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Assessment of Electrical Energy Consumption in Some Selected Tertiary Institutions Administrative Buildings in Niger State

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Abstract
High electrical energy consumption in public buildings and institutions poses a significant challenge, particularly in developing countries like Nigeria. Inadequate empirical studies on building energy use have resulted in a lack of electrical energy data, especially in tertiary institutions where bulk metering is common. This study aimed to assess the electrical energy consumption in selected administrative buildings of tertiary institutions in Niger State, with the goal of reducing electrical consumption and improving energy efficiency. Experimental data collection involved direct field measurements using a real-time Efergy wireless energy (EW4500) monitoring device. Current transformer sensors were attached to the main distribution panels of the administrative buildings at the Federal University of Technology Minna, Niger State Polytechnic Zungeru, and Niger State College of Education Minna. The objectives included evaluating electrical energy consumption, comparing total consumption across buildings, and analyzing energy consumption patterns. Results indicated that the Senate building at FUT Minna had the highest consumption rate at 2604.7 KWh/m², followed by Niger State Polytechnic Zungeru at 2579.1 KWh/m², both exceeding the global benchmarks of 128 to 130 kWh/m² set by the Chartered Institute of Building Services Engineers (CIBSE) and the Building Energy Efficiency Guideline for Nigeria (BEEGN). In contrast, COE Minna's administrative building, with consumption levels averaging 1579.1 KWh/m², generally fell within these benchmarks. The elevated energy consumption at FUT Minna and Niger State Polytechnic Zungeru was primarily attributed to operational inefficiencies, such as the continuous operation of HVAC systems and equipment during non-essential hours, even when buildings were not fully occupied. Hourly consumption patterns revealed peak usage during early working hours, with significant seasonal variations; however, both FUT Minna and Niger State Polytechnic Zungeru exhibited high energy use during off-peak periods, reflecting poor energy management practices. To address these inefficiencies, the study recommends conducting comprehensive energy audits and installing energy-efficient appliances at FUT Minna and Niger State Polytechnic Zungeru. Additionally, implementing smart metering, occupancy sensors, and optimized HVAC controls would significantly enhance monitoring and reduce energy consumption. These measures are critical for improving energy efficiency and ensuring sustainable operations in both institutions.

Keywords: Electrical Energy Consumption, Tertiary Institutions, Administrative Buildings, Energy Efficiency, Sustainable Energy Practices

1. Introduction

The global increase in energy consumption, particularly in the building sector, has reached alarming levels due to population growth, increased demand for building services, and higher comfort levels (Pérez-Lombard *et al.,* 2008; International Energy Agency IEA, 2015; Allouhi *et al.,* 2015). Buildings account for approximately 40% of global electrical energy consumption, with projections indicating further growth due to rising living standards (Xing *et al.,* 2011; Urge-Vorsatz *et al.,* 2013; Nejat *et al.,* 2015; Ibn-Mohammed *et al.,* 2015). Emerging economies are experiencing the fastest increases, with energy use growing at an annual rate of 3.2%, compared to 1.1% in developed countries (IEA, 2017). In Nigeria, the challenges of energy consumption are particularly pronounced in tertiary institutions, where the recent 50% increase in electricity tariffs has significantly exacerbated the financial burden on schools (Oladeinde, 2021). Institutions such as the University of Lagos (UNILAG) and the Federal University of Technology Minna have struggled to meet these rising costs, often resorting to measures like rationing electricity usage (Funmi, 2021; Iyabo, 2021). This financial strain is compounded by inefficient energy usage, which not only impacts operational budgets but also contributes to resource depletion and environmental degradation (Choong *et al.,* 2012). The administrative buildings of tertiary institutions are critical for this study due to their size, functions, and energy consumption trends. These buildings typically house essential administrative functions that support the overall operations of the institution, making their energy efficiency vital for reducing operational costs. This highlights the need for targeted energy assessments to identify inefficiencies and implement effective energy management practices. Moreover, insufficient information and benchmarks on energy consumption in Nigerian tertiary institutions hinder efforts to promote energy-saving initiatives (Bosch and Pearce, 2003; Entrop *et al.,* 2010). Addressing these challenges is crucial, as electrical energy consumption in universities is influenced by various factors, including building type, age, occupancy, operating hours, equipment, and weather conditions (Unachukwu, 2010). Addressing energy availability and consumption is critical for the functioning of tertiary institutions, impacting academic, social, and economic activities (Akanmu *et al.,* 2019). Therefore, this paper seeks to assess the electrical energy consumption in selected administrative buildings of tertiary institutions in Minna, Niger State, with the aim of reducing consumption and improving energy efficiency. By focusing on these specific buildings, the study aims to provide insights that can inform better energy practices and contribute to sustainable operations within the educational sector.

2. Literature Review

Energy is a crucial determinant of socio-economic growth and quality of life globally (American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE, 2013; Kousksou *et al.,* 2014). The rising energy consumption in buildings is alarming, with an average annual growth of 3.15% between 2005 and 2011, and global energy consumption predicted to reach 14 Gtoe/year by 2020, further increasing to 16.03 Gtoe/year by 2022 (Energy Information Administration EIA, 2008; EIA, 2022). Developed nations exhibit significant energy demands in the building sector: the US consumes about 40% of its energy in buildings, China consumes over 25%, and the UK's building sector accounts for 40-50% of energy use and over 100 million tons of CO2 emissions annually (Pout *et al.,* 2002; Perez-Lombard *et al.,* 2008; Bouchlaghem, 2012). In India, the building sector consumes 35% of total energy (Manu *et al.,* 2016), while Nigeria's building sector consumes about 40% of its electricity supply amidst inadequate and erratic supply (Akinbami and Lawal, 2009; Aderemi *et al*., 2009; Noah *et al.,* 2012). Despite the alarming trends in energy consumption, there is a notable lack of comprehensive studies focusing specifically on Nigeria and West Africa. While several studies have modeled and examined electricity demand determinants in both developed and developing countries, local research remains sparse. For instance, Ekpo *et al.* (2011) found that real GDP per capita, population, and industrial output drive electricity consumption in Nigeria, but the study did not delve into the specific energy consumption patterns of educational institutions. This gap is significant, as educational institutions are major energy consumers and face unique challenges related to energy management. In the context of higher education, studies such as those by Ward *et al*. (2008) and Hawkins *et al.* (2012) have identified correlations between energy consumption and factors like building size and occupancy in UK universities. However, similar analyses in Nigerian tertiary institutions are limited. For example, Adekunle *et al*. (2008) surveyed energy consumption at the University of Lagos, highlighting cooling load as the highest consumer, yet this study did not explore the broader implications of energy inefficiencies or provide actionable recommendations for improvement. Furthermore, while studies like those of Odunfa *et al.* (2015) have explored the impact of building orientation on energy demand in Nigeria, they do not address the operational inefficiencies that contribute to high energy consumption in administrative buildings. This study aims to fill this critical gap by focusing on the energy consumption patterns of administrative buildings in selected tertiary institutions in Niger State, providing insights that are currently lacking in the literature. Effective evaluation and assessment of energy use in buildings necessitate established criteria or indicators. Poel *et al.* (2007) describe energy-efficient buildings as those using "the amount of energy actually consumed or estimated to meet the different needs associated with a standardized use of the building." Cody (2009) adds that "energy efficiency is the relationship between the quality of the internal thermal environment in a building and the amount of energy consumption required to maintain this environment." Both definitions underscore the need for quantifying energy consumption, albeit with different occupant-related specifics. Standardization is crucial to ensure objective comparative analyses, taking into account parameters such as floor area and fuel type to avoid misleading conclusions (Deng and Burnett, 2000). This necessitates a responsive assessment approach tailored to specific buildings or building sets. Categorizing the built environment by purpose—residential, institutional, industrial, educational, recreational, and commercial—is an important step. Office buildings, in particular, consume significant energy despite their seemingly low proportion. For instance, office buildings in Canada and the USA are among the highest energy consumers (Perez-Lombard *et al.,* 2008; Lam *et al.,* 2010; EIA, 2009a). Similar trends are observed in Europe, Hong Kong, and China (Ürge-Vorsatz *et al.,* 2006; Li, 2008). Classifications serve as benchmarks to examine sectorial energy consumption profiles. The UK's Energy Consumption Guide (ECG19) and CIBSE Guide F highlight energy benchmarks and Energy Use Intensity (EUI) values for different building types (CIBSE, 2004). For example, CIBSE (2004) benchmarks for office buildings are 128 KWh/m^2/year for good practice and 226 KWh/m^2/year for typical practice. The Building Energy Efficiency Guideline for Nigeria (BEEGN) categorizes office buildings as follows:

- Under 130 KWh/m^2/year: best practice air-conditioned office.
- 130 - 210 KWh/m^2/year: good practice air-conditioned office.
- 210 - 320 KWh/m^2/year: typical existing air-conditioned office.
- Over 320 KWh/m^2/year: poorly performing air-conditioned office.

The globally accepted performance indicators are Energy Use Index (EUI), Energy Cost Index (ECI), and Carbon Emission Index (CEI). EUI, a widely used indicator in spatial context assessments, is calculated as follows:

$$\text{EUI (KWh/m}^2\text{/year)} = \frac{Total\ annual\ energyconsumption}{Total\ floor\ area\ of\ building} \quad (1)$$

Numerous EUI results for offices and other buildings have been reported globally (Deng and Burnett, 2000; Li, 2008; Perez-Lombard *et al.,* 2008; Saidur and Masjuki, 2008). Although no global threshold for building energy consumption exists, localized applications are crucial for developing specific evaluation frameworks. Economic indicators such as running costs can incentivize energy efficiency, particularly in developing countries (Zmeureanu *et al.,* 1999; Momodu *et al.,* 2010). Benchmarking is essential for raising awareness and improving the efficiency of non-domestic buildings (Carbon Trust, 2009). Whole-building benchmarking, using statistical standards, provides a simplified yet effective method for assessing energy performance (Wang *et al.,* 2016). Suitable reference benchmarks are crucial for accurate comparisons, especially where comprehensive performance data is lacking (Federal Ministry of Power, Works and Housing FMPWH, 2016).

3. Materials and Methods

A case study research strategy was adopted for this study to observe and analyze rising electrical energy consumption in a real-world context using multiple sources of evidence (Robson, 2003; Yin, 2009). Case study research is particularly suited to situations where context plays a significant role, especially when the boundaries between the subject of study and its context are not clearly evident (Yin, 2009).

3.1 Selection of Case Study Buildings

The administrative buildings selected were from three tertiary institutions: the Federal University of Technology Minna (FUT Minna), Niger State Polytechnic Zungeru, and Niger State College of Education Minna (COE Minna). These institutions were chosen based on their size, operational significance, and impact within Niger State's educational sector. As key administrative centers, these buildings represent a substantial portion of energy consumption within each institution. Their continuous, high-density use by faculty and staff during work hours makes them ideal for assessing patterns in energy use and identifying inefficiencies. The total ground floor area for each institution’s administrative buildings was 16001.67m^2 at Senate building, 16,597.40 m^2 at Niger State Polytechnic Zungeru and 14,981.51 m^2 at COE Minna. These buildings were analysed at both their final design (architectural drawing) and operational stages to understand their real-time energy consumption and management practices.

3.2 Instrumentation and Setup

Hourly electricity use profiles were recorded using an Efergy Wireless Energy (EW4500) monitoring device, which captures energy consumption trends over time. This device comprises three main components:

1. Current Transformer (CT) Scanner: Measures the current passing through the live wire of the feed cable.
2. Transmitter Unit: Transmits measured data to a display unit.
3. Display Unit: Displays real-time data on energy usage, demand profile, and cost of consumption.

The CT sensors were clipped onto the main distribution panel of each administrative building’s electricity distribution board. The sensor measures current inductively, transmitting data wirelessly to the display unit for analysis.

Display Unit Transmitter Unit CT Sensor Unit

Figure 3.1: Efergy Wireless Energy (Efergy E2 classic energy monitor components)

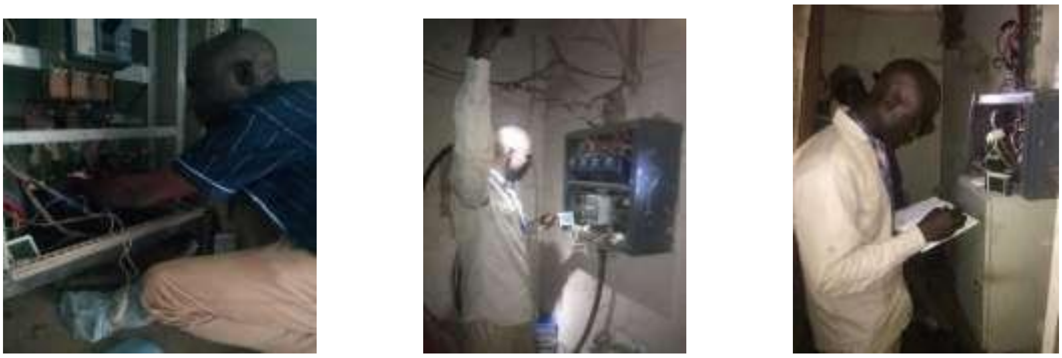

Figure 3.2: Clipping the jack-plug on the live wires at Zungeru Polytechnic and Niger State College of Education administrative blocks the main panel distribution board (MPDB).

Figure 3.3: Connection at the Zungeru Polytechnic and Niger State College of Education administrative buildings MPDB.

3.3 Sampling Strategy and Data Collection

To capture variations in energy demand, two sampling windows were established:

1. Morning Session (8:00 - 10:00 a.m. and 11:00 - 12:00 p.m.)
2. Afternoon Session (1:00 - 2:00 p.m. and 3:00 - 4:00 p.m.)

These sessions were chosen to reflect peak operational hours when energy consumption would likely be highest, given that each building's typical operational hours were 8:00 a.m. to 4:00 p.m., Monday through Friday. The exclusion of weekend and nighttime data presents a limitation in this study, as it does not account for non-operational periods, which could provide further insight into energy management practices.

3.4 Data Validation

The Efergy Wireless Energy monitor automatically calibrated before each measurement session to ensure precision. Additionally, data validation was conducted by comparing multiple readings over a set period, verifying that measurements were consistent and within the expected range. Any significant anomalies were re-measured to confirm accuracy.

3.5 Data Analysis

The collected data was quantitatively analyzed using Microsoft Excel. This software allowed for statistical analysis of energy patterns across different time frames and buildings, facilitating a comprehensive evaluation of consumption trends, peak usage hours, and inefficiencies across the three institutions. This systematic approach enabled the identification of key operational inefficiencies and the proposal of targeted recommendations to enhance energy efficiency in tertiary institutions in Niger State.

4. Results and Discussion

The study analysed electrical energy consumption within selected administrative buildings of three tertiary institutions: the FUT Minna, Niger State polytechnic Zungeru, and COE Minna. These institutions rely on electricity supplied from the national grid and generators. The lack of smart meters required direct monitoring through the Efergy wireless energy (ew4500) device**.**

4.1 Hourly consumption patterns

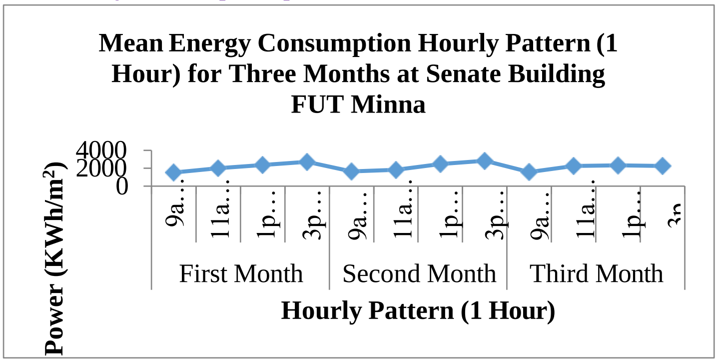

Figure 41: The mean energy consumption hourly pattern at Senate Building

Hourly energy consumption patterns revealed peaks during early working hours (9 a.m. To 12 p.m.) Across all institutions, as illustrated in Figures 4.1–4.3. At FUT Minna's senate building, energy consumption rates rose to 1522.75 kwh/m^2 in the morning, further increasing after lunch to 2350.25 kwh/m^2, reaching a peak of 2705.5 kwh/m^2 before declining as the day progressed. The early peak is attributed to heightened activity as staff begin work, requiring lighting, HVAC, computers, and other office equipment. The midday reduction correlates with the lunch break, where many occupants either leave or reduce their energy usage. Post-lunch increases suggest resumed high usage of energy-intensive devices.

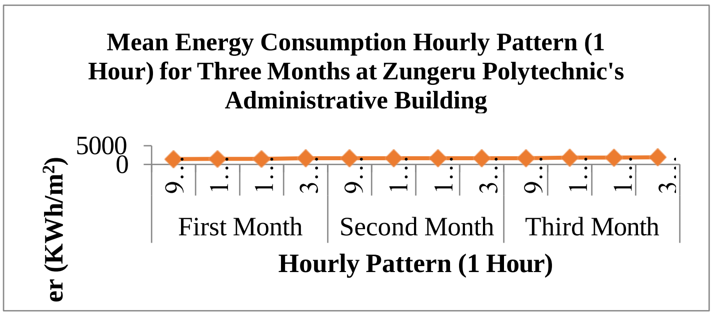

Figure 4.2: The mean energy consumption hourly pattern at admin block

For the administrative block of Niger State polytechnic Zungeru, hourly patterns displayed similar trends but with comparatively lower energy values, reaching peaks between 1433.75 kwh/m^2 and 1915.25 kwh/m^2. This comparatively lower usage may be due to fewer energy-intensive activities and reduced operational demands during off-peak hours. The increased number of people in the building means that more energy is required to keep the building functioning, such as lighting, and cooling; people tend to be more productive in the morning and require more energy intensive equipment to get their work done, such as computers, printers, and other office equipment and the higher energy consumption during this time was also likely due to the fact that more people are using the building's amenities. The decline in energy usage during lunch hours was likely due to the fact that many people leave the building to get food or take a break, thus reducing the number of people in the building and the associated energy consumption.

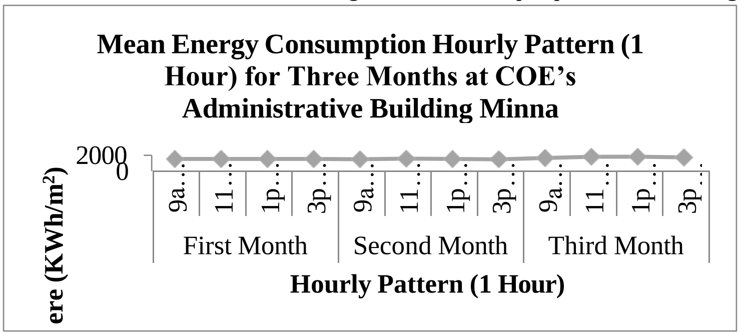

Figure 4.3: The mean energy consumption hourly pattern at COE administrative block

As shown in Figure 4.3, there was a stable trend variation in the mean energy consumption for the period of three months during when the research was conducted. There was an increase of energy consumed at 9am to 12pm, decreased during launch hours and an increase after launch hours for the first two months while for the third month there were rise in energy consumption. The mean energy consumed values were as followed; 1557.25 KWh/m^2, 1530.5 KWh/m^2, 1555.5 KWh/m^2, 1518.25 KWh/m^2, 1512.5 KWh/m^2, 1564.5 KWh/m^2, 1544.5 KWh/m^2, 1486 KWh/m^2, 1667.5 KWh/m^2, 1813.5 KWh/m^2, 1813 KWh/m^2, and 1741.5 KWh/m^2. The decline in energy consumption during lunch hours may be due to the fact that many people take lunch breaks and may turn off their equipment or reduce their energy usage during this time. It is also possible that there are energy-saving measures in place that are activated during these hours, such as occupancy sensors that turn off lights when a room is unoccupied.

4.2 Variation Comparison of Mean Energy Consumed at the Studied Administrative Buildings

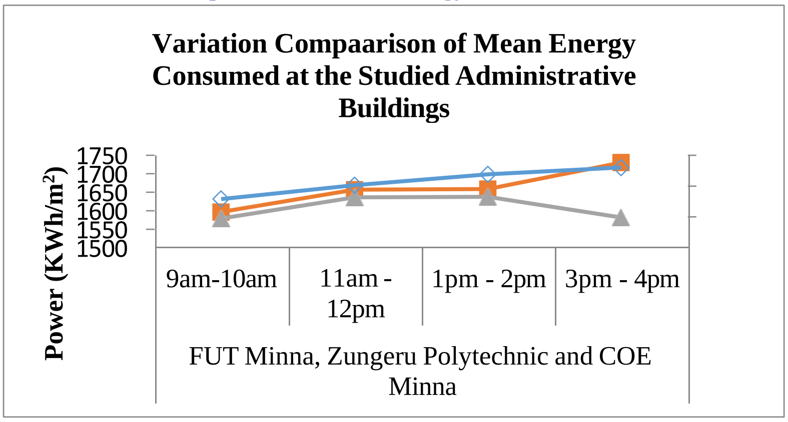

Figure 4.4: Variation Comparison of Mean Energy Consumed at the Studied Administrative Buildings

A comparative assessment indicates that Fut Minna consistently exhibited higher energy consumption compared to Niger State polytechnic Zungeru and COE Minna. Factors contributing to this discrepancy include the larger building area, higher occupancy, and increased reliance on HVAC systems at FUT Minna. These systems are frequently in use, even during off-peak hours, contributing significantly to elevated consumption levels. In contrast, COE minna demonstrated more consistent, lower energy consumption rates, peaking at approximately 1741.5 kwh/m^2. This indicates better energy management practices, likely including controlled hvac usage and possibly energy-saving policies or occupancy sensors that reduce energy demand when spaces are unoccupied

4.3 Operational inefficiencies and recommendations

The operational inefficiencies observed at FUT Minna and Niger State polytechnic Zungeru, such as continuous HVAC operation and high usage during off-peak hours, underscore the need for energy management improvements. These institutions would benefit from implementing smart metering, occupancy sensors, and optimized hvac controls to manage peak and off-peak energy usage effectively. Additionally, conducting comprehensive energy audits could further identify specific sources of inefficiency, allowing tailored solutions to minimize waste and improve sustainability.

5. Conclusion and Recommendations

The study assessed the electrical energy consumption in the administrative buildings of the FUT Minna, Niger State Polytechnic Zungeru, and COE Minna, focusing on typical operational conditions without smart metering. Results indicated that the Senate building at FUT Minna and the administrative block at Zungeru Polytechnic exhibited energy inefficiencies, especially in offices utilising air conditioning, where energy consumption exceeded established benchmarks. In contrast, the COE Minna administrative block's energy performance aligned more closely with benchmarks, sugg - 7esting better efficiency. Key contributors to high energy use at FUT Minna and Zungeru Polytechnic include building size, extensive cooling needs, and a higher density of electronic equipment. These findings highlight the importance of targeted energy management strategies in large, equipment-intensive administrative buildings to improve overall efficiency and reduce carbon emissions. The study's limitations include the absence of smart meters for precise, continuous monitoring and restricted sampling times (daytime hours only), which might not capture total daily energy variations. Future research should consider including nighttime and weekend measurements, alongside real-time smart metering, to provide a comprehensive profile of energy use. To enhance energy efficiency and establish effective energy management in Nigeria's tertiary institutions, the following recommendations are proposed: Initiate systematic energy audits across all administrative buildings to pinpoint high-consumption areas and equipment. Audits should specifically target HVAC systems and other major energy users, providing a basis for subsequent interventions. Investing in smart meters and energy monitoring systems such as Kill-

A-Watt and Belkin Conserve Insight will enable real-time data collection, offering administrators detailed insights into energy consumption patterns. This data can help manage peak loads and improve energy distribution. Develop and enforce institutional policies focusing on energy conservation. Training administrative staff on energy-efficient practices—such as turning off equipment when not in use, using energy-saving settings on devices, and reducing reliance on air conditioning—can foster a culture of conservation. Replace incandescent and fluorescent lighting with LEDs, install occupancy sensors in low-traffic areas, and encourage the use of energy-efficient office equipment. These steps can substantially reduce energy waste. By adopting these recommendations, Nigeria's tertiary institutions can reduce operational costs, lower carbon emissions, and serve as models of energy efficiency in educational administration.

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