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Energy Efficiency and Carbon Emission Reduction in Institutional Lighting: A case study of Twin Theater Lecture Room.

[1*1] I.Y. Pindiga,[2,] S. U., Muhammad, [3]M.A. Mohammed & [4]S. Fofana.

[1]Department of Electrical/Electronic Engineering. University of Applied science and Engineering Technology Gambia. P. O. Box. 989 Kanifing. Banjul. The Gambia.
[2]Department of Mechanical Engineering, Kaduna Polytechnic, P.M.B 2021 Kaduna. University of Applied science and Engineering Technology Gambia. P. O. Box. 989 Kanifing. Banjul. The Gambia
[3]Department of Mechanical Engineering, [4]Department of Physics. Kaduna State University.

Abstract

Improper lighting conditions in educational institutions may impact both the health and working capacity of students. significant amount of energy consumption is generally attributed to lighting systems since most institutions are still utilizing non-efficient illuminants, including incandescent, tungsten halogen, and high intensity discharge light bulbs. This study aims to conduct a preliminary energy audit of the twin theatre building using physical survey by counting the numbers lamps, their wattage and the hours of usage. The lighting system integrating day lighting with weather conditions requires a simulation tool and to compare the power consumption with the base case and proposed case. Propose energy-saving strategies evaluate the impact on energy efficiency of lightings systems. Renewable Energy and Energy Efficiency Technology Screen (RET Screen) is a software used in this study to analyze greenhouse gasses. Energy consumption from the two scenarios was compared, and emission savings was evaluated. The preliminary energy audit utilized RET Screen to calculate base case energy consumption, considering lightings systems quantity, operating hours. The software RET Screen was used to develop the energy model and Greenhouse gas emissions reduction. The study case to be a Twin theater of a Kaduna state university main campus. and the electrical energy expenses decreasing by 10.512 kWh per year of the Twin theatre, which is over 75%. The greenhouse gases (GHG) emissions dropped by 149.8 kgCO2 eq. annually of the Twin theater which is about 47.3% This analysis supports the advantages of using LEDs instead of fluorescent lamps, also reduces GHG emissions despite the high lumen deterioration of LEDs.

Key words: Energy. Carbon Emission. Lighting systems. Buildings. RET Screen. LED.

1.0 Introduction

[1] *Corresponding Author e-mail: ismailayusufpindiga@gmail.com

The global lighting sector accounts for 10% of energy consumption in the building sector (Oladigbolu *et al.*, 2021). Lighting is provided in institutional buildings, indoor and outdoor for providing comfortable working environment, (Shyam, 2014). University buildings consumed about 43% of the energy supplied and the lighting energy consumption can be up to 25% of the total energy used (Abdullahi *et al.*, 2018). In addition, Efficient lighting of lecture theater is one of many technologies that can help in constructing a cleaner future and have a positive environmental impact, (Ashirbekov *et al.*, 2020). Today, most university buildings consist of various energy-consuming facilities. According to the United Nations Environment Program's report named. Rapid transition to energy-efficient lighting is an integrated policy approach, which indicate that lighting systems worldwide consume 20% of the total amount of electricity coupled with 6% of CO2 emissions.(UNEP, 2013).

Furthermore, policymakers should consider the direct energy and cost savings benefits associated with a transition to energy efficient lighting and take into account the resulting associated benefits to economic and environmental, (UNEP, 2013).Due to the long operating hours and a large number of lamps installed in the institutional buildings, its electrical energy demand for lighting tends to be higher than the residential sector, (Hong & Rahmat, 2022). Today LED lamps are now the global leading lighting technology as many countries have started to phase-out fluorescent and halogen lamps besides incandescent lamps for a brighter and cleaner future as well as saving on electricity bills, (Pireci & Vu, 2022). Although the potential benefits of shifting to energy-efficient LED lighting in buildings located in different parts of the world have been demonstrated by some studies, (Gan *et al.*, 2013). Replacing traditional inefficient lamps with energy-efficient LED lamps, the operating costs can be reduced by up to 60%, as well as providing a better illumination level , and new lamps also last much longer than traditional bulbs, reducing maintenance costs significantly, (Babatunde *et al.*, 2019). Energy audit is very important activity in the effective control of energy costs, which involves a comprehensive assessment of facility energy efficiency to include techno-economic analyses and recommendations of the appropriate energy conservation measures, (Owolabi *et al.*, 2020). Replacement of sodium lamps in outdoor lighting installations with LED sources on a mass scale is a source of hope for significant savings in electricity, but also a source of numerous concerns.(Tabaka, 2021) Therefore, there is a need to evaluate the consequences of replacing old lighting technology with modern LED sources.

This paper examines the feasibility of LED lamp in replacing the conventional fluorescent lamp. In addition, analysis of carbon dioxide emission reduction with energy saving strategies have been proposed using RET Screen software vision 9.1. Subsequently, the economic benefits of the respective energy saving strategy have been quantified (Ganoe *et al.*, 2014)

Global lighting sector accounts for 10% of energy consumption in the building sector *(Krarti et al.*, 2017). Efficient light system assessments are widely spread and presented in many journals demonstrating relatively consistent financial and environmental advantages. For example.(Hong & Rahmat, 2022) study the application of this approach to a selected library in Brunei Darussalam showed that an energy-efficient light-emitting diode (LED) lighting system would make the building greener. We projected reductions in lighting energy consumption by 6.7 times (3.98 kWh/m2/year), its associated emissions by 8 times (0.59 kg CO2 and electricity costs by 8.7 times (B$7.07/m2/year) by 2050 if existing lamps in the library are retrofitted with LED lamp. Furthermore, Results from the study(Sekyere *et al.*, 2012) showed that the cost of illumination ranges from $0.061 per thousand Lux hours (klxh) for Goshen solar lantern to $0.261 per Klux for Gent lite solar lantern with kerosene lantern costing $0.227 per klxh. The analysis established that switching to the solar-LED and CFL systems would have a payback time of less than two years when replacing the wick-type kerosene lantern with between $11.60 and $61.60 to save annually. When evaluated in terms of total cost of ownership, the solar-powered LED and CFL systems emerged as the most cost-effective solution. Emissions analysis conducted revealed that the solar-powered systems save between 80.15 and 256.49 kg CO2/year. The annual CO2 emissions per kerosene lantern were estimated to be 60.99 kg. However, (Saputri *et al.*, 2023) study the installation of photovoltaic modules in Probolinggo which still has shortcomings in terms of public street lighting. From the simulations carried out, concluded that Probolinggo is feasible for the installation of the solar power plant. The total power generated is 10,145 MWh. Then, by using RET Screen, a photovoltaic installation fee of Rp142,978,410,000 was obtained. and annual maintenance costs of Rp1,281,870,000. According to (Enongene *et al.*, 2017) study ,switching incandescent lamps with CFL and LED results in a reduction in lighting related greenhouse gas (GHG) emissions from dwellings by 66.6% and 83.3% respectively. The benefits attributed to energy efficiency and conservation include reduction in energy consumption, operating cost, duration of lighting fixture replacement, the heat generated by the incandescent lamps and improvement in energy performance of buildings (Abolarin *et al.*, 2013).It include participation in the global energy sustainability and contribution to the fight against greenhouse gases

Advantage of transitioning from traditional light bulbs to LEDs are presented in the official website of the Energy Department of USA. Two reasons were highlighted as the most important ones:

- Incandescent bulbs rated as the least efficient in all types of bulbs, since they give out 90% of the used energy as heat, and only 10% as light.
- LEDs will work from 15 to 25 times longer compare with traditional bulbs and will have lower energy usage, on average 25–30%.(US Department of Energy, 2017).

- Switching to energy efficient lighting is one of the fastest ways to cut your energy bills. Lightbulbs are easy, fast, and inexpensive to replace, but they aren't your only option for saving money and energy on lighting.

In the EU, around 10% of the total electricity consumption is used for lighting, ranging from 5% in Belgium and Luxemburg to 15% in Denmark and the Netherlands. (Ameen *et al.*, 2021)

Many study show that, the energy efficiency of the lighting system may be improved by about 60% by simply replacing the traditional lighting systems with modern LED-technology-based systems. (Ameen *et al.*, 2021). However. another studies by (Tabaka, 2021) considered 156 LED sources of different spectral distributions and a wide range of color temperatures from 1000 K to 9753 K as well as different color rendering index (CRI) values. Showed that the replacement of sodium lamps with LED sources is not necessarily associated with an increased negative impact on the effect of light pollution. In addition, Energy efficiency in lighting involves building architecture, selection of proper luminaries and light sources (Dhingra, 2009). light sources are responsible for an energy consumption of around 1/6 to 1/5 of the worldwide electricity production, and the use of semiconductor light sources reduces energy consumption and significantly reduces carbon dioxide emissions into the atmosphere (Baran *et al.*, 2020).

In the literature, the number of publications related to lighting energy conservation and carbon emission planning in buildings using RET Screen software on the incandescent lighting substitution with LED sources is relatively in institutional buildings and the focus is mainly laid on studies of individual buildings (Ganoe *et al.*, 2014).

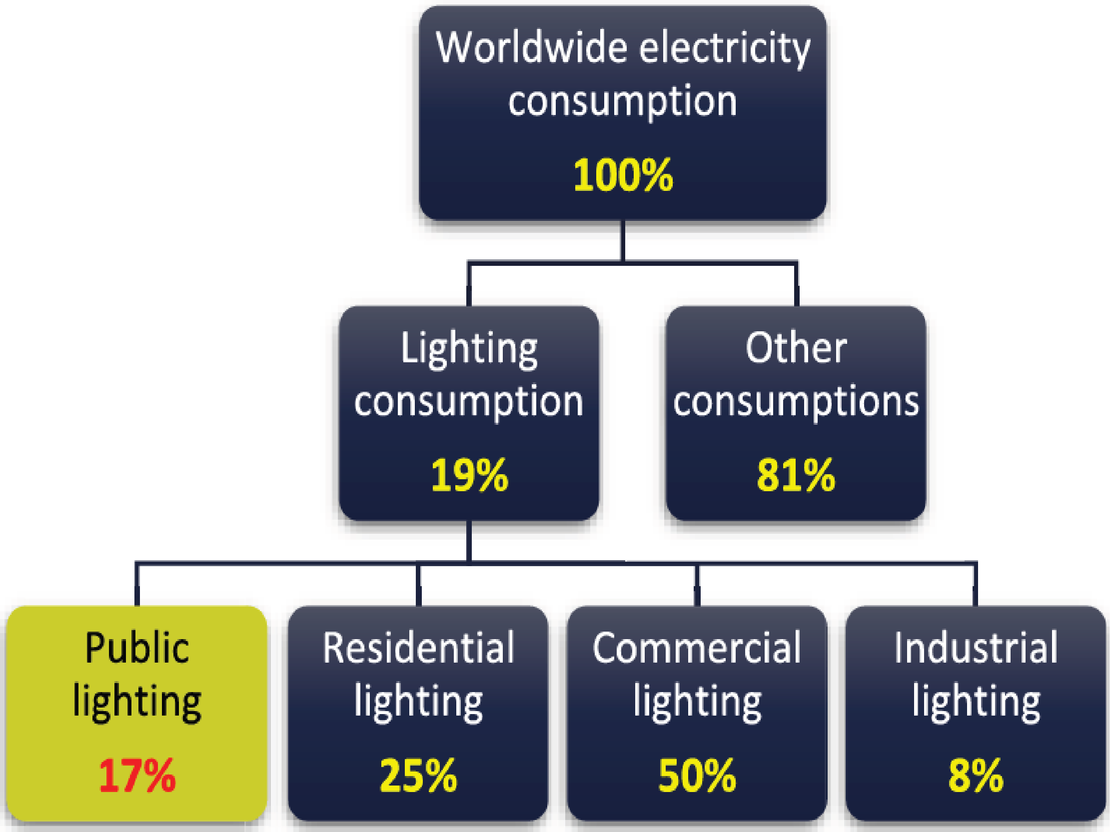


Figure 1: Share of public lighting from worldwide electricity consumption.

2.0. Methodology

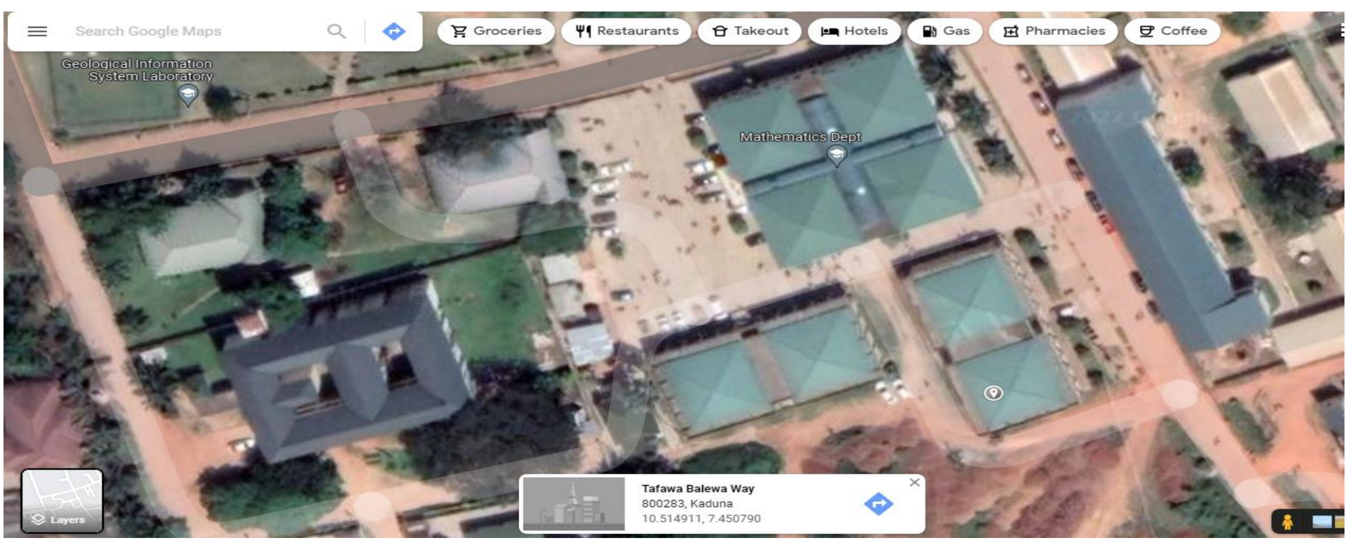
The electric energy consumption for lighting on yearly basis must be calculated for each type of the lighting system taking into consideration the differences in nominal power of light source as well as the fact that light sources are not equally engaged during one year. Based on the collected data about the number, power and type of lighting systems, as well as the working hours of each light source, the annual electric energy consumption for lighting is calculated with the RET Screen software. Besides, this phase of analysis includes detailed inspection of building under study. However, energy performance of a lighting system is influenced by many factors. These typically include the illumination level required for the type of space being, the lamp and fixture type selected such as incandescent. compact fluorescent, the luminous efficacy and electricity load for each lamp, the total number of fixtures installed, and finally, the operating hours of the lamps.

RET Screen Software can be used to estimate the energy use and savings, costs, emission reductions, financial viability and risk for building lightings systems and equipment's in improving energy efficiency measures in the twin theatre building of Kaduna state University main campus. However, the software contains a database of lamp and fixture efficiency for lighting systems such as incandescent; halogen; fluorescent; high- and low-pressure sodium; mercury vapour; metal halide and light emitting diode (LED) lamps. RET Screen computer program consists of 6 steps to evaluate energy efficiency and GHG emissions reduction of lightings systems, (Ganoe *et al*., 2014). it includes.

first step of the "Energy Model," the following information is downloaded to the system:

- The language: English.
- The currency in which the monetary data
- The Units in metric or empirical
- Project locations.

Typical Twin theater building of Kaduna University main campus was considered in the model. Base case, representing the current state of the system or facility and the proposed case, containing the improvements to be analyzed. In the vein. RET Screen is directly responsible for an estimated $ 8 billion in energy savings. In addition, the use of software contributes to the decrease of greenhouse gas emissions by 20 million tons per year, as stipulated by NASA Research Center (Nicolae *et al*., 2018).



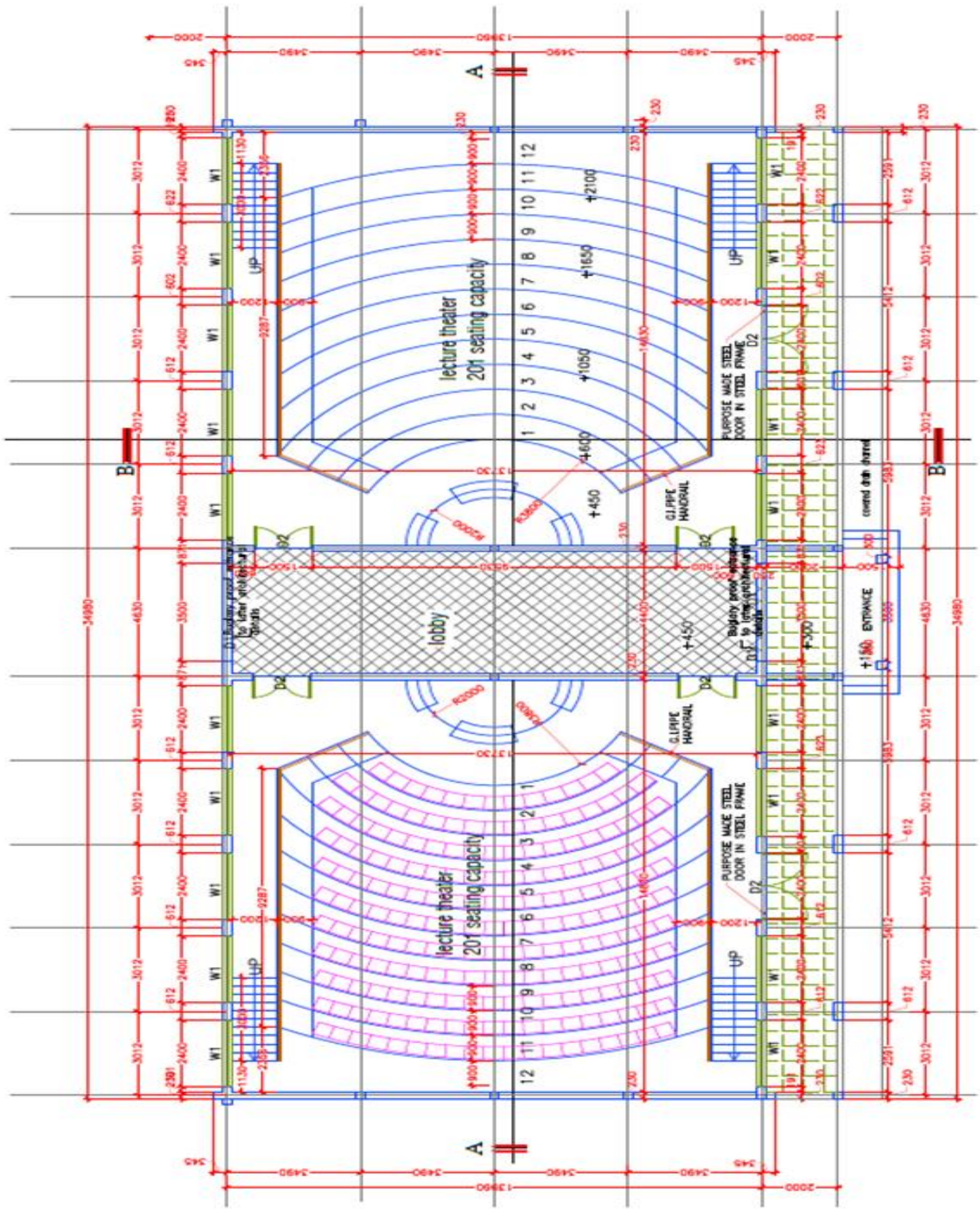


Figure 4: 2D Drawing of Twin Theatre.

To conduct the energy conservation of lightings systems in the twin theatre using RET Screen software, the climate data from the RET Screen database must be selected. The closest location containing the required data is Kaduna North in Kaduna town site (latitude 10.5^{0}N and longitude 7.4^{0}E. The weather data for this location contains monthly mean values of ambient air temperature, relative humidity, amount of precipitation, solar radiation–horizontal, atmospheric pressure, wind speed, ground temperature, heating and cooling degree days respectively. The feasibility analysis was based on comparing the base case (installed fluorescent lights), to the proposed case (installation of LED lights). Furthermore, an on-site lighting audit had to be performed to create an energy model to represent the first case accurately. However, energy calculations for the base case were performed by identifying average energy consumption from the installed lamps in the twin theatre.

RET Screen Expert software (Ganoe *et al.*, 2014) was chosen as a decision support tool to compare the two cases. This platform makes a-step analysis that includes the energy model, GHG analysis, amount of energy saved, and percentage saved of all lightings in the twin theatre building under study. Figure 5 below shows the methodology flow chart of the study.

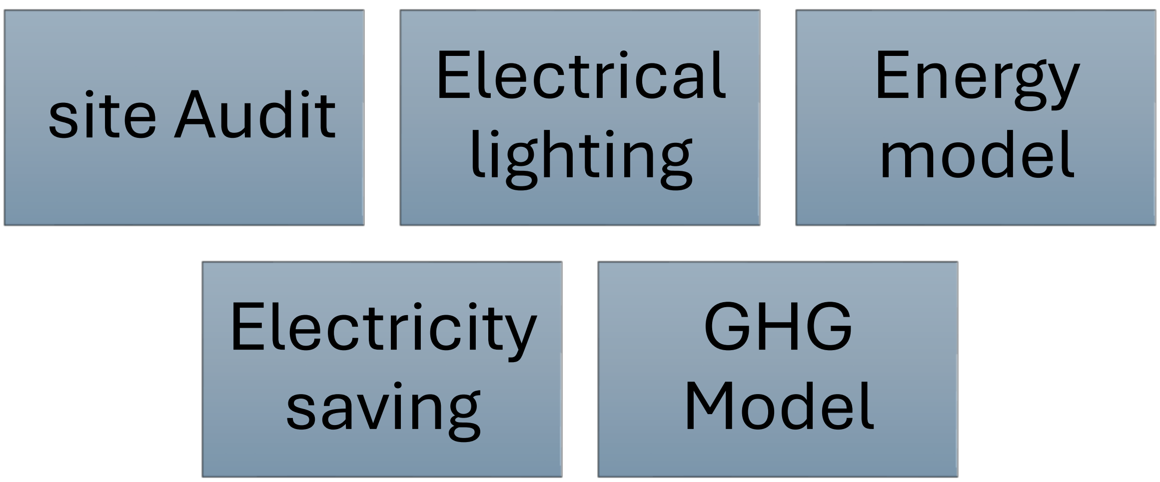


Figure 5: Research Framework

2.1. Energy model

The significant factor for the analysis of a lamp was the amount of luminosity generated per device, which is equal to power multiplied by luminous efficiency. LED lamp model was chosen for the proposed case such that it generates equal illumination level. GHG analysis in this part, the assessment of the reduced amount of GHG emissions in the proposed scenario is provided. Using the REScreen software, the user can analyze comprehensive projects regarding the implementation of most clean energy technologies, and it offers the opportunity to increase the energy efficiency of lighting of twin theater building, consequently, to decline its greenhouse gas emissions. In addition, the basis of the program is to compare two cases: the base case, representing the current state of Lighting system or facility and the proposed case, containing the improvements to be analyzed.

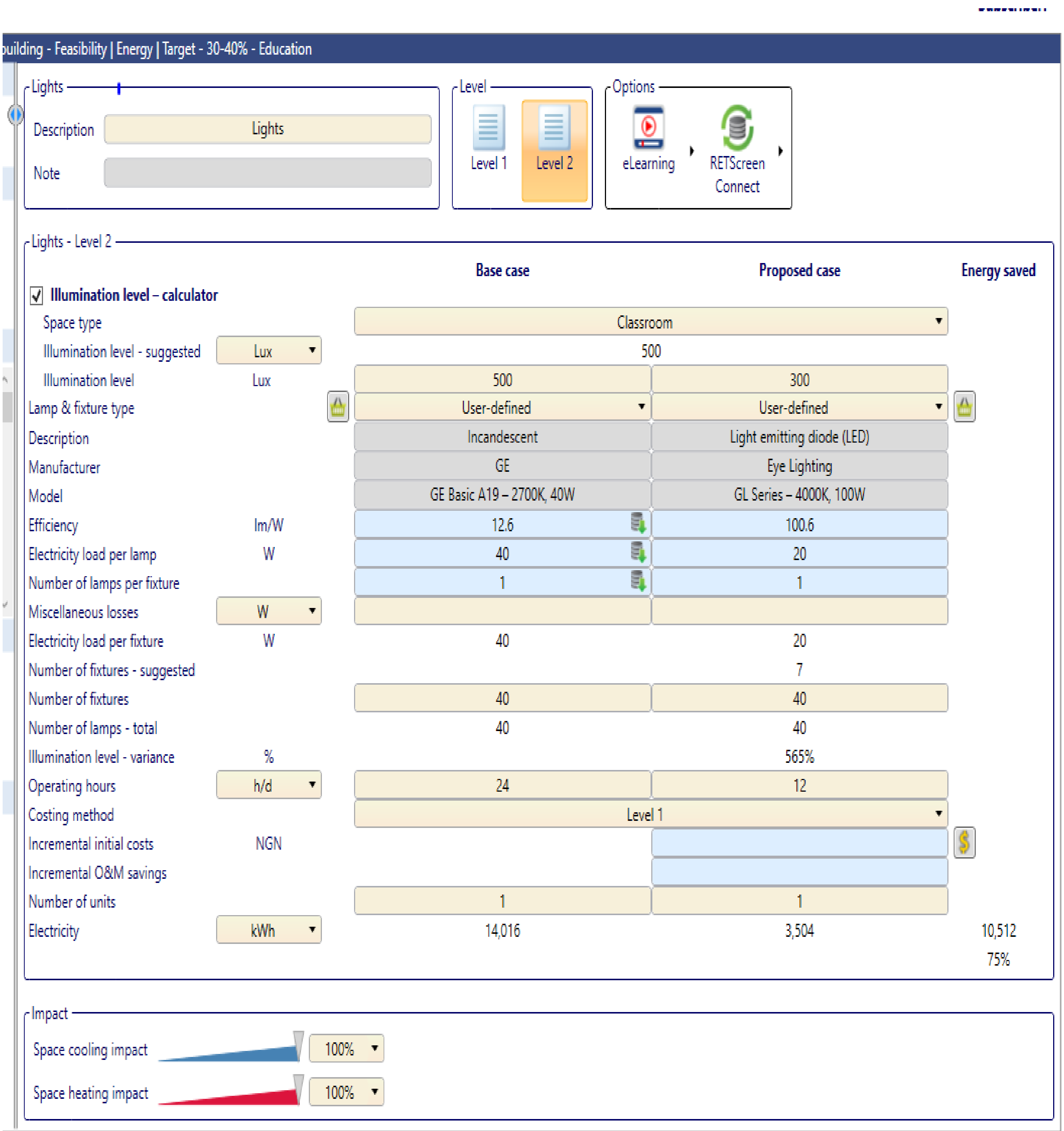


Figure 6: Energy saving by replacing the lighting system of Twin theatre building.

3.0. Results and Discussion

The building is in the Kaduna State University of Kaduna North Local Government. In this study, the lighting situation in the existing twin theatre building is assessed to understand its current state and identify potential areas for improvement. In order to determine the electric energy consumption for lighting, it is important to evaluate the working hours of light bulbs per day taking into consideration that light bulbs do not work equally long during working day and they are only used during weekends. The preliminary energy audit's base case energy consumption was determined using RET Screen by considering the quantity of lightings system and operating hours.

3.1. Optimized Lighting System

The energy saved and emissions savings on energy were simulated based on the lighting system measures proposed. Fig.6 depicts the lighting system simulation for the proposed strategy. However, the energy consumed after implementing the proposed strategy (optimized lighting system) was 14,016 kWh, equivalent to 47.3% which was 3,504 kWh less than the 10,512-kWh energy consumed by the base case lighting system which implying 75% energy savings in terms of lighting systems in the twin theatre building in Kaduna state University. (KASU) main campus. This demonstrates that implementing an optimized lighting system strategy can improve building efficiency, as shown in the proposed case in figure 6. LEDs have an efficiency of 100 lm/W and 2% miscellaneous losses. The overall electricity reduction was estimated at 75%, as detailed in Figure 6.

3.1.2. Greenhouse gas emission reduction Twin theater.

Renewable Energy and Energy Efficiency Technology Screen (RET Screen) is a software utilized to calculate the reduction in GHG. CO2, CH4, and N2 O are the gases that are calculated in the software to study the reduction in the analysis of the emission of these gases. The data on the reduction in CO2 emission and the data on energy generation for the location were used as a case study. Reduction of the amount of GHG was calculated using “RET Screen software.” A worksheet for the analysis of GHG emissions is also used. To have the emission analysis on the RET Screen software, the user needs to identify and find the following variables and their values, which represent the required inputs:

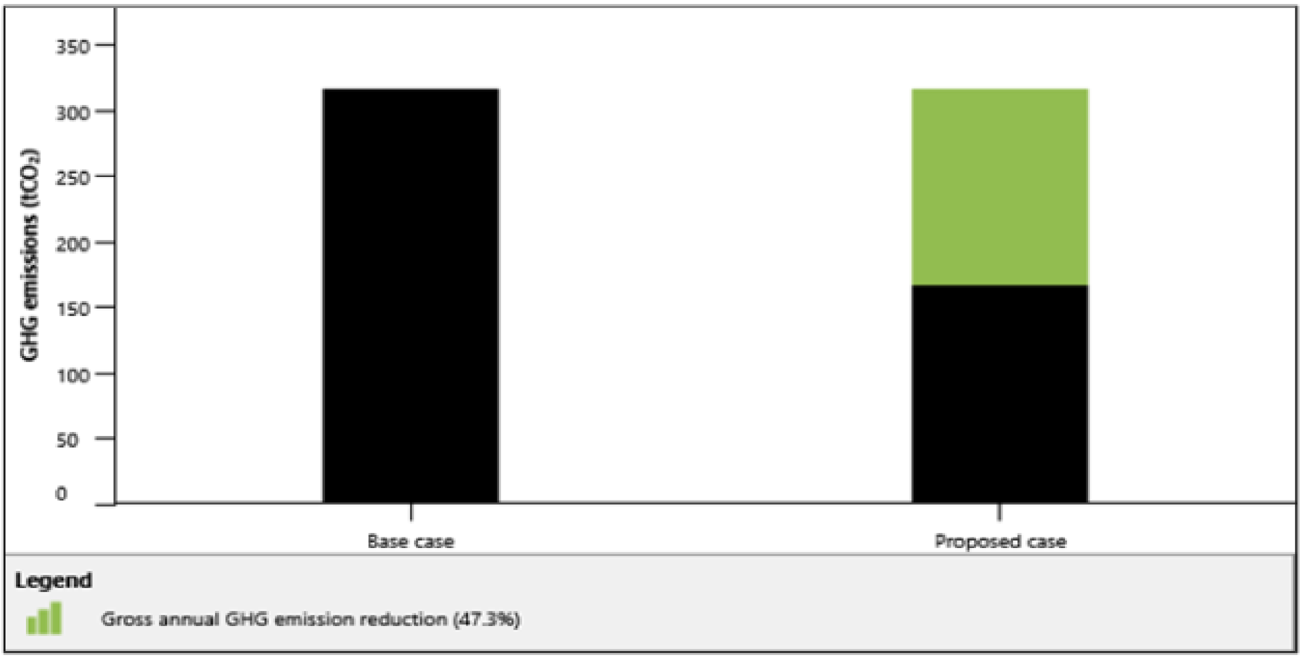
- The region of the country.
- Identify the type of fuel from the software list.
- Identify the emission factors for CO2, CH4, and N2 O for the fuel used.

- Identify the electricity generation efficiency for the identified fuel type.
- Identify the percentage of the losses of transmission and distribution for the electric system used.
- Identify the GHG emission factor for the electric system used.

Figure7: Presents GHG emission factor, Transmission and Distribution losses (T&D losses) and GHG emission factor of institutional building under study based on the data obtained from the RET Screen Expert. The value of the GHG emission factor is calculated by considering T&D losses, while the Gross GHG emissions factor excludes T&D losses. Emissions produced by fluorescent light bulbs associated with Mercury disposal were not considered. However, the Overall, GHG emission analysis showed that the replacement of conventional light bulbs (base case) by LED bulbs (proposed case) results in a significant reduction of CO_2 emissions. Annual gross GHG emissions reduction is 149.8 tCO_2, of the building under study equivalent to 47.3% In addition, according to Fig.7, the base case generated approximately 3I6.8 tCO_2, whereas implementing the combined proposed strategy generated approximately 166.9 tCO_2, implying that implementing the two proposed will help reduce carbon dioxide emissions by 24%. In addition, less energy use leads to a decrease in carbon dioxide emissions, aligning with global efforts to combat climate change. The reduction in greenhouse gas emissions is a positive contribution to environmental conservation and the mitigation of climate-related challenges. This clearly supports the claim that the proposed strategies are sustainable and environmentally friendly and should thus be implemented.

GHG emissions

GHG emissions



GHG emissions		
Base case	316.8	tCO_2
Proposed case	166.9	tCO_2
Gross annual GHG emission reduction	149.9	tCO_2

Figure 7: Gross annual GHG emission Reduction of Twin Theater Building

Conclusion

The benefits of this study displayed the vital role played by using efficient lighting systems which provided positive impact toward energy efficiency through lighting systems, coupled with global concerns over climate change, there is a clear rationale for the reduction in energy consumption in lightings in institutional buildings. However, switching from fluorescent to LED lighting in a twin theater building of Kaduna state University considering lumen degradation is presented. by replacing the inefficient incandescent lighting system with a LED-based system. The results showed that the annual energy savings reduction was 75% (from 14016 kWh – the base case to 3504kWh – proposed case). Switching light sources from fluorescent to LED significantly reduced electricity use by 10.512 kWh per year of the twin theater, more than 78%, decreasing and reducing emissions associated with the generation of electricity. Furthermore, the change would also reduce GHG emissions of 149.8 tCO_2, of the building under study which is equivalent to 47.3%.

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