Comparative Assessments of CFLs, Incandescent and LEDs Bulbs for Energy Efficient Lighting System in Building

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Abstract
Compact Fluorescent Lamps (CFLs) and Light Emitting Diode (LEDs) are fast replacing incandescent bulbs in most residential buildings because they are designed to fit into most lamp holders originally designed for incandescent bulbs. The aim of this work is to look at to what extent the usage of Compact Fluorescent Lamps (CFLs) or Light Emitting Diode (LEDs) can help reduce energy demand and how energy wastage in residential buildings due to lighting can be addressed by using energy efficient lamps. Energy meter was used to measure the actual energy in kWh (kilowatt-hour) of each bulb. Lux meter was used to measure the luminance (brightness) between CFLs, LEDs and Incandescent bulbs. Lighting point calculation for a three bedroom flat was carried out and the number of lighting points required to light up the building was calculated. An estimate of energy consumed for one year by the different bulbs using the readings from the energy meter was done and the prices of the bulbs was compared to ascertain if the cost outweighs the energy consumption. The prices of incandescent bulbs when compare to CFLs and LEDs in local stores is far cheaper than CFLs and LEDs with a burden of huge cost in lighting the incandescent bulbs due to energy wastage. Lighting design calculation for a three bedroom flat was carried out using IES (Illuminating Engineering Society) recommendation for different area. It was observed that LEDs bulbs can save almost 86.4% energy consumed by Incandescent bulbs while using CFLs bulbs can save 78.8% energy consumed by incandescent bulbs. Hence, LEDs is the most energy efficient bulb, by using LEDs in every home there will be a reduction of over 80% energy consumption due to lighting when compared to incandescent.
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1. Introduction
In Nigeria energy poverty has led to closure of many small and medium scale businesses, even the big businesses suffer from this energy poverty while the nation's hunger for electricity consumption is growing at an increasing rate. In light of this crisis, it becomes essential to educate consumers about energy and its rightful usage, and the necessary steps that consumers should take to reduce their demand for electricity as well as high energy bills.
The provision of reliable, secure and affordable energy services are central to addressing energy crisis, including poverty, inequality, climate change, food security, health and education. They are also required for wealth creation and economic development. Today more than 1.1 billion people worldwide lack access to electricity supply according to International Energy Agency (IEA2017). Internationally, energy efficiency is recognized as the most cost-effective means of reducing dependence on fossil fuels as well as an essential component of sustainable energy policy. Two of the many available energy efficient lighting technological options are the compact fluorescent lamp (CFL) and light emitting diode (LED) – which can directly replace a standard incandescent lamp.

2. Materials/ Methodology
The experiment was conducted by obtaining CFL Bulbs, LED Bulbs and Incandescent Bulbs from open market. An energy meter was used to measure the energy consumed by each bulbs in one hour and a lux meter was used to determine the light brightness (Luminance) of each bulb. Lighting design calculations for a three-bedroom flat were carried out for each type of bulb to determine the power consumption of each bulb for one year.

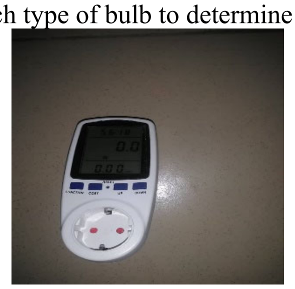

Fig.1a Plug-in Energy Monitor Power Meter

Fig.1b Victor Lux Meter

2.1 Power Measurement/Power Calculations

A plug type energy meter was used to measure the voltage, current, energy consumed in one hour and the power factor. AC power = volts x amps x PF (power factor). Table 1 shows the energy consumed by the various bulbs in hour.

2.1a Incandescent Bulbs

Table 1 Reading from Energy Meter and Lux Meter

Rated wattage (W)	Measured Wattage (W)	Measured Voltage (V)	Measured Current (Amps)	Energy Consumed in 1 Hr (KWH)	Power Factor	Brightness (Lux)
40	31	200.4	0.158	0.031	1	9.9
60	51.3	203.6	0.260	0.057	1.00	12.7
100	92.5	207.5	0.442	0.114	1.00	44.2
200	126.4	205.8	0.609	0.127	1.00	72.5

The table 1 above shows the actual power consumed, current and the supply voltage by the different rated incandescent bulbs when measured with energy meter and lux meter.

2.1b Compact Fluorescent Bulbs

Table 2 Reading from Energy Meter and Lux Meter

Rated wattage (w)	Measured Wattage (w)	Measured Voltage (V)	Measured Current (Amps)	Energy Consumed in 1 Hr (kwh)	Power Factor	Brightness (Lux)
11	8.2	207.6	0.060	0.007	0.56	19.3
18	12.5	207.2	0.84	0.011	0.66	45.7

The table 2 above shows the actual power consumed, current and the supply voltage by the different rated compact fluorescent bulbs when measured with energy meter and lux meter.

2.1c LED Bulbs

Table 3 Reading from Energy Meter and Lux Meter

Rated wattage (w)	Measured Wattage (w)	Measured Voltage (V)	Measured Current (Amps)	Energy Consumed in 1 Hr (KWH)	Power Factor	Brightness (Lux)
5	4.8	208.1	0.037	0.005	0.60	27.6
7	6.3	208.0	0.051	0.006	0.56	34.6
9	9.4	202.1	0.061	0.053	0.75	52.2
13	12.6	203.6	0.081	0.012	0.72	84.5
18	18.1	208.1	0.125	0.017	60	125

The table 3 above shows the actual power consumed, current and the supply voltage by the different rated LED bulbs when measured with energy meter and lux meter.

3.0 Light Design Consideration and Calculation for a thee bedroom flat

Table 4 IES Level for Some Selected Environment

Item No.	Home Environment	Lux Level
A	Living Room	50
B	Bedroom	50
C	Kitchen	150
D	Bathrooms	100
E	Dining Room	300
F	Rest Room	150
G	Reading room	300
H	Food Store	150
I	Perimeter / Surroundings	100
J	Laundry Room/ Wash Room	100
K	Corridors	I00

According to IES each environment has a recommended lux level. Shown above is the recommended IES lux level used in the light point design consideration.

Table 5 Equivalent Wattages and Light Output of Incandescent, CFL and LED Bulbs.

Light output	LEDs	CFLs	Incandescent
Lumen	Watts	Watts	Watts
450	4-5	8-12	40
750 - 900	6-8	13-18	60
1100 -1300	9 -13	18-22	75-100
1600 -1800	16-20	23-30	100
2600-2800	25-28	30-55	150

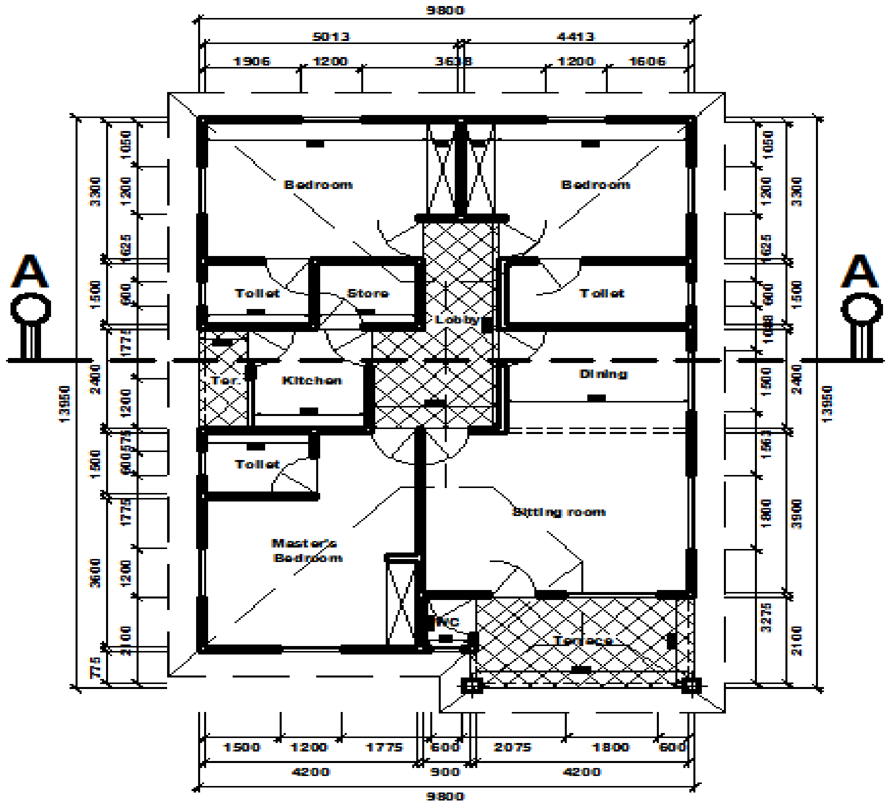

Figure 2 Three Bedroom Floor Plan with Dimensions

3.1 Calculations

Lighting design calculation of a three bedroom flat was carried out to determine the number of bulbs required to light up the building. The formula for the number of bulbs required to light up an area is given as

$$N = \frac{E\ X\ A}{\mathrm{Cu\ X\ Mf\ X}\ \emptyset} \qquad \text{Equation (1)}$$

Where N = Number of Fittings

E = the illuminance level of the area.

A = Area of the room or environment (m^2)

$\emptyset$ = Average Lumen from the type of Light used in the design.

Cu = Coefficient of Utilization

Mf = Maintenance factor;

From the Floor Plan in figure 2 above, the various calculations for each section is shown below.

Assuming Mf = 0.8 and Cu = 0.5. 40watts and 60 watts incandescent bulbs were used which have a corresponding lumen as (8-12) watt, (13-18) watt CFL and (4-5) watt, (6-8) watt LED bulbs as shown from the table.

Sitting Room with luminance of 50 lux $N = \frac{50\ x\ 3.9\ x\ 4.2}{0.5x0.8\ x\ 450} = 4.55 \approx 5$ bulbs

Bedroom 1 $N = \frac{50\ x\ 3.8\ x\ 3.3}{0.5x0.8\ x\ 450} = 3.48 \approx 4$ Bulbs

Bedroom 2 $N = \frac{50\ x\ 4.4\ x\ 3.3}{0.5x0.8\ x\ 450} = 4.03 \approx 4$ Bulbs

Bedroom 1 bathroom $N = \frac{100x\ 3.6\ x\ 1.5}{0.5x0.8\ x\ 450}$ = 3Bulbs

Bedroom 2 bathroom $N = \frac{50\ x\ 2.1\ x\ 1.5}{0.5x0.8\ x\ 450}$ = 1.75 ≈ 2Bulbs.

Dinning $N = \frac{300\ x\ 2.4\ x\ 3.6}{0.5x0.8\ x\ 900}$ = 9.6 ≈ 10 bulbs

Masters bedroom $N = \frac{50\ x\{\ (3.6x4.2)\ +(1,5x2.1)\}}{0.5x0.8\ x\ 450}$ = 5.07 bulbs.

Master Bathroom $N = \frac{100x\ 2.1\ x\ 1.5}{0.5x0.8\ x\ 450}$ = 1.75 ≈ 2 Bulbs

Kitchen = $N = \frac{150\ x\ 2.4\ x\ 2.2}{0.5x0.8\ x\ 450}$ = 4 Bulbs

Store $N = \frac{150\ x\ 1.5\ x\ 1.98}{0.5x0.8\ x\ 450}$ = 2.475 ≈ 2 Bulbs

Terrace 1 $N = \frac{100\ x\ 4.2\ x\ 2.1}{0.5x0.8\ x\ 450}$ = 4.9 ≈ 5 Bulbs

Terrace 2 $N = \frac{100\ x\ 2.4\ x\ 1}{0.5x0.8\ x\ 450}$ = 1.33 ≈ 1 Bulb

Lobby $N = \frac{50\ x\ 4.4\ x\ 3.3}{0.5x0.8\ x\ 450}$ = 4.033 ≈ 4 Bulbs.

Left and Right Side Outdoor $N = \frac{30x\ 13.95\ x\ 1.5}{0.5x0.8\ x\ 900}$ = 2.325 ≈ 2 x 2= 4 Bulbs

Back and Front side Outdoor $N = \frac{30x\ 9.8\ x\ 1.5}{0.5x0.8\ x\ 900}$ =1.6 ≈ 2 x2 = 4 Bulbs.

From calculations it could be seen that 59 bulbs are required of 18 60watt of incandescent bulbs or 18 (13-18) watt bulbs of CFL or 18 (6-8) watt LED bulbs and 41 40watts incandescent bulbs or 41 (8-12) watts CFL bulbs or 41(4-5) watt LED bulbs.

Table 6 Cost Comparison between LEDs, CFLs and Incandescent Light Bulbs

LED Bulbs	Cost	CFL Bulbs	Cost	Incandescent	Cost
5W	₦400=$1.11	11W	₦350=$0.974	40W	₦100=$0.278
7w	₦450=$1.25	18W	₦400=$1.11	60W	₦100=$0.278
9W	₦500=$1.39			100W	₦150=$0.417
13	₦600=$1. 67			200W	₦200=$0.556

1 USD ($) = Naira ₦359.492

3.2 Cost of Energy

The energy consumption for a period of one year was estimated. By making assumption that the bulbs were switched ON for 11 hours (7 Pm to 6am every day). The readings from kilowatt meter were used for this calculation and diversity factor of 0.65 was applied to the load because not all the bulbs will be ON/OFF at the same time.

3.2a Energy Consumption of Incandescent Bulbs

In the design calculation forty-one 40watt bulbs and eighteen 60watt bulbs are required.
Kwh Readings for 40watts bulbs ---- 0.031kwh from table 1
Assumed Energy Consumed in a day = 11x 0.031kwh = 0.341kwh x bulbs = 13.981kwh
Kwh reading for 60watt bulbs ----0.057kwh from table 1
Assumed Energy consumed in a day = 11 x 0.057kwh = 0.627kwh x 18 bulbs = 11.286kwh
Total kWh consumed in one day = 13.981kwh + 11.286kwh = 25.267kwh
Applying a diversity factor of 0.6 to the kWh we have 0 .6 x 25.267kwh = 15.1602kwh
Kwh consumed in one year = 15.1602kwh x 365 days = 5533.473kwh
Cost of electricity per kWh by Benin Disco (Energy Distribution company in Nigeria) ₦24.08 = $0.06698
Estimated cost of lighting the building in one year 5533.473 kWh x ₦24.08
₦133, 246.0298k = $370.644

3.2b Energy Consumption of CFL Bulbs

In the design calculation forty-one 11watt bulbs and eighteen 18watt bulbs are required.
Kwh Readings of 11watt bulbs ---- 0.007Kwh from table 2
Assumed Energy Consumed in a day = 11x 0.007kwh = 0.077kwh x 41bulbs = 3.157kwh
Kwh reading for 18watt CFL bulbs ----0.011kwh from table 2
Assumed Energy consumed in a day = 11 x 0.011kwh = 0.121kwh x 18 bulbs = 2.178kwh
Total kWh consumed in one day = 3.157kwh + 2.178kwh = 5.335kwh
Applying a diversity factor of 0.6 to the kWh we have 0 .6 x 5.335kwh = 3.201kwh
Kwh consumed in one year = 3.201kwh x 365 days = 1,168.365kwh
Cost of electricity per kWh by Benin Disco ₦24.08
Estimated cost of lighting the building in one year 1168.365 kwh x ₦24.08
₦28, 040.76 =$77.99

3.2c Energy Consumption of LED Bulbs

In the design calculation forty-one 5watt bulbs and eighteen 7watt bulbs are required.
KHW Readings of 5watt bulbs ---- 0.005KWH from table 3
Assumed Energy Consumed in a day = 11x 0.005kwh = 0.055kwh x 41 bulbs = 2.255kwh
Kwh reading for 7watt bulbs ----0.006kwh from table 3
Assumed Energy consumed in a day = 11 x 0.006kwh = 0.066kwh x 18 bulbs = 1.188kwh
Total kWh consumed in one day = 2.255kwh + 1.188kwh = 3.443kwh
Applying a diversity factor of 0.6 to the kWh we have 0 .6 x 3.443kwh = 2.0658kwh
Kwh consumed in one year = 2.0658kwh x 365 days = 754.017kwh
Cost of electricity per kWh by Benin Disco ₦24.08
Estimated cost of lighting the building in one year 754.017kwh x ₦24.08
₦18, 156.729k =$50.51

3.3 Analysis/ Result

The percentage Energy saved by CFLs in one year.
Energy used by incandescent in one year 5533.473kwh.
Energy used by CFLs in one year 1168.365kwh
Energy saved by CFLs in one year 5533.473kwh – 1168.365kwh = 4365.105kwh

$$\text{Percentage} = \frac{4365.105}{5533.473}\,x\,100\% \quad = 78.8\%$$

The percentage Energy saved by LEDs in one year.
Energy used by incandescent in one year 5533.473kwh.
Energy used by LEDs in one year 754.017 Kwh
Energy saved by CFLs in one year 5533.473kwh – 754.017kwh = 4779.463kwh

$$\text{Percentage} = \frac{4779.463}{5533.473}\,x\,100\% \quad = 86.4\%$$

Cost of Bulbs

The initial cost of bulbs to light up the three bedrooms flat is taking into consideration. 59 bulbs is need based on our calculation using IES standard.
From table 6 it can be seen that the cost of the various types of bulbs required is summed up to

a. cost of incandescent bulbs required = N5,900 = $16.41
b. Cost of CFL bulbs required = N21,550 = $60
c. Cost of LED bulbs required = N25,400 = $70.66

4.0 Conclusion

The most energy efficient bulbs with good light output with little current consumption is LED the percentage energy saved when compared with incandescent bulbs is 86.4% which is more than the 78.8% saved by CFL. Energy saved is directly proportional to savings in energy bill. The low cost of incandescent bulbs in the market cannot outweigh the savings in electricity at the long run. The difference between CFL and LED in terms of energy savings is about 10%. Using LEDs as the standard light bulb will help to reduce energy wastage due to lighting thereby reducing energy demand and making energy available for other purposes.

Acknowledgement

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