Digital Innovations & Contemporary Research in SCIENCE, ENGINEERING & TECHNOLOGY
Vol. 13. No. 2, 2025 Series

Article Citation Format
Taiwo, O.I., Adebiyi, K.A, Jekayinfa, S.O & Ajayeoba, A.O. (2025): Modelling Approaches for Energy Evaluation - An Overview and Comparison. Journal of Digital Innovations & Contemporary Research in Science, Engineering & Technology. Vol. 13, No. 2. Pp 39-58. www.isteams.net/digitaljournal
dx.doi.org/10.22624/AIMS/DIGITAL/V13N2P4

Article Progress Time Stamps

Article Type: Research Article
Manuscript Received: 15th March, 2025
Review Type: Blind Peer
Final Acceptance: 7th May, 2025

Modelling Approaches for Energy Evaluation - An Overview and Comparison

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ABSTRACT

The energy usage in business buildings is crucial for economic, environmental, and operational factors. It involves the efficient conversion of energy sources, including electricity, fossil fuels, and renewable energy, into usable forms for heating, cooling, lighting, and equipment operation. In Nigeria, primary energy consumption involves the direct use of energy resources like natural gas or solar power, whereas secondary consumption refers to electricity produced from primary energy sources. Effective energy utilization can produce significant economic advantages by reducing operational costs and improving profitability. Implementing energy efficiency measures can reduce greenhouse gas emissions and align with international climate goals. Energy security is an essential aspect of energy utilization in Nigerian tertiary institutions, which often operate as semi-autonomous organizations housing several energy-intensive structures that facilitate academic, administrative, residential, and recreational functions. The primary variables affecting the energy footprint in Nigerian tertiary institutions include lecture halls, administration buildings, dormitories, and residential facilities. Understanding energy consumption patterns at these institutions is crucial for developing strategies to improve energy efficiency and reduce environmental and socio-economic impacts. Policy deficiencies and ineffective implementation hinder energy efficiency in Nigerian tertiary institutions, as many universities lack formal energy management plans, demonstrate low awareness among students and staff, and encounter security challenges. The energy consumption in Nigerian tertiary institutions is influenced by academic calendars, infrastructural limitations, and sustainability efforts. Energy Modelling is a crucial tool in the strategic planning, design, and operational management of business buildings within higher education institutions. The effectiveness of energy Modelling is largely influenced by the appropriateness of the employed Modelling method. Data availability, accuracy standards, scalability, adaptability, cost, and temporal constraints are essential criteria. Case studies from several tertiary institutions illustrate the effectiveness of energy Modelling in improving energy efficiency in business buildings. The effective execution of energy management strategies requires the amalgamation of Modelling and monitoring, the adaptation of models to reflect unique usage patterns, interdisciplinary cooperation, engagement with policies and stakeholders, continuous feedback and model enhancement, along with benchmarking and goal setting.

Keywords: Modelling, Energy, Higher Education Institution, Electricity

1. INTRODUCTION

The energy consumption of business buildings significantly impacts a nation's total energy usage. Business buildings comprise a diverse array of structures, including offices, retail outlets, hotels, and institutional edifices such as educational institutions and hospitals, according to Cao et al. *et al.,* (2016). These structures necessitate energy for multiple functions, including heating, ventilation, air conditioning (AC), lighting, office machinery, and other electrical devices (Aljashaami *et al.,* 2024). The rising energy demand in business buildings has substantial economic and environmental consequences, requiring a thorough comprehension of energy consumption patterns to improve efficiency and sustainability. In numerous nations, including Nigeria, commercial structures significantly impact the national energy consumption.

Nigeria is currently undergoing swift urbanization, with an overall population growth rate of 2.6% and a projected growth rate of 4.2%. The continuous urbanization has precipitated an increase in housing and energy demands (Lawal *et al.,* 2024). The elevated energy demand arises from reasons including antiquated building designs, inefficient appliances, and restricted implementation of energy-efficient technologies. Moreover, dependence on fossil fuels for electricity production intensifies greenhouse gas emissions, highlighting the necessity for energy-efficient alternatives (Nagaj *et al.,* 2024). The operation of buildings constitutes 30% of energy consumption and 27% of greenhouse gas emissions in the European Union (Vandenbogaerde, *et al.,* 2023). With the increasing worldwide energy demand, the attainment of sustainable energy use in business buildings has emerged as a priority for policymakers, building managers, and researchers.

Energy conservation is minimizing superfluous energy usage through behavioural modifications and improved operating techniques (Costanzo *et al.,* 1986). Energy management entails the implementation of intelligent technology, including energy management systems (EMS) and automated controls, to monitor and optimize energy consumption in real time. The integration of renewable energy sources, such as solar photovoltaic (PV) systems and wind energy, helps minimize dependence on conventional energy sources and lowers carbon emissions (Razmjoo *et al.,* 2021). Considering these tactics, it is crucial to investigate diverse methods for assessing energy use in business buildings to enhance energy efficiency and sustainability. Tertiary institutions, such as universities, polytechnics, and colleges, are significant energy consumers in Nigeria. These institutions necessitate energy for educational activities, administrative operations, research laboratories, dormitory accommodations, and recreational amenities.

The elevated energy requirements in tertiary institutions frequently result in heightened operational expenses and environmental repercussions, rendering energy efficiency an essential factor (Wadud *et al.,* 2019). Energy efficiency at Nigerian higher institutions is crucial due to the nation's energy difficulties. Nigeria endures chronic energy supply deficiencies, characterized by recurrent power outages and dependence on expensive alternative power sources, including diesel and petrol generators (Mohammed *et al.,* 2013). These issues impede the efficient functioning of academic institutions, diminishing production and escalating costs. Improving energy efficiency enables educational institutions to reduce energy expenses, enhance sustainability, and support national energy conservation initiatives. The main aim of this research is to examine several Modelling methodologies for assessing energy consumption in business buildings and higher education institutions.

Energy Modelling is essential for comprehending energy consumption trends, pinpointing inefficiencies, and formulating strategies to optimize energy utilization. Diverse Modelling strategies have been established to assess energy consumption in buildings, each possessing unique benefits and drawbacks (Li *et al.,* 2017).

2. CHARACTERISTICS OF BUSINESS BUILDINGS IN TERTIARY INSTITUTIONS

Business Buildings in higher education institutions fulfil a diverse array of academic, administrative, and service roles. These structures frequently accommodate faculties, departments, lecture halls, conference rooms, seminar rooms, faculty offices, research centres, IT laboratories, libraries, and student assistance centres (Jamieson, 2003 and Garba, *et al.,* 2022). Their design and operational characteristics are distinct and varied, affecting their energy consumption patterns. A key characteristic of commercial structures in higher education institutions is their multifunctionality. These structures provide both academic and administrative functions, resulting in fluctuating occupancy patterns during the day and academic year. During peak periods, such as practical lessons in laboratories and workshops, energy consumption significantly increases due to heightened usage of lighting, air conditioning systems, computers, heavy machinery (particularly in engineering workshops), and other electrical devices.

Moreover, these edifices frequently amalgamate traditional and contemporary architecture. Antiquated structures may experience inadequate insulation, obsolete air conditioning systems, and restricted compatibility with intelligent energy technologies. Conversely, contemporary buildings are likely designed with energy efficiency and sustainability as priorities, integrating sophisticated lighting systems, energy-efficient windows, and renewable energy technologies. Moreover, the spatial configuration and architectural design of commercial structures significantly impact energy use. Elements like as orientation, window-to-wall ratio, and internal zoning significantly influence heating, cooling, and lighting requirements. Furthermore, the existence of equipment-intensive areas, such as computer laboratories or multimedia rooms, presents distinct energy issues, especially regarding thermal comfort and indoor air quality. These characteristics highlight the necessity of customized energy Modelling methods that accurately represent the distinct operational and physical features of commercial buildings in higher education institutions (George, and Wooden, 2023).

2.1 Energy Utilization in Business Buildings

Energy utilization denotes the consumption of energy resources for various activities within buildings, industries, and other infrastructures, encompassing the efficient conversion of energy sources such as electricity, fossil fuels, and renewable energy into usable forms for heating, cooling, lighting, and equipment operation. In commercial edifices, energy consumption encompasses all activities that facilitate daily operations, including the functioning of office equipment, air conditioning systems, elevators, and security systems. Energy consumption can be classified into major and secondary categories. Primary energy consumption entails the direct utilization of energy resources such as natural gas or solar power, whereas secondary consumption pertains to the utilization of electricity generated from primary energy sources (Hitchin, 2019). In the Nigerian corporate sector, both types are essential, with electricity serving as the primary secondary energy source, frequently augmented by alternative sources like generators due to unreliable power supply.

The utilization of energy in business buildings holds significant economic, environmental, and operational value. The importance of effective energy consumption can be examined from various viewpoints:

i. **Economic Implications:** The efficient use of energy decreases operational expenses and enhances profitability (Lukic, 2021). Organizations that use energy-efficient technology, like LED lighting and intelligent HVAC (heating, ventilation, and air conditioning) systems, can substantially reduce energy costs, hence enhancing financial sustainability.
ii. **Environmental Sustainability**: Commercial structures substantially contribute to carbon emissions owing to elevated energy consumption, especially when dependent on fossil-fuel-powered generators (Sam-Amobi *et al.,* 2019). Implementing energy efficiency measures reduces greenhouse gas emissions, fosters environmental sustainability, and aligns with global climate objectives (Filonchyk *et al.,* 2024).
iii. **Operational Efficiency and Productivity**: Effective energy utilization improves the comfort and functionality of work environments. Insufficient energy provision or ineffective utilization can hinder operations, resulting in diminished output. Optimizing steady and effective energy utilization enhances work conditions, benefiting employees, customers, and overall business performance (Kozusznik *et al.,* 2019).
iv. **Energy Security:** Nigeria encounters difficulties in energy supply, as recurrent power outages disrupt commercial activities (Ado and Josiah, 2015). Enhanced energy utilization measures, including demand-side management and renewable energy integration, bolster energy security by diminishing dependence on unreliable grid power and expensive backup generators.

Considering these elements, comprehending energy consumption patterns, especially in institutions such as universities and business buildings, is essential for formulating methods to enhance energy efficiency.

3. COMMON ENERGY CONSUMPTION PATTERNS IN TERTIARY INSTITUTION BUILDINGS IN NIGERIA

Tertiary institutions in Nigeria, including universities, polytechnics, and colleges of education, are among the nation's primary public energy consumers. These schools frequently function as semi-autonomous entities with numerous energy-intensive facilities that facilitate academic, administrative, residential, and recreational endeavours. Considering Nigeria's tropical climate, infrastructure constraints, and increasing student demographics, the energy consumption patterns in these institutions mirror both operational requirements and adaptive strategies to environmental and socio-economic factors. Energy consumption trends in Nigerian tertiary institutions are predominantly shaped by various interconnected factors. This encompasses the nature and purpose of structures, the frequency and timing of educational activities, meteorological factors (notably temperature and humidity), access to grid energy, and the prevalence of personal electronic devices.

The principal factors influencing the energy footprint in these institutions are elaborated upon below.

i. **Lecture Halls and Administrative Buildings:** Lecture halls and administrative buildings are crucial to academic life and represent some of the biggest energy consumption areas in Nigerian tertiary institutions. These structures function for prolonged hours, occasionally extending late into the evening, thereby requiring constant energy use for illumination, ventilation, and electrical equipment. The hot and humid climate of Nigeria necessitates extensive use of air conditioning units, fans, and dehumidifiers to ensure thermal comfort for students and staff. Academic endeavours necessitate the utilization of audio-visual apparatus, including projectors, public address systems, and computers. The shift to smart classrooms and e-learning platforms has augmented electricity consumption. Administrative offices likewise depend on digital equipment for data administration, communication, and student services, thereby augmenting the overall energy consumption. Nonetheless, energy use in these structures is not consistently efficient. Numerous edifices are deficient in energy-efficient attributes, such occupancy sensors, daylight harvesting systems, or enough insulation. This frequently leads to overconsumption and waste, particularly when lighting and cooling systems are operated manually and indiscriminately.

ii. **Hostels and Residential Buildings**: Student accommodations and staff residences are essential elements of campus infrastructure. These residential zones utilize energy predominantly for illumination, gadget charging, and culinary activities. Numerous public colleges, particularly those providing subsidized housing, frequently have overcrowded dormitories as a result of increasing student enrollment without a corresponding enhancement in infrastructure (Telewa, 2020), hence exerting additional strain on the current electrical systems. Students commonly utilize an array of electrical devices, including electric kettles, telephones, computers, fans, and occasionally, compact refrigerators and electric cookers (Lee *et al.,* 2022). Although certain universities offer centralized cooking facilities, numerous students depend on personal electric cooking appliances, hence augmenting the home electricity demand. Air conditioning is infrequent in older or budget hostels; nonetheless, ceiling and standing fans are extensively utilized to mitigate the extreme heat, particularly in the northern and southern parts of Nigeria. Moreover, inconsistent electricity supply frequently compels institutions to utilize diesel-powered generators, so elevating both operational expenses and carbon emissions.

iii. **Laboratories, workshops, and research centre:** particularly within the domains of science, engineering, and medicine, exhibit some of the greatest energy demands per unit area in higher education institutions. These facilities necessitate a consistent and uninterrupted power supply to function specialized apparatus, including autoclaves, centrifuges, oscilloscopes, incubators, fume hoods, and high-performance computers. Energy usage in these buildings is influenced more by the nature of activities than by occupancy rates. Practical classes for students that entail the operation of sensitive equipment, such as CNC lathe machines, milling machines, and hardness testing machines, necessitate a continuous supply of electricity. The insufficient power supply from the national grid has compelled numerous institutions to construct specialized generators or inverters for essential laboratory equipment. This backup power strategy is inefficient, costly, and environmentally unsustainable, highlighting the necessity for improved energy planning and investment in renewable resources.

iv. **Libraries and ICT Centres**: Contemporary libraries in Nigerian higher institutions are progressively digitalized, necessitating a robust ICT infrastructure. Computers, servers, routers, printers, and scanners are perpetually utilized during operational hours, and several institutions strive to ensure uninterrupted access to digital resources. As a result, these structures possess considerable energy requirements for both gadget operation and climate regulation to avert overheating and ensure appropriate functionality. In institutions where the primary library functions as an ICT centre, the aggregate demand for computers and air conditioning is substantial. These centres typically contain servers and data storage systems that necessitate uninterrupted power and cooling systems, hence increasing energy consumption. Furthermore, the implementation of learning management systems (LMS), online registration portals, and digital examination platforms would likely increase dependence on ICT infrastructure. Insufficient investment in energy-efficient technologies may present a considerable barrier to energy management in higher education institutions.

v. **Recreational amenities and Street Lighting**: Another frequently neglected aspect of energy consumption at higher campuses is recreational and outdoor amenities. These encompass sports complexes, student union edifices, places of worship, and auditoriums, which facilitate a variety of events from social assemblies to formal ceremonies. These spaces generally necessitate sound equipment, lighting rigs, projectors, and air conditioning, particularly during substantial gatherings or evening events (Ezeh and Emmanuel, 2020). Street illumination significantly contributes to institutional energy consumption. For security purposes, campuses are outfitted with comprehensive networks of external lighting, a significant portion of which functions continuously during the night (Peng, et al. 2024). In certain instances, these lights utilize inefficient incandescent or fluorescent bulbs rather than energy-efficient LED counterparts, resulting in higher electricity consumption.

4. INTERDISCIPLINARY CONCERNS IN ENERGY CONSUMPTION TRENDS AMONG NIGERIAN HIGHER EDUCATION INSTITUTIONS

The energy consumption in Nigerian tertiary institutions is not exclusively determined by the architectural kinds or the activities performed within them. Numerous comprehensive, systemic concerns known as cross-cutting issues influence the utilization, management, and conservation of energy across campuses. These challenges encompass all domains of energy utilization, including academic, residential, recreational, and administrative facilities. Comprehending these systemic problems is essential for formulating realistic and effective energy optimization measures in higher education institutions. The energy consumption patterns in Nigerian tertiary institutions are significantly shaped by a complex interplay of structural and operational factors that span various facility types and functions. These pervasive issues constitute a complicated network of restrictions that impede energy efficiency and sustainability, which encompass the following:

i. **Unstable and Insufficient Power Supply**: A prevalent issue is the unreliable electricity provision from the national grid. The energy system in Nigeria is beset by recurrent outages, voltage instability, and load shedding, which considerably affects the functioning of higher education institutions. The outcome is a significant reliance on alternative energy sources, particularly diesel or petrol generators, which are costly to operate and detrimental to the environment (Leahy, *et al.,* 2019). This unreliability results in irregular academic operations, particularly in laboratories and ICT-dependent classrooms, where even little delays can impede experiments, data processing, or online learning. At several universities, entire departments organize their work based on expected power interruptions, demonstrating the profound impact of this issue on institutional productivity.

ii. **Obsolescence and Inefficient Infrastructure**: Numerous tertiary institutions in Nigeria were constructed some decades ago and have not experienced substantial infrastructure enhancements. Electrical systems, comprising wiring, distribution boards, and transformers, frequently exhibit obsolescence and lack the capacity to accommodate contemporary energy demands. Furthermore, the majority of older structures are deficient in insulation, energy-efficient illumination, and automated systems for controlling air conditioning and lighting. The lack of energy-efficient design in numerous buildings results in excessive consumption, particularly in lecture halls and dormitories where lights and fans may remain perpetually activated (Sundberg *et al.,* 2010).

iii. **The absence of energy audits and consumption data:** constitutes a significant obstacle to energy efficiency in Nigerian educational institutions. Most organizations lack precise data regarding their energy consumption, the areas of highest usage, and the locations of waste. In the absence of this data, making evidence-based decisions or justifying investments in energy-saving technologies becomes challenging. The lack of metering infrastructure, particularly sub-metering by building or department, results in aggregated energy bills, thereby obscuring individual energy consumption patterns. The absence of transparency obstructs accountability and complicates the promotion of appropriate usage among staff and students.

iv. **Restricted Funding and Investment**: Financial limitations are a significant overarching challenge. Most public tertiary institutions in Nigeria rely on government funding, which is frequently inadequate for infrastructure enhancements or the implementation of renewable energy systems (Jacob *et al.,* 2021). Capital-intensive initiatives, like solar photovoltaic installations, smart meters, and energy-efficient air conditioning systems, are generally deprioritized in favor of competing demands such as salaries, academic program growth, and facility upkeep. Despite institutional willingness to undertake energy efficiency programs, finance methods and credit facilities for public-sector infrastructure projects are constrained, while bureaucratic processes further impede procurement and execution.

v. **Reliance on Fossil Fuel Generators**: Due to grid instability, numerous institutions depend significantly on fossil fuel generators. This guarantees uninterrupted power for essential processes, but incurs significant environmental and financial expenses. Diesel and petrol generators substantially contribute to greenhouse gas emissions, hinder sustainability objectives, and incur elevated operational expenses, particularly due to volatile fuel prices (Barbosa, *et al.,* 2022). In several institutions, generators serve as the exclusive power supply for critical facilities such as laboratories and ICT centres, where uninterrupted operation is essential (Dare-Adeniran, *et al.,* 2024). This generates a dilemma in which organizations allocate a significant fraction of their constrained budgets to fuel instead of investing in sustainable energy options such as solar power.

vi. **Inadequate Policies and Ineffective Implementation**: At both institutional and national levels, policy deficiencies obstruct energy efficiency. Although certain universities possess sustainability offices or development masterplans, these initiatives frequently suffer from inadequate funding and insufficient enforcement. In numerous instances, explicit energy management strategies are absent to direct the acquisition of appliances, lighting systems, or air conditioning units. Moreover, governmental energy policies often favor residential and industrial sectors, offering less specific assistance to the education sector. The lack of explicit norms and incentives hinders higher institutions from implementing sustainable energy technologies or enforcing energy conservation practices throughout campus communities.

vii. **Limited Awareness and Behavioural Challenges**: A notable obstacle is user behaviour. Energy inefficiency in higher education institutions frequently stems from insufficient understanding among students and faculty. Common activities, like keeping lights and appliances activated when not in use, excessive dependence on air conditioning, and unlawful operation of high-energy gadgets in hostels, substantially contribute to wasteful energy consumption (Obaju, *et al.,* 2019). There is a pervasive deficiency in training or awareness initiatives on energy conservation. Unlike several institutions in wealthy nations that utilize energy dashboards, award systems, and awareness weeks to enhance energy literacy, Nigerian colleges have not formalized such initiatives. Altering user behaviour involves both awareness and institutional means for enforcement and motivation.

viii. **Security Issues and Energy Consumption:** Energy consumption associated with security is an additional pervasive concern. In response to the increasing incidents of campus insecurity, schools are making substantial investments in exterior lighting and monitoring systems. Although essential for safety, these systems markedly elevate nighttime energy use. The majority of security lights lack motion sensors or daylight timers, resulting in continuous operation even when unwarranted. Insufficient planning and the lack of intelligent lighting systems contribute to energy consumption for security, representing another avenue for potential waste.

4.1 Energy Consumption Trends in Tertiary Institutions

Energy usage in tertiary institutions, especially within the Nigerian setting, has discernible patterns shaped by academic calendars, infrastructure constraints, and emerging sustainable policies. These patterns are predicated upon the subsequent factors:

i. **Peak Demand Periods**: Energy consumption in tertiary institutions exhibits significant cyclicality, closely correlated with the academic calendar. Demand often diminishes during holiday periods and experiences a substantial increase during academic sessions when students, faculty, and administrative personnel are actively utilizing university facilities. During these intervals, institutions frequently have difficulties in reconciling demand with available supply, resulting in recurrent blackouts, reliance on generators, and implementation of energy restriction measures. The apex consumption intervals typically align with:

- **Lecture periods**: High use of lecture halls, laboratories, offices, and ICT centres during the day.
- **Examination seasons**: Extended hours of study, increased lighting and cooling loads in libraries, classrooms, and hostels during evenings and nights.
- **Workshop and laboratory activities**
- **Registration and matriculation periods**: High foot traffic and extended use of administrative systems, printing services, and student portals, all of which contribute to electricity usage

ii. Reliance on Backup Power Sources: The inconsistent energy supply from the national grid has rendered backup power sources essential rather than ancillary in the majority of Nigerian tertiary institutions. These mostly comprise diesel-powered generators, with petrol generators and inverter systems being less prevalent. Numerous universities designate dedicated generator time slots for entire departments or laboratories, illustrating the normalization and structuring of their dependence on non-grid energy sources. This dependency displays several significant patterns in energy consumption:

- **Operational Cost Escalation**: Running generators for several hours daily significantly increases fuel expenses, especially with volatile global oil prices and domestic fuel subsidy reductions (Steinbuks and Foster, 2010).
- **Carbon Footprint**: The continuous use of fossil fuel generators contributes to greenhouse gas emissions and undermines the environmental sustainability goals of institutions.

- **Maintenance and Downtime**: Generators require regular servicing and are prone to mechanical faults, which affects the reliability of backup systems and leads to further disruptions in academic and administrative activities.

iii. **Adoption of Renewable Energy Solutions:** Nigerian educational institutions are increasingly adopting renewable energy technology, especially solar photovoltaic (PV) systems, in response to escalating energy costs and environmental issues. This signifies a progressive transition in energy consumption patterns and underscores a gradual advancement towards more sustainable and resilient energy systems. Despite the praiseworthy nature of these efforts, widespread adoption remains impeded by substantial initial capital expenditures, insufficient regulatory incentives, and a scarcity of technical competence in the management of renewable energy systems.

iv. Emerging Trends in ICT and Digital Learning: The swift digitization of education has concurrently altered energy demand towards information and communication technology (ICT) infrastructures. Servers, computer laboratories, e-learning platforms, and virtual classroom configurations necessitate a continuous power supply, especially during and subsequent to the COVID-19 epidemic, which expedited online and blended learning paradigms. This transition compels institutions to reevaluate their energy strategy to align with contemporary technology realities that were less significant ten years prior.

v. Energy Consumption in Specialized Facilities: Research laboratories, medical centres, workshops, and scientific computing facilities are substantial energy consumers inside tertiary institutions. In contrast to typical classrooms or offices, these units continue to consume power during academic breaks if research or data processing is in progress. Consequently, they constitute a significant, non-seasonal element of campus energy use patterns. These facilities often require continuous power supply for sensitive experiments or refrigerated storage (for microorganisms) and power-hungry equipment such as centrifuges, autoclaves, CNC machines and fabrication machinery.

4.2 Factors Influencing Energy Utilization in Business Settings in Nigeria

Numerous factors affect energy use in business buildings and organizations in Nigeria. These elements can be classified into economic, technical, environmental, and behavioural categories.

i. Economic Factors:

- **Electricity Tariffs:** The cost of electricity significantly affects energy consumption patterns (Chen, 2017). Businesses tend to reduce usage when tariffs are high but may resort to alternative sources such as generators, which can be more expensive in the long run.
- **Fuel Prices:** Since many businesses rely on generators due to power outages, fluctuating fuel prices impact overall energy costs. High fuel costs often push businesses to explore energy efficiency measures.

ii. Technical Factors

- **Building Design and Infrastructure:** Older buildings often lack energy-efficient designs, leading to higher consumption due to poor insulation and inefficient lighting systems. Newer buildings with modern designs can incorporate energy-saving technologies such as smart meters and automated lighting.
- **Equipment Efficiency:** The type of electrical appliances and machinery used in business settings affects energy utilization. Energy-efficient appliances and AC systems can significantly reduce consumption.

iii. Environmental Factors

- **Climate Conditions:** Nigeria's hot climate increases the need for air conditioning, leading to higher energy demand (Isaac and Van-Vuuren, 2009). Regions with extreme temperatures have higher cooling needs, which directly impact energy consumption patterns (Okonkwo and Eboh, 2022).

- **Renewable Energy Availability:** The availability of alternative energy sources, such as solar and wind power, influences energy utilization (Hamed and Alshare, 2022). Institutions that integrate solar panels reduce their dependence on fossil fuels and grid electricity.

iv. **behavioural and Institutional Factors**

- **User Awareness and behaviour:** Energy utilization is influenced by how individuals use electricity. Educating staff and students on energy conservation practices can help reduce unnecessary consumption.
- **Government Policies and Regulations:** Policies on energy efficiency and renewable energy adoption impact how businesses manage energy. Government incentives for solar energy installations and energy audits encourage businesses to adopt sustainable energy solutions.

4.3 Analysis of Outcomes and Effectiveness in Energy Utilization Evaluation

The effectiveness of modelling approaches depends largely on the following:

i. **Accuracy and Reliability** Data-driven models such as ANN and SVM have significant accuracy in forecasting energy usage patterns (Chen *et al.,* 2022), especially when extensive datasets are accessible. Nevertheless, their performance may be suboptimal in situations characterized by restricted or absent data. Simulation models, despite being data-intensive, offer significant reliability in assessing design alternatives and retrofits. Their precision markedly enhances when adjusted with real consumption data. Hybrid models provide a compromise, improving precision and reactivity. A hybrid model that integrates real-time sensor data with simulation results enhanced energy forecast accuracy by 30% relative to standalone methods.

ii. **Practical implementation**: Simulation tools require significant expertise and time, which can be a barrier in some institutions (Dudding, et al., 2018). Statistical models and rule-based systems are more straightforward to implement, however they may exhibit limited adaptability. Hybrid models, although potent, entail significant implementation expenses and technological requirements.

iii. **Cost and Energy Savings:** Case studies demonstrate that Modelling-based interventions can result in energy savings of 15–40%, contingent upon the technique and context (Alvur *et al.,* 2024).

5. MODELS FOR ENERGY ASSESSMENT: A SYNOPSIS AND COMPARISON

The growing need for sustainable energy practices has heightened the necessity for precise energy assessment methodologies, particularly in business buildings inside higher education institutions. These environments are intricate, comprising several energy-consuming systems including lighting, heating, ventilation, air conditioning (AC), computing facilities, and laboratory apparatus. Diverse Modelling methodologies have been established to comprehend, predict, and enhance energy use. The following models are included:

a. **Statistical models** employ historical energy consumption data to identify correlations between energy usage and variables such as occupancy, weather conditions, and operational schedules. Prevalent methodologies encompass regression analysis, time-series forecasting, and machine learning methods. Linear regression is frequently employed for its simplicity and interpretability (Krstić and Teni, 2017), associating energy consumption with independent variables like outdoor temperature or occupancy rates. Time-series models, such as Auto Regressive Integrated Moving Average (ARIMA), excel in identifying seasonal trends in energy usage. Machine learning techniques, including Support Vector Machines (SVM) and Artificial Neural Networks (ANN), are extensively utilized for their capacity to model nonlinear relationships and extract insights from complex datasets (Zhang *et al.,* 2018). The total energy consumption equation or model depends on the total summation of all the energy consumption in the case study. For example, according to Mardani *et al.,* 2015, Energy consumption of space heating and cooling, Energy consumption of lighting, Energy consumption of hot water, and Energy consumption of appliances can be determined according to equations 1, 2,3 and 4 respectively.

$$E_d = \sum_{i=1}^{i=24} \sum_{j=1}^{j=M} \frac{e_{ji} + q_{ji}}{COP_j} \qquad 1$$

Where Ed is the daily energy consumption for heating/cooling of the building (MJ/day); eji is the heating/cooling load (MJ) of zone j at hour i; qji is the ducted system and air distribution system heating/cooling loss(MJ) in zone j at hour i; COP_j is the coefficient of performance of the heating/cooling system at zone j; and M is the total number of conditioned zones in the building.

$$\boldsymbol{E} = \frac{\left(\frac{I_{mean}}{L_{eff}}\right) \times h \times A_{floor} \times \left(\frac{N_p}{N_r}\right)}{1000} \qquad 2$$

where E is the daily electric lighting energy consumption (kWh/day); Imean is the average luminance level required; h is the hours of artificial lighting on for a day; Leff is the luminance efficacy (lum/W); Afloor is the house floor area (m2); Np is the number of occupants; and Nr is the number of rooms in the house.

$$Q_w = N_p \times T_b \times F_s \qquad 3$$

where Qw is the daily water usage for shower (litre/day); Np is the number of occupants (user input variable); and Tb and Fs are the shower time and shower flow rate, respectively.

$$E = \frac{H_a \times W_a + h_{sby} \times W_{sby} + h_{off} \times W_{off}}{1000} \qquad 4$$

where W_a, W_{sby} and W_{off} are the power (Watts) in active, standby and off modes, respectively, which can be referenced to the appliance information given by the manufacturers; h_a, h_{sby} and h_{off} are the time (hour) spent in active, standby and off modes, respectively.

b. **Simulation models** depict the physical and operational attributes of buildings *et al.,* 2022to replicate energy performance across diverse scenarios. Simulation models require comprehensive inputs, including building geometry (Bazjanac, 2010), materials, air conditioning configurations, schedules, and climatic conditions. They enable users to evaluate various design or retrofit scenarios to forecast future energy use. These models are especially efficacious during the design and retrofitting phases of structures owing to their predictive capabilities.
c. **Hybrid models** integrate different Modelling paradigms, generally merging data -driven (statistical or machine learning) and physics-based (simulation) methodologies to develop more comprehensive and adaptable tools (Wang). This integration improves forecast accuracy, particularly in contexts where physical systems are comprehensively understood yet influenced by erratic human behaviour or external variables.

d. **Heuristic Models:** Heuristic approaches employ experience-based methodologies, rules of thumb, or search algorithms to identify satisfactory solutions for intricate issues (Desale, *et al.,* 2015). Examples encompass genetic algorithms (GA), Particle Swarm Optimization (PSO), and simulated annealing, which are frequently utilized to optimize energy consumption patterns (Özsoy, *et al.,* 2020).
e. **Agent-Based Models (ABM)**: Agent-Based Modelling employs a bottom-up methodology wherein individual agents (e.g., inhabitants, devices, systems) are represented with distinct rules and behaviours (Rixon *et al.,* 2005). Agent-based models (ABMs) are employed to simulate the interactions among agents and between agents and their environment over time. This method is particularly effective for Modelling user behaviour and its effect on energy consumption in institutional contexts, where energy usage patterns are significantly shaped by human activities.
f. **Rule-Based Systems**: Rule-based models depend on established logical rules or expert knowledge to regulate or assess energy consumption (Peña, *et al.,* 2016). They are frequently utilized in Building Energy Management Systems (BEMS) to execute functions such as activating or deactivating air conditioning systems according to occupancy or time schedules. These systems are comparatively straightforward to deploy and necessitate minimal computational resources.
g. **Optimization models** concentrate on identifying the optimal configuration or decision set to achieve a certain target, such as minimizing energy expenses, maximizing comfort, or decreasing emissions within established restrictions (Iqbal, *et al.,* 2014). These models employ linear, nonlinear, or mixed-integer programming to address intricate energy planning challenges.

Table 1 delineates the merits, shortcomings, relevance to commercial structures inside tertiary institutions, and overall application of different Modelling methodologies.

5.1 Criteria for Selecting Suitable Modelling Approaches

Energy Modelling is essential for the strategic planning, design, and operational management of business buildings in higher education institutions. Accurate Modelling of energy usage enables stakeholders to pinpoint inefficiencies, assess design alternatives, and formulate energy-saving programs. The efficacy of energy modelling is significantly determined by the suitability of the modelling methodology use. This selection is not random; it is founded on the following:

i. **Purpose of the Modelling:** The key motivation for choosing an energy modelling approach is the objective of the modelling exercise (Mancarella *et al.,* 2016). Clearly delineating the intended use, whether for predictive analysis, real-time monitoring, retrofit assessment, or energy benchmarking, aids in choosing the best appropriate methodology.
ii. **Data Availability**: Data is fundamental to energy Modelling. The accessibility, detail, and dependability of data substantially affect the viability of various tactics. Statistical models necessitate extensive, high-resolution information encompassing past energy use, occupancy rates, meteorological data, and equipment records.
iii. **Complexity of the System**: Tertiary institution facilities typically encompass varied usage profiles, such as lecture halls, offices, labs, cafeterias, and dormitories, each possessing unique operational characteristics. This systemic complexity should inform the Modelling technique; in complex and dynamic systems, hybrid models that amalgamate simulation and statistical methodologies provide the adaptability to represent both dynamic physical processes and behaviour-driven usage patterns.
iv. **Resources and Expertise**: The technical and human resource requirements for various Modelling techniques differ markedly; simulation and hybrid models typically necessitate specialized software such as eQUEST and EnergyPlus (Lamichhane, 2021), substantial computing resources, and personnel with expertise in thermodynamics, building systems, and energy analytics. Institutions with restricted access to resources may find it more

feasible to use simpler models, such as linear regression or benchmarking tools, which necessitate minimal computational power and technical expertise.

v. **Accuracy Requirements**: The requisite level of Modelling precision is a vital factor; high-accuracy applications, such as energy performance contracting or policy formulation, may require comprehensive and validated simulation models capable of delivering intricate insights into energy dynamics.

vi. **Scalability and Flexibility**: Adaptable models that can assimilate with current building management systems (BMS) or data platforms improve long-term functionality and response to evolving energy objectives or infrastructure enhancements.

vii. **Cost and Time Constraints**: Practical restrictions, including budgetary limitations and project deadlines, frequently serve as critical determinants; simulation-based methodologies can be resource-demanding, necessitating weeks or months for data collection, model development, and calibration. Conversely, statistical models and benchmarking tools can frequently be deployed swiftly and at a reduced expense, rendering them appropriate for initial evaluations or expedited diagnostics.

viii. Therefore, efficient energy Modelling necessitates a correlation among energy systems, energy consumption, accessible renewable energy, and the implications of energy policy, as seen in Figure 1

5 Implications for Future Evaluation

The significance for the future of energy Modelling in higher education institutions are:

i **Adoption of Hybrid Approaches**: Future assessments should incorporate a combination of several Modelling techniques—statistical, simulation, and analytical—to leverage the advantages of each method. Hybrid models can offer a comprehensive understanding of energy dynamics and enhance decision-making.

ii **Focus on User-Centric Modelling**: Integrating user behaviour and occupancy patterns into Modelling frameworks is crucial. Given that human activities substantially influence energy consumption, forthcoming models should incorporate behavioural analytics, maybe utilizing agent-based Modelling or machine learning methodologies.

Table 1: Major Areas of Differences of Energy Evaluation Models

Modelling Approach	**Strengths**	**Weaknesses**	**Applicability to Business Buildings in Tertiary Institutions**	**General Applicability**
Statistical Models(e.g., regression, ANN, SVM)	Fast and efficient, Good for real-time and short-term predictions and Requires less physical detail	Dependent on historical data, Lacks physical system representation and Poor in unseen conditions	Real-time energy monitoring, Anomaly detection and Short-term forecasting using smart meters	Commercial and residential buildings, Smart grid demand forecasting/Utility and scale load prediction
Simulation Models(e.g., EnergyPlus, TRNSYS)	Detailed and customizable, Ideal for evaluating designs/retrofits and Scenario testing for ECMs	Time-consuming to build and calibrate, Requires technical expertise and High data demands	Building design and retrofit analysis, Long-term energy planning and Policy and strategy testing	Architecture and engineering design, Green certification support and National energy policy simulations
Hybrid Models(e.g., ML + Simulation)	High accuracy and adaptability, Predictive/interpretable and Real-time and long-term use	Complex to implement, Costly in terms of computation and expertise	Smart campus management, Dynamic AC scheduling and Energy-saving optimization	Smart cities, Industry 4.0 energy systems and Integrated building management systems
Heuristic Models(e.g., GA, PSO)	Solves complex optimization problems, Handles nonlinearities and uncertainty	No guarantee of global optimality, Needs careful tuning, Problem and specific performance	Multi-objective energy optimization, Retrofit and scheduling trade and off analysis	Power system design, Load shedding and demand-side management and Energy-efficient scheduling in industries
Agent,Based Models (ABM)	Captures occupant behaviour and interaction, Reflects real-life complexity	High computational cost, Complex to validate and High data requirements	Modelling occupant, driven energy use and Behavioural simulations for better forecasting	Urban planning, Smart home energy feedback, Demand and side management research

Modelling Approach	**Strengths**	**Weaknesses**	**Applicability to Business Buildings in Tertiary Institutions**	**General Applicability**
Rule,Based Systems	Easy to implement, Low computational demand and Uses expert knowledge	Static and inflexible and Inefficient under dynamic conditions	AC and lighting control based on schedule and Basic energy management systems	Small-scale building controls, Embedded systems for appliances, Simple automation tasks
Optimization Models(e.g., Linear/Nonlinear Programming)	Finds best solutions under constraints, Suitable for strategic planning and Supports integration of renewables	Needs detailed modelling, Sensitive to data quality and assumptions	Long-term cost and emission reduction planning, Renewable integration and demand response strategies	National grid energy modelling, Renewable integration plans and Industrial energy management

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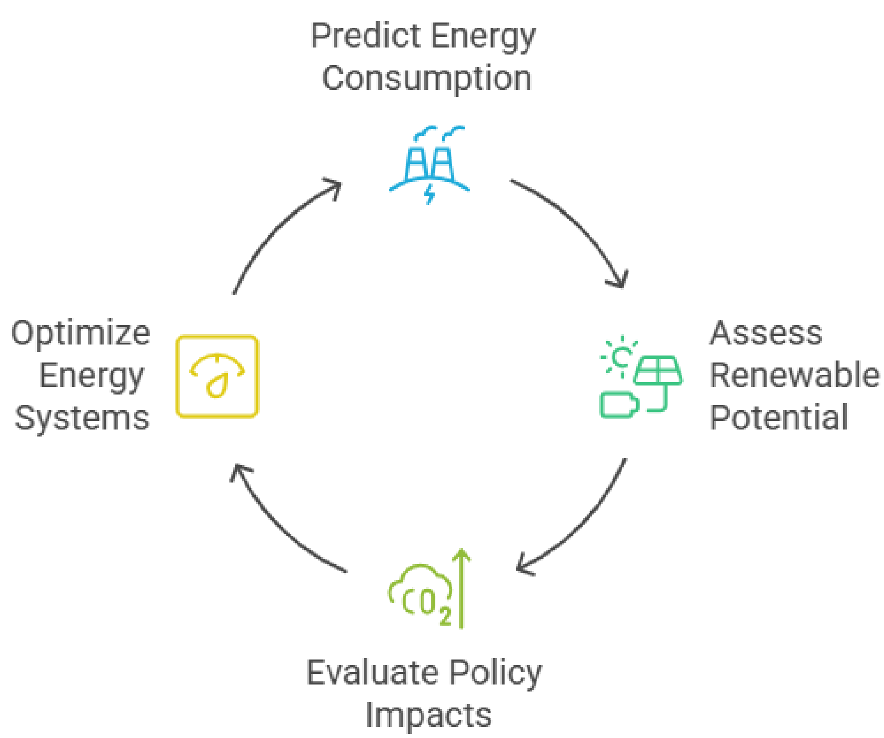

Figure 1: Effective Energy Modelling

i. **Scalability and Replicability**: Models should be designed for scalability to ensure that effective techniques can be duplicated across other buildings or institutions. Modular Modelling frameworks and open-source platforms can improve replicability and decrease expenses.
ii. **Utilization of Advanced Technologies**: Emerging technologies, like the Internet of Things (IoT), Building Information Modelling (BIM), and Artificial Intelligence (AI), should be leveraged to enhance the precision and responsiveness of energy models.
iii. **Emphasis on Sustainability Goals**: Future energy assessments must correspond with institutional sustainability initiatives and international climate targets.
iv. **Capacity Building and Training:** Investment in training and capacity building is essential to enable staff and stakeholders to interpret Modelling outcomes and execute proposed improvements. Educational institutions may integrate energy Modelling into academic curricula to develop internal expertise.
v. **Policy Integration and Incentives**: Institutions ought to promote policies that enhance energy efficiency via incentives, grants, or regulatory structures. Energy Modelling can substantiate the cost-benefit analysis of retrofitting investments and policy execution.

5.4 Advantages of Energy Modelling for Operational Efficiency

Energy Modelling provides multiple advantages that directly enhance the operational efficiency of business buildings in higher education institutions. These advantages encompass energy conservation, cost efficiency, optimized system performance, increased comfort, and assistance in achieving sustainability objectives.

i. Informed Decision-Making Energy Modelling offers comprehensive insights into energy dynamics, empowering stakeholders to make data-driven choices regarding system enhancements, retrofits, and operational strategies. For instance, Modelling can assess the possible effects of transitioning from traditional lighting to LED systems or from single-zone to variable air volume air conditioning systems.
ii. Energy Modelling facilitates the identification of inefficiencies and the simulation of corrective measures, thereby supporting initiatives that decrease utility expenses (Mawson and Hughes, 2019).
iii. Improved System Design and Integration In the design phase of new constructions or significant renovations, energy Modelling allows architects and engineers to evaluate several configurations and identify the most efficient systems. It also enables the incorporation of renewable energy technologies, such as solar photovoltaic systems or wind turbines, by evaluating their performance under specific site conditions.
iv. Performance monitoring and continuous improvement models associated with real-time monitoring systems facilitate continuing performance assessment (O’Neill *et al.,* 2021). These technologies may recognize anomalies, detect underperforming equipment, and suggest modifications, promoting a culture of continual enhancement.
v. Enhanced Indoor Environmental Quality (IEQ) energy Modelling facilitates the evaluation of thermal comfort, daylight accessibility, and air quality, all of which influence occupant health and productivity. In business buildings with extended occupancy hours, enhancing indoor environmental quality through Modelling leads to improved academic and administrative results.
vi. Institutions seeking sustainability certifications benefit from energy Modelling, as it supplies the necessary performance documentation for compliance. This also elevates the institution's reputation and aligns with overarching environmental stewardship objectives.
vii. Energy models facilitate institutions in prioritizing investments according to the return on energy savings (Adenuga, *et al.,* 2019).

viii. Tertiary institutions gain from internal energy Modelling skills, serving as instruments for academic education and research. Students can participate in experiential learning regarding sustainability and energy systems, promoting innovation and skill development.

ix. The energy Modelling methodologies employed in one business facility can be modified and expanded to additional buildings within the organization (Hong *et al.,* 2020). This facilitates the formulation of comprehensive campus-wide energy strategies and bolsters institutional sustainability objectives.

x. Elevated Energy Efficiency Results in Enhanced Performance and Output (Oró *et al.,* 2015; Kamal *et al.,* 2019).

xi. Risk Mitigation and Resilience Modelling enables organizations to evaluate the effects of prospective scenarios, including climate change and energy price fluctuations, while formulating risk mitigation measures (Syri *et al.,* 2008). Resilient building systems guarantee operational continuation amid interruptions.

6. CONCLUSION

The review of Modelling methodologies for energy assessment in higher education institutions indicates that no singular methodology is universally applicable. Statistical models provide rapid insights, simulations facilitate comprehensive analysis, and hybrid methodologies deliver optimal flexibility and accuracy. Optimization and heuristic models offer effective instruments for strategic energy planning, whereas agent-based models enhance our comprehension of behavioural factors. The amalgamation of these Modelling tools has demonstrated efficacy in improving energy efficiency, decreasing operational expenses, and advancing sustainability objectives in business buildings within higher education institutions. Nonetheless, obstacles including data constraints, substantial initial expenses, and the necessity for proficient personnel persist.

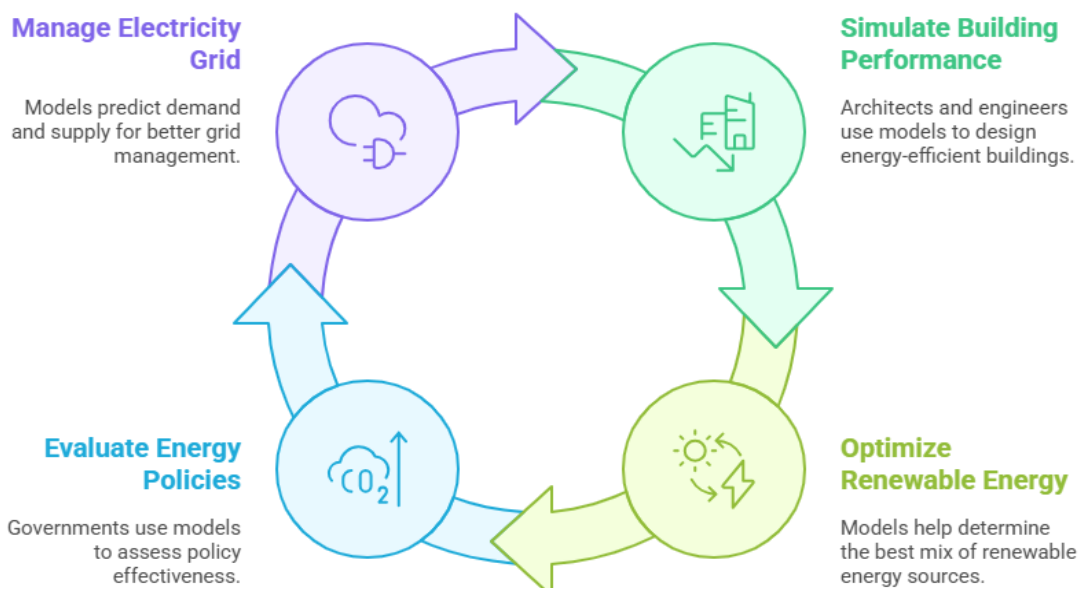

Figure 2: Application of Energy Modelling

The implementation of energy Modelling in business buildings of higher education institutions offers significant prospects for improving operational efficiency and sustainability. Consequently, the applications of energy Modelling facilitate building energy management, renewable energy integration, policy formulation, and grid management, as illustrated in Figure 2. By encapsulating the distinctive attributes of these structures and employing sophisticated Modelling techniques, institutions can enhance energy efficiency, minimize expenses, and elevate occupant well-being. The varied case studies from international institutions demonstrate that customized energy Modelling techniques provide significant advantages, including performance monitoring, system optimization, strategic planning, and policy formulation. The incorporation of energy modelling into the operational and strategic frameworks of expanding and modernizing tertiary institutions will be essential. It not only advances immediate energy efficiency objectives but also fosters long-term institutional resilience and environmental accountability.

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