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BIM Based Energy Management for Sustainable Facility Management

by

Shah Rukh Khan

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This thesis is dedicated to my parents and my siblings. For their endless love, support and encouragement.

CERTIFICATE OF APPROVAL

BIM Based Energy Management for Sustainable Facility Management

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1. Khan, S. R., & Ali, M. An Overview on Relation Between Energy and Facility Management Models Using BIM Tools. *1st International Conference on Engineering and Applied Natural Sciences* (ICEANS-2022). May 10-12. Paper 694. 2022.

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Abstract

Facility management is a key management discipline that oversees the ongoing maintenance and operations of any organization and acts as a point of convergence for data from many diverse sectors. Any facility's operations and maintenance phase manage the highest flow of information throughout its lifecycle and accounts for around two-thirds of the overall lifecycle expenditures. This indicates that facility managers have a very important role to play. In the current period of climate change emergency, where more attention is being placed on the demands to reduce energy use and carbon emissions, a facility once constructed may very well continue to operate for decades. 40% of the world's energy use and 28% of its carbon emissions are attributed to buildings. Additionally, it has been stated that 70% of modern buildings use more energy than is necessary for their operations. As a result, there is a huge opportunity to reduce energy use, which is why buildings remain at the forefront of climate change policy. To make our buildings more energy efficient, building energy modeling (BEM) has shown to be a very effective approach. However, BEM is a time-consuming and expensive process because it involves a substantial quantity of manual data input. Building information modeling (BIM)-based BEM has emerged as a more efficient method in recent years due to its ability to do away with manual entry methods and allow BEM tools to immediately access data from the pre-designed BIM model. BIM-based BEM thus gives facility managers a very favorable option to assess and optimize the energy consumption of their buildings, which would lead to both significant cost savings and a decrease in harmful CO_2 emissions.

This research places a strong emphasis on the use of BIM for building energy modeling and seeks to shed light on the potential role it could play in educating facility managers on how to better understand the energy performance of their buildings and, in turn, take better energy-saving measures. For this purpose, three residential buildings located in Islamabad, Pakistan were selected as case studies. Then the architectural 3D models of the selected case studies were created by using Autodesk Revit, a BIM authoring tool. Once the architectural models were complete, they were then subjected to cloud-based energy analysis in the Revit extension known as Autodesk Insight. Insight then examined the model for a variety of potential scenarios and generated several data sets as a result. Based on the local conditions, three factors were chosen for the optimization measures namely roof insulation, PV-surface coverage, and PV panel efficiency. The panel efficiency in the case of solar panels was kept at 20.4%. An extensive building energy analysis was carried out in four distinct phases. The goal of applying these factors in various phases was to identify the most effective factors and parameters for energy optimization of the case study buildings.

After the BIM-based energy analysis for all case study buildings had been performed it was determined that both R38 and R60 had similar impact on the energy performance of the case study buildings and therefore it is more feasible and economical due to its thinner profile. It was also determined that the energy performance of all case study buildings improved the most after the application of the combined parameters of R38 roof insulation and 90% PV-surface coverage. Cost analysis was performed in the end to determine the economical aspect of the energy optimization measures and it was confirmed that R60 insulation is a more expensive option in comparison to R38 insulation. For PV panels, the cost increases with the increase in coverage area.

Keywords: Facility Management, Building Information Modeling, Building Energy Modeling, Buildings, Sustainability.

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Abbreviations

AECO	Architectural, Engineering, Construction, and Owner-Operated
BAS	Building Automation Systems
BEM	Building Energy Modeling
BEMS	Building Energy Management Systems
BIM	Building Information Modeling
BSI	British Standards Institution
CMMS	Computerized Maintenance Management Systems
DT	Digital Technology
EDMS	Electronic Document Management Systems
EMS	Energy Management Systems
EPA	Environmental Protection Agency
EU	European Union
FM	Facility Management
GHG	Greenhouse Gases
IEA	International Energy Agency
IFMA	International Facility Management Association
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
O&M	Operations & Maintenance
SFM	Sustainable Facilities Management
WWR	Window to Wall Ratio

Chapter 1

Introduction

1.1 Background

The adoption of Building Information Modeling (BIM) is progressing gradually in nations all over the world and is motivated by the potential for enhanced project partner collaboration, design quality, and productivity While some question if BIM has already been able to deliver the benefits promised [1], There has undoubtedly been a lot of work done, and important lessons have been learned along the way, particularly during the design and building phases. Of course, the BIM attitude extends throughout the whole life cycle of a building, from its design through construction as well as operations and maintenance (O&M), and finally to its ultimate demolition. There has been a lot of interest in the study of Digital Technology (DT) in construction methods. Although the use of various DTs in Facility Management (FM) has been expanding, there hasn't yet been a comprehensive analysis of all of the DT research and developments in FM [2]. Compared to the design and construction phases, there has been even less research on DTs and implementation in the areas of renovation, retrofitting, and refurbishing, which are significant components of FM [3].

Yet, the FM and O&M domains in general could use more efficiency and better information management because they suffer heavily from data dispersal [4]. For better information management in FM, multiple information systems are in operation such as Computerized maintenance management systems (CMMS), Energy Management Systems (EMS), Building automation systems (BAS), computer-assisted facilities management (CAFM), and Electronic Document Management Systems (EDMS). During the construction and design of a project, the O&M costs often get neglected by project stakeholders despite research demonstrating that they account for more than half of the overall lifespan costs. This figure can even reach up to 80% for major infrastructure projects such as highways and bridges [5]. According to the British Standards Institution (BSI), O&M includes all aspects of running a building throughout its useful life [6]. FM encompasses all multiple disciplines to ensure functionality, comfort, safety, and efficiency of the built environment by integrating people, place, process, and technology [7]. FM blends people, property, and technology to improve an organization's performance and provide a better experience for consumers and workers. A facility's physical and functional attributes can be represented digitally in a building information model [8].

The use of BIM also helps in improving energy efficiency in buildings [9, 10]. Although least commonly used, the aspect of BIM known as BIM 6D enables simulation of the building's actual energy behavior and can result in an energy savings of 50% in general [10]. BIM at present offers one of the most promising techniques to attain digitization in the construction sector. While most projects, whether in business, government, or research are focused on the use of BIM in the planning or building phases, effective use of BIM for FM and energy modeling is relatively uncommon [10]. This research focuses on the usage of BIM for FM and in the process endeavors to identify the basic information needed for an efficient BIM-enabled Building Energy Model. FM has become one of the fastest-growing professions in the past three decades [11]. The decisions taken by a facility manager can have a positive or negative impact on the environment. The facility managers are at the forefront of organizational behavior change and are in a position to affect the behavior of people working at all levels of business where they are responsible for managing facilities [12]. The role of FM is of paramount importance for the sustainability of any facility [13]. The use of FM for space occupancy enhances the overall operation and increases occupant satisfaction [14]. FM is critical for the efficient running of an organization, but there is still an opportunity for the discipline of FM to grow in terms of sustainability, and a building's negative impacts on its occupants and the environment can be minimized through sustainable facilities management (SFM) [15]. The requirement for efficiency and adaptability is increasing in FM due to maintenance, complicated systems, and expected resource efficiencies. Meeting the demands of the sector, however, has proven to be nearly impossible due to limited human and mechanical resources. The value added by digitization will help firms get past the problem of having insufficient resources to meet demands, particularly in the healthcare industry [16].

A greater emphasis is laid on adequate consideration of end-user demands and information accuracy [17]. Frameworks of both processes of FM and BIM have been examined to identify the possible constraints (26), which were then improved through semi-structured interviews with certified industry and academic experts. The research concluded that the industry players must devote extra resources to assist overcome the constraints so that a wider deployment of BIM for FM is ensured [18]. Buildings consume a significant quantity of nonrenewable energy, resulting in negative environmental consequences thus raising concerns about buildings' energy efficiency. BIM could be used to estimate and simplify the energy requirements of such buildings [19]. BEM technologies and methods may be used to simulate and assess building energy performance [20]. Even though there remain some obstacles to effective integration into FM and (O&M), the majority of people endorse the advantages of a BIM integration and are calling for action.

1.2 Research Motivation and Problem Statement

The most time-consuming and costly components of a building's life cycle are its operations and upkeep. FM operations that are properly set up and implemented using efficient and effective approaches may assist in increasing the lifespan of the buildings and delay their degradation. Throughout a project's life cycle, facility information is generated and updated continuously, impacting both the present and future state of a particular facility's features. Therefore, it is of paramount importance for the facility managers to keep up-to-date information regarding the building to improve their services and enhance the facility's life. It is a very known fact that the construction sector is one of the world's top energy consumers. The energy consumption by buildings during the past decade has considerably risen and has resulted in the 28% of the total CO_2 global emissions [21]. Because residential buildings are known for consuming the most energy [22], by renovating these buildings, there is a significant chance to save energy. Thus, the problem statement is as follow;

The amount of energy used by the building industry over the last few decades has significantly increased, with residential buildings being the largest consumers. The rising energy demand is not only causing a depletion of natural resources, but also a rise in utility costs, which place a significant financial burden on inhabitants. One of the key causes of conventional buildings being the biggest consumers of electrical energy is also their ineffective energy efficiency measures. If used for energy retrofitting of existing residential buildings, BIM-enabled energy optimization supported by its BIM energy analysis can aid in reducing energy consumption and help facility managers in resolving issues with building energy analysis/optimization, thus helping in realizing the dream of sustainable energy use in the future.

1.2.1 Research Questions

- How much energy optimization factors impact the efficiency of the buildings with respect to the ASHRAE 90.1 standard benchmark?
- How is the building's orientation with respect to north influencing their energy consumption?
- What is the impact of Roof Insulation on the energy performance of the case study buildings?
- How much the factor of PV-Surface Coverage impacts the energy performance of the case study buildings?

- What parameters of the energy optimization factors improve the energy performance of the case study buildings the most in case of combined application?
- What will be the cost of the proposed energy optimization measures?

1.3 Overall Objective of the Research Program and Specific Aim of this MS Research

The overall objective of this research programme is to emphasize the significance of integrating BIM based BEM into FM practices to maximize energy efficiency of our buildings and thus contribute towards a sustainable future.

The specific aim of this MS research work is to develop building energy models of selected case studies to accomplish energy optimization using BIM.

1.4 Scope of Work and Study Limitations

Three residential buildings were selected as case studies, and their building energy models were created that predict each building's energy usage. All the selected case study buildings were energy efficient buildings and this research attempted to further optimize their energy performance. The energy analysis of the models was then carried out to assess the operational energy of the buildings in the form of the Energy Use Intensity (EUI) value, which is the standard benchmark of building energy usage. The 3-D models are developed using Autodesk Revit and Autodesk Insight. These two software are finalized because there are no inter-operability concerns. When there would be no inter-operability issues among two software then the data communication between them would be a seamless procedure without the need for manual information exchange or data transformation [23]. Autodesk insight generates results based on different factors that can impact the energy performance of the building such as roof construction, PV surface coverage, PV-panel efficiency, PV-payback limit, building orientation, window to wall ratio, windows shades, window glass, wall construction, infiltration, plug load efficiency, daylighting and occupancy controls, HVAC, operating schedule, and lighting efficiency. Based upon the local conditions, three factors i.e., Roof Insulation, PV- Surface Coverage, and PV – Panel Efficiency were chosen as energy optimization measures, as particular consideration must be paid to the geographic location and climate conditions when choosing the energy optimization factors [23]. These optimization measures were selected because Roof insulation and PV solar panels together offer a feasible and cost-effective solution to improve the energy efficiency of residential buildings [24]. Priority is given to roof insulation while retrofitting older buildings since they frequently have old, poorly insulated roofs composed of a variety of materials, many of which also need repair work to provide appropriate weather protection. As a result, cooling and heating needs are raised [24]. Moreover the PV panel's efficiency determines how much electricity can be generated from solar energy [25]. After implementing these optimization strategies, the energy consumption of the buildings was assessed again to record any changes in the EUI values, which eventually affects the total cost of utilities. The energy analysis was performed for the whole year including all seasons.

The study is only focused on residential buildings in the Islamabad region, and it only takes into consideration the operational phase of the selected buildings. All of the multi-story buildings selected as case studies are limited to eight storeys. The impact of energy optimization measures on carbon footprint of the buildings is not explored. The orientation of the PV panels is not considered in this study. Moreover, the impact of wall insulation on the energy performance of the case study buildings is also not considered in this study.

1.4.1 Rationale Behind Variable Selection

Only residential buildings were included in the energy analysis because they consume the highest amount of energy of all the buildings. Moreover, among the different attributes of FM, energy management entails a huge operating cost and has a direct environmental impact. In light of the growing importance of sustainability initiatives and the rising energy costs, BEM may help facility managers improve energy efficiency which would lead to a reduced amount of energy consumption and overall costs thus contributing towards promoting sustainable energy use.

1.5 Novelty of Work, Research Significance, and Practical Implementation

The building industry significantly contributes to global energy usage. This is one of the factors contributing to the rising need for energy efficiency solutions in buildings. According to the International Energy Agency (IEA), the goal of lowering energy consumption that would influence building performance has made the topic of energy efficiency more relevant globally during the past ten years [26]. Scientists throughout the world are working on BEM to formulate the techniques that would impact an overall decrease in building energy consumption because of the growing need for more energy-efficient buildings [27]. There is a general lack of understanding between FMs, who are professionals in their respective disciplines but are often ignorant of BIM and procedures in building projects, and BIM experts, who almost exclusively have backgrounds in either construction or architecture. However, the FM professionals must provide information input in order to make BIM models useful throughout the operational phase. The entry of such data is typically left to designers since facility managers typically lack competence in using BIM and modeling tools, and designers in turn have little understanding of the ensuing FM needs [28]. The novelty of this study is that there are no best practices in place to direct participants, including owners and FM professionals, through the process of collecting the relevant information for energy optimization. By looking at energy usage and consumption trends in several case studies, this study may be able to help with that issue by aiming to integrate sustainability and FM themes into formal practices.

Since the inception of the BIM development, the advantages of BIM in FM have been predicted, promising an improvement in information flow and productivity. These assertions, however, lack any concrete evidence and are frequently ambiguous when describing how precisely FM professionals may benefit from them [29]. This research attempts to consolidate those claims by utilizing BIM for energy analysis and optimization of the selected case studies. Sustainability and Energy Management is an important aspect of the FM domain and the BEM will help FMs in mitigating energy consumption by supplying them with comprehensive information.

In this contemporary era where there is an increased focus on reducing the exploitation of the planet's natural resources and instead look towards more sustainable alternatives, the findings of this study can help owners and FMs in developing sustainable strategies using BIM for lowering energy consumption throughout the building operations phase which will also result in significant annual monetary savings.

1.6 Brief Methodology

This research is designed for optimizing the energy use in residential buildings by applying comprehensive simulation possibilities and using computer software applications for energy analysis. Data exchange between BIM and BEM software is not a simple process and frequently necessitates manual intervention, which is time-consuming and leads to models that are not optimized and are less energy-conscious. The requirement for manual information interchange between various applications becomes unnecessary when the BIM and BEM techniques are integrated into the same programme [23]. The use of Autodesk Revit thus emerges as a viable and desirable alternative for proper interoperability between the BIM and BEM techniques, utilizing the same software such as Insight 360 for energy analysis, and on this basis, the two software, Autodesk Revit and Autodesk Insight were finalized for energy analysis.

During the literature review, different research studies related to the use of BIM for energy management purposes in FM are explored. Three case studies of multi-storey residential buildings were selected.

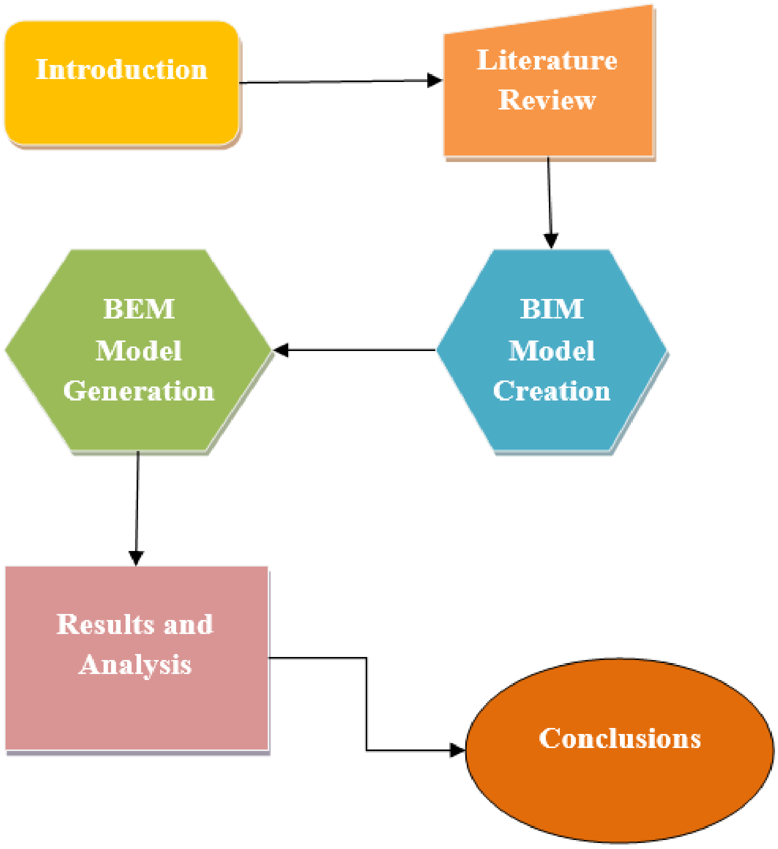


FIGURE 1.1: Methodology Flowchart

Following the creation of their BIM models in Autodesk Revit, the energy analysis for conventional buildings was carried out using Autodesk Insight to determine the operational energy of the buildings in the form of EUI values. The energy analysis was then again performed to track any changes in the EUI value for each building after the optimization measures had been implemented. The findings of the analysis are discussed in detail in the results and discussions section, based on which conclusions are formed and recommendations are made.

1.7 Thesis Outline

There are five chapters in this thesis which are stated as:

Chapter 1: This chapter serves as the thesis introduction and covers the background, research motivation, and problem statement, The overall and specific aim of the work, scope of work and its limitations, brief methodology, and thesis outline.

Chapter 2: This chapter provides a brief literature review of the previous work related to FM, discusses the recent trends in FM, provides the overview of the different attributes of the FM and what role does energy management play in FM. It also analyzes literature relevant to the different tools and techniques used for energy analysis.

Chapter 3: It gives information on the methods used to carry out this study. It describes the tools and techniques used to carry out this research analysis and formulation of results.

Chapter 4: This chapter discusses the results obtained from the energy analysis performed for the different case studies.

Chapter 5: It draws conclusions and makes recommendations based on the research's findings.

Bibliography

Chapter 2

Literature Review

2.1 Background

Energy is a necessary societal demand and is crucial to the socioeconomic growth of any community. It is a fact that the O&M phase of a building project is the longest and accounts for the largest proportion of cost and energy consumption. The phase of O&M is the emphasis of FM. Given the rising focus on sustainability in the modern period, FMs must think about conserving energy and resources while ensuring profitable operations in order to ensure efficient or sustainable facilities. BIM is now often used in the construction industry's design and construction phases. However, the use of BIM in the field of FM is still in its infancy and there is a need to fully explore its potential. This chapter provides a comprehensive review of the relevant literature from the past two decades in order to analyze the recent developments that emphasize the role of BIM for SFM.

2.2 Facility Management (FM)

Since the 1980s, the field of FM has evolved from solitary building maintenance by single individuals to managers in charge of vast portfolios of various buildings. The fact that FM has remained as a term with an unclear definition is partially a result of this progression and the industry's overall diversity. The IFMA's attempt at specification, which is widely acknowledged, is as follows: "Facility Management is an organizational function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business." [7]. A further indication of the diversity of the field is the fact that IFMA identified 11 core competencies (Figure 2.1) of the industry from task analysis and interviews with practitioners worldwide [30].

Figure 2.1: Core Competencies of FM According to IFMA [30]

While IFMA emphasizes collaboration and diversity, Atkin and Brooks [31], stress the potential advantages for business operations by defining FM as an integrated approach to maintain, enhance, and modify an organization's building to promote a fertile environment that promotes the organization's primary goals. Regardless of the point of view, there is general agreement that FM is a multidisciplinary craft that unites experts from a variety of highly specialized domains. These experts are joined by the building facility and the ability to significantly improve its operations. FM thus becomes a point of convergence for data from diverse sectors, and the proper organization, storage, and serving of this data is a significant problem that still has to be satisfactorily resolved. FM is concerned with O&M of a building [32]. Considering that it accounts for more than 80% of the building costs in some cases, FM is crucial for a building, although its significance is frequently disregarded [33].

To assist in successful and efficient maintenance and daily operations, FM offers an integrated approach to sustaining and upgrading a building. The operating period of a building has undoubtedly the highest information flux of any stage during its life cycle [34]. During the handover, the building owner and affiliates get a substantial bundle of information that has been compiled over months of design and construction by several project partners and disciplines. FM professionals then have to rearrange this data from the handover documents for use in later phases of the building life cycle [35]. Additionally, a great deal more information is gathered while the building is being used, including a history of maintenance orders and repairs, incoming mail, information on the building's residents, surveillance footage, sensor data, and much more. During the operating phase, FM teams usually invest a substantial amount of time and effort in acquiring information from various combinations of electronic data and paper documents. In this case, finding, categorizing, confirming, and copying information requires constant repetitious work, which costs a significant amount of money [36].

In addition to construction and environmental quality, the standard of living for many people in residential buildings is influenced by the quality of the facilities inside. The effectiveness of the facilities operation and administration, in turn, determines how well they perform [37]. According to the findings, the FM sector is faced with many significant challenges, including the need for improved data integration and interoperability, greater consideration of long-term strategic goals, increased knowledge management, improved performance measurement, and improved training and skill development for facilities managers to effectively handle the prodigious range of FM services [34]. The efficient and successful functioning of daily operations and building upkeep depends on information. However, the FM industry still struggles with information management, mostly because of the unique nature and fragmentation of information. In the architectural, engineering, construction, and owner-operated (AECO) industry, these two fundamental variables are considered to be the primary contributors to knowledge loss [34].

The existing flaws have not been disregarded, and over the last few years, FM firms have tried to address the problem by producing FM information systems like CMMS, EDMS, EMS and BAS [38]. CMMS are employed by facility managers to keep their building information up to date [39]. The CMMS systems, which are in charge of handling the database of details relating to maintenance and human resource operations, are a key component of this technological stack [40]. The market for CMMS is noteworthy because it is marked by a significant variety of individual solutions, a relatively small number of major software corporations serving a worldwide market, and a considerable number of local players. No matter what, every CMMS addresses a certain set of essential functionalities, such as task scheduling, asset management, work order management, and inventory management.

Computerization simplifies asset information collection and retrieval, however, CAFM systems have limitations in knowledge acquisition and automated data analysis [38]. CMMS typically handles the management of data generated during the operating stage. The building itself, as well as the numerous pieces of machinery inside it, contain a significant amount of information that needs to be manually entered into the systems; this is a labor-intensive and error-prone process [41]. BIM is already well-established in the construction sector and has the ability to not only offer spatial context but also automate the time-consuming initial entry of data by extracting operationally useful data straight from the building models [42]. Through the use of a single integrated model across the design and construction stages, BIM has caused a paradigm shift in the management, sharing, and transformation of information [34].

Inferring from the literature that is currently available, it can be said that the discipline of FM serves as a nexus for several specialized fields. Given that a building's operational phase has the biggest informational influx and nearly accounts for 80% of the building's lifecycle costs, FM is extremely important. Numerous information systems, such as CMMS, BAS, and EDMS, have been used to simplify the information management processes, however they have not entirely succeeded in solving the issue. As a result, by automating the procedures involved in information management across the many stages of a building's lifecycle, BIM in the modern era has the potential to revolutionize the FM industry.

2.2.1 Attributes of Facility Management

FM is an interdisciplinary business function that unites various disciplines under one heading to ensure the efficient operation of the organization. For a building to operate effectively in the stages following occupancy, FM is crucial. FM has historically been associated with cleaning, repairing, and maintaining buildings; however, today it refers to "an integrated approach to maintaining, improving, and adapting the buildings of an organization to create an environment that strongly supports the primary objectives of that organization." [43]. According to Lavy and Shohet [43], the following attributes are essential to the effective implementation of FM: service needs administration, service planning, service performance evaluation, supplier and contractor management, health and safety procedures, risk management, and service coordination.

According to Pittet et al. [44], FM refers to a broad range of services, including supply management, domestic services like cleaning and security, property management, financial management of the building, human resources administration associated with the building, health and associated risks of the building, and maintenance. The collaboration of several players from various fields, including architects, civil engineers, plumbers, etc., is necessary for an FM project. Teams work independently from teams in other areas to establish several business processes throughout such initiatives.

The five primary disciplines of FM, according to Kim et al. [45], are goal setting, operations, human resource management, monitoring and evaluation, and community involvement. BIM enables the capture of data produced during multiple phases, such as maintenance history, warranty and service information, quality metrics, assessments and monitoring, emergency plans, and other information to be used in various FM areas like O&M tasks, environmental assessment, and energy analysis simulation, thus minimizing errors, duration, and costs [46]. IFMA lists 11 key competencies for FM, including occupancy and human factors, O&M, sustainability, facility information and technology management, risk management, communication, quality and performance, leadership and strategy, real estate, project management, finance, and business [30]. Demirdöğen et al. [47], determined that the building's FM phase, which includes workspace planning and management operations to ensure business continuity, accounts for 60% of the overall life-cycle expenses.

Building information from a BIM model may be utilized in FM to create layouts, charts, or other visual representations of a building's state that can be shown digitally or in printed form. The control of energy usage, facility security, and the monitoring of maintenance and repair work are only a few examples of the various FM-related uses for this [32]. All FM organizations around the world have a great interest in improving facility for existing buildings. Housing project owners, planners, and developers are keen to improve the quality of the upcoming projects based on feedback from the facility's present inhabitants, especially for recurrent projects. There hasn't been much study linking occupant needs and satisfaction to FM practices or the design of upcoming facilities [48].

Martin et al. [49], highlighted that to ensure the functioning, safety, comfort, and integration of people, places, and technology, FM, one of the AEC/O fields, is in charge of overseeing the operational period of buildings or infrastructure and associated functions. BIM and other semantic technologies are useful in this situation. The FM domain may be divided into many services and competency clusters based on research done by several scholars. Different approaches (insourcing, total FM, public-private partnerships, etc.) are used to carry out these activities, although outsourcing is the most common one. O&M services are a crucial component of the competence areas. Its goal is to enable the facility and its necessary systems to operate effectively, consistently, safely, and securely in compliance with existing laws and standards. Building maintenance tasks necessitate the use of an extensive information system to store and retrieve information about different building equipment. BIM may be viewed as a tool or a strategy for overcoming information management difficulties throughout the life cycle of a building.

BIM enables users to get extensive information represented by objects and their properties; it is semantically based and object-oriented; it features 3D modeling capabilities. gives different data sources a uniform platform for use in everyday

O&M tasks, allowing for the integration of data on technical specifications, scheduled operations, and building performances (simulated or observed) to speed up decision-making [50]. Godinho et al. [51], also identified some of the FM operations, such as scheduling preventative maintenance or disaster and emergency preparedness, and concluded that using 7D BIM for them may be beneficial. According to Ng et al [52], one component of FM is the utilization of shared facilities, which benefits both the user and the supplier by allowing the supplier to make more effective use of the space available to them while also saving money. The role of a facility manager involves combining many daily operations, including management of business operations, health and safety, code compliance, energy management, and sustainability management [53].

According to Wei and Akinci [54], current work on FM has emphasized using location-based services (LBS) to support on-demand accessibility to model information and on-site documents. For FM services that are location-based, quick and reliable indoor localization is crucial. Moreover, Yuan et al. [55], noted that the automated classification of building materials has been a prominent study topic throughout the last few decades due to its value in facility and construction management. There is a need for an integrated platform that can handle information spread across numerous databases and accommodate the diverse activities in the various phases of FM. The speed of updating databases during O&M phases is expected to decrease by 98% thanks to developments BIM [56]. The fact that O&M consumes the most time out of all the building phases places FM in a very important position. Asset management, preventative maintenance scheduling, energy efficiency and sustainability, retrofits, reconstruction and renovation, lifecycle management, and space management are just a few of the different areas of FM that are crucial for the successful operation of a facility.

2.2.2 BIM Enabled Facility Management

Buildings are becoming smarter, and so consequently the technologies used to operate them are also advancing. BIM is a process-driven technology used to map and quantify a building's physical attributes and it is fast becoming one of the most popular technological tools that organizations can use nowadays. BIM can be used for everything from building design and construction to facility maintenance. The primary objective is straightforward: quantify as much of a building as possible and use the information to help with better FM decisions. Since its inception, the advantages of BIM in FM have been predicted, promising an improvement in information flow and productivity. These assertions were frequently ambiguous in how specifically facility managers would profit from them and lacked any concrete evidence to support them. 22 in-person interviews and 77 online surveys with FM experts were conducted by Gerber et al. [38], in an initial effort to consolidate these assertions. The study's primary goals were to: identify prospective FM application areas for BIM; define the needs for data sharing; assess the implementation of BIM in FM in its current state today; and, lastly, identify problems and constraints. Gerber et al. [38], discovered a list of potential BIM FM uses (Figure 2.2) that were either endorsed by BIM users or users outside the domain, they suggested that the following be implemented first among these: locating components, enabling real-time data access, evaluating maintainability, and automatically generating digital assets. These elements touch on some of the more pressing issues in the FM field, notably making implicit information, concealed in people' areas of expertise, explicit and switching from a reactive to a preventative style of facility maintenance.

BIM models are preferable to conventional two-dimensional CAD drawings because they are displayed in three dimensions, include more data parameters linked to their components, and are created to be inter-operable across disciplines. The representation of a building's physical and functional attributes is a crucial component of BIM. The building's envelope, its mechanical components, its location and orientation, and its dimensions are some of its physical attributes. Structure analysis properties, energy analysis variables (thermal resistance, electrical load, etc.), maintenance records, fire safety evaluations, and FM information are just a few examples of the functional properties of BIM [57]. A BIM model's integration of both physical and functional attributes makes it relevant to several disciplines and promotes cooperation among stakeholders in the development and

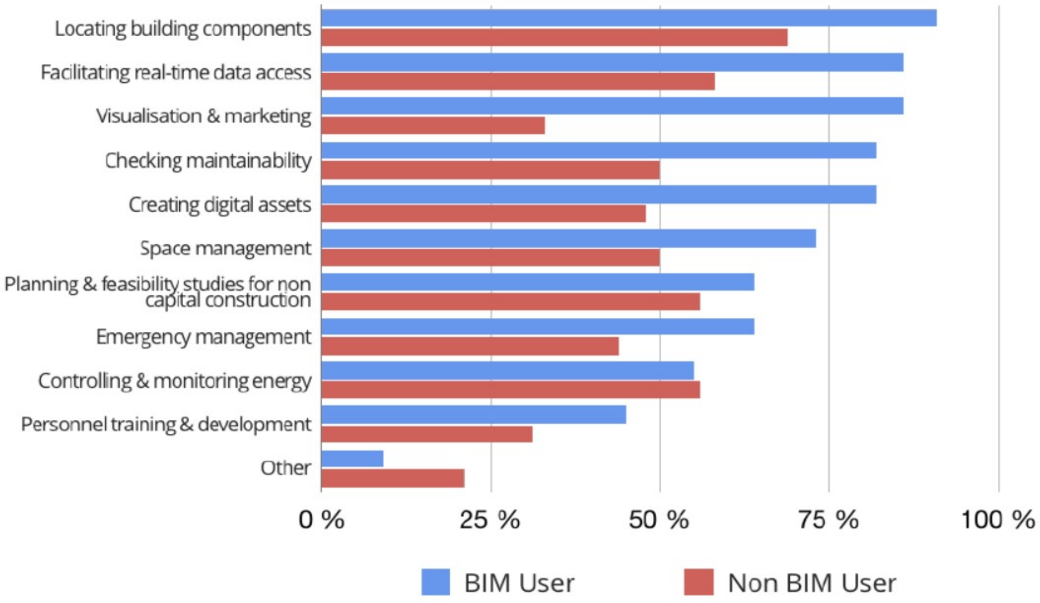


FIGURE 2.2: Potential BIM FM application areas [35]

use of data-rich models of buildings [58]. Construction stakeholders may benefit from a visualization feature using BIM for individual projects so they can see the project's overall state and all of its aspects [59].

BIM technology has typically been applied mostly during the design and building phases of a facility, with fewer uses during the O&M stages. The management of diverse information utilized during a facility's whole lifespan has also been anticipated to be a key function of BIM technology. Traditionally, staff personnel from various disciplines, such as structural, architecture, and MEP, pass along project documentation (mechanical, electrical, and plumbing). Conflicts may arise as the life cycle advances along if the building documents are misread due to differences in knowledge. BIM offers data-enriched 3D models that offer details for every stage of the project life cycle [60].

BIM may be used during all stages of a life cycle of a building, which are categorized as design, construction, O&M, and retrofit & renovation [61]. Although BIM is a useful tool for all stages of a building's lifetime, the O&M phase of a facility can benefit most from its use as the O&M phase has a significant impact on a building's overall life cycle cost [62]. Additionally, it can be expensive when there is a lack of compatibility across various software applications, with the O&M phase accounting for two-thirds of the interoperability expenditures [63]. To facilitate a more seamless transfer from design and construction to the building's owner for facilities management, BIM is typically developed with this issue in mind. A BIM model should ideally provide a credible database for facility managers to access and evaluate data, store crucial information for many stakeholders, and enable a smooth transfer across various phases [39]. Information is the most significant FM necessity, and the intrinsic power of BIM for FM is often associated to facilitating and improving data and information handover to team members of the FM staff [64].

It is clear from prior research and industry adoption that there are several advantages to combining BIM with FM. An FM-ready BIM model can be helpful for commissioning and closeout, quality control and assurance, energy management, repairs and maintenance, and space management [38]. Even though BIM has mostly been utilized for design and construction, there is growing interest in employing BIM models for FM. When used during the operating phase, BIM models also tend to increase a facility's sustainability. Chong et al. [65], reviewed BIM for sustainability and discovered that real-time FM-enabled BIM systems can assist in improving existing buildings efficiencies by reducing energy consumption. Additionally, as BIM is recognized for speeding up the retrofitting process, facility owners who wish to promote increased energy efficiency might employ BIM for sustainable design principles while renovating a building [66]. The visualization capability of a BIM model containing facility data is another benefit of FM coupled with BIM, Its ability to combine information that is typically dispersed onto a single platform, reduce data duplication, provide rapid access to stored data, and provide a spatial perspective through visualization is a remarkable advantage [32].

While most prior research for BIM was concentrated on the design phase, the latest studies for BIM increasingly cover FM, which encompasses maintenance and renovation throughout the operation phase [67]. Numerous studies have examined how FM-enabled BIM might be utilized for certain scenarios as research leans towards using BIM in the operations phase [68]. Three scenarios—daily O&M, emergency

O&M, and statutory evaluation were examined in a study by Lu et al. [62], to compare traditional O&M procedures with BIM-assisted processes. As compared to the BIM-assisted method, the old procedure had a significant drawback in the form of dispersed information. Because of this major inefficiency, several information acquisition activities in the conventional process took longer to complete than they did in the BIM-assisted process. In the old method, many tasks were repeated by the staff, which points to substantial inefficiency. The traditional method also had a problem with finding the right facility information among dispersed files and having to confirm it. This occurred because floor plans were kept as their original hardcopies or incomplete CAD drawings, whereas facility data was kept in spreadsheets and hardcopy forms.

Through the employment of O&M procedures that take into account the social, environmental, and economic advantages of all business choices,FM is now moving attention towards a long-term perspective. As the built environment as a whole continues to expand, the FM industry is actively pursuing a sustainable development plan [12]. The three primary pillars of sustainable buildings—economic, environmental, and social benefits—are positively impacted by SFM, which adds value to businesses, organizations, and governments that include SFM in their development direction [13].

AECO sector is progressively realizing the value of BIM as a tool to boost built environment productivity. The implementation of BIM in FM offers exciting potential. With its visualization tools, 4D and 5D capabilities, and capacity to assist sustainability and Life Cycle Assessment (LCA), BIM can help in lowering building energy consumption and promote energy analysis, endorse sustainability and minimize occupational dangers [69]. The ability of a BIM model to integrate both physical and functional attributes of a building make it an attractive option in terms of linking professionals from several disciplines thus fostering cooperation among all the stakeholders that may contribute heavily towards a data-rich model of the facility. The traditional information gathering processes are tedious and time consuming. BIM expedites the information acquisition and extraction processes thus showing the potential to make the discipline of FM more efficient.

2.2.3 Sustainable FM

Sustainability in the context of FM includes, among other things, activities with minimal negative environmental impact and the supply of space that is cost-effective in the long run. The facility may need to continue operating for several decades in a setting where demand to cut energy use and, consequently, carbon emissions, is projected to grow rapidly. An organization should adopt a long-term perspective on the operability of any facility so that it is aware of its commitments and liabilities going forward. Sustainability is establishing a balance between the needs of the environment and modern lifestyle demands. Competition for limited resources has led to increased global pressures, and mounting evidence of climate change is focusing attention on strategies to lessen human impacts. Long acknowledged as essential, increased energy efficiency is now accompanied by a greater awareness of environmental issues [31]. These and other difficulties are faced by businesses and their FM as they work to make their facilities compliant, functional, and economical. It is now expected of facility managers to contribute information on energy use and savings, as well as other sustainability-related topics. When retrofitting a building, facility owners aiming for increased energy efficiency might employ BIM in conjunction with sustainable design concepts [70]. When compared to the construction phase (21%) the building's operating period has a greater influence on the environment (up to 85%) [71].

Moving towards more sustainable facilities that can anticipate and accommodate changes in functionality and end-user requirements calls for innovative thinking and solutions. The world population expanded five times between 1850 and 2010, while per capita energy consumption climbed eight times as well [72]. The evaluation of a building's carbon footprint is a part of its whole LCA process. 33 % of the world's GHG are attributed to buildings, and 85.4 % of these emissions are produced during the building operations phase. Because BIM can offer much of the data and mathematical tools required for carrying out a LCA, it can be useful in expediting the assessment of carbon emissions across a building's life cycle [73]. A rich supply of the engineering data required for LCA may be provided by BIM. Additionally, during a building's whole life cycle, the stage of O&M is most crucial for reducing GHG [74]. The world's future depends on significantly lowering consumption, protecting natural resources, and adopting sustainable lifestyles. Energy efficiency, water savings, recycling, air quality, pollution control, vehicle and transportation reductions, and ecological site layout are conventional sustainability management approaches in FM. The sustainability of a facility is also greatly impacted by sustainable maintenance and procurement. Organizations should create meaningful, quantifiable sustainability initiatives and implementation strategies with clearly defined targets while keeping a sharp awareness of the need to achieve a balance between corporate needs and social and environmental responsibilities [75].

In comparison to the numerous sustainable design and construction initiatives, greater consideration needs to be given to the integration of the sustainability agenda through FM techniques in the O&M phase. Based on its influence on the LCA of a building and its possible negative effects on the environment, O&M is a crucial phase [76]. Few managers are able to embrace sustainability concepts completely and integrate them into their operations because sustainability practices in the FM sector are still in their infancy. Previous research has found many obstacles, including a lack of information, a gap between capability and skills, and a resistance to new practices among FM personnel and organizations. Since professional capacity is essential to create competency and encourage the sustainability agenda in an organization, the knowledge gap, lack of sustainability expertise, and difficulties encountered in the process of knowledge transfer are underlined in particular [77]. Since FM established itself as a discipline and profession in the building and real estate sectors in the late 1980s, its influence has been steadily expanding. In contrast to O&M, which is focused on activities occurring in buildings to support an organization's core business, the creation of FM as a discipline signifies a paradigm shift. The FM's scope has expanded to cover building O&M as well as real estate development and both short- and long-term building usage [78].

Facility managers can have an impact on the design process, resulting in buildings that are better adapted to address business goals, more appealing to clients, easier to commission, maintain, control, and administer, more cost-effective to operate, and better able to meet tenant needs [79]. Despite the chance to advance the sustainability agenda and make meaningful and noticeable impacts, the FM profession currently lacks convenient access to the specialized expertise, tools, and accompanying case study resources required to make this a reality [80]. The organization's sustainability goals can be accelerated through the effective use of human resources [81]. Organizations all over the world are emphasizing the need to reduce GHG as a result of the approaching threat of climate change, which has forced a worldwide response to the challenge across every domain. Professionals in FM are under growing pressure to consider the oper-ability of any facility in the long term. The world's per capita energy consumption has multiplied since 1850, and because the non-renewable resources available on Earth are relatively limited, this exploitation cannot continue indefinitely. It is, therefore, necessary for the facility managers to develop policies that contribute towards promoting energy efficiency and sustainable lifestyles among the different communities.

2.3 Role of Energy Management in FM

Facility managers are now beginning to embrace the idea of smart energy management as a way to monitor and control an organization's energy usage and ensure that it is used more efficiently as they become more aware of the environmental impact that their buildings have. Tracking and lowering energy consumption can result in significant cost savings, lessen the impact of rising energy prices, and also benefit the environment in this time of climate emergency. Establishing an energy management strategy is one of the most promising ways to cut down on energy use and associated costs [82]. It is rather an uncomfortable fact that buildings are responsible for around 40% of global energy consumption [83]. The management and administration of a company's energy system are extremely important to position that firm as the market leader within its industry over the long term [84]. One of the most important and complex issues for sustainable development is the need for energy. Given the rising standard of living and the population's ongoing growth, it is clear that the rise in energy demand is an unavoidable trend. The major causes of the rising energy issues that every city will have to address are the ongoing rise in energy consumption and the depletion of traditional energy resources. Meanwhile, a variety of time-consuming and tedious jobs have been automated as a result of the constantly rising energy demand and humans willingness to constantly raise their quality of life [85]. One of the sectors with the fastest rising energy consumption is buildings. According to estimations, 40–45% of the total energy consumed by buildings in the European Union (EU) is utilized for residences, making up around two-thirds of the total. The residential and tertiary sectors' annual energy consumption growth rates are 1.0% and 1.2%, respectively, in the present decade. Energy use in the above-mentioned EU sectors is therefore to blame for almost 50% of the emissions of GHG [86].

Roof is an important component of the buildings envelope that plays a critical role in the conductivity of thermal loads across the buildings therefore affecting its energy performance and efficiency. The effect of a roof structure of a building and climate on energy use is closely related [87]. The thermal load on a building is often highest on the roof, making it an excellent choice for insulation. In addition, compared to wall insulation, the payback period for roof insulation is shorter. It is advised to apply extensive insulation as rooftops are often exposed to sunlight for the most of the day [88]. When choosing an insulation level for the building's roof, too little insulation still results in higher energy consumption, while too much insulation may be too expensive compared to alternative ways to reduce energy usage. Applying an appropriate amount of roof insulation is therefore crucial [24]. Overall, the retrofit of the roof has been noted to have a better impact on the building's energy performance than the retrofit of other building envelope components [89]. It is preferable to combine PV generation with roof insulation at the same time [90]. Although the cost of insulating material rises as insulation material thickness grows, the cost of heating and cooling decreases [91]. Keeping in mind the performance and economic implications, a thorough assessment should be done before the selection of the insulation material.

PV systems efficiently increase existing buildings' energy efficiency [92]. Buildings may reduce their reliance on the electrical grid by placing solar panels on their rooftops. Considering three levels of roof coverage for the buildings—50%, 75%, and 100%, Franzoi et al. [93] concentrated on energy communities at the size of apartments and buildings and found that PV-panels coverage contributed to self-sufficiency and self-consumption in the communities. To optimize the energy performance of their buildings, Al-Saeed et al. [94] investigated the impact of 60%, 75%, and 90% PV-Surface Coverage. They investigated the options of 16%, 18.6%, and 20.4% for solar panel efficiency. They came to the conclusion that the use of PV panels resulted in a significant decrease in the primary energy consumption and that higher PV panel efficiency leads to additional design improvements in energy performance. Using an Autodesk Revit plugin, Kumar et al. [95] examined the effects of PV surface coverage of 75% & 90% on an institutional building. In order to obtain the most optimum level of energy efficiency in their research, Amani and Soroush [96] employed photovoltaic solar panels with a yield of 20.4% and surface coverage of 90%, and the payback limit of the panels was set as 30 years. PV panel energy production is mainly impacted by the local climate, roof design, tilt angle, and panel orientation among the other factors [97]. It has been observed that a solar panel's orientation angle affects how much energy it produces throughout the day [98]. The key to increasing economic efficiency is to optimize the orientation of the PV panels [99]. Their azimuth (orientation) and tilt angle have a considerable impact on the amount of solar radiation striking the solar panels. In general, solar panels are pointed towards south in the northern hemisphere and towards north in the southern hemisphere [100].

Residential and commercial buildings have been using more energy on a consistent basis recently, mostly because of their HVAC systems. The amount and quality of the energy used every day in buildings is influenced by expected energy loads, transportation, storage, and user behavior. But with the advancement of technology, it is now possible to precisely monitor, gather, and store the vast amounts of data generated by this process, and the use of data science methods to improve energy efficiency is presently generating a lot of interest. Data science is being employed to solve issues like the following in the field of building energy management: predicting energy demand to adjust production and distribution;

analyzing building operations and equipment conditions and failures to reduce operation and maintenance expenses [101]. Reduced energy demand will result in lower prices, lower carbon emissions, and less use of energy (gas and/or electricity) [31]. In many regions buildings facing north are found to be very energy efficient [102]. The solar gains are significantly influenced by the building's direction. In all climates, it has been determined that north or south is the optimal orientation. The optimal orientation is a crucial component of the architectural design of the building since it improves energy efficiency without requiring additional expenditure [103]. The IEA predicts that direct building CO_2 emissions must fall by 50% and indirect building sector emissions must fall by 60% by 2030 to minimize greenhouse emissions and reach a net-zero carbon building stock by 2050 [104].

One of the popular optimization technique for lowering building energy usage is the installation of thermal insulation on the exterior walls of the existing buildings [105]. The wall is a crucial component of the building envelope and a significant contributor in capturing up to 25–30% of thermal energy loss. For this reason, it is essential to enhance the thermal performance of outside walls through thermal insulation in order to obtain energy efficiency [106]. Wall and roof insulation are important when it comes to insulating the building envelope's components, however roof insulation has more importance and delivers better results in comparison to wall insulation since it is more directly exposed to sunlight, especially in the summer [107]. Lighting, electrical devices, and HVAC systems also account for a fair share of the building's energy use. According to several assessments, the building uses a significant amount of its energy for internal climate control [108]. By improving the performance of HVAC systems, it is possible to cut energy consumption by 50% while keeping a generally comfortable indoor environment [109]. As part of efforts to conserve energy and protect the environment, buildings should use less energy for space cooling. Energy expenses for HVAC are highly influenced and greatly reduced by thermal insulation therefore making it a highly recommended and prioritized choice for energy optimization [110].

Moreover, enhancing the building envelope's insulation is given the highest priority in the majority of building codes for energy efficiency [111], and roof insulation is said to offer the highest potential savings and better results when compared to insulating the other parts of a building envelope including walls [112]. In the present period, the construction industry and building codes are primarily focused on decreasing operational energy by extensively retrofitting all existing buildings and generating renewable energy [113]. It has been determined that roof insulation along with PV-panels offers the most feasible and economical options for the energy optimization of existing residential buildings [24].

According to estimates, 70% of existing buildings use more energy than is necessary for their operations. Cutting back on energy use not only results in financial savings but also increases equipment life, thermal comfort, indoor air quality, productivity, and labor costs, all of which relieve facility managers' workloads and make a contribution to the building's effective operation [114]. Over 48% of Pakistan's total energy consumption is made up of the domestic (also known as residential) sector demand [115], 18% of energy is used by hospitals [116], while around 27.5% of the energy is used by industrial sector [117]. Numerous studies from multiple countries have established that the majority of their building stock is made up of residential buildings [118, 119]. It is therefore critical to enhance the energy performance of residential buildings, which will subsequently lead to a decrease in the amount of energy used on a global scale. Despite the urgent need to combat climate change, global energy usage and the associated CO_2 emissions are still rising [120]. Due to their tremendous potential to increase energy efficiency and produce renewable energy, buildings have a huge influence on the environment and are at the forefront of climate change policy [121]. However, the development, assessment, and oversight of these regulations could only be successful if energy data were accessible, not just for the entire sector but also for different building types and energy services. Unfortunately, finding information about buildings among the available sources is rather difficult. Fewer studies have been done on this sector than on industry or transportation due to issues with data collecting and elaboration [122]. Users and owners may better understand their patterns of consumption and find cost-effective energy-saving solutions by breaking down building energy consumption into energy services, often known as end-uses [123].

Via heat exchange (conduction), solar heat gain (radiation), ventilation (infiltration), and daylighting, window-to-wall-ratio (WWR) influences a building's energy usage and occupant comfort [124]. Throughout a building's life cycle, WWR has a significant impact on many design and performance elements, including aesthetics, material utilization, daylighting, HVAC size and operational energy usage [125]. It has been noted that using tempered glass instead of clear glass decreases the necessary cooling and heating demands for single and double-pane windows. An increase in glass thickness for a single-pane window decreases the heating load substantially while marginally raising the cooling load [126]. Windows and shading systems play an important role in building energy savings as they are a major energy-consuming component of the envelope [127]. According to several studies, effective lighting controls may substantially save annual energy use [128]. Plug loads, or the energy used by devices plugged into outlets, have a big influence on how much energy a facility uses all together. Therefore, it's necessary to manage this area of rising electricity usage to promote energy security [129]. Numerous occupant characteristics, such as the number of occupants, have varying but major impacts on electricity use. By modifying only the tenants' behavior, the total energy usage for a building can be reduced by 10–30% [130].

To reduce wasteful behavior through an energy-efficient use of resources, individual habits are crucial. By 2100, low-energy practices, which include new technological options and new usage habits, might cut the energy consumption of buildings by more than 10% [131]. Using building simulation modelling, Fang and Cho [132] examined how to improve the energy efficiency of a case study building in three cities with different climatic conditions. They found that the three cities' average EUI values for energy performance were 121.1 for Miami, 87.0 for Atlanta, and 127.7 for Chicago. They noted that Atlanta's EUI was significantly lower than that of the other two cities. In terms of EUI, Atlanta's average value was lower to Miami's and Chicago's by a number of 34.1 and 40.7 , respectively. Agdas et al. [133] found a difference of 5.52 between the EUI values of LEED buildings (172.64) and non-LEED buildings (178.16) during their energy use assessment of buildings but considered it to be not significant and determined that the EUI values were comparable. When evaluating the energy efficiency of buildings, the differences of

30, 50, and 100 in the EUI values for different buildings were termed as significant variations by Yik et al. [134]. According to the United States environmental protection agency (EPA), Residential, Commercial and Industrial customers each accounted for roughly one third of the US electricity consumption. Whereas the transportation activities accounted for less than one percent of the total electricity use however this figure is expected to rise with the introduction of electric vehicles [135]. The electricity consumption breakdown can be seen in Table 2.1.

Table 2.1: Electricity Consumption by Sector in US [104]

Sector	**Electricity Use (%)**
Residential	37
Commercial	35
Industrial	27
Transportation	0.2

Except for time-of-use tariffs and incentives for adopting efficient technology, governmental actions are rarely ever used to bring about these improvements. Buildings Energy Management Systems (BEMS) might contribute significantly in two ways in this regard. By spotting inefficiencies, benchmarking, and scheduling load and energy consumption, metering would, on the one hand, give users information to enhance buildings' efficiency and spot areas for cost-savings [136]. To lower energy use and CO_2 emissions, it is critical to make our buildings more energy-efficient [137]. The rise in energy demand is a trend that cannot be avoided given the improving standard of living and the population's continued growth. Buildings are among the areas where energy use is increasing most rapidly. To ensure that the energy performance of their facilities is within established boundaries, organizations must take the initiative. As per estimates, 70% of current buildings consume more energy than is required for their operations therefore buildings are at the forefront of climate change policy and have a significant impact on the environment due to their enormous potential to boost energy efficiency and produce renewable energy. This places a significant amount of responsibility on facility managers to be aware and knowledgeable about the energy performance of their buildings to recognize potential improvement areas and thus reduce consumption for improved energy management.

2.4 Building Energy Modeling using BIM for Energy Management

To help architects and designers comprehend how their choices will affect the environment, BEM aims to quantify buildings' energy performance. BIM is a digital, model-based representation that enables the sharing and use of design-related data among various stakeholders at every step of a building's lifecycle. The development of BIM offers an opportunity to overcome the limitations of traditional BEM, such as long and tedious model preparation, inconsistent models, and expensive implementation, and it encourages the integration of BEM into the digital design process for buildings. Utilizing the BEM technology, which compares and selects systems and subsystems, allocates annual energy budgets, achieves compliance with energy requirements, and reduces costs, is one of the most efficient ways to accomplish building energy efficiency [138]. However, BEM is a complex process that involves a large amount of manual data entry and often requires an expert to do the tasks for accuracy purposes [139]. Also, BEM is not fully integrated and synced with the digital design and planning phases, which leads to poor implementation of energy-efficient approaches in the early stages of design. Furthermore, BEM has not yet benefited from the ongoing flow of information in digital modeling. For example, even though the information required for BEM is already present in digital design models (BIM models), re-entering it manually into BEM tools is deemed to be labor-intensive, time-consuming, and expensive [140]. BIM-based BEM, a revolutionary strategy built on BIM technology, has recently come into existence. BIM-based BEM makes BEM a more efficient, affordable, user-friendly, useful, consistent, and accurate process by creating the input for BEM tools from the pre-designed BIM model (which includes data on architectural design and mechanical loads, material properties, and HVAC system). The goal of achieving a building's energy efficiency is easier to attain when designers use the BIM-based

BEM technique to analyze design possibilities and make decisions regarding design quickly [140]. It was discovered by Sadineni et al. [141], that BIM might be a useful tool for assisting designers in making appropriate material and component choices with higher energy performance in the early design phases. In the study, Autodesk Revit 2018 and GBS were used as BIM and energy consumption assessment tools for examining the impact of various building components on energy performance. The discovered that HVAC systems and the orientation contribute significantly to the energy performance. Singh, P. and A. Sadhu [142] investigated the use of BIM for assessing the influence of the building's components on the energy consumption of the building in a region with a moderate climate. They subsequently found that using BIM to modify the design parameters, which may alter a building's energy consumption, is an efficient strategy to lower energy costs, with the HVAC system often having the most impact.

With the aid of additional building energy efficiency technologies, Motalebi et al. [66], enhanced BIM in some ways. To increase the capability of evaluating the environmental effect and the interaction capacity of BIM, they respectively incorporated LCA theory and Digital twins technology into BIM. The results revealed that BIM performed well in both pieces of study. In light of this, it is clear that identifying important architectural factors that may have an impact on the building's energy performance is essential for the design of green buildings, and BIM contributes to the efficient modeling and energy analysis of buildings. In their study, Tahmasebinia et al. [143], sought to extract energy data and settings from BIM software. Regression analysis was carried out by the researchers using statistical techniques, and the variables' precision was also verified. Throughout the trial, Revit served as the primary modeling tool, and the modeling outcomes from Revit were subsequently imported into Insight & GBS for analysis. It was observed that the WWR percentage had the strongest relationship with energy use. The building's design also directly affects how efficiently it uses energy. Given the same architectural parameters, it was discovered that buildings with diamond shapes use the most energy. The most energy-efficient structures, however, were those with triangular shapes. Because a building's geometry determines both its zone and its perimeter length, compact geometry buildings should be prioritized in design. For the electrical market management to assure grid security and lower financial risks, the precision of building energy consumption projection is of the utmost importance. For a variety of goals, including long-term plans and short-term optimization of energy systems within buildings and the power grid, accuracy and speed of load forecast are essential criteria. Despite the lengthy and repetitious modeling procedure, it is preferable to utilize physical models because of their dependability, interpret-ability, and precision [144].

To achieve a net-zero carbon building stock by 2050, BIM-based BEM is crucial to sustainable design [145]. Mohammed et al. [146], in their research examined the impact of several shading options on the cooling load of Darwin, Australia's town hall building, and recommended the best shade option. The chosen case study building was modeled in Autodesk Revit for this purpose, and the energy was evaluated in terms of heat and daylight. According to the findings, the building's cooling demand was reduced by 5% as a result of the horizontal fins. In contrast, increasing the device's angles and length resulted in an 8% increase in savings. The findings showed that overhangs were more energy-efficient than fins, giving a 9.2% energy savings. With design and length adjustments, the cooling reduction savings grew to 15.5%. To reveal the best external shading devices through a comparison study on the thermal performances of residential building external shading devices. Kim et al. [147], carried out an energy simulation using a computer model generated for Korean residential buildings. The overall amount of energy used by a building is significantly influenced by its envelope. To analyze and enhance the energy-efficient building envelop, modern techniques such as BIM and Building Performance Simulation (BPS) offer sophisticated and affordable solutions [148].

With the help of the BIM Revit software, Fitriaty and Shen [149] were able to calculate the incident solar radiation and color-represent the various levels that were experienced in various parts of the building envelope related to the Sun's path and the impact of the surrounding environment. The findings showed that a building's roof is the best location for PV panels installation due to the roof's high incidence solar radiation levels, which remain largely remain constant throughout the year. Autodesk Revit is among the most popular, effective and inclusive BIM tools. Existing studies reveal that scholars prefer to use Autodesk Revit for analyzing the sustainability and efficiency of the buildings [19]. Sadeghifam et al. [150] used Revit Architecture software to create a case study of a two-story residential building and energy analysis tools (EnergyPlus) to analyze it. The investigation detected current energy consumption patterns, and by replacing components with new energy-efficient materials, the optimum level of energy consumption was identified. The results demonstrated that altering ceilings and ceiling materials is the most efficient strategy to lower energy consumption in residential buildings in tropical areas. In order to enhance the implementation of efficient energy-saving measures, Barone et al. [151] tested the BIM to BEM method as a useful tool for the maritime sector. Autodesk Revit and OpenStudio were used as BIM and BEM tools. The investigation compared several strategies to lower the annual primary energy use at a maritime passenger port in Naples as the case study. The potential of the suggested strategy is demonstrated by the significant primary energy savings (ranging from 24 to 41%) and CO_2 emissions reductions (ranging from 16 to 34 tonnes CO_2/year) for the analysed building.

Analyzing various possibilities to reduce a project's environmental effect is achievable from digital BIM models, which provide details of how the project will operate throughout its useful life. These models enable simulations of electrical energy consumption, material carbon footprints, and the overall energy included in the project to create alternative designs and assess the outcomes taking into account the practicality of the suggested scenarios [9].

BIM is a component of the Industrial Revolution 4.0, which also heavily emphasizes virtual reality and digital twins. A rising interest in lowering buildings' energy use is reflected in the European Green Pact 2050 because they now account for 40% of the energy consumed in Europe. In this regard, achieving acceptable BIM and BEM inter-operability is crucial for integrating the digital world in the construction sector and, consequently, for boosting competitiveness through cost savings [152]. BEM has proven to be a very effective strategy for achieving energy efficiency in our buildings. However, BEM requires a very detailed amount of manual data input which makes it a laborious and expensive process. In recent years, BIM-based

BEM has shown to be a more effective strategy because it does away with manual entry procedures and instead allows BEM tools to draw information directly from the pre-designed BIM model.

2.5 Summary

From the above discussion, it can be concluded that FM serves as a point of convergence for data from many diverse sectors and that FM is crucial since a building's operational phase experiences the greatest informational influx and incurs more than half of the overall lifecycle expenditures. Asset management, preventative maintenance planning, energy efficiency and sustainability, retrofits, reconstruction and renovation, lifecycle management, and space management are just a few of the many attributes that FM brings together under a single umbrella to ensure the efficient functioning of the facility. BIM streamlines the processes for acquiring and extracting information, demonstrating the potential to improve the effectiveness of the industry of FM. Professionals in FM are under increasing pressure to take sustainability into account when considering the long-term operations of any facility and to create policies that encourage promoting energy efficiency, the reduction of carbon emissions in the O&M phase, and sustainable lifestyles among various communities. Buildings are at the forefront of climate change policy because they have a substantial impact on the environment due to their massive potential to increase energy efficiency. This puts a lot of responsibility on facility managers to be aware of the energy performance of their buildings to identify potential improvement areas and subsequently reduce consumption for enhanced energy management. There are a range of options available for energy optimization of buildings including roof insulation, PV-surface coverage, increasing the efficiency of PV-panels, wall construction/insulation, HVAC systems, and lighting controls among others. BIM-based BEM simplifies the process of achieving the goal of a building's energy efficiency by enabling designers to swiftly analyze the design options.

Chapter 3

Experimental Scheme

3.1 Background

This chapter describes the methodology used throughout the whole research process as well as the scientific techniques used in this study to accomplish the intended objectives. Buildings are responsible for approximately 40% of the global energy use and two thirds of the overall carbon emissions. From the previous studies it is uncovered that buildings use 70% more energy than is necessary for their operations. This is quite a worrying situation and demands serious consideration to optimize the energy performance of our buildings. After reviewing the literature, different energy optimization techniques and measures have been investigated by many researchers to enhance energy performance of the existing buildings, however, the energy optimization of existing buildings in the domain of FM has been found to be a particularly unexplored area of study. For this purpose, a BIM-based BEM approach is adopted to optimize the energy needs of the existing residential buildings by considering three factors of roof insulation, PV-surface coverage, and PV-panel efficiency, to evaluate their influence on the energy performance of the buildings. In this chapter, the case study buildings and their specifications, the steps for creation of BIM and BEM models, considered phases and materials, and procedures for the analyzed parameters are discussed in detail.

3.2 Case Study Buildings

The majority of the research literature evaluated utilizes multiple software programs to perform energy analysis and optimization. Though there is a majority of research studies conducted on energy optimization throughout the world they are not specifically linked to the discipline of FM in most cases. This aspect still thus remains a grey area and requires attention. The geographical and climatic conditions significantly impact the energy consumption of the facilities. Even if the construction projects share many common characteristics, the majority of research studies stated in the previous chapter were conducted outside Pakistan. An extensive study is necessary to analyze the energy performance of buildings for a specific country. Three residential buildings located in Islamabad, Pakistan were selected as case studies. The selected case study buildings were energy efficient and this research focused on further optimizing their energy performance. All the case study buildings were limited to eight storeys. The case study buildings were visited in person, and the relevant organizations provided the primary information about the building, including architectural drawings and the type of structures. The aspect of how occupant behavior influences the building energy use is not considered in the study. All the case study buildings are frame structures, and reinforced concrete buildings having partition walls made up of bricks. The buildings specifications are listed in **Table 3.1**. The buildings typical plans, elevations and sections can also be seen in **Figure 3.1**.

3.3 Energy Modeling of Buildings using Revit and Insight

BIM technology is focused on the creation and management of simulated illustrations of a building or facility in a computer-generated environment. BIM provides information about the building's geometry, spatial connections, geographic location, and quantities and attributes. BIM may be used by engineers and architects to quickly study and simulate a variety of design concepts.

Table 3.1: Case Study Buildings Specifications

Buildings	**Total Cumulative Area (sq ft)**	**Orientation w.r.t True North**	**Storeys**	**Roof Area (sq ft)**	**Floor Area (sq ft)**			**Remarks**
					Min Floor Area	**Max Floor Area**	**Avg Floor Area**	
B1	9865	11º Clockwise	B+G+5+M	1312	1213	1414	1366	One & Two Bed Apartments
B2	8790	320º Clockwise	B+G+5+M	1159	1120	1204	1191	One Bed Apartments
B3	17520	141º Clockwise	B+G+5+M	2381	2400	2484	2472	Studio & Two Bed Apartments

FIGURE 3.1: Typical plans and sections of the case study buildings

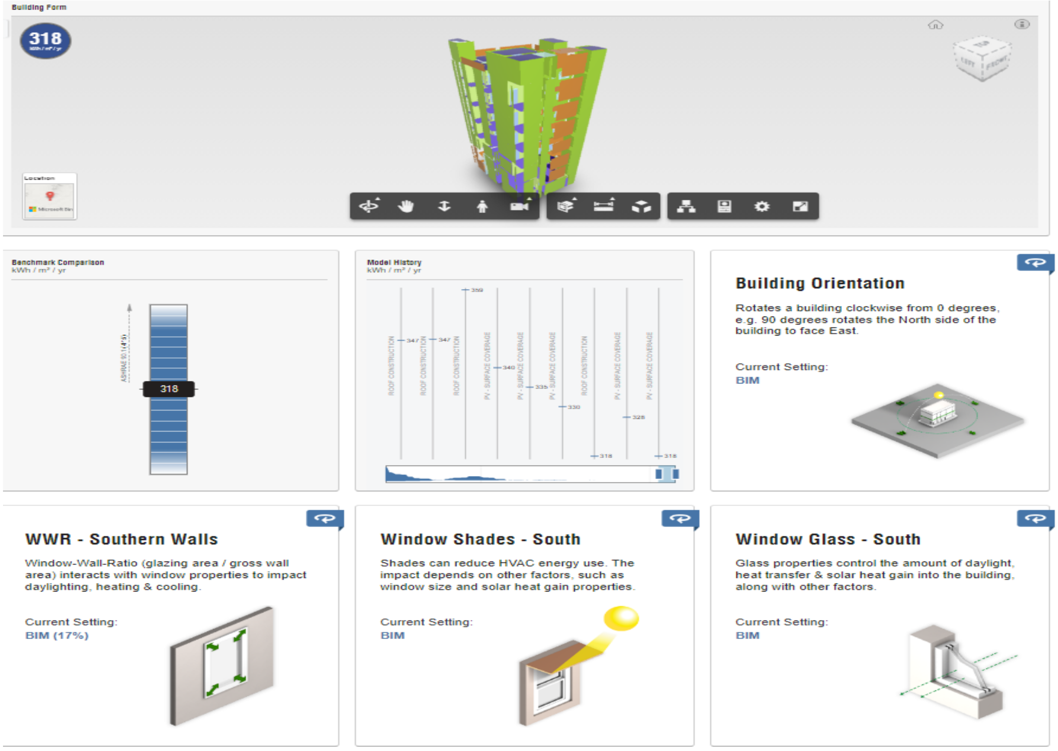
The BIM model may be updated and modified throughout the building lifecycle. The BIM model can then be utilized for various tasks such as Scheduling, Estimation, and, Building Energy Modeling and Simulation. The 2D drawings from each of the case studies that were a part of this study were utilized to create their

3D models on Revit. Then, using the input data for each building, Insight360, a Revit plugin, analyzed the annual energy consumption of these architectural 3D models.

All the 3D virtual models are created using Autodesk Revit. Autodesk Revit is the current market leader and best-known BIM authoring tool for architectural design. Due to the benefits of using BIM technology, which compiles all the data of a real building into a single virtual model, Revit software has become more and more popular in architectural design. The first step in the energy modeling process is to prepare BIM models of the proposed buildings in Revit which is a BIM authoring software. Each model is created in accordance with the original dimensions given in the 2D CAD drawings. Acquiring the architectural drawings and then preparing the 3D BIM models and afterwards their conversion into energy models is a time-consuming task. The 3D feature of Revit, in particular, gives a broad variety of viewing angles and allows for the addition, removal, modification, and ability to observe building components from various perspectives.

After the creation of the BIM model, an energy analytical model was created and that same model was then submitted to Autodesk Insight for a detailed energy analysis. Insight creates the BEM based on a wide range of inputs provided by Revit including location, weather data, and orientation of the building. The model is then examined by Insight in a variety of situations, and a number of options and alternatives are presented to assess and evaluate the building's energy performance. Insight on its interface displays the different factors that can affect the energy performance of the building in the form of widgets as can be seen in Figure 3.2.

Throughout the building's useful life, a BEM may be used as a design tool to forecast the building's energy performance. This tool investigates several possibilities and situations concerning the climatic environment, building orientation, and building envelope material. This helps the relevant stakeholders to make informed decisions to improve the buildings energy performance and achieve energy savings. Using Insight360, the BIM model in this research was transformed into a BEM. Insight tracks the building's energy consumption in terms of Annual Cost



Building Orientation

Rotates a building clockwise from 0 degrees, e.g. 90 degrees rotates the North side of the building to face East.

Current Setting:
BIM

WWR - Southern Walls

Window-Wall-Ratio (glazing area / gross wall area) interacts with window properties to impact daylighting, heating & cooling.

Current Setting:
BIM (17%)

Window Shades - South

Shades can reduce HVAC energy use. The impact depends on other factors, such as window size and solar heat gain properties.

Current Setting:
BIM

Window Glass - South

Glass properties control the amount of daylight, heat transfer & solar heat gain into the building, along with other factors.

Current Setting:
BIM

FIGURE 3.2: Insight Interface

and EUI values. The EUI values have been used throughout this research to assess the buildings' energy performance. Based on literature review, any reduction of 30 or above in terms of the EUI value after optimization measures will be termed as significant reduction, whereas the reduction for EUI values below the number of 6 will be deemed as not significant, whereas the difference between EUI values falling in between 6 and 30 will be regarded as moderate reduction. Both the 3D and Energy Models of all three buildings can be seen in Figure 3.3, Figure 3.4, and Figure 3.5. To submit the architectural model to the cloud-based energy analysis platform, the BEM were developed based on the factors listed in Table 3.2 below. The location of all the case study buildings was set to Islamabad in the energy setting interface.

TABLE 3.2: Inputs for Energy Modeling

Serial No.	Input
1	Libraries/Families (Database)
2	3-D architectural Model
3	Location

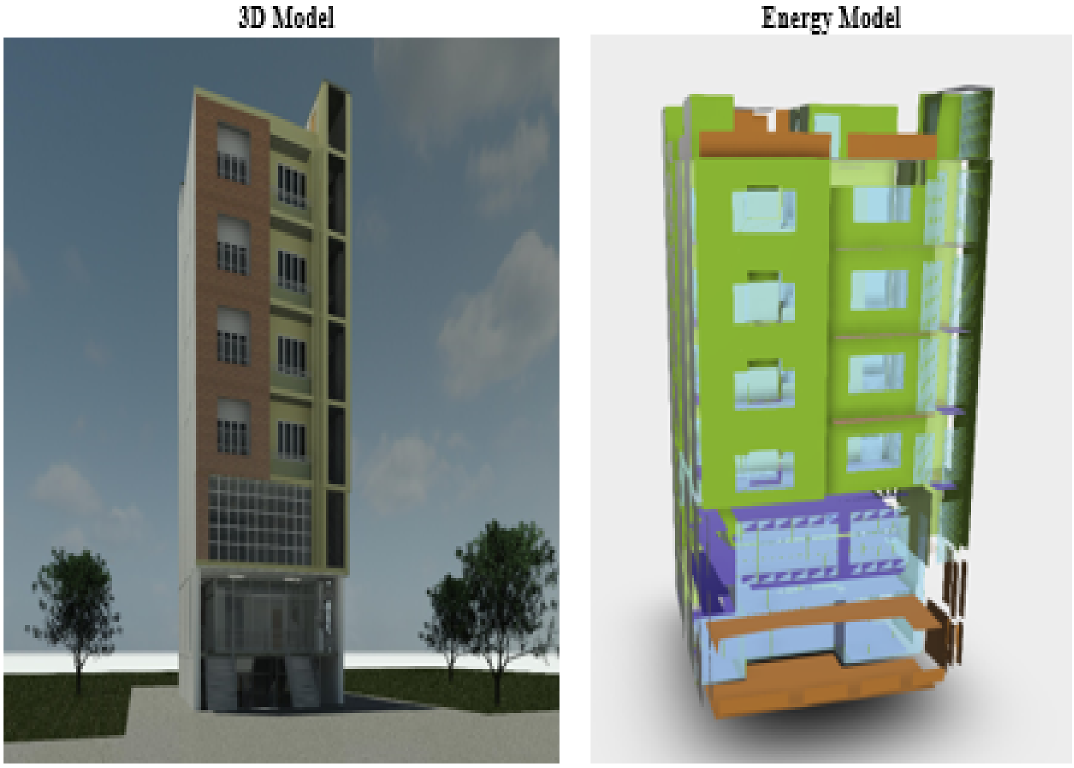


FIGURE 3.3: 3D and Energy Models of Building 1

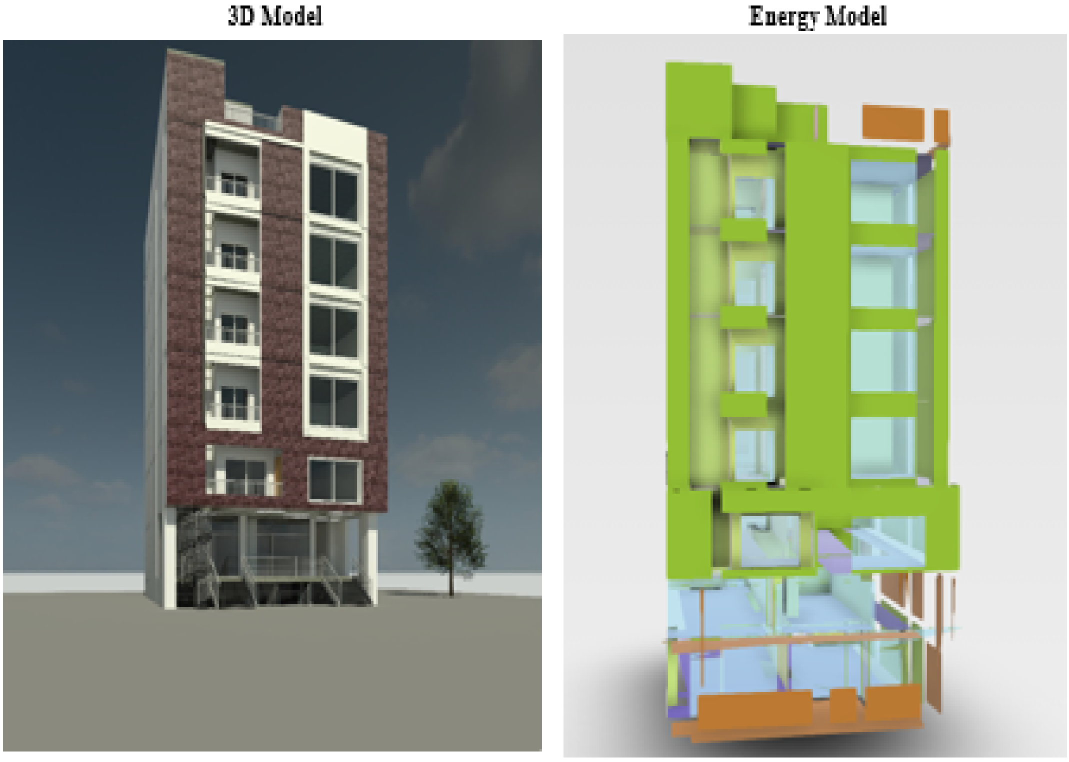
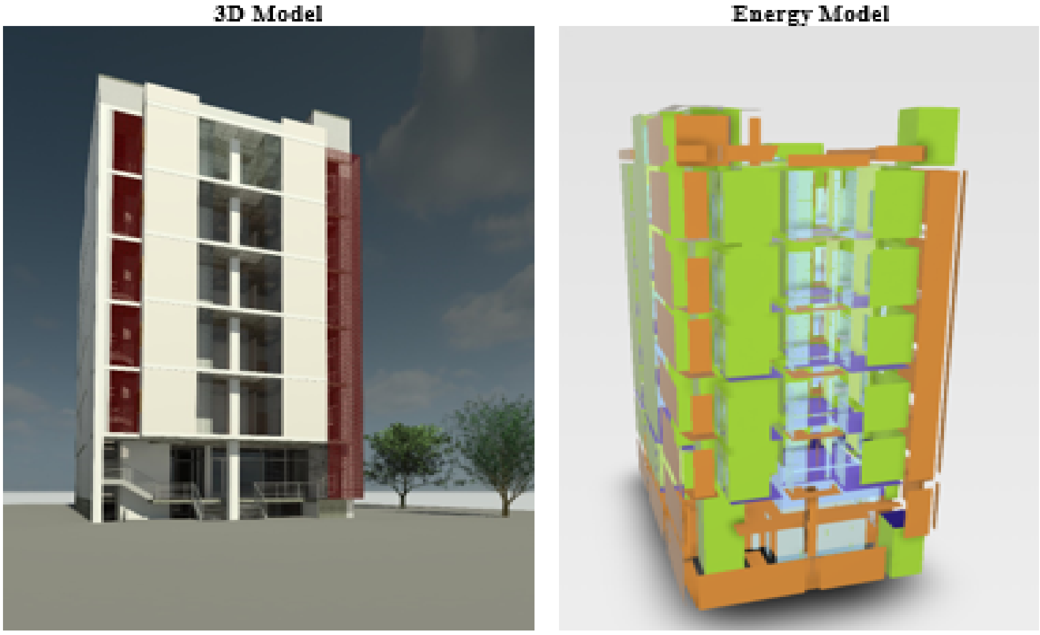


FIGURE 3.4: Revit 3D and Energy Models of Building 2



3D Model

Energy Model

Figure 3.5: 3D and Energy Models of Building 3

3.4 Considered Phases and Materials

Building energy analysis is generally performed after the completion of the architectural 3D model. The energy analysis gives architects, engineers, and facility managers a better understanding of the energy performance of a building during the design phase of a new facility or before the refurbishment measures are implemented. This information enables them to make changes that will increase the building's energy efficiency, therefore, increasing its sustainability. In this research, energy analysis is performed on the architectural models of all case study buildings. The orientation of all the buildings to the sun path has been accounted for during the energy analysis. The energy analysis has been carried out for four distinct phases, with different factors and parameters being employed in each phase as can be seen in Table 3.3.

3.4.1 Phase I (Typical Conventional Buildings)

In this phase of energy analysis no amount of Roof Insulation was considered and for this purpose the factor of "Roof Construction" on the interface of Autodesk

Table 3.3: Selected factors and adopted parameters in each phase

Factors	**Adopted Parameters**			
	Phase-I	**Phase-II**	**Phase-III**	**Phase-IV**
Roof Insulation	NIL	R38, R60	NIL	Decided based on Phase II results
PV-Surface Coverage	NIL	NIL	60%, 75%, 90%	Decided based on Phase III results
Panel Efficiency	NIL	NIL	20.40%	20.4 %

Insight was set to uninsulated. Similarly no PV- Surface Coverage was considered and the factor of PV-Surface Coverage was set to 0%.

3.4.2 Phase II (With Roof Insulation Only)

In this phase, to assess the performance of the buildings as a result of the roof insulation, the parameter of roof insulation was applied only. The factor of “ Roof Insulation ” was applied in a phase-wise manner by considering the parameters of R38 and R60 in the option of “Roof Construction” provided on the Autodesk Insight interface. The option of “Roof Construction” on the Autodesk Insight interface evaluates the energy performance of a building for uninsulated roof surface and also evaluates the impact of the varying levels of roof insulation on the energy performance of a building [153]. The factor of PV Surface Coverage was not considered in this phase.

3.4.3 Phase III (With Solar Panels Only)

In this phase, the energy performance of the buildings was evaluated by applying the factor of PV Surface Coverage only. The factor of the “ Roof Insulation ” was not considered in this case. Based on an extensive literature review and because of the fact that Autodesk Insight provides three parameters of 60%, 75%, and 90% for the factor of PV Surface Coverage, the energy performance of the case study buildings was assessed for all these three parameters.

3.4.4 Phase IV (With Optimized Parameters from Phase II and Phase III)

In this phase, the energy performance of the case study buildings was analyzed for both “ Roof Insulation ” and PV Surface Coverage in terms of their combined application.

3.4.5 Materials

3.4.5.1 Roof Insulation

R38 and R60 roof insulation were considered for the study. The price of the insulation material is determined based on the R-value per inch for 1 ft^2 of the insulation material. In the construction industry, the R-value is used to describe a material’s thermal resistance and has a unit of $F.ft^2.h/Btu$. It reveals how much heat (in Btu) will pass through a 1 ft^2 sample of a 1-inch-thick insulating material. There are multiple options available in the market for roof insulation purposes. The thermal conductivity of the specific material determines the thickness of an insulation required to attain an R38 or R60 value. For the purpose of roof insulation and to determine the cost of insulation, Extruded polystyrene (XPS) having an R value of 5.88 is considered in this study based on its easy availability in the local market of Islamabad. The thickness of the Extruded polystyrene sheets to achieve R38 value is determined as 6.46 inches whereas to achieve the value of R60, the thickness required would be 10.2 inches.

3.4.5.2 PV – Panels

Solar panels with a panel efficiency of 20.4 % were considered for the study. Solar panel efficiency refers to a solar panel’s ability to convert sunlight into usable electricity. The payback limit for the solar panels was set at 30 years on the Autodesk Insight interface. Payback period refers to the time span during which an investment generates enough net revenue to cover its investment expenditures.

In the solar study option in Autodesk Revit, the time for the sun in the sun settings was set from sunrise to sunset, the PV-Panels then only converts the sunlight incident on them during that interval to electricity.

3.5 Procedures for Analyzed Parameters

3.5.1 Energy Calculations

To determine the effectiveness of the energy optimization measures, the energy analysis results of Phase I were compared with the rest of the Phases. The comparison was done to assess how much the energy performance of the existing buildings had improved for the applied factors and parameters, which would then help the facility managers and owners in the selection of the best option. The following factors and the associated parameters were used to make this comparison.

- Conventional vs Proposed Insulation
- Conventional vs Proposed Coverage

The results of the simulations of the various phases were compared to determine how much of a difference the ”Roof Insulation” measures made and how much the PV solar coverage contributed to the energy consumption optimization.

3.5.2 Cost Analysis

The step of cost estimation outlines the cost evaluating procedure for the different factors and parameters involved in the energy analysis process. The costs for each parameter of the factor of roof insulation and PV surface coverage were determined based on the unit price in the city of Islamabad. The cost and other details of the different energy optimization factors are also shown in **Table 3.4**.

TABLE 3.4: Energy Optimization Factors Details

Sr. No	**Considered Parameters**		**BIM**		**For Islamabad**		
	Factors	**Parameters**	**Allocation**	**Description**	**Allocation**	**Description**	**Unit Price (Rs)**
1	Insulation	R38	Roof Construction	Grade of Insulation – R38 Building Envelope component - Roof	Jumbolon Board or High Density Extruded Polystyrene (XPS) sheets	R-Value (1 inch thickness) – 5.88 F°ft^2-h/Btu Required thickness – 6.46 inches	55 per sft (1 inch thickness)
		R60	Roof Construction	Grade of Insulation – R60 Building Envelope component - Roof	Jumbolon Board or High Density Extruded Polystyrene (XPS) sheets	R-Value (1 inch thickness) – 5.88 F°ft^2-h/Btu Required thickness – 10.2 inches	55 per sft (1 inch thickness)
2	Solar Panels	60 % Coverage	PV-Surface Coverage	PV Panel Efficiency – 20.4 % PV Payback Limit – 30 years	Jinko Solar Panels	PV Panel Efficiency – 20.49 % Maximum Power – 460 Watts	80 per watt
		75 % Coverage	PV-Surface Coverage	PV Panel Efficiency – 20.4 % PV Payback Limit – 30 years	Jinko Solar Panels	PV Panel Efficiency – 20.49 % Maximum Power – 460 Watts	80 per watt
		90 % Coverage	PV-Surface Coverage	PV Panel Efficiency – 20.4 % PV Payback Limit – 30 years	Jinko Solar Panels	PV Panel Efficiency – 20.49 % Maximum Power – 460 Watts	80 per watt

3.6 Summary

This chapter outlines the steps for creating and analyzing the building energy models and the relevant factors. Three buildings located in the Islamabad region were selected as case studies. Autodesk Revit was used to develop the 3D models of the selected buildings. The energy models of these 3D models were then generated by using Autodesk Insight which is a Revit plugin. To determine the impact of the three factors—Roof insulation, PV-surface coverage, and Panel Efficiency—on the energy performance of the building, a thorough building energy analysis is performed in four phases. In the initial phase, the energy analysis is performed for the typically conventional buildings, The initial phase is then followed by various energy optimization measures that are applied in a phase-wise manner. The simultaneous cost variations associated with the examined factors and parameters were also evaluated to better comprehend the economic implications of these energy optimization measures. The results obtained are discussed in chapter 4.

Chapter 4

Results and Analysis

4.1 Background

This chapter discusses the results of the energy analysis performed for the three case study buildings in a detailed manner. The energy analysis is conducted after modeling of the buildings according to the dimensions provided in the 2D CAD drawings. The building's annual energy use is tracked in EUI values, which serve as a key indicator when benchmarking the energy performance of buildings. EUI is the yearly energy consumption of a building divided by its total area and has a unit of kWh / m^2 / yr. It thus gives the value for resulting energy usage per area per year. After the creation of building energy models, their energy performance is assessed both in their conventional state, and after the phase-wise application of the energy optimization measures.

4.2 Comparative Energy Analysis – Phase Wise

4.2.1 Phase-I

In the first phase, the energy analysis of the selected case studies is performed without considering any energy optimization measures. The EUI value obtained in this phase would then be set as a baseline for each building and compared with the EUI values obtained in the other three phases of the phases to analyze the influence of the energy retrofitting measures on the energy performance of the building. As can be seen in Figure 4.1, on the Autodesk Insight interface the parameter for the factor of PV-Surface Coverage has been set to 0% and the parameter for the factor of Roof Construction has been set to uninsulated.

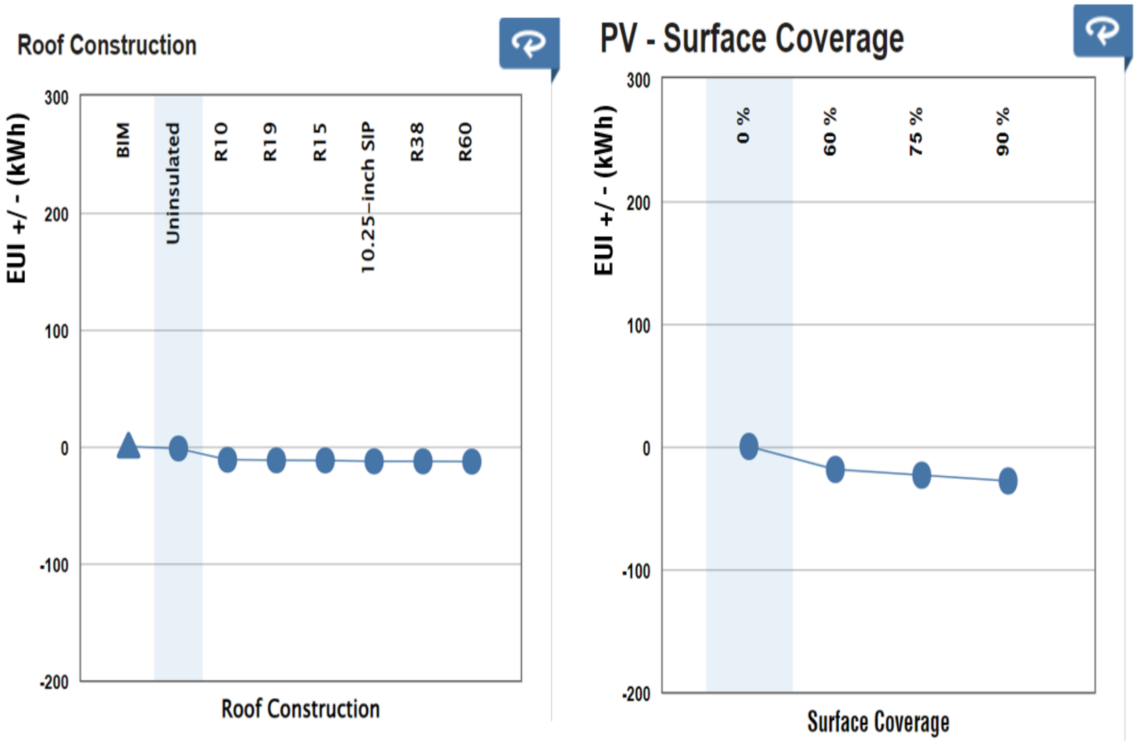
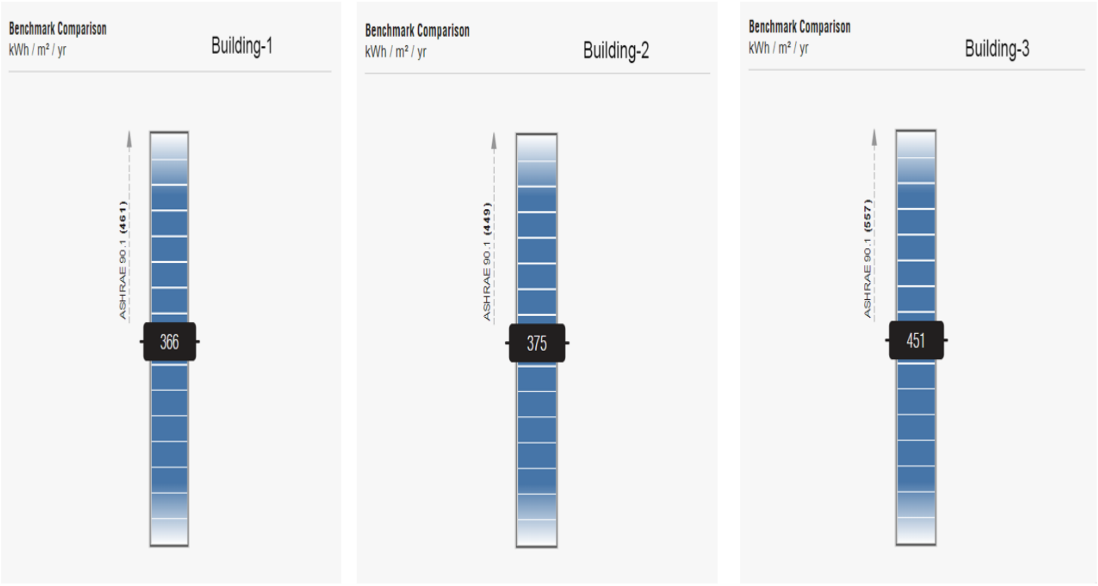


FIGURE 4.1: No Energy Optimization Measures Applied

The energy analysis in the first phase was performed for all case study buildings and the resultant EUI values for each of the building can be seen in Figure 4.2. The EUI value obtained for building 1 is 366 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark for building 1 is 461 kWh / m^2 / yr. Similarly, the EUI value for building 2 is 375 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark is 449 kWh / m^2 / yr, while for building 3 the EUI value obtained is 451 kWh / m^2 / yr and the value of ASHRAE benchmark is 557 kWh / m^2 / yr. Hence it has been verified that all the case study buildings are energy efficient buildings. The case study buildings had varying WWR, and orientations as well as there were variations among the sizes of rooms and apartments which all impact the energy performance and therefore variation among the EUI values can be seen for the respective buildings. The floor area of a building is one of its most important aspects since it has a significant impact on its overall energy use as reported by Song et al. [154]. Furthermore, It has also been reported previously by Abanda and Byers that a building's orientation has a strong effect on its total energy use [155].



(a) (b) (c)

FIGURE 4.2: EUI values for Phase 1; (a) Building 1, (b) Building 2, (c) Building 3

4.2.2 Phase-II

In this phase of the energy analysis, only the factor of "Roof Insulation" was applied to all the buildings as an energy optimization measure. To assess their impact on the energy performance of the buildings, two types of roof insulation namely R38 and R60 were applied. As can be seen in be in Figure 4.3, in the factor of Roof Construction on the Autodesk Insight interface, the parameter was first set to R38 to assess the impact of R38 roof insulation and then to R60 to assess the impact of R60 roof insulation on the energy performance of the case study buildings in terms of EUI value.

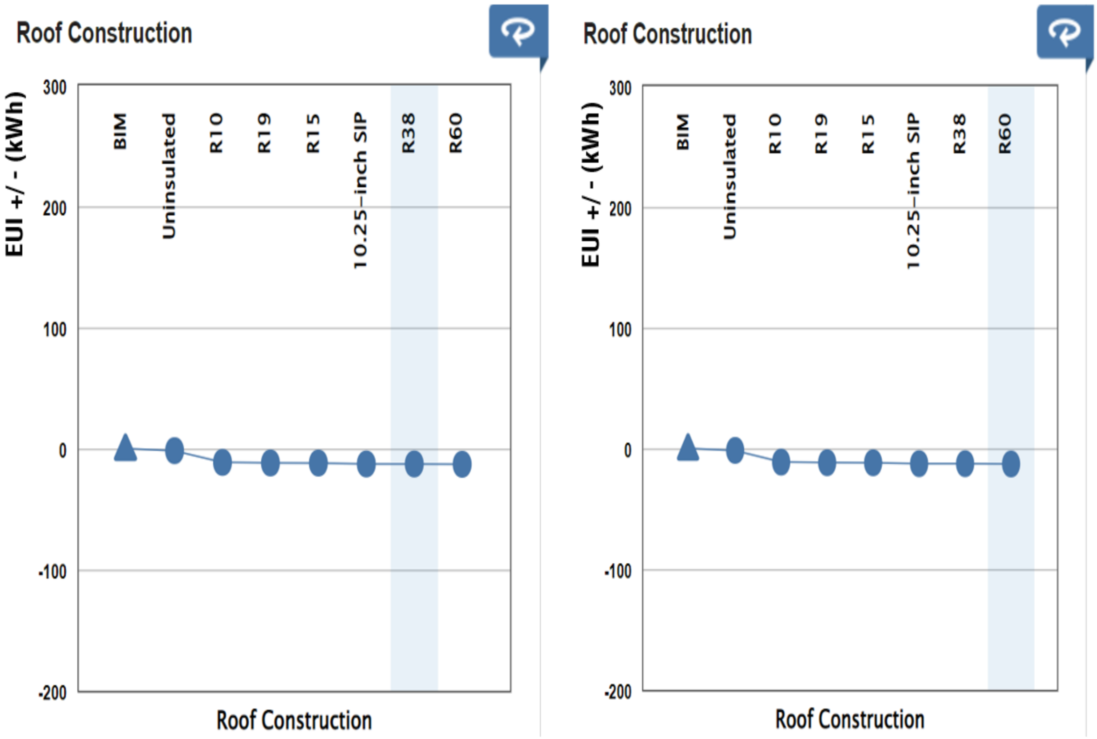


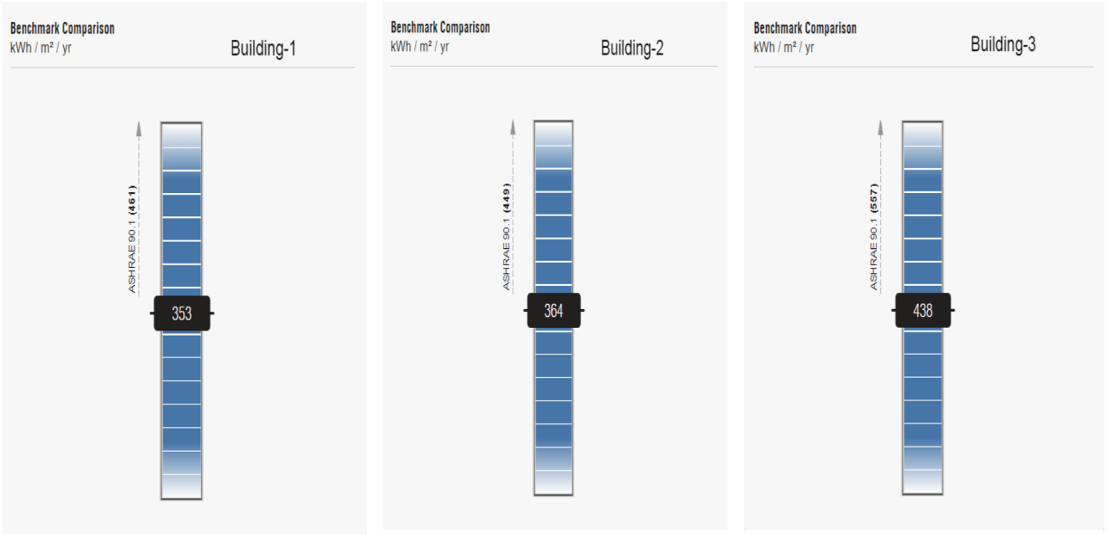
Figure 4.3: Types of Roof Insulation Applied

4.2.2.1 Roof Insulation - R38

In the first instance of the Phase II analysis, the roof insulation of R38 was applied to all three case study buildings. The EUI values of the buildings after the application of R38 insulation can be seen in Figure 4.4. The EUI value obtained for building 1 in this scenario is 353 kWh / m^2 / yr whereas the value of ASHRAE 90.1 benchmark is 461 kWh / m^2 / yr. The EUI value for building 2 is 364 kWh / m^2 / yr and the value of its ASHRAE 90.1 benchmark is 449 kWh / m^2 / yr. For building 3 the EUI value is 438 kWh / m^2 / yr and the ASHRAE 90.1 benchmark value is 557 kWh / m^2 / yr.

4.2.2.2 Roof Insulation - R60

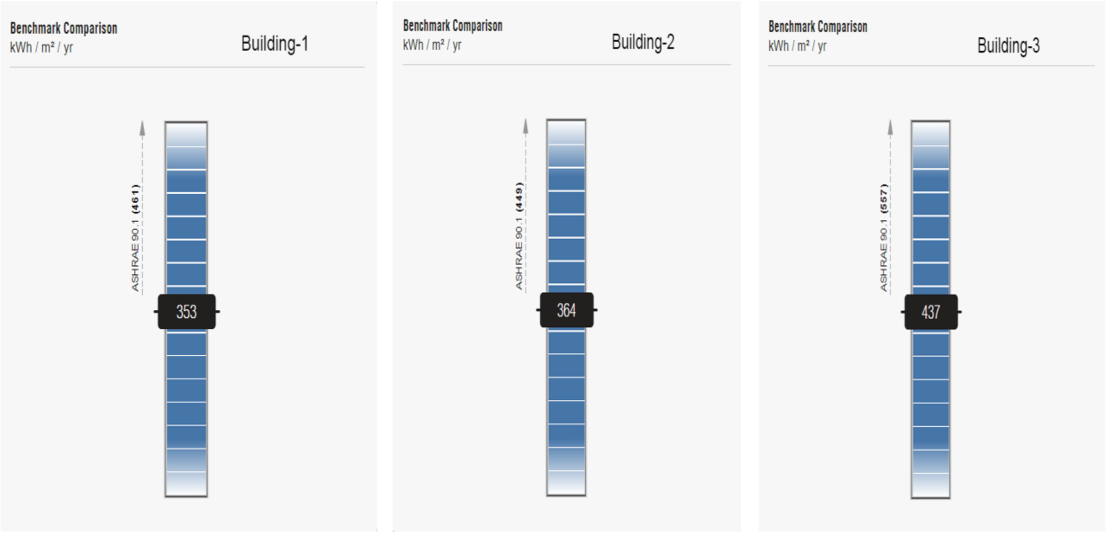
In the second instance the R60 roof insulation was applied to all buildings and the EUI values of the buildings after the application of R60 insulation can be seen in Figure 4.5. The EUI value for building 1 is 353 kWh / m^2 / yr, while the ASHRAE 90.1 benchmark value is set as 461 kWh / m^2 / yr. For building 2 the EUI value



(a) (b) (c)

FIGURE 4.4: EUI values for R38 Roof Insulation; (a) Building 1, (b) Building 2, (c) Building 3

is 364 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark value is 449 kWh / m^2 / yr. In case of building 3 the EUI value is 437 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark value is 557 kWh / m^2 / yr.



(a) (b) (c)

FIGURE 4.5: EUI values for R60 Roof Insulation; (a) Building 1, (b) Building 2, (c) Building 3

So, after comparing the results of both R38 and R60 insulation it can be noticed that there isn't any much of a difference between the EUI values of the buildings for both types of insulation. Although R60 insulation has increased thickness when compared to the R38 insulation but it still doesn't have any major impact on the energy performance of the case study buildings. For both R38 and R60 insulation the EUI value of building 1 was reduced by a value of 13 kWh / m^2 / yr from its initial phase when it was uninsulated. For building 2 the EUI value reduced by 11 kWh / m^2 / yr for both R38 and R60 insulation. In case of building 3, for R38 insulation the EUI value was reduced by 13 kWh / m^2 / yr and for R60 insulation the EUI value was reduced by 14 kWh / m^2 / yr from its initial phase. From this it can be determined that the R38 insulation in the Islamabad region works just as well as that of R60 insulation for buildings with similar number of storeys. For such scenarios it is stated by Jie et al. [156] that although thicker insulation may result in lower energy use for buildings, thicker insulation also results in an increased amount of costs, therefore it is important to balance the expense of the insulation with the energy savings.

4.2.3 Phase-III

The "PV Surface Coverage" factor was used as an energy optimization measure in the third phase of the energy analysis for all case studies. The factor of "Roof Insulation" was not applied in this phase. As can be seen in Figure 4.6, and Figure 4.7, for the factor of PV-Surface Coverage on the Autodesk Insight interface, the parameters were set to 60%, 75%, and 90% in three different steps to assess their impact on the energy performance of the case study buildings in terms of EUI value.

4.2.3.1 60% PV – Surface Coverage

In this situation of Phase III, the energy performance of all the buildings was analyzed for 60% PV – Surface Coverage. The EUI values for the three case study buildings after applying this parameter can be seen in Figure 4.8. For building 1 the EUI value is 347 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark value is 461 kWh / m^2 / yr. Similarly for building 2 the EUI value is 356 kWh / m^2 / yr and the ASHRAE 90.1 benchmark is 449 kWh / m^2 / yr. For building 3 the

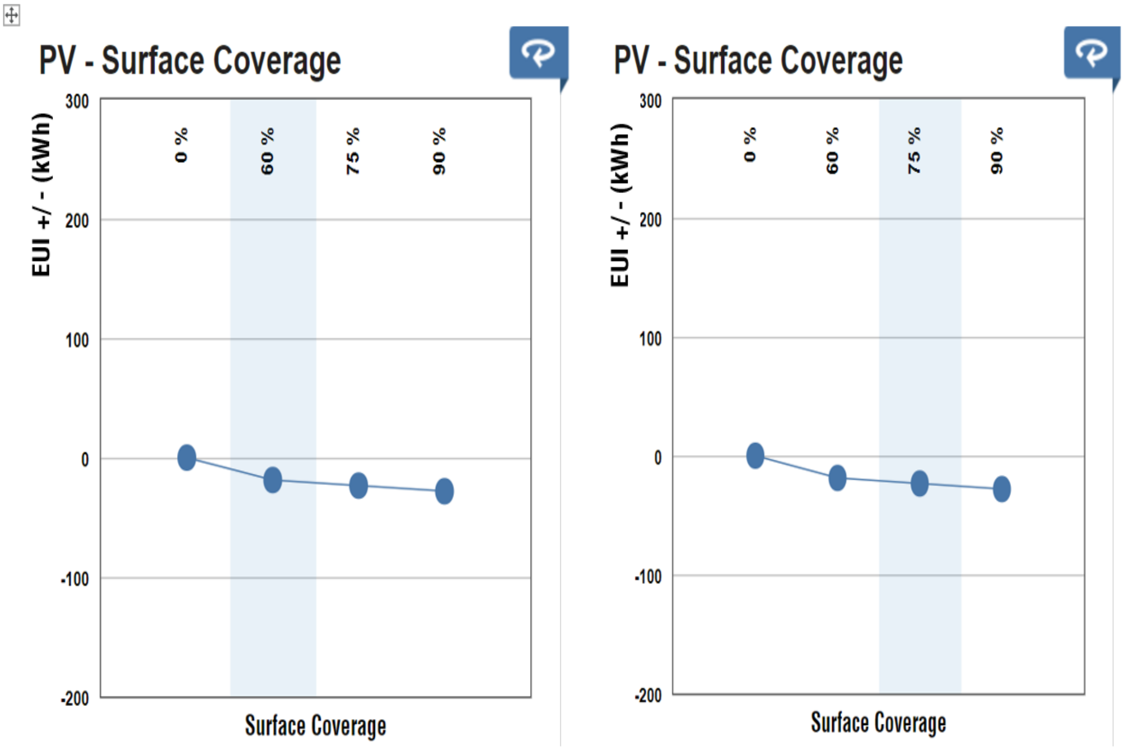


FIGURE 4.6: PV Surface Coverage

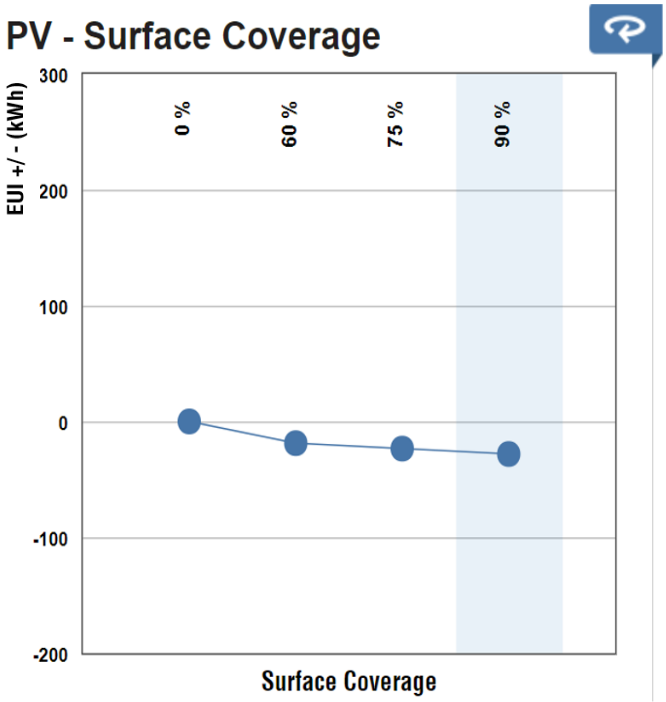


FIGURE 4.7: PV Surface Coverage

EUI value is 425 kWh / m^2 / yr and the value of ASHRAE 90.1 benchmark is 557 kWh / m^2 / yr.

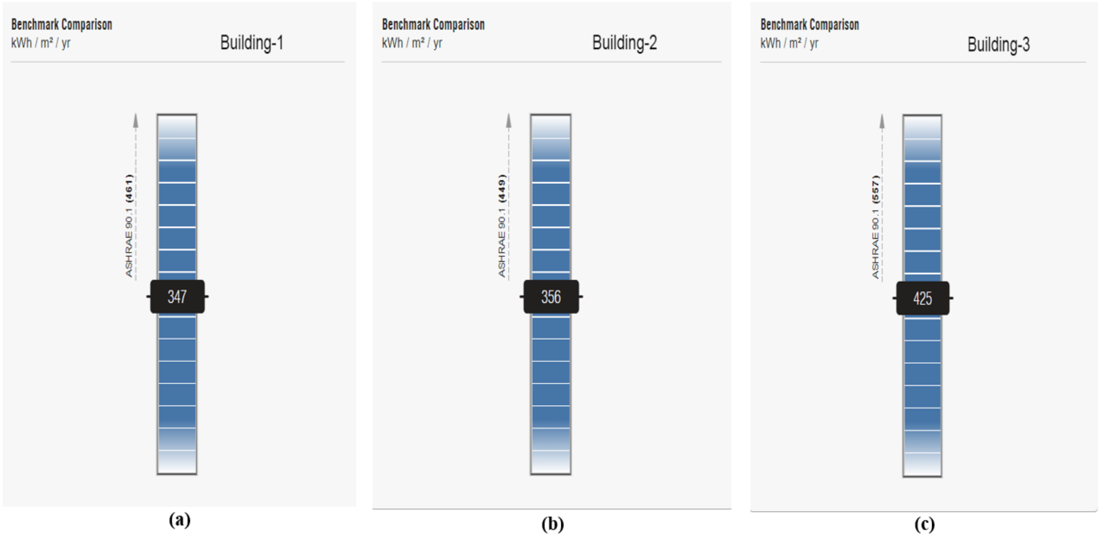


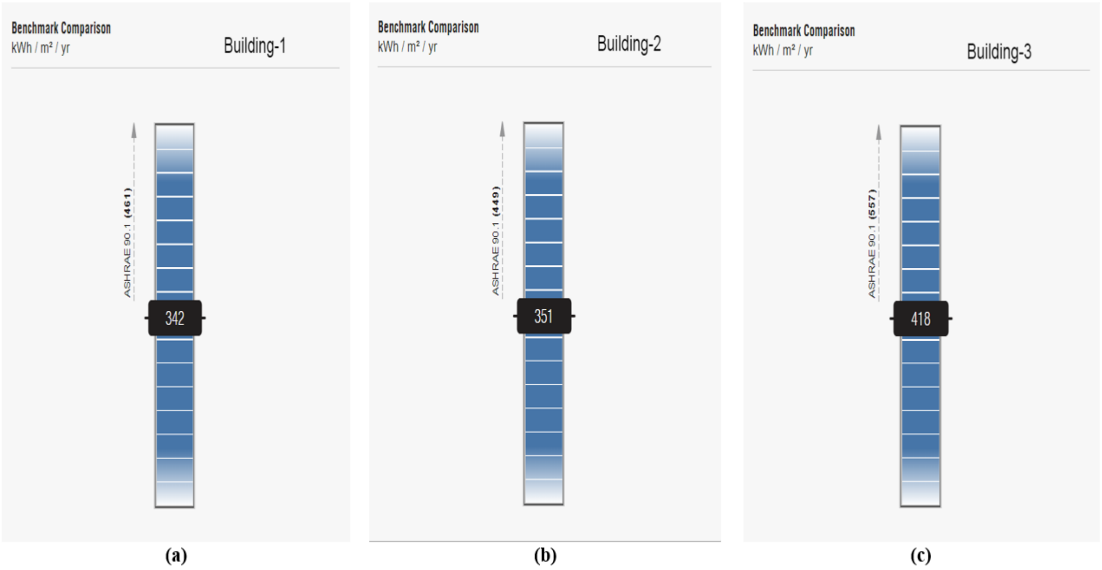
FIGURE 4.8: EUI values for 60% PV - Surface Coverage; (a) Building 1, (b) Building 2, (c) Building 3

4.2.3.2 75% PV – Surface Coverage

In this scenario, the energy performance of the case study buildings was analyzed after applying 75% PV surface coverage. The EUI values for the buildings after applying this parameter can be seen in Figure 4.9. The EUI value for building 1 is 342 kWh / m^2 / yr and the value of ASHRAE 90.1 benchmark is 461 kWh / m^2 / yr. Similarly, the EUI value for building 2 is 351 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark value is 449 kWh / m^2 / yr. The EUI value for building 3 is 418 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark value is 557 kWh / m^2 / yr.

4.2.3.3 90% PV- Surface Coverage

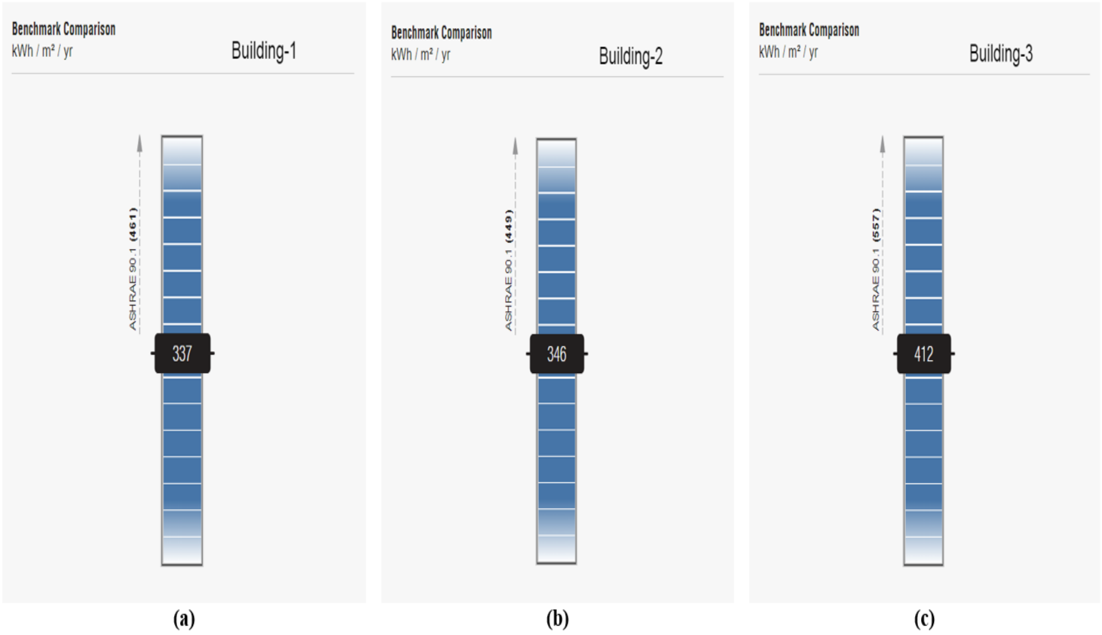
In this instance the parameter of 90% PV- Surface Coverage was applied to the case study buildings and their energy performance was analyzed. The EUI values for the case study buildings can be seen in Figure 4.10. The EUI value obtained in this case for building 1 is 337 kWh / m^2 / yr while the value of ASHRAE 90.1 benchmark is 461 kWh / m^2 / yr. The EUI value for building 2 is 346 kWh / m^2 / yr and the ASHRAE 90.1 benchmark value is 449 kWh / m^2 / yr. The EUI



(a) (b) (c)

FIGURE 4.9: EUI values for 75% PV - Surface Coverage; (a) Building 1, (b) Building 2, (c) Building 3

value for building 3 is 412 kWh / m^2 / yr whereas the ASHRAE 90.1 benchmark value is 557 kWh / m^2 / yr.



(a) (b) (c)

FIGURE 4.10: EUI values for 90% PV - Surface Coverage; (a) Building 1, (b) Building 2, (c) Building 3

So as a result, it can be deduced from this phase of the energy analysis that by installing the solar panels the energy performance of the case study buildings can be fairly improved. The 60% PV coverage significantly improved the energy performance of the buildings when compared to their baseline energy performance in Phase I. It is worth noting that by increasing the PV Surface Coverage from 60% to 75% the energy performance of the buildings was only slightly improved, however when the PV Surface Coverage was increased to 90%, an apparent improvement in the building's energy performance could be seen. The attainment of maximum energy savings due to 90% PV surface coverage is also reported by Amani and Soroush [96].

4.2.4 Phase-IV

The combined parameters of "Roof Insulation" and "PV Surface Coverage" were applied together in the final phase of the energy analysis to investigate their influence on the energy performance of the case study buildings. Because R38 roof insulation has a thinner profile than R60 insulation and therefore offers a more economical alternative, it was preferred for this phase of the project after it was noticed in the second phase that both R38 and R60 roof insulation almost have the same impact on the energy performance of the case study buildings. We moved forward with the 60% and 90% PV- Surface Coverage options for the parameter "PV Surface Coverage" since it can also be argued that the 60% and 90% solar coverage demonstrated to be more impactful in terms of PV Surface Coverage. So, in this phase the R38 roof insulation was used together with varying solar coverages of 60% and 90%. By doing this it presents us with a very accurate picture of how the application of both optimization measures could influence the energy performance of the buildings.

4.2.4.1 R38 Roof Insulation and 60% PV – Surface Coverage

In the first stage of Phase IV, the energy performance of the all the case study buildings was analyzed after applying the optimization factors of R38 roof insulation and 60% PV – Surface Coverage combinedly, the impact of which can be seen in Figure 4.11 in the form of EUI values. The EUI value for building 1 is 334 kWh / m^2 / yr and the ASHRAE 90.1 benchmark value is 461 kWh / m^2 / yr. For building 2 the EUI value in this stage is 345 kWh / m^2 / yr and the ASHRAE

90.1 benchmark value is 449 kWh / m^2 / yr. The EUI value for building 3 is 412 kWh / m^2 / yr while the value of ASHRAE 90.1 benchmark is 557 kWh / m^2 / yr.

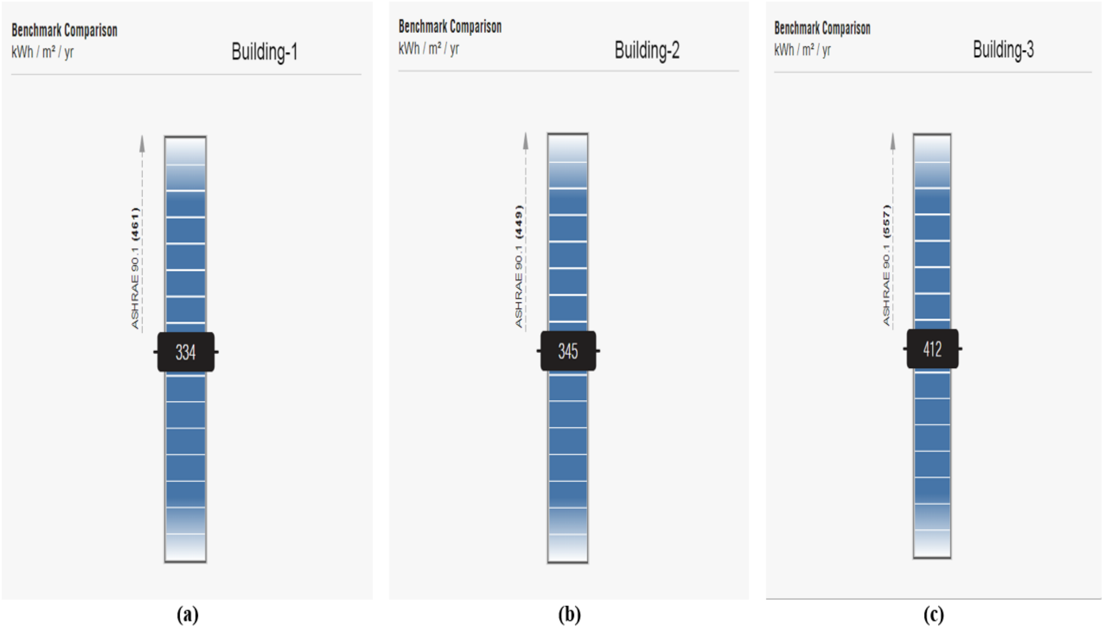


FIGURE 4.11: EUI values for R38 Roof Insulation & 60% PV - Surface Coverage; (a) Building 1, (b) Building 2, (c) Building 3

4.2.4.2 R38 Roof Insulation and 90% PV – Surface Coverage

In the second stage of phase 4 the energy performance of the case study buildings was analyzed after the combined application of the optimization factors of R38 roof insulation and 90% PV – Surface Coverage. The impact results can be seen in the form of EUI values in Figure 4.12. The EUI value for building 1 in this stage is 325 kWh / m^2 / yr and the value of ASHRAE 90.1 benchmark is 461 kWh / m^2 / yr. For building 2 the EUI value is 336 kWh / m^2 / yr while the ASHRAE 90.1 benchmark value is 449 kWh / m^2 / yr. Similarly for building 3 the EUI value is 399 kWh / m^2 / yr and the ASHRAE 90.1 benchmark value is 557 kWh / m^2 / yr. Thus, it can be determined that the energy performance of all the case study buildings enhanced the most after the application of the parameters of R38 roof insulation and 90 % PV- Surface Coverage. Energy optimization after application of PV panels and optimum insulation is also reported by D'Agostino et al. [24] who have advocated it as an economical measure for energy efficient buildings.

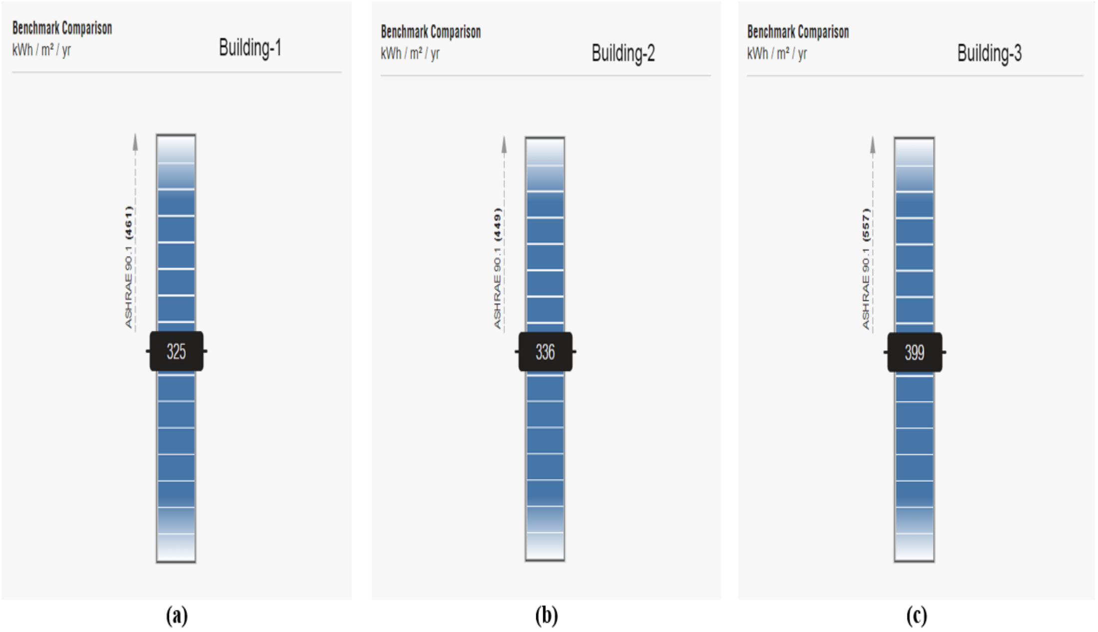


FIGURE 4.12: EUI values for R38 Roof Insulation & 90% PV - Surface Coverage; (a) Building 1, (b) Building 2, (c) Building 3

4.3 Comparative Energy Analysis of the Case Study Buildings

This section discusses the impact of the energy optimization measures implemented in four different phases on the energy performance of the case study buildings. The EUI values of the case study buildings for all phases are mentioned in **Table 4.1**. The building 1 lies at 11∘ clockwise from the true north, and its Phase I EUI value, without any optimization measures, was 366 kWh/ m^2 /yr. It can be noticed that the building 1's ASHRAE 90.1 benchmark is 461 kWh/ m^2 /yr, which indicates that it is an energy-efficient building per ASHRAE 90.1 standard. After applying the roof insulation in Phase II, its EUI value was reduced by 13 to 353 kWh/ m^2 /yr for both R38 and R60 roof insulation showing moderate reduction and indicating that both types of insulation had the same influence on the building's energy efficiency. The EUI value for building 1 in Phase III was reduced by 19 to 347 kWh/ m^2 /yr after applying a 60% PV-Surface Coverage factor showing moderate reduction, the EUI value was reduced by 24 to 342 kWh/m^2/yr after applying a 75% PV-Surface Coverage factor showing moderate reduction while for 90% PV-Surface Coverage factor the EUI value reduced by 29 to 337 kWh/

m^2 /yr still showing moderate reduction. The 90% PV - Surface Coverage factor, thus, had the most significant impact on lowering the EUI value of building 1 in Phase III. When the two energy optimization factors of R38 roof insulation and PV-Surface Coverage were applied combinedly to building 1 in Phase IV, the EUI value of 334 kWh/ m^2 /yr was observed for the parameters of R38 roof insulation and 60% PV-Surface Coverage showing significant reduction and for R38 roof insulation and 90% PV-Surface Coverage the EUI value was reduced by 41 to 325 kWh/ m^2 /yr thus showing significant reduction. So, it can be said that in Phase IV, the energy performance of the building 1 was enhanced the most by the application of the combined parameters of R38 roof insulation and 90% PV–Surface Coverage.

Building 2 is oriented 320○ clockwise to true north, and in the first phase, the EUI value of 375 kWh/ m^2 /yr was obtained for it without the use of any optimization measures. In Phase II, the factor of roof insulation was employed, and R38 and R60 roof insulation were employed. It should be noted that the EUI values were reduced to 364 kWh/ m^2 /yr for both insulation showing moderate reduction and indicating that their impacts on enhancing the energy performance of building 2 are approximately identical.

With variable parameters of 60%, 75%, and 90%, the PV-Surface Coverage factor was employed in Phase III. Consequently, the EUI value for 60% PV-Surface Coverage was reduced by 19 to 356 kWh/m^2/year showing moderate reduction, the EUI value obtained for 75% PV-Surface Coverage was 351 kWh/ m^2 /year also showing moderate reduction, and the EUI value for 90% PV-Surface Coverage was 346 kWh/ m^2 /year showing moderate reduction. Similar to building 1, building 2's energy performance was enhanced most favorably by 90% PV - Surface Coverage in Phase III. In Phase IV, the EUI value achieved after using the combined parameters of R38 roof insulation and 60% PV - Surface Coverage was 345 kWh / m^2 / yr showing significant reduction, while the EUI value obtained after applying the combined parameters of R38 roof insulation and 90% PV - Surface Coverage was 336 kWh / m^2 / yr also showing significant reduction. So, it can be said that the application of the combined parameters of R38 roof insulation and 90% PV -

Surface Coverage led to the most significant improvement of building 2's energy efficiency. Building 2's ASHRAE 90.1 standard value of 449 kWh/ m^2 /yr further supports the fact that the building complies with the requirements for energy efficiency provided by in ASHRAE 90.1 standard.

Building 3 is oriented 141$\circ$ clockwise to true north and in the first phase of the energy analysis an EUI value of 451 kWh/ m^2 /yr was obtained in the conventional uninsulated state without any energy optimization measures being applied. The ASHRAE 90.1 standard benchmark for building 3 is 557 kWh / m^2 / yr which also confirms the energy efficiency of building 3. In Phase II, the factor of “Roof Insulation” was applied and two different types of insulation namely R38 insulation and R60 insulation were applied for energy optimization purposes. The EUI value of 438 kWh/ m^2 /yr was achieved for R38 roof insulation and for R60 roof insulation the EUI value of 437 kWh/ m^2 /yr was achieved and so both the roof insulation resulted in moderate reduction of the energy use.

Using the varied parameters of 60%, 75%, and 90%, the influence of the factor PV-Surface Coverage was evaluated on building 3 in Phase III. The EUI value for 60% PV-Surface Coverage was 425 kWh/ m^2 /yr showing moderate reduction, for 75% PV-Surface Coverage it was 418 kWh/ m^2 /yr showing significant reduction, and for 90% PV-Surface Coverage the EUI value was also significantly reduced to 412 kWh/ m^2 /yr. Therefore, it can be noted that the use of 90% PV - Surface Coverage is the best for enhancing the energy performance of building 3 in Phase III. In Phase IV, the combined effects of ”Roof Insulation” and ”PV-Surface Coverage” were examined in relation to building 3's energy efficiency. The EUI value achieved with R38 roof insulation and 60% PV - Surface Coverage was 412 kWh/ m^2 /yr showing significant reduction, whereas the EUI value with R38 roof insulation and 90% PV - Surface Coverage was 399 kWh/ m^2 /yr also showing significant reduction. Therefore, the building energy performance of building 3 was the most enhanced after the application of combined parameters of R38 roof insulation and 90% PV – Surface Coverage out of all the considerations in the four phases.

4.4 Cost Analysis

This section discusses the impact of each of the energy optimization measure with respect to cost on the case study buildings. The total cost for each type of energy optimization measure for the case study buildings can also be seen in **Table 4.2**. The total cost is obtained by multiplying the Islamabad based cost per unit of the insulation material and solar panels with the roof area of each building and the considered percentage of roof area. So, the total cost obtained for the application of R38 roof insulation on building 1 is Rs 4,66,154, the cost obtained for building 2 is Rs 4,11,793, and similarly the cost obtained for building 3 is Rs 8,45,969.

Variations among the case study buildings with respect to cost for insulation purposes can be attributed to the difference of their roof areas. Similarly, in case of R60 roof insulation, the total cost obtained for building 1 is Rs 7,36,032, the total cost determined for building 2 is Rs 6,50,199, whereas for building 3 the total cost obtained is Rs 13,35,741. In case of solar panels, for 60% PV surface coverage the cost for building 1 is Rs 11,77,600, the cost for building 2 in case of 60% PV surface coverage is Rs 10,30,400, and the cost determined for building 3 is Rs 21,71,200. For 75% PV surface coverage, the cost evaluated for building 1 is Rs 14,72,000, the cost for building 2 is Rs 12,88,000, and the cost estimated for building 3 is Rs 26,86,400.

In case of 90% PV surface coverage over the roof area, the cost of Rs 17,66,400 is estimated for building 1, for building 2 the cost obtained is Rs 15,82,400 and for building 3 the cost of Rs 32,38,400 is determined. It is important to remember that all the cost analysis is performed on the basis of Islamabad unit price determined for the respective energy optimization measures. A higher cost is observed for R60 insulation when compared with the R38 insulation. The reason for this can be attributed to the increased thickness of the R60 insulation in comparison to R38 insulation. Similarly, the cost increases along with the increased percentage of the PV-Surface Coverage area.

Table 4.1: Comparative Energy Analysis of the Case Study Buildings

	Phase I - Energy Usage (kWh / m^2 / yr)	**Phase II - Energy Usage (kWh / m^2 / yr)**		**Phase III - Energy Usage (kWh / m^2 / yr)**			**Phase IV - Energy Usage (kWh / m^2 / yr)**	
Energy Optimization Factors Applied	**NIL**	**Roof Insulation – R38**	**Roof Insulation – R60**	**PV-Surface Coverage – 60%**	**PV-Surface Coverage – 75%**	**PV-Surface Coverage – 90%**	**R38 Roof Insulation & 60% PV Surface Coverage**	**R38 Roof Insulation & 90% PV Surface Coverage**
Building 1	366	353	353	347	342	337	334	325
Building 2	375	364	364	356	351	346	345	336
Building 3	451	438	437	425	418	412	412	399

Table 4.2: Cost Analysis of the Case Study Buildings

Sr. No	Current Study Consideration		Considered Roof Area Percentage	Total Cost (Rs)*		
	Factors	**Parameters**		**Building 1**	**Building 2**	**Building 3**
1	Insulation	R38	100%	4,66,154/-	4,11,793/-	8,45,969/-
		R60	100%	7,36,032/-	6,50,199/-	13,35,741/-
2	Solar Panels	60 % Coverage	60%	11,77,600/-	10,30,400/-	21,71,200/-
		75 % Coverage	75%	14,72,000/-	12,88,000/-	26,86,400/-
		90 % Coverage	90%	17,66,400/-	15,82,400/-	32,38,400/-

* Total Cost = [unit cost from last column of Table 3.4] x [roof area from fifth column of Table 3.1] x [fourth column of Table 4.2]

4.5 Summary

In this chapter, energy analysis was conducted using BIM software for the three case study buildings in four different phases. Two energy optimization measures of “Roof Insulation” and “PV-Surface Coverage” were considered in the analysis. In the first phase the energy analysis of the 3 buildings was performed in their conventional state without applying any optimization measures. In Phase II, the energy performance of all the case study buildings was examined after applying the “Roof Insulation” factor only with two different types of insulation used namely R38 and R60 roof insulation, the factor of PV-Surface Coverage was not considered in this phase. In Phase III, the energy analysis for the three case study buildings was conducted by only applying the factor of “PV-Surface Coverage” with three varying parameters of 60%, 75%, and 90% PV-Surface Coverage. In Phase IV, the energy analysis for the case study buildings was performed by considering both the factors of “Roof Insulation” and “PV-Surface Coverage” and the parameters of R38 Roof Insulation along with 60% and 90% PV-Surface Coverage were considered after examining the results of Phase II and Phase III. After the energy analysis had been performed for all the case study buildings in the four phases, it was revealed that the energy performance of all the case study buildings was enhanced the most after the application of the combined parameters of R38 Roof Insulation and 90% PV-Surface Coverage. Furthermore, the EUI value of all buildings after the application of energy optimization factors remained well below the ASHRAE 90.1 benchmark therefore verifying the energy efficiency of all the case study buildings. Cost analysis was also performed in the end to determine the econoimic impact of the energy optimiztion measures.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

FM serves as a point of convergence for data from many diverse sectors and is concerned with the phase of O&M. FM professionals are facing an increased amount of pressure to optmize the energy performance of their concerned facilities. This study thus explores the BIM based BEM approach to assist FM personnel in optimizing the energy performance of the existing residential buildings. The following conclusions have been drawn from this research:

- The energy efficiency of all the case study buildings was very much improved after the application of energy optimization measures and the EUI values for all the buildings were well below the ASHRAE 90.1 benchmark values.
- All the case study buildings had varying orientations with respect to true north which appears to impact their energy performance and consequently the EUI values. However, variations were also noted among the factors such as Floor area and WWR of the case study buildings which also impact the energy performance.

- In terms of energy optimization, almost same impact was observed for both types of R38 and R60 roof insulation on the energy performance of the case study buildings.
- In case of PV-Surface Coverage, a noticeable impact was observed for the parameters of 60% and 90% PV-Surface Coverage whereas the EUI value of the case study buildings only slightly improved for 75% PV-Surface Coverage in comparison to 60% PV-Surface Coverage.
- In case of the combined application of energy optimization factors, the energy performance of the case study buildings improved the most for the combined parameters of R38 Roof Insulation and 90% PV-Surface Coverage.
- In terms of roof insulation, the R60 insulation is found to be more capital intensive than R38 insulation. In case of PV-surface coverage, the cost increases as the PV-surface coverage is increased.

Keeping in mind the above conclusive points, it can be said that the energy optimization measures are an effective way of improving the energy performance of existing buildings. R38 is an economical option for roof insulation as it has almost the same impact on energy performance of the buildings as that of R60 insulation. The energy performance of the case study buildings improved the most after combined application of R38 Insulation and 90% PV-Surface Coverage.

5.2 Recommendations

Based on the findings of this research, the following recommendations are made for future research works:

- Estimation of the impact of energy optimization measures on carbon footprint of the existing residential buildings using BIM.
- Impact of PV-panels orientation on energy performance of the existing residential buildings.

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