International Journal of Scientific & Engineering Research Volume 12, Issue 6, June 2021 Edition
ISSN 2229-5518

Energy Audit and Optimal Power Supply for a Hotel Building in Benin City, Nigeria.

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Abstract— Energy consumption is very important to humudin beings and there is the driving force to increase the amount of energy generated due to the type of development in terms of buildings, and the amount of energy required for the building. In Nigeria for example there are a high energy shortage and the frequent breakdown of generating stations down to the distribution of the energy in a given view of the high electricity demand. Lack of electricity brings about poverty in the country where business activities are short down due to the required energy to drive the economy. In this study, an energy audit of a two-story building hotel was performed to determine the nature and type of loads within the building. Based on the load report and energy consumption for 2 years, three alternative energy sources (national grid, diesel generator, and photovoltaic [PV] system) were considering using various load-sharing ratios. The result reveals that though the Photovoltaic solar system is a renewable energy source that reduces the production of greenhouse gases generated by burning diesel also noiseless. The network analysis using IPM 3005 FLEXIBLE QUALITY TESTER was used to get the actual building consumption irrespective of the manual audit carried out on the facility.

Index Terms— energy audit; load profiling; renewable energy optimization; photovoltaic power system; techno-economic analysis; building energy demand; renewable energy

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1 INTRODUCTION

The rising worldwide shortage of petroleum emphasizes the need for alternative energy sources that are both inexpensive and clean. The “energy crisis”, resulting from among alternative sources (wind, tide, wave, Geothermal, biomass, Magneto-dynamic, the most pollution-free limitless source is solar energy.

The basic resource for all solar energy systems is the sun. Solar energy appears to be the most promising among the non-conventional source of energy. The sun’s great energy release is the result of an elaborate chemical process in the sun’s core – a process of thermonuclear fusion like the reaction in the hydrogen bomb. Sun radiates the energy of about 3.5 x 1023 KW into space and only 2 x 1014 Kw reaches the earth.

This amazing solar energy, which is non-exhaustible and completely pollution-free, could drive civilization forever if it could be properly and economically harnessed. However, has got some serious drawbacks such as energy density per unit area is very low. It is available for only a part of the day and cloudy and hazy atmospheric conditions largely reduce the energy received.

Therefore, in harnessing solar energy and the means for the generation of electrical power large areas to collect a sufficient amount of energy and the means to store it will be required. Electrical energy can be generated from renewable and non-renewable sources, and it is one of the major sources of energy that can be easily converted from one form to another. The demand for electricity in commercial buildings is on the increase, especially in Africa, as a result of the rapid growth and development of the economy and due to urbanization. Several sub-Saharan African countries are plagued with poor energy infrastructure, with the electricity generated in Africa accounting for just 4% of the global electricity consumption (Eia, 2008, Moyo, 2009)

In Nigeria alone, the electricity required to drive the economy cannot be met by the national grid alone due to inadequate power generation, low transmission, and distribution infrastructure coupled with other challenges, leading to frequent power outages and network instability (Agbetuyi, Adewale, Ogunluyi, & Ogunleye., 2011, Awosope, 2014, Olukoju, 2004, Oseni, 2011, Samuel, Katende, Awosope, & Awelewa, 2017). Nigeria as a country currently generates less than 15% of the estimated national energy demand of 31,000 MW as of 2015 (Adekitan, Adetokun, Shomefun, & Aligbe, 2018). This is a threat to economic growth and the advancement of the modern built sector (Imaah, 2014). 78% of Nigerians have less than 12 hours daily access from World Bank report. The data from Nigeria Electricity Regulatory Commission (NERC) is that 55% of citizens connected to the grid are in tariff bands D and E which are less than 12 hours supply.

The energy efficiency of buildings is an important issue to building and which also leads to cost (Dinardi, Dinardi, & Torne, 2018, Siggelsten, 2018). Energy consumption in commercial buildings can be reduced using several approaches such as energy awareness programs and consideration of user behavioral impact (Adewale, Adekitan, Idoko, Agbetuyi & Samuel, 2018). But all these approaches have little impact on the energy demand. A more effective measure is an upgrade in the design of the power source. Commercial buildings have a great energy-saving potential (Ghenai & Bettayeb, 2017, Keerthi Jain et al., 2017), and this can be realized via an adequate assessment of building energy demand and alternative supply source comparative techno-economic analysis. The building energy audit conducted by Woo and Moore (2019) revealed that housing tenure types have a more significant effect on energy consumption as compared with the physical condition of the building, and likewise, the study also empha-

sized the importance of considering the socio-economic status of the occupant of buildings when developing energy efficiency models for multi-residential buildings. According to Makaremi, Schiavoni, Pisello, and Cotana (2018), a sizable amount of energy can be saved by increasing the indoor surface reflectance properties of buildings, but there is no single design solution for optimal energy savings and high visual quality. To save energy in buildings, a compromise between the quality of the indoor environment and the energy savings may be required (Merabtine & Maalouf, 2018).
In this study, the electrical energy demand and supply-source alternatives for a commercial building in Nigeria are evaluated using a 2-story hotel building as a case study. The design and selection of an optimal and cost-effective energy source combination would serve as a solution to the growing energy demand of the modern-day office, leading to cost and energy savings.

2 MATERIALS AND METHOD

2.1 Data collection

All required information regarding the case study was acquired during physical facility assessment, detailed survey, and energy audit. Also, relevant data on the two-story building hotel complex under study were provided by the establishment concerned. According to Ian Shapiro (2009). An energy audit can be classified into three levels, and these are walkthrough, general, and investment grade depending on the thoroughness and the scope of the audit. For this study, data were collected on the building's layout and electrical energy requirements for ventilation, air conditioning, lighting, and so forth.

2.2. Load Computation

An energy assessment is fundamentally the first step of an energy audit, and it is an assessment, a survey, and data-based analysis of the energy flows towards developing an energy management plan or model for the system or building, to reduce the total energy consumption without any negative consequence on the system's output. Second, inferences were made based on the data obtained from the audit, and designs are created for a cost-effective energy supply and efficiency. The building energy audit was conducted using manual walkthrough computations and network analysis using **IPM 3005 FLEXIBLE QUALITY TESTER** to determine the actual consumption of the hotel.

2.3 Total Power in KW

The test simply shows a maximum of 21.9KW is the power consumed (Phase value) while the 3 phases cumulatively approximately 70KW on the average

Fig 1.1 simplify the test results

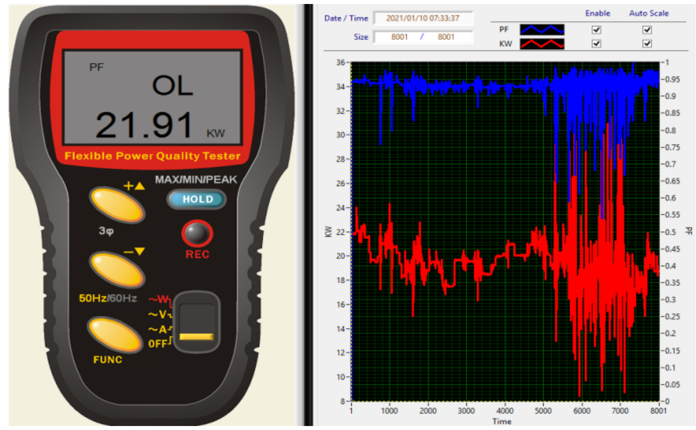


Figure 1.1 Powers in KW

2.4 Voltage Quality

The maximum Voltage values on phase to phase and phase to neutral are 412V and 244.6V respectively was recorded in the analysis across the three phases and against the neutral (Running on BEDC)
The voltage looks similar on all the phases running on generator

2.5 Current Measurement

A maximum load current value 101A was recorded in the phases during the analysis across the three phases due to consecutive increase or loading
The current look similar on all the phases without much difference, so we can say that phases are balance across.

2.6 Frequency Measure

A maximum frequency measurement was 50.04 Hz maximum and about 49.89 minimum

2.7 Manual Load Calculation

The following table contains a summary about all the electrical loads running estimated to be connected to the electrical network

TABLE 1
Energy Consumption Estimate

LOAD AND CONSUMPTION ESTIMATE				
S/ No	DESCRIPTION OF ITEM	RATING	QTY	ACTIVE POWER (KW)
1	Air conditional	2hp	10	15kw
2	Air conditional	1.5hp	44	41kw
3	Computer	200w	7	1.4kw
4	Pumping machine	2hp	4	6.1kw
5	Deep freezer	650w	2	1.3kw
6	Standing fridge	500w	7	3.5kw
7	Water heater	1.5kw	34	51kw
8	External light (fence)	20w	60	1.2kw
9	Spot light	6w	125	0.7kw
10	Round fitting	12w	150	1.8kw
11	Round fitting	18w	111	2kw
12	Television	180w	43	7.7kw
13	Fan	800w	6	4.8kw
14	Printer	85w	4	0.3kw
15	Hand Dryer	1.5kw	1	1.5kw
16	Drying machine	4.5kw	1	4.5kw
17	Washing machine	1.5kw	1	1.5kw
18	Washing machine	2kw	1	2kw
19	Pressing iron	1.6kw	1	1.6kw
20	Micro wave	1.2kw	2	2.4kw
21	Screen	250w	1	0.3KW
	TOTAL IN KW			151.6KW

Note from Table 1:

The table above captures all the energy demands of both running and idle machines, appliances, and bulbs, with consideration of possible future inclusions that could further increase the load demand of the hotel.

The rating of the items was deduced from running machines and equipment nameplates from various manufacturers

The active power (kW) was computed using the power of 0.82 deduced from our analysis results of the network.

Operational hour daily is 24hrs

70kw x 24hrs = 1,680kWh

In Nigeria, the official work hour for most hotels is usually operated 24hrs. For this project, we are assuming that the hotel runs for 24hrs daily from Monday through Sunday. This implies that a seven-day workweek is used. Using 365 workdays per year and over the next 2 years, there are 730 workdays, not taking into cognizance the average number of public holidays in a year.

2.8 Investigation of the unit cost of energy from alternative power sources

A relative cost analysis is performed based on a one (1) year running period of the hotel building. The thermo-economic method can be used to determine the unit cost of energy (Moran, 1982, Oh et al., 2014). Therefore the power generated from (generator, renewable sources) is defined by the cost-balance equation as follows in Equation (1);

$$C_f E_z^f + \sum C_k = C_w E_z^w \tag{1}$$

The terms are defined as follows:

C_f – Fuel cost per unit

E_z^f – Fuel consumption rate

C_k – Components of the capital cost

C_w – Unit cost of electrical energy

E_z^w – Rate of electrical energy generation

For renewable energy sources without fuel (e.g. solar energy), the cost-balance equation is defined in Equation (2) as follows:

$$\sum C_k = C_w T_c E_z^w \tag{2}$$

$$T_c = \frac{\text{Electricity generated by the energysystem annually}}{\text{Annual capacity of the energy system}} \tag{3}$$

The capacity factor T_c can be replaced with the utilization factor of the energy system given in Equation (4)

$$T_c = \frac{\text{Total hours of operation annually}}{365 \times 24} \tag{4}$$

2.9 The national grid

The total energy consumption in (kW) by the electrical fittings, devices, and power loads in the building is 191kw from the result of the manual energy audit from the hotel facility. Also, from power audit using IPM 3005 FLEXIBLE QUALITY TESTER which was run for 24hrs on the 3 phase a cumulatively approximately 70kWh on the average was a record on the usage of energy consumption daily both on weekends and when the hotel is fully booked. The national energy tariff for commercial users is 62.33 Naira/kWh as determined by National Energy Regulatory Council (NERC) from September 1st, 2020. Since hotels are run on 24hrs service 70kW x 24hrs = 1,680kWh

The total cost of daily consumption = Total daily consumption (kWh) × Tariff Therefore 1,680 62.33= 104,160Naira/day
Then expected bill for a period of one month is
104,160 x 30days = 3,124,800 Naira
For the 2 years assuming a constant NERC tariff, the energy cost for the hotel complex is obtained as follows:
Energy cost over 2 years = 3,124,800 × 730 = N2,281,104.000

2.10 Diesel generator

The total load demand of the hotel complex was found to be 70kW, and with a power factor of 0.8, the load in kVA is 87.5kVA. For this analysis, a Cummings 3-phase, 415-V, 50-Hz diesel engine generator with engine model NTA855-G1A, 6 Cylinder is selected, with a capacity of 312 kVA and fuel (automotive gas oil) consumption rate of 48L/hr with a full load, with a lube oil capacity of 39 L with a second 100kva backup generator in the case of total blackout.
Cost of purchase and installation = 25,000,000 Naira
Cost of diesel with yearly inflation considered = 240 Naira/L
Daily diesel consumption = 1,488 L
Daily diesel cost = 48 × 24 × 240 = 276,480 Naira
Total daily energy consumption = 1,680kWh/day
Annual maintenance cost = N1, 000,000.00
Factoring all cost over 2 years = 25,000,000 + (276,480 × 730) + (1,000,000×24) = 250,830,400 Naira
Daily cost of using generator = $\frac{250,830,400}{730} = 343,603.288 Naira$
Monthly cost of using generator = 343,603.288 x 30 days =10,308,098.6 Naira
Per unit cost = $\frac{Daily\ Cost\ of\ Energy}{Total\ Daily\ Consumption(kWh)} = \frac{343,603.288}{1,680} = 204.5 Naira\ kWh$

3 Photovoltaic solar energy systems

A photovoltaic system, also PV system or solar power system is a power system designed to supply usable solar power employing photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as the balance of system (BOS). As PV systems convert light directly into electricity, they are not to be confused with other solar technologies, such as concentrated solar power or solar thermal, used for heating and cooling. PV systems range from small, rooftop-mounted, or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems account for a small portion of the market. Operating silently and without any moving parts or environmental emissions, PV systems have developed from being niche market applications into a mature technology used for mainstream electricity generation.
Figure 2.1 a typical solar PV system set up on a building's rooftop.
Source: the grid by media Stanford rooftop photovoltaic panels.

(a) (b)

3.1. Design parameters for this study

Rated terminal DC voltage: 48V
Operational hours per day: 24hrs
The photovoltaic system will serve as the main source of energy backup which will supply power for 24hrs daily.
Days of autonomy: 1.5 days
Depth of discharge: 50%
The amperage of battery: 2,490 AH

3.2 Battery sizing

Estimated kWh capacity = Total building energy requirement × Days of autonomy =
1,680 × 1.5 = 2,520 kWh
Depth of discharge = 50% (~0.5)
Battery loss factor = 0.9
For the operation of the facility for 24hrs,
The total building energy requirement x 2 (based on the discharge rate of 50% of the battery)
Therefore 2 x 1,680 = 3,360 kWh
Design kWh capacity = $\frac{3,360}{0.5\ x\ 0.9} = 7,466.7 kWh$
Converting kWh to Wh of the design capacity 7,466.7 x 1000 = 7,466,700Wh
Ampere hour rating = $\frac{7,466,700}{48} = 155,556.25\ Ah$
Number of batteries required = $\frac{155,556.25}{2490} =$ 62.47 (~64 flooded deep-cycle batteries)

3.3 Inverter sizing

The inverter is required to handle the load of 70kW. Hence, a 100kW pure sine wave Three-Phase inverter is recommended in the case of expansion of the hotel, thereby creating space for more equipment.

3.4 PV Panel sizing

Table 2

Rating of solar panel

Specification	Rating Value	Units
Power output	270	Watts
Maximum Power Voltage	32.32	Volts
Maximum power current	8.35	Amps
Open Circuit Voltage	37.70	Volts
Maximum system voltage	1000	Volts
Short Circuit Current	8.94	Amps
Series Fuse	15	Amps
Solar Radiate	1000	Watt /M2
Test Temperature	25	oC
Mechanical Load Tested	2400	Pa
Production Tolerance	0~ +3	%

Total Kilowatt-hours needed per day = 1,680kWh/day.
Watt-hours needed from the PV system = 1,680,000 × 1.3
The panel generation factor (Nigeria) = 3.596
The overall Watt-peak rating $=\frac{1,680,000\ x\ 1.3}{3.596} = 607,341.49$Watt-peak
PV power rating per module = 270Wp
The number of solar panels needed for the design $= \frac{607,341.49}{270} =$ 2,249panels
Hence, 2,249 solar panels of 270 Wp will be required to supply the building's electrical energy requirements.

3.5 Charge controller

The solar charge controller rating per string = I_{SC} × 1.3
I_{SC} = Total short circuit current of the PV array
P_m = 270 Wp
V_m = 49.27 V (DC)
I_m = 8.12 A
V_{oc} = 61.10 V
I_{sc} = 8.62 A
Minimum rating of the single solar charge controller = (2,249 × 8.62 A) × 1.3 = 25,202.294 A
Using strings of six PV modules per controller = (6 × 8.62 A) × 1.3 = 67.24A
Hence, 450 charge controllers of 60 A can be used

In other to evaluate the cost of a PV system the lifespan of a typical PV is 25 years and with a product warranty of 10 years. The battery warranty of 5-15 years for non-grid systems and hybrids while the warranty on inverters varies between 5 and 10 years. For the maintenance cost of the solar PV system, only two major things need to be considered over the 25 years; and these are the inverter maintenance and cleaning of the solar PV every 6 months

Table 3

Cost estimate for setting up the solar PV system

S/No	Equipment	Specifications	Quantity	Estimated rate	Amount (₦)
1.	Batteries	Deep-cycle battery	64	6,000,000	384,000,000
2.	Solar PV panel	270 W, 32 V	2,249	50,000	112,450,000
3.	Charge controller	60 A, 48 V	450	52,000	23,400,000
4.	Inverter	100 kW	1	2,500,000	12,500,000
5.	Combiner boxes		486	41,000	19,926,000
6.	Panel rack		1	1,900,000	1,900,000
7.	Battery rack		1	800,000	800,000
8.	AC breaker		1	110,000	110,000
9.	Change over switch		1	100,000	100,000
10.	Distribution box		1	130,000	130,000
11.	Cables and accessories			800,000	800,000
	Total Cost				**582,260,000**

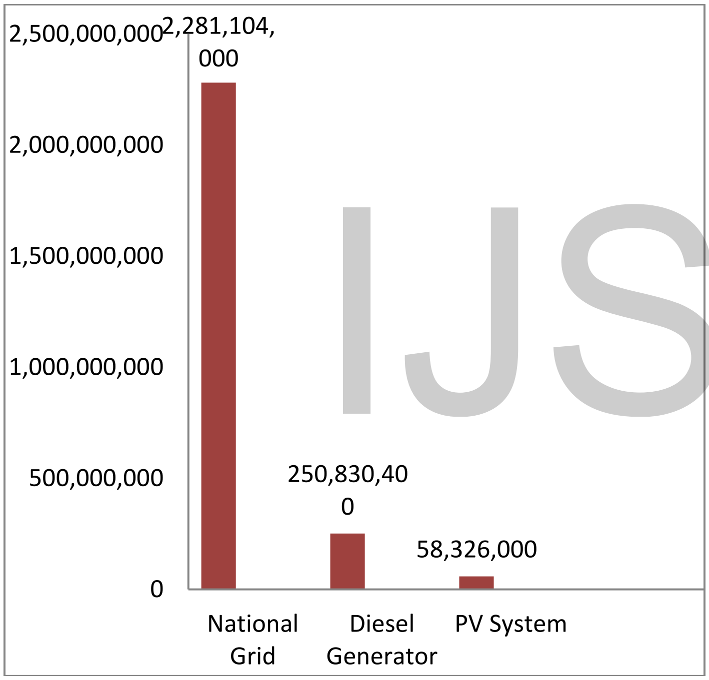
Cost of acquisition and installation = 582,260,000 Naira
Annual cost of maintenance = 50,000 Naira
Factoring all cost over 2 years = 582,260,000 + (50,000 × 2) = 58,326,000 Naira
The daily cost of using a solar PV system $\frac{58,326,000}{730} = 79,898.63$

Per unit cost $= \frac{\text{Daily Cost of energy}}{\text{Total daily consumption kWh}} \quad \frac{79,898.63}{1,680} = 47.56$ Naira/kWh

3.6 Comparative load sharing for the alternative energy sources

In a micro grid, load sharing is the proportional division of the total kW and kVAR load between multiple energy sources in a parallel system. The reliable operation of microgrids can be achieved by properly sharing the load demand among available energy sources within the microgrid. The load sharing depends on the type of energy sources and the characteristics of the microgrid where most of these energy sources are based.

The grid integration of renewable energy sources (solar PV system) increases the uncertainties as the power generation from renewable energy sources relies heavily on natural sources (e.g. sunlight) which are unpredictable. In such cases, load sharing becomes more challenging as the reliability of the grid degrades. A proper load-sharing technique is necessary to enhance the reliability and cost of the microgrid.
This study employs the technique of applying a simple ratio to divide the load demand among the alternative sources, to find the cost of using different combinations of energy sources to power the load was carried out. Via a comparative analysis, the most cost-effective means can be determined; three load-sharing scenarios are considered for this purpose.



Graph 3.6.1 Using graph to illustrate 2 Year cost of National grid, Diesel Generator, and PV System

4 Recommendations
Due to government agreement with distribution companies (Discos) in Nigeria, the electricity tariff has been attempted to be increased by three (3) times. Also Six years down the line, no megawatts had been added and no power plant had been built by either the investors or the government. So the need for a solar PV system, which are;
(a) Reduces Electricity Bills
(b) Diverse Applications. ...
(c) Low Maintenance Costs Technology Development
(d) Weather-Dependent based in sub-Sahara Africa
(e) Solar Energy Storage Is Expensive but very effective

5 CONCLUSION
The energy demand of a two-story building hotel complex in the south-southern region of Nigeria was profiled and analyzed to determine the cost-effective approach for powering the building's electrical load. Three sources of electrical energy were considered and these are PHCN public grid supply, diesel generator, and solar PV system. The unit cost of energy for the three alternative sources was determined using the initial setup capital and the operational running cost analysis over 2 years. From the result obtained it show that energy from the national PHCN grid is the cheapest, but this is a challenge by network instability, fluctuations, and insecurity in supply which disrupt the business activities. Generally, the use of diesel generators is a very effective substitute to the undependable public supply, the burning of fossil fuel is a major cause of greenhouse gases worldwide, the various governments are putting in constant mechanism to protect the ozone layer by reducing the sources of ozone-depleting substances. The solar PV system is a renewable source of energy, which is very clean and sustainable. The solar PV system is usually very high in the initial setup of the system coupled with the installation cost. But as the year continues the rate of cost/maintenance of the PV system becomes very cheap with zero emissions. Therefore that informs the study in other to develop an effective energy supply that will not be a problem to the environment and people living in it.

ACKNOWLEDGMENTS
The author wishes to express his immense gratitude to Mr. Constant Oseki who brought the machine that was used for the power auditing, Also providing the location for the audit and Mr. Victor Anthony who help to take a reading of the facility.

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