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Evaluation of Energy use Intensity and Cost of Institutional Buildings using Building Information Modelling

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Abstract:- Energy consumed by institutional buildings at their operational phase is one of the significant sources of carbon discharge throughout their service life and directly affects global warming. Therefore, it is vital to analyse the energy use intensity (EUI) and energy cost of institutional buildings at Kaduna State University using Building Information Modeling (BIM) technology. It is for these reasons that this study investigates the energy performance of an institutional building using BIM technology. In this study, the faculty of pharmaceutical science at Kaduna State University was selected for assessment. Autodesk Revit 2019 software was used to generate a 3-D model of the faculty building and also to analyse the cooling and heating loads. Nine different scenarios of the building model were created for both energy use intensity (EUI) and energy cost using Autodesk Insight 360. Each scenario of the model was optimized, and the EUI and energy cost scores were compared with the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE 90.1) Standard. Furthermore, Autodesk Green Building Studio (GBS) was used to validate the EUI, while energy cost optimization scores were obtained using Autodesk Insight 360. Simulation results showed that the EUI and energy cost of the faculty building before optimization were 247 kWh/yr and $\$20.1/m^2/yr$, respectively, while after optimization they were 171 $kWh/m^2/yr$ and $\$16.3/m^2/yr$, respectively. Thus, a savings of 76 $kWh/m^2/yr$ was optimised, and the EUI and energy cost scores were compared with the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE 90.1) Standard. Furthermore, Autodesk Green Building Studio (GBS) was used to validate the EUI, while energy cost optimization scores were obtained using Autodesk Insight 360. Simulation results showed that the EUI and energy cost of the faculty building before optimization were 247 kWh/yr and $\$20.1/m^2/yr$, respectively, while after optimization they were 171 $kWh/m^2/yr$ and $\$16.3/m^2/yr$, respectively. Thus, a savings of 76 $kWh/m^2/yr$ and, with the exchange rate of \$1 to \$485, a conversion of $\$3.8/m^2/yr$ of the EUI and energy cost, respectively, of the building under study were achieved. Hence, the use of BIM technology has clearly shown that it can be used for optimization of EUI and energy costs in institutional buildings, thereby reducing carbon dioxide discharge and expenditures.

Keywords*:- Autodesk, Efficiency, Energy, Revit.*

I. INTRODUCTION

Achieving a sustainable campus requires minimizing the impact of buildings on the environment by reducing energy consumption [1]. The building sector is responsible for over 40% of the world's total primary energy consumption and up to 30% of the total carbon dioxide emissions, indicating that this sector has a major role to play in tackling climate change issues. Currently, energy efficiency in buildings is the main objective of energy policy at the national and global levels; however, the present methods and techniques for energy simulation of buildings are time-consuming and difficult. Moreover, they suffer from a lack of high interaction competency between the theoretical and real energy data [2].

Building Information Modeling (BIM) is a modern technology developed which might be different from present methods use depending on the content of the model. For example, a model might include information about the building geometry, envelope components, materials, costs, the heating, ventilation, and air conditioning (HVAC) system, electrical systems, and the thermal properties of materials [3]. Many researchers and institutions have given different guidelines and improvements to BIM [4]. In addition, for a better understanding of the energy performance of a building and because energy waste must be reduced, some tools have appeared in recent years to simulate the energy demand and consumption of a dwelling. The utilization of BIM methodologies could be a helpful tool to achieve it [5]. In many institutional buildings, such as universities, energy efficiency has become a critical issue because the electricity usage has always rapidly increased and the university needs to spend a considerable amount of money annually to support the electricity consumption. It has been estimated that, on a smaller scale, a higher education institution with a population of 31,302 students produces 234,765tCO_2 through the usage of electricity [6].

There are useful of factors which affect energy consumption such as building size, location, orientation, building envelop, (HVAC) system and operating schedule [7]. In addition, since energy consumption and CO_2 emissions are key concerns for worsening environmental impacts, it is important to know the amount of energy consumption and CO_2 emissions by the building to determine the intensity of these in the environment. Energy can be saved by utilising more efficient technology to have higher levels of comfort with less cost by using daylight as a primary light source, which helps in reducing building energy demand [8].

However, with the rising awareness of environmental sustainability, institutions and governments are looking toward effective construction and demolition management practices. For this purpose, practitioners have also been working hard to create BIM-based tools for estimating the waste from the demolition of buildings. Previous literature was reviewed in relation to energy analysis in institutional buildings, with more emphasis on the design stages due to the large share of energy consumption in the buildings. It is expected that energy performance assessment using BIM would save a lot of money and time for institutions in Nigeria [9]. The main goal of this study is to evaluate the potential of BIM in energy management and analysis of an existing institutional building using Autodesk Revit as the BIM-modeling software. This work also aims to analyze the energy use intensity, Energy use by end users and annual fuel consumption using Autodesk Revit as the BIM-Modelling software. The Autodesk Revit add-in allows creating the Building Energy Model based on the Revit Building Information Model [10].

Furthermore, existing research on energy retrofitting in the country does not take into account the latest technologies and methods, such as BIM. Adoption of BIM to retrofit existing buildings is currently a developing research area, and the research is at a basic level, especially in Nigerian institutions. This shift in retrofit studies towards using BIM is due to the numerous advantages and savings that can be achieved if BIM is implemented properly [11]. According to where it was established [12], one vital way of conserving energy is through appropriate building orientation. The orientation of a building is often determined by the site topography and/or location. The conventional building performance was analyzed using Autodesk Revit, which included various variables such as energy use intensity, lifecycle energy use and cost, annual carbon emissions, monthly heating and cooling loads, monthly peak demand, monthly electricity, and fuel consumption [13]. According to [14], they investigated how to use EnergyPlus to construct a model to accurately simulate complex building systems as well as the interrelationships among these systems, such as HVAC, lighting, and domestic hot water. They made a comparison between the annual energy consumption result of EnergyPlus and the ASHRAE 90.1 base model. The simulation results show that the electricity consumption and annual cost were reduced by 4.7% and 7.75%, respectively.

In addition, [15] used Revit software 2009 to export IBM details in order to use them in Autodesk Ecotect and Autodesk Green Building Studio to implement his duty at a national primary school, "Sonna National School." He concluded that using BIM would be useful for improving the building's performance for investors, governments, and institutions. Furthermore, Autodesk Insight provides an effective and cohesive experience for improving building energy performance. It has a robust BIM integration that allows the visualization, interaction, and specification of building performance data earlier in the design process [16]. Furthermore, Autodesk Insight results permit the evaluation of energy consumption (kWh/m^2/year) via Energy Use Intensity (EUI). To permit the optimization of the energy model, it allows the manipulation of different options of parameters such as building orientation, window-wall ratio, window shades, window glass, types of walls and roof construction, infiltration rate, lighting and plug-load efficiency, daylighting and occupancy controls, HVAC systems, operations schedules, photovoltaic panel efficiency, payback limits, and coverage. This optimization occurs manually by the user and shows how to increase or decrease the energy demand of the study case when selecting different options. Similarly, according to [17], the effect of the building envelope on energy savings in dwellings was studied in several cities in Saudi Arabia using the EnergyPlus package. They reported that an optimal energy savings of 22.7%–39.5% could be achieved depending on the city. However, [18] proposed that the life cycle energy use of buildings depends on the operating (80–90%) and embodied (10–20%) energy of the buildings. Normalized life cycle energy use of conventional residential buildings falls in the range of 150 -400kWh/m^2/year (primary) and office buildings in the range of 250-550 kWh/m^2/year per year (primary). He also proposed that the life cycle energy demand can be reduced by reducing its operating energy. Based on the foregoing, BIM technology has a high potential to reduce EUI and energy costs in buildings and will be used for energy analysis in this study.

II. RESEARCH METHODOLOGY

This describes the methods, steps required, and scientific approaches adopted for the attainment of the proposed objectives. A comprehensive and critical literature review was conducted to establish the research gap. 2-D data was obtained from the Kaduna State University (KASU) main campus. 3-D models were generated from the 2-D data obtained for faculty of pharmaceutical for the purpose of the Energy analysis of building with the help of Autodesk Revit and green building studio software, a case study of Kaduna State University Main Campus building project is located at pharmaceutical science building. Energy analysis was performed on the virtually developed 3-D model.

The following steps were taken for the energy simulation of the faculty building:

- Drawings and information about the building were studied.
- A 3D model of the building was created from the 2-D drawings collected using the Autodesk Revit software.
- The energy settings, such as building type, building operating schedule, type of HVAC system, etc., were dependent on your needs.

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- The faculty building was Located in your building using Internet Mapping Service inbuilt in Autodesk Revit.
- A building energy model was automatically created using the analyse panel in the Revit software.
- Analysis and run results are available in Autodesk Insight over the cloud.
- Energy use of the building was estimated using green building studio.

The steps are also summarized and presented in Figure 1 below through the initial collection of drawings; information about the building is not included.

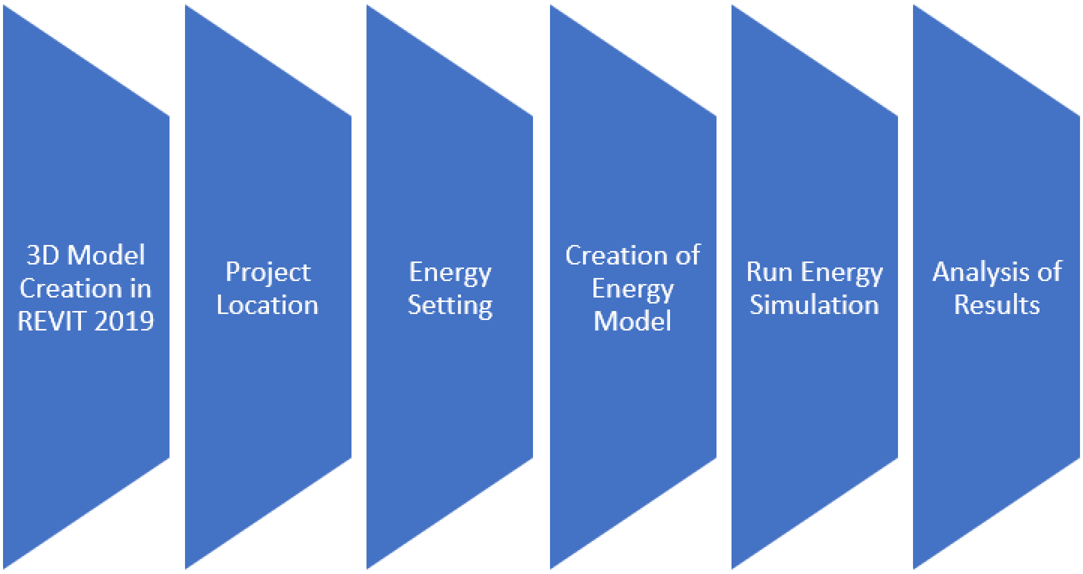

Fig. 1: Energy Analysis

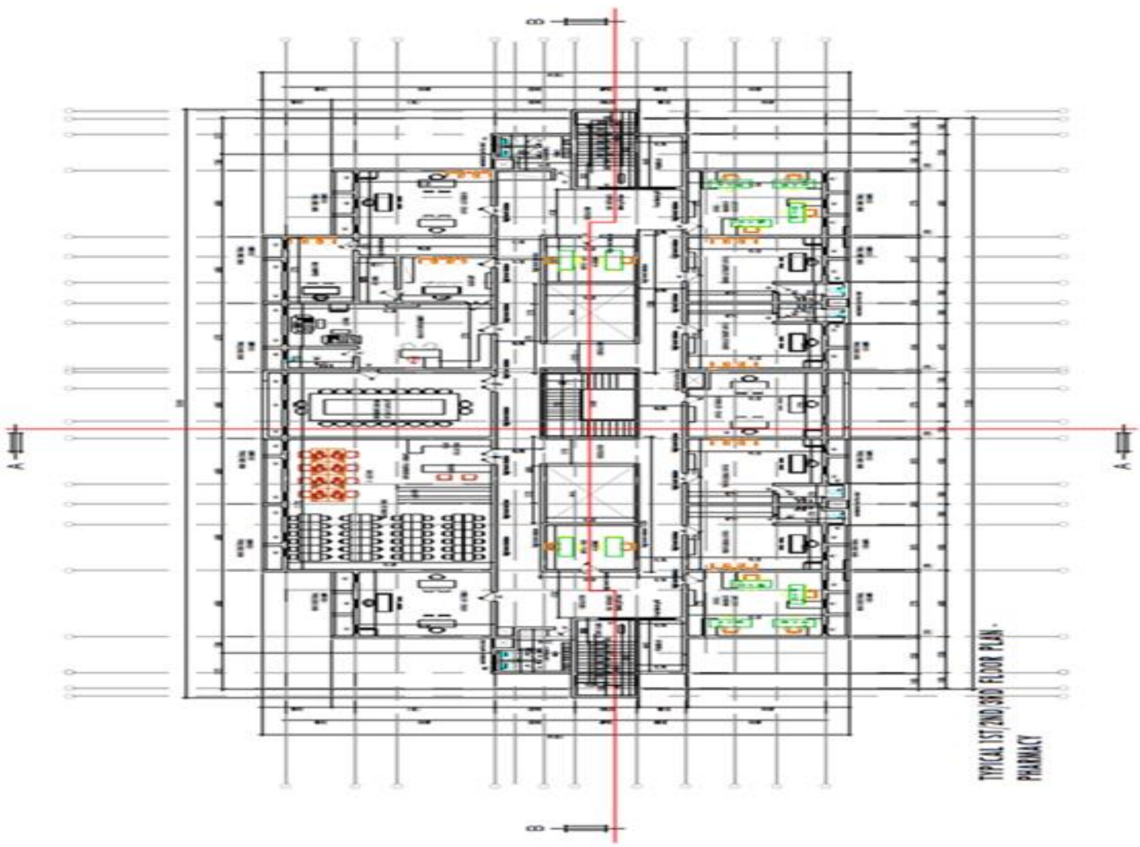

Fig. 2: 2-D drawing of the pharmaceutical science faculty building

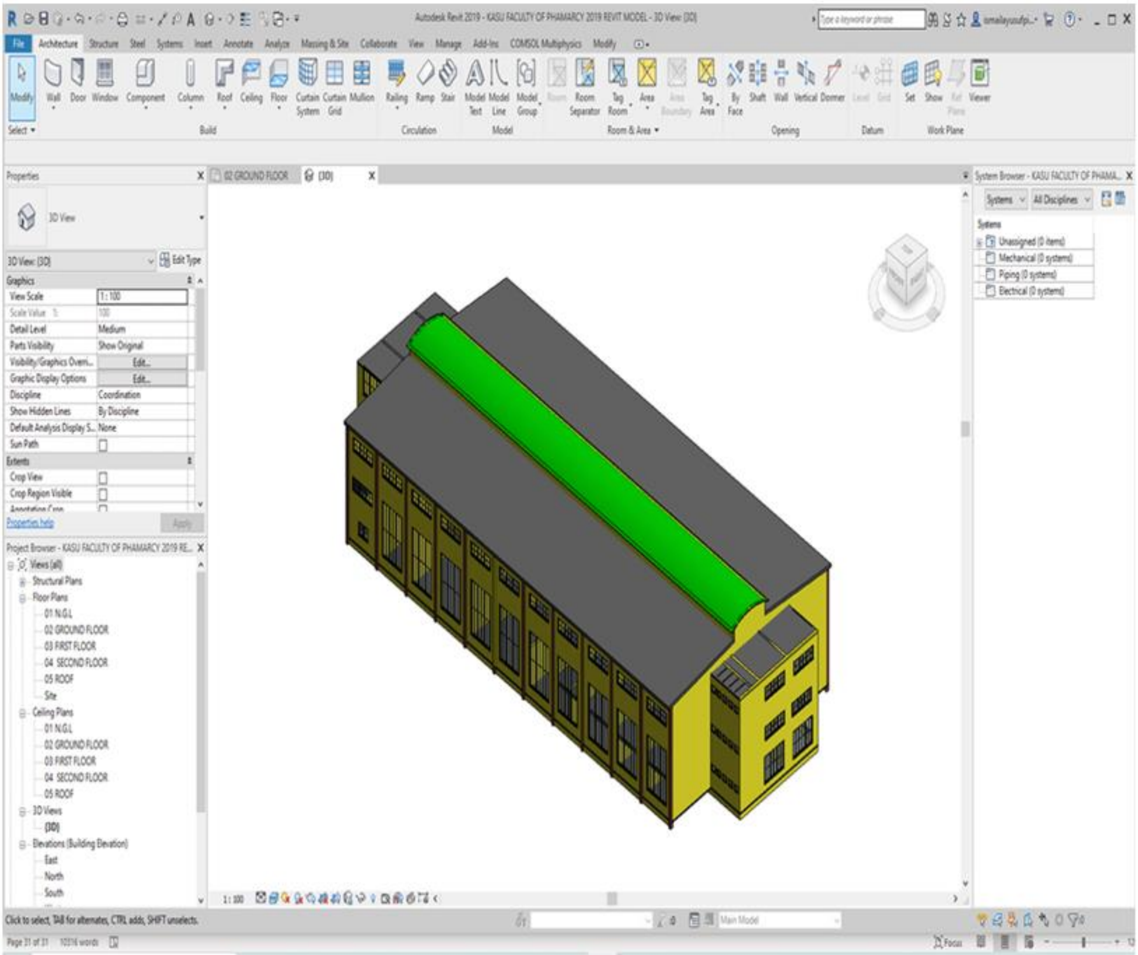

Fig. 3: 3-D drawing in Revit software of the pharmaceutical science faculty building

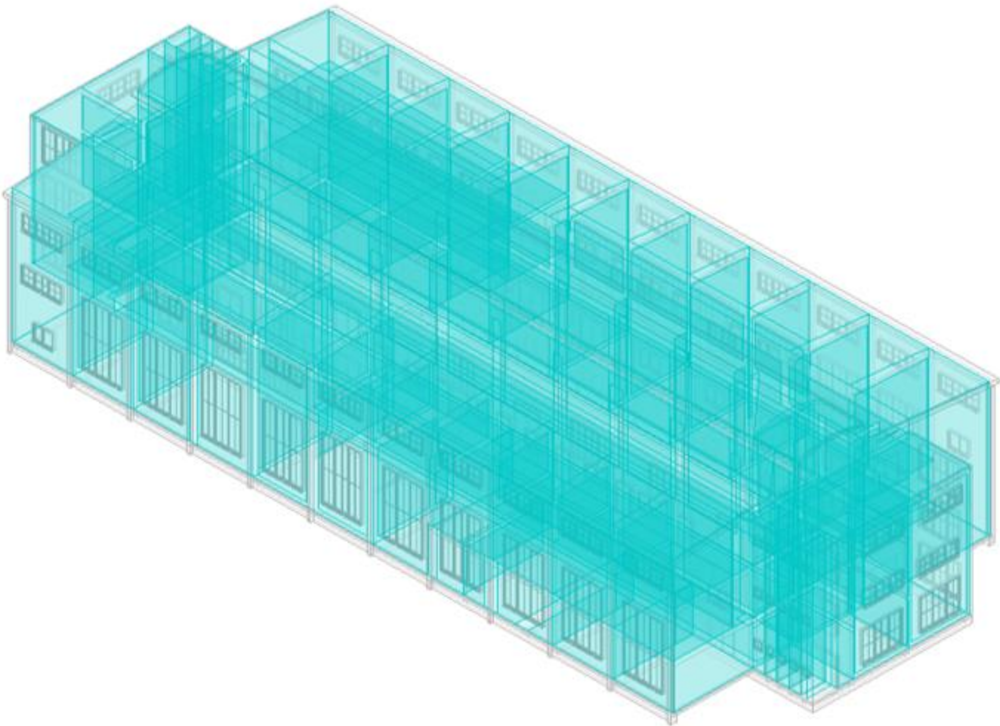

Fig. 4: Energy model in the Revit software drawing of the pharmaceutical science faculty building

Energy analysis of the Faculty of Pharmaceutical Science building was performed sequentially. At first, according to all relevant information, a 3D model of the building was created using Autodesk Revit 2019. A 3D model was used to visualize the different parts of the building. Then the energy analysis was performed using Autodesk Revit 2019 in association with Green Building Studio. The Revit file was transferred to Green Building Studio in gbXML file format. To reduce the energy consumption and CO_2 emission from building there are various types of way as like usage of green roofing, proper orientation of building, proper window wall ratio, usage of high performance glass in window, usage of high insulation materials in the walls related with low thermal conductivity The existent typical building was located at Kaduna state University Main Campus building which consist of three departments with Total floor area of 3589m^2 with structure of frame brick concrete. Presented in Figure 2 is the 2-D drawing of the pharmaceutical science faculty building.

The following steps were performed to prepare the 3-D model of the pharmaceutical science faculty building for the case study:

- The faculty of pharmaceutical science building on the Kaduna State University main campus was selected for energy analysis.
- A site visit was conducted to see the building physically.
- A meeting was conducted several times with the physical planning department and the respective engineers who were responsible for the construction of the building.
- All the relevant information for the building, such as the building plan, material properties, HVAC system, etc., was collected.
- According to information about the material and plan, an architectural model of the proposed building was prepared in Autodesk Revit® 2019.

In proceeding further**,** design factors were determined which included building orientation, of the faculty of pharmaceutical science and material properties were selected during the period of creating 3D model of the building in Autodesk Revit 2019. Then an energy simulation was performed. After performing the energy analysis, the life cycle energy use, cost, and carbon dioxide emissions were determined. Furthermore, an energy model was created by selecting the building location, HVAC system, building type, and material properties, as shown in Figure 3. Then an energy simulation was performed.

A. Energy Analysis Process Using Gbs and Optimization

The general process of energy performance evaluation, which is categorized into the effects of influencing factors and energy analysis, was followed to evaluate the energy performance. A gain, the influencing factors include climate, design and occupant, Occupant and climatic information were taken to the BIM tool as location is specified, Design factors which depend on the building orientation, building types like whether it is office building, residential building or others were considered. Materials information that was used in preparing the 3D model of the building in Revit 2019 is extracted in the form of gbXML files and imported into the energy analysis tool.

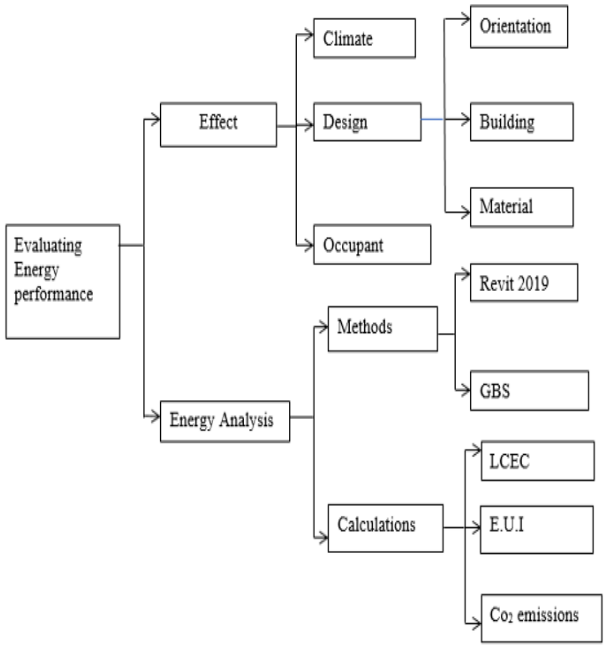

Fig. 5: Energy analysis using green building studio and optimization flow chart

The second category of energy performance evaluation is energy analysis. Two BIM tools were used to analyze the energy. After preparing the energy model in Revit 2019, the energy analytic model was prepared by selecting the building location and building type as the institutional building of Kaduna State University's main campus at Kaduna North, Kaduna, Nigeria. The building and operating schedule were set at 24 hours per day and 7 days per week (24/7).

After performing the energy analysis, the following items were determined:

LCEC: Life Cycle Energy Cost

EUI: Energy Use Intensity

CO_2 emission

According to the results of the Green Building Studio shown in Figure 6, the annual energy cost and lifecycle cost of the faculty of pharmaceutical science building are $45,483 and $619,479, respectively. The lifecycle energy for electricity and fuel consumption is 14,320,419 kW and 2,665,581 MJ, respectively. It can also be seen in Fig. 6. HVAC has the highest percentage of the annual electric end use and an insignificant percentage of the annual fuel end use, as shown in Figure 7.

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Energy, Carbon and Cost Summary	
Annual Energy Cost	$45,483
Lifecycle Cost	$619,479
Annual CO_2 Emissions	
Electric	0.0 Mg
Onsite Fuel	4.4 Mg
Large SUV Equivalent	0.4 SUVs / Year
Annual Energy	
Energy Use Intensity (EUI)	505 MJ / m² / year
Electric	477,347 kWh
Fuel	88,853 MJ
Annual Peak Demand	178.2 kW
Lifecycle Energy	
Electric	14,320,419 kW
Fuel	2,665,581 MJ

Fig. 6: Annual energy cost and lifecycle cost of the faculty of pharmaceutical sciences building

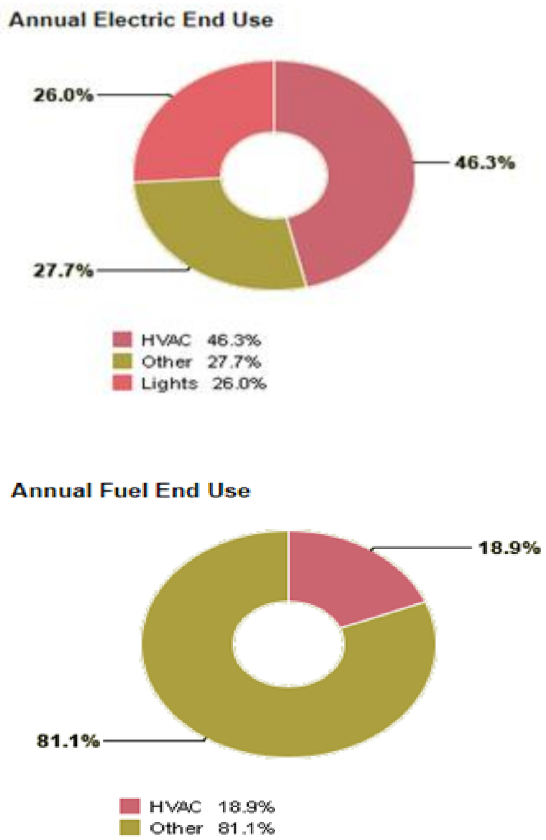
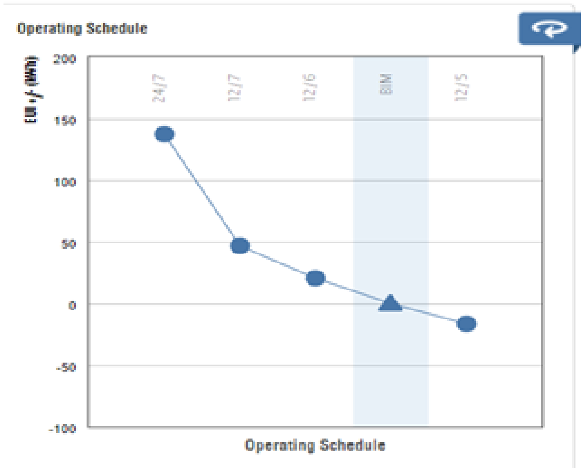


Fig. 7: Annual electric end-use and annual fuel end-use

III. RESULTS AND DISCUSSION

EUI was calculated by dividing the total energy consumed by the building in one year by the total gross floor area of the building. Furthermore, the energy consumption of the building was calculated as energy use intensity (EUI) in kWh/m^2 per year based on the energy setting of the project. The analysis report has many design options such as operating schedule, plug-in load efficiency, HVAC systems, building orientation, and lighting efficiency to change and control the energy consumption of the building. The analysis report not only provides us with the EUI of the building but also the energy cost of the building per square metre per year. Presented in Figure 8 is the graph of EUI versus different design criteria, which are operating schedule, plug load efficiency, HVAC, and lighting efficiency, respectively.



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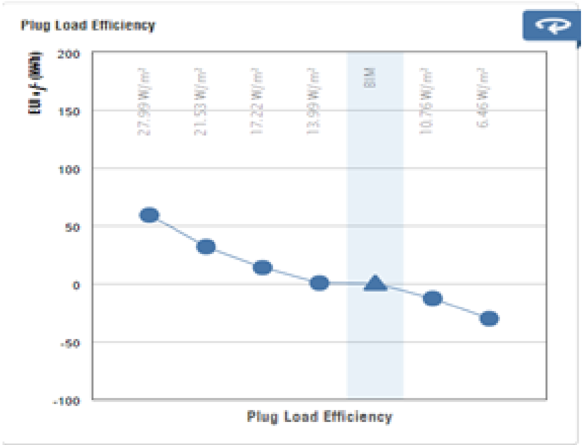

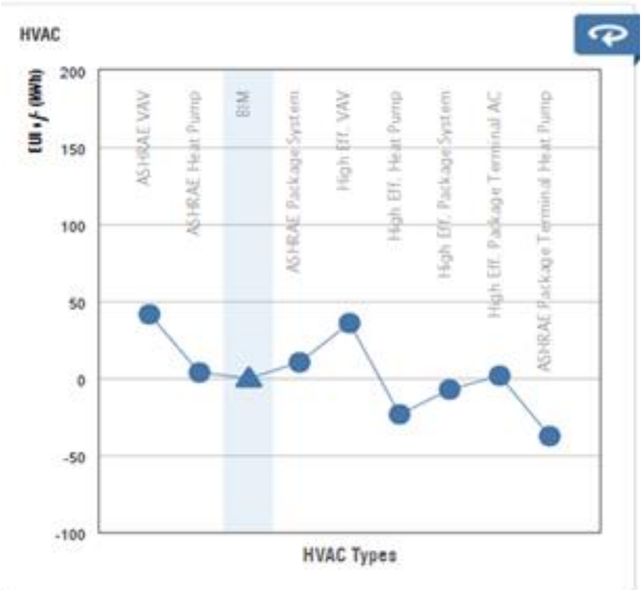

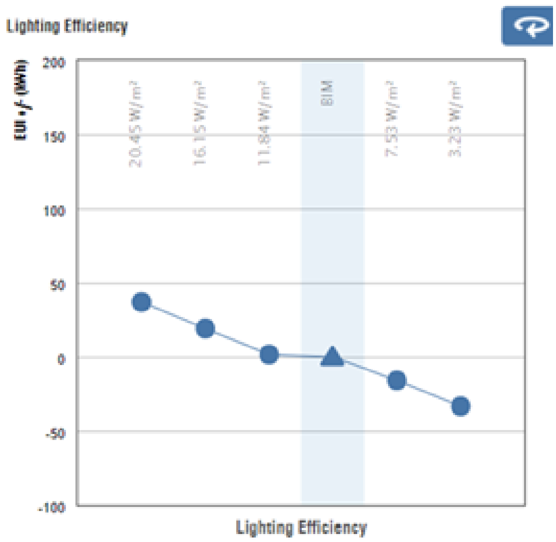

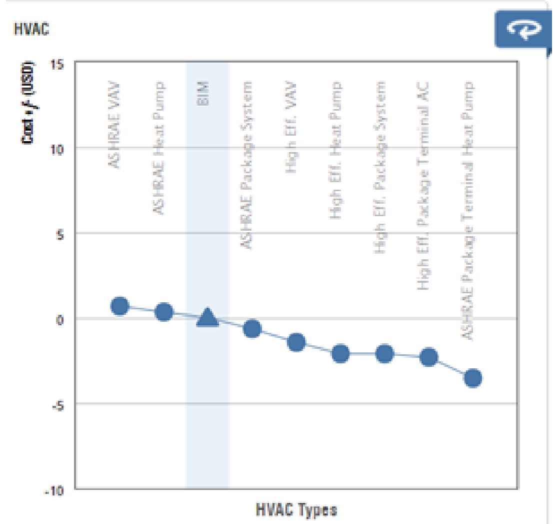

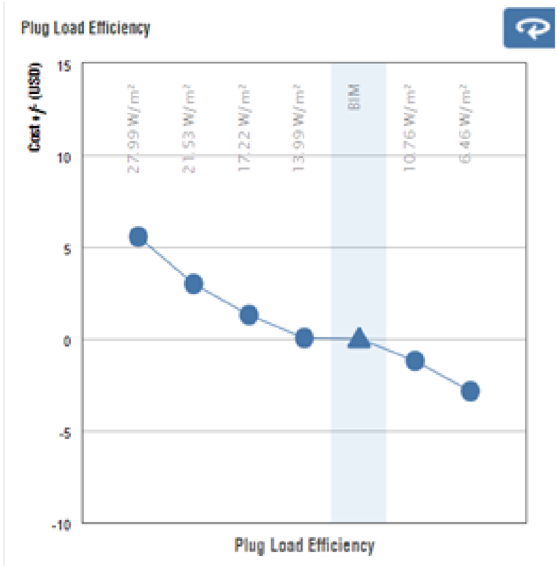

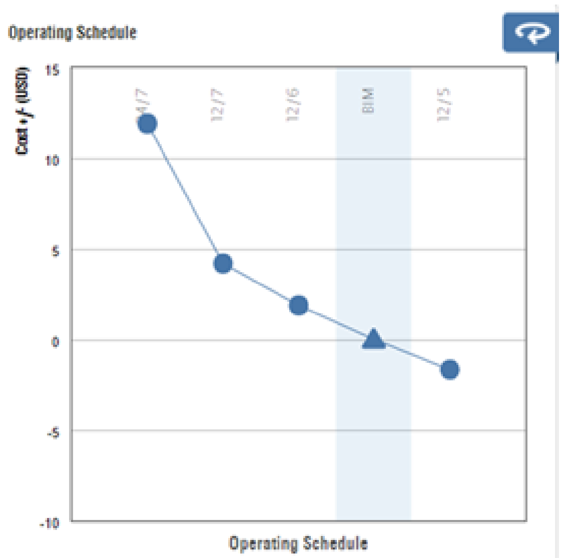

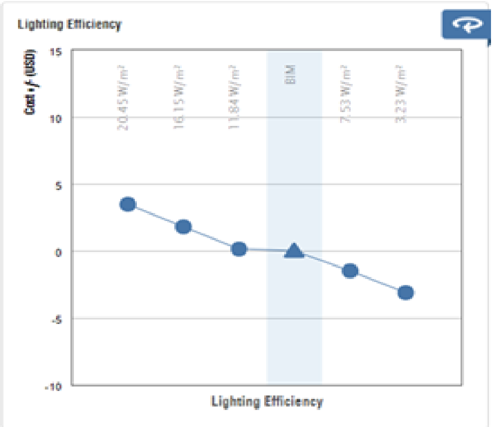

Fig 8: The graph of EUI versus different design criteria

In order to moderate the overall energy use intensity of the building, the range of each design criteria were changed so as to understand how much the change in design of individual features such as window to wall ratio, operating schedules, may affect the energy consumption of the whole building. It should be noted that whenever the operating schedule of the building changed from 12/7 to 24/7, the EUI value also changed by a significant amount. Similarly, each of the individual design criteria in the process of reducing the energy consumption of the building was changed in a similar manner. As presented in Figure 9, the range of energy use intensity and energy cost before and after changing design criteria.

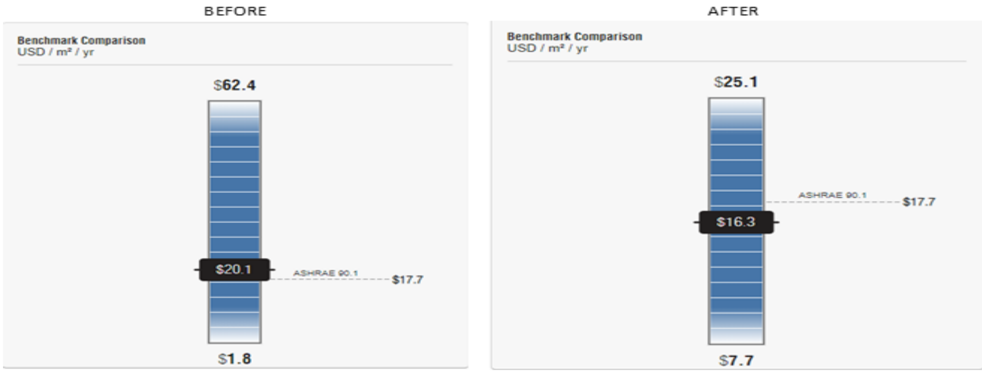

Fig. 9: Energy cost benchmark comparison of pharmaceutical science faculty buildings

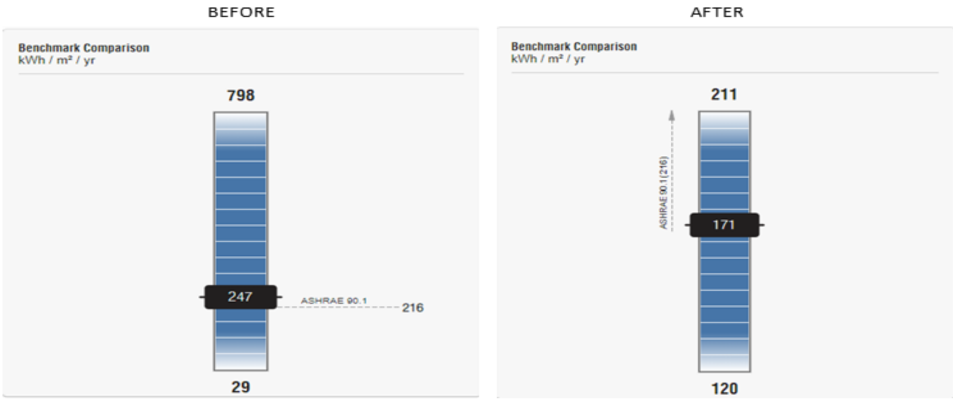

Fig. 10: Range of energy use intensity and energy cost before changing design criteria

IV. CONCLUSIONS

An energy performance evaluation of the faculty of pharmaceutical science building on Kaduna State's main campus was conducted. Results obtained from the study indicated that the EUI of the faculty building before optimization was 247kWh/m^2/yr., and after optimization it was 171kWh/m^2/yr.

Thus, enabling EUI savings of 76kWh/m^2/year, which is a significant improvement, Likewise, energy cost before optimization was $20.1/m^2/yr., and after optimization it was $ 16.3/m^2/yr., thereby providing a savings of $3.8/m^2/yr. With the exchange rate of $1 to $485, the conversion is $3.8/m^2/yr. The annual energy cost and life cycle cost of the building housing the faculty of pharmaceutical science are $45,483 and $619,479, respectively. The lifecycle energy for electricity and fuel consumption is 14,320,419kW and 2,665,581MJ, respectively. And the breakdown of energy consumption by the end use systems has been analyzed figuring out the HVAC system accounting for 46,38%, Lighting, 27.7% and 26.0% for others of the total energy usage, which has the highest proportion when compared with other end-users in the building under study. Therefore, the use of BIM technology has clearly shown that it can be used for optimization of EUI and energy costs in institutional buildings. Hence, it is recommended that BIM technology be widely adopted for use in energy performance evaluation in the building sector to enable massive reductions in carbon dioxide discharge and expenditures.

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