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ENERGY EFFICIENCY PROCESS IMPROVEMENT IN THE INDIAN REAL ESTATE INDUSTRY

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Abstract. This study addresses the significant environmental impact of the rapidly expanding Indian real estate sector by examining energy efficiency practices through building information modelling (BIM) simulations. Employing a mixed-method approach, the research combines qualitative data from reputable literature sources and quantitative data collected via a questionnaire survey, chosen for its practicality and effectiveness in reaching a large sample size. The statistical approach involves factor analysis, utilizing the Kaiser–Meyer–Olkin (KMO) test and principal component analysis (PCA) to explore underlying data structures and identify key variables. Findings highlight the importance of boosting BIM adoption, customizing energy efficiency measures to local contexts, fostering industry collaboration, implementing monitoring mechanisms, and investing in research and development. These recommendations aim to guide industry stakeholders, policymakers, and researchers in promoting sustainable development and enhancing energy efficiency in the Indian real estate market.

Keywords: *BIM, real estate, energy efficiency, energy modelling, sustainable development, India.*

INTRODUCTION

The real estate business is a powerful force in the world economy, influencing economic trends and metropolitan landscapes on a scale that few other industries can match. Its broad, far-reaching effect is crucial to financial expansion and development, shaping residential and commercial spaces and determining the architectural fabric of whole cities (Sonar & Patil, 2023; Anindita et al., 2022). Nevertheless, there is a significant downside to this dominance: the industry's enormous energy use and major contribution to environmental damage (Naeem et al., 2020; JaiSai et al., 2022). As the main component of the real estate industry, buildings are responsible for 36 % of the world's energy use and greenhouse gas (GHG) emissions. Between 1995 and 2015, the indirect GHG emissions from buildings and industry increased by 78 % and 84 %, respectively (Hertwich & Wood, 2018). These two sectors accounted for most of the growth in indirect GHG, which was concentrated in developing nations. This grim reality emphasizes how urgently creative solutions to maximize energy performance in the real estate industry are needed.

The real estate sector in India plays a crucial role in the nation's economic structure (Kumar et al., 2018). India's growing middle class, increasing urbanization, and growing population have all contributed to a strong demand for housing, infrastructure, and corporate space. But this quick growth has come with a lot of difficulties, the most significant of which is the industry's growing consumption of energy and environmental effects. India's diverse climate, which ranges from the intense heat of the desert to the deluges of the monsoon, makes it necessary to use context-sensitive techniques for tackling sustainability issues in the built environment (Zaki, 2021).

Despite advancements, there remains a significant gap in fully utilizing BIM-based simulations for energy efficiency in the Indian real estate industry (Chan et al., 2019; Altohami et al., 2021). Current research often overlooks India's unique opportunities and constraints, resulting in suboptimal outcomes and missed chances for sustainable development. This study examines the intersection of BIM and energy optimization in India's real estate sector, aiming to identify best practices through empirical analysis and stakeholder discussions (Azhar et al., 2015). The findings have global implications for sustainable building design and management. The study aims to provide stakeholders with the knowledge and tools to navigate the complexities of real estate, energy, and sustainability using BIM and advanced simulation methodologies. To evaluate and highlight key factors affecting energy efficiency practices, the study set the following objectives. Conduct a thorough literature review to identify key variables related to energy-efficient practices in the Indian real estate sector, including BIM parameters, energy consumption factors, and current standards.

- Gather information from Indian industry stakeholders on their understanding and use of BIM, energy efficiency standards, and barriers to BIM implementation.
- Apply factor analysis to the collected data to identify underlying factors significantly impacting BIM-based energy efficiency practices in Indian real estate.
- Present factor analysis findings, highlighting key variables influencing BIM-based energy efficiency and providing actionable recommendations.

1. LITERATURE REVIEW

1.1. Definitions and Importance of Energy Efficiency (EE)

The concept of energy efficiency (EE) is seen as a critical element in attaining sustainability. This is mostly accomplished by optimizing the use of energy-efficient resources and reducing the production of waste. In addition to fulfilling long-term goals, EE tries to provide people with comfort, boost productivity, and secure a nation's economic progress. These might be accomplished using existing sophisticated technology, methods, and strategies. There is no general definition of

EE because it might vary for each industry. For example, in the process sector, EE refers to energy conservation and consumption reduction as assessed by energy usage in the entire system (Na et al., 2021). EE in smart manufacturing improves resource utilization efficiency and ensures efficient job allocation for long-term energy optimization (Wu et al., 2018). Furthermore, EE in construction implies consuming less energy for the same amount of work, which reduces greenhouse gas emissions, global warming, and reliance on fossil fuels. However, the goal of the EE is limited to a single domain, allowing for EE in just one approach. Malinauskaitė et al. (2020) describe energy efficiency (EE) as lowering emissions, improving energy security, increasing competitiveness, and making energy usage more affordable for everybody.

The notion of EE dates to the oldest civilizations when human ingenuity resulted in the creation of primitive procedures aimed at optimizing the use of energy resources. These ancient cultures used techniques such as plant-based insulation in their homes, optimal kitchen stove design, and animal power for a variety of chores. However, EE was first thoroughly investigated during the Industrial Revolution of the 18th and 19th centuries. The broad adoption of electricity and the proliferation of electric appliances over the twentieth century resulted in considerable improvements in electrical efficiency (Petralia, 2020). This period witnessed the advancement of improved motors, transformers, and lighting systems, eventually leading to the broad adoption of compact fluorescent lights (CFLs) and, subsequently, light-emitting diodes (LEDs) (Weisbuch, 2018; Guarnieri, 2018; Hurley et al., 2018). Furthermore, the energy crises of the 1970s, caused by geopolitical wars and oil embargoes, elevated EE to the forefront of global awareness. Governments reacted with measures to encourage EE, such as appliance efficiency regulations, building rules, and research programs to produce energy-saving technology. Building efficiency enhancements included greater insulation, energy-efficient cooling and heating systems, passive solar architecture, and the incorporation of smart building (SB) technology (Weerakoon et al., 2023). Smart meters, energy management systems (EMS), and devices with internet access enable consumers and companies to maximize EE and waste reduction (Lange et al., 2020; Benavente-Peces, 2019). Moving forward, achieving EE will need coordinated efforts to remove impediments, develop innovation, and encourage behavioural change.

1.2. Energy Performance in the European Union (EU) and Worldwide

Residential, commercial, and industrial real estate significantly impact the environment through energy usage, greenhouse gas emissions, and resource depletion (Mondal et al., 2021; JaiSai et al., 2022). Globally, buildings are major contributors to energy consumption and emissions, influenced by operations, lighting, heating, cooling, and material production (Aliero et al., 2021). To meet sustainability goals and reduce environmental impact, the real estate industry must reduce energy use and emissions. Energy-efficient construction, retrofitting with energy-saving technologies, and renewable energy adoption can lower the sector's carbon footprint (Ali et al., 2020; Nematchoua et al., 2021; Pauliuk et al., 2021).

Regulations, incentives, and sustainability certifications are crucial for promoting and rewarding sustainable practices (Song et al., 2022; De Melo, 2023). According to Zhong et al. (2021), implementing these techniques could halve real estate emissions by 2060, but to meet the 1.5 °C target, emissions reductions must triple. The European Environment Agency (2023) projects a 1.5 % decrease in the EU's final energy consumption (FEC) in 2022 compared to 2021, with primary energy consumption (PEC) dropping by 4 %. Despite these improvements, achieving the 2030 goals requires more rapid and decisive action to cut energy use.

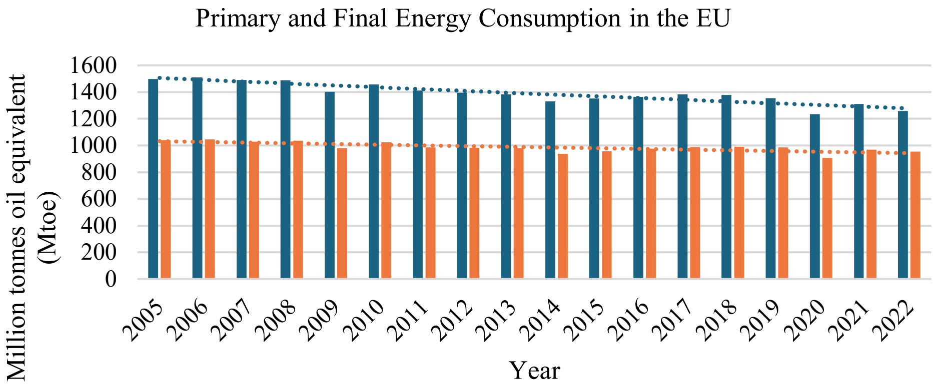

Fig. 1.1. PEC and FEC in the EU from 2005 to 2022 (EEA, 2023).

Figure 1.1 shows a comprehensive time series of EE advances in Europe since 2005, with overall reductions being more significant for primary (–16 %) than for final energy consumption (–8 %). The substitution of fossil fuels and nuclear energy by renewables in electricity generation often decreases PEC while not impacting FEC, and the EU's renewable energy share has more than quadrupled since 2005.

1.3. Energy Performance in India

The Indian real estate sector faces critical challenges in energy usage and efficiency as urbanization and industrialization accelerate, leading to a significant rise in energy consumption with environmental and economic consequences. Despite India's relatively low per capita energy consumption compared to developed countries, it has increased significantly in recent years due to urbanization and improved living standards (see Fig. 1.2).

India's energy landscape has changed dramatically because of rising energy output to satisfy rising demand brought on by population, urbanization, and economic expansion. Although coal and oil continue to dominate the energy mix, government initiatives such as the National Solar Mission have supported clean energy sources including wind and solar power. Policies encouraging environmentally friendly energy use in the real estate industry can benefit greatly from monitoring annual patterns of energy generation (see Fig. 1.3).

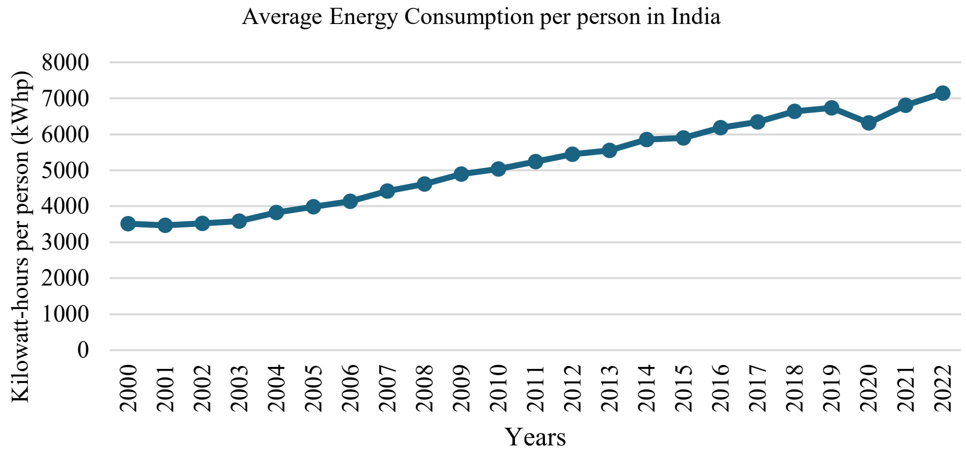

Fig. 1.2. Average energy consumption per person in India 2000–2022 (Ritchie et al., 2022).

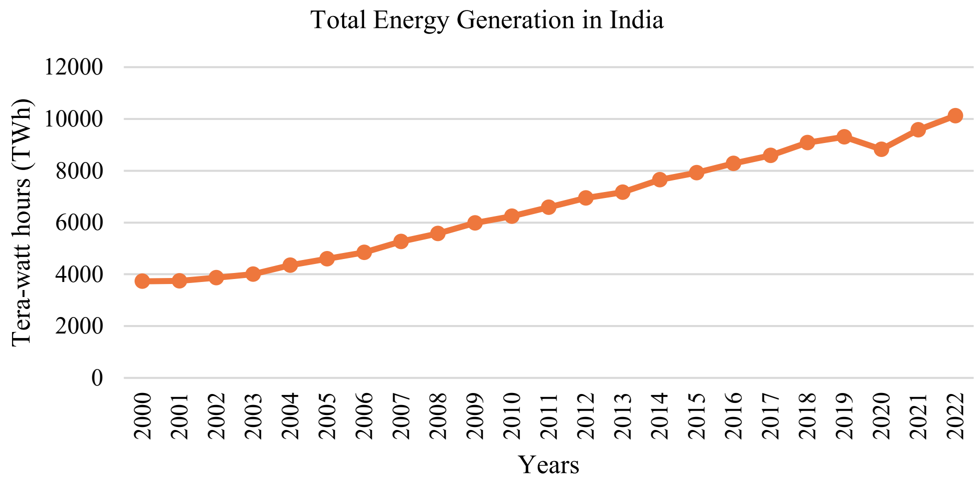

Fig. 1.3. Total energy generation in India 2000–2022 (Ritchie et al., 2022).

To mitigate the negative effects on the environment and the economy caused by increased energy consumption because of urbanization and rising living standards, the Indian real estate industry must adopt energy-efficient techniques.

2. RESEARCH METHODOLOGY

The research concludes with an exploratory investigation, a praiseworthy method for gathering high-quality data. The Indian construction industry takes a methodical approach to examining the elements that influence EE practices. This technique relies mostly on statistical methods of analysis. Figure 2.1 shows a potential approach framework.

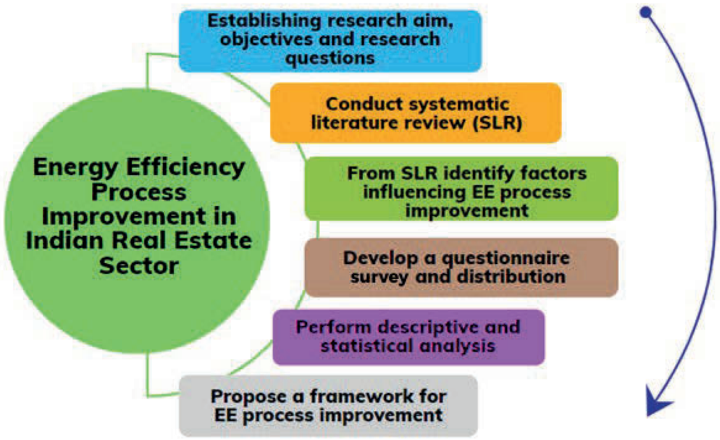

Fig. 2.1. Methodical framework followed in research design (developed by the author).

This study investigates energy efficiency (EE) process enhancements in the Indian real estate sector utilizing a quantitative research methodology and a questionnaire survey. Selected because of its feasibility and effectiveness in obtaining a substantial sample size, the survey tackles logistical and geographic obstacles in India. The three elements of the questionnaire are as follows: The first section collects demographic data, such as occupation status, industry experience, and region of residence or employment, offering an understanding of the varied backgrounds of the respondents. The second portion emphasizes the use of BIM to identify important drivers and barriers and focuses on the opinions of participants on variables influencing EE practices. The last portion looks at the state of BIM adoption in India today and the obstacles it faces, as well as how it might help EE initiatives. The goal of this all-inclusive strategy is to compile a variety of perspectives and experiences to guide EE process enhancements within the Indian real estate industry.

2.1. Statistical Methodology

Factor analysis was used as a statistical tool to investigate the underlying structure of the data acquired through the questionnaire survey in this study. Factor analysis is a multivariate statistical tool that identifies underlying correlations between variables. It seeks to minimize data dimensionality by identifying common elements that explain correlations between observable variables. In this study, two main statistical tests were undertaken to examine the adequacy of the data for component analysis and the number of factors to be extracted: the Kaiser–Meyer–Olkin (KMO) test and the principal component analysis (PCA).

Kaiser–Meyer–Olkin (KMO) Test: The KMO test is a sample adequacy metric that assesses the amount of variation between variables that may be common. It evaluates the correlation matrix's suitability for component analysis by analysing the strength of correlations between variables. The KMO statistic ranges from 0 to

1, with values nearer to 1 suggesting a greater fit for factor analysis. The mathematical formula for the KMO test is as follows:

$$KMO = \frac{\sum_i \left(\sum_j r_{ij}^2\right)^2}{\sum_i \sum_j r_{ij}^2 + \sum_i \sum_j \sum_{j \neq k} r_{ij}^2},$$

where r_{ij} represents the correlations between variables i and j.

In this study, the KMO test was used to determine if the data accurately measured the structures of interest associated with EE strategies in the Indian real estate sector.

Principle Component Analysis (PCA): PCA is a dimensionality reduction approach that turns the original variables into a new set of orthogonal variables known as principal components. These components contain the most volatility in the data while reducing information loss. The component matrix and rotated component matrix generated by PCA offer information about the variable loadings on each component, making interpretation easier. The component matrix shows the correlation coefficients between the original variables and their derived components. It assists in determining which factors are most closely related to each component. Consider $\mathbf{X}$ to be a $n \times p$ data matrix, where n represents the number of observations and p indicates the number of variables. The first step in PCA is to centre the data by removing the mean of each variable. The centred data matrix is represented as $\mathbf{S}$.

$$\mathbf{S} = \frac{\mathbf{X}^{\mathrm{T}}\mathbf{X}}{n-1},$$

where $\mathbf{X}^{\mathbf{T}}$ is the transpose of $\mathbf{X}$.

The covariance matrix's eigenvectors and eigenvalues are then determined. The eigenvectors indicate the data's highest variability directions, whilst the eigenvalues show the amount of variability explained by each eigenvector. In the context of the research, PCA was used to discover crucial success criteria for managing building projects in India. By reducing a large number of variables to a smaller collection of relevant components, PCA can aid in identifying underlying patterns or correlations between variables, as well as providing insights for optimizing project management procedures in India's construction business.

After performing factor analysis on the results of the survey, the scree plot can be used to decide the number of factors to retain. The mathematical formulation of the scree plot can assist in determining when adding more features does not significantly increase the model's explanatory power. This will help to pick the important success criteria for managing construction projects.

3. RESEARCH FINDINGS

3.1. Descriptive Analysis of the Results

The results of the research provide a complete overview of the EE environment in the Indian real estate market based on a thorough evaluation of survey responses from a varied range of industry specialists. From engineers and real estate developers to designers, architects, and government officials, each stakeholder's perspective offers a comprehensive understanding of current practices, difficulties, and potential for enhancing EE processes.

The study explored the Indian real estate industry's engagement with energy efficiency (EE) practices by examining respondents' professional backgrounds (see Fig. 3.1). Engineers (43.1 %) were the largest group, underscoring their role in energy-saving programs. Real estate developers (30.5 %) and designers/architects (11.2 %) showed significant involvement, reflecting a shift towards sustainable practices. Facility managers (6.7 %) contributed insights on operational aspects, while government personnel (4.1 %) highlighted the importance of policy and regulation. Additionally, 4.4 % of respondents were students and educators, indicating broader social interest in EE issues. This diverse composition provides a comprehensive view of EE practices in the Indian real estate sector, showcasing the collaborative efforts of various stakeholders in promoting sustainable development.

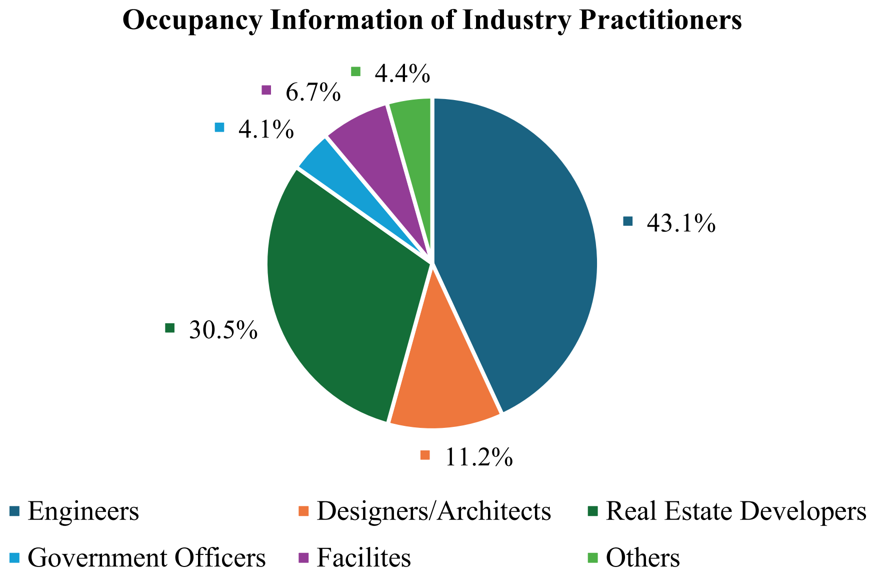

Fig. 3.1. Respondents' occupancy information (developed by the author).

The survey examined respondents' experience levels in the Indian real estate sector (see Fig. 3.2). Most respondents had 5–10 years of experience (38.8 %), indicating many mid-career professionals with extensive knowledge. Additionally, 31.9 % had 1–5 years of experience, reflecting a substantial number of recent entrants bringing fresh ideas. Newcomers with less than one year of experience made up 18.1 %. Those with 10–15 years of experience accounted for 9.5 %, representing seasoned experts, while only 1.7 % had more than 15 years, offering valuable historical context. This range of experiences highlights the diverse perspectives influencing EE practices in the sector.

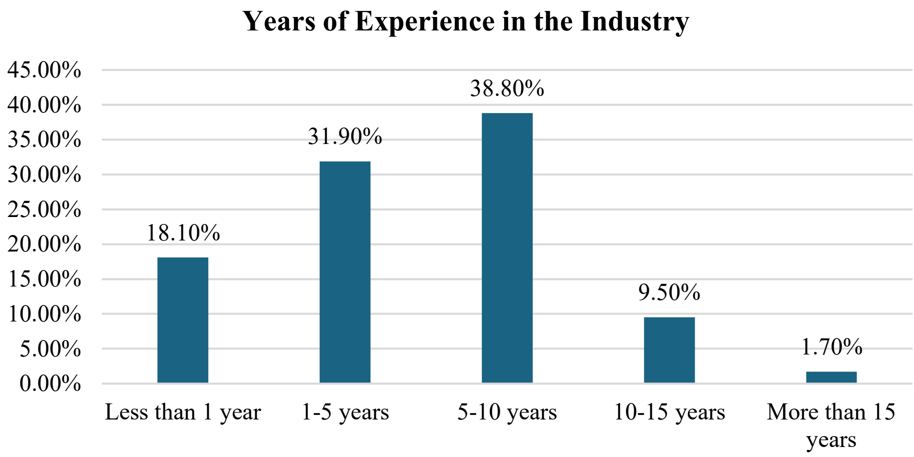

Fig. 3.2. Responders' years of experience in the real estate sector (developed by the author).

The study analysed the geographic distribution of respondents in the Indian real estate industry to understand regional influences on energy efficiency (EE) practices (see Fig. 3.3). Results showed a balanced representation: 54.6 % were from South India and 45.4 % from North India. This highlights the national significance of EE issues, with professionals from both regions working to promote sustainable development. The high response rate from South India suggests that many EE projects in Karnataka, Tamil Nadu, and Kerala are influenced by local infrastructure, laws, and market conditions. Respondents from North India, including Delhi, Uttar Pradesh, and Rajasthan provided insights into regional challenges like urbanization, climate change, and policy implementation.

The survey examined the use of BIM technology in the Indian real estate sector and found that 61.2 % of respondents use it, showing widespread adoption to enhance project efficiency, collaboration, and decision-making. This aligns with global trends in digital transformation in construction. However, 38.8 % of respondents do not use BIM, indicating an implementation gap likely due to cost, lack of knowledge, or perceived challenges. The survey highlights the importance of promoting wider BIM adoption to maximize digitalization benefits in the industry (See Fig. 3.4).

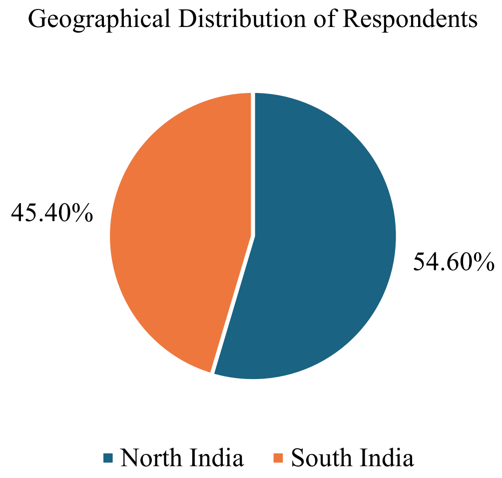

Fig. 3.3. Geographical distribution of survey participants (developed by the author).

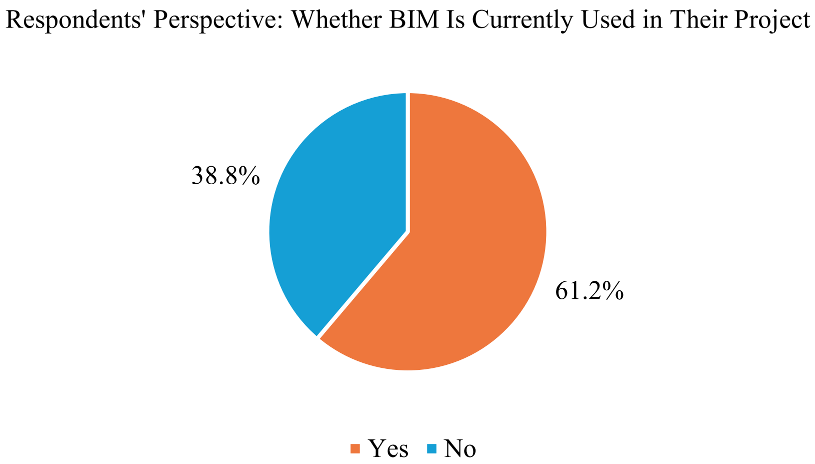

Fig. 3.4. Survey participants' perspectives on current BIM usage in India (developed by the author).

The survey assessed BIM's effectiveness in enhancing energy efficiency (EE) among users (see Fig. 3.5). A majority (60.4 %) found BIM "very effective" for EE, highlighting its role in supporting energy-efficient design and analysis. Additionally, 26.4 % considered it "somewhat effective," acknowledging its benefits while noting areas for improvement. A smaller group (11 %) remained neutral, showing some uncertainty about BIM's impact. Only 2.2 % found BIM "ineffective," indicating potential challenges but also the need to address these issues to fully leverage BIM for sustainable development. Notably, no respondents rated BIM as "very ineffective," suggesting overall positive recognition of BIM's contribution to EE in real estate projects.

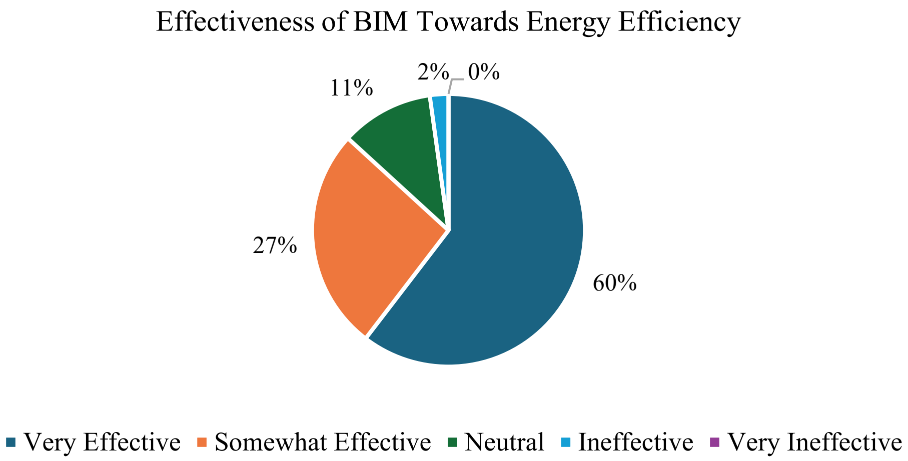

Fig. 3.5. Respondents' views on effectiveness of BIM towards EE (developed by the author).

The varied perspectives on BIM's impact on energy efficiency (EE) practices highlight its complex role in advancing sustainability goals (see Fig. 3.6).

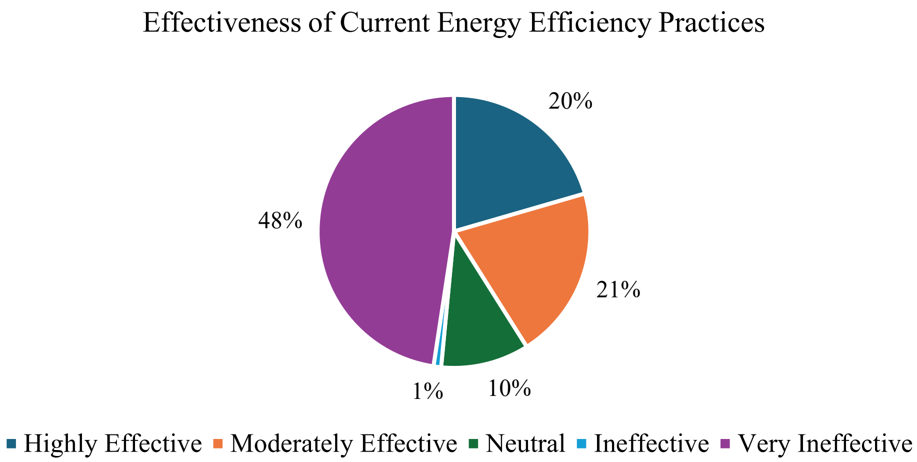

Fig. 3.6. Perspectives on effectiveness of current EE practices (developed by the author).

Survey responses about the effectiveness of current EE measures in South and North India showed a balanced view: 38.8 % found these measures "highly effective," and another 38.8 % found them "moderately effective," indicating confidence in their impact while acknowledging areas for improvement. Additionally, 19.8 % were neutral, reflecting uncertainty and the complexity of EE challenges. Only a small minority (1.7 % and 0.9 %) rated current EE initiatives as "ineffective" or "very ineffective," pointing to gaps needing further study and targeted solutions.

The assessments underscore the need for continuous monitoring and adaptation of energy efficiency (EE) techniques in India to meet sustainability goals across diverse buildings and locations. A survey showed that 76.7 % of respondents find standard rating techniques like BREEAM and LEED effective, though 23.3 % highlighted the need for contextual adaptation. Respondents' insights on aligning these systems with local goals include a 20–25 % reduction in energy intensity by 2030 (44.3 %), meeting the ECBC's 30–50 % energy use reduction target (52.6 %), incorporating 20 % renewable energy by 2030 (22.7 %), achieving a 10 % energy usage reduction across sectors (13.4 %), and linking sustainable growth to a $ 5 trillion GDP by 2025 (16.5 %).

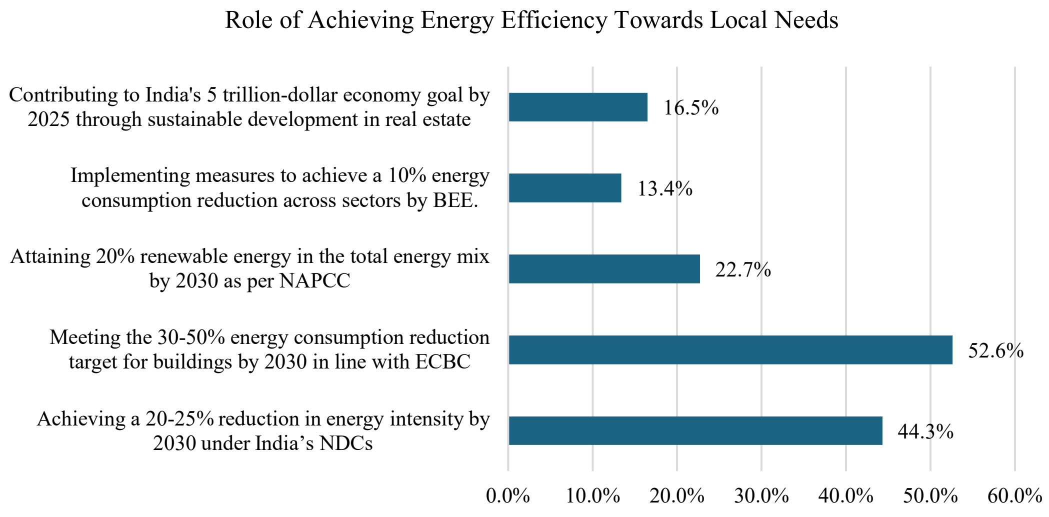

Fig. 3.7. Role of achieving EE towards local needs (developed by the author).

The real estate industry can significantly advance India's energy efficiency and sustainability targets by using established frameworks like BREEAM and LEED, benefiting both the environment and the economy.

3.2. Factor Analysis for Energy Efficiency Process Improvement

This study aims to assess key factors impacting energy efficiency (EE) practices in the Indian real estate market using BIM simulations. Utilizing SPSS Version 27 for comprehensive factor analysis, it explores the interactions influencing EE applications. The goal is to provide insights into the diverse nature of EE in the Indian real estate market, contributing to environmentally conscious practices. Table 3.1 summarizes descriptive data on the perceived relevance and efficacy of various EE factors, showing mean scores, standard deviations, and the analytical sample size (N).

Table 3.1. Descriptive Statistics (developed by the author based on SPSS results)

Descriptive statistics			
	Mean	**Std. deviation**	**Analysis *N***
Building orientation and layout	4.46	0.651	116
Building envelop insulation and material selection	4.43	0.563	116
Energy-efficient HVAC systems	4.33	0.707	116
Efficient window placement and glazing	4.31	0.751	116
BIM and other software tools	4.13	0.808	116
Smart building techniques	4.30	0.749	116
Advanced energy modelling	4.28	0.680	116
Building energy codes	4.33	0.766	116
Government policies	4.10	0.817	116
Incentives or mandates	4.19	0.745	116
Capital investment and LCA	4.27	0.651	116
Favourable ROI	4.17	0.794	116
Cost-effective technologies	4.14	0.721	116
Incentive facilities and flexible financing	4.22	0.747	116
Training and capacity building	4.34	0.661	116
Regular maintenance	4.41	0.699	116
Monitoring and feedback mechanism	4.32	0.741	116

Respondents highly value key factors for enhancing energy efficiency, with “Building orientation and layout” and “Building envelope insulation and material selection” receiving top ratings (4.46 and 4.43). Other important criteria include “Energy-efficient HVAC systems,” “Efficient window placement and glazing,” and “Building energy codes,” all rated above 4.3. “BIM and other software tools” and “Government policies” received lower ratings (4.13 and 4.10) but showed greater variability in perceptions. Financial and capacity-building aspects like “Incentives or mandates,” “Capital investment and LCA,” and “Training and capacity building” were rated above 4.0, highlighting their varied but significant role in energy-efficient initiatives.

Table 3.2 shows the results of the Bartlett and Kaiser–Meyer–Olkin (KMO) tests. The Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of sphericity indicate the dataset's suitability for factor analysis. The KMO value of 0.917, well above the 0.5 criterion, suggests a high degree of shared variance among variables, favourable for component analysis. Additionally, Bartlett’s sphericity test yields a significant result, with a chi-square value of 1094.831 and a p-value of 0.000, indicating that the correlation matrix significantly differs from an identity matrix and that linkages between variables are appropriate for factor analysis.

Table 3.2. Sample Adequacy Test (developed by the author based on SPSS results)

KMO and Bartlett's test		
Kaiser–Meyer–Olkin measure of sampling adequacy		0.917
Bartlett's test of sphericity	Approx. chi-square	1094.831
	df	136
	Sig.	0.000

Together, these findings give empirical evidence to support the propriety of doing factor analysis on the dataset. Table 3.3 shows the total variance explained by the PCA performed on the dataset. The table displays the starting eigenvalues and rotation sums of squared loadings for each component, as well as the per cent of variance and cumulative percentage explained by each component.

Table 3.3. Total Variance Explained (developed by the author based on SPSS results)

Total variance explained						
Component	**Initial eigenvalues**			**Rotation sums of squared loadings**		
	Total	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**
1	8.457	49.748	49.748	3.937	23.159	23.159
2	1.214	7.142	56.890	3.501	20.592	43.750
3	1.005	5.909	62.799	3.238	19.049	62.799
4	0.825	4.850	67.650			
5	0.727	4.276	71.926			
6	0.628	3.696	75.622			
7	0.603	3.548	79.170			
8	0.546	3.212	82.382			
9	0.488	2.872	85.254			
10	0.455	2.674	87.928			
11	0.400	2.351	90.279			
12	0.388	2.282	92.561			
13	0.307	1.806	94.367			
14	0.288	1.693	96.060			
15	0.269	1.581	97.641			
16	0.224	1.318	98.959			
17	0.177	1.041	100.000			
Extraction method: Principal component analysis.						

The PCA reveals that the first component, with an eigenvalue of 8.457, accounts for 49.748 % of the total variance, highlighting a key underlying dimension in energy efficiency techniques in the Indian real estate sector. The second and third components, with eigenvalues of 1.214 and 1.005, contribute

7.142 % and 5.909 % of the variance, respectively, totalling 62.799 %. Together, the first three components capture a significant portion of the dataset's structure. The variation explained by each successive component decreases, with the first seven components accounting for about 79.170 % of the total variance overall. The PCA provides valuable insights into the underlying dimensions driving the observed heterogeneity in EE methods, offering a basis for further analysis for industry stakeholders.

In addition, Fig. 3.8 illustrates the scree plot obtained from the factor analysis.

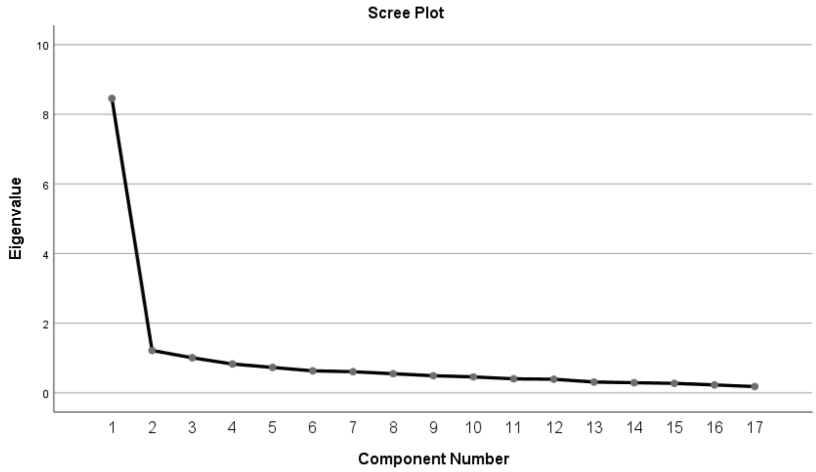

Fig. 3.8. Scree plot (developed by the author based on SPSS results).

Table 3.5 displays the component matrix computed from the dataset.

The rotated component matrix illustrates the relationships between original variables and rotated components, enhancing the understanding of underlying dimensions revealed by PCA. Using varimax rotation with Kaiser normalization, the analysis shows the correlation coefficients between variables and components. Higher coefficients indicate stronger links, highlighting variables' contributions. The matrix reveals that variables are primarily associated with specific components, indicating distinct dimensions of EE practices in the Indian real estate market. For example, "Incentives and mandates" and "Favourable ROI" correlate strongly with the first component, suggesting a financial dimension, while "Cost-effective technologies" aligns with the second component, indicating cost-effectiveness. "Monitoring and feedback mechanism" and "Regular maintenance" correlate with the third component, linked to operational practices. These insights help in understanding the diverse nature of EE measures and form the basis for targeted strategies to promote sustainability in the sector.

A thorough examination of descriptive statistics, sampling adequacy tests, PCA, and component matrices reveals key insights into EE procedures in the Indian real estate sector. Descriptive statistics highlight the relevance of factors like building design, government laws, and financial incentives in promoting EE projects. Positive KMO and Bartlett's sphericity test results confirm the dataset's suitability for factor analysis. PCA identifies multiple dimensions influencing EE practices, while the rotated component matrix clarifies relationships between variables and components. Overall, these findings provide a detailed understanding of factors driving EE practices and support targeted interventions for sustainability in Indian real estate.

Table 3.5. Rotated Component Matrix (developed by the author based on SPSS results)

Rotated component matrix			
	Component		
	1	**2**	**3**
Building orientation and layout	0.238	0.762	0.070
Building envelop insulation and material selection	0.143	0.684	0.288
Energy-efficient HVAC systems	0.331	0.761	0.105
Efficient window placement and glazing	0.151	0.603	0.435
BIM and other software tools	0.302	0.509	0.407
Smart building techniques	0.237	0.518	0.535
Advanced energy modelling	0.295	0.251	0.687
Building energy codes	0.445	0.567	0.259
Government policies	0.576	0.107	0.439
Incentives or mandates	0.720	0.333	0.281
Capital investment and LCA	0.589	0.194	0.368
Favourable ROI	0.727	0.364	0.152
Cost-effective technologies	0.792	0.191	0.208
Incentive facilities and flexible financing	0.668	0.379	0.245
Training and capacity building	0.585	0.207	0.514
Regular maintenance	0.279	0.227	0.728
Monitoring and feedback mechanism	0.274	0.175	0.795

CONCLUSIONS

The real estate sector significantly impacts the global economy, metropolitan environments, and economic developments, yet it also contributes substantially to energy consumption and GHG emissions.

In India, the fast-expanding real estate sector faces unique sustainability and EE challenges due to diverse climatic conditions. This study investigates EE techniques using BIM simulations to highlight key factors affecting sustainable growth in the Indian market.

Key findings include the urgent need for innovative solutions to enhance energy performance, a lack of understanding in leveraging BIM-based simulations for EE, and insufficient awareness of India-specific opportunities and constraints, leading to suboptimal outcomes. Through empirical analysis and stakeholder discussions, the study offers best practices and recommendations tailored to the Indian context, with broader implications for global sustainable building design and management. These findings underscore the importance of proactive measures to address EE issues in the Indian real estate sector.

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