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Proceeding Paper

A Data Envelopment Analysis to Benchmark Hotel Energy Consumption in an Urban Locality †

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Abstract: The benchmarking of hotel energy use comprehensively identifies the controllable and uncontrollable factors affecting energy performance, including building characteristics, management strategies, operations, and maintenance systems. Other factors include climatic conditions, floor areas, operating hours, occupancy rates, and guest populations. A benchmarking study on energy consumption patterns in significant hotels (each with less than 100 rooms and an average staff strength of 40 employees), situated in the university town of Nsukka (longitude 70 23′ E, latitude 60 52′ N), Nigeria, was performed using the data envelopment analysis (DEA) methodology. The DEA, a linear programming technique that measures the relative performances of units, was chosen as a benchmarking methodology due to its ability to handle multiple inputs and outputs. Following a correlation test, energy use intensity, diesel consumption, and the number of employees were selected as the analysis inputs, while the occupancy rate was chosen as the output variable. Data on these variables spanning 12 months were collected using questionnaires, interviews, site visits, and oral conversations with hotel managers to ensure validity. Grid-supplied electricity accounted for most of the hotels' energy needs, followed by diesel used in generators. More than 70% of the electricity use was for HVAC. From the DEA, Hotel 3 (DMU H3) had a technical efficiency score of 1, whereas adjustments were recommended for improving the efficiency scores of the other hotels, which were deemed inefficient. DMU H7 had the lowest efficiency score (0.474) and the highest identified savings for electricity and diesel. The analysis also revealed that occupancy rates were generally low in the months of June and July, coinciding with the high rainfall season with its accompanying decline in outdoor activities. Consistent with this, electricity consumption was highest in the Christmas and Easter holiday months of December, January, and April following increased travel-related activities.

Keywords: hotel energy consumption; data envelopment analysis; hotel benchmarking; building energy efficiency

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1. Introduction

The global hotel industry, a multi-billion-dollar sector focused on guest comfort, faces challenges related to high energy consumption [1]. Service areas in hotels tend to consume more energy, and thermal losses occur in their public areas [2]. The rising energy costs and increasing customer demands pose a dilemma for hotel owners who aim to balance cost reduction with maintaining service quality.

A European study by the Hotel Energy Solutions group [3] showed that HVAC and domestic hot water (DHW) accounted for 72–75% of the energy used in hotels, while lighting accounted for 8–9%, and catering accounted for 15%. However, energy costs in hotels can be minimized by adopting excellent management practices as highlighted by Suriyaprabha and Subbiah [4]. Unachukwu and Onyegegbu [5], in their publication on the electrical energy consumption pattern of a cement company in Nigeria, defined energy conservation as it relates to energy efficiency.

This study, conducted in the University City of Nsukka, Nigeria, recognizes the need to assess and improve energy utilization in hotels. The purpose of the study is to investigate energy management practices in Nsukka hotels and benchmark their energy consumption to determine effectiveness. The objectives include assessing energy consumption, calculating energy costs, identifying wastage areas, proposing energy management recommendations, and comparing cost savings achieved through these measures. The study also seeks to identify key factors influencing energy consumption in hotels in Nsukka, Nigeria.

It pinpoints inefficiencies in energy costs and emphasizes the importance of minimizing energy waste. To analyze energy use in hotels, end-use patterns are usually surveyed and energy audits are conducted, as indicated by Lu et al. [1]. Energy audits involve site investigations, data collection and analysis, cost–benefit ratio analysis [2], documentation of findings, and the implementation of action plans. The collected data were analyzed using energy benchmarking, regression-based analysis, clustering techniques, and DEA. Energy benchmarking compares a hotel's energy performance to similar establishments [6]. This was carried out to help improve energy efficiency or put in place better energy-efficient strategies.

2. Materials and Methods

Ten hotels were selected for this study: New Ikenga Hotel, Kennan Lodge Hotel, Golden Valley Hotel, Jucony Hotel, See New Hotel, CEC Guest House UNN, Grace Manor Hotel, Old Carolina Hotel, Discovery Lodge, and Jerry Marriot Hotel, all located within the Nsukka metropolis.

Data availability on energy consumption in the hotel industry in Nigeria is limited and, in Nsukka, non-existent. There is no central database for periodic documentation, and in most cases, hoteliers do not recognize the need for energy audits and may not have conducted an audit since inception. Thus, the data used in this research were generated from primary sources, which included personal visitations to the selected hotels and the administration of a questionnaire. The questionnaire requested building information, energy indexes, and building operation characteristics to quantify the energy consumption within the selected hotels. The lead researcher visited each hotel to interview the managers, collect cost-related data from the hotel accountants and worked with the service departments to get data on various energy consuming equipment noting their rating and operational hours. Also, electricity cost data were matched with data collected from the Electricity distribution company. All the data collected using this questionnaire were subjected to a correlation test. Table 1 shows the correlation between the inputs and outputs.

Table 1. Zero-order correlation coefficients for all variables in this study.

	1.	2.	3.
1. Occupancy rate	---		
2. Number of employees	**0.42**	---	
3. Electricity unit	**0.54**	0.03	---
4. Diesel consumption	**0.55**	**0.32**	**0.58**

Note. Bold coefficients are significant ($p > 0.05$).

Benchmarking Hotel Energy Consumption Using Data Envelopment Analysis (DEA)

The DEA as a benchmarking approach can consider multiple inputs and outputs and can be used on both large and small samples of hotels [7]. The DEA evaluates a set of decision-making units (DMUs) showing how well they convert inputs to outputs. These DMUs are then located on their efficiency frontiers. For the best application of the DEA approach, the minimum number of DMUs must be at least twice the sum of the total inputs and outputs [6]. Also, all inputs must be positively correlated to at least one output [7]. Studies conducted with the application of DEA in hotels have involved the use of different accounting and non-financial data for input variables and outputs [7]. Katarina et al. [8] have compiled some of these influential factors. Details of energy efficiency analysis using data envelopment analysis (DEA) have been comprehensively presented in Abbas et al. [9]. For the purpose of this study, we applied the constant return to scale (CRS) model with an input orientation, which assumes that the returns to scale are constant such that all the DMUs are operating at optimal scale [10]. The model inputs were energy use intensity (EUI), number of employees, and diesel consumption, while the output was the occupancy ratio. In order to clarify this methodology, a sample hotel, New Ikenga Hotel is defined as 'DMU_i'; one input, EUI, is noted as 'j', and one output, the occupancy ratio, is noted as 'k'.

$$\text{Hence, the objective is to obtain } max\frac{\sum_{k=1}^{1} v_k y_{kp}}{\sum_{j=1}^{3} u_j x_{jp}};\ \text{subject to } \frac{\sum_{k=1}^{1} v_k y_{kH1}}{\sum_{j=1}^{3} u_j x_{jH1}} \leq 1;$$

where $\forall\ i$ and v_k, $u_j \geq 0\ \forall\ k, j$; y_{ki} = amount of output k produced by DMU_i, x_{ji} = amount of input j utilized by DMU_i; v_k = weight given to output k; and u_j = weight given to input j. The DEA fractional models can be converted to a linear programming method as follows:

$$max\sum_{k=1}^{1} v_k y_{kp} \text{subject to } \sum_{j=1}^{3} u_j x_{jp} = 1 \text{ and } \sum_{k=1}^{1} v_k y_{ki} - \sum_{j=1}^{3} u_j x_{ji} \leq 0;$$

where $\forall\ i$ and v_k, $u_j \geq 0\ \forall\ k, j$.

A Data Envelopment Analysis Program software popularly known as DEAP version 2.1 that uses two text files and runs on a DOS system was used for this study. The inputs and ouputs variables were then populated separately into the two text files and other operating instructions were set such as model selection time periods, number of inputs, outputs, DMUs considered and the file names. The software then generates detailed and easy to understand reports where sequence numbers are used to reference the DMUs.

3. Results and Discussion

3.1. Variables for the Data Envelopment Analysis

3.1.1. Occupancy Ratio

The monthly occupancy ratio data were collected from the hotels for a period of one year—2021. DMU H2 recorded the highest mean occupancy rate of 79.75%, while DMU H7 had the lowest mean occupancy ratio of 26%. Most of the DMUs recorded their highest occupancy ratios in the month of December. This may not be unrelated to the boom due to the festivities during this period as it also impacted their January figures. Generally, the occupancy ratios were lowest in June and July, as these are the peak of the rainy season, when there is a decline in outdoor activities and events.

3.1.2. Energy Use Intensity

Figure 1 shows the annual EUI for the surveyed hotels. To aid a detailed analysis of the energy performances of all DMUs, the monthly EUI for each hotel was also obtained. The collected data showed that the surveyed hotels had a mean EUI of 51.42 kWh/m^2/year. DMU H5 recorded the highest EUI of 97.77 kWh/m^2/year, while the lowest EUI was recorded by DMU H10, with 17.68 kWh/m^2/year. Although the EUI varied for each hotel, most of them showed that electricity consumption in January, April, and December was above the mean electricity consumption. These months were also the top three in terms of occupancy ratios. There is usually a high level of activities in these periods arising from the celebration of Christmas and Easter holidays. Similarly, the consumption was lowest at the end of the second quarter into the third quarter, when the lowest occupancy ratios were recorded.

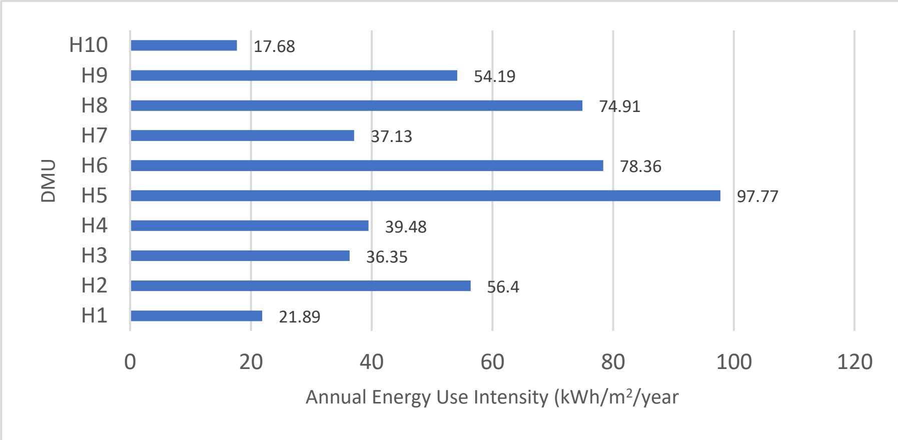

Figure 1. Annual energy use intensities of the surveyed hotels (DMUs).

3.1.3. Diesel Consumption

Figure 2 shows that the DMUs consumed an average of 22,970 liters of diesel for their annual operations. This quantity is higher than the diesel used by DMU H3, which had the least annual diesel consumption of 11,682 liters. DMU H2 recorded the highest diesel consumption of 39,790 liters, which correlated with its high occupancy ratio.

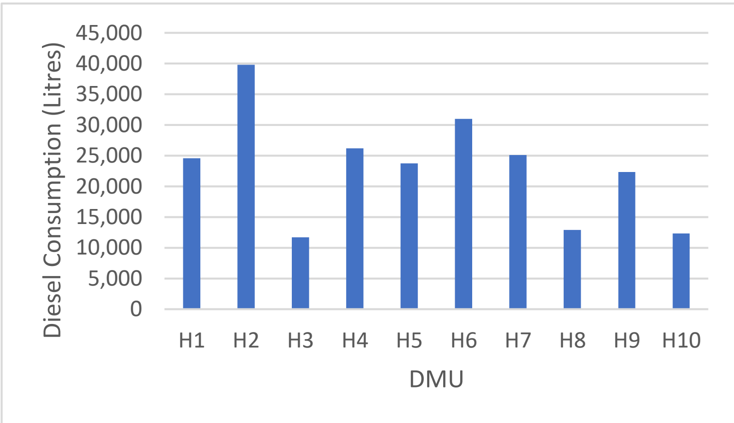

Figure 2. Annual diesel consumption of the DMUs.

On a monthly basis, the DMUs used the most diesel quantities in December and April, the months in which they had high average occupancy ratios of 62.3 and 57.9, respectively. It generally appeared that the quantity of diesel consumed increased as the occupancy ratios increased.

3.1.4. Number of Employees

The number of employees remained constant for all DMUs during the period this research was conducted.

3.2. Data Envelopment Analysis of Energy Efficiencies in the Surveyed Hotels

Technical Efficiency

The analysis was performed with the DEAP Version 2.1 software. Input-oriented CRS multi-stage DEA modeling was used to obtain the technical efficiencies of the hotels (DMUs) over the period of twelve months, as shown in Figure 3. The technical efficiencies of the DMUs obtained for each month and the summary of peers are presented in Tables 2 and 3, respectively.

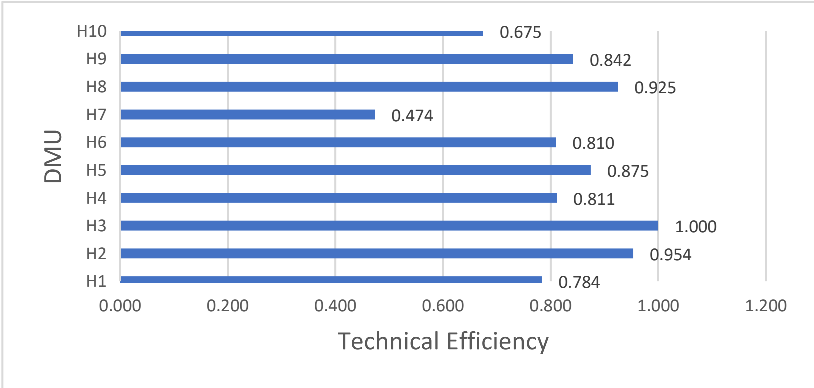

Figure 3. Technical efficiencies of DMUs over a one-year period.

Table 2. Monthly technical efficiencies of the DMUs.

DMUs	January	February	March	April	May	June	July	August	September	October	November	December
H1	1.000	1.000	0.687	0.867	1.000	0.719	0.460	0.435	0.836	1.000	1.000	0.401
H2	0.555	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.889
H3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
H4	1.000	0.964	0.733	0.823	0.463	0.736	0.989	0.509	1.000	0.965	0.698	0.857
H5	0.812	1.000	0.931	0.892	0.729	1.000	1.000	0.941	1.000	1.000	0.550	0.639
H6	0.664	0.760	0.862	0.879	0.790	1.000	0.897	0.875	0.846	0.993	0.639	0.514
H7	0.611	0.330	0.377	0.354	0.261	0.448	0.386	0.398	0.434	0.591	0.747	0.745
H8	0.803	0.769	1.000	0.950	0.993	0.993	0.941	0.855	0.908	1.000	0.889	1.000
H9	0.750	0.719	1.000	1.000	0.880	0.862	0.653	0.775	0.772	0.750	1.000	0.943
H10	0.593	0.320	1.000	0.713	0.592	0.596	0.598	0.767	1.000	0.834	0.580	0.504

Highest value 50th percentile Lowest value.

Table 3. Summary of peers.

DMUs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H1	H1	H1	H10, H2	H3, H2	H1	H3, H2	H2, H3	H3, H2	H10, H2	H1	H1	H3
H2	H4, H1	H2	H2	H2	H2	H2	H2	H2	H2	H2	H2	H3
H3	H3	H3	H3	H3	H3	H3	H3	H3	H3	H3	H3	H3
H4	H4	H3, H2	H3, H9, H2	H3, H9, H2	H2, H3	H5, H6, H3	H3, H2	H3, H2	H4	H5, H3	H3, H9	H3
H5	H3	H5	H9	H9	H3	H5	H5	H3	H5	H5, H3	H9	H3
H6	H3, H4	H3, H2	H8, H9, H3	H3, H9, H2	H3	H6	H5, H3	H3	H5, H4	H5, H3, H8	H3, H9	H3
H7	H4, H1	H3, H2	H9, H2	H3, H9, H2	H3	H3, H6, H2	H3, H2	H2, H3	H4, H5	H5, H3	H9, H3	H3
H8	H3	H3	H8	H9, H3	H3	H5, H3	H5, H3	H3	H3, H4	H8	H3, H1	H8
H9	H3	H3, H5	H9	H9	H3	H3, H5, H6	H5, H3	H3	H5, H4	H5, H3	H9	H3
H10	H1, H3	H3, H2, H1	H10	H3, H2	H3, H1	H2, H3	H2, H3	H3, H2	H10	H1, H2	H2, H3	H3

Table 2 shows that, for the month of January, DMUs H1, H3, and H4 had an efficiency score of 1, while DMU H2 had the least technical efficiency of 0.555. Therefore, DMU H2 needs to improve its efficiency by 44.5% to achieve the efficiency frontier in January. This model suggests that DMU H2 is peers with DMU H4 and DMU H1. For an inefficient firm, a peer set identifies the firm to aspire to as a reference [11]. Therefore, DMU H2 can achieve similar levels of efficiency by following the input–output trends of either DMUs H4 or H1. If the EUI, diesel consumption, and number of employees of DMU H2 are adjusted to be equal to 68.3% of equivalent values for DMU H4 or 14.5% of the values for DMU H1, an efficiency score of unity will be obtained. Similarly, in the month of February, four DMUs are on the efficiency frontier, while the others require varying degrees of improvement. The least efficient DMU in this month, H10, can attain an efficiency score of 1 if its inputs are adjusted to the input–output trends of its peers: DMUs H3, H2, and H1. Following these observations, similar inferences can be made for the remaining months.

3.3. Potential Annual Savings from Recommended Adjustments for the Surveyed Hotels

The DEA analysis showed that only DMU H3 was efficient, having a technical efficiency score of 1. All other DMUs had varying degrees of inefficiency, as well as slack and radial movements. These adjustments show the potential savings the DMUs will realize while raising their technical efficiency score to 1.

Figure 4 shows that all but one of the surveyed hotels had some amount of potential savings should they implement the recommended adjustments to improve their energy performance. DMUs H7, H1, and H10 had the highest potential savings of over NGN 8.91 million (USD 11,598.06), NGN 7.03 million (USD 9150.88), and NGN 6.12 million (USD 7966.34), respectively, while DMUs H2, H8, and H3 operated more efficiently, with potential savings of less than NGN 2 million (USD 2603.38) in a year.

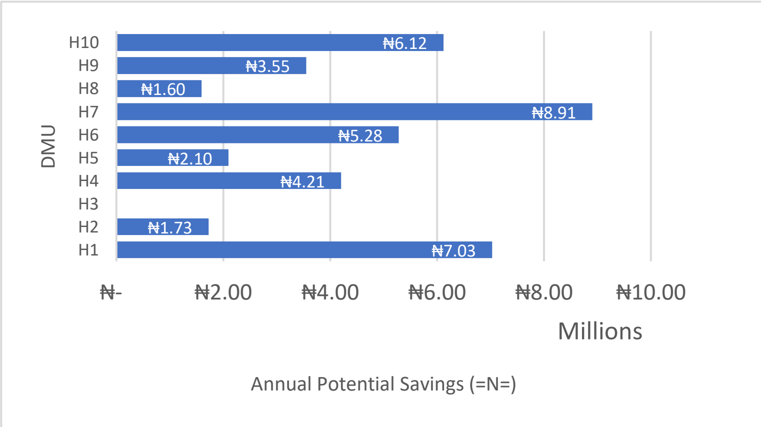

Figure 4. Potential annual savings from recommended adjustments for the DMUs.

4. Conclusions

Notably, the hotels relied more on electricity for their energy needs complemented by diesel for their backup electricity generators and gas for cooking. It was also observed that more than 70% of the electricity was used for HVAC, indicating the weight impact of cooling energy use on the total energy used by hotels in the study environment. We have shown that significant savings opportunities exist in the studied hotels. Such savings potentials can similarly be identified in other hotels to improve profitability and reduce the environmental burden of their operations. This research is significant due to Nigeria's energy supply challenges, including inadequate power supply from the national grid. Hoteliers can benefit from this study as it explores a methodology for assessing energy losses, improving energy efficiency, and exploring alternative energy sources like solar while engaging in routine servicing of their generators. Also, they can invest in energy-efficient HVAC systems and implement occupancy-based lighting controls to reduce energy consumption during low-occupancy months.

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Conflicts of Interest: The authors declare no conflict of interest.

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