Electrical Consumption Monitoring and Variance Analysis in Selected Institutional Buildings: Basis for Energy Efficiency Management

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ABSTRACT Energy efficiency has become a strategic priority in higher education institutions due to rising operational costs and sustainability commitments. This study analyzes electrical consumption patterns and variance across selected institutional buildings to support data-driven energy efficiency management. A descriptive-analytical design was employed using secondary data from monthly electrical monitoring records, focusing on average consumption, current usage, differential values, and percentage changes. Results indicate significant variation in energy consumption across facilities, reflecting differences in operational demand, occupancy, and system efficiency. Several buildings exhibited increased consumption relative to baseline levels, suggesting potential inefficiencies or shifts in utilization patterns. Variance analysis further revealed disparities in energy performance, highlighting the need for facility-specific management strategies. The findings emphasize the importance of integrating real-time monitoring systems, standardized reporting, and energy management systems (EMS) to optimize electricity use. The study contributes to institutional sustainability efforts by providing empirical evidence for policy development, infrastructure improvement, and behavioral interventions aligned with Sustainable Development Goal 7.

Keywords : Energy efficiency, electrical monitoring, institutional consumption, sustainability, utility management, variance analysis

INTRODUCTION

The increasing demand for energy efficiency in higher education institutions reflects broader global efforts to address sustainability, cost management, and environmental responsibility. Across many countries, universities are increasingly expected to contribute to climate action initiatives while maintaining operational efficiency and fiscal accountability. In this context, energy consumption has emerged as a critical area of concern, particularly as institutions expand their infrastructure, integrate advanced technologies, and accommodate growing student populations. In State Universities and Colleges (SUCs), electrical consumption constitutes a substantial portion of operational expenditures, making it a key factor in institutional planning and resource management. Consequently, there is a growing need for systematic monitoring and management strategies that can effectively regulate energy use while supporting sustainability goals.

Traditionally, institutional energy monitoring has focused on descriptive reporting of consumption levels, primarily through monthly billing records and basic meter readings. While this approach provides a general overview of energy use, it is limited in its capacity to identify inefficiencies, detect abnormal consumption patterns, and support predictive decision-making. Descriptive monitoring often fails to capture the underlying factors influencing energy use, such as operational schedules, equipment performance, and user behavior. As a result, institutions relying solely on traditional monitoring methods may struggle to implement targeted interventions or optimize energy utilization. The transition toward data-driven energy management systems (EMS) has addressed these limitations by enabling institutions to integrate monitoring, analysis, and intervention strategies for improved energy performance. Through the use of structured data analysis, EMS frameworks provide insights that support evidence-based decision-making and continuous performance improvement (Bolchini et al., 2017; Chagnon-Lessard et al., 2021).

Recent advancements in smart energy systems have further enhanced the capacity of institutions to monitor and manage electrical consumption. The integration of Internet of Things (IoT)-based monitoring devices, smart meters, and real-time analytics has enabled more precise tracking of energy use across facilities. These technologies allow institutions to move beyond static reporting toward dynamic and adaptive management approaches. For instance, real-time data analytics can identify peak demand periods, detect anomalies, and support automated control systems that adjust energy use based on operational needs. Such capabilities contribute to the development of predictive energy management strategies that minimize wastage and improve efficiency. Studies indicate that institutions implementing comprehensive EMS frameworks achieve more effective energy optimization through the integration of technological, behavioral, and organizational components, highlighting the importance of a holistic approach to energy management (Kourgiozou et al., 2021; Abdelbasier et al., 2022).

Despite these advancements, the implementation of effective energy management practices in SUCs remains uneven and constrained by several challenges. One of the primary issues is the inconsistency and heterogeneity of electrical consumption data, which may result from outdated infrastructure, lack of standardized metering systems, and limited data governance frameworks. Without reliable and consistent data, institutions face difficulties in conducting accurate analysis and making informed decisions. Additionally, financial constraints and limited technical expertise may hinder the adoption of advanced monitoring technologies and energy management systems. Beyond technical and institutional factors, energy consumption patterns are also influenced by human behavior, occupancy levels, and operational practices. User habits, such as inefficient use of lighting, air-conditioning systems, and equipment, can significantly affect overall energy demand. These combined factors contribute to variability in energy use, highlighting the need for analytical approaches that extend beyond simple monitoring and incorporate both technical and behavioral dimensions (Samara et al., 2022).

In this regard, variance analysis provides a systematic and practical method for evaluating differences between expected and actual energy consumption. By comparing baseline consumption levels with current usage, institutions can identify deviations that may indicate inefficiencies, operational changes, or shifts in demand. Variance analysis not only facilitates the detection of irregularities but also supports the evaluation of energy performance over time. This analytical approach is particularly useful in institutional settings where energy use is influenced by multiple interacting factors. However, despite its potential, localized studies examining electrical consumption variability in SUCs remain limited, particularly within the Philippine context. Much of the existing literature focuses on large-scale or international case studies, which may not fully reflect the operational realities of local institutions. This gap underscores the need for context-specific research that integrates data analysis with institutional conditions and constraints.

Anchored in Systems Theory, which conceptualizes energy consumption as the outcome of interacting components within a dynamic system, this study views institutional buildings as interconnected units influenced by operational, behavioral, and technological factors. Within this framework, energy use is not determined by a single variable but emerges from the interaction of multiple system components. This perspective supports the use of baseline consumption and variance analysis as diagnostic tools for identifying inefficiencies and guiding management interventions. By understanding energy consumption as a system-level phenomenon, institutions can develop more comprehensive strategies that address both immediate inefficiencies and underlying structural factors.

This study aims to analyze electrical consumption patterns and variance across selected institutional buildings as a basis for energy efficiency management. Specifically, it seeks to determine the average electrical consumption based on the previous three-month period, assess the current electrical consumption levels of each monitored facility, compute the differential between average and current consumption, evaluate percentage changes in consumption across facilities, and propose recommendations for improving institutional energy efficiency. Through this approach, the study contributes to the development of data-driven strategies that support sustainable energy management in higher education institutions.

METHODOLOGY

Research Design

This study employed a descriptive-analytical research design to examine electrical consumption patterns and variance across selected institutional buildings as a basis for energy efficiency management. The design is appropriate for analyzing quantitative data derived from existing records, enabling the identification of trends, deviations, and potential inefficiencies in energy use. By integrating descriptive statistics with variance analysis, the study provides a systematic approach to evaluating institutional energy performance.

Study Area and Sample Selection

The study was conducted within selected institutional buildings of a State University and College (SUC), where electrical consumption constitutes a significant portion of operational expenditure. The facilities included in the study were selected using purposive sampling, based on three primary criteria: (1) availability of consistent electrical consumption records, (2) functional diversity of buildings (e.g., academic, administrative, and support services), and (3) relative level of energy usage. This approach ensured that the sample captured variations in operational characteristics and energy demand across facilities.

The inclusion of buildings with differing functions allowed for a more comprehensive analysis of consumption patterns, as energy use is influenced by occupancy levels, equipment utilization, and operational schedules. By selecting facilities that represent typical institutional operations, the study enhances the relevance and applicability of its findings to broader energy management practices within higher education institutions.

Data Source and Instrumentation

The study utilized secondary data obtained from the institution's official electrical monitoring records. These records consisted of monthly electrical consumption data per facility, as documented by the institution's maintenance or utilities office. The use of institutional records ensured that the data reflected actual energy usage, rather than estimates or projections.

The primary "instrument" in this study was the structured data recording system used by the institution, which relies on calibrated electrical meters compliant with standard measurement protocols. These metering devices provide accurate and consistent readings of electricity consumption, thereby supporting the validity of the data. The reliance on officially recorded data enhances content validity, as the measurements directly correspond to the variables being analyzed—namely, electrical consumption levels.

Data Collection Procedure

Data collection involved the systematic retrieval and organization of electrical consumption records over a defined monitoring period. Monthly consumption data for each selected facility were compiled and arranged according to the study variables. The previous three-month consumption data were used to establish a baseline, while the most recent month represented current consumption levels.

The collected data were encoded into a structured dataset to facilitate analysis. To ensure accuracy, records were verified against institutional logs and cross-checked for completeness. Any discrepancies or missing entries were addressed through consultation with the relevant administrative office, ensuring that the dataset used in the analysis was reliable and consistent.

Variables and Measures

The study analyzed five key variables: previous three-month consumption, which represents the total electricity usage over the prior three months; average consumption, which is the computed baseline derived from the mean of the three months; current consumption, referring to the electricity usage for the most recent monitoring period; differential consumption, defined as the difference between average and current consumption; and percentage change, which expresses the relative change in consumption as a percentage. The average consumption served as the baseline for comparison, representing typical energy use under normal operational conditions. Differential values indicated increases or decreases relative to this baseline, while percentage change provided a standardized measure of variation across facilities, enabling consistent comparison of energy performance.

Statistical Treatment of Data

Descriptive statistical techniques were applied to analyze the data. The mean (average) was computed to establish baseline consumption for each facility. Variance analysis was conducted by calculating the **differential between average and current consumption**, allowing for the identification of deviations from expected usage patterns.

Percentage change was calculated using the formula:

$$\text{Percentage Change} = \frac{\text{Current Consumption} - \text{Average Consumption}}{\text{Average Consumption}} \times 100$$

This method enabled comparison of consumption variability across facilities, regardless of scale. The combined use of mean, differential, and percentage change provided a comprehensive framework for evaluating energy performance.

Reliability of Data

To ensure the reliability of the data, a data consistency check was conducted. Electrical consumption records were cross-verified across reporting periods to identify inconsistencies, anomalies, or missing values. Data entries were compared with institutional records to confirm accuracy, and any irregularities were clarified through consultation with responsible personnel.

The use of standardized metering systems further supports reliability, as measurements were obtained using calibrated devices that follow consistent recording procedures. This ensures that the observed trends in consumption reflect actual variations rather than measurement errors.

Limitations of the Study

The study is subject to limitations associated with the use of secondary data. Specifically, the dataset does not capture real-time fluctuations in energy consumption, nor does it account for behavioral factors such as user practices and occupancy variations. Additionally, potential delays in data recording and reporting may affect the temporal precision of the analysis. Despite these limitations, the data provide a reliable basis for identifying general trends and variations in electrical consumption. Future studies may incorporate real-time monitoring systems and behavioral analysis to enhance the depth and accuracy of findings.

Ethical Considerations

Ethical standards were observed throughout the study. The data used were institutional records accessed with appropriate authorization from the relevant administrative office. No personally identifiable information was included in the dataset, ensuring confidentiality and data privacy. As the study did not involve human participants, formal ethical clearance was not required. The data were used solely for academic and research purposes, and findings were reported objectively and accurately.

RESULTS AND DISCUSSION

Average Electrical Consumption (Baseline Analysis)

The analysis of average electrical consumption established a baseline for understanding typical energy usage across institutional facilities. As shown in Figure 1, the computed three-month averages indicate clear variation in energy demand among buildings, confirming that electrical consumption is not uniform across facilities. This variation reflects differences in building function, operational intensity, and occupancy patterns within the institution.

Facilities such as the Graduate School and ITRDC Building exhibit higher baseline consumption levels compared to other facilities, indicating sustained and consistent energy demand. These buildings likely support energy-intensive operations, including continuous use of air-conditioning systems, office equipment, and extended working hours. In contrast, facilities such as Baterna and Multi Crop Fund show comparatively lower baseline consumption, suggesting reduced operational load or more efficient utilization of electrical systems. This distribution of consumption highlights the heterogeneity of institutional energy use and reinforces the need for facility-specific analysis.

Findings suggest that baseline consumption is primarily shaped by structural and operational characteristics rather than random variation. Buildings with specialized functions or higher occupancy naturally require more energy to support their activities. This observation aligns with studies indicating that energy demand in institutional buildings is strongly influenced by operational intensity, building usage, and equipment load (Bolchini et al., 2017; Samara et al., 2022). Thus, higher baseline consumption should not be immediately interpreted as inefficiency but rather as a reflection of functional requirements.

These patterns can be attributed to the interaction between technical systems and human behavior. Energy-intensive infrastructure, such as HVAC systems and lighting networks, contributes significantly to baseline consumption, while user practices further shape energy demand. For example, extended usage of equipment and inconsistent energy-saving behaviors can increase baseline levels over time. This interaction reinforces the idea that energy consumption is both a technical and behavioral phenomenon.

These findings can be explained using Systems Theory, where institutional energy consumption is viewed as an interconnected system of inputs, processes, and outputs. Baseline consumption represents a state of operational equilibrium, where energy use reflects normal system functioning. Establishing this equilibrium is critical, as it provides a reference point for detecting deviations and evaluating performance. As supported by Kourgiozou et al. (2021) and Abdelbasier et al. (2022), accurate baseline data enhances the effectiveness of energy monitoring systems and supports data-driven decision-making.

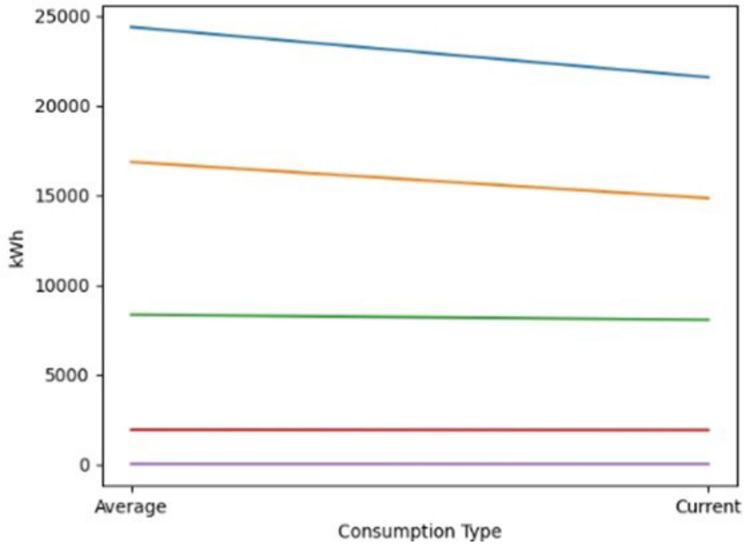

Figure 1. Average vs current electrical consumption per facility.

Current Electrical Consumption

The current electrical consumption levels represent the present state of energy use across facilities and provide a basis for comparison with baseline consumption. As illustrated in Figure 1, current consumption values show noticeable variation across buildings, with several facilities recording higher usage compared to their average levels.

The results indicate that facilities such as the Graduate School and ITRDC Building exhibit increased current consumption, suggesting a rise in operational demand or changes in facility utilization. This increase may be attributed to factors such as higher occupancy, extended operational hours, or intensified use of electrical equipment. On the other hand, facilities with minimal differences between average and current consumption demonstrate more stable energy use patterns, indicating relatively consistent operational conditions.

The interpretation of these findings highlights the dynamic nature of energy consumption in institutional environments. Unlike baseline consumption, which reflects equilibrium, current consumption captures real-time system behavior, influenced by both internal and external factors. This variability underscores the role of behavioral practices, as user actions such as inefficient equipment use or failure to adopt energy-saving measures can significantly affect consumption levels.

These observations are consistent with existing research indicating that energy consumption in institutional settings is influenced by both technological systems and human behavior (Chagnon-Lessard et al., 2021; Samara et al., 2022). The interplay between these factors creates fluctuations in energy demand, making it necessary for institutions to adopt monitoring systems that can capture real-time variations.

Current consumption reflects the adaptive state of the energy system, where energy use responds to changing operational conditions. This reinforces the importance of continuous monitoring and data analytics in energy management. The integration of real-time monitoring systems enables institutions to detect changes promptly and implement corrective actions, thereby improving overall efficiency (Chagnon-Lessard et al., 2021).

Differential in Consumption

The differential in electrical consumption—computed as the difference between average (baseline) and current consumption (Average – Current)—provides a clear measure of deviation from expected energy use patterns across facilities. As illustrated in Figure 2, all selected buildings recorded negative differential values, indicating that current consumption exceeded baseline levels in every facility.

The results show substantial variation in the magnitude of these differentials. The Graduate School recorded the largest negative differential (−2800.00 kWh), followed by the ITRDC Building (−2013.33 kWh), reflecting significant increases in energy consumption relative to their baseline levels. In contrast, the Mosqueda Facility (−280.00 kWh) exhibited a moderate deviation, while the Baterna Facility (−18.50 kWh) and Multi Crop Fund Facility (−2.50 kWh) showed minimal differences. This distribution highlights that while increased consumption is evident across all facilities, the extent of deviation varies considerably, indicating differences in operational intensity and energy management practices.

The consistent presence of negative differentials across all facilities suggests a system-wide upward shift in energy consumption, rather than isolated increases. However, the magnitude of these deviations provides critical insight into facility-specific conditions. Buildings with large differentials, such as the Graduate School and ITRDC Building, likely experienced increased operational demand, higher occupancy, or intensified use of energy-dependent systems. These facilities may also reflect greater dependence on equipment such as air-conditioning units, computers, and specialized devices that contribute significantly to energy load. Conversely, facilities with minimal differentials demonstrate relatively stable consumption patterns, suggesting consistent operational conditions or more controlled energy usage.

Deviations can be explained by a combination of technical and behavioral factors. Increased reliance on cooling systems, particularly during periods of higher temperature, can substantially elevate energy demand. Similarly, extended operating hours and increased utilization of electrical equipment contribute to higher consumption levels. Behavioral practices—such as inefficient switching of appliances, prolonged equipment use, and lack of energy-saving awareness—further amplify these increases. Additionally, some deviations may be associated with technical inefficiencies, including aging electrical infrastructure, poor maintenance, or suboptimal equipment performance. These findings are consistent with studies emphasizing that variations between expected and actual energy consumption are driven by both operational demands and user behavior (Bolchini et al., 2017; Samara et al., 2022).

From an energy management perspective, differential analysis serves as a critical diagnostic mechanism for identifying inefficiencies within the institutional energy system. By quantifying the gap between baseline and current consumption, institutions can detect anomalies, evaluate the severity of deviations, and prioritize facilities requiring immediate intervention. Facilities with large negative differentials represent high-priority areas for energy audits, system optimization, and behavioral interventions, while those with minimal deviations may serve as reference points for efficient energy practices. This supports the findings of Kourgiozou et al. (2021), who emphasize the role of variance analysis in improving system performance and guiding energy management decisions.

Within the framework of Systems Theory, differential values represent deviations from system equilibrium, indicating a shift in the balance between energy input and operational processes. In this context, baseline consumption reflects a stable system state, while negative differentials signal increased system demand or inefficiency. These deviations function as feedback mechanisms, providing essential information for system regulation and adjustment. Facilities with larger deviations indicate areas where the system is under greater stress or operating beyond optimal conditions, while smaller deviations reflect relative stability and control.

The implications of these findings underscore the need for targeted and data-driven energy management strategies. Persistent increases in consumption may lead to higher operational costs and increased environmental impact, particularly in terms of carbon emissions. Addressing these challenges requires a combination of technological improvements, such as upgrading to energy-efficient equipment, and behavioral strategies, including awareness programs and policy enforcement. Furthermore, integrating continuous monitoring systems and data analytics can enhance the institution's ability to detect and respond to deviations in real time, thereby improving overall energy efficiency.

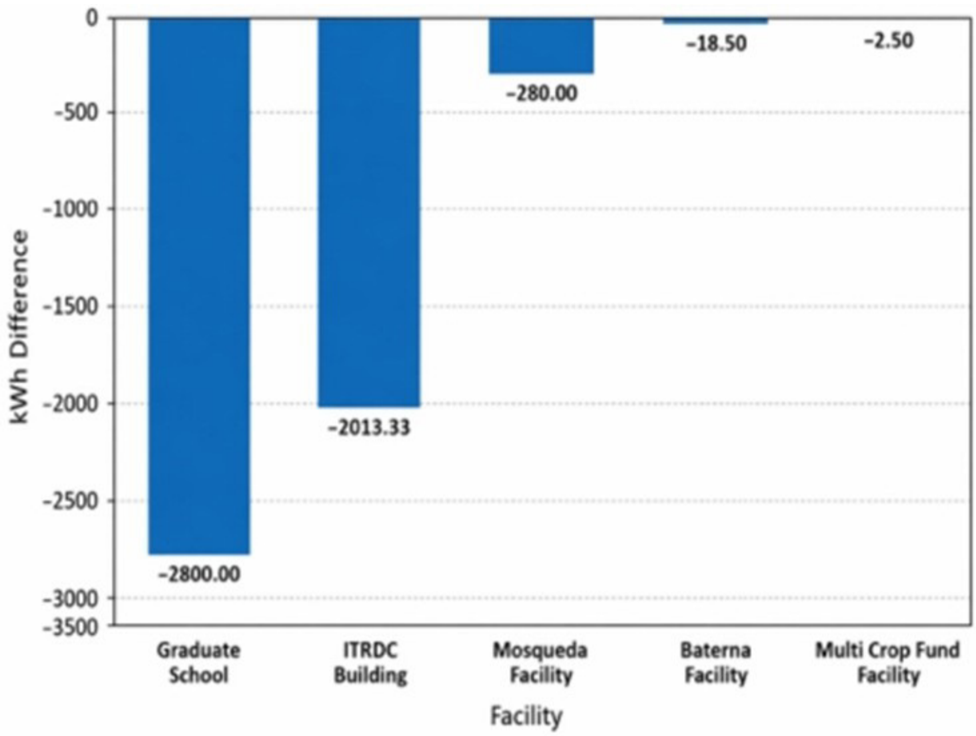

Figure 2. Differential in electrical consumption.

Percentage changes in Consumption

Percentage change analysis provides a normalized measure of variation in energy consumption across facilities. As presented in Figure 3, the ITRDC Building recorded the highest increase (11.95%), followed by the Multi Crop Fund Facility (11.54%) and Graduate School (11.49%), while Mosqueda (3.36%) and Baterna (0.96%) exhibited lower changes. The results indicate that most facilities experienced notable increases in energy consumption, particularly those exceeding 11%, suggesting significant deviations from baseline conditions. These increases may be associated with higher operational demand, inefficient energy use, or shifts in facility utilization.

The interpretation highlights that percentage change is a critical indicator of performance variability, enabling comparison across facilities regardless of scale. Facilities with high percentage increases require immediate attention, while those with minimal changes demonstrate more stable and controlled energy use patterns.

These variations lies in the combined effects of infrastructure, operational practices, and user behavior. Facilities with higher increases may lack efficient systems or effective energy management practices, while those with lower changes may benefit from better control mechanisms. This observation aligns with studies emphasizing that energy variability is influenced by both technical and behavioral factors (Samara et al., 2022).

Percentage change reflects the responsiveness of the energy system to changing conditions. High variability indicates instability, while low variability suggests controlled system behavior. As supported by Kourgiozou et al. (2021) and Abdelbasier et al. (2022), normalized metrics such as percentage change are essential for evaluating energy performance and guiding decision-making.

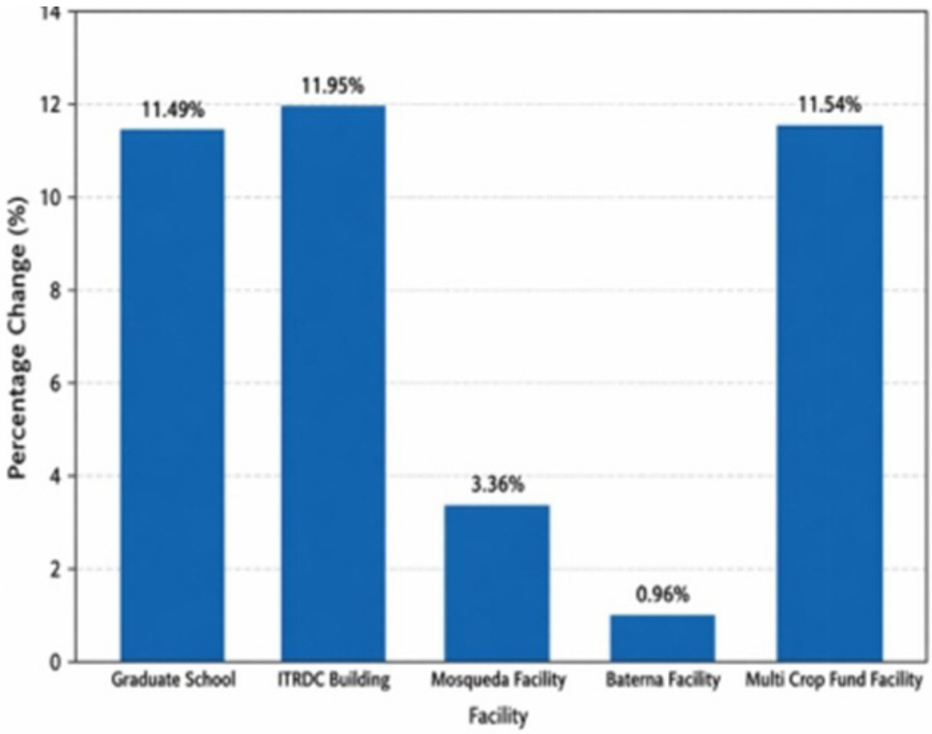

Figure 3. Percentage change in electrical consumption per facility.

Recommendations for Energy Efficiency

The study underscores the importance of implementing data-driven energy management strategies to address increasing consumption levels and variability across facilities. Facilities with high differentials and percentage increases, such as the Graduate School and ITRDC Building, should be prioritized for targeted interventions.

One key recommendation is the adoption of Energy Management Systems (EMS), which integrate real-time monitoring, data analytics, and automated controls to optimize energy use. These systems enable institutions to track consumption patterns, detect anomalies, and implement timely interventions, thereby improving efficiency (Kourgiozou et al., 2021; Abdelbasier et al., 2022).

In addition, real-time monitoring and standardized reporting systems are essential for maintaining data accuracy and supporting decision-making. Continuous monitoring allows institutions to identify trends and respond effectively to changes in consumption. Technical interventions, such as upgrading to energy-efficient equipment, including LED lighting and high-efficiency HVAC systems, can significantly reduce baseline consumption. At the same time, behavioral strategies, such as awareness campaigns and training programs, are necessary to promote responsible energy use among staff and students.

From a systems perspective, these recommendations aim to restore and optimize system equilibrium by addressing both structural and behavioral components of energy consumption. By integrating technological, organizational, and behavioral strategies, institutions can achieve sustainable energy management and align with broader goals such as SDG 7 (Affordable and Clean Energy).

CONCLUSION

This study highlights the value of a systematic and data-driven approach in analyzing electrical consumption patterns within institutional settings. By integrating baseline, current consumption, differential, and percentage change analyses, it provides a comprehensive framework for understanding variations in energy use across facilities. The findings demonstrate that energy consumption is influenced not only by technical infrastructure but also by operational demands and user behavior, emphasizing the need for a holistic energy management approach. The results further underscore that effective energy efficiency management requires the alignment of technological systems, organizational practices, and behavioral interventions. Facilities with greater variability indicate areas for targeted improvement, while those with stable consumption offer models for best practices. This reinforces the importance of continuous monitoring and variance analysis in supporting informed decision-making. Overall, the study contributes to institutional sustainability by offering a practical basis for improving energy management strategies. Future efforts should focus on real-time monitoring, adoption of energy management systems, and strengthening institutional policies, alongside further research on predictive and behavioral approaches to enhance energy efficiency.

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