

BIM-Based Optimum Design and Energy Performance Assessment of Residential Buildings

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Abstract - Rapid urbanization and rising energy demands have made energy-efficient residential building design essential for sustainable development. Since a major portion of building energy consumption occurs during the operational phase, assessing energy performance during the early design stage is crucial. This study presents a Building Information Modeling (BIM)-based approach for optimizing energy consumption in a 1,400 sq ft residential building located in Aundh, Pune, India. A detailed model was developed using Autodesk Revit, and various design alternatives were evaluated by considering parameters such as building orientation, wall materials, roof insulation, glazing systems, lighting efficiency, and HVAC configurations. BIM-integrated energy simulations enabled comparison of different design options and identification of optimal solutions. The baseline building consumed 16,300 kWh/year (125.2 kWh/m²/year) with an annual energy cost of ₹1,38,550. By adopting AAC block walls, improved roof insulation, low-emissivity glazing, and enhanced daylight utilization, annual energy consumption was reduced to 9,246 kWh/year (71.0 kWh/m²/year), achieving a 43.3% reduction. The additional investment of ₹1,53,260 yielded a payback period of 2.55 years and a 30-year net present value of ₹16,45,510, demonstrating BIM's effectiveness in supporting sustainable and energy-efficient residential design.

Key Words: Building Information Modeling, Energy Simulation, Thermal Performance, Sustainable Design, Lifecycle Analysis, Revit, Autodesk Insight 360, Residential Buildings, Tropical Climate, Energy Efficiency

1.INTRODUCTION

The building sector accounts for approximately 30-40% of global energy consumption and contributes significantly to greenhouse gas emissions. Residential buildings, in particular, represent a substantial portion of total building energy use, especially in developing economies like India where urbanization rates are accelerating rapidly. In the Indian context, residential buildings consume energy during their operational phase—spanning 30 to 50 years—making the design phase critical for long-term sustainability outcomes. Traditionally, building design has prioritized structural adequacy, aesthetic appeal, and immediate cost minimization. However, this approach often results in buildings with suboptimal energy performance, leading to higher operational costs and greater environmental impact over the building lifecycle. Energy performance assessment is frequently conducted late in the design process or deferred to post-

construction phases, limiting the opportunity for cost-effective design modifications.

Building Information Modeling (BIM) represents a paradigm shift in how buildings are designed, analyzed, and constructed. BIM integrates architectural, structural, MEP, and performance data into a unified digital environment, enabling collaborative analysis and evidence-based decision-making. When coupled with energy simulation tools, BIM facilitates iterative optimization of design parameters to minimize operational energy consumption while maintaining occupant comfort and functional requirements.

2. II.LITERATURESURVEY

1. BIM And Orthogonal Test Methods to Optimize the Energy Consumption of Green Buildings. Published Year – 2024

The paper by Xiaojun LI, Mincho LIN, Ming JIANG,C.Y.JIM,KeLIU,HuipinTSENG.The construction industry's rapid growth significantly impacts energy consumption and environmental health. It is crucial to develop optimization strategies to enhance green building energy efficiency and encompass comprehensive analysis methods.

This study aims to introduce and validate a novel framework for optimizing energy efficiency design in green buildings by integrating Building information Modelling (BIM) technology, Life Cycle Cost (LCC) analysis, and orthogonal testing methods, focusing on enhancing energy efficiency and reducing life cycle costs. The optimization parameters for the building envelope are identified by analyzing energy consumption components and key green building factors. The orthogonal testing method was applied to streamline design options. Building Energy Consumption Simulation (BECS) software and LCC analysis tools were employed to calculate each optimized option's total annual energy consumption and the current lifecycle costs. Using the efficiency coefficient method, each optimal station scheme's energy consumption and economic indicators were thoroughly analysed. The framework's validity and applicability were confirmed through an empirical analysis of a campus green building case in Fujian Province, demonstrating that the optimized framework could reduce energy consumption by

4.5 Whim per year and lower costs by 38.89 Yuan/m² compared to the reference building. The case study highlights the framework's significant benefits in enhancing environmental performance economic gains. The results provide optimum parameter selection and offer scientific and technological support for the design of building energy efficiency, promoting optimization techniques and sustainable development within the construction industry.

2. BIM-Based Optimum Design and Energy Performance Assessment of Residential Buildings. Published Year – 2020

The paper by A. Amir, R Soroush, and N.Amani This research focuses on improving the energy use of residential buildings through Building Information Modelling (BIM) technology. Buildings make up a large part of global energy consumption, especially over their life-times. This makes energy efficiency in building design key for sustainable development. The authors took a conceptual design approach, creating multiple building models with Autodesk Revit software and using a top-down design method. They assessed energy use by examining various building components at the same time. These components included building orientation, window-to-wall ratio, shading, window glazing type, wall and roof construction, HVAC systems, lighting efficiency, occupancy controls, and photovoltaic panels. Energy simulations and parametric studies showed that using BIM for energy performance assessments can greatly cut energy costs, with savings of up to 58.46% over 30 years compared to the initial building model. The BIM method allows for quick generation and updating of energy models. This reduces mistakes and the duplicate data processing often seen in traditional energy evaluation methods. The study focused on a residential building located in a mild climate (Gilan province, Iran). There, optimized building features like triple-glazed windows, improved HVAC systems, and photovoltaic panels were used to achieve these savings.

The findings highlight the benefits of BIM technology for decision-making during the early stages of design. This approach leads to high energy efficiency while lowering the environmental impact. Key findings reveal that BIM most frequently benefits cost reduction and control throughout the project lifecycle, with significant time savings also reported. Positive effects are also seen in improved communication, interoperability issues, alongside the need for better training and awareness to fully realize BIM's advantages.

3. Building Energy Optimization using BIM: A Study on Institutional Building.

Published Year – 2024

The paper by M.S. Yuvaraj, Shaik Nurulla, D.V. Purushotham, A. Yaswanth Krishna, V. Krishna Sai,

B. Lokesh Babu, P. Azaruddin In many facets of the construction industry, including energy management to encourage the development of green buildings, Building Information Modelling (BIM) is one of the contemporary data information platforms and management technologies that is widely employed.

The goal of this study was to optimize an institutional building's energy consumption by analyzing and evaluating its energy performance using BIM-provided capabilities. The Civil Engineering block of Sree Vidyanikethan Engineering College in Tirupati, taken into consideration for the investigation. The 2D blueprint obtained from the engineering department and BIM technologies were used to create the necessary building model. The Green Building Studio (GBS) tool and Autodesk Insight 360 were utilized to conduct an energy analysis and derive the energy usage figures. The structural elements that are contributing to the high energy demand, such as the area between windows and walls, the width of the chajja relative to the height of the window, etc.,

were identified, and the BIM model underwent the required alterations to optimize the energy consumption. Comparing the data obtained in the two aspects, it was found that there was a 30% reduction in energy costs and a roughly 29.76% drop in energy use.

4. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry.

Published Year – 2011

The paper by S. Azhar, Ph.D., A.M. Asce Building information modeling (BIM) is a promising development in the architecture, engineering, and construction (AEC) industry. With BIM technology, a digital model of a

building is created. This model, called a building information model, can be used for planning, design, construction, and operation of the facility. It allows architects, engineers, and builders to visualize the construction in a simulated environment. This helps identify any potential design, construction, or operational issues. BIM introduces a new approach within AEC that promotes collaboration among all project stakeholders. This paper discusses current trends, benefits, risks, and future challenges of BIM in the AEC industry. The findings offer valuable insights for AEC professionals considering BIM technology for their projects.

5. Designing a BIM energy-consumption template to calculate and achieve a net-zero-energy house.

Published Year – 2021

The paper by S.E. Sayary, O. Omar HEM is not simply a drafting tool or advanced CAD. BIM is a collaboratively generated and maintained data-rich information source, especially when it comes to the energy calculation process and beyond. Due to growing awareness around energy conservation, numerous projects and initiatives have occurred to promote the development of low and net-zero-energy homes. The widespread adoption of photovoltaic rooftop systems has shown that solar panels be an effective solution to that energy demand, nowadays, the idea that BIM is not just software has been decided upon. In this paper, a new approach was used to calculate energy consumption using a BIM template designed for this purpose. The greatest value derived from BEM was in the template designed to neutralize energy consumption by calculating the number of photovoltaic panels needed to achieve a net-zero-energy home. The BIM prototype developed is considered a useful model, intended to be used by every day, non-specialists to aid and disseminate energy knowledge in order to achieve a zero-energy home, as well as to be used as a decision-support tool, incorporating energy simulation into the early design process of zero-energy buildings in architectural practice. Finally, the group of users in order to fine-tune and develop the design parameters of the template.

6. Effective energy consumption parameters in residential buildings using Building Information Modeling.

The paper by N. Amani, A.A. Reza Soroush Building information modeling can help predict energy efficiency in the future by visualizing dynamic data patterns. This study aimed to examine the key factors of energy consumption using BIM technology, which evaluates a building's energy performance. First, three general building designs were

modeled using Autodesk Revit Software to assess the proposed layouts. Next, the main building form for energy modeling and analysis was chosen. Autodesk Revit 2020 was also used to analyze climate data and determine the building's energy consumption index. Finally, we selected the most efficient mode by examining various energy consumption scenarios. The results showed that using building information modeling to adjust factors affecting energy consumption can save energy costs by up to 58.23% in block D. Energy savings for block C and the western lobby were 51.03% and 43.05%, respectively. Based on energy use intensity, cost savings for blocks C, D, and the western lobby were estimated at 16.67%, 16.30%, and 11%, respectively. Parametric studies on alternative energy use intensity optimization schemes indicated that the base building model could achieve 16.30% savings over a 30-year period. Therefore, we concluded

that optimizing energy consumption would reduce emissions of harmful pollutants and help protect and sustain the environment.

7. Project Benefits of Building Information Modelling (BIM).

Published Year – 2013

The paper by D. Bryde, M. Broquetas, and J. Marc Volm. This study looks into the benefits that Building Information Modelling (BIM) brings to construction projects by examining secondary data from 35 projects that used BIM. BIM is seen not only as a tool for creating geometric models of buildings, but also as a resource for managing construction projects through integrated policies, processes, and technologies. The paper discusses various aspects of project success that BIM impacts, such as cost, time, quality, coordination, communication, and risk management. Key findings show that BIM mainly helps reduce costs and improve control throughout the project lifecycle, with notable time savings also reported. There are positive effects on communication, coordination, and construction quality. The challenges mostly focus on software usability and interoperability issues, as well as the need for more training and awareness to fully take advantage of BIM. The authors conclude that BIM is a useful tool for project management in construction, enhancing integration and collaboration among stakeholders. They call for more promotion, education, and cost/benefit analyses to encourage wider BIM adoption, while also recognizing ongoing challenges in software and human management that need resolution.

8. Study on BIM-Based Optimization of Energy Parameters in Residential Buildings.

Published Year – 2020

Authors: N. Amani, A. A. Reza Soroush. Effective energy consumption parameters in residential buildings using Building Information Modeling (BIM) are an effective tool for enhancing energy efficiency in buildings by visualizing and analyzing dynamic building data. This study focused on identifying key energy consumption parameters in residential buildings using BIM-based energy performance evaluation. Three different residential building layouts were modeled in Autodesk Revit, and the most efficient design was selected for detailed energy analysis. Climatic data were incorporated to calculate energy consumption, and multiple scenarios were tested by modifying performance parameters. The results showed significant energy savings: Block D achieved a maximum of 58.23%, Block C 51.03%, and the western lobby 43.05%. Energy Use Intensity (EUI) analysis estimated cost

savings of 16.30–16.67% for the blocks and 11% for the lobby.

3. METHODOLOGY

The methodology for BIM-based optimum design and energy consumption assessment of residential buildings involves creating multiple conceptual building designs using BIM software such as Autodesk Revit with a top-down design approach. From these concepts, the main building form is selected for detailed modeling. Energy consumption of the building is then simulated using integrated energy analysis tools, incorporating factors like building materials, equipment, and geographic location. Various design alternatives are iteratively evaluated through parametric studies to identify options that minimize energy usage. A trade-off analysis is applied to ensure compliance with energy efficiency standards, and the optimal design is selected based on criteria such as energy cost savings and sustainability over the building's lifecycle. This integrated BIM approach significantly reduces time and cost while enabling comprehensive evaluation of energy performance ultimately supporting the development of energy-efficient residential buildings with substantial energy cost savings long-term user residential buildings.

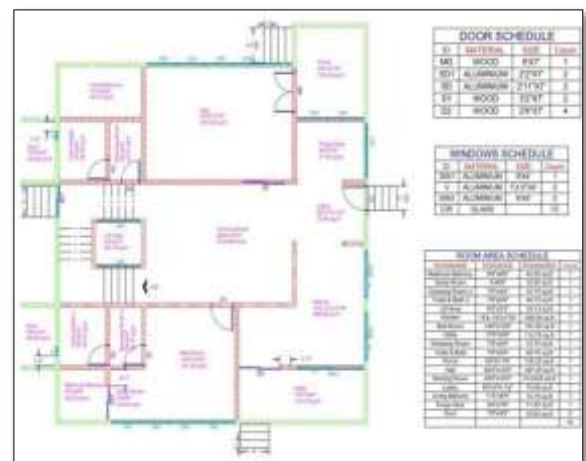


Fig -1: Plan

Autodesk Revit 2021. The model incorporates complete building geometry, structural frame, fenestration systems, MEP components, and material specifications. The building comprises three residential floors with a ground floor multipurpose space, situated in Aundh, Pune (coordinates: 18.56°N, 73.83°E).

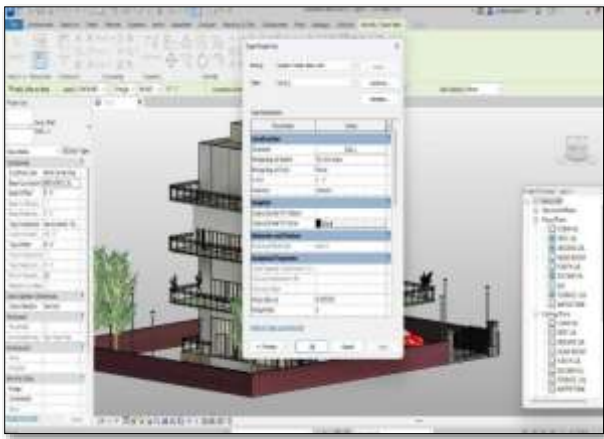
3.2 Energy Simulation Framework

Energy performance analysis was conducted using Autodesk Insight 360, integrated with Revit 2021. The analysis encompassed annual energy simulation incorporating site-specific weather data for Pune. Project location, building type classification (residential), occupancy patterns (70% daytime, 100% nighttime occupancy), and operating schedules were configured to reflect typical residential use patterns.

3.3 Parametric Design Optimization

Systematic parametric studies evaluated the influence of key design variables on annual energy consumption: (1) wall material substitution (red brick masonry vs. AAC blocks); (2) roof insulation enhancement; (3) glazing system selection (clear single glass vs. low-emissivity double glazing); (4) window frame material (wood vs. uPVC); (5) exterior surface reflectivity (dark vs. light colors); and (6) daylighting optimization through window placement refinement. Each parameter was systematically varied while holding others constant to isolate individual effects.

Fig -2: BIM Model



3.4 Energy Considerations

The image is a presentation slide about a project that uses Building Information Modeling (BIM) to design and estimate residential buildings. The project's main goal is to reduce energy consumption through passive design strategies and by integrating systems for rainwater harvesting and greywater reuse.

1. Electrical Energy

The project focuses on minimizing electricity consumption through intelligent design and efficient systems. By incorporating energy-saving appliances, efficient lighting, and smart control systems, residents benefit from lower electricity bills, reduced environmental impact, and a more sustainable lifestyle. The approach ensures that every kilowatt-hour is used wisely and effectively.

2. Solar Energy

Solar energy plays a central role in achieving energy independence. The design includes solar panels that capture sunlight and convert it into clean, renewable electricity. This system is eco-friendly, low-maintenance, and particularly effective in sunny climates. Harnessing solar power not only cuts reliance on the grid but also supports the vision of a self-sufficient, green home.

3. Thermal Energy

Thermal comfort is a key priority. The building's design reduces the need for air conditioning or heating by optimizing insulation, natural shading, and ventilation. As a result, indoor spaces remain comfortable year-round while significantly lowering energy use. This leads to greater comfort, smaller energy bills, and a more sustainable carbon footprint.

4. RESULT AND DISCUSSION

The residential building considered for the study has a built-up area of 1,400 sq ft (130.1 m²) and is located at DP Road, Aundh, Pune (18.56°N, 73.83°E), which falls under the warm and humid climatic zone characterized by summer temperatures ranging from 30–42°C and winter temperatures from 10–28°C.

Parameter	Value
Building Area	1,400sqft(130.1sqm)
Location	DPRoad,Aundh,Pune(18.56°N,73.83°E)
Building Type	Residential(3-story)
Climate Zone	WarmandHumid(Summer:30-42°C,Winter: 10-28°C)
Occupancy	5residentsper unit
Occupancy Schedule	70%duringday,100%duringnight

Table 1: Building details

Building Envelope Characteristics(Traditional Materials):

The baseline building envelope consists of conventional construction materials, including red brick masonry walls, RCC roofing, single clear glazing, wooden window frames, and dark exterior paint with high solar absorptivity. These characteristics contribute to higher heat gain and increased cooling demand, thereby resulting in greater annual energy consumption and reduced thermal efficiency.

Material	Specification
Walls	RedBrickMasonry(k-value:0.81W/m·K)
Roofing	ConventionalRCCRoof(k-value:1.50W/m·K)
Glazing	ClearSingleGlass(U-value:1.05W/m ² ·K)
Window Frames	WoodenFrames(U-value:0.15W/m ² ·K)
External Paint	DarkColour(HighSolarAbsorption:α≈0.85)

Table 2: Building Material Characteristics

Energy Savings Summary:

Metric	Baseline	Optimized	Savings	% Reduction
Annual Energy (kWh)	16,300	9,246	7,054	43.3%
EUI (kWh/sq m/year)	125.2	71.0	54.2	43.3%
Annual Cost (₹)	1,38,550	78,591	59,959	43.3%
Monthly Cost (₹)	11,546	6,549	4,997	43.3%
Annual CO ₂ (tons)	13.04	7.40	5.64	43.3%
30-Year CO ₂ (tons)	391.2	222.0	169.2	43.3%

5. CONCLUSION

This BIM-based study conclusively demonstrates that systematic optimization of building materials and design parameters, grounded in detailed energy simulation and life cycle analysis, can deliver substantial energy, economic, and environmental benefits for residential construction in tropical Indian climates. The 43.3% energy reduction achieved, coupled with a 2.55-year payback period, establishes energy-efficient design not merely as an environmental aspiration but as a pragmatic economic decision for residential property owners and developers. The research validates Building Information Modeling as an essential tool for modern sustainable design practice, enabling data-driven decision-making at critical early design stages. The integration of BIM with energy performance analysis shifts the design paradigm from "how to minimize first costs" to "how to optimize lifecycle fundamental reorientation essential for achieving India's sustainable development and climate action goals."

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