 

# A Comparative Analysis of Carbon Footprints of Selected Office Buildings in Jos, Nigeria

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**Abstract**
Carbon Foot Print (CFP) is a parameter used in appraising and examining office, residential and commercial building's energy efficiency during design, construction, renovation and operations. It is also a bases of determining the environmental impact of a building at any point of its life-cycle. In this research, data was obtained from measured energy use as opposed to in-situ audited energy use. An E2 Wireless Electricity monitor was used to obtain this data. eQUEST 3-65 software was used for the purpose of simulation of energy consumption. This research indicated a Carbon Foot Print (CFP) of between 21 to 41 kWh/sqm/year for the buildings studied in Nigeria. This gives an average of 31 kWh/sqm/year for the three (3) buildings studied. Similar buildings in North America and Europe have CFP of up to 150 kWh/sqm/year. This low CFP is not unconnected with the fact that these buildings lack standard HVAC equipment and other energy consuming devices that are required standards features in developed regions. On the positive side, this low CFP indicates that the Carbon Foot Print, and by extension, the environmental impact of the buildings in developing regions are also low. This research is part of a larger study on energy use and assessment in developing diaspora.
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## 1.0 INTRODUCTION

Carbon footprint is the quantity of the greenhouse gas (GHG) emissions that are directly and indirectly produced by activities of man or accumulated over the life stages of elements of the built environment, product or services. (Wiedemann, Minx, 2007, & Krishna Prasad, et al 2022). 75% of $CO_2$ emissions are produced in cities and these cities consume between 60 and 80% of energy produced. (UNSDG, 2020). This situation becomes more challenging as the world population living in cities reaches 55% and this percentage is expected to reach 68% in 2050. (DESA, 2019). These blossoming cities and its dwellers require energy to function and as a by-product, various GHG are produced (Crawley, 2008) & (Marszal, 2008).

Carbon dioxide ($CO_2$), methane (CH4), nitrous oxide ($N_2O$) and hydrofluorocarbons (HFCs) are the main greenhouse gases (GHG). $CO_2$ is the GHG that is emitted the most, reaching 80% of the total. In addition, it is mainly produced by human activities. (IEA, 2018 & IEA, 2021). As earlier submitted, 75% of $CO_2$ emissions are produced in cities and building industry and the built environment are one of the largest consumers of energy and material use worldwide (Airaksinen & Matilainen, 2010). Buildings therefore, becomes an important study aspect in the energy savings target and to combat climate change while contributing to energy security.

The proper management of this energy is crucial considering the fact that energy is regarded as the prime mover of any economy, and the engine of growth around which all sectors of the economy revolve (Adeniran, 2004). For instance, Nigeria generates, on the average 4,000 megawatts of power as oppose to the calculated demand of 40,000 megawatts. The effect on the economy is best imagined. This conundrum is made worse by an ever-increasing demand for power (Babatunde & Shaibu 2008). It therefore follows that in a cash-strapped developing economy such as Nigeria, the need to judiciously utilize and account for the meager energy that is being generated becomes paramount. Secondarily will be the effect on the environment.

Doris, Cochran, &Vorum (2009) and IEA (2011) also stated that by a factor of scale, government policies formulation as energy conservation tool, are the most effective mean of tackling energy crisis. The recent Building Energy Efficiency Guideline (BEEG) proposed by Nigeria government also comes to mind here. However, Nnaji (2012) stated that government agencies are the most critical sources of power generating and distribution company's illiquidity. Establishing the Carbon Foot Print (CFP) of government buildings will therefore be part of the solution to the energy crisis in most developing countries, as this will serve as an incentive and a Test-Bed for energy policy formulation by government agencies and eventual decimation of these vital findings to the lower echelons of the energy use conundrum.

## 2.0 STATEMENT OF THE PROBLEM

Research activities into Carbon Foot Print (CFP) are non-existing in Nigeria. Studies in energy performance in Nigeria have largely been limited to industrial sectors, academic institutions or investigations into climatic influences as a function of thermal comfort measurement as indicated by users. The preferred method of data acquisition and subsequent assessment has mainly been simple audit that is commonly referred to as Walkthrough. In Unachukwu (2010), after data collection as to energy use were established, it proposed an Energy Management Unit for the University under study. While, in Akpama & Okoro (2010), data was obtained through inspection, survey and analysis of energy flows in the institutions studied. Changes in user behaviour were recommended as an energy saving measure. Adekunle, Olatunde, & Sunday (2008) presented the results of a walk-through energy audit conducted in a university and recommended means of tackling the problem from the demand end by focusing on the areas of potential savings flagged by the energy audit. In Ogunsote & Ogunsote (2003), the emphasis was the analysis of different comfort parameters or indices with special reference to the climate in Nigeria. Ogbonna (2008), was focused on domestic energy demand for different living spaces in different house types. Energy outflow levels were also calculated while thermal comfort ranges were established.

An exception is Mu'azu (2011), this research, conducted in Abuja-Nigeria, falls within the ambit of a comprehensive general audit and it carried out energy audit of government buildings in Abuja. Using SPSS based correlation analyses; it was able to garner information useful to the architects in understanding the relationship between their design decisions and energy use implications in the context of a developing country.

This research will however be focused on assessment of Carbon Foot Print (CFP). Here, data was obtained from measured energy data in real time as opposed to audited energy data. An E2 Wireless Electricity monitor was used to obtain this data (See Fig 3 and 4). eQUEST 3-65 software was used for the purpose of simulation of energy consumption (See Fig 5) All of these have not been carried out for Office buildings in Nigeria. These are the gaps in knowledge that this research intends to be focused on.

## 3.0 AIM OF THE STUDY

The aim of this study is to evaluate the Carbon Foot Print (CFP) of some selected office buildings in Jos, Nigeria. This is to establish relative energy efficiency in comparison to other regions of the world and potential impact of these buildings on the environment.

### 3.1 Building Energy Performance Index

According to the National Academy of Sciences (2010), "one very rarely encounters an explicitly stated definition of 'energy efficiency." However, building energy efficiency can be defined as the provision of a constant level of energy service while using less energy (Goldstein & Eley, 2014).

Literature reveals that the terms Energy Efficient Indices or Carbon Foot Print (CFP) have been used interchangeably (See Bassi, 2015., Larsen & Ditlefsen, 2013). However, Energy Efficient Indices or Carbon Foot Print (CFP) are parameters used to appraise and examine office buildings, residential and commercial building's energy efficiency during design, construction, renovation, and operation of a building under research. These indices work by answering question such as: "How does the energy intensity of this building compare with its peers and by extension, how efficient is this building?" These questions are paramount in the context of a comprehensive energy management program that would be required in the pre and post construction evaluation in the context of energy performance analysis.

The evaluation of building energy performance would require the understanding of the interaction of an engineered system (Gross floor area in m2) with operation and maintenance (O&M) practices vis-à-vis occupant demands and behaviour (Total building energy consumption in kWh/year). In other words, post construction building energy management is efficient and contextual, when it is based on quantitative and objective measurements and predictions. These measurements are therefore a function of total building energy consumption (kWh/year) and Gross floor area (m2). The calculation is thus:

Calculation of Energy Performance Indices (CFP (CARBON FOOT PRINT)):

**Carbon Foot Print (CFP) = TBEC / GFA**

where:

a) TBEC: Total building energy consumption (kWh/year)

b) GFA: Gross floor area (m2)

Using this method, Bassi (2015), opined that most buildings in North America and Europe have Carbon Foot Print (CFP) of less than 150 kWh/sq m/year. Energy-conscious building design has been shown to reduce Carbon Foot Print (CFP) to 100 to 150 kWh/sq m/year in India (Bassi, 2015). The research conducted by Larsen & Ditlefsen (2013) indicated that most office buildings in Malaysia and Singapore have Energy Efficient Index greater than 100 kWh/m2/year (See Fig 1).

 

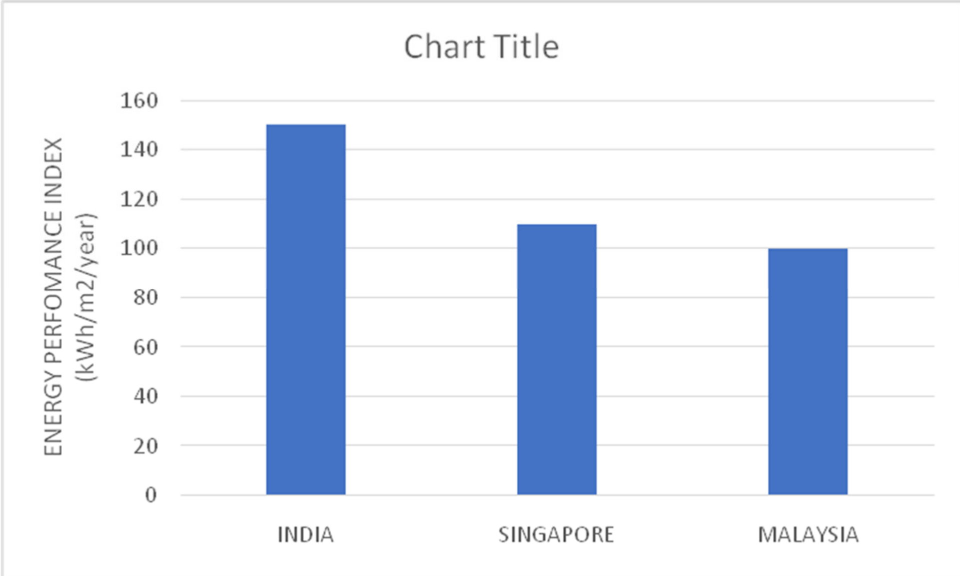


Fig 1: Average Carbon Foot Print (CFP) of Office Buildings in Some Third World Countries. (Source: Larsen &Ditlefsen (2013)

**4.0 METHODOLOGY OF STUDY**

The data acquisition was carried out in the month of April 2014 in Jos, Nigeria. The location had an altitude above sea –level of 1286 meters. The GPS location is given as Lat. (N)$9^0$ 58' 01.83 and Long. (E)$8^0$ 52' 21.63. This location was obtained with a cobra GPS 100 device (See Fig 2). All Offices under study were selected randomly, east-facing and naturally ventilated (NV). The period of study was between 8.00hrs and 15.00hrs week days (See Fig 8). This period represents the official working hours in these locations.

Measurements were taken at hourly intervals within these working hours. (See Fig 8). Objective data obtained from Measurement Instruments were put through Bar Graphs and Tables. The instruments enumerated below were used to obtain objective data as tabulated in Table 2 and Figure 8.

**4.1 Wireless Electricity Monitor**

An E2 Wireless Electricity monitor was used to evaluate, in real time, electricity consumption of the building under research. This is attached by a CT Sensor to the live cable of the service panel. The CT Sensors relays the amount of current being drawn to the transmitter and ultimately to the monitor. The monitor records time, date, energy used and carbon emission as a result of energy consumption. It has a voltage range of 110v to 400v and a measuring current of 50mA to 200A.

**4.2 Global Positioning System**

A Cobra GPS 100 global Positioning System receiver was used to obtained global location of building of interest. This device provided accurate positioning to within 3 meters, if held in any position open to the sky. It offers information as to current positioning, altitude above sea level, bearing and time of the day (See Fig 2).

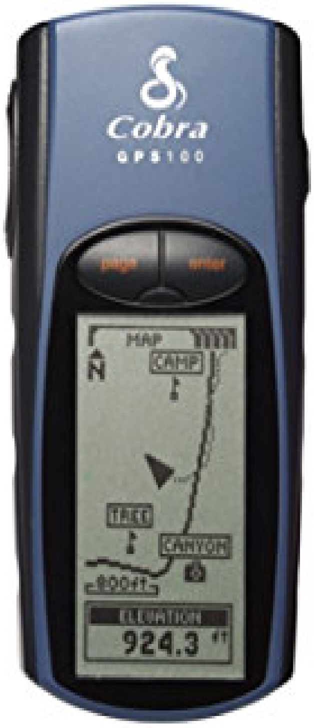


Fig 2: A Cobra GPS 100 Global Position Locating System

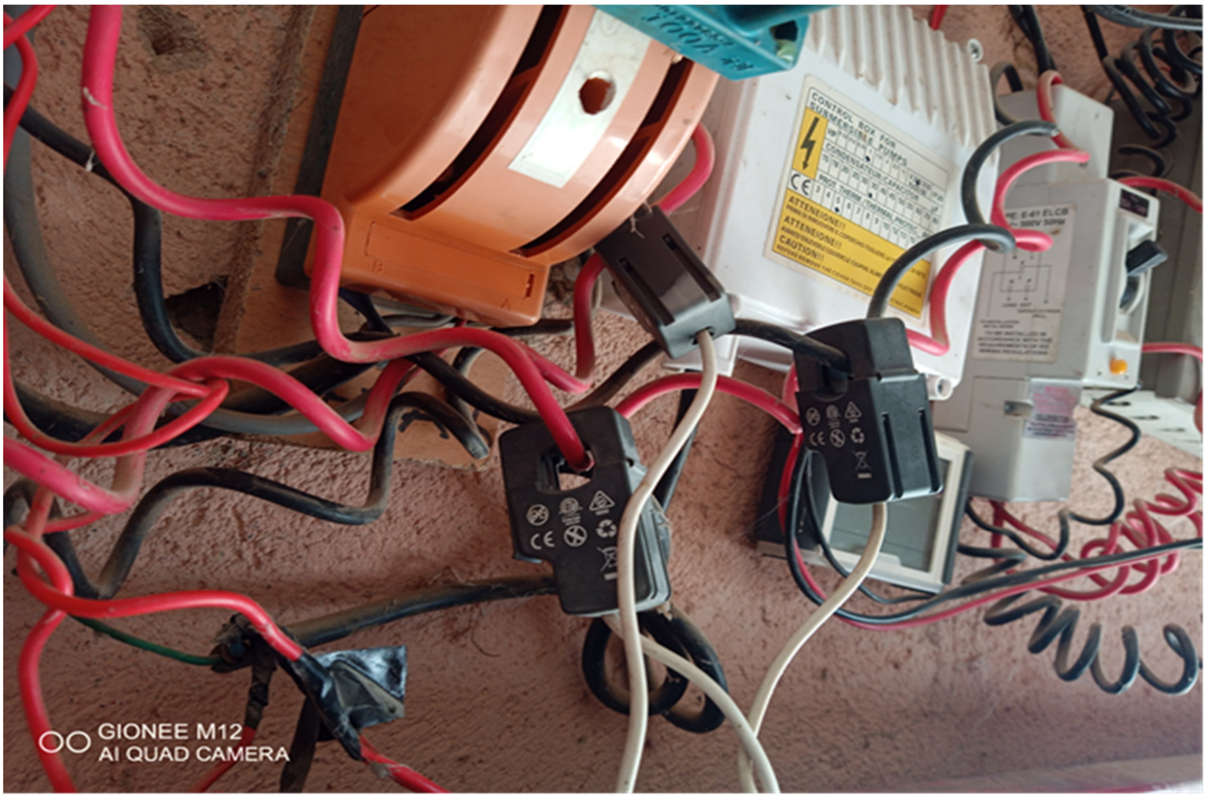


Fig 3: Wireless Energy Monitoring Device Installed at Point of Supply in Office Building.

 

Fig 4: Wireless Energy Monitoring Device Indicating Readings.

**4.3 The Buildings**

Out of the ten (10) buildings studied for the initial larger research, three (3) were randomly selected for computerized Carbon Foot Print (CFP) analysis (See Table 2). All the buildings studied had Ground Floor Slabs composed of 300mm Non-Reinforced Concrete Slab, while one (1) had Upper Floor slabs consisting of 150mm Reinforced Concrete Slab. 50% had floors finished with Cement Sand Screed overlaid with Terrazzo.

They all had vertical walls made of 230mm Hollow Sandcrete Blocks finished with 13mm Cement/Sand Mortar rendered smooth with Emulsion Paint. Window types were casement Aluminum Windows with 5mm thick glass-infill and Wooden Flush Doors in Metal Frames. Ceilings are 13mm Cement/sand plaster to upper floor slab while Ceiling type for the ground floor buildings are 5mm Asbestos Ceiling Boards. The Roofs are made of long span Aluminum Roofing Sheets. Other building parameters required for simulation are enumerated in Table 2.

**5.0 FIELDWORK**

The field work consists of obtaining objective data for the purpose of Carbon Foot Print (CFP) analysis. Objective data was obtained from instruments readings.

**5.1 Sample Area Characteristics**

Jos town in Plateau state is characterized by rocky terrain (topography) giving rises to plateaux and plains, hills and valleys. It enjoys a unique climate (temperate climate) than must of the rest of Nigeria. It is at an altitude of 1,217m (3,993) above sea level. The wet season starts from April – October and the dry season starts from November- March. The mean annual rainfall is about 320mm in the month of August with an average monthly temperature ranging from $21^c$-$25^c$. From mid-November to late January, night time temperatures drop as low as $11^c$. Daily solar radiation averages over 4300wh/m2 per annum annually. The sun rises from the east at altitudes of between 80 and 350 between 6hrs to 7hrs daily throughout the year. For most periods in the year, the sun sets in at relatively low altitudes at the west.

Data acquisition for the purposes of Carbon Foot Print (CFP) assessment was carried out in Jos, Nigeria. The studies were executed in ten (10) different administrative buildings within Jos city, Nigeria. In all, four (4) survey sessions were conducted in this Naturally Ventilated (NV) building in the month of April 2014. In obtaining objective data using instruments earlier enumerated, there was the need to conduct the instrument data session for all offices in each randomly selected building simultaneously on same day. This is to ensure integrity, fidelity and interoperability of data collected.

**5.2 Methods of Objective Data Analysis.**

Objective data was obtained from instruments; data presented were analyzed using simple charts. This is to grant visual correlation to relationships between the variables under study. This enhances understanding of subsequent objectives inputs and inferences.

*5.3 Simulation Analysis*

The energy performance simulation tool used for this purpose is the eQUEST 3-65 (Fig 5). The simulation was carried out using the Modeling Parameter in Table 1. Weather files for the purposes of computer simulation were not available for the area of study. There was the need to locate regions with similar weather characteristic as the study area with existing weather files. Literature review reveals that Tampa, Florida has the closest weather attributes to Jos, Nigeria (See Table 1).

This simulation was for one-year period and it showed a primary area of energy consumption as Area Lighting, Task Lighting and Miscellaneous Equipment. Energy consumption readings were obtained in hourly bases; from the start of a typical working day to its close (800hrs to 1500hrs). It should also be noted that all the building studied had no central HVAC equipment (See Table 2).

**Table 1: Comparison of Meteorological Data for Jos and Parts of North America**

| S/No | City | Mean Temp ($^{O}$c) | T. Max ($^{O}$c) | T. Min ($^{O}$c) | Monthly Rainfall (Mm) | Total Rainfall Per Year (Mm) | Number of Rain Days | Mean Rh @0900 Gmt % | Mean Rh @1500 Gmt % |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **Jos, Nigeria** | 22.4 | 27.7 | 17.4 | 93.8 | 1126 | 80 | 72 | 46 |
| **02** | **Florida, Tampa** | 21.5 | 28 | 18 | 108 | 1289 | 135 | 87 | 57 |
| **03** | **Hawaii** | 21.1 | 32 | 26 | 135 | 1618 | 120 | 50 | 70 |
| **04** | **Louisiana** | 19.1 | 26 | 16 | 133 | 1592 | | 88 | 61 |
| **05** | **Atlanta, Georgia** | 17 | 32 | 22 | 105 | 1263 | | 82 | 52 |

Source: National Climatic Data Center (NCDC) America, **www.worldweatheronline.com** and Department of Geography and Planning University of Jos, Nigeria.

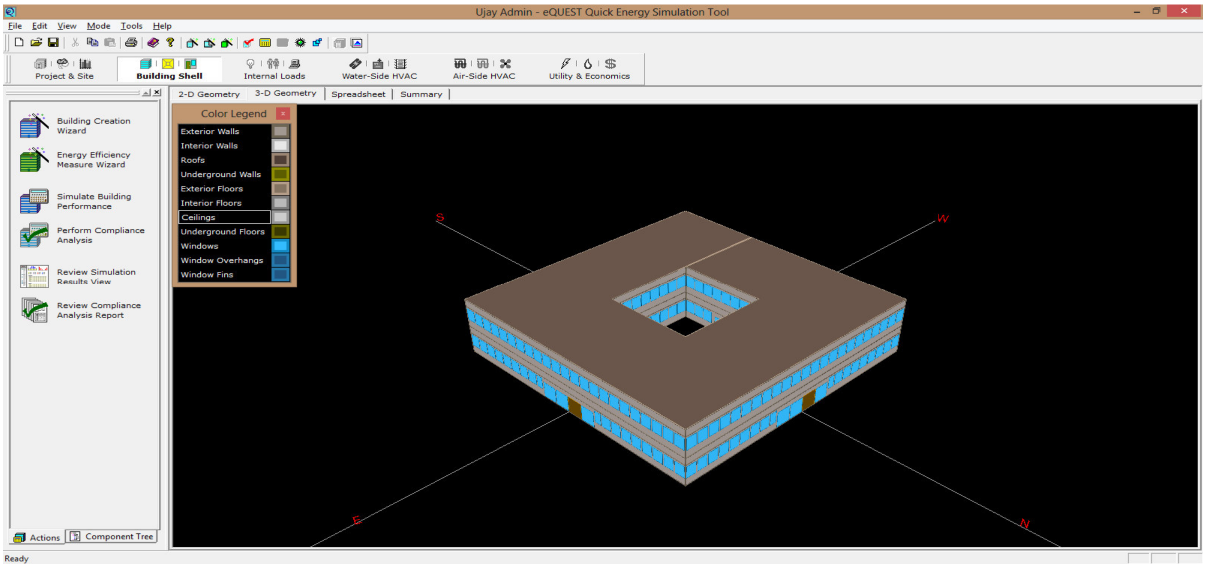


Fig 5: Screen-Shot of Computer Simulated Model.

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**Table 2: Input and Output Data for Measured and Simulated Schemes.**

| MODELLING PARAMETER | BUILDING ID | | |
|---|---|---|---|
| | UJ/ADMIN | NIPSS/ADMIN | MIN/LSTP |
| **SHAPE OF BUILDING** | SQUARE/ATRIUM | RECTANGLE | RECTANGLE |
| **ENERGY ZONING PATTERN** | 1 PER FLOOR | 1 PER FLOOR | 1 PER FLOOR |
| **FLOOR HEIGHT** | 10FT | 10FT | 10FT |
| **NUMBER OF FLOORS** | 2 | 2 | 1 |
| **WEATHER FILE** | WEATHER DATA TAMPA FLORIDA | WEATHER DATA TAMPA FLORIDA | WEATHER DATA TAMPA FLORIDA |
| **HVAC EQUIPMENT** | NONE | NONE | NONE |
| **BUILDING AREA** | 1,524 $m^2$ | 648 $m^2$ | 273 $m^2$ |
| **USAGE DETAIL** | 8AM TO 3PM | 8AM TO 3PM | 8AM TO 3PM |
| **SEASON CYCLES** | 2 | 2 | 2 |
| **SEASON PERIOD** | 01/03 to 30/09 and 01/10 to 30/04 | 01/03 to 30/09 and 01/10 to 30/04 | 01/03 to 30/09 and 01/10 to 30/04 |
| **OCCUPANCY RATE (%)** | 90 | 70 | 50 |
| **DAYLIGHT CONTROL** | NONE | NONE | NONE |
| **ENERGY SIMULATED** | 5.78 kWh | 1.91 kWh | 0.98 kWh |
| **ENERGY MEASURED** | 4.07 kWh | 1.33 kWh | 1.11 kWh |
| **LEVEL OF ACCURACY** | 70.4% | 69.6% | 88% |
| **PERFORMANCE INDEX ($M^2$/kWh/Year)** | 32 | 41 | 21 |
| **CARBON EMISSION/HOUR** | 2.27 $KgCO_2$ | 0.74 $KgCO_2$ | 0.69 $KgCO_2$ |
| **CARBON EMISSION/$M^2$** | 671.4 | 875.7 | 395.7 |

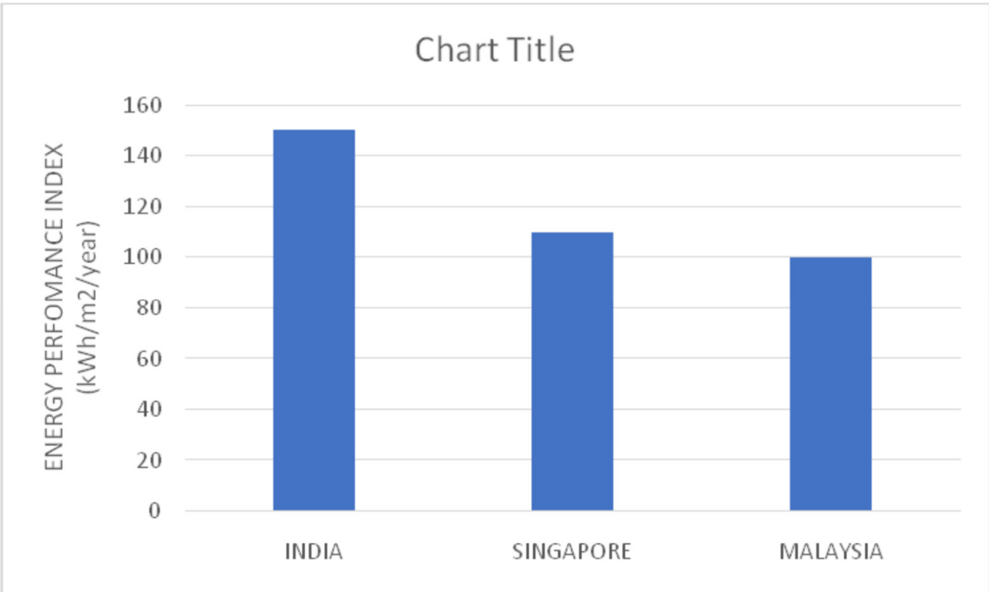


Fig 6: Average Carbon Foot Print (CFP) of Office Buildings in Some Third World Countries.

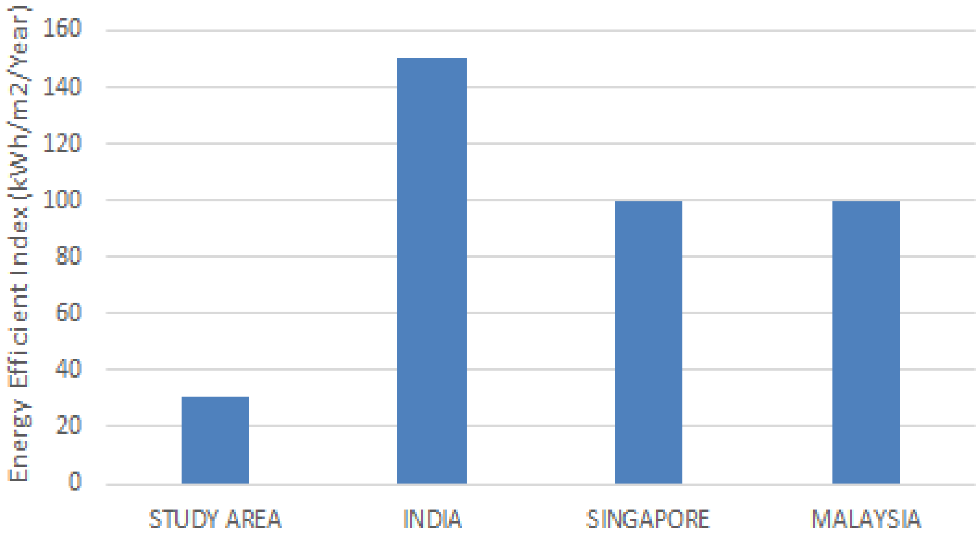


Fig. 7: Average Carbon Foot Print (CFP) of Office Buildings in Some Third World Countries Including Study Area (Larsen and Ditlefsen, 2013)

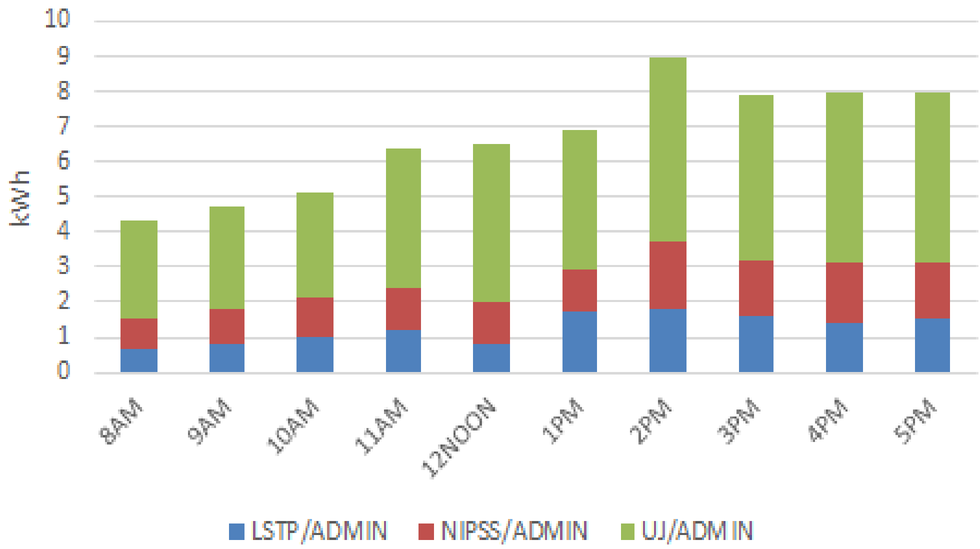


Fig 8: Combined Graph of Real Time Energy Use (Average Kwh Every Hour) For the 3 (Three) Buildings Measured.

**6.0 ANALYSIS OF FINDINGS**

Table 2 shows a Carbon Foot Print (CFP) of between 21 to 41 kWh/sq m/year for the building studied here in Nigeria. This gives an average of 31 kWh/sq m/year for the three (3) buildings studied. Superficial observation of data obtained by simulation indicates that buildings with smaller floor area had better low Carbon Foot Print (CFP) results. Only two (2) of the buildings studied had same rectangle shape. The effect of this shape on Carbon Foot Print (CFP) would be a subject of further study.

This general low Carbon Foot Print (CFP) is not unconnected with the fact that these Building lack HVAC equipment and other energy consuming devices that are required standards in developed and some developing region. On the positive side, this low Carbon Foot Print (CFP) indicates that the Carbon Emission Footprint of these buildings studied are low and so are the negative environmental impact. For similar buildings in North America and Europe have Carbon Foot Print (CFP) of about 150 kWh/sq m/year (See Fig 6).

**7.0 CONCLUSION**

This research shows that similar buildings in South East Asia have Carbon Foot Print (CFP) of about 150 kWh/sq m/year (See Table 3). Energy-conscious building design has been shown to reduce Carbon Foot Print (CFP) to 100 to 150 kWh/sq m/year in India (Bassi, 2015). According to research conduct by Larsen and Ditlefsen (2013), most office buildings in Malaysia and Singapore have Energy Efficient Index greater than 100 kWh/m2/year. However, Table 2 shows a Carbon Foot Print (CFP) of between 21 to 41 kWh/sq m/year for the building studied here in Nigeria. This gives an average of 31 kWh/sq m/year for the three (3) buildings studied which is remarkably lower than the above-mentioned researches. The absence of certain energy consuming equipment that are essentials in some climes might be the reason. Examples are HVAC devices and other modern office paraphernalia. On the positive side, this low Carbon Foot Print (CFP) indicates that the Carbon Emission Footprint of these buildings studied are low.

This research has been able to establish substantial implementable findings in the areas of Carbon Foot Print (CFP) using administrative buildings as Test-Bed. This should lead to significant understanding of energy savings in administrative buildings. The incentives for these savings to be transformed into energy conservation policy for downward implementation becomes high. Substantial implementation of these energy conservation policies would lead to cumulative saving for government and corporate bodies locally. Globally, the long-term benefit of this would be sustainable designs which will in-turn reduce environmental challenges such as global warming.

**Table 3: Average Carbon Foot Print (CFP) of Office Buildings in Some Third World Countries and Nigeria**.

| S/NO. | BUILDING/ REGIONS | PERFORMANCE INDEX (/kWh/ $M^2$YEAR) |
|---|---|---|
| 01 | NIGERIA | 32 |
| 02 | MALAYSIA | 100 |
| 03 | SINGAPORE | 100 |
| 04 | INDIA | 150 |

***Source: Larsen and Ditlefsen (2013) and Author's field work.***

## 7.0 RECOMMENDATION

Amongst Green House Gases (GHG), $CO_2$ is the most emitted amongst gases that causes greenhouse effectively accounting for up to 80%. As earlier stated, 40% of these gases are produced in buildings. Therefore, any measure that mitigates its emissions, impact the improvement of environmental quality (Beerepoot & Beerepoot 2007). The following suggestions are proposed for reduction of $CO_2$ emissions.

1) Occupant's behavior has been shown to have an effect on energy use and by extension Carbon Foot Print of a building. (Leth-Petersen & Togeby 2001). User-education as to trending preferences in sustainable habit would go a long way in mitigating excess GHG emissions. It has been shown that $CO_2$ emissions can be reduced by 20% or more only through a change in user behavior within buildings. (Beerepoot & Beerepoot 2007).
2) Efforts should be put in place to ensure that nonpolluting energy source are utilized in generating electricity. Some examples of nonpolluting energy sources are Solar and Nuclear power. The use of nuclear power as a source of energy in Nigeria is virtually non-existence while solar energy is at its nascent stage. The lowest $CO_2$ equivalent emissions are achieved when a mix of bio-based, renewable energies or nuclear power are used to supply energy for the office buildings. (Airaksinen, & Matilainen, 2011).
3) There is need for policy framework that creates awareness in users and provide regulations guiding the built environment from design stages to post occupation activities. For it has been found that energy performance regulations have improved energy conservation Doris (Cochran, & Vorum, 2009). Efforts are in the offing to establish a National Building Code for Nigeria.
4) Constructing low-energy buildings and minimizing the floor area of buildings directly drives the reduction of $CO_2$ emissions from buildings. (Cong, et al. 2015). Due to the high cost of construction in Nigeria, there is a deliberate attempt by designer to reduce floor area so as to reduce cost. The unintended merit is the reduction in areas requiring temperature control and lighting. This further explains the relatively lower emission from buildings studied.
5) In this particular research, location, clime and building types was necessarily delimited. There would be need for similar research to be conducted in other seasons and location within developing countries. This is to expose this research framework and associate tools to further use and thus granting validity to these tools.
6) Energy simulation softwares often require specific building codes and specific types of construction materials. Some of the materials choices obtainable in drag-down menus in these softwares are not applicable in the region under study. This limits the ability of these tools to accurately predict Carbon Foot Print (CFP) of buildings in sub-Saharan regions. Energy simulation tools with broader technical capability would be needed for future research.
7) Two (2) of the buildings studied had similar rectangle shape. Further studies may be required to establish the effect of building with other shapes and orientation on Carbon Foot Print (CFP) other than the ones studied.

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