CHAPTER 62

Estimating Project Cost of Energy-Compliant Building

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ABSTRACT

Energy-efficient buildings are structures specially designed to reduce energy consumption while sustaining or improving comfort and functionality. These buildings attain efficiency through various combinations of design, construction techniques, materials, and technologies that help minimize energy use for lighting, heating, cooling, and other operations. In the current scenario, energy-efficient buildings are essential for mitigating climate change by reducing greenhouse gas emissions and addressing rising energy costs through lower consumption. Energy conservation is therefore the need of the hour, for which energy-efficient buildings need to be encouraged, and stakeholders' concerns about heavy initial capital investment must be addressed with a justified and rational analysis. This research zeroes in on investments related to the initial cost of building envelopes and does a comparative analysis of different materials that can be used in energy-efficient buildings with those used in conventional buildings. The energy conservation building code (ECBC) is taken into consideration for designing building envelope and deriving costs associated with the materials and operation of the building taking special attention on HVAC (Heating, Ventilation and Air conditioning) systems. The research highlights using efficient materials to offset the additional expenditure for incorporating them. The findings of this research include an alternative analysis of conventional and energy-efficient building materials. It further examines the trade-off of choosing energy-efficient materials over conventional options.

Keywords: Energy-efficient buildings; Building envelopes; Building materials; HVAC.

1.0 Introduction

There has been a recent surge in interest in green buildings which is mainly driven by environmental concerns and a push for resource optimization that has sparked numerous research endeavours worldwide with an aim to increase understanding of the cost implications of sustainable construction. This study aims to estimate the project cost of an energy compliant building by studying a wide array of studies which will provide a holistic review of the economic landscape surrounding green buildings.

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This project aims to explore and address the critical aspects of energy-compliant buildings by focusing on energy compliance standards, the application of advanced tools and techniques, and the estimation of project costs. The economic aspect of green buildings is an important factor for employing sustainable practices. Research done by Lu *et al.* (2023) highlighted the role of Building Information Modeling (BIM) in cost reduction and an increased collaboration between multidisciplinary teams. The presence of a complex relationship between green building variables and property value was highlighted by Utomo *et al.* (2022), while Lee *et al.* (2023) showcased that energy-saving benefits can offset the initial construction costs of the Zero Energy Buildings (ZEBs).

Additionally, researchers have looked into the various methods to assess the green building economics and also introduced quantitative methodologies like regression models and a hybrid qualitative-quantitative method as Case Based Reasoning (CBR) (Alshamrani (2017); Leśniak *et al.* (2018). Others looked into administrative and engineering solutions that focused on strategies for cost optimization and validated the long-term savings associated with high-performance designs (Clark *et al.* (2000); Basten *et al.* (2018). Further studies identified the need for a holistic perspective regarding the assessment of green building projects throughout its lifecycle. Barathi *et al.* (2022) highlighted economic feasibility and Manjunath *et al.* (2021) research highlighted the environmental benefits of sustainable materials, while Gashaw *et al.* (2023) cemented the importance of the holistic evaluation models and Illankoon *et al.* (2017) highlighted a balanced consideration of economic, social, and environmental factors. Some studies also revealed the deterrents of sustainable construction practices such as the significant effect of policy interventions and technological advancements.

Dalirazar *et al.* (2023) by employing the PESTEL framework identified the barriers to adoption and proposed solutions, while Ashokkumar *et al.* (2020) emphasized a positive correlation between indicators of sustainability and certification levels. Furthermore, research by Saini *et al.* (2022) looked into combating climate change by making sustainable practices a necessity and Mohanta *et al.* (2022) highlighted the improvement of facility management. India has many topographic variations to understand its effect on sustainable construction practices and costs. Literature on regional variations and contextual factors influencing green building economics was referenced. A region- specific evaluation model for Ethiopian projects was developed by Gashaw *et al.* (2023) while Reddy *et al.* (2018) highlighted the importance of context-specific frameworks in India which involved local context, regional variations, and climatic conditions. The local certification patterns and regulatory interventions in Poland and Kolkata were studied by Plebankiewicz *et al.* (2019 and Kumar *et al.* (2021), respectively. Through this study we aim to understand the financial prospects associated with sustainable construction practices as well as calculating the costs of energy-compliant buildings in India, in accordance with the GRIHA (Green Rating for Integrated Habitat Assessment) and IGBC (Indian Green Building Council) certification which has been of the utmost importance in construction industry. GRIHA (Green Rating for Integrated Habitat Assessment) and IGBC

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(Indian Green Building Council) rating systems which promote sustainable building practices by assessing the building parameters centering on energy efficiency, water conservation, waste management, and indoor environmental quality are especially designed for the Indian conditions.

2.0 Research Objective

The research objective includes

- review and analyze numerous green building systems in the Indian context.
- investigate various tools and techniques applied in green building.
- compare cost packages of conventional building and energy-compliant building.

3.0 Review of Literature

This literature review highlights the approaches and various findings in the area of energy-compliant building design and cost analysis. Building Information Modeling (BIM) has played a key role in transparent valuation processes evidently that support AI models for life cycle cost analysis in green buildings and encourage multidisciplinary collaboration. Green buildings are found to be economically viable despite having greater construction costs on the trade-off of reduced operating costs. While evaluating green buildings, other techniques including Case-Based Reasoning (CBR),

Work Breakdown Structure (WBS), and Regression Models are helpful in identifying various cost components. Research indicates that implementing an initial cost prediction mode is essential to the project's economic viability. While it is confirmed that green building variables collectively influence property value rather than individually, it is not feasible to conduct a complete assessment of a project at this time.

Therefore, the project must be divided into work packages for better results. Research indicates that energy-compliant buildings can lead to substantial cost savings. Overall construction cost reduction is visible in the reports (up to 15.2% and 30%, respectively) by adopting sustainable materials and practices (Prajwal *et al.* (2021); Manjunath *et al.* (2021). This indicates the economic viability of energy-compliant designs. Reddy *et al.* (2018) gives us an in-depth understanding of sustainable building assessment tools, comparing LEED, GRIHA, IGBC, and BREEAM.

The study emphasizes the need for a new Sustainable Building Assessment Tool (SBAT) specially designed for India's unique climatic and regional conditions. It emphasizes the dire need of qualitative and quantitative methods for effective evaluation. Study of Plebankiewicz *et al.* (2019) gives us an analysis on the costs and benefits of green certification for office buildings in Poland, highlighting the need for integrated assessment systems. As mentioned above, India has three widely followed ratings systems for green buildings: LEED

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(Leadership in Energy and Environment Design), GRIHA (Green Rating for Integrated Habitat Assessment), and BEE (Bureau of Energy Efficiency) which are the key players in driving energy efficient by setting certain standards that makers need to comply. This helps ensure that buildings are affordable to build over the long term and acts as an important business case for governments considering new building codes, rating systems etc. Some of the tools and techniques include Life Cycle Cost (LCC) analysis, payback period Net Present Value (NPV), sensitivity analysis regression & life cycle cost analyses. Life cycle costing Blomberg *et al.* Case-Based Reasoning (CBR), Work Breakdown Structure (WBS), green construction, Critical Path Method Techniques (Wei *et al.*, 2013; Singh *et al.*, 2022).

The methods used are to identify major cost driver factors, predict maintainability performance (Mohanta *et al.*, 2022), and enable collaboration among stakeholders. Although the construction costs of a green building are higher, there is mounting evidence that they are financially justified given the significant savings in operating expenses and energy expenditure (Barathi *et al.*, 2022). Studies such as Prajwal *et al.* (2021) and Manjunath *et al.* show cost reductions of up to 15.2% and 30%, respectively, in sustainable materials & methods (2021). Accurate first-cost estimation models are critical for the success of projects (Gashaw *et al.*, 2023).

4.0 Research Methodology

In this study, a hypothetical commercial building model is created through BIM interface. Four different scenarios are evaluated doing variations in building envelopes and subsequent variation in civil, mechanical and electrical component cost. The layout for commercial building is shown in Figure 1. A 165-meter square floor area commercial office building has been taken in this study. Location of the building is assumed to be in Mumbai, India (Climatic zone- warm and humid). The analysis has been done to understand the cost variation between conventional and ECSBC building, their effect on HVAC requirements and building envelope selection. Autodesk Revit (BIM) software is used for the analysis of building models.

4.1 Comparison between conventional and energy efficient building

The present study is based on the standards for energy-efficient buildings that have been set by ECSBC and a comparison between envelope material for super ECSBC building and conventional building has been made. The building is considered for a hot and humid geographical area i.e. Mumbai, India. This study focuses majorly on the building envelope of energy-efficient and conventional buildings. The major concern is to cater to the building by minimizing the cooling load using different low U-value materials. The materials for conventional buildings are adopted from the general practice; for energy efficient buildings super ECSBC guidelines are being followed.

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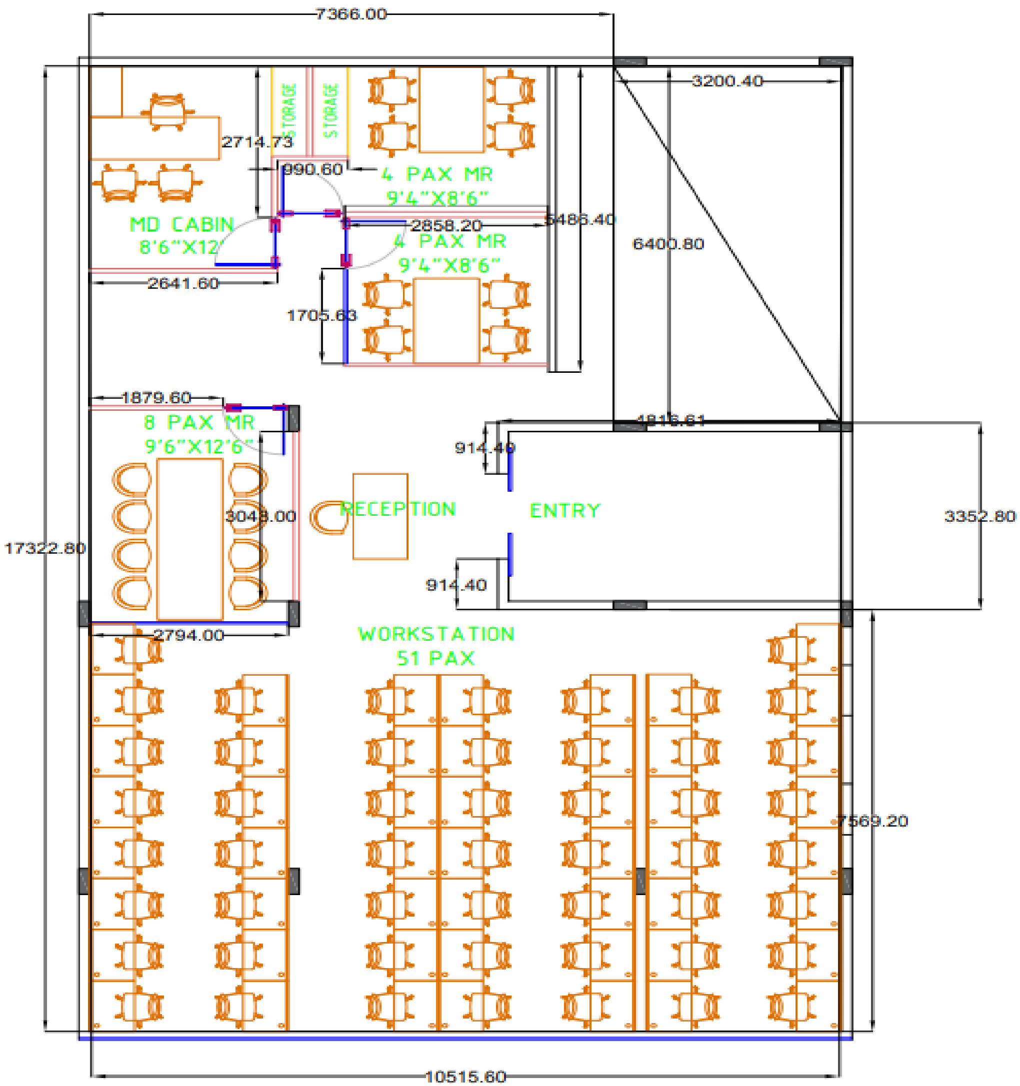
Figure 1: Building Layout



Source: Compiled by author

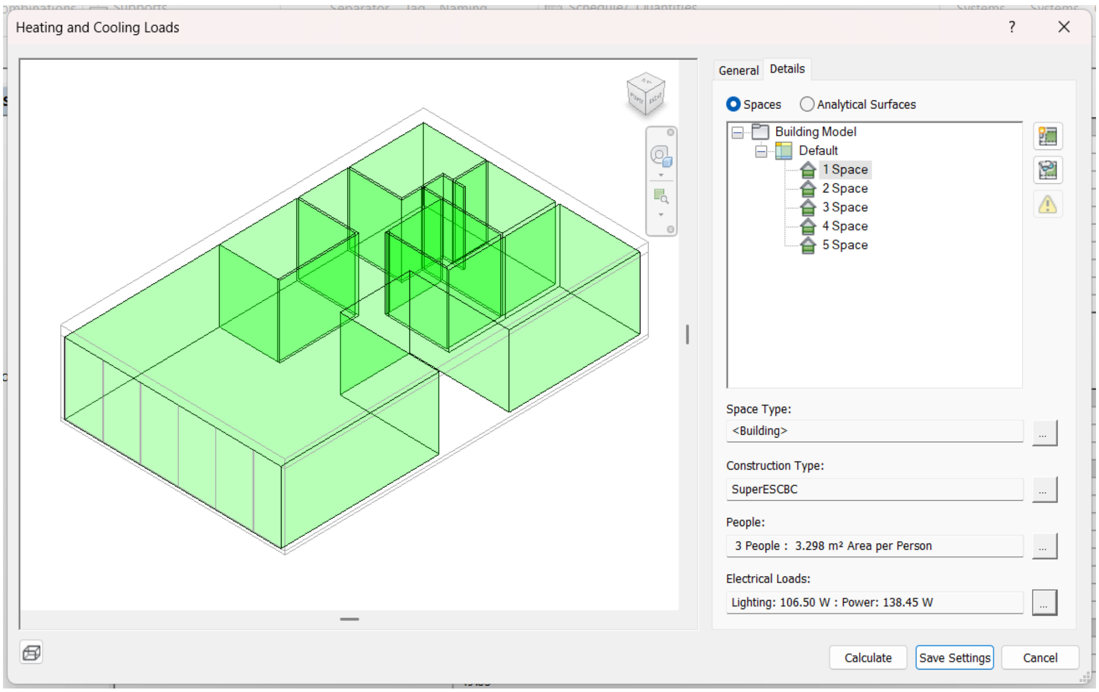
4.2 Load calculation

We utilized the appropriate software, Revit, and followed the necessary steps to perform the load calculation. Below are the materials that can be used for the envelope of both kinds of buildings and their respective U-values which will help to identify the best-suited material for the construction.

Table 1: Thermal Properties of Building Materials

Category	Conventional	Scenario1 (ECSBC)	Scenario2	Scenario3
Heat transfer coefficient value for roof, W/m^2K	2.54	0.17	0.17	0.17
Heat transfer coefficient value for wall, W/m^2K	2.08	0.18	0.4	0.7
Heat transfer coefficient value for glass, W/m^2K	3.76	1.4	1.4	1.4
Solar Heat Gain Coefficient for glass	0.86	0.26	0.26	0.26

Figure 2: Heating & Cooling Load Calculation Dialogue Box in Revit



Source: compiled by author

For the simulation of HVAC load in Revit, the materials with low U-value that ranges between Super ESCBC standards are selected for the energy-compliant building, and materials with higher U-values are selected for conventional buildings. The materials were selected based on the availability in the market and the software. Heat gain for a building depends on the material of the envelope. Lower U-value materials are advised to reduce the HVAC load. Using Autodesk Revit software building model is simulated to get a better understanding of variations in the HVAC load of conventional and energy-efficient buildings.

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Table 2: Load Calculation Assumption

Occupant	71
Sensible gain (W)	73.27
Latent gain (W)	58.61
Equipment load (W/m^2)	13.99
Lighting load (W/m^2)	10.76

5.0 Data Analysis and Findings

A single-story building located in Mumbai, India to analyze and compare the envelope costs of two building types: a conventional building and an energy-compliant building. The comparison will be conducted concerning their respective energy consumption profiles, that is, HVAC power requirements as well as initial construction costs.

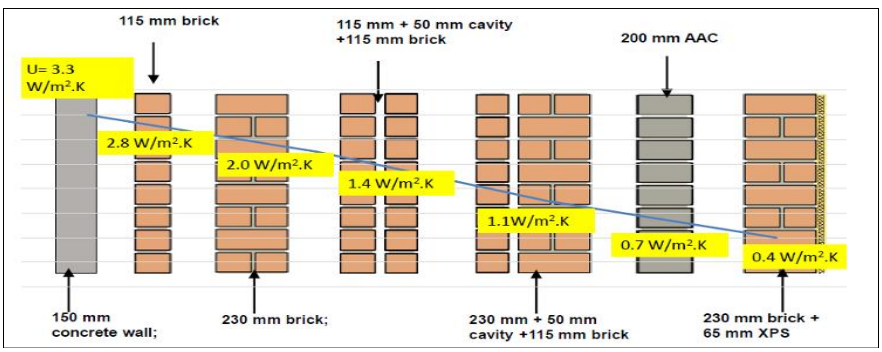
5.1 Conventional and energy-efficient building material u-value and BOQ comparison

Building Type: Office; Location: Mumbai, India; Area: 164 m^2; Volume: 550.93 m^3

Table 3: Comparison of load calculation

	Conventional Building	Energy Efficient Building Scenario 1(ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2(Conventional Brick with 65mm XPS)	Energy Efficient Building Scenario 3(ACC Block)
Total Load(W)	52,510	36,285	37,633	39,067
Sensible Load(W)	41,765	26,807	28,155	29,589
Latent Load(W)	10,745	9,478	9,478	9,478
Airflow(L/s)	3,004.50	1,808.80	1,910.70	2,019.10
Heating Load(W)	5,780	1,704	1,920	2,213
Heating Airflow(L/s)	317.6	217.6	217.6	217.6

Figure 3: U value of Building Materials used in Study



Source: https://beepindia.org

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5.2 Assumption

Unitary air conditioning cost = 35,118 INR per TR (as per Market Studies).

5.3 Comparison of building envelope cost

Major cost components are brickwork, concreting and insulation work.

Table 4: Comparison between the Cost of Building Envelopes for Different Scenario

Scenario	Conventional Building	Energy Efficient Building Scenario 1 (ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2 (Conventional Brick with 65mm XPS insulation)	Energy Efficient Building Scenario 3 (ACC Block)
Construction Cost (INR)	9,20,976	12,78,193	13,39,905	11,80,993

5.4 Comparison of AC cost

Table 5: Comparison of Cost of Air Conditioning

Scenario	Conventional Building	Energy Efficient Building Scenario 1(ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2 (Conventional Brick with 65mm XPS insulation)	Energy Efficient Building Scenario 3 (ACC Block)
AC Cost (INR)	5,24,312	3,62,067	3,75,763	3,90,108

5.5 Variation in initial and AC cost

Table 6: Variation in Cost for Different Scenario

Scenario	Energy Efficient Building Scenario 1(ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2 (Conventional Brick with 65mm XPS insulation)	Energy Efficient Building Scenario 3 (ACC Block)
Total Initial Cost (Conventional building) (INR)	14,45,288	14,45,288	14,45,288
Total Initial Cost (Energy Efficient building) (INR)	16,40,260	17,15,668	15,71,101
Percentage Variation	13.49% Higher	18.7% Higher	8.705% Higher

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6.0 Conclusion, Limitations and Recommendations

The key objectives associated with energy-compliant building are addressed by looking into the tools and techniques applied and estimating the project cost. The study emphasized the significance of following standards like the Energy Conservation and Sustainable Building Code (ECSBC) and Super ECSBC, which are essential for reducing energy consumption and encouraging sustainability. It pointed out the use of advanced tools such as Building Information Modeling (BIM) for simulating building performance and estimating life cycle costs, alongside methodologies like Case-Based Reasoning (CBR) and Work Breakdown Structure (WBS) for cost optimization. The cost analysis showed us that while energy-efficient buildings have higher initial construction costs, they provide long-term savings in operational and maintenance expenses, especially in HVAC systems. By using low U-value materials and advanced insulation, these buildings reduce cooling loads, showing economic viability over their lifecycle.

The research also highlighted the variation in initial and HVAC system costs, emphasizing the importance of choosing energy-efficient materials due to their lower HVAC operation and maintenance costs. It showed that energy-compliant buildings have reduced operational costs in the long run and that the comparative load between energy-compliant and conventional buildings increases with building area. The correct selection of energy-efficient materials was found to have a prominent impact on HVAC load. Moreover, the study tried to bridge the gap between BIM technology and end-users, providing insights that can facilitate more decision-making in sustainable construction projects. Overall, the research provides a compelling case for adopting energy-compliant building practices, offering a framework for sustainable and economically efficient construction projects.

6.1 Limitation

Challenges associated with the green building are as follows:

- The cost of energy-efficient buildings will be reduced with the availability of energy efficient materials locally.
- The amount of carpet area plays a significant role in total savings and this study have been conducted on a small carpet area.

6.2 Recommendations

Creation of Open-Source Modules to find the complete project cost for small to medium size projects which can be used by owners to make a preliminary decision. The use of locally found materials should be encouraged to reduce costs. The energy complaint building should be designed to fulfil the requirements of green building standards in order to attain its desired certification.

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