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Enhancing Energy Efficiency In Institutional Buildings Through Simulation-Based Analysis: A Case Study From Kerala, India

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Abstract: In response to growing energy demands and environmental concerns, this project focuses on enhancing the energy efficiency of an institutional building through simulation-based analysis using eQUEST software. By modelling critical parameters such as HVAC systems, lighting, plug loads, occupancy schedules, and building envelope features, the study aims to identify potential inefficiencies and explore strategies for improved performance. This approach supports data-driven decisions that promote sustainability, cost-effectiveness, and energy-conscious design in the built environment.

Index Terms - Energy Modelling, Energy Analysis, eQUEST, HVAC Systems, Energy Efficiency, Sustainable buildings.

I. INTRODUCTION

As the built environment expands, its role in global energy consumption and environmental impact becomes increasingly significant. Institutional buildings, with their large floor areas and long operating hours, face unique energy challenges due to their continuous reliance on mechanical and electrical systems. Modern design now goes beyond structural strength, emphasizing energy efficiency and sustainability. One of the most effective ways to support this shift is through energy modelling—a process that simulates a building's energy performance to identify inefficiencies and guide improvements. In this study, eQUEST software was used for its powerful yet accessible simulation capabilities. Built on the DOE-2 engine, eQUEST allows users to assess how design elements like HVAC systems, lighting configurations, and building envelopes influence energy use. By replicating real-world conditions, the tool enables engineers to make data-driven decisions that reduce energy demand, cut operational costs, and support climate-responsive design.

II. LITERATURE REVIEW

Nima Amani (2024), concentrated on a academy in Iran and delved how structure exposure, natural ventilation, and renewable energy systems affect energy use. The study showed that solar panels, wind turbines, and well-placed windows bettered natural lighting and thermal comfort, contributing to sustainable and cost-effective academy design.

Saroj Lamichhane et al. (2024), assessed energy performance in two marketable structures using eQUEST simulation software. They linked HVAC setpoints and reversal controls as crucial factors impacting energy use. The exploration stressed the significance of estimation and fine-tuning control systems to enhance energy effectiveness.

Jiafang Song et al. (2015), anatomized energy consumption in a university library in China and linked air exertion systems as the dominant energy druggies. Using eQUEST, the study showed that conforming lighting power viscosity and inner temperatures could ameliorate overall energy performance in institutional spaces.

III. METHODOLOGY

The study began with a literature review to explore current practices in building energy efficiency. Data such as building layout, occupancy patterns, and utility records were gathered to support accurate modelling. Key energy-related parameters including HVAC systems, lighting, and envelope details were identified and integrated into an energy model developed using eQUEST. The simulated results were compared with actual energy use to evaluate performance gaps and uncover inefficiencies. Based on the analysis, targeted strategies were proposed to enhance the building's overall energy efficiency.

IV. STUDY AREA

This study focuses on the administrative block of Ilahia College of Engineering and Technology in Muvattupuzha, Kerala a region with a warm, humid climate. Built in 2003, the building supports a range of academic, administrative, and public functions. It was selected for analysis due to its varied space usage, complex layout, and the availability of building data. The structure includes libraries on the ground floor, administrative offices and a seminar hall on the first floor, lecture halls and faculty spaces on the second, and a large auditorium with balcony seating on the upper levels. Constructed with RCC framing and CMU walls, the building also features aluminium cladding, glazed panels, tiled flooring, and a GI sheet roof supported by steel trusses. These design and material elements, along with its climate exposure, make it a fitting subject for energy performance evaluation.

V. DATA COLLECTION

To enable accurate simulation, detailed information was collected on the building's energy use and systems. A lighting audit revealed potential for daylight-based controls due to the high window-to-wall ratio. Data on HVAC systems, electrical equipment, and occupancy schedules were gathered through on-site visits and staff input. Utility bills from January to December 2024 were reviewed to understand actual energy consumption patterns. Additional details on the building envelope, plug loads, and local climate were also compiled to support effective modelling in eQUEST and identify areas for performance improvement.

VI. IDENTIFICATION OF KEY PARAMETERS

Understanding what drives building energy use is essential for identifying opportunities to improve efficiency. In this study, several critical parameters were considered. **HVAC systems** are major energy consumers, and their performance depends on design, control, and maintenance. **Lighting loads** also impact consumption, especially when outdated fixtures increase both energy use and internal heat. **Plug loads** from everyday devices add to demand, particularly when idle equipment draws standby power. The **building envelope**, including walls, roofs, and windows, influences heat transfer and cooling needs, while **thermostat settings** affect how efficiently indoor temperatures are maintained. **Occupancy patterns** shape how lighting and ventilation systems operate, and **equipment efficiency** plays a role in overall consumption. Additionally, **building size and orientation** influence solar gain and daylighting, and **climatic conditions**, especially in warm-humid regions like Kerala, significantly affect cooling requirements. Each of these parameters was carefully integrated into the energy model to ensure realistic simulation results.

VII. BUILDING ENERGY MODELLING

The energy model of the administrative block was created using eQUEST to closely replicate the building's actual performance. Given the building's complex design and the availability of detailed data, a comprehensive modelling approach was used. Essential inputs such as floor plans, functional zones, building envelope details, HVAC systems, internal equipment loads, and occupancy schedules were incorporated to reflect realistic operating conditions. The model was further refined using the detailed data edit mode, which

allowed for fine-tuning and calibration against real utility data. This process provided accurate simulation results, helping to pinpoint inefficiencies and develop practical strategies for improving energy efficiency.

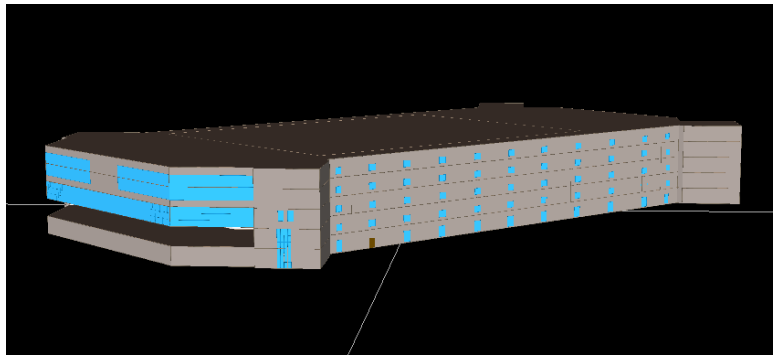


Figure 1: Building Energy Model inside Equest

VIII. BUILDING PERFORMANCE ANALYSIS

i. Monthly Energy Consumption by End use

The monthly breakdown of energy use reveals how various building systems contribute to overall electricity consumption throughout the year. Cooling systems account for the largest share, with energy demand rising significantly during the warmer months due to seasonal temperature increases. On the other hand, lighting and equipment loads remain steady across all months, indicating that their usage is driven more by routine occupancy and internal operations than by changes in outdoor climate.

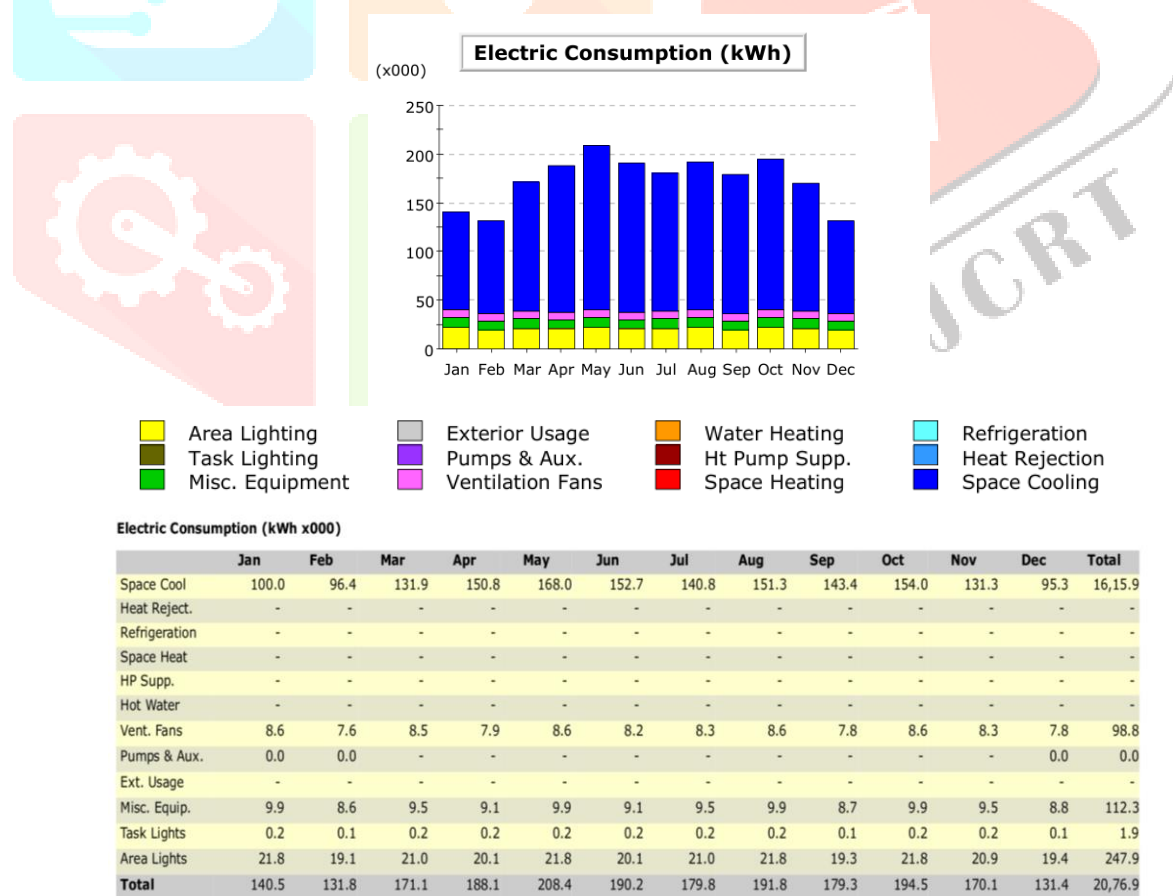


Figure 2: Monthly Energy Consumption by End use

IX. COMPARATIVE ANALYSIS OF ACTUAL VS SIMULATED ENERGY PERFORMANCE

The "Actual vs Simulated Monthly Energy Consumption" graph shows notable differences between real-world and modelled energy use, with actual consumption consistently exceeding simulated values in most months.

Table 1: Actual VS Simulated Energy Consumption Data

SI No.	Month	Actual energy consumption (kWh)	Simulated energy consumption (kWh)
1	January	191.52	140.50
2	February	203.05	131.80
3	March	213.87	171.10
4	April	209.68	188.10
5	May	209.38	208.40
6	June	202.66	190.20
7	July	190.58	179.80
8	August	179.20	191.80
9	September	174.25	179.30
10	October	182.65	194.50
11	November	190.90	170.10
12	December	189.47	131.40

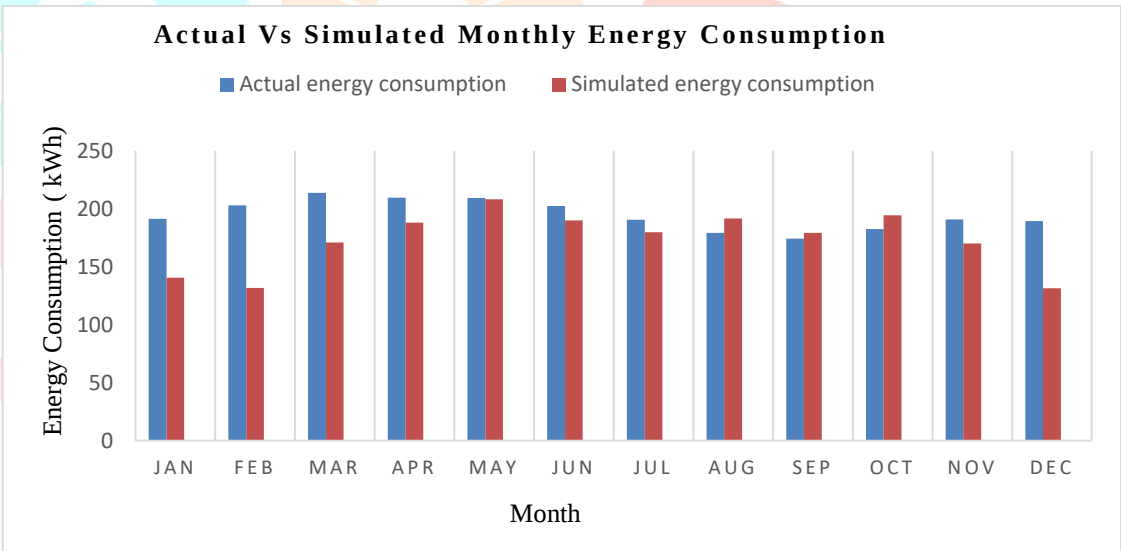


Figure 3: Graph Showing Actual VS Simulated Energy Consumption

This indicates operational inefficiencies not fully captured in the model, especially during cooler months like January and December. In contrast, closer alignment between actual and simulated values in summer suggests the model accurately reflects cooling loads.

X. RECOMMENDATIONS

- i. **Upgrade window glazing** by installing low-emissivity, high-performance glass. This helps reduce unwanted heat gain, improves indoor comfort, and aligns with ECBC (Energy Conservation Building Code) guidelines.
- ii. **Improve HVAC performance** by switching to energy-efficient VRF (Variable Refrigerant Flow) systems and incorporating demand-controlled ventilation. These changes can significantly lower cooling loads and enhance overall system efficiency.
- iii. **Modernize lighting systems** by replacing conventional fixtures with LEDs and adding smart controls like motion sensors and daylight-based dimming. This reduces energy use while maintaining adequate lighting levels.

- iv. **Strengthen thermal insulation** by applying cool roofing materials and insulating exterior walls. These upgrades reduce heat transfer, lighten HVAC demand, and improve the building envelope's energy performance.
- v. **Adopt renewable energy** by installing rooftop solar panels. This offsets part of the building's electricity consumption and supports long-term energy sustainability.

XI. CONCLUSIONS

This study highlights the practical benefits of using energy modelling to enhance building performance, especially in institutional environments. By simulating the energy usage of an educational facility in Kerala through the eQUEST platform, the research was able to pinpoint areas where energy was being wasted and suggest specific improvements. These included upgrading to better-insulated glazing, modernizing HVAC systems for greater efficiency, replacing outdated lighting with LED fixtures and smart controls, and reinforcing insulation in the building envelope.

Implementing these strategies could lead to substantial reductions in electricity consumption and operational costs, while also helping the building meet modern sustainability and energy efficiency standards like those set by the ECBC. Beyond this specific case, the study emphasizes the broader value of data-driven, simulation-based methods for evaluating and optimizing building performance. It demonstrates how such tools can inform targeted retrofitting decisions, support climate-responsive design, and contribute to long-term sustainability goals in the built environment.

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