ENHANCING ENERGY EFFICIENCY IN EXISTING BUILDINGS WITH BIM-BASED RETROFITTING

FINAL YEAR PROJECT UG 2020

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This thesis is dedicated to our parents.

For their love, support, and prayers throughout our lives.

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ABSTRACT

In Pakistan, buildings account for as much as 50% of overall energy use. Owing to a changing way of life, this consumption keeps rising and exacerbates the energy issue, which not only causes misery for the country but also costs it billions of dollars every year.

Energy-efficient housing has the potential to save approximately thirty percent of energy use, but sadly, Pakistan currently lacks an energy-efficient housing strategy. The goal of this research is to introduce building efficiency energy to Pakistan, as there has been a resurgence of interest in this field worldwide. This project aims to significantly reduce energy use by improving the thermal efficiency of 99 percent of existing buildings, rather than focusing on new construction.

The study leverages Building Information Modeling (BIM) to streamline and optimize the retrofitting process, ensuring precise implementation and monitoring of energy-efficient interventions. BIM facilitates the integration of various building components and systems, enabling detailed analysis and visualization of energy flows and thermal performance. This holistic approach not only enhances the accuracy of energy simulations but also improves decision-making throughout the retrofitting process. By utilizing BIM, the project underscores the potential of technology-driven solutions to address Pakistan's energy crisis, demonstrating that even minor retrofitting measures can yield substantial energy savings and economic benefits. This research advocates for the widespread adoption of BIM-based retrofitting strategies as a viable and sustainable solution for enhancing the energy efficiency of existing buildings in Pakistan.

The approach employed includes basic passive retrofitting methods that are easily accessible to Pakistan's general income quintile population, like double-glazed windows and thermal insulation sheets. A Plaza was selected and the reliable Energy Plus Software was used to simulate the outcomes. A 28.9% yearly reduction in energy usage was made possible by the methodology, which had a 2-year economic payback period. The annual energy saving after retrofitting was around Rs 55 lacs.

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CHAPTER I

INTRODUCTION

1.1 Background

There’s a significant correlation between energy and the economic growth of a country. In the wake of global concerns regarding energy efficiency and sustainability, there is a growing imperative to retrofit existing buildings to enhance their energy performance. This project, titled "Enhancing Energy Efficiency in Existing Buildings with BIM-Based Retrofitting," aims to investigate the profound benefits of retrofitting in existing building design. Through the integration of Building Information Modeling (BIM) principles and practices, the project endeavors to create a new model that fosters energy efficiency and sustainability in retrofitting efforts. The goal is to provide actionable recommendations based on empirical findings to address the pressing challenges in this domain.

1.2 Research Significance

The significance of this research on enhancing energy efficiency in existing buildings through BIM-based retrofitting is profound and multifaceted. Buildings are major consumers of energy, contributing significantly to global carbon emissions. Addressing the inefficiencies within existing structures is crucial for sustainable development and environmental conservation. By leveraging Building Information Modeling (BIM), this project provides a systematic and precise approach to retrofitting, enabling detailed analysis and simulation of energy performance improvements. BIM's capacity for detailed visualization and data management facilitates optimized retrofitting strategies that are tailored to specific building characteristics. This research not only aims to reduce energy consumption and operational costs but also enhances occupant comfort and extends the lifecycle of buildings. Moreover, it contributes to the growing body of knowledge on sustainable architecture and smart building technologies, offering practical insights and methodologies that can be adopted globally. Thus, this study is pivotal in driving the transition towards greener, more energy-efficient urban environments.

1.3 Research Gap

a) **Lack of Case Studies on BIM in Green Retrofitting:** There is a dearth of comprehensive case studies demonstrating the successful application of BIM in green retrofitting. Existing studies either focus solely on new buildings or apply BIM for retrofitting purposes unrelated to energy efficiency, underscoring the need for research in this specific area.

b) **Limited Guidance on BIM-Based Retrofitting Models and Associated Simulation Software:** Despite the growing interest in BIM, there is inadequate guidance in the literature concerning the development of BIM-based retrofitting models tailored to improve energy efficiency.

c) **Insufficient Emphasis on Practical Implementation:** Existing literature often provides high-level insights and recommendations without delving into the practical implementation of BIM-based retrofitting solutions. This gap underscores the need for detailed guidance on translating simulation results into actionable retrofit strategies.

1.3 Problem Statement

Existing buildings constitute a significant portion of the global building stock, many of which were erected prior to the establishment of modern energy efficiency standards. Retrofitting presents a promising opportunity to convert these structures into more sustainable and energy-efficient assets. However, the process is hindered by several critical gaps in existing knowledge and practice.

1.4 Reason for Project Selection

The choice of the project titled 'Enhancing Energy Efficiency in Existing Buildings with BIM-Based Retrofitting' arises from the critical need to tackle sustainability challenges in the built environment. This project aims to unravel the complexities of retrofitting processes, evaluate the effectiveness of BIM-based stimulations, and provide actionable insights for industry professionals. By bridging the gap between theoretical understanding and practical implementation, this research aims to play a key role in advancing sustainable building practices.

1.5 Objectives

The primary objectives of this research project are outlined as follows:

a) **Identify the Benefits of Retrofitting Existing Buildings using BIM:** Through a comprehensive analysis, uncover the multifaceted benefits of retrofitting existing buildings using BIM technology.

b) **Develop a Building Information Modeling (BIM) Model using Retrofitting Principles and Practices:** Create an innovative BIM-based model that integrates retrofitting principles and practices to enhance energy efficiency and sustainability.

c) **Propose Recommendations for Retrofitting Existing Buildings:** Based on empirical findings and simulation results, formulate practical and sustainable recommendations tailored to specific building needs and conditions.

By addressing these objectives, this research project aims to bridge the existing gaps in understanding the benefits of retrofitting in existing building design. The integration of BIM technology and retrofitting principles will provide a robust framework for building professionals and decision-makers to visualize and plan retrofitting projects effectively. Ultimately, the proposed recommendations strive to contribute to a more sustainable and energy-efficient built environment, aligning with key Sustainable Development Goals (SDGs) including

- Affordable and Clean Energy (SDG 7)
- Industry, Innovation, and Infrastructure (SDG 9)
- Sustainable Cities and Communities (SDG 11)

CHAPTER 2

LITERATURE REVIEW

2.1 Retrofitting

Retrofitting is the process of improving or modifying an existing structure to enhance its performance, functionality, or efficiency (Azhar, 2008). This may entail upgrading different elements, such as building systems, materials, or technologies, to align with current standards, regulations, or specific requirements. In the realm of energy efficiency, retrofitting typically focuses on implementing alterations in existing buildings to decrease energy consumption, reduce environmental impact, and improve overall sustainability. Retrofitting initiatives can involve enhancements in insulation, lighting, HVAC (heating, ventilation, and air conditioning) systems, and the incorporation of cutting-edge technologies like Building Information Modeling (BIM) to optimize energy efficiency and overall building performance (Eastman, 2011).

2.2 Key Performance Indicators for Sustainability Assessment

The Key Performance Indicators (KPIs) for sustainability assessment in a building encompass a range of factors, covering energy efficiency, water usage, indoor air quality, waste generation, material selection, transportation impact, biodiversity conservation, social impact, life cycle costing, and carbon footprint (Ghaffarian et al., 2017). Below, detailed explanations and relevant formulas are provided for each:

2.2.1 Energy Efficiency

The assessment of a building's energy performance entails a thorough examination of its efficiency in utilizing energy to meet operational needs. This evaluation encompasses the balance between energy consumption and conservation efforts. Simply put, it examines how efficiently the building uses energy for cooling or heating while minimizing waste (Nielsen and Karlsson, 2018).

The Energy Efficiency Ratio (EER) is a specific formula employed to quantify energy efficiency. It is determined by dividing the cooling output (the amount of cooling the system provides) by the energy input (the amount of energy the system consumes) as shown in Eq. (i). The formula is expressed as:

$$EER = \frac{Cooling\ output}{Energy\ Input} \qquad \text{(i)}$$

A higher EER, calculated using Eq. (i), indicates superior energy efficiency, suggesting that the building achieves more cooling output for a given amount of energy input. This ratio is particularly relevant in context of air conditioning and HVAC systems, where effective cooling is essential for comfort but should be achieved with minimal energy consumption (Reinhart et al., 2006).

To summarize, Energy Efficiency, as measured by the Energy Efficiency Ratio, provides a quantitative assessment of how well a building manages its energy resources for cooling, offering valuable insights into its overall sustainability and environmental impact.

2.2.2 Water Usage

Water Usage is a crucial metric in sustainability evaluations for buildings, focusing on assessing a building's water consumption and its efficiency in utilizing this essential resource. This key performance indicator (KPI) provides insights into how well a building manages its water resources while considering conservation measures.

Essentially, the assessment looks into the volume of water consumed by the building and how efficiently this water is utilized. It involves examining not only the total water usage but also the implemented practices to minimize waste and optimize efficiency, contributing to sustainable water management.

The Water Use Efficiency as shown in Eq. (ii) is a specific formula crafted to quantify the efficiency of a building's water usage concerning its size. The formula is represented as:

$$Water\ Use\ Efficiency\ = \frac{Water\ Used}{Building\ Area} \qquad \text{(ii)}$$

Eq. (ii) calculates the ratio of water used to the total area of the building. A higher Water Use Efficiency value indicates more effective water utilization concerning the building's size, reflecting sustainable water practices. It takes into account not only the absolute water consumption but also the proportional efficiency in using water resources.

In summary, Water Usage, as measured by Water Use Efficiency, provides a quantitative assessment of a building's water management practices, offering valuable insights into its overall sustainability and responsible use of water resources.

2.2.3 Indoor Air Quality (IAQ)

Indoor Air Quality (IAQ) is a critical metric in sustainability assessments, focusing on the evaluation of the quality of air within a building for the health and comfort of its occupants. This key performance indicator (KPI) provides valuable insights into how well a building ensures a healthy and comfortable indoor environment.

The assessment revolves around the measurement of pollutants present in indoor air and their potential impact on the well-being of occupants. It considers various factors such as the concentration of pollutants, ventilation systems, and overall air circulation within the building. The goal is to maintain optimal air quality that supports the health and comfort of those inside the building (Liang et al., 2021).

The Indoor Air Quality Index as shown in Eq. (iii) is a specific formula devised to quantify the overall indoor air quality based on pollutant concentrations. The formula is expressed as:

$$Indoor\ Air\ Quality\ Index = \frac{Sum\ of\ Pollutant\ Concentrations}{Number\ of\ Pollutants} \qquad \text{(iii)}$$

Eq. (iii) calculates an index that reflects the average concentration of pollutants present in indoor air. A lower index value indicates better indoor air quality, reflecting a healthier and more comfortable environment for building occupants.

In summary, Indoor Air Quality (IAQ), as measured by the Indoor Air Quality Index, provides a quantitative assessment of a building's commitment to maintaining a healthy and comfortable indoor environment, with a focus on minimizing pollutants and optimizing air quality.

2.2.4 Material Selection

Material Selection is a vital component of sustainability assessments, focusing on examining the sustainability of materials used in construction while considering their environmental impact. This key performance indicator (KPI) provides insights into how responsibly a building selects and utilizes materials, aiming to minimize its ecological footprint.

The assessment entails a thorough examination of the materials employed in construction, considering factors such as their origin, production processes, and end-of-life disposal. It emphasizes the importance of selecting materials with minimal environmental impact throughout their life cycle, from extraction to disposal.

The Life Cycle Assessment (LCA) as shown in Eq. (iv) is a specific formula designed to quantify the overall environmental impact of materials used in construction. The formula is expressed as:

$$Life\ Cycle\ Assessment\ (LCA) = \frac{Total\ Environmental\ Impact}{Functional\ Unit} \qquad \text{(iv)}$$

Eq. (iv) calculates the ratio of the total environmental impact to the functional unit, providing a measure of the sustainability of the chosen materials. A lower LCA value indicates a more environmentally friendly material selection, reflecting the building's commitment to sustainable construction practices(Lu et al., 2016).

In summary, Material Selection, as assessed by the Life Cycle Assessment, offers a quantitative evaluation of a building's approach to choosing environmentally sustainable materials, contributing to overall sustainability and responsible construction practices.

2.2.5 Life Cycle Costing

Life Cycle Costing is a crucial metric in sustainability assessments, focusing on assessing the economic sustainability of a building over its entire life cycle. This key performance indicator (KPI) provides insights into the long-term financial implications of constructing and maintaining the building (Gundes, 2016).

The assessment involves a comprehensive evaluation of all costs associated with the building, including initial construction costs, operating and maintenance expenses, and potential future costs. It aims to consider the economic sustainability of the building by analyzing the financial impact over its entire life span.

The Net Present Value (NPV) can be calculated by using Eq. (v). It is a specific formula designed to quantify the economic sustainability of the building. The formula is expressed as:

$$Net\ Present\ Value\ (NPV)\ =\ \Sigma\ \frac{Cash\ Inflows}{(1+r)^t} - \Sigma\ \frac{Cash\ Outflows}{(1+r)^t} \qquad \text{(v)}$$

Eq. (v) calculates the net present value, considering the time value of money, by discounting both cash inflows and cash outflows over the building's life cycle. A positive NPV indicates that the project is financially viable and generates value over time, contributing to economic sustainability (Guinée, 2016).

In summary, Life Cycle Costing, as assessed by Net Present Value, offers a quantitative evaluation of a building's economic sustainability, providing valuable insights into its long-term financial viability and responsible financial management practices.

2.2.6 Carbon Footprint

Carbon Footprint is a pivotal metric in sustainability assessments, focusing on measuring the total greenhouse gas emissions associated with a building. This key performance indicator (KPI) provides insights into the environmental impact of the building's activities, particularly in terms of contributing to climate change.

The assessment involves quantifying the greenhouse gas emissions resulting from various sources related to the building, including energy consumption, transportation, and other operational activities. It aims to gauge the building's overall contribution to carbon emissions, emphasizing the need to minimize its environmental footprint.

The Carbon Footprint is calculated by using Eq. (vi). It is a specific formula designed to quantify the total greenhouse gas emissions concerning the building's size. The formula is expressed as:

$$Carbon\ Footprint\ =\ \frac{Total\ Greenhouse\ Gas\ Emissions}{Building\ Area} \qquad \text{(vi)}$$

Eq. (vi) calculates the ratio of total greenhouse gas emissions to the building's area, providing a normalized measure of its environmental impact. A lower Carbon Footprint value indicates more sustainable practices, reflecting the building's commitment to reducing its contribution to climate change(Čuček et al., 2012).

In summary, Carbon Footprint, as measured by the Carbon Footprint formula, offers a quantitative assessment of a building's environmental impact, contributing valuable insights into its overall sustainability practices and efforts to mitigate climate change.

These KPIs offer a comprehensive overview of a building's sustainability, considering environmental, social, and economic dimensions. The provided formulas are illustrative and may be customized based on specific methodologies and measurement units. It is essential to align them with the standards and requirements of the sustainability assessment being conducted.

2.3 Benefits of Retrofitting Existing Buildings with BIM

Numerous studies highlight the benefits of retrofitting existing buildings using Building Information Modelling (BIM) technology. BIM enables stakeholders to visualize, analyze, and optimize building performance throughout its lifecycle. By integrating energy modeling tools into BIM platforms, researchers have demonstrated significant energy savings potential through informed decision-making in retrofit projects (Caterino, 2021). BIM facilitates collaboration among architects, engineers, and contractors, streamlining communication and coordination processes. Furthermore, BIM's parametric capabilities allow for iterative design optimization, resulting in more cost-effective and sustainable retrofit solutions (Vitiello et al., 2019).

2.4 Challenges and Limitations in BIM-Based Retrofitting

Despite its promise, BIM-based retrofitting encounters several challenges and limitations. Chief among these is the complexity of existing building systems and the heterogeneity of available data sources. Retrofit projects often lack comprehensive as-built information, leading to uncertainty and inaccuracies in BIM models. Moreover, interoperability issues between various BIM software platforms hinder seamless data exchange and collaboration among project stakeholders. Additionally, the implementation of BIM in retrofitting projects necessitates a paradigm shift in industry practices and workflows, requiring substantial investments in training and organizational change management (Khaddaj and Srour, 2016).

2.5 Case Studies and Best Practices

Several case studies demonstrate successful applications of BIM in retrofitting existing buildings for energy efficiency. For instance, the renovation of historic structures using BIM-enabled energy analysis tools has resulted in substantial energy savings while preserving architectural integrity. Similarly, commercial office buildings retrofitted with BIM-based energy management systems have achieved significant reductions in energy consumption and operational costs (Zhao et al., 2021). Best practices emerging from these case studies include early stakeholder involvement, integrated design processes, and post-occupancy performance monitoring to ensure the long-term effectiveness of retrofit interventions (Maghsoudi et al., 2022).

2.6 The Energy Conservation Building Code 2023 (ECBC-2023)

The Energy Conservation Building Code 2023 (ECBC-2023) was developed with the purpose of improving energy efficiency in buildings. This code provides minimum requirements for energy efficient designs and construction of buildings and includes international best practices appropriate to Pakistan's environment. It covers a broad range of factors, including energy efficient and low-emission construction materials, passive building design, energy appliance monitoring devices, electric vehicle charging points, energy management systems, building insulation, and renewable and geothermal energy.

CHAPTER 3

METHODOLOGY

To achieve our research objectives, the following methodology will be employed:

a) **Literature Review**: Conduct a thorough review of existing literature to gather insights into the benefits, BIM models, and recommendations for retrofitting in existing buildings.

b) **Data Collection and Analysis**: Gather data from existing buildings, including architectural plans, energy consumption data, and environmental conditions. Analyze this data using BIM and simulation software to identify energy inefficiencies.

c) **Develop initial BIM Model**: Create a comprehensive BIM-based model for existing buildings that aimed at improving energy efficiency.
   This model will serve as a visual representation and a benchmark of potential changes.

d) **Develop and Simulate Retrofitting Model:** : Create a comprehensive BIM-based model for existing buildings that incorporates potential retrofitting strategies aimed at improving energy efficiency.
   Use simulation software to evaluate the performance of the BIM-based retrofitting model.

e) **Retrofitting Trials:** Perform Retrofitting trials on building envelope by incorporating different retrofitting aimed at improving energy efficiency and economic sustainability.

f) **Comparison and Optimization:** Compare different trials and calculate energy efficiency percentages, retrofitting costs, cost savings, and payback period**.**

g) **Recommendations**: Based on the simulation results and energy efficiency analysis, propose practical and sustainable retrofit solutions. These recommendations will be tailored to the specific building's needs and conditions.

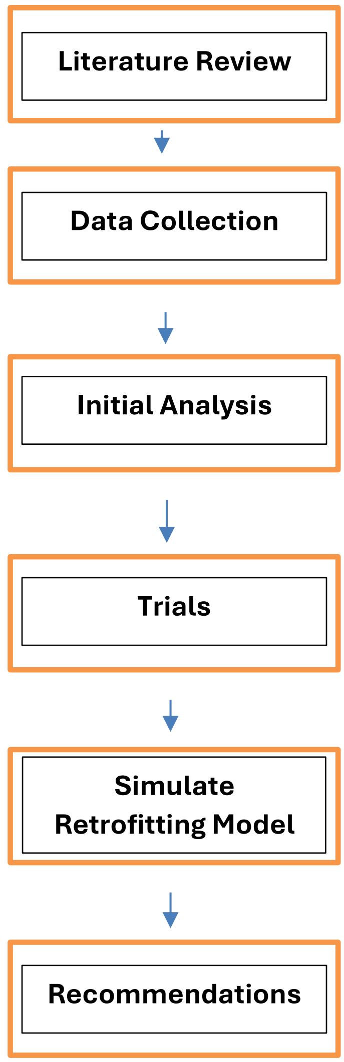

Figure 1 Methodology flow chart

3.1 Literature Review

The first step (as shown in Figure 1) involves conducting a thorough review of existing literature. This will include examining scholarly articles, case studies, and industry reports to gather comprehensive insights into the benefits and challenges of retrofitting existing buildings for energy efficiency. The main points that were obtained are :

a) Specific types of energy that require improvement (Nielsen and Karlsson,2018)
b) Types of Energy Efficiency Measures for Retrofitting (Fernandes et al., 2021)
c) Benefits of Retrofitting Existing Buildings (Khairi et al., 2017)

d) Old and New Ways of Retrofitting
e) Challenges of Adopting BIM in Retrofitting
f) Identification of potential gaps or limitations

3.2 Data Collection and Analysis

The second phase involves the collection of data from existing buildings. This data includes architectural plans, historical energy consumption records, and information on the environmental conditions surrounding the buildings.

The location of an existing building is plot No 9, Block C, Sector Multi Residencia Orchard Housing Scheme District Council Attock. One of the floor plans is shown in Figure 2. This is just an illustration, all other 2D Architectural and Structural Drawings were available in Autocad’s (.dwg) format. The building was selected because it features a typical design commonly found in the region, making it a representative sample for studying standard architectural practices. It uses construction materials and techniques prevalent in the local area, providing insights into sustainable practices that are practical and feasible within the local context. Additionally, the building is situated in an area with varied climatic conditions, allowing for the assessment of energy performance and the effectiveness of conservation strategies under different weather scenarios, thereby enhancing the applicability of the results.

The Reasons for selecting the building were:

a) Typical building design
b) Local construction materials and techniques
c) Varied climate representation

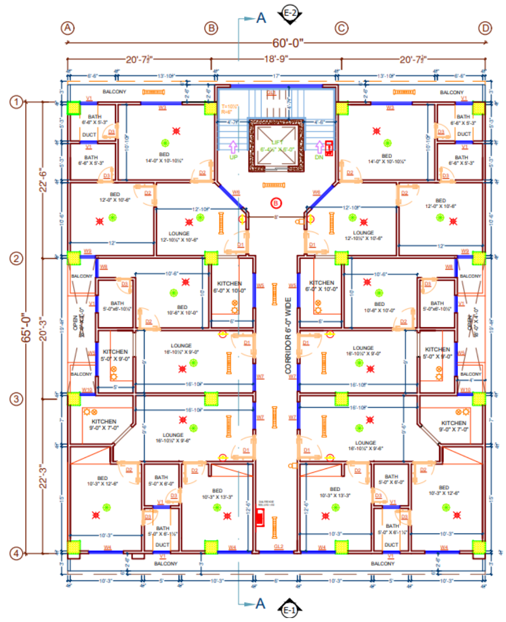

Figure 2 CAD Drawing

3.3 Develop Initial BIM Model

In the third step, an initial BIM-based model of the existing building was developed as shown in Figure 3. To convert a 2D drawing into a 3D model in Revit, start by importing the 2D drawings. Then, define the levels and create grids to establish the building's framework. Next, model the floors and build the walls by tracing over the 2D lines. Insert doors and windows, followed by adding the roofs. Place structural elements like beams and columns, finalize the details, and continuously review and adjust the 3D model to ensure accuracy and completeness. The model in Figure 3 integrated all collected data and serve as a detailed visual representation of the buildings' current state. The initial model will act as a benchmark, highlighting potential areas for improvement.. It will also provide a robust foundation for testing various retrofitting strategies by simulating their impact on energy efficiency. This approach enables the evaluation of different methods and materials, allowing for precise adjustments and improvements. By assessing the potential energy savings and performance enhancements of each strategy, it ensures that the most effective and sustainable solutions are implemented.

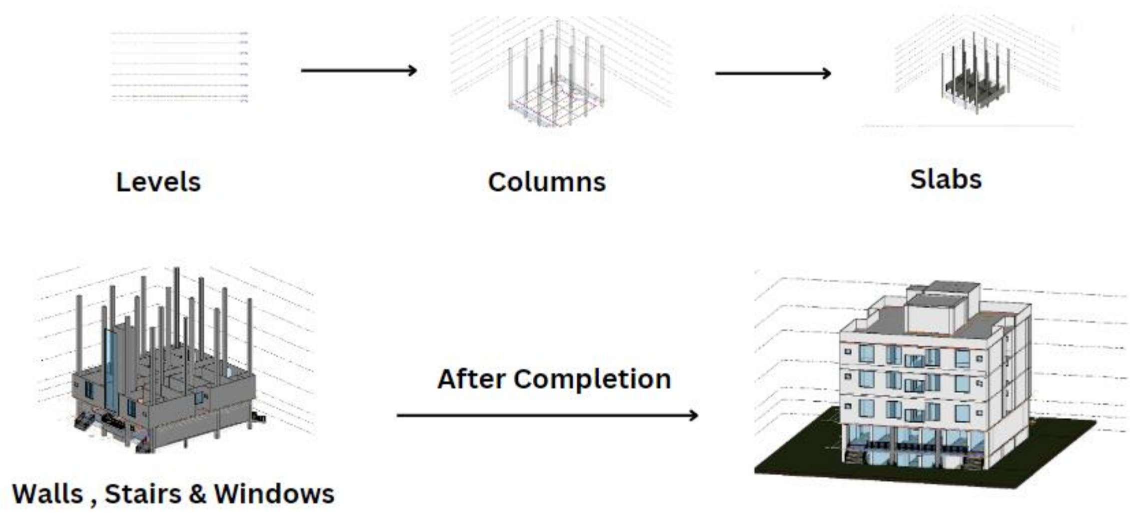

Figure 3 Initial BIM Model

3.4 Develop and Simulate Retrofitting Model

The fourth phase involves developing a comprehensive BIM-based retrofitting model. This model will incorporate potential retrofitting strategies identified during the literature review and data analysis phases. Using simulation software, the performance of the retrofitting model will be evaluated under different scenarios. The simulations will provide insights into how various retrofitting measures can improve energy efficiency, allowing for the assessment of their feasibility and effectiveness.

Use ECBC 2023 as the building code for developing an energy-efficient Retrofitted Model.

3.5 Retrofitting Trials

In the fifth step, retrofitting trials will be conducted on the building envelope. Different retrofitting techniques will be applied in controlled settings to assess their impact on energy efficiency and economic sustainability. These trials will provide practical insights into the implementation of retrofitting strategies and their real-world performance. The results will be meticulously documented to inform subsequent analysis and optimization efforts.

3.6 Comparison and Optimization

Following the trials, a comparative analysis will be performed. Different retrofitting scenarios will be compared to determine their energy efficiency improvements, retrofitting costs, cost savings, and payback periods. This comparative analysis will identify the most effective and economically viable retrofitting strategies. Optimization techniques will be applied to refine these strategies, ensuring that they deliver maximum energy savings at minimal costs.

3.7 Recommendations

Based on the simulation results and energy efficiency analysis, the final step involves proposing practical and sustainable retrofit solutions. These recommendations will be tailored to the specific needs and conditions of the buildings studied. They will provide actionable insights for stakeholders looking to improve the energy efficiency of existing buildings using BIM-based retrofitting. The recommendations will be designed to be adaptable and scalable, ensuring they can be applied to a wide range of building types and contexts.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

An extensive overview of the benefits and ramifications of using BIM-based retrofitting to improve the energy efficiency of existing buildings is revealed when considering the analysis and outcomes of this project in a larger perspective. This part provides a thorough grasp of the many opportunities and problems that exist in the field of sustainable building practices by acting as the hub where theoretical insights and actual implementations intersect. The viability, efficacy, and scalability of BIM-based retrofitting solutions are clarified through a thorough analysis of empirical data, case studies, and simulation results. Furthermore, this analysis highlights the complex dynamics involved in the shift to energy-efficient built environments by shedding light on the interactions between technology advancements, regulatory frameworks, and stakeholder participation. By combining a variety of viewpoints with factual data, this effort helps

4.2 KPIS and Energy Code

The key performance indicators (KPIs) utilized in this research are the heating and cooling loads of the buildings. These KPIs are critical metrics for assessing energy efficiency, as they directly relate to the amount of energy required to maintain comfortable indoor temperatures. By focusing on heating and cooling loads, the study can precisely measure the impact of retrofitting strategies on energy consumption. Reducing these loads not only lowers energy use but also decreases operational costs and carbon emissions, contributing to overall building sustainability. The analysis of these KPIs provides clear, quantifiable data that can be used to evaluate the effectiveness of different retrofitting measures and optimize them for better performance.

The energy code referenced in this research is the Energy Conservation Building Code (ECBC) 2023 of Pakistan. The ECBC 2023 sets forth mandatory and voluntary guidelines for energy efficiency in building design, construction, and operation. It includes standards for thermal performance, HVAC systems, lighting, and renewable energy integration, among other aspects. By adhering to the ECBC 2023, this research ensures that the retrofitting strategies proposed not only aim to enhance energy efficiency but also comply with national regulations and best practices. Compliance with the ECBC 2023 guarantees that the retrofitted buildings will meet or exceed current energy performance benchmarks, thereby promoting sustainable development and reducing the environmental impact of the built environment. The Logo of National Energy Efficiency & Conservation Authority (NECCA) is shown in Figure 4. NEECA is an Authority under the Ministry of Energy (Power Division) that functions as the federal focal point for initiating, driving, and coordinating energy conservation efforts across different sectors of the economy. The National Energy Efficiency and Conservation Authority has issued ECBC 2023 to be applicable across the country.

Figure 4 National Energy Efficiency & Conservation Authority

4.3 Trials/Combinations

4.3.1 Base Model Analysis

Figure 5 below shows the base model properties that show that the building is not built according to energy efficiency standards.

The initial BIM model reveals that the building does not comply with current energy efficiency standards. Detailed analysis of the model shows that the building's envelope lacks proper insulation, leading to significant thermal losses. In Figure 5 the windows are single-glazed, which contributes to high heat transfer and poor thermal performance. Additionally, the building's orientation and the materials used in construction do not optimize energy conservation. The absence of energy-efficient HVAC systems further exacerbates the inefficiency, resulting in elevated heating and cooling loads. These deficiencies underscore the necessity for retrofitting to enhance the building's energy performance. By addressing these issues, the retrofitting process aims to reduce energy consumption, improve occupant comfort, and align the building with the Energy Conservation Building Code (ECBC) 2023 of Pakistan. The initial model serves as a critical benchmark, highlighting areas where significant improvements can be made through targeted retrofitting strategies.

Mass Exterior Wall	Lightweight Construction - Typical Mild Climate Insulation
Mass Interior Wall	Lightweight Construction - No Insulation
Mass Exterior Wall - Underground	High Mass Construction - Typical Mild Climate Insulation
Mass Roof	Typical Insulation - Cool Roof
Mass Floor	Lightweight Construction - No Insulation
Mass Slab	High Mass Construction - No Insulation
Mass Glazing	Double Pane Clear - No Coating
Mass Skylight	Double Pane Clear - No Coating

Figure 5 Base Model Properties

Figure 6 presents the results of the base model analysis, illustrating the monthly peak demand for district cooling and heating. The Upper graph in Figure 6 shows the district cooling peak demand in kilojoules per hour (kJ/h) across the months:

- In January, the cooling demand starts at around 250 kJ/h.
- There is a gradual increase from February (about 275 kJ/h) to April (approximately 350 kJ/h).
- The cooling demand remains relatively high and stable from May to September, peaking around 400 kJ/h in July and August.
- A noticeable decrease begins in October (about 350 kJ/h), with further drops in November (approximately 300 kJ/h) and December (around 250 kJ/h).

The lower graph in Figure 6 depicts the district heating peak demand in kilojoules per hour (kJ/h) throughout the year:

- High heating demand is observed in January and February, both peaking around 210 kJ/h.
- The demand decreases significantly in March (approximately 160 kJ/h) and continues to decline through April (about 100 kJ/h) and May (around 60 kJ/h).
- From June to September, the heating demand is minimal, almost negligible.
- An increase in demand begins in October (about 80 kJ/h) and continues rising through November (approximately 140 kJ/h) and December (around 200 kJ/h).

This analysis highlights the seasonal variations in energy demands, with peak cooling in the summer months and peak heating in the winter months.

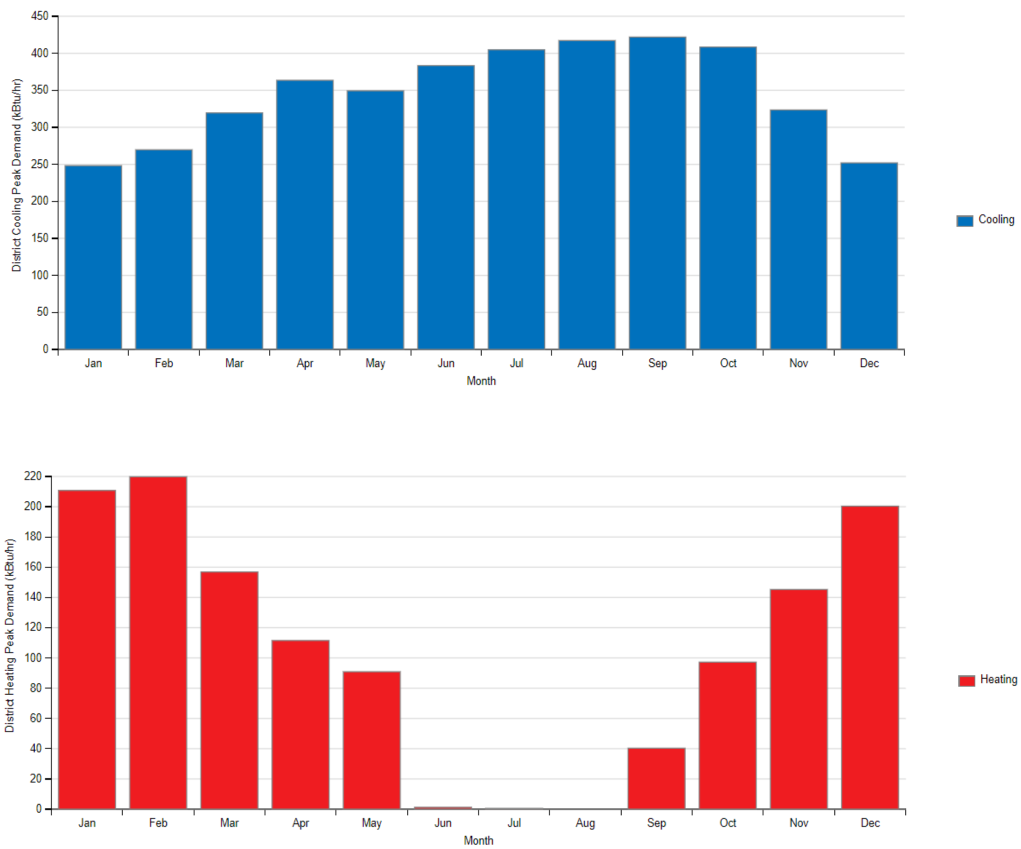

Figure 6 Base Model Results

4.3.2 Trial 1 (Wall Insulation)

In the first retrofitting trial, the focus was on enhancing the thermal performance of the building envelope by improving wall insulation. The materials selected for this trial included a combination of brick, polystyrene insulation, dense concrete, and dense plaster. This layered composition was designed to significantly reduce the building's overall thermal transmittance (U-value).

The chosen materials for the wall assembly were bricks which provide structural strength and moderate thermal mass. Polystyrene Insulation offers excellent thermal resistance, significantly reducing heat transfer. Dense Concrete adds thermal mass, helping to stabilize internal temperatures. Dense Plaster provides a smooth finish and additional thermal mass. The U-value of the new wall assembly was calculated to be 0.0969 BTU/(H·FT^2·°F), which is substantially lower than the threshold of 0.100 BTU/(H·FT^2·°F) set by the National Energy Efficiency & Conservation Authority (NEECA) of Pakistan. This low U-value indicates superior insulation performance, minimizing heat loss during winter and heat gain during summer.

Upon implementing the new insulation strategy in the BIM model, the heating and cooling loads were reassessed using simulation software. The results showed a marked reduction in both heating and cooling demands compared to the base model. This decrease can be attributed to the improved insulation provided by the polystyrene layer, which significantly reduces the rate of thermal exchange through the walls.

The primary reason for the substantial reduction in heating and cooling loads is the enhanced thermal resistance of the insulated walls. By incorporating polystyrene insulation, the walls' ability to prevent heat transfer is greatly improved, resulting in a more stable indoor temperature. This stability reduces the need for active heating and cooling systems, leading to lower energy consumption and operational costs.

Figure 6 illustrates the monthly peak demand for district cooling and heating, while Figure 7 shows the district cooling and heating consumption for Trial 1. Here's a detailed comparison of the two:

- Peak demand steadily increases from January to April, reaching around 350 kJ/h.

- From May to September, peak demand remains high, peaking at around 400 kJ/h in July and August.
- A decline is observed from October, with demand dropping to around 250 kJ/h by December.
- Cooling consumption shows a similar trend, starting low in January (~20 MBtu) and increasing through the spring.
- From May, consumption increases significantly, peaking in June and July at around 120 MBtu.
- Cooling consumption begins to decline from September, with a noticeable drop by December (~50 MBtu).
- High heating demand is observed in January and February, both peaking around 210 kJ/h.
- Demand decreases significantly from March through May.
- An increase in demand is seen again from October, peaking around 200 kJ/h in December.

Seasonal Trends for both peak demand and consumption for cooling and heating follow similar seasonal trends, with high values in winter for heating and in summer for cooling. Peak vs. Total Usage Peak demand figures represent the highest usage moments, while consumption figures represent the total energy used over the month. Thus, the base model analysis shows peak usage rates, while Trial 1 in Figure 7 shows overall energy consumption. The magnitude of Values Peak demands is measured in kilojoules per hour (kJ/h), while consumption is in British thermal unit(MBtu). This reflects the instantaneous peak versus the accumulated monthly usage.

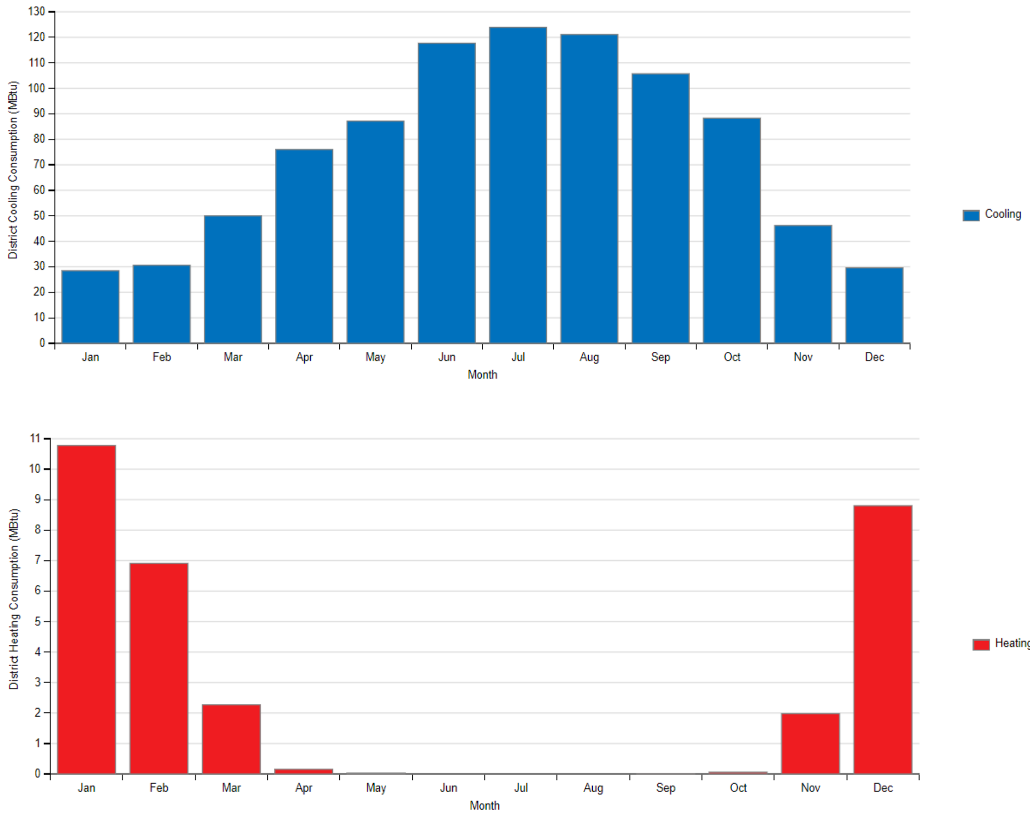

Figure 7 Trial 1 Results

4.3.3 Trial 2 (Wall + Windows Insulation)

In the second retrofitting trial, the focus was extended beyond wall insulation to include the enhancement of window performance. The materials used for the wall insulation remained the same as in Trial 1—brick, polystyrene insulation, dense concrete, and dense plaster—resulting in a U-value of 0.0969 BTU/(H·FT^2·°F). Additionally, Low-E double glazing windows were installed, characterized by a solar heat gain coefficient (SC) of 0.2 and a U-value of 0.3533 BTU/(H·FT^2·°F), both of which comply with the National Energy Efficiency & Conservation Authority (NEECA) standards.

The wall assembly materials were brick for structural integrity and moderate thermal mass. Polystyrene Insulation provides high thermal resistance and minimizes heat transfer. Dense Concrete to add thermal mass and stabilize internal temperatures. Dense Plaster for a smooth finish and additional thermal mass. For the windows, Low-E double glazing was chosen.

Low-E Coating reflects infrared radiation, reducing heat transfer. Double Glazing provides an additional layer of insulation compared to single glazing. The combination of these materials ensured that both the wall and windows contributed to significant energy efficiency improvements.

After implementing the wall and window retrofitting measures in the BIM model, the heating and cooling loads were recalculated. The results, as shown in the figure, indicate that the heating load was reduced to 32,065 kBtu and the cooling load to 680,732 kBtu. These values represent a considerable decrease from the base model, highlighting the effectiveness of the combined wall and window retrofitting.

The addition of Low-E double glazing windows in conjunction with improved wall insulation provides a dual approach to enhancing the building's thermal performance. The Low-E coating on the windows reflects infrared heat, reducing heat gain during summer and heat loss during winter. This results in a lower demand for heating and cooling, thereby reducing energy consumption.

Figure 6 presents the results of the base model analysis, showing monthly peak demand for district cooling and heating. In comparison, the current figure displays the district cooling and heating consumption for Trial 2 in Figure 8.

For cooling, the base model's peak demand peaks around 400 kJ/h from June to September, decreasing to about 250 kJ/h in January and December. In Trial 2, cooling consumption peaks around 100 MBtu in July and August, dropping to about 10 MBtu in January and December.

For heating (as shown in Figure 8), the base model's peak demand peaks around 210 kJ/h in January and February, with minimal demand from June to September. In Trial 2, heating consumption peaks around 11 MBtu in January and December, with minimal to no consumption from May to September.

Both figures in Figure 8 reflect high cooling needs in summer and high heating needs in winter. Trial 2’s consumption values (MBtu) align with the peak demands of the base model analysis (kJ/h), highlighting overall monthly energy use versus peak hourly rates. This comparison underscores the seasonal variability in energy demand and consumption, essential for effective energy management and resource allocation.

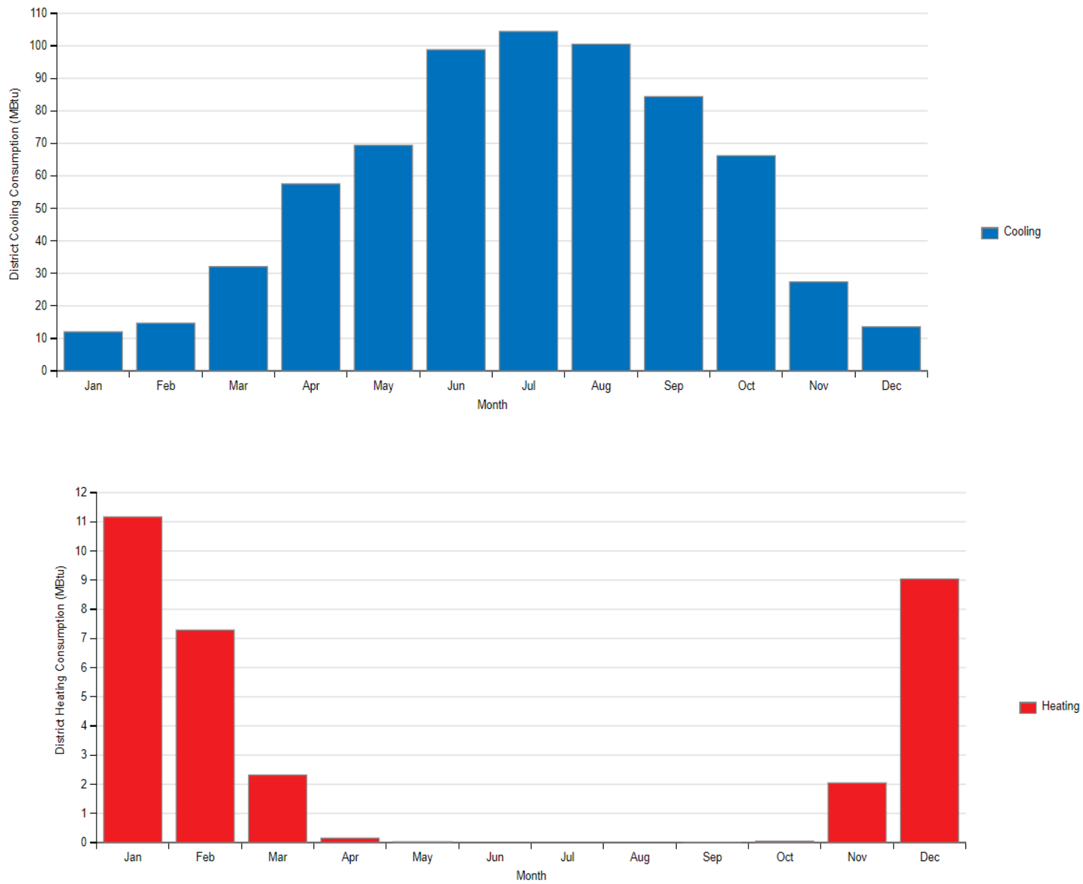

Figure 8 Trial 2 Results

4.3.4 Trial 3 (Wall + Windows + Roof Insulation)

The third retrofitting trial extended the scope of energy efficiency improvements to include the roof, in addition to the wall and window enhancements implemented in the previous trials. The aim was to create a comprehensive retrofitting strategy that addresses all major components of the building envelope. The materials used for the walls and windows remained the same. Brick, polystyrene insulation, dense concrete, and dense plaster for the walls, and Low-E double glazing for the windows. For the roof, the materials chosen were a waterproof covering, 4 inches of polyurethane insulation, and plasterboard. This combination resulted in a U-value of 0.0387 BTU/(H·FT^2·°F), significantly below the NEECA standard of 0.078 BTU/(H·FT^2·°F).

Walls are made of brick, polystyrene insulation, dense concrete, and dense plaster (U-value is 0.0969 BTU/(H·FT^2·°F)). Windows are Low-E double glazing (SC: 0.2, U-value: 0.3533 BTU/(H·FT^2·°F)).

For the roof, the selected materials were Waterproof Covering, to protect the building from water ingress and enhance durability, and Polyurethane Insulation (4 inches) which provides excellent thermal resistance, significantly reducing heat transfer. Plasterboard adds a finishing layer and additional thermal mass. The low U-value of the roof assembly (0.0387 BTU/(H·FT^2·°F)) indicates exceptional insulation performance, ensuring minimal heat loss or gain through the roof.

After incorporating the roof insulation into the BIM model along with the previously implemented wall and window improvements, the heating and cooling loads were recalculated. The comprehensive retrofitting resulted in further reductions in energy consumption. The precise values of heating and cooling loads for this trial were observed to be significantly lower than those recorded in the base model and the previous trials, highlighting the effectiveness of a holistic approach to building envelope retrofitting.

The inclusion of roof insulation addressed a critical area of heat transfer, as roofs are often a significant source of energy loss due to their exposure to the external environment. The 4-inch polyurethane insulation provides a high R-value, reducing the rate of heat transfer and improving thermal resistance. This leads to a more stable indoor climate, reducing the need for heating and cooling.

Figure 6 presents the results of the base model analysis, showing monthly peak demand for district cooling and heating. In comparison, Figure 9 displays the district cooling and heating consumption for Trial 3.

For cooling, the base model's peak demand reaches around 400 kJ/h from June to September, decreasing to about 250 kJ/h in January and December. In Trial 3 (as shown in Figure 9) , cooling consumption peaks around 100 KBtu in July and August, dropping to about 20 KBtu in January and December. For heating, the base model's peak demand peaks around 210 kJ/h in January and February, with minimal demand from June to September. In Trial 3, heating consumption peaks around 10 KBtu in January and December, with minimal to no consumption from May to September. Both figures reflect high cooling needs in summer and high heating needs in winter. Trial 3's consumption values (KBtu) closely resemble those of Trial 2 (as shown in Figure 8), indicating a similar pattern in energy use.

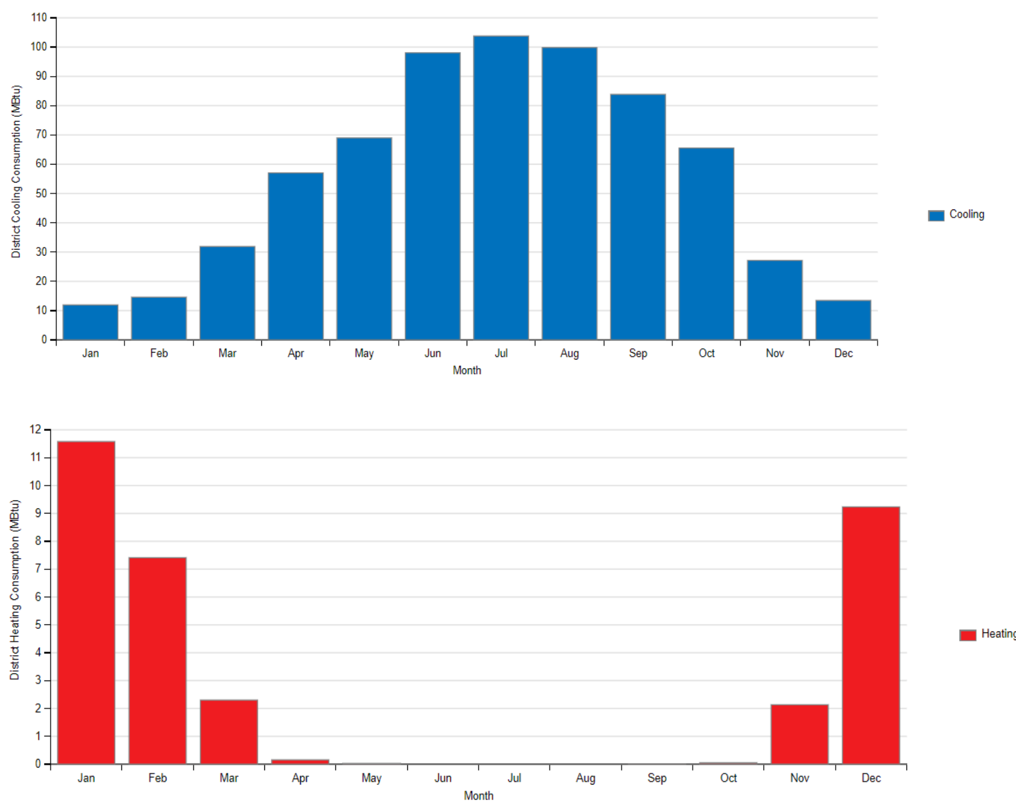

Figure 9 Trial 3 Results

4.3.5 Trial 4 (Windows + Roof Insulation)

The fourth retrofitting trial focuses on enhancing the energy efficiency of the building by improving the insulation of the roof and windows. The materials used for the roof include a waterproof covering, 4 inches of polyurethane insulation, and plasterboard, resulting in a U-value of 0.0387 BTU/(H·FT^2·°F). For the windows, Low-E double glazing was selected, with a solar heat gain coefficient (SC) of 0.2 and a U-value of 0.3533 BTU/(H·FT^2·°F), both of which comply with the National Energy Efficiency & Conservation Authority

(NEECA) standards. These selections ensure superior thermal performance, minimizing heat loss in winter and heat gain in summer. The roof insulation's high R-value contributes significantly to energy savings by maintaining indoor temperatures. Additionally, the Low-E coating on the windows reduces infrared and ultraviolet light penetration without compromising visible light transmission. Both the roof and window specifications are designed to enhance overall energy efficiency, promoting a sustainable and cost-effective living environment. By adhering to NEECA standards, this construction not only meets regulatory requirements but also aligns with modern environmental sustainability goals.

Figure 6 presents the results of the base model analysis, showing monthly peak demand for district cooling and heating. In comparison, Figure 10 displays the district cooling and heating consumption for Trial 4.

For cooling, the base model's peak demand reaches around 400 kJ/h from June to September, decreasing to about 250 kJ/h in January and December. In Trial 4 (as shown in Figure 10), cooling consumption peaks around 105 KBtu in July and August, dropping to about 18 KBtu in January and December.

For heating, the base model's peak demand peaks around 210 kJ/h in January and February, with minimal demand from June to September. In Trial 4 (as shown in Figure 10), heating consumption peaks around 14 KBtu in January and December, with minimal to no consumption from May to September.

Both figures reflect high cooling needs in summer and high heating needs in winter. Trial 4’s consumption values (KBtu) show a slightly higher heating consumption compared to Trial 2 (as shown in Figure 8), but cooling consumption remains quite similar. This comparison underscores the seasonal variability in energy demand and consumption, essential for effective energy management and resource allocation. Trial 4 shows a 24.01% improvement in energy efficiency, with total annual consumption of 709,441 kBtu for cooling and 52,519 kBtu for heating.

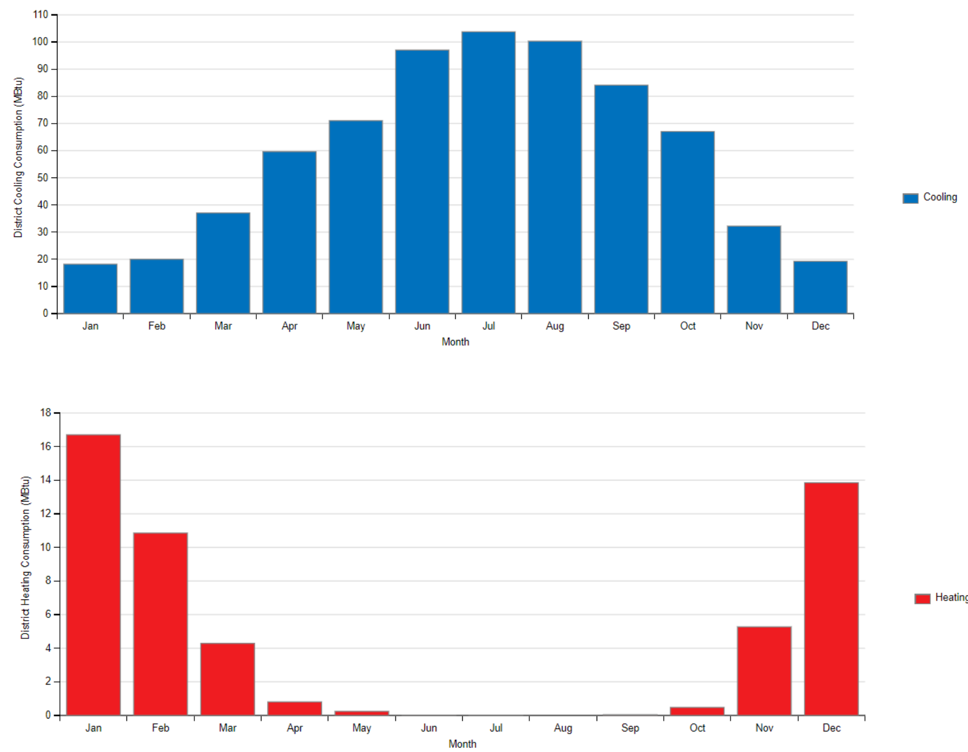

Figure 10 Trial 4 Results

4.4 Comparison

The effectiveness of the retrofitting strategies was evaluated by comparing the annual heating and cooling loads of the base model with those of the four retrofit trials. The base model represents the original building configuration with no retrofitting measures implemented. The following sections provide a detailed comparison of each trial against the base model, highlighting the improvements in energy efficiency.

The energy efficiency improvement for each trial was calculated using the Eq. (vii) as shown below:

$$Energy\ Efficiency\ Improvement = \frac{Base\ Model\ Load - Trial\ Load}{Base\ Model\ Load} \times 100\% \quad \text{(vii)}$$

Where the base Model Load in Eq. (vii) is the sum of the base model's heating and cooling loads.Trial Load in Eq. (vii) is the sum of the heating and cooling loads for each trial.

4.4.1 Summary of Results

As shown in Table 1, the base model's annual energy consumption is 947,315 kBtu for cooling and 55,428 kBtu for heating. Trial 1 demonstrates a 6% improvement, with energy consumption reduced to 904,635 kBtu for cooling and 30,975 kBtu for heating. Trial 2 shows a significant 28.9% improvement, with cooling consumption at 680,732 kBtu and heating at 32,065 kBtu. Trial 3 achieves the highest improvement of 29.3%, with 676,021 kBtu for cooling and 32,880 kBtu for heating. Finally, Trial 4 indicates a 24.01% improvement, with cooling consumption at 709,441 kBtu and heating at 52,519 kBtu. This analysis highlights the varying degrees of energy efficiency improvements achieved in each trial.

Table 1 Comparison of Trials

Trials	Description	Cooling Load (kBtu)	Heating Load (kBtu)	Energy Efficiency
Trial 1	Wall Insulation	904635	30975	6%
Trial 2	Wall Insulation	680732	32065	28.9%
	Low E Double Glazing Window			
Trial 3	Wall Insulation	676021	32880	29.3%
	Roof Insulation			
	Low E Double Glazing Window			
Trial 4	Roof Insulation	709441	52519	24.01%
	Low E Double Glazing Window			

4.5 Optimal Retrofit Measure

In trial 2 the combination of wall and window insulation offers a balanced approach to improving energy efficiency, making it a viable option for retrofitting existing buildings.

It provides substantial energy savings while remaining economically feasible, making it an optimal retrofit measure for enhancing building performance and sustainability.

In evaluating the effectiveness of retrofitting trials, we prioritize both

a) Energy Efficiency
b) Economic Sustainability.

Walls and windows typically constitute the majority of the building envelope surface area. They directly interact with the external environment, influencing heat gain in summer and heat loss in winter. Due to their larger surface area compared to the roof, walls and windows have a more significant impact on the building's overall thermal performance. Any improvements in their insulation properties result in substantial reductions in heating and cooling loads.

Walls and windows are primary pathways for heat transfer between the interior and exterior of the building. Inefficient insulation in these areas leads to significant energy losses, driving up heating and cooling demands. The thermal conductivity of materials used in walls and windows directly affects heat transfer rates. Enhancing insulation in these components effectively reduces heat flow, thereby improving energy efficiency.

While the roof plays a crucial role in shielding the building from external weather elements, its surface area is typically smaller compared to the combined area of walls and windows.

As a result, even though improvements in roof insulation can contribute to energy savings, their impact may be proportionally smaller compared to enhancing insulation in walls and windows.

Retrofitting the roof with insulation materials involves additional expenses such as material costs, labor, and installation. However, the energy efficiency gains achieved may not always justify the higher investment, especially when considering the relatively smaller impact of roof insulation on overall building performance.

By focusing on wall and window insulation in Trial 2, we strike a balance between effectiveness and cost-effectiveness, maximizing energy savings while minimizing retrofitting expenses. We get an energy efficiency of 28.9% as given in Table 2.

Table 2 Optimal Retrofit Measure

Trials	Description	Cooling Load (kBtu)	Heating Load (kBtu)	Energy Efficiency
Trial 2	Wall Insulation	680732	32065	28.9%
	Low E Double Glazing Window			

4.6 Cost-benefit analysis

The initial annual energy bill before retrofitting amounted to Rs 1,90,00,000 as given in Table 3. This represents the cost incurred by the building owner or occupant to meet heating and cooling demands without any energy-efficient measures in place.

With the implementation of Trial 2, the annual energy bill saw a significant reduction, amounting to Rs 1,35,09,000. This reduction is attributed to the improved energy efficiency resulting from wall and window insulation measures.

The difference between the energy bills before and after retrofitting represents the annual energy savings achieved through Trial 2. In this case, the annual energy savings amount to Rs 54,91,000.

The payback period refers to the time it takes for the initial investment in retrofitting measures to be recouped through energy savings. In the case of Trial 2, the payback period is estimated to be around 2-3 years.

This means that the cumulative energy savings accrued over the payback period will eventually cover the initial investment in implementing Trial 2

.

Table 3 Cost Analysis

Annual Energy Bill Before Retrofitting	Annual Energy Bill After Retrofitting	Annual Energy Savings (A)
Rs 1,90,00,000	Rs 1,35,09,000	Rs 54,91,000

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, retrofitting existing buildings using Building Information Modeling (BIM) offers a multifaceted approach to enhancing energy efficiency, sustainability, and economic viability. Through the utilization of BIM-based simulations and data-driven insights, stakeholders can achieve significant benefits in terms of reducing energy consumption, extending building lifespan, and ensuring cost-effectiveness.

Firstly, retrofitting with BIM enables a targeted approach to reducing energy consumption by identifying and addressing inefficiencies such as thermal leaks and inefficient HVAC systems. By leveraging BIM-based simulations, stakeholders can evaluate the performance of various retrofitting strategies, leading to optimized energy usage and reduced waste.

Secondly, retrofitting using BIM facilitates proactive maintenance and targeted interventions to extend the lifespan of existing buildings. Through comprehensive condition assessments and analysis, BIM models enable stakeholders to identify structural weaknesses and material degradation, allowing for timely repairs and improvements that preserve valuable assets and minimize future repair costs.

Lastly, retrofitting with BIM ensures cost-effectiveness by enabling accurate cost estimation and informed decision-making. By assessing the feasibility and cost implications of retrofitting options before implementation, stakeholders can allocate resources efficiently and prioritize measures based on their potential return on investment. Additionally, BIM-based retrofitting helps avoid costly mistakes and rework by identifying potential conflicts or issues early in the planning and design phase.

In conclusion, this research has undertaken a systematic exploration of retrofitting strategies aimed at enhancing energy efficiency in existing buildings. Through a comprehensive methodology that included a thorough literature review, data collection, BIM modeling, simulation, and retrofitting trials, we have gained valuable insights into the benefits and challenges of retrofitting interventions. Our findings underscore the critical importance of addressing energy inefficiencies in existing buildings to mitigate environmental impacts and achieve long-term sustainability goals.

The key findings of this study highlight the potential of BIM-based modeling and simulation software in identifying energy inefficiencies and evaluating the performance of retrofitting measures. By leveraging these tools, we have been able to develop targeted retrofitting solutions tailored to the specific needs and conditions of individual buildings. Moreover, our research contributes to the existing body of knowledge by providing practical guidelines for implementing energy-efficient retrofitting strategies and conducting cost-benefit analyses to assess their economic viability.

Despite the significant contributions of this research, certain limitations must be acknowledged. Challenges such as data availability constraints and the complexity of simulation software may have impacted the accuracy and comprehensiveness of our findings. Additionally, the scope of this study may not fully encompass all potential retrofitting strategies and their implications, necessitating further research in this area.

5.2 Recommendations

Moving forward, we offer several recommendations based on the findings of this study. Firstly, we advocate for the widespread adoption of BIM-based modeling and simulation tools in the retrofitting process to enhance efficiency and accuracy. These technologies enable stakeholders to visualize potential retrofitting scenarios, assess their impact on energy consumption, and optimize cost-effective solutions.

Secondly, our cost-benefit analysis highlights the importance of considering both short-term costs and long-term savings when evaluating retrofitting strategies. By prioritizing measures with high energy-saving potential and favorable payback periods, building owners and stakeholders can maximize the return on investment while reducing the environmental footprint.

Furthermore, we recommend the development of comprehensive implementation guidelines to facilitate the adoption of energy-efficient retrofitting solutions in practice. These guidelines should address key considerations such as project management, stakeholder engagement, regulatory compliance, and performance monitoring.

For future study area identify potential areas for future research and development in the field of building retrofitting and energy efficiency. This could include exploring advanced simulation techniques, evaluating emerging retrofitting technologies, or assessing the long-term performance of retrofitting measures.

Industry Implications is to Discuss the broader implications of the research findings for the building industry, policy makers, and sustainability practitioners. Highlight the importance of integrating energy efficiency considerations into building design, construction, and maintenance practices.

In conclusion, this research provides valuable insights and recommendations for advancing energy-efficient retrofitting practices in existing buildings. By leveraging BIM technologies, conducting rigorous analysis, and fostering collaboration among stakeholders, we can accelerate the transition towards sustainable building practices and contribute to a greener and more resilient built environment.

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