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Evaluation of Energy Performance of Main Administrative Office Buildings of Universities in North-Central Nigeria

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Abstract
The adverse effect of increasing energy demand on global climate has made buildings objects of research globally. Generally, in Nigeria, lack of building energy data and specifically energy consumption information related to building facilities in universities has been given less attention where bulk-metering has been the common practice. Consequently, energy demand of individual building remains unknown. Hence, Energy Use Index (EUI) was adopted as energy performance indicator for main administrative office buildings of federal universities in North-Central Nigeria. This study been exploratory in nature adopted a case study technique. Simple energy audit was conducted in the absence of individual monthly energy bills. The end-uses disaggregation shown that cooling load accounted for more than 40% of annual energy consumption. Also, the derived EUI of 197.85KWh/m^2/yr was above benchmark for similar buildings globally. This outcome implies that the buildings are energy inefficient and need for sub-metering and regular energy audit.
Keywords: Energy audit, Energy consumption, End-uses, Energy Use Index, Office buildings.

1. Introduction

Environmental sustainability is one of the threatening issues facing the entire world in the 21st century. This has been traced to rapid increasing energy demand for comfortable living standards for growing global population (Rai, 2004). The adverse effect of increasing energy demand particularly greenhouse gas emission has been strongly linked with global warming (Building Research Energy Conservation Support Unit [BRECSU], 2000; ECN, 2015) and cumulatively the dreaded case of climate change as established by quite a number of empirical studies globally (Mazria, 2003; Doughty & Hammand, 2004; Kasozi &Tutesigensi, 2007; Perez-Lombard et al., 2008; Rahbarianyazd, Raswol, 2018). However, improving energy efficiency of buildings had been proven to be fundamental to climate change mitigation by monitoring energy performance of buildings, which also has inherent economic advantage (EC,2003; IEA, 2008). This scenario has made building energy efficiency an integral part of most environmental discourses, thus made buildings object of research globally. Building sector had been found to be accounted for approximately 30% to 45% consumption of energy supply globally (Pout et al., 2002; Huovila, et. al., 2007; UNDP, 2010; Asimakopoulus, et. al., 2012). Moreover, the larger percentage of energy consumed by the generality of building industry globally was found to be consumed during the occupancy or operational phase with cooling energy being the dominant end-use in most cases among other end-uses that included lighting, appliances and building services (Cole & Kernan, 1996; Heiselberg, 2012a; Horsely, 2004; Suzuki & Oka, 1998). Meanwhile, non-domestic buildings, particularly office buildings had been identified as the building type that consumed largest energy during operational phase. This feat had made office buildings a major target for energy reduction globally (Ravetz, 2008; Sadrzadehrafiei, et al., 2012; DEEC, 2013; Chung & Rhee, 2014). In this light, most developed nations have gone to the extent of establishing benchmarks for various building categories and components towards energy reduction for sustainable built environment, while most developing nation including Nigeria are lagging behind in this noble objective (Janda, 2009; Iwaro & Mwasha, 2010). Tertiary educational institutions particularly universities are indispensable organisations globally because of the critical services being rendered to the nations. According to European Commission Joint Research Centre [ECJRC], (2012) universities had been classified has as high energy consuming organisations owing to possession of large stock of buildings and subsequently are expected to report their energy use and improve their efficiency as part of their cooperate responsibilities (Maimunah & Shehu, 2010). In the same vein, Adekunle et al. (2008) had equally stressed the need for monitoring and controlling of energy consumption in Nigerian universities owing to limited supply in order to achieve the aim of teaching, research and community development. However, buildings in universities in Nigeria practise bulk-metering system which make determining energy consumption of individual building a major challenge. Generally, in Nigeria paucity of building energy data which is as a result of inadequate empirical studies on building energy use and absence of local benchmarks were known facts (Mua'zu,2011). This is visible in limited effort that has been geared towards establishing the actual energy end-use distribution for various building categories (Imaah, 2004b; Fadamiro & Ogunsemi, 2004). Also obvious is less attention given to studies related to energy use of buildings in Nigeria universities. Having identified these problems, this study investigated energy consumption and pattern of energy end-uses distribution with the cumulative aim of determining the performance benchmark for main administrative office buildings of universities in North-Central Nigeria being a typical office building similar in both design and operations to other public office buildings.

2. Review of Literature

2.1 Brief Global Perspective of Energy Use in Buildings

The building sector which has been strongly associated with consumption of almost 40% of global energy supply (Huovila et.al., 2007). Nevertheless, in recent decades there has been a continuous increase in the global energy use by the built environment. The annual average energy growth between 2005 and 2011 was estimated to be 3.15%. The global energy consumption rate was 8.92Gigaton of oil equivalent/year (Gtoe/year) in 2011 according to International Energy Agency [IEA] in 2014. This value was projected to rise to 14 Gtoe/year by the year 2020; this invariably means that there is a growing trend in energy consumption of the global building industry. This scenario is expected to continue with the dynamics of energy demand particularly countries with emerging economies in Africa, South America, South-east Asia and Middle East (IEA, 2004). This is not unconnected to the fact that energy is significantly necessary and a major determinant of socio-economic development and quality of life of citizenry all over the world (Kousksou, et al., 2014; ASHRAE, 1990). In European countries, built environment and their interrelated activities were valued to account for around 40-45% of total energy demand (United Nation on Environmental Programme UNEP [UNEP], 2007). Brief overview of building energy demand of few developed nations shows that, building sector in United States of America consumes approximately 40% of total energy supply and is accountable for nearly 40% of greenhouse gas emissions (Springer Science and Business Media, 2017). Similarly, in China the building industry was found to be responsible for consumption of above 25% of entire energy supply, this value is expected to rise to about 35% by year 2020. Furthermore, the situation in United Kingdom revealed that building industry accounted for between 40-50% of total energy use and greenhouse gases emission which is over 100 million tons of CO_2 per annum. Equally, in India it was reported that building sector accounted for nearly 35% of the of the total energy supply (Manu, et al., 2016). Studies have shown that public buildings were responsible for larger consumption of global energy supply in comparison to residential buildings. Precisely, office buildings have been established as one of the highest consumers amidst non–domestic buildings (Ravetz, 2008). According to investigation by Kumar et al (2010) fossil fuel that has harmful greenhouse gasses has by-product had been reported to account for largest supply of 79% of world energy while the renewable energy (clean energy) is just about 18% and 3% from Nuclear power source.

2.2 Review of Energy Situation and Office Buildings Energy Consumption in Nigeria

The energy consumption scenario in Nigeria is closely similar to the global reported cases from industrialized nations, building sector was reported to consume around 40% of electricity supply from the national grid (Akinbami, 2010). However, with epileptic nature and the gross inadequacy of power supply being experience in Nigeria, approximately about 40% of the entire populace were estimated to have access to electricity supply from the central supply and these categories of people were majorly urban dwellers (Anigbogu, 2011; UNDP, 2011). The erratic and inadequacy of energy supply is augmented by back-up generators (Adenikinju, 2005). This probably explained why electricity supply to office buildings in Nigeria through back-up power is about 75% of the time energy is required (Batagarawa, et al., 2011). In Nigeria, few numbers of studies have looked at energy consumption of built environment particularly office buildings. Mambo and Mustapha (2016) had earlier exposed the open-ended nature of how much energy is consumed by average building in Nigeria. Also, Mua'zu (2012) investigated operational energy consumption of selected office buildings in Abuja Nigeria to understand their status and energy performance. The derived performance was between 13KWh/m^2 /yr to 134KWh/m^2/yr, this result was attributed to prevalent suppressed energy supply. Also, Batagarawa (2013) investigated the likelihood of incorporating phase change material (PCM) on building envelope to save energy and improve indoor comfort. The end-use distribution results shown that cooling, equipment and lighting loads was 40%, 48%, and 12% of the annual energy consumption respectively. Furthermore, Mua'zu (2015) derived a typical performance baseline for 22 office buildings in Abuja. The end-uses disaggregation findings shown that 59%, 43%, 15% and 4% for cooling, equipment, lighting and services respectively and the EUI ranged between 90 KWh/m^2 /yr -134 KWh/m^2 /yr. In like manner, Salihu et al. (2016) examined the demand, supply and consumption of energy in office buildings in Kaduna metropolis. The study revealed that cooling, equipment and lighting loads accounted for 51%, 35% and 14% of energy demanded. It was obvious that all these studies were out of academic environments. The few studies had attempted to examine energy consumption in universities included by Adekunle et.al. (2008) that examined electricity consumption and demand in University of Lagos, Nigeria. The study concluded that electricity accounted for 79% of energy use among other sources that included kerosene, diesel, fire wood, liquified petroleum gas, charcoal and firewood. The study further revealed that space cooling and lighting are the major end-uses which accounted for 33% and 7% respectively. Also, Adebisi et al. (2019) x-rayed energy performance of selected administrative buildings in tertiary education that included university, polytechnic and college of education in Niger state, Nigeria. The study derived performance benchmark at 181.34

KWh/m^2/a while the end-uses distribution for VAC, Lighting, Equipment and building services consumed 45.6%, 9.6%, 44.4% and 0.003% respectively. This implies that limited attention has been given to energy consumption of individual building most importantly administrative office building to understand their operational energy consumption pattern and performance towards a sustainable campus. This scenario created the huge gap that was filled by this study.

3. Methodology

This study is exploratory in approach via case study technique as it has been used for similar studies globally (Francis, 2001; Ogbonna, 2008; Batagarawa, 2013; Mua'zu, 2015; Adebisi, et al., 2019). The case study buildings were picked using purposive sampling, the buildings studied were main administrative office buildings of five out of seven (7) federal universities in North-Central Nigeria (Figure 1). This is so because one is uncompleted and the other newly completed has not been put into use. The required data was collected by conducting simple walkthrough energy audit in the absence of monthly energy bills because the universities buildings were not metered separately. The audit was conducted using building energy survey form and observation checklists as adapted from similar research studies (Mua'zu, 2012; Batagarawa, 2013; Adebisi, et al., 2019). Also, Energy Use Index (EUI) was used as performance indicator been the most widely used globally, because it allows for accurate comparison among buildings of different sizes. EUI is the summation of total energy use per unit floor area of condition space per annum. Hence; EUI (KWh/m^2 /yr) is expressed as:

$$\frac{\text{Total annual energy consumption}}{\text{Total floor area of building}}$$

Annual energy consumption estimation was carried out using mathematical model adopted from studies of similar characteristics (Batagarawa, 2013; Rosenberg, 2014; Adebisi, et al., 2019). The detail of the mathematical model is express as follows:

Qa = energy rating x quantity x duration of use (hours) ………equation (1)

Where Qa is the quantity of energy consumed by appliance; obtained from manufacturers/label/maintenance manual.

$QA = Qa_1 + Qa_2 + Qa_3 + Qa_n$……. equation (2)

Where QA = total energy consumed by appliance

Qa_1, $Qa_{2……}$ Qa_n = different appliances. The same equation (2) is applied for Ventilation (QV), air conditioning (QC) and lighting (QL). Hence,

$QV = Qv_1 + Qv_2 + Qv_3 +\dots Qv_n$……..equation (3)

$QC = Qc_1 + Qc_2 + Qc_2 + Qc_n$ ………..equation (4)

$QL = Ql_1 + Ql_2 + Ql_3 + Ql_n$…………….equation (5)

So total energy consumption (QT),

QT=QA+QV+QC+QL…………. equation (6)

Also, total energy supply (QS),

$QS = Q_P + Q_G$…………equation (7)

Where Q_P, energy from primary source, and Q_G energy from generator.

However, some assumptions were made in the course of the estimation which were in line with energy audit conducted by Energy Commission of Nigeria (ECN) in conjunction with Japan international cooperation Agency (JICA) in 2017 on selected public office buildings in Abuja. These assumptions included:

i. Appliances such as electric kettles, printers, and photocopy machines are assumed to be actively used for 2 hours daily while other appliances like computers, air-conditioners, fans, lighting and refrigerators are used for averagely 8 hours daily.
ii. Number of operational days in a year was taken to be number of official working day in Nigeria which is 247days.

The annual energy consumption was further disaggregated into end-uses; Ventilation and Air-conditioning (VAC), lighting, equipment and building services in the absence of no heating load. Meanwhile, for ethical reasons the buildings were coded with acronyms CSB 1-CSB 5 meaning case study building one to five in the course of data presentation, analysis and interpretation of results. The data was analysed using descriptive statistics that included tables, percentages. Furthermore, a base case model being a simplified hypothetical case that derived its characteristics from the existing buildings was generated based on the cumulative average values of primary data collected for all the five case study buildings. Revit 2017 software was used to produce 3D model of the base case building. This was later imported into DesignBuilder V6.0 2017 simulation software to estimate the annual energy and energy use index to validate the mathematical model estimation. DesignBuilder V6.0 2017 had been checked and validated internationally for its accuracy in modelling and energy calculations capability in accordance with the European Standard EN15265 (DesignBuilder, 2011). Consequently, a performance baseline was derived in terms of EUI for this category of office buildings. Meanwhile, in the absence of local benchmark in Nigeria, the results were compared with Chartered Institute of Building Service Engineers (CIBSE) in UK and South African Building Regulation SANS 10400-XA benchmarks for office buildings where climate is similar to Nigeria.

Figure 1. Pictorial views of the case study buildings (Author, 2022)

4. Results

4.1 Outcomes of Field Survey Exercise

The results of the building configuration revealed that all the case study buildings were mixed-mode in nature (combination of artificial and natural ventilation strategies) and incidentally have their main axis of orientations (longest side) in the North-East/South-West direction where the openings were majorly located. The plan layout of the buildings cut across, narrow, compact, compact/composite and courtyard plan system. The gross floor areas (GFA) of the surveyed buildings were 4,661.13m^2, 6,339.52m^2, 6292.13m^2, 3327.15m^2, 1242.36 m^2 for CSB 1, CSB 2 and CSB 3, CSB 4, CSB 5 respectively. The conditioned floor area (CFA) accounted for 67% (CBS 1), 79% (CBS 2), 83% (CBS 3), 84% (CBS 4) and 90% (CBS5). Furthermore, average number of floors was estimated to be 3 while floor to ceiling height was approximately 3.1m. The glazing was made of single pane of 4mm thick glass which cut across clear/transparent, tinted or reflective glass materials which were evenly distributed along the main axis accounted for about 51%, 70%, 75%, 65% and 20% of the total external surface area for CSB 1, CSB 2 and CSB 3, CSB 4 and CSB 5 respectively. All external opaque walling materials and internal partitions for all the buildings were 225 x 225 x 450mm hollow sandcrete blocks which were plastered on both surfaces and finished with different colours of texcote and emulsion paints as the case may be, have an estimated U-Value of 1.4W/m^2K. The ground floor were solid concrete slabs laid directly on the soil and finished with ceramic and granite tile while the suspended floors were mostly conventional 150mm solid reinforced concrete slab also finished with various types of ceramic and granite tiles. The average estimated U-value of ground floor and suspended floors are 4.4W/m^2K and 6.7W/m^2K respectively. Also, the roof covering for all buildings was longspan aluminium sheets of different colours and suspended ceiling with calculated U-value of 0.39W/m^2K. The U-Values for building envelope materials were estimated using Also, Chartered Institute of Building Service Engineers (CIBSE) (2007) formula for calculating materials thermal transmittance value. Furthermore, external shading was a noticeable feature on all buildings. The shading devices types cut across vertical, horizontal, combination of vertical and horizontal and overhang with varying depth of 450mm, 600mm and 900mm. Conclusively, all buildings have their operating hours conforming to the standard eight (8) hours working period in Nigeria which started from the hours of 8am to 4pm with isolated cases of working beyond official hours. The occupancy density of these buildings stood at 19.84m^2, 16.13m^2, 21.32$m^{2,}$ 15.33m^2 12.18m^2 for CSB 1, CSB 2, CSB 3, CSB 4, and CSB 5 respectively. These occupancy density values were higher than the range of values of 0.65 m^2 minimum and 10.3m^2 maximum as stipulated in National Building Code of Nigeria (2006). The base case model being a simplified hypothetical case that derived its characteristics from the existing buildings was generated for this study from the preliminary data collected during field study. Based on this premise, the summary of the significant base case parameters and their sources is presented in Table 1 while 3D building geometry modelled with Revit 2017 which was later imported to DesignBuilder V6.0 2017 for estimating annual energy consumption is presented in Figure 2.

Table 1. Base Case Parameters and their Sources

Base case description	Parameters	Source
Orientation	NE/SW (longer side)	Fieldwork
Plan form	Rectangular /courtyard plan form	Fieldwork
Number of floors	3	Fieldwork
Floor to ceiling height	3.1	Fieldwork
Number of occupants	243	Fieldwork
Occupancy density	17	Fieldwork
Gross floor area	4138m	Fieldwork
Condition floor area	3292m^2 (80%)	Fieldwork
Each floor area	1103m^2	Fieldwork
Building volume	13219m^3 (occupants x density x building height.)	Fieldwork
Window to wall ratio	57%	Fieldwork
External opaque wall	225 x 225 x 450mm hollow sandcrete blocks (1.4W/m^{2}K)	Fieldwork
Shading device	Horizontal/vertical (600mm deep)	Fieldwork
Internal partition	225 x 225 x 450mm hollow sandcrete blocks (1.4W/m^{2}K)	Fieldwork
Glazing type	Tinted reflective glass	Fieldwork
Glazing thickness	4mm	Fieldwork
Ground floor	Solid concrete slab (4.4W/m^{2}K)	Fieldwork
Other floors	Solid r.c slab with dropped ceiling (6.7W/m^{2}K)	Fieldwork
Roofing	0.36W/m^2	Fieldwork

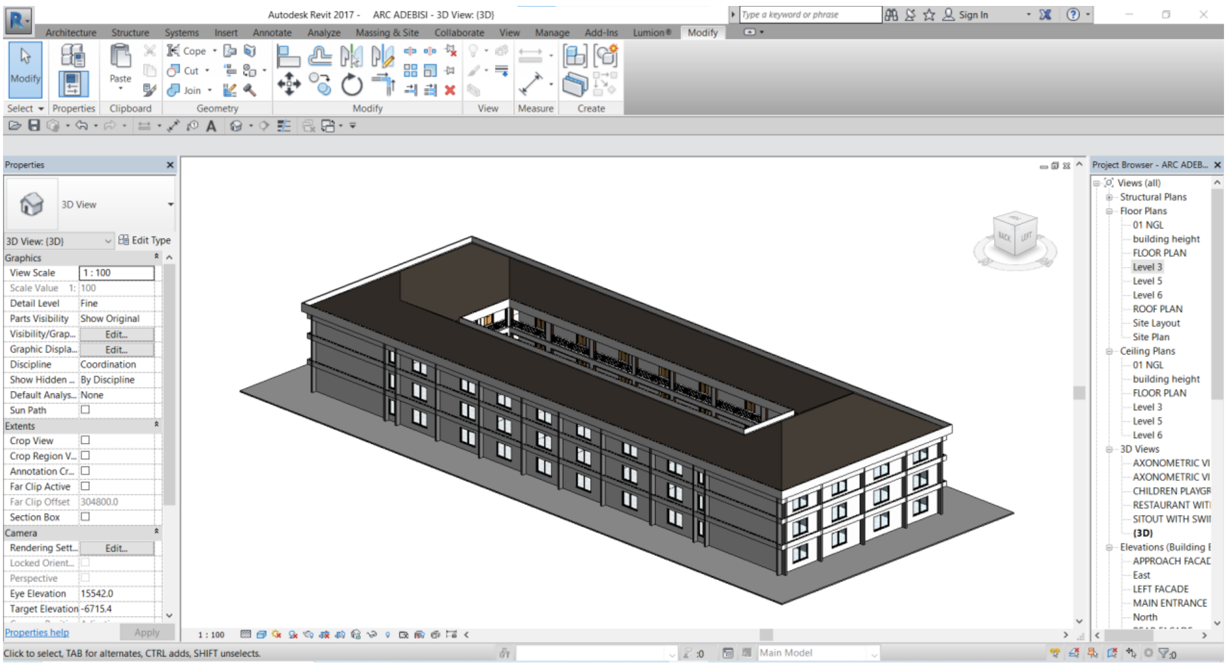

Figure 2: Base Case 3D Building Model (Author, 2022)

4.2 Energy Use Index (EUI) and End-Use Disaggregation

The total energy consumed on an annual basis by each of the case study building was computed and the respective EUI estimated. Meanwhile, the disaggregating energy consumption into end-uses gives an insight into quantity of energy demanded by each end-use in a building. Based on this premise, the end-uses is classified into ventilation and air-conditioning (VAC), lighting, equipment and building services in the absence of no heating load. The VAC represented the aggregated annual energy used for ventilation and air-conditioning. The lighting load was the annual cumulative loads demanded by the lighting system of the buildings while the equipment otherwise referred to as appliances load accounted for the overall annual energy consumed by the equipment and other electrical appliances being used by the occupants. Finally, the building services load determined the annual energy use by building service equipment like lift, escalator, water pump machine and the likes available in any building. Therefore, the annual energy consumption (primary and generator) which averagely was estimated to be 63% to 37% and the corresponding EUI is presented in Table 2. In reference to Table 2 the derived EUI performance baseline stood at 197.85 KWh/m$^{2/}$a. In like manner, the annual energy consumption was disaggregated into end-uses. The results for all the five buildings audited were presented in Table 3. Finally, the results of the annual energy consumption and the estimated EUI from the base case model are 978,452.33 KWh and 233.91 KWh/m$^{2/}$a respectively.

Table 2. Annual Energy Consumption and Energy Use Index

Case study building	Annual energy consumption (KWh)	EUI (KWh/m$^{2/}$a)
CSB 1	767,862.34	164.74
CBS 2	1,943,240.32	306.53
CSB 3	976,432.44	155.18
CSB 4	464,675.33	117.87
CSB 5	295,214.22	237.64
Derived Performance baseline	197.85 KWh/m$^{2/}$a	

Table 3. Disaggregation of annual energy into end-uses

Case study building	VAC (KWh)	Lighting (KWh)	Equipment (KWh)	Building services (KWh)
CSB 1	358,189.37	79,294.20	330,358.42	20.35
CBS 2	913,264.67	194,324.03	835,593.33	58.29
CSB 3	411,078.05	84,949.62	447,475.46	39.06
CSB 4	185,870.13	60,407.79	217,932.73	46.99
CSB 5	117,790.47	50,186.41	126,942.11	8.86
Cumulative % average	42.17%	10.54%	44.03%	0.003%

5. Discussion

Proper orientation of buildings played a significant role in energy consumption of buildings an established by extant literature This study is conducted in a tropical hot and humid climate in Nigeria. However, for effective energy efficiency, buildings in the tropical climate were expected to reduce their exposure to solar radiation and most openings (windows) were recommended to be along the main axis of East/West directions. This implies that longer side where most (openings) windows are located should be facing the North/south direction. Coincidentally, all the case study buildings had their main axis of orientation in the North-East/South-West direction which exposed most opening to direct effect of solar radiation. Although, the buildings introduced shading devices and a courtyard system which is a borrowed idea from traditional architecture in Nigeria that allows for efficient day-lighting and improves ventilation. Improper orientation still significantly responsible for the high energy consumption particularly the cooling loads which partly accounted for high Energy Use index recorded. The buildings did not adopt any advanced energy efficient envelope technology, rather the building envelope materials observed in term of waling, flooring, glazing and roofing materials were in line with conventional provisions of National Building Code (2006) in Nigeria.

The derived EUI performance benchmark for buildings under study was 197.85 KWh/m$^{2/}$a from the fieldwork while simulated EUI result was 233.91 KWh/m$^{2/}$a. These results shown that simulated value is slightly higher than the fieldwork result, this scenario may be owing to stable and uninterrupted energy flow in the building simulation as against the daily interruption/alteration between generator and mains supply observed in the fieldwork. However, in the absence of availability of local benchmark and attempt to compare the results with global best practises this value in comparison to CIBSE (2004) benchmark for similar office building which stood at 33KWh/m^2 and 54KWh/m^2 respectively for good and typical benchmarks. This implies that the EUI obtained from this study is far above good and typical best practice benchmarks. This may be owing to the difference in climatic conditions under which the CIBSE based its benchmarks on compares to warm climate experienced in Nigeria as well as gap in technological advancements between the countries. Therefore, CIBSE benchmarks may not be adoptable for office buildings in Nigeria. Notwithstanding, comparing these results to South African Building Regulation SANS 10400-XA benchmarks established in 2011 where the climate is similar to Nigeria but technology is a bit more advanced compared to Nigeria. The benchmarks stated that EUI under 130KWh/m^2/yr, between 130-210KWh//m^2/yr, 210-320KWh//m^2/a were established for best, good and typical practices

respectively while any case of EUI more than 320KWh//m$^{2/}$yr was categorised as poor performing office building. The derived EUI performance benchmark for the buildings under study was 197.85 KWh/m$^{2/}$a fell short of best practice. These outcomes implied that these buildings are not energy efficient. However, these buildings could be refurbished to improve their energy efficiency being the usual practise globally.
Furthermore, the annual energy consumption was disaggregated into end-uses. End-uses values affords the opportunity of determining the sources of considerable energy demand where savings can be significant. Therefore, the results of disaggregation into various end-uses for all the five buildings audited as presented in Table 3 revealed that aggregately VAC, Lighting, equipment and building services consumed 42.1%, 10.54%, 44.03% and 0.003% of the annual energy consumption. The results implied that VAC (cooling load) as a weather induced load contributed to more than 40% of energy use in this category of office buildings. These outcomes had validated and re-affirmed the dominance of cooling loads as equally submitted by global reports on similar office buildings and earlier studies on office buildings in Nigeria (Batagarawa, 2013; Mua'zu, 2015; Salihu, *et. al*., 2016; Adebisi, et al., 2019). This implies that cooling loads is an avenue where significant energy saving can be achieved.

6. Conclusion

Based on extant literature, issue of energy use by individual buildings in Nigerian universities has generally been given less attention specifically their main administrative buildings being a typical public office building in design and operations. However, having compared the performance with other global best practises, it was clearly evident that these buildings are not energy efficient. Although, these buildings could be refurbished to improve their energy efficiency being the usual practise globally. Notwithstanding, disaggregated end-uses consumption pattern equally affirmed the dominance of cooling loads which is line with global reports and a pointer to where significant energy savings could be achieved. Hence, there is need to give required attention to bio-climatic variables particularly the proper building orientation as it goes a long way to determine energy balance of buildings in tropical climate like Nigeria. Also, universities managements through facilities managers of these universities' buildings should adopt regular energy audit and embrace sub-metering technique of major buildings particularly main administrative buildings. This act will serve as part of their cooperate responsibilities and will ensure clear understanding of energy consumption of individual building and be of great assistance to overall energy management in the university community.

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