DISAGGREGATING PRIMARY ELECTRICITY CONSUMPTION FOR OFFICE BUILDINGS IN NIGERIA

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ABSTRACT

This paper presents the findings of an investigation of electricity consumption in mechanically cooled Nigerian office buildings.

A quantitative survey into 15 office buildings is conducted using questionnaire and observation techniques. The recorded primary data of monthly electricity consumption in three cities in Nigeria are tested for their alignment to the weather profile and regression analysis shows major discrepancies.

Results show that cooling, lighting, and appliance loads account for approximately 40%, 12% and 48% respectively. Cooling consumption is not dependent on the climatic profile. This exercise is beneficial to prepare a primary dataset for validating building performance simulation results.

INTRODUCTION:

Electricity is indisputably the fundamental energy resource for industrial, commercial and domestic activity in the modern world. Although a major oil producer and investor in the electricity sector, Nigeria holds a low 69th place in per capita electricity consumption globally (CIA World factbook, 2011).

The country has large amounts of natural resources utilized for energy generation (both conventional and renewable sources); but yet is bedevilled with unexpected and long periods of power outage, or fluctuating currents. Ibitoye and Adenikinju (2007) estimate that up to 60% of the population are unconnected to the national grid, especially those in remote areas. Political instability, mismanagement, limited funds, long period of return of investment and maintenance neglect all result in electricity generation deficit, poor utility performance, and weak transmission and distribution infrastructure; all factors contributing to the electricity crisis.

There are presently more than 150 million people living in Nigeria, and the power sector is only capable of generating around 3,500 MW of electricity, well below all economic projections and the country's consumer and business needs, despite government investment of around USD1 billion annually in the sector (Corporate Nigeria, 2011).

Energy use in the commercial sector in Nigerian offices is dominated by electricity supply. Cooling, lighting, hot water, and powering of appliances are powered by electricity. The erratic electricity supply in Nigeria has resulted in reliance on 'back-up' power generators. The trend of using fossil based fuel to power back-up generators in Nigeria has negative impacts on climate change, pollution, and profit for businesses.

Long term solutions are required in sector reforms; decentralization of the power sector; and sustainable development and consumption across all sectors. Energy conservation and efficiency in electricity consumption is necessary to decrease loads on a failing network; sizing of back-up and other alternative generators including renewable energy in the short term; while reducing green gas house emissions from the existing building stock.

Electricity consumption analysis

Using demand-side calculations rather than supply-side, the three techniques commonly used for electricity consumption analysis are (Swan and Ugursal, 2009);

- Statistical (parametric and non-parametric): (Parti and Parti, 1980) and (Day et al., 2003)
- Intelligent computer systems techniques (O'Sullivan and Keane, 2005).

In this research, a parametric statistical method is adopted, using a mixture of cooling degree days and correlation. The aim of this investigation is to generate primary data on electricity consumption in modern offices in Nigeria. This data will be used to validate building energy simulation results.

METHODOLOGY

This investigation is the first of a 2-phase research into energy conservation and efficiency in Nigerian office buildings; the fieldwork and the computer simulation phases. A combination of the 2 constitutes a sensitivity analysis process, using perturbation techniques to test the effects of modifying the building envelope, building services, and occupant

behaviour on electricity consumption (Lam et al., 2008).
The information recovered from the fieldwork stage will serve as data input and validation of results for a second phase of building performance simulation to test alternative technologies for saving building energy consumption.
The methodology used in this research is informed by that employed by Day et al (2003) and Lam et al (2008). A similar method is employed by Pedrini et al (2002) with a slight variation in sequence of actions. The work was initiated with intelligent computer simulation, then an audit. The work here is the reverse; initiated by audit before simulation.

Sampling

The selection of sample is based on the following criteria;

- Access to the building;
- HVAC system
- Design climate and;
- Electricity consumption data.

Access to the building: Willingness of office buildings' management to participate in the investigation imposed access as criteria for selection based on security, bureaucratic or privacy. Access into the office buildings was approved only by the head of the organisations, which then referred the activity to the appropriate department.
HVAC system: The scope of this research covers only mixed mode ventilated buildings. However, these buildings are a combination of open and cellular plan configurations. Natural ventilation during work hours is difficult due to occupancy, peak internal load, casual internal gains, and peak solar radiation coincidence, leading to a reliance on mechanical cooling.
Design climates: Nigeria falls within the area labelled as a warm–humid region. There is variation of climate as one moves from the coast to the northern parts of the country and the climate of a particular location varies with the time of the year, latitude of the location and landscape (Ajibola, 2001). See Figure 2 and Table Table 1. Due to confidentiality issues, the 5 buildings presented here will be referred to as buildings 1-5.
Nigerian design climates are classified into four by Komolafe and Agarwal (1987) in (Ajibola, 2001).
The cities proposed to represent each zone are as follows; North- Kaduna; Middle band- Abuja; South- Lagos; Extreme south- Port Harcourt. However, it was not possible to visit Port Harcourt because of political and security issues.

Figure 1- Map of Nigeria showing sample cities

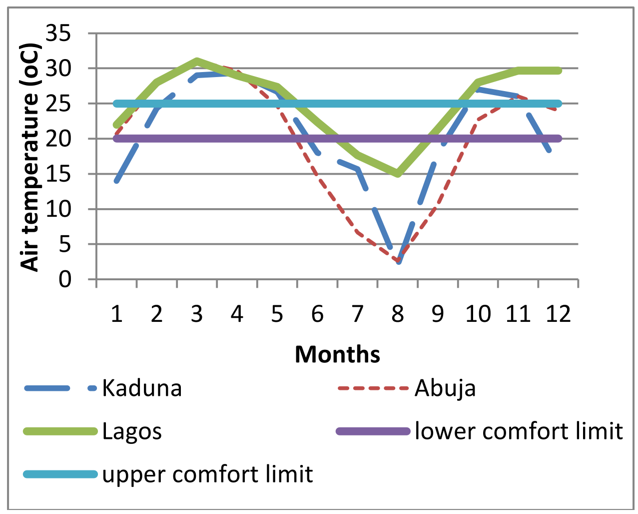

Figure 2 Air temperature profiles for some Nigerian cities (Nigerian meteorological agency) and thermal comfort band based on the effective temperature index (Ogunsote and Prucnal-Ogunsote, 2002)

Kaduna: There are two marked seasons in Kaduna; the dry, windy harmattan which is a northeast trade wind, characterized by dust, intensified coldness and dryness and the wet seasons. On the average, the city experiences a rainy season from May to September. Annual average temperatures range between 10^{o}C - 31.6 ^{o}C. The average annual temperature is 25^{o}C and average annual precipitation is 1192mm. Mean daylight hours is 12hrs.
Abuja: Abuja experiences three weather conditions annually. This includes; a warm, humid wet season beginning from April and ends in October; and a dry season from November to March. In between the two, there is a brief interlude of harmattan. Daytime

temperatures reach as high as 30°C and night time lows can dip to 12°C. The high altitudes and undulating terrain of the Abuja act as a moderating influence on the weather of the territory. The average annual temperature is 27°C and average annual precipitation is 1221mm. Mean daylight hours is 12hrs.

Table 1Climatic data of some Nigerian cities

	Kaduna	Abuja	Lagos
Temperature range (°C)	20-32	26-30	26-30
Mean annual Air temperature (°C)	26	28	28
Precipitation	1192	1221	1538
Humidity	5-95	20-91	34-99
Daylight hours	12	12	12
Wet season	5months. May-September	7 Months. April-October	6 months. April- July (heavy) and October-November (weaker)
Dry season (Harmattan)	7 months. October - April	5 months. November-March (brief harmattan in December)	6 months. August-September and December-March
Neutrality temperature, Tn (°C)	26	26	26
Cooling Degree Days/annum	213	291	303

Lagos: There are two wet seasons in Lagos, with the heaviest rains falling from April to July and a weaker rainy season in October and November. There is a brief relatively dry spell in August and September and a longer dry season from December to March. Monthly rainfall between May and July averages over 300 mm, while in August and September it is down to 75 mm and in January as low as 35 mm. The main dry season is accompanied by harmattan winds, which between December and early February can be quite strong. The average temperature in January is 27°C and for July it is 25°C. On average the hottest month is March; with a mean temperature of 29°C; while July is the coolest month. Average annual precipitations is 1538mm, and mean daylight hours is 12hrs.

Electricity consumption data

Data required from the investigation are in the following categories;

- Building characteristics
- Occupancy schedule
- Site sketch
- 3 year electricity from utility use records
- Corresponding 3 year electricity from back-up generator use records
- Cooling load
- HVAC
- Lighting load
- Appliances

Energy audit

An energy audit of each building was conducted using a uniform data collection process and tools; self administered questionnaire and observation. The audit required key personnel such as the facility manager, energy manager or estate manager depending on the management structure, in collaboration with information and communication technology departments, and even finance departments to produce and calculate required data. Essential data collected was; a three year record of metered electricity consumption and those of alternative back-up power generator usage; building and site characteristics; occupancy schedule; and an inventory of lighting, cooling, and general office appliances.

Key loads making up total electricity consumption that emerged both in literature and during the investigation are cooling, lighting, and appliances. Aggregate load calculations are based on the formula

$$Qa = \text{Energy rating} * \text{Qty} * \text{hours of use} \qquad \text{Eq (1)}$$

Qa is electricity consumption per annum (kWh) for each aggregate appliance, energy rating is provided by the manufacturer (kW), Qty is quantity of aggregate appliances and hours of use are estimated by the buildings operational schedule. The assumption that the appliances run at the specified rating may lead to errors related to inefficiency of the appliances; other errors may arise from the assumption of hours of use by appliances.

Total consumption per annum;

$$Qt = Qu + Qg \qquad \text{Eq (2)}$$

And also

$$Qt = Qc + Ql + Qa \qquad \text{Eq (3)}$$

Qt is the total consumption per annum, Qu is consumption recorded by the smart meter provided by the Utility Company and Qg is the calculated consumption from the back-up power generator based on recorded hours of use, all per annum. Qa is appliances load, Qc and Ql are cooling and lighting loads respectively. All Q are in (kWh).

Electricity consumption from utility Qu, is recorded from actual bills, whereas electricity consumption from back-up generators is calculated from a record of actual hours of use. Difference of back-up power recorded and total working is the utility supply hours. These hours are converted to percentages and compared with that of utility to calculate the electricity supplied by the back-up generators. This way, the errors due to inefficiency and sizing are minimised The formula used is;

$$Qg = (Qu * G)/U \quad \text{Eq (4)}$$

Where U and G are percentage of time that utility and back-up generators are in use respectively.

Cooling load is consumption from the cooling systems installed estimated from an inventory of the units in the building. The cooling load is calculated with the equation:

$$Qc = N * H * R \quad \text{Eq (5)}$$

Where N is number of units, H is annual hours of use and R is energy rating of the unit.

In instances where there are variations in types or specification in the units;

$$Qc = Qc1 + Qc2 + Qc3.........+Qcn \quad \text{Eq (6)}$$

Where $Qc_{(1\text{-}n)}$ represent the variations in type and specifications.

Hours of use are based on operational schedules recorded in the questionnaire.

Lighting load, Ql is calculated the same way, with;

$$Ql = N * H * R \quad \text{Eq (7)}$$

Where N is number of units, H is annual hours of use and R is energy rating of the unit.

And

$$Ql = Ql1 + Ql2 + Ql3.........+Q\ln \quad \text{Eq (8)}$$

Where $Ql_{(1\text{-}n)}$ represent the variations in type and specifications. Hours of use are based on operational schedules recorded in the questionnaire.

Appliances loads encompass all other aggregate end-uses that do not fall under cooling and lighting. The difficulty therefore in using the same method of calculation as with cooling and lighting loads lies in accurate estimation of hours of use for the multiple types of appliances that constitute this end use. A better formula was;

$$Qa = Qt - (Qc + Ql) \quad \text{Eq (9)}$$

RESULTS AND DISCUSSION:

Building descriptions

All the buildings are made of the same wall construction method most common in Nigeria of hollow sandcrete blocks with standard mix proportion of 1:6 cement-sand ratios. The size of the block used is 225 x 225 x 450 mm for external walls or 225 x 225 x 150 mm for internal walls with one-third of the volume as cavity. All the buildings have single pane glazing and no wall insulation. The buildings have generally similar appliances in use such as photocopiers, ICT systems, lighting fixtures and cooling systems. The setting for all buildings is urban. See Figure 7 for graph of electricity consumption, cooling degree days, and air temperature profiles of the 5 buildings.

Building 1 is a small single storey bank branch in the northern city of Kaduna. It is cellular and open plan with clear single pane glazing. There are security bars across the windows, internal blinds and, external overhangs for shading. Wall to window ratio is 16%, and the Gross floor area (GFA) is 250 m^2. There are 20 occupants in the building, giving occupancy of 12.5 m^2 per person. Operational hours are week days: 8am-5pm (2250 annual hours).

Building 2 is a 4 storey government office in the central city of Abuja. It is cellular and open plan with security bars; tinted glazing, and internal blinds for shading. Wall to window ratio is 18% and the gross floor area is 1200 m^2. There are 130 occupants in the building, giving occupancy of 9.23 m^2 per person. Operational hours are week days: 8am-5pm (2250 annual hours).

Building 3 is also a 4 storey government office in the central city of Abuja. It has a combination of open and closed plan layout of offices. Windows are tinted and reflective, with internal blinds in some areas, external overhangs and window hoods for shading. Wall to window ratio is 73%. And the gross floor area is 3218 m^2. There are 125 occupants in the building, giving occupancy of 25.8 m^2 per person. Operational schedule is week days: 8am-6pm; and Saturdays: 8am-12pm (2818 annual hours)

Building 4 is the 13 storey head office of a bank. It is serviced by 3 elevators. These factors account for higher consumption values. It is cellular and open plan. Windows are clear and recessed with, security bars. Wall to window ratio is 10% and the gross floor area is 8184 m^2. There are 600 occupants giving occupancy of 13.6. m^2 per person. Operational schedule is week days: 8am-5pm (2250 annual hours).

Building 5 is a 4 storey regional branch of a bank in the southern city of Lagos. It is cellular and open plan. Windows are tinted with internal blinds, and iron security bars. Wall to window ratio is 20%.and gross floor area is 2944 m^2. There are 130 occupants giving occupancy of 21.5 m^2 per person.

Operational schedule is week days: 8am-5pm (2250 annual hours).

Table 2 Building description

Building	1	2	3	4	5
Cooling degree days per annum	246	267	267	267	301
Occupants	20	130	125	600	137
Work hours	Week days: 8am-5pm (2250 annual hours)	Week days: 8am-5pm (2250 annual hours)	Week days: 8am-6pm Saturdays: 8am-12pm (2818 annual hours)	Week days: 8am-5pm (2250 annual hours)	Week days: 8am-5pm (2250 annual hours)
Gross floor Area	250	1200	3218	8184	2944
Occupancy	12.5	9.23	25.8	13.6	21.5
Average annual utility consumption (kWh)	35,094	141,400	190,779	657,590	157,501
Average annual back-up electricity consumption (kWh)	5,713	48,399	127,186	1,777,929	717,505
Average total annual consumption (kWh)	40,807	189,799	317,965	2,435,519	875,006
Energy use intensity (kWh/M^2)	163	158	99	298	203
Percentage of back-up power usage during work hours (%)	14	26	40	73	82
Cooling load (kW)	5,625	99,563	225,548	749,925	427,950
Lighting load (kW)	6,387	59,542	46,328	81,326	60,197
Office appliance load (kW)	28,795	30,694	46,089	1,604,268	386,859

Degree day calculations

There are no published design degree days for Nigerian cities except those calculated by Ajibola (2001). In this work, degree day calculations were based on a 3 year 2005-2007 daily average dry bulb air temperature profile provided by the national meteorological agency. A cooling degree day is calculated as that which the average air temperature for that day is more than the neutrality temperature. Assumptions for degree day calculations are:

1. Only cooling is required for comfort in all buildings, therefore HVAC is synonymous to cooling within the document
2. Operational schedules used are based on the building managements' specifications and not actual measured use.
3. Nigeria has an average of 11 public holidays annually.

The thermal comfort range for Nigeria is 20°C-25°C as calculated by Ogunsote and Prucnal-Ogunsote (2002) based on the effective temperature index (ET). Effective temperature index is a generally accept index for the calculation of thermal comfort (Szokolay, 2004).

The neutrality temperature adopted for the calculation of cooling degree days was determined using the formula shown in

$$Tn = 17.8 + 0.38(Tave) \quad \text{Eq (1)}$$

(de Dear and Brager, 1998)

$$Tn = 17.8 + 0.38(Tave) \quad \text{Eq (1)}$$

T_n is neutrality temperature, and T_{ave} is mean monthly temperature.

Thermal comfort temperatures for cooling degree days are calculated with base temperatures corresponding to neutrality temperatures of 26 °C, 26.3 °C, and 26.4 °C for Kaduna, Abuja and Lagos respectively based on equation 1.

A test was conducted on base temperatures of 20 °C, 22 °C, 24 °C, 25 °C and the neutrality temperatures mentioned above to determine the best value to use as base temperature (Day et al., 2003). R^2 recorded were 0.005, 0.003, 0.005, 0.29 and 0.36 respectively, indicating the adequacy of using the neutrality temperatures as base temperature having the highest R^2.

Normalization and energy use index (EUI)

Electricity consumption, be it total or aggregate end-use values are normalized with thermal comfort parameters; such as gross floor area, occupants, and cooling degree days; to account for variations in those parameters. In this work, electricity consumption is normalized by gross floor area to give the Energy use indicator/index (EUI), also called a normalised performance index (NPI).

Building 1-5 have their EUIs at 163, 158, 99, 298, and 203 kWh/m^2 respectively. Nigeria is in the process of developing her building energy use benchmark so it is not possible to compare it with national NPIs. EUIs for buildings 1-5 are; 23, 83, 70, 92,145 kWh/m^2 for cooling load; 26, 50, 14, 10, 20 kWh/M^2 for lighting load; and 115, 26, 14, 196, 131 kWh/m^2 for appliances load respectively. The aggregate end-uses for cooling, lighting and appliances' loads are 40%, 12% and 48% respectively, see Table 4.

Base load

This is defined as the non-weather related energy use such as artificial lighting, office appliances, lifts and escalators. From the scatter plot of CDD against

Table 2

Cooling: Cooling systems in all five buildings are; air-source heat pumps in reverse function to produce cooling, which are also called split units ranging in energy rating from 750 -1450 kW; a few dual hosed portable units ranging from 5000-6000kW; wall units ranging from 750-1450kW, and a precision unit specifically installed to cool a data centre. None of the buildings have heating systems. Cooling loads for buildings 1-5 are 5625, 99,563, 225,548, 749,925, 425,950 kWh. The cooling load accounts for an average of 40% of electricity consumption in the buildings. It is the second largest consumer.

Table 3 Correlating monthly electricity consumption and CDD

Building	R^2	Scatterplot baseload (kWh)	Calculated baseload (kWh)
1	0.007	3439	35, 182
2	0.124	29062	90,236
3	0.102	-10359	92,417
4	0.15	-165521	1,685,594
5	0.024	44098	447,056

Lighting: A variety of lighting fixtures such as incandescent, fluorescent, sodium and mercury lamps are installed in the buildings ranging from as little as 18w to 500w. Lighting loads for buildings 1-5 are 6,387, 59,542, 48328, 81,326 and 60,197 kWh respectively. This load accounts for 12% of electricity consumption, the least end-use consumer.

Appliances: These include elevators, water pumps, ICT equipment, security doors and even cell phone chargers. They also include UPS used for temporary back-up for some appliances in some of the offices like Building 3, 4, and 5. Appliance load for buildings 1-5 are 28,795, 30,694, 46,089, 1,604,268, 386,859 kWh respectively. This accounts for 48% of consumption, the largest consumer.

electricity consumption, the constant C is also the baseload. However, R^2 for all five buildings are very low indicating the performance line is not a good one and hence the baseload from the scatter plot is not valid. The combined consumption of lighting and appliances is more suitable for the baseload calculation as shown in Table Table 3. Baseload for buildings 1-5 are 35,182, 90,236, 92,417, 1,685,594, 447,056 kWh respectively.

Electricity consumption by end use

The aggregate end-uses are cooling, lighting and office appliances See

Table 4 Electricity consumption by aggregate end-use

Building	Cooling rate (kWh/M2)	Lighting rate (kWh/M2)	Appliances Rate (kWh/M2)
1	23	26	115
2	83	50	26
3	70	14	14
4	92	10	196
5	145	20	131
Average	83	24	97
%	40%	12%	48%

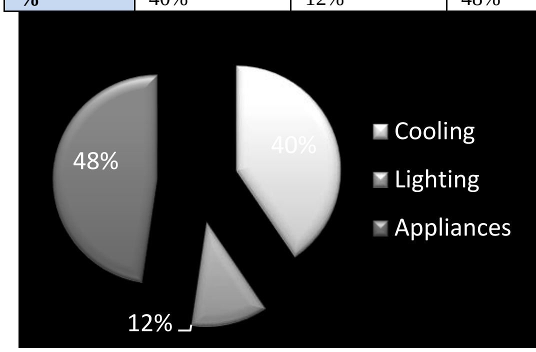

Figure 3- Electricity consumption by end uses

CONCLUSIONS:

Due to erratic power supply, electricity consumption data collection in Nigeria needs a delicate approach. Electricity consumption is a combination of utility and back-up generator consumptions. During the energy audit process, the hours of electricity generated by the utility and by other alternative sources needs to be documented and a method of estimation employed to calculate the total consumption.

Data collected is aggregated to end-uses; cooling, lighting and appliances usable for sensitivity analysis using perturbation techniques. Cooling, lighting and appliance loads account for 40%, 12% and 48% respectively.

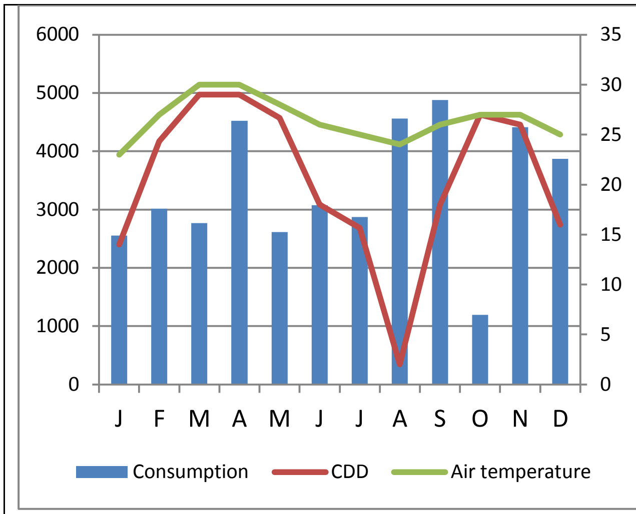

Figure 4 CDD and electricity consumption in building 1

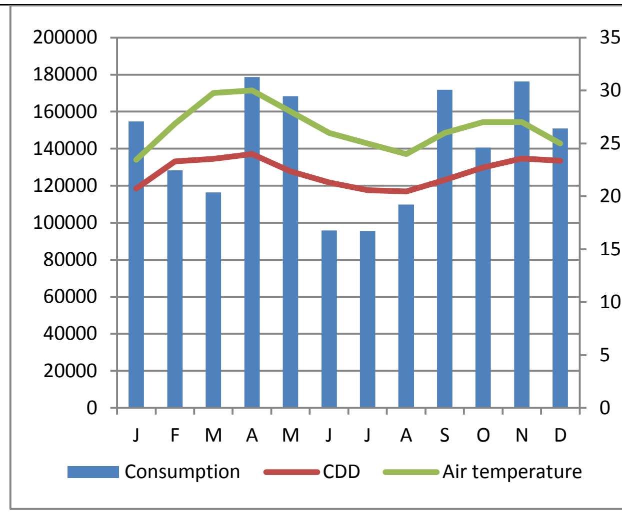

Figure 5 CDD and electricity consumption in building 4

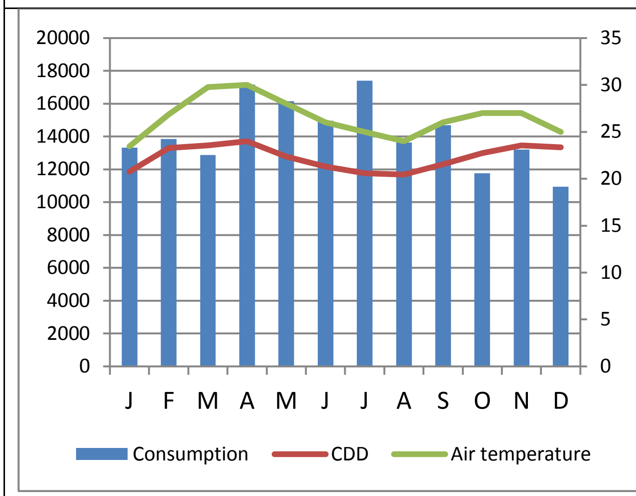

Figure 6 CDD and electricity consumption in building 2

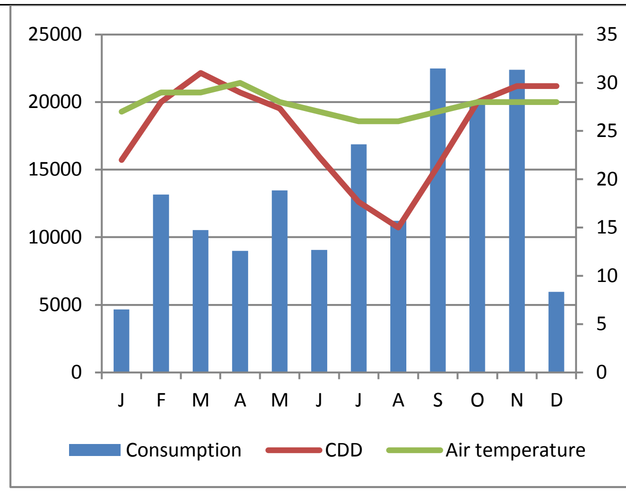

Figure 7 CDD and electricity consumption in building 5

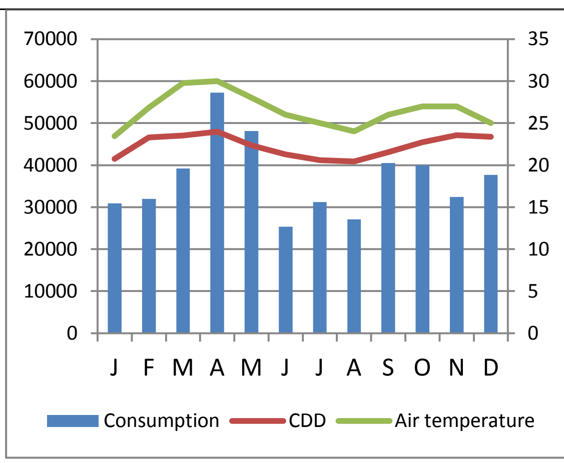

Figure 8 CDD and electricity consumption in building 3

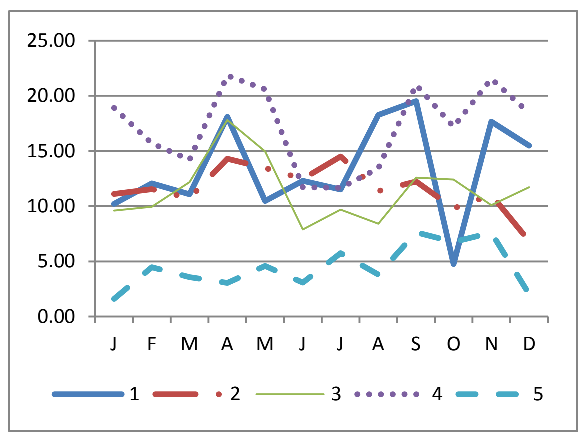

Figure 9 Electricity consumption trends in buildings 1-5

The highest R^2 recorded is 0.36 for base temperature equal to neutrality temperatures of 26 °C, 26.3 °C, and 26.4°C for Kaduna, Abuja and Lagos respectively.

A mismatch between electricity consumption and cooling degree days is reflected by the low R^2 values. Cooling load especially presents a significant opportunity, consuming up to 40% of electricity and showing a poor correlation when compared with cooling degree days.

This indicates an opportunity for energy efficiency in terms of modifying the building construction, the cooling system, and occupants behaviour.

The period investigated in the energy audit was three years. It was noted that shortening the period to a year for the correlation of electricity consumption and cooling degree days may improve the R^2 recorded. Results indicate that the period of three years may have inexplicable variations other than cooling degree days. A representative year is recommended for this type of analysis.

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