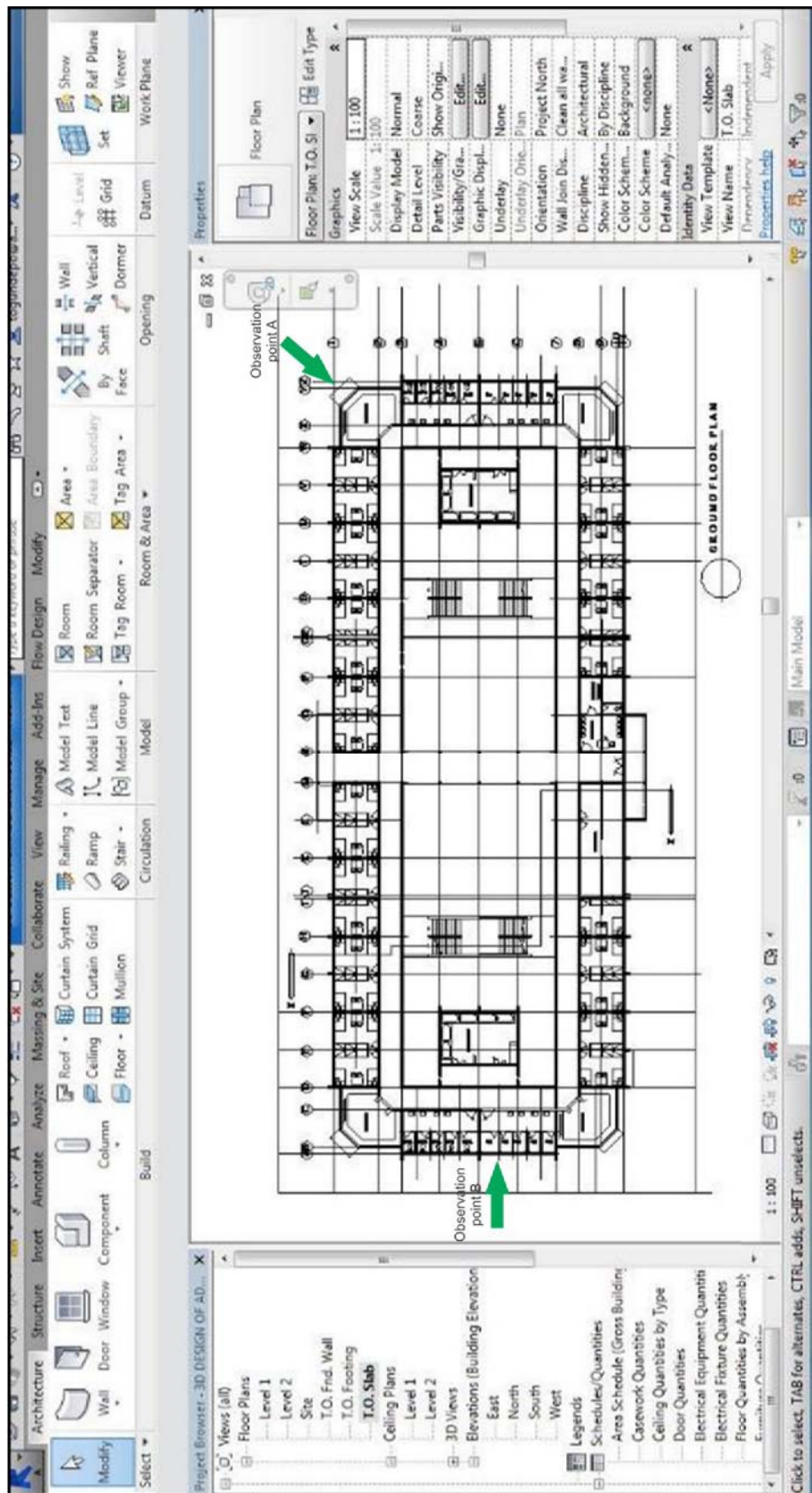


Figure 2: Typical floor plan of the Adeniyi hostel done with the aid of Autodesk Revit Architecture

Table 1: Showing Building Elements

Element	Material	u-value
Wall		
Option 1	Insulated concrete form wall (ICF) 10''thick example expanded polystyrene	0.20
Option 2	Concrete massive unit 8'' without insulation e.g brick	1.81
Roof		
Option 1	roof metal with high insulation	0.16
Option 2	Continuous roof Deck with high insulation (green roof)	0.17
Shades		
Option 1	$\frac{1}{4}$ of window height	
Option 2	$\frac{1}{3}$ of window height	



Figure 3: View from observation point A



Figure 4: View from observation point B

The simulation made use of some assumption where precise and accurate data could not be reached. The energy result was based on a minimum of 279 persons actively occupying the building, fully maximizing the lighting load, the plug load and the HVAC system. The plug loads (laptops, phone chargers, irons etc.), the lighting loads (energy saving bulbs), and the HVAC system (ceiling fan) were the basics considered for electrical energy consumption in the simulation process with consistent power supply in the hostel.

4. Results and Discussion

4.1 The Base run Simulation

The nearest weather station to the project site is spontaneously selected by the Green Building Studio to obtain relevant information that will be used during the simulation. The existing building base run revealed the annual energy use intensity (EUI) of 1,502MJ/sm/year base on electricity and fuel. The annual Energy consumption of 402,168kwh on electricity while 1,085,439MJ base on fuel (703,678.83kwh) with an annual peak demand of 82.9kw and annual energy cost of 45, 828USD. The life cycle electrical use gave 12,065,043KWh and 32,563,171MJ as the life cycle fuel use. This is based on a 30-year life cycle and 6.1% discount rate for cost as shown in Table 2.

Table 1: Data from base run simulation

Location	Akure , Nigeria
Weather station	1574528
Outdoor temperature	Max 35°CMin:13°C
Floor area	851m ²
External all area	2,911m ²
Average lighting power	11.19W/m ²
People	279 people
External window ratio	0.08
Electrical cost	\$0.09/kWh
Fuel cost	\$0.78/Therm
Energy use intensity	
Electricity EUI	238kwh/sm/yr
Fuel EUI	644mj/sm/yr
Total EUI	1,502mj/sm/yr
Life cycle energy use/cost	
Life cycle electricity use	12,065,042kwh
Life cycle fuel cost	32,563,171MJ
Life cycle energy cost	\$62,154

*30-years life and 6.1% discount rate for costs

4.2 Alternative Design Simulations

The estimated energy used for each alternative design was obtained with results shown in Table 3. Alternative design C offers the highest reduction in energy with the combination of insulated concrete form wall (ICF) 10'' (250mm) thick such as expanded polystyrene, roof metal with

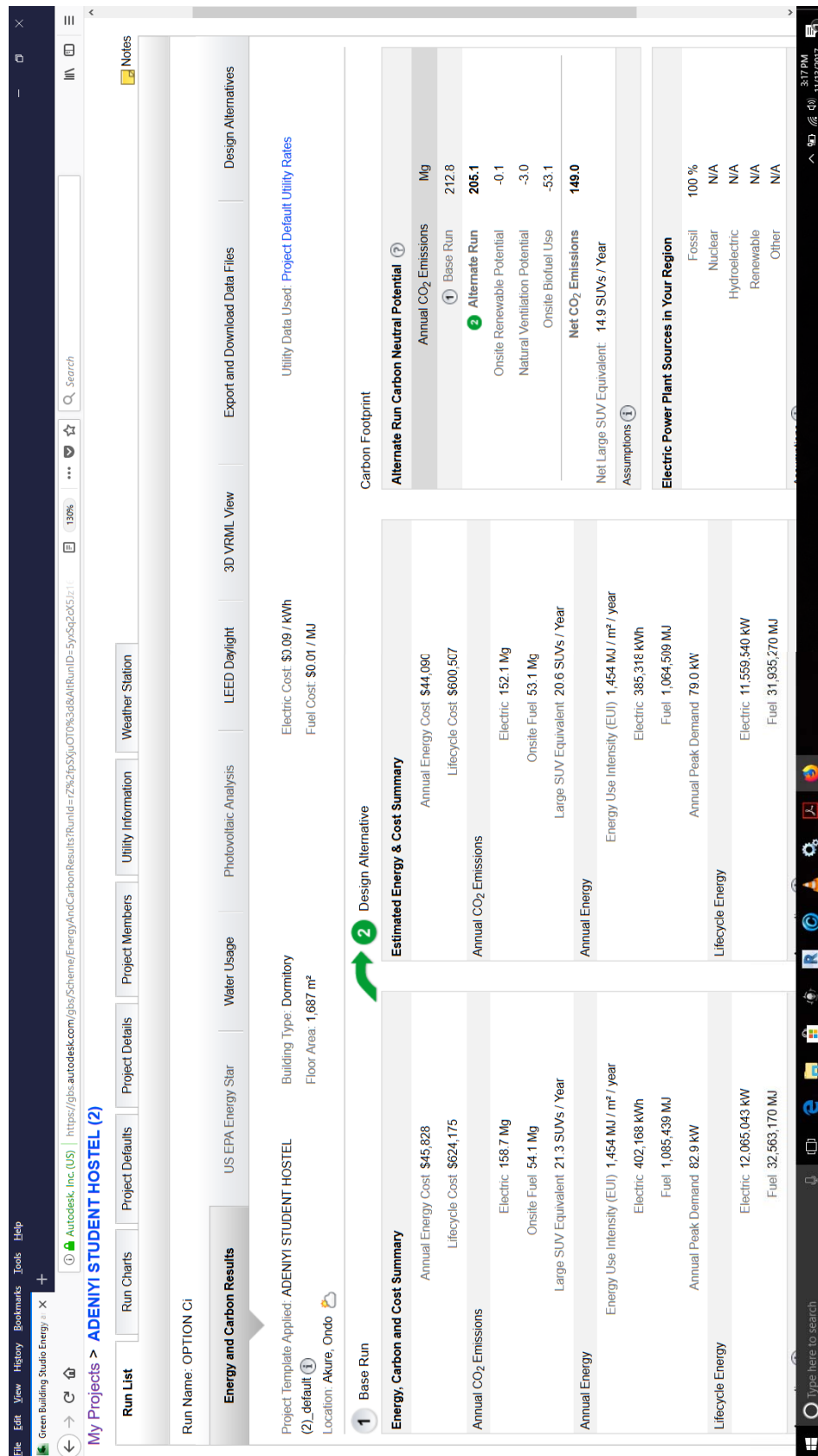


Figure 5: Simulation result for design alternative C

high insulation, shading of $\frac{1}{3}$ of the window height. This reduced the electrical energy use from the original 402,168 kWh/year to 385,318 kWh/year saving about 16, 850 kWh power use over the course of a year and saving 1738USD annually.

Table 3: Energy analysis results for design alternatives

AD*	W*	R*	S*	Annual energy		Total annual energy consumption (Kwh)	Energy saving based on electricity use	Annual energy cost (USD)
				Electricity Kwh	Fuel MJ			
A	1	1	1	385,911	1,065,013	681747.94	16,257	44150
B	1	2	2	385,342	1,063,717	680818.94	16,826	44096
C	1	1	2	385,318	1,064,509	680737.16	16,850	44090
D	1	2	1	385,924	1,064,339	681573.72	16,243	44146
E	2	2	2	400,022	992,236	675643.11	2,146	44942
F	2	1	1	401,201	994,780	677377.67	967	45068
G	2	1	2	400,420	994,516	676674.44	1,748	44988
H	2	2	1	400,799	994,446	677034	1,369	45023

*AD – Alternative Design, W – Wall, R – Roof, S -Shading

Alternative design B made use of 10” (250mm) thick insulated concrete form wall (ICF), thick such as expanded polystyrene, continuous roof deck with high insulation (green roof), shading of $\frac{1}{3}$ of the window height. It can be deduced that the walling material has a considerable impact on energy efficiency than the other components. The energy use increased when the option 2 of the wall types; Concrete massive unit 8” without insulation e.g. brick which has a higher u-value was used.

From Figure 4, it can be deduced that approximately 60 percent of electricity is consumed from the grid while 40 percent is expelled on fuel. Solar heat gain (based on the climatic condition of location), nature of activities of students within spaces, the building components (wall, shades, roof etc.) could also be a constituting factor for the persistent use of electrical appliances to help ensure a thermal balance in all spaces. However, if the actual number of occupants was used as a basis for this simulation the energy consumption will increase drastically.

5. Conclusion

The use of BIM technology during the design phase can efficiently improve the overall performance of a building [32]. The building performance analysis presents different design alternatives which enable the designer to identify the most cost-effective and energy-efficient solutions. The building energy demand is influenced by several factors such as building envelope, building components, occupant behaviour, building orientation, building size and shape [7]. The impact of the building envelop cannot be overemphasized base on the influence its components have on solar heat gain by the building. Combination of materials for the building envelope with better U-values will cut down some excesses on the energy used by electrical equipment to make spaces within the building thermally comfortable. Assessing the energy needs of a building before construction assists the designer to undertake fundamental research into design alternatives with various levels of environmental friendliness. This study shows that the optimum energy saving can be achieved by considering several design alternatives, especially focusing on the walling material. This could provide useful benchmarks of the sensitivity of various technical strategies to the overall performance of the building and

in informing energy policy decisions. This investigation has been successful in proving that building envelope has a substantial impact on energy consumption.

Building energy efficiency technologies should be applied in Nigerian architectural practice. This can be achieved through continuous professional development programmes, training courses and researches geared towards energy efficiency. The knowledge and skills of applying sustainable principles should also be incorporated into architectural education in Nigeria. However, the reduction in electricity consumption in student housing can be achieved by sensitizing students about energy conservation, the use of appliances and the design of the rooms. Further research will focus on a cost-benefit analysis of these design options.

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