CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Energy Optimization of a Residential High Rise Building using BIM for Sustainability

by

Irbaz Hasan

A thesis submitted in partial fulfillment for the degree of Master of Science

in the

Faculty of Engineering
Department of Civil Engineering

2020

To my beloved sister

Who has been always a symbol of Affection, Happiness and Bliss. We may separate by distance but always joined by Love

CERTIFICATE OF APPROVAL

Energy Optimization of a Residential High Rise Building using BIM for Sustainability

by

Irbaz Hasan

(MCE183051)

THESIS EXAMINING COMMITTEE

S. No.	Examiner	Name	Organization
(a)	External Examiner	Engr. Dr. Hassan Ashraf	COMSATS, Wah
(b)	Internal Examiner	Engr. Dr. Ishtiaq Hassan	CUST, Islamabad
(c)	Supervisor	Engr. Dr. Syed Shujaa Safdar Gardezi	CUST, Islamabad

Engr. Dr. Syed Shujaa Safdar Gardezi
Thesis Supervisor
June, 2020

Engr. Dr. Ishtiaq Hassan
Head
Dept. of Civil Engineering
June, 2020

Engr. Dr. Imtiaz Ahmad Taj
Dean
Faculty of Engineering
June, 2020

Author's Declaration

I, **Irbaz Hasan** hereby state that my MS thesis titled "**Energy Optimization of a Residential High Rise Building using BIM for Sustainability**" is my own work and has not been submitted previously by me for taking any degree from Capital University of Science and Technology, Islamabad or anywhere else in the country/abroad.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw my MS Degree.

Irbaz Hasan

(MCE183051)

Plagiarism Undertaking

I solemnly declare that research work presented in this thesis titled "**Energy Optimization of a Residential High Rise Building using BIM for Sustainability**" is solely my research work with no significant contribution from any other person. Small contribution/help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Capital University of Science and Technology towards plagiarism. Therefore, I as an author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS Degree, the University reserves the right to withdraw/revoke my MS degree and that HEC and the University have the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized work.

Irbaz Hasan
(MCE183051)

Acknowledgements

I would like to express my gratitude to my respected supervisor **Engr. Dr. Syed Shujaa Safdar Gardezi** for his kind guidance and advice. His persuasion was very precious for the achievement of this research work.

I would also like to thank the BIM Centre of Excellence and Capital University of Science and Technology (CUST).

Irbaz Hasan

(MCE183051)

Abstract

Moving towards sustainable development, environmental, economic, and social sustainability are our main concerns. The construction industry has become the third major contributor by emitting the average 40% of GHG to the environment. Worldwide, energy demand is constantly increasing. Pakistan has been facing energy challenge from previous decades, and the energy shortage in Pakistan is almost 5,000 Mega Watts, making difficult to fulfill the energy demand especially in the summer season. Energy is an essential part of life, and many are looking for affordability. However, with the ever-increasing population and increasing financial constraints, energy crises are becoming serious day by day. Apart from many solutions, with the help of proper design, construction and operation, significant energy savings can be achieved. The main objective of the research thesis work is to achieve sustainability in the building industry by introducing BIM-based energy solutions with the help of performance analysis. The specific purpose of this thesis is to perform energy analysis and optimization. A sixteen-story high rise building is selected as a case study. The 3-D parametric modeling of the building is developed in a virtual environment using Revit Architecture. Based on the developed virtual model, the energy models were generated by adopting the BIM process through the INSIGHT360. The energy performance was achieved through the Cloud computing process. However, in order to observe the energy consumption patterns, a specific rotation schemed of the building was devised. The true North position was taken a baseline and then rotating a 45° lap to a 360° circle. The study found that 45° among the eight different orientations had a minimum annual consumption of 267 kWh/m^2/yr and chosen for optimization. The optimum value is 97 kWh/m^2/yr, which shows 50% energy savings w.r.t baseline value. The study demonstrates that adopting virtual technology in the design phase can help achieve optimal sustainable design solutions by addressing energy requirements in the early stages of the design. It helps to minimize energy-related effects and helps to solve problems related to energy analysis/optimization. The study has highlighted that with the application of virtual reality like BIM, several alternative designs for a selection of optimum efficient design can be achieved at an early

stage of planning and design to ultimately support and manage the challenges of energy crises.

Contents

List of Figures

List of Tables

Abbreviations

AC	Air Conditioning
ACH	Air Changes Per Hour
AEC	Architecture Engineering and Construction
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEM	Building Energy Modeling
BIM	Building Information Modeling
BIPV	Building Integrated Photovoltaics
CAD	Computer-Aided Design
CMU	Concrete Masonry Unit
CO	Carbon Oxide
EA	Energy Analysis
EU	European Union
GA	Genetic Algorithm
gbXML	Green Building eXtensible Markup Language
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
ICF	Insulated Concrete Form
IEA	International Energy Agency
IES	Integrated Environmental Solutions
KWh	Kilo Watt Hour
LC	Life Cycle
LCC	Life Cycle Cost
LCCE	Life Cycle Carbon Emission
LED	Light Emitting Diode

LEED	Leadership in Energy and Environmental Design
M	Meter
MEP	Mechanical Electrical and Plumbing
MS	Masters of Science
MW	Mega Watt
PM	Post Meridiem
PSO	Particle Swarm Optimization
PV	Photovoltaics
R	Resistance (Thermal)
SIP	Structural Insulated Panels
SQL	Structured Query Language
UNEP	United Nations Environment Programme
US	United States
USDOE	United States Department of Energy
VAV	Variable Air Volume
VE	Virtual Environment
WRT	With Respect To
WWR	Window to Wall Ratio
YR	Year

Chapter 1

Introduction

1.1 Background

Energy Analysis (EA) is a discipline to examine the performance of building systems. EA is a basic scenario comparison of building models that compares things like building orientation, building envelope construction, glazing percentages and materials, and basic systems. GHG emissions and energy utilization are firmly connected. According to Tusher et al. [1], globally 27% of overall energy consumption and 17% of CO2 productions were due to the housing sectors. Jin et al. [2] stated that globally, 20% to 40% of total energy usage is due to the building sector. Sandberg et al. [3] suggested that new sustainability requirements have been progressed by the environmental impact from the built environment regarding the building's performance throughout life cycle cost and energy.

According to the World Green Council, buildings are using 40% of energy, 32% of natural resources, and responsible for 36% of Greenhouse gas emission as shown in figure 1.1. The trend in the world about energy usage has been mounting serious concern about supply problems, energy fatigue, and hefty environmental effects [4]. The energy demand is continuously rising because of global energy consumption. The construction sectors and built structures are collectively responsible for total energy consumption and CO2 emissions nearly about 36% and 40% respectively [5]. Substantial energy savings can be attained if the building designs are proper along with construction and operation [6]. Pakistan is an extremely energy

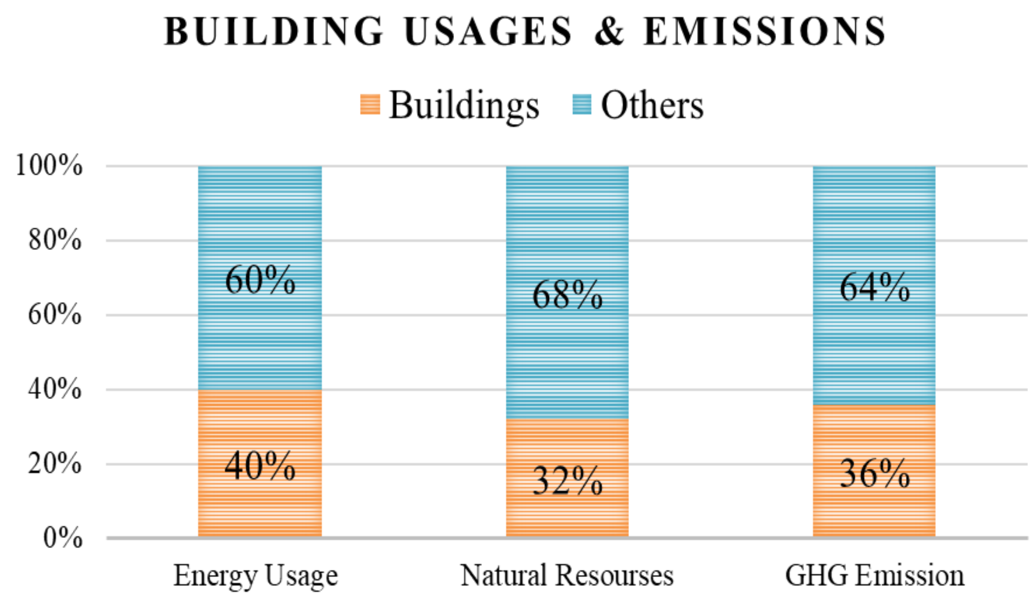


FIGURE 1.1: Building Usages according to the World Green Building Council 2010

lacking country. It is at 164th on world ranking with 475 kWh/capita/year usage with the highest energy intake for domestic purposes. 45.9% of the total is the annual energy utilization by the domestic zone, Around half of the total energy utilized in the buildings is for heating, ventilation, and Heating, ventilation, and air conditioning (HVAC) and lighting appliances [7].

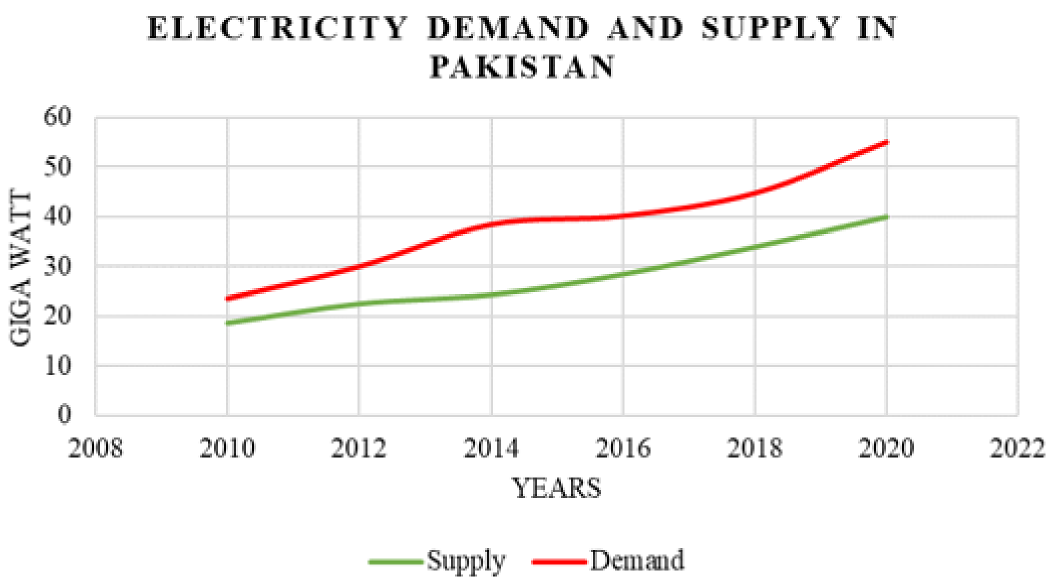


FIGURE 1.2: Electricity Demand and Supply in Pakistan [8]

Figure 1.2 illustrates that the gap between energy supply and demand in Pakistan is increasing. As you can see in the above figure that in 2010 the gap was approximately 6 Giga Watt which has increased to about 15 Giga Watt in 2020. To attain the European Union (EU) climate and energy goals, energy analysis of buildings is a key component, in particular, 20% of energy savings and a 20% decrease of greenhouse gases released by 2020. Sameul et al. [4] reported that worldwide energy demand will upsurge by over one-third in the period of 2020 to 2035. Energy analysis and optimization have gained momentum due to the use of Building Information Modeling (BIM) that upgrades the simulation process of energy analysis. At the conceptual design phase of planned projects, BIM users assess many alternate designs and select vital energy approaches and schemes.

1.2 Research Motivation and Problem Statement

Energy has become an essential part of life, and many are expecting an affordable price for it conveniently [10]. In recent years, the usage of the energy in the buildings has been on the rise, due to the population increase, economic growth, and extremely luxurious life [6]. However, the world has scarce natural resources i.e. water, wood, oil, natural gas, and coal that are depleting with time. If major oil and gas suppliers stop their supply around the world, then many countries including Pakistan would face serious energy crises. The expanding rate of urbanization in late decades has seen an accelerated development of high rise buildings around the world [9]. Energy performance of the high rise structures needed more attention to achieve sustainability goals [4]. Furthermore, an increase in carbon footprint, greenhouse effect and toxic emission in the form of gas, liquid and solid cause the increase in global warming and other secondary effects like a flood, a rise in temperature and snow melting etc. To avoid this overwhelming situation, people are working hard to find alternative solutions. Either we generate more energy using natural resources or optimize energy usage, to reduce energy issues in buildings and to achieve a sustainable future.

- Energy demand from buildings and buildings construction continues to rise over time. In Pakistan, building energy uses are irregular and comprise several factors, e.g. the size of the building, time spent in the building, building type, seasonal changes, and occupiers' behavior patterns. Form the previous decades, Pakistan is bearing energy crises. Pakistan creates about 81% of its power through natural assets e.g. oil and gas, which costs us about 9.4 billion dollars. Presently, tall and thin structures are needed for huge urban areas where space is constrained. Population growth, improvement in the building facilities and luxury levels, increase in time consumed in the structures, have elevated energy usage.

BIM-enabled energy optimization of the commercial building supported by its BIM modeling energy analysis can help to minimize the energy-related after-effects and guide to solve problems related to building energy analysis/optimization. It has the potential to naturally integrate energy-efficient techniques into building design, improve performance, simulation speed, and the accuracy of energy simulation.

1.3 Research Objectives

The objective of the study is to promote the optimization of energy patterns in the buildings.
The overall objective of the research program is to achieve sustainability in the performance assessment of the building sector by introducing BIM-based energy solutions.
"The specific aim of this Master of Science (MS) research work is to execute energy performance analysis on a selected case study of commercial high rise building to achieve energy optimization using BIM by rotating it to 360° circle with the lap interval of 45°."

1.4 Scope of Work

Optimization of the energy performance of a virtually developed 3-D parametric model of a conventional commercial building using Building Information Modeling. Energy modeling, analysis, and optimization are performed on:

- Autodesk Revit
- Autodesk Insight

1.5 Limitations of Work

- Only the operational phase has been accounted for.
- The case study of a commercial building.
- 0° to 360° rotations with respect to building centerline with the lap interval of 45° is undertaken for analysis.

The operational phase means when the construction phase will be completed and the building was in use. The case study of commercial high rise buildings was not still reported and there is a need to analysis the commercial high building energy usages in the context of Pakistan conditions. This energy usage will be further optimized for sustainability. 8 rotation with the lap interval 45° in a circle will be taken for analysis and a true north orientation.

1.6 Brief Methodology

Different stages of research are shown in figure 1.3, starting from the literature review and problem statement along with the identification of the research gap. The selection of a case study and its 3-D modeling for Energy analysis is completed after that. On the basis of this energy analysis, energy optimization and recommendations are done.

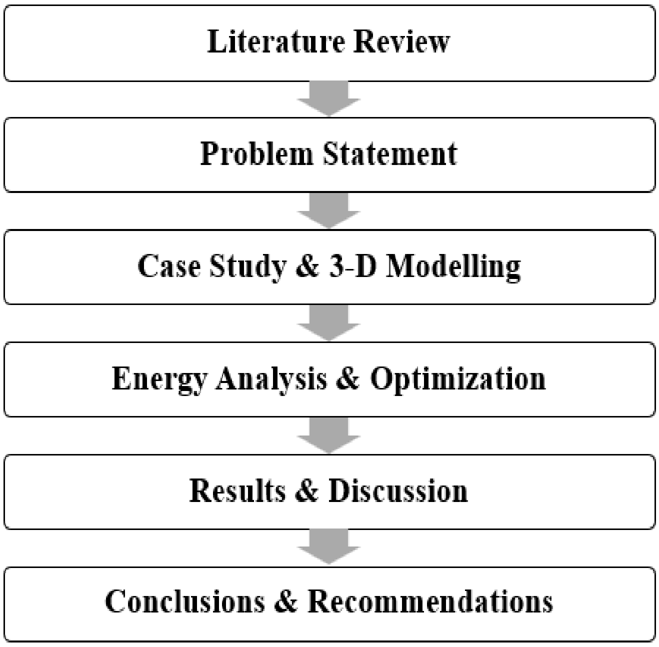


FIGURE 1.3: Brief Methodology

1.7 Thesis Outline

The thesis layout comprises of five main chapters. These are:

Chapter 1: In the introduction, the background of the study including a brief overview of building energy analysis, research motivation, problem statement, research objectives, and methodology, along with thesis layout is explained.

Chapter 2: It provides a detailed and critical review of the literature related to previous researches on BIM-based energy simulation background, energy analysis, and application of BIM for energy optimization. The research gap has also been formulated in this part.

Chapter 3: It provides details of the methodology adopted to conduct this study. It explains the tools and methods adopted to do the research analysis and formulation of results.

Chapter 4: This chapter explains the fine points of the results and subsequent discussions of the research.

Chapter 5: In this chapter, conclusion, and recommendations have been presented on the basis of findings and results.

Chapter 2

Critical Literature Review

Energy is an essential requirement of society and plays a vital role in its socio-economic development. Over time, energy utilization is growing tremendously due to the quick shoot up in world population and high standard of living; to meet the energy demand according to society requirement is very challenging as well as economic development. The availability of electricity has now become a compulsory requirement.

As the world is developing, continuous energy and power supply are required to maintain a reasonable standard of living and support ecosystem [11]. The population is expected to reach more than 9 billion by 2040 if it increased with an average rate of 3.4% per year. Meanwhile, global energy necessities are probable to enlarge by 30% [12].

2.1 Energy and Environment

Climate change due to global warming is the burning issue that threatens the survival of mankind. Energy usage of the building, indoor-outdoor environment, and carbon footprint were substantially affected by anthropogenic activities. According to the European Commission of Buildings 2015, building stocks in the EU are accountable for nearly 36% of GHG emissions and 40% for energy utilization, mainly used in the entire operation-phase [13].

Gourlis and Kovacic [14] stated that the recent trends in energy consumption had elevated significant concerns about excessive impacts on the environment, cause supply chain problems and energy exhaustion, globally. The World Green Building Council in 2010 identified that nearly 32% of global natural resources were utilized by the building sector, the world's energy use having account of 40%, and as a consequence greenhouse gas (GHG) emitted nearly about 30% [15].

Global energy demand is growing with the recent changes in the environment which cause the upsurge in global warming[19]. Sameul et al. [4] Observed that "global energy demand will escalate by over one-third in the period of twenty years from 2015 to 2035." Due to population growth, rapid urbanization and quick industrialization energy demands are constantly increasing [10].

Environmental effects from the built environment including energy use, global warming potential, and waste have posed new sustainability necessities regarding the building's performance throughout its life cycle in terms of energy and cost [3]. Water preservation, decrease in energy usage, sustainable procurement of different products and items, development in the industry, reduction in the waste, recycling and reuse, change in the climatic conditions, and biodiversity is the prime constituents of sustainable development.

The major annual contribution to greenhouse gas arises from buildings [16]. Sustainable development in the building sector can deliver social benefits including but not limited to enhancing occupants' comfort level and health, creating aesthetic pleasures, reducing stress on the infrastructure and improving labor productivity [17].

Environmental benefits of sustainable development in the buildings included preservation of water, reduction in the toxic emissions, improving the quality of air and water, decreasing the waste, controlling the temperature, preservation of the ecosystem, protecting and restoring the natural resources [18]. Substantial progress in terms of sustainability assessment of energy systems, considering economics, environmental emissions, and technological efficiency, has been shown by the researchers [20].

2.2 Energy and Built Environment

Greenhouse gas emissions and energy utilization are dependent on one another. Globally, Residential sectors are responsible for nearly about % and 17% of total energy utilization and CO_2 release, respectively [1]. In residential areas, the HVAC system and lighting are the primary sources of energy consumption according to recent studies. Many studies have shown that the total energy use of the building was greatly affected by cooling and heating appliances [21]. In contrast, energy utilization has duly affected the construction of materials: to begin with the embodied energy usage for the manufacture of materials. Furthermore, its influence on energy usage at the operational stage. Different studies on energy analysis stated that the overall energy required in the life cycle of the building ranged from 10% to 20% for embodies stage and according to the United Nations Environment Program (UNEP) 80% to 90% for operational period [22]. Though, recent studies mainly focused on the improvement of HVAC equipment for the decrease in utilization of energy in the buildings while usage of energy-efficient materials for optimizing energy consumption was rare [1].

Hamdy et al. [5] stated that 40% of energy usage and 36% of the EU's CO_2 emissions are due to the buildings. A major portion of the energy was used in the buildings to achieve a better and cozy indoor environment, which can be obtained through the usage of HVAC, lighting, and other appliances. Although, building energy utilization is the function of various factors, including time spent in the building, its type, shape, climate, and seasonal variation along with behavior patterns of occupants. Li and Yao [14] indicated that "population growth, increased levels of building services, facilities, comfort level, increased time spent on buildings, and increased building energy use".

In developed countries, buildings, commercial, residential and institutional types utilize round about 35 to 40 percent of the overall estimated energy depletion, with power or energy consumption range from 50-65% [2]. Only 10-20% of energy is used throughout the processing and extraction of raw materials, as well as in the manufacturing process for construction. According to Kuo et al. [23] 20 to 40 percent of total fuel utilization was due to the building sector and one-third of global greenhouse gas emissions.

Computational simulation allows the calculation of the energy used by the proposed building models. It incorporates thermal, solar, and airflow modeling and is concerned with the geometry, materials, control, and systems of the building [24].

2.3 Energy Consumption Concerns

Energy and its interrelated issues are the key global concerns nowadays, The International Energy Agency (IEA) in 2013 indicated that the key human cause of global warming is coal usage and consequently CO_2 release which touched a historic soaring figure of 13,113 Million Tonnes and 31,342 Million Tonnes, respectively [25]. Global energy usage is expected to grow by 28% between 2015-2040, while in Asia's 51% energy utilization upsurge is likely to be the biggest in the world. Recent studies stated that globally, account for the people having no electricity is more than 1.4 Billion and most of them in Africa. In Pakistan and India, nearly about 25 Million and 400 Million people are directly affected respectively. In 2017, Pakistan saw a shortfall of about 6500 MW [26].

2.4 Energy and Building Design Characteristics

The building industry utilizes a substantial share of its energy needs; The United States (US) Energy Information Association accounts for the global energy consumption up to 20.1% for the construction industry [27]. The energy consumed by the structural buildings mostly depends on different conditions like design, material, climatic and functional conditions. Structural construction materials are significant factors in this respect. The mode of consumption varies according to material types, thermal properties, dimensions, and kinetic behavior. Along with other factors of order like consumption of energy by lighting, heating, cooking and different appliances; weather conditions such as building type, residents, building usage, equipment size, energy efficiency, functional time and performance of equipment; Building location, the time period of every season, temperature (hot and cold), wind speed and weather are important factors in defining energy consumption trends [28].

Most of the energy is used by the construction industry, material, and land area, it has no doubt that the human environment has key implications, and in the construction industry that sustainable growth is inevitable. The use of suitable materials for distinct building sections is one of the peak significant factors that differentiate long-lasting buildings from short-lived, which is a key factor in sustainable development [29].

According to the US Department of Energy, windows make up more than 10% of the building's energy load and therefore have a significant influence on total energy consumption [30]. The main contributor to energy consumption is the construction industry in the world, reaching values of 20% to 40% in developed countries, far exceeding other sectors such as industry or transport. In the stock of large-scale housing biggest cost-effective energy savings potential is found [31].

2.5 Energy Analysis

Building energy efficiency analysis term discusses the evaluations plus assessments directed to govern the performance of the structure or building environment; It includes various analysis such as solar, heat, ventilation, daylighting, building mass, orientation, and optimization of a building and (HVAC) system [4]. Energy and performance analysis is done after the initiation stage. The lack of coordination in the design process led to an incompetent procedure of modifying the design of building or structure to attain performance criteria [32]. Building system analysis includes various functional features which include energy utilization and distribution, structural integrity, ventilation, heating cooling or temperature controlling circulation, lighting efficiency [33].

The identification and implementation of building energy-saving are not possible without the usage of energy performance analysis tools. Proper use of building energy analysis tools leads to precise and cost-effective energy analysis, which depicts total energy utilization and saving prospects [34]. According to the United

States Department of Energy (USDOE) in 2013, account for the registered energy simulation tools in the Building Energy Software tools directory is more than 400 [35]. The table is given below shows the dominant energy simulation tools used in education such as Ecotect, Insight and Green Building studio, etc. Insight is the latest simulation tool by Autodesk. Green Building Studio and EnergyPlus are mostly used. Design-Builder, HEED, and CONTAM etc. are mostly used in the Industrial sector as shown in the table.

Table 2.1: Dominant Energy Simulation Tools [36]

In Education	**In Industry**
1. Ecotect	1. Design Builder
2. Energy Plus	2. DOE-2
3. IES-VE	3. HEED
4. eQUEST	4. CONTAM
5. Green Building Studio	5. Radiance
6. INSIGHT360	6. Energy-10

EU climate and energy goals were attained by the efficient energy buildings, such as reducing emissions of greenhouse gases as well as primary energy savings by 20% [5]. The energy analysis results give a good idea to the design team about the energy gain and loss by the proposed building in a year which will further facilitate to estimate the overall cost of energy utilization during the operational phase of building [33].

The experts of the building industry identified that poor scope definition in the buildings was one of the key causes of project failure. This poor scope definition leads to the negative impacts of projects in terms of cost, time, and operational characteristics. Analysis of energy efficiency is carried out alongside with the measurement of scope development. Energy analysis can be included as part of the building/project design parameter analysis in accordance with the construction capacity analysis [32].

2.6 Energy Analysis and BIM

BIM is one of the rich data unified conceptualization that is used to analysis the building and helps in the decision making throughout the life of the building started from planning to demolition phases of building. A model that has been developed by BIM can be used as a consistent source of information. It also illustrates the physical and functional behavior of a building or any infrastructure[1]. The idea of BIM refers to simulation technology and connected usual processes for generating, communicating, and analyzing building models [31]. The National BIM Standard of U.S (2013) stated that the BIM is a cloud-enabled shared source of knowledge for info about the facility. It forms an authentic base for decision making throughout the life cycle of the facility; From the initial beginning to the end is defined. Since the mid-2000s, BIM has been used mostly for architectural design, as it provides not only 3D building components for architectural drawing but also detailed information and elements for quantitative take-off, cost decrease, and process management [37]. It has been the subject of debate and used for sustainable building designs in recent years [38].

BIM has been used up to 57% of all sustainable projects in the world [39]. BIM has often been documented as an appropriate tool for supporting collaborative planning in research and practice, with various planning processes facilitating communication and information exchange between participants. BIM advocates benefits as maximizing efficiency and quality by reducing time effort [13]. BIM has attained acceptance in a short period of time. It is an effective tool used for the advancement of building design throughout the simulation and operational phases [40]. The efficient building design using BIM and the interaction of Building Information Modeling (BIM) to Building Energy Modeling (BEM) is non-linear and multiplex. The correct and effective information delivery over the design requires an inclusive prescription or guidance [41].

In the AEC industry, the application of various engineering software with the help of computers having a vital role which cannot be overlooked. BIM is a smart and parametric simulated illustration of the building that considers throughout the life of the project in the design and documentation phase [42]. BIM is an important mechanism for collecting and transporting data between project participants and, as a result, is a leading tool for analyzing and making their decisions [43]. BIM has also used to optimize the design of buildings and improve their sustainability. Particle Swarm Optimization (PSO) is the optimization method used with the parameters of Life Cycle Cost (LCC) and Life Cycle Carbon Emissions (LCCE) for the designs [38].

The studies have shown that BIM-enabled thermal simulations can be utilized to attain zero net energy buildings for an improved replacement in multidisciplinary design optimization [44]. Other studies recommended life cycle assessment in design and conjugated application of BIM to decrease the environmental effects to the building constituents [45]. A geometric view of thermal data of buildings and materials using BIM reduces uncertainty in identifying the energy modeling process [46]. Some studies have been considered creating an envelope by BIM to compute energy utilization for thermal resistance (R) of building material used during construction [1]. BIM is used for the management of construction projects along with geometric modeling of the building's energy performance. BIM's opportunity to explore multidisciplinary information and link it to energy performance was explored in a model to determine the efficiency of the LEED of a non-residential building [47].

The application of BIM to structural and energy analysis are stated with 27% and 25%, respectively, its main use still looks to be the rapid development of 3-D geometric models and 3-D coordinates with a usage or practice frequency of 60% [48]. Automation of the modeling process is a major advantage of the application of BIM in energy simulations of buildings that can reduce time, lower cost, and human error compared to the traditional energy modeling process [49]. Carvalho et al. [50] detailed that approximately 20% of total cost savings can be possible in the BIM-enabled sustainable construction of the building.

2.7 Energy Optimization

Change in the climate and global warming, energy security, and substantial cost saving are the key ingredients of the improved or optimized energy-efficient building [5]. Energy efficiency measures, along with improved structure or system integration, are comprised in the design stage, combined with improved system integration. Facilities are built on a continuous succession of all stakeholders built on a succession of manual measurements. In the early design and preconstruction stage, the best effective conclusions about the energy-efficient buildings were made [32]. BIM-based energy modeling tools are adopted to predict energy savings in the design stage of low-energy buildings [37].

2.8 Previous Energy Optimization Studies

The exploration of energy patterns and their impacts have been a keen area of research in recent years with ever-increasing population, this has become more challenging for future concerns.

TABLE 2.2: Previous Energy Optimization in the World

Sr. N.	**Authors /Years**	**Scope**	**Tool Used**	**Findings / Results**
1	Cho et al., 2011	Energy Efficient Building	1. EnergyPlus 2. SketchUp 3. Revit 4. IES-VE	a. Larger windows increased the total energy consumption. b. The recommended orientation is either north or south [32].
2	Cho et al., 2009	Problems with the ArchiCAD model transfer to Ecotect	1. Archi CAD 2. Ecotect	a. Elements have lost their assigned names. e.g. floor becomes ceilings. b. Change in material properties. e.g. floor to wall [39].

3	Mishra & Goel, 2019	The Highly Efficient Architectural Shape Of The Building	1. Revit 2. Green Building Studio	Hexagonal shape with 90° orientation w.r.t true north gives the most effective results in terms of occupancy and energy savings [9].
4	Tushar et al., 2019	Optimization of Energy Utilization	1. Revit	a. 47% lessen energy utilization for heating/cooling can be attained by Better-quality. insulation along with 87% decrease in Greenhouse Gas release [1].
5	Oti & Abanda, 2020	Review of information modeling systems	-	Interoperability needs and supply chain are the key considerations for stakeholders [51].
6	Liu et al., 2015	BIM-enables optimization	1. PSO algorithm	Total cost and carbon emission can be reduced by 30% and 31% respectively [38].
7	Jalaei & Jrade, 2015	Energy analysis tools linking with the green building certification system in BIM	1. Revit 2. Ecotect 3. IES-VE	a. Sustainable materials can be selected in the early design phase and better decision making regarding energy saving [33].
8	Nguyen et al., 2014	Review of simulated optimization approaches	-	a. TRNSYS and EnergyPlus are frequently adopted. b. GenOpt and Matlab optimization toolboxes are commonly used engines. c. Metaheuristic research algorithms are GA & PSO [52].

9	Gerrish et al., 2017	BIM applications as a performance optimization tool	1. IES-VE 2. Revit 3. Dynamo 4. Python	a. AEC industry is overdue the use of BIM and various other platforms. b. Preventing the holistic adoption of new tools and processes due to conventional procedures. c. Designers and operators must adopt new technologies [53].
10	Keskin & Salman, 2018	Implementation of BIM for energy analysis	1. Revit 2. Insight	BIM implementations can provide cost and time savings for energy analysis practices [34].
11	Saberi et al., 2017	BIPV system with energy simulation	1. Rhinoceros 3-D plug-in 2. EnergyPlus	a. BIPV glazing material increases energy consumption. b. Ideal WWR is 8% after adding photovoltaics [54].
12	Carvalho et al., 2019	To optimize and assess the energy efficiency using BIM	1. Revit 2. Green Building Studio	a. The design process can speed up by enabling BIM along with efficient and sustainable design. b. The energy efficiency of the project can be improved within the limited resource using BIM [50].
13	Farzaneh et al., 2018	Framework for BIM to create a BEM	1. Revit 2. IES-VE 3. Open Studio 4. SketchUp	a. There is a lack of interoperability between the currently available MEP and BEM tools. b. Due to the multifarious calibration process and huge modeling effort, operational stages are not comprised of BIM objects [40].

14	Gourlis & Kovacic, 2017	Energy Analysis of the industrial building	1. Revit 2. EnergyPlus 3. SketchUp 4. OpenStudio	a. The application of 3-D BIM modeling provides nearly about 50% savings in terms of energy. b. Computerized BIM to BEM requires fewer assets and efforts for optimization. c. To minimize BIM to BEM uncertainties, interoperability concerns of the tool have to be improved [13].
15	Farzaneh et al, 2019	Review of using BIM for BEM during the design process		Level of effort can be reduced using this framework for energy-efficient building [55].
16	Khan & Ghadge, 2019	BIM-enabled analysis	1. Revit 2. Insight 3. Green Building Studio	a. Resource usage is optimized and enhances project performance. b. Data integration was problem-solving. c. Analysis, applications and design deliverables workflow can be improved using BIM. d. The gbXML (file format) is a promising solution for data interoperability. e. It helps the practitioners in designing the facility with the least impact on the environment. f. It significantly reduces the cost and time [17].
17	Singh & Sadhu,	Energy assessment	1. Revit	a. The overall cost can be affected by changes in the internal and external configuration of a structure.

	2019	of buildings using BIM	2. Green Building Studio	b. North and south sides having the highest potential for Solar. c. 15° and 60° orientation uses minimum energy for each case [47].
18	Treeck et al., 2018	BIM for Energy Analysis	1. CAD	a. BIM is beneficial in the technical services of the building. b. For HVAC energy concerns and decision making in the construction phase [56].
19	Zhang et al., 2018	BIM-enabled analysis of energy usage	1. Revit 2. SQL	a. Embodied energy usage is 90% and concrete is 51% of total embodied energy. b. Transportation 5% of total energy consumption and staff transportation is 75.6% [25].
20	Chen et al., 2019	Energy Optimization integrated with Photovoltaic façade	1. EnergyPlus	a. The window geometry, thermal and optical properties are proved to be most important to the PV envelope design. b. Net Energy demand can be reduced up to 48.77% [57].

The conclusion of enlisted references from previous studies related to environmental concerns of energy is that energy demand and consumption is increasing rapidly with time and cause severe environmental impacts such as global warming & GHG emission. Similarly, a previous literature review on Energy concerns in Pakistan concludes that in Pakistan, about 25M people are directly affected by energy shortage due to low power generation capacity. Energy analysis clearly identifies the areas where we can achieve energy conservation by reducing energy consumption. By adopting energy optimization measures in the early design phase, we can significantly reduce the net energy demand resulting in substantial cost saving. The last aspect is energy and technology, which includes the application of modern tools for analysis and optimization. The application of modern tools helps to predict and forecast the energy performance of the building which can be further optimized for sustainable development.

2.9 Energy Concerns in Pakistan Context

The energy demand has shot up due to the increase in population and economic development in the world. The electricity generation in Pakistan is still dependent on common thermal natural resources. Although, these resources can no longer rely on a primary option of energy increase in prices and a severe impact on the environment [58].

For domestic energy use, Pakistan is considered in those countries in which energy is highly being consumed. The total fuel consumption per year is nearly up to 46% and 26% for the domestic sector and industrial sector respectively. Buildings and electronic appliances for HVAC consume about half of the energy [7]. Per capita, the energy consumption of Pakistan is 475 kWh/Year and in the world ranking it is 164. Pakistan energy shortage is round about 5,000 MW while in summer and winter it comes to worst load-shedding. The installed power capacity of Pakistan is about 19,500 MW in which 13,500 MW is only produced. Pakistan is experiencing critical energy crises, and this is most noticeable when there is a power shortage in the urban areas at 6 to 8 pm and in the rural areas at 12 to 16 pm [59].

The total power generation capacity is 25,374 MW according to the Pakistan Board of Investment report. However, the actual output will be from 20,000 to 24,000 MW and the maximum power demand will reach from 23,000 to 25,000 MW. The estimated electricity demand and supply from 2010 to 2030 are noticeable for constantly raising in the yearly growth rate of 5% to 7% in demand for energy [58]. The low energy consumption and high indoor environmental quality in the design of buildings are often achieved by reducing the energy performance of buildings [60]. The professionals must take decisions and a range of activities at each design stage for high-performance buildings in the design process. The building project in the general design process consists of three stages: Basic Design Concept, Final Design Concept, and Developmental Design according to the ASHRAE Green guide [55].

Energy-conservation is a long-term and time-consuming progression, but in the long term, it can be very advantageous. Pakistan must adopt energy-saving practices and equip itself in the current time as the developed world. The rapid development of energy-saving buildings is essential to counteract the growing energy crisis and associated environmental impacts in Pakistan. Innovations in existing building-design can help the country reduce the energy crisis. The energy demand has soared up due to the increase in population and economic development in the world. The electricity generation in Pakistan is still dependent on common thermal natural resources [7].

Chapter 3

Research Methodology

This chapter describes the methods and scientific approaches adopted for the achievement of the proposed objectives.

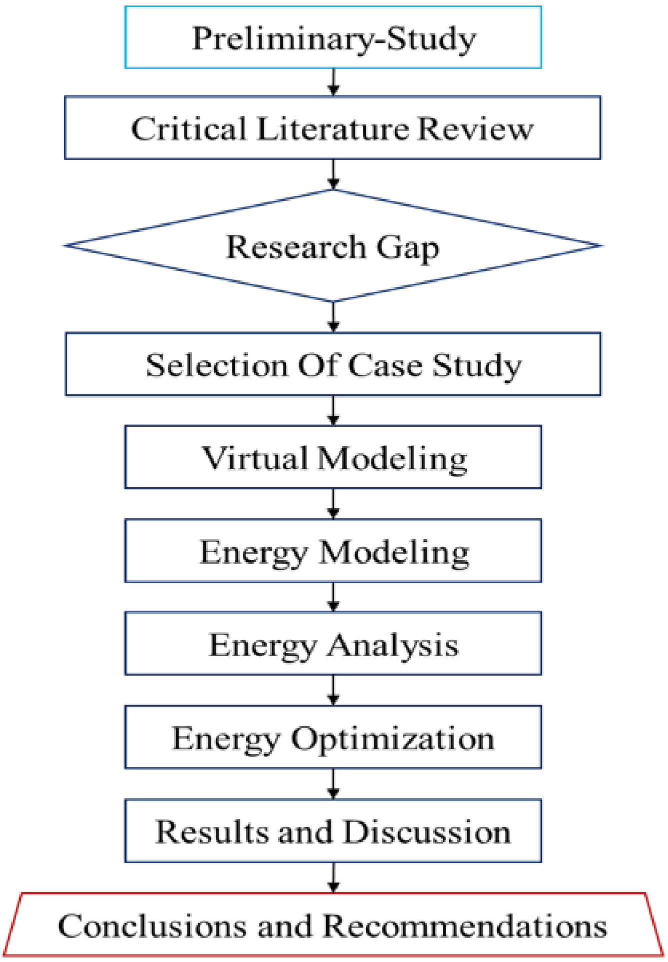


FIGURE 3.1: Paradigm of Research Design

A comprehensive and critical literature review was conducted to establish the research gap that is discussed in the section of the case study later on. A case study of a commercial high-rise building was selected. The secondary data was obtained from the concerned organization. Energy optimization performed on the virtual developed 3-D model. Figure 3.1 shown above illustrates the flow of the research methodology adopted in the research work.
This research work has been designed for analysis and optimizes energy usage in the early design phase of construction projects. It will also help to achieve goals of sustainability by less energy consumption. Based on the research objectives, a critical and comprehensive review of the literature was conducted. In the related areas of research work and identify the energy optimization methods, tools, and techniques and the research gap along with the trends in the world about energy usage and sustainability requirements in the building sector.

3.1 Case Study

In most of the studies, either energy analysis or optimization of the building was done using Softwares. The majority of the studies were conducted outside Pakistan. Even though some of the characteristics of construction projects are similar worldwide. But specific country conditions require research in detail. The rapid development of energy-saving buildings is essential to counteract the growing energy crisis and associated environmental impacts in Pakistan. This aspect was still a grey area requiring attention. So, a case study stratagem was applied to deliver an in-depth exploration of the BIM-based energy analysis and energy optimization of the structure according to the environmental and geographical conditions of Pakistan. A conventional residential high rise building was selected in Islamabad, Pakistan, as a case study for BIM modeling, energy analysis, and optimization. There are 16 floors of the building with a total area of 98765.65 square feet. Concrete filled columns are used during construction; walls are made up of blocks and plaster over them. Conventional wooden doors and aluminum glass windows used. The building's location is the capital city of Pakistan as shown in figure 3.2 shown

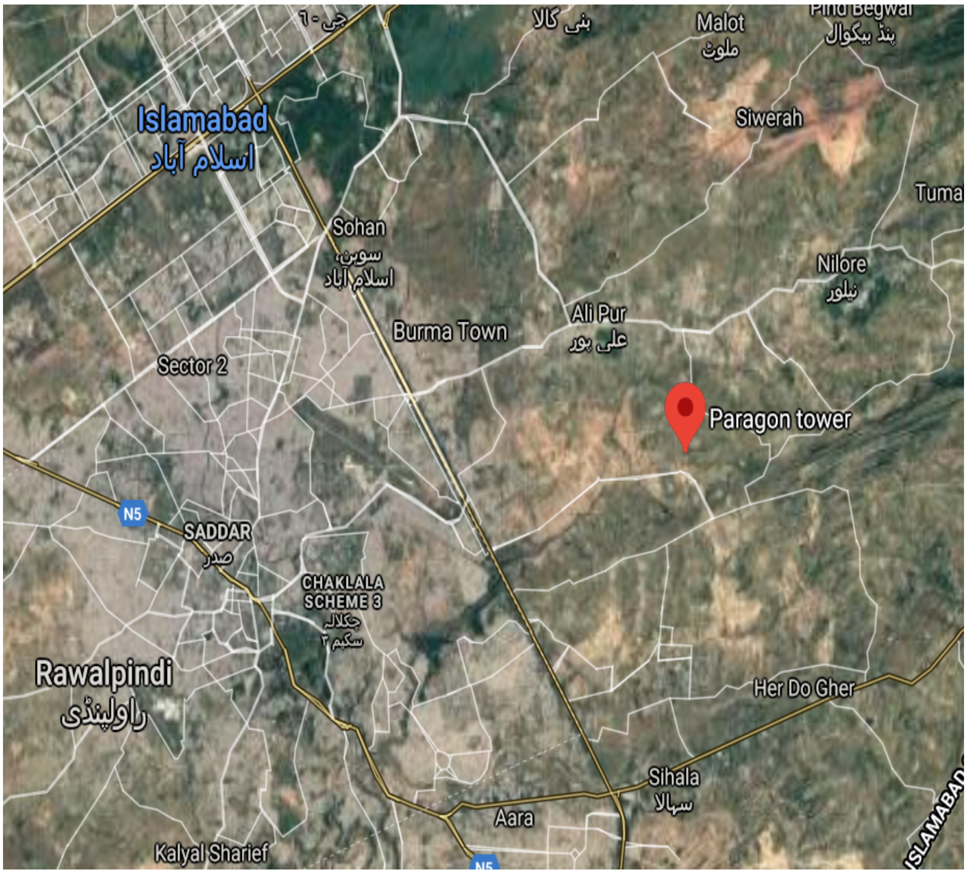


FIGURE 3.2: Location of the Case Study

above. This structure is comprised of concrete columns, block filled walls insulated by plaster, conventional wooden door, and glass windows. It consists of 16 floors along with the ground floor and basement.

3.1.1 Building Information Model

BIM technology is concerned with the generation and managing of simulated illustration of a building or facility in a computer-generated environment. In BIM-enabled building design procedures, architects can apply the BIM technique to investigate various design conceptions in a short period of time. Architects can continue to reinforce the BIM model in the illustrative design After the conceptual design has been completed. After the formation of the BIM model, energy simulation and analysis can be done on the basis of the building's geometry and info inside the BIM model. In this case, the Revit model is developed on the basis of 2-D drawings.

3.2 Energy Optimization Flow

BIM simulation workflow illustrated in figure 3.3 shown below;

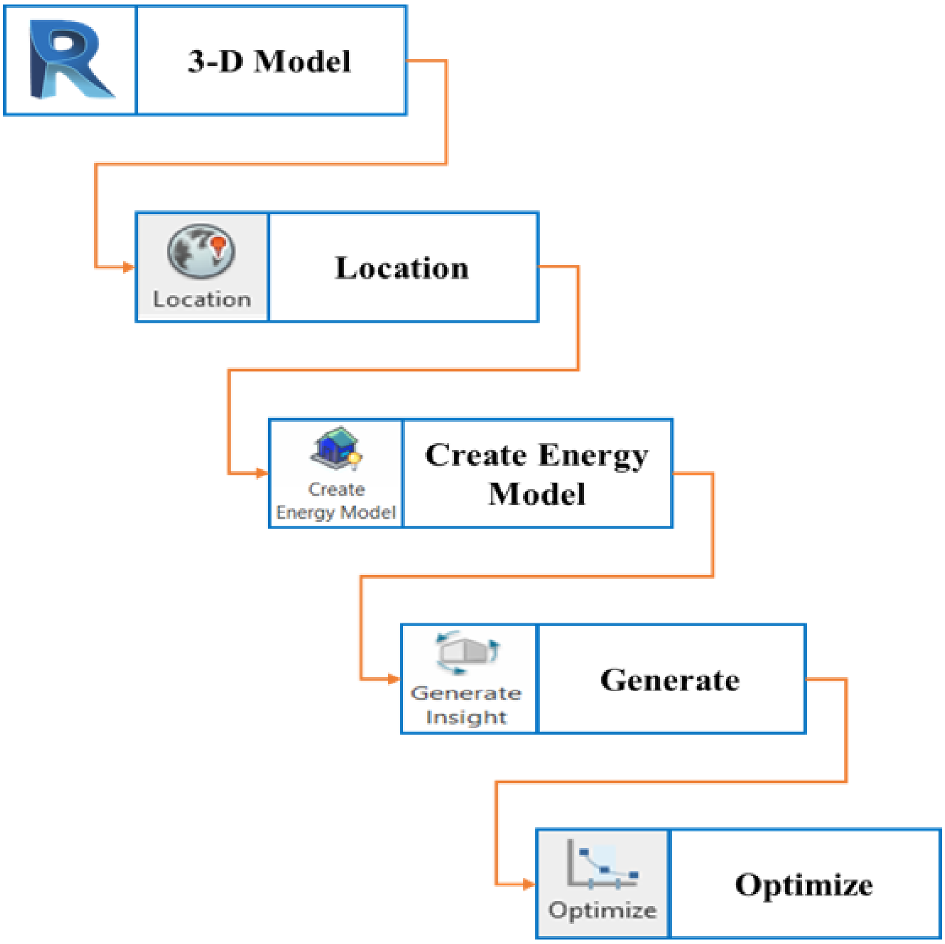


FIGURE 3.3: Simulation Work Flow

3.2.1 Creation of Virtual Model

Revit is a 3-D modeling software used as one of the best BIM tools. It is one step ahead of conventional CAD software used for drawings. The key benefit of the Revit is its 3-D aspect in the overall database. This means that everything is integrated and interconnected and, an alteration will be replicated everywhere throughout the stage. For example, if you remove a door, that door no longer exists in plans, sections, elevations, or even schedules. Using architecture Revit, the 2-D drawings were transformed into the 3-D virtual model. Figure 3.4 shows the BIM model of Revit can be seen in the figure below.

Figure 3.4: Revit 3-D Model Elevation

3.2.2 3-D Model to Energy Model

BEM is a computer simulation of a building that is used to determine or estimate energy use. The key objective of energy-modeling is to make precise energy-saving decisions on a building. For this purpose, the user builds the initial building or model in the simulation software under existing or standard conditions and then re-simulates the building. In this research, the BIM model was transformed into

Building Energy Model (BEM) using Insight360. This is a gbXML model that has been created through energy modeling using Insight. Thermal zoning according to the geometry is created that we can expand the model to see the constituents of the analytical model.

The perspective view of the energy model used for cloud computing is shown in figure 3.5 below.

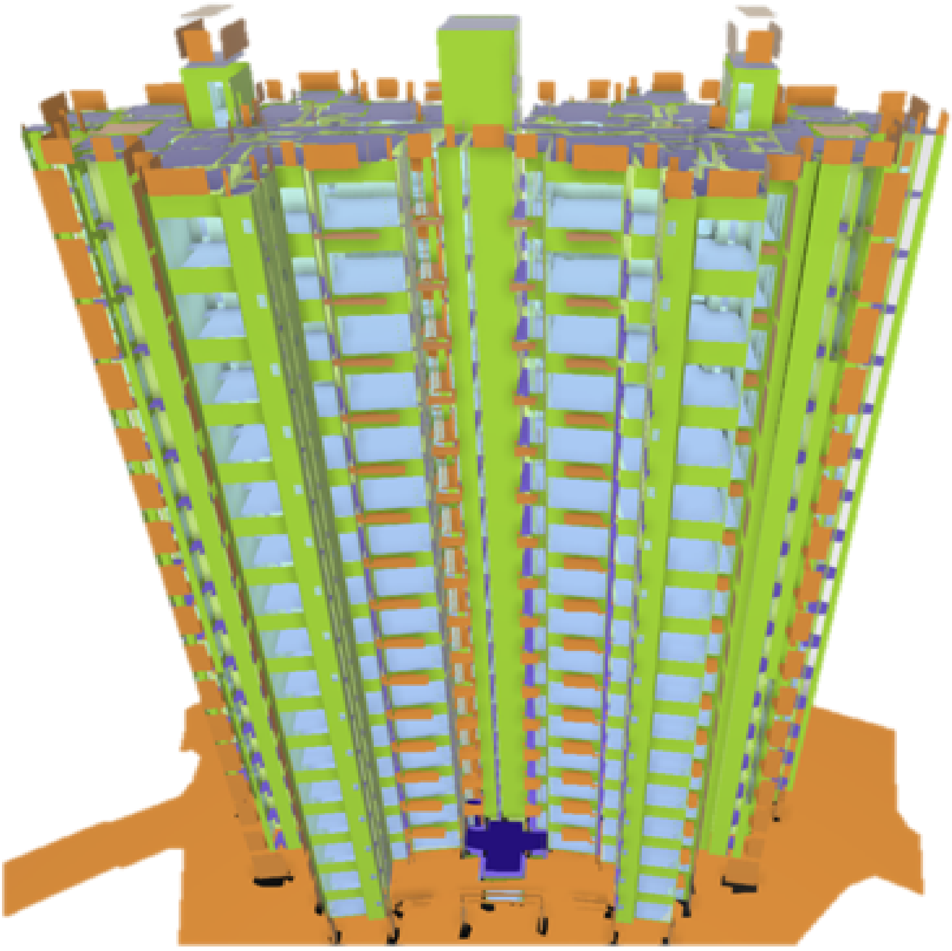


FIGURE 3.5: Insight Energy Model

Cloud-based energy analysis was performed. However, the following considerations shown in the table below are vital for such analysis. Insight is the latest energy analysis and simulation tool. In the energy setting interface, first of all, the location of the building was set which Islamabad the Capital City of Pakistan. In the location settings, it will opt for weather stations in the selected city.

Table 3.1: Inputs for Energy Modeling

Serial No	Inputs
1	Information library/Families (Database)
2	3-D model
3	Location of building

3.3 Energy Analysis

Building energy analysis is typically done after the completion of architectural drawings and building documents. Information on the geometry of the building is obtained from architectural drawings that reflect the architect's outlook of the building in a conventional way. The results provide the potential of BIM in energy optimization and sustainability or green design, inclusive of the subsequent characteristics. The best building orientation and alignment for minimal energy use or cost impacted by various factors.
In current work, cloud-based Energy analysis was performed on the building by rotating it in a circle (360°) with a lap interval of 45° with respect to the baseline of building. However, the proposed location which is 37° was set as a baseline as shown in figure 3.6.

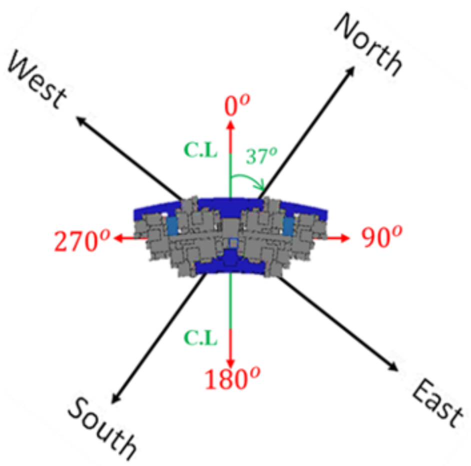


Figure 3.6: Proposed Orientation of the Building

3.4 Energy Optimization

Energy optimization corresponding to energy utilization in the built environment to benefits for the climate and for people. Optimization of energy usage in the building will be helpful to reduce the abrupt environmental and climatic changes. Energy optimization of the building leads towards the maximum energy saving, this leads towards minimization of the total cost. Building optimization is performed before the construction, rebuild or retrofits initiates on the site. Effective designed buildings or structures can scale down the energy utilization and cost while raising comfort level and quality of life for the residents of the building.
In this research, Energy optimization was performed on the building by rotating it into 360° circle with a lap interval of 45° with respect to building baseline. However, the proposed location, which is 37°, was set as a baseline for analysis.

3.4.1 Scheme of Rotations

Rotation scheme adopted in work detailed in Table 3.2 below;

TABLE 3.2: Scheme of Rotations

Serial No.	**True North and Eight Rotations w.r.t Building Centerline**	**Angle**
1	True North	37°
2	Rotation 1	0° or 360°
3	Rotation 2	45°
4	Rotation 3	90°
5	Rotation 4	135°
6	Rotation 5	180°
7	Rotation 6	225°
8	Rotation 7	270°
9	Rotation 8	315°

3.4.2 Energy Optimization Parameters

Table 3.3 below shows the factors and their corresponding optimization range used during the energy analysis and optimization. The cloud base analysis gives us this inbuild sixteen parameters after the energy analysis of the building.

TABLE 3.3: Range for Energy Optimization

S.No.	Factors	Optimization Range
1	Orientation	0° to 360° with the lap of 45° (8 Alignments)
2	Annual Energy Usage	Simulated Value
3	Window Wall Ratio	95% - 0%
4	Window Shades	1/6, 1/4, 1/3, 1/2 and 2/3 (Win Height)
5	Window Glass	Sgl Clr, Dbl Clr, Dbl LoE, and Trp LoE
6	Wall Construction	Uninsulated, R13-Wood, R13-Metal, R2-CMU, R38-Wood, 14-inch-ICF, 12.25-inch-SIP, and R13+R10 Metal
7	Roof Construction	Uninsulated, R10, R15, R19, R38, 10.25-inch-SIP and R60
8	Infiltration	2.0, 1.6, 1.2, 0.8, 0.4, 0.2 and 0.1 (ACH)
9	Lighting Efficiency	20.45, 16.15, 11.84. 7.53 and 3.23 (W/m^2)
10	Daylighting and Occupancy Control	None, Daylighting Control, Occupancy Control, and Daylighting & Occupancy Control
11	Plug Load Efficiency	27.99, 21.53, 17.22, 13.99, 10.76 and 6.46 (W/m^2)
12	HVAC	ASHRAE Heat Pump, ASHRAE VAV, ASHRAE Package System, High Eff. VAV, High Eff. Package System, High Eff. Package Terminal AC and ASHRAE Package Terminal Heat Pump
13	Operating Schedule	24/7, 12/7, 12/6 and 12/5
14	PV Panel Efficiency	16%, 18.6% and 20.4%
15	PV Surface Coverage	0%, 60%, 75% and 90%
16	PV Payback Limit	10 yr, 20 yr, and 30 yr

Chapter 4

Results and Discussions

The current chapter details the result and discussion in the research work on the selected case study. The energy analysis has been presented along with the various trends and patterns at different building orientations. The energy consumption patterns have been completed and comprehensive comparative analysis has been formulated. Different factors affecting these patterns have also been discussed and optimization has been performed.

4.1 Energy Analysis

The selected case study was developed in the form of a 3-D model using a virtual parametric prototype by the adoption of BIM. In order to study the energy pattern, the energy model of the virtual model was generated. Insight 360 helped to generate the energy model. Energy analysis of building was performed using the Insight plug-in of Revit at eight different orientations with respect to its centerline of the building has been adopted with an angle difference of 45°. Figure 4.1 illustrates the rotation mechanism for the study. Building centerline at True north is our baseline for comparative analysis.

The geographical location of the energy model remains one of the important aspects to study energy issues. In order to achieve a realistic picture, the exact location of the proposed building was included in the cloud computing analysis.

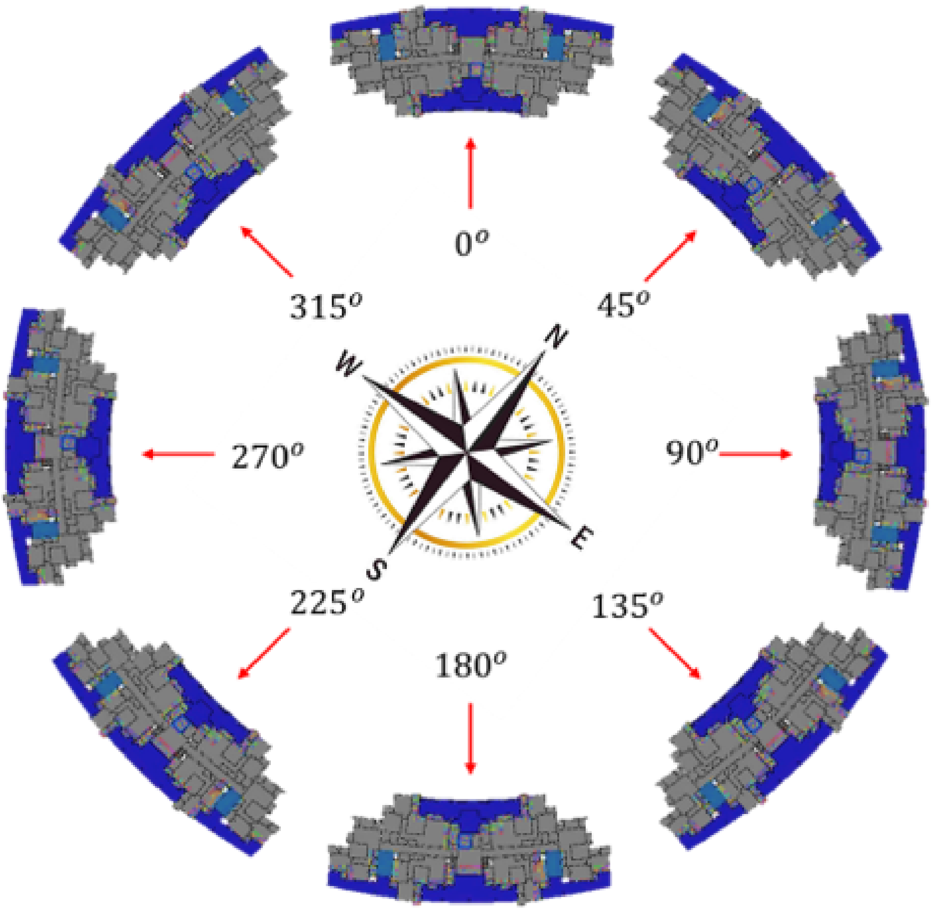


FIGURE 4.1: Rotation Mechanism

Cloud computing was a cyclic process required to be repeated with each rotation pattern as shown in figure 4.2.

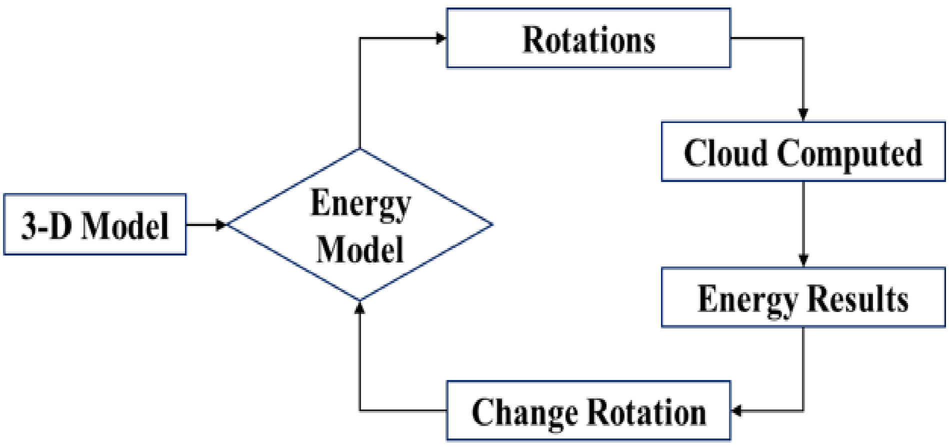


FIGURE 4.2: Cloud Computing Cycle

4.2 Building Orientation

The orientation of a green or sustainable building to be built in the position of the building on the site for the project according to sun and wind direction, in relation to the sidewalks, the streets, and the landscaping. Energy analysis was performed on eight orientations to get the least energy consumption value that will be discussed below.

4.2.1 True North Orientation

Baseline orientation for comparing other values when the centerline is at True North. The average energy consumption achieves at true North orientation was 270 kWh/m^2/yr. The upper limit remained 974 kWh/m^2/yr and lower limit 47 kWh/m^2/yr. According to ASHRAE 90.1 benchmark value is 250 kWh/m^2/yr was observed as shown in figure 4.3.

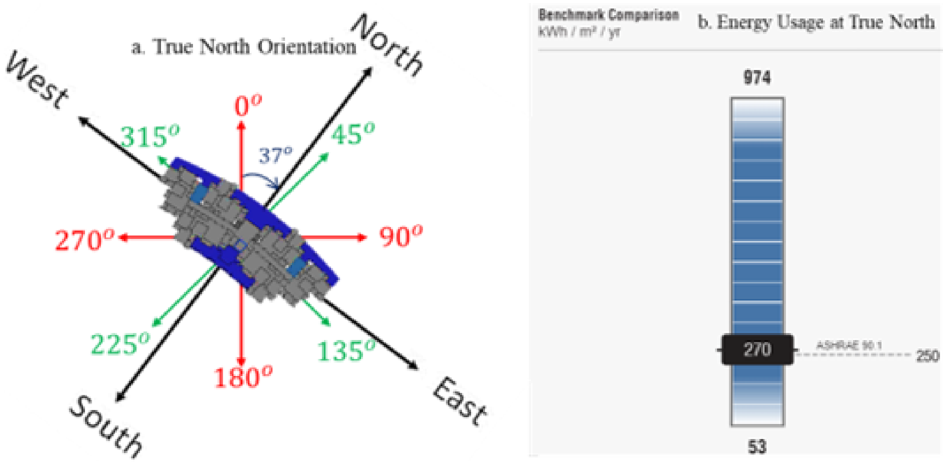


FIGURE 4.3: Energy Consumption at True North Orientation

4.2.2 Rotation: 01

At Rotation 01, we take the center of the building at 0° degrees. However, in position, the true North was at an angle of 37° anti-clockwise. At this position, an average energy of 276 kWh/m^2/yr was observed, which was 7 kWh/m^2/yr than the baseline orientation. The upper and lower limit values were observed 45 and 1005 kWh/m^2/yr, respectively. However, in this case the ASHRAE 90.1 benchmark value is increased to 286 kWh/m^2/yr. This location has also become 360o with the same results when one rotation is completed.

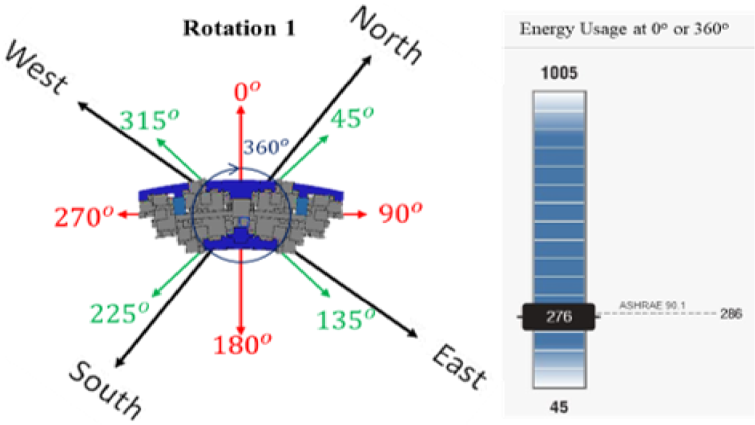


FIGURE 4.4: 0° or 360° Orientation

4.2.3 Rotation: 02

Rotation 02 was performed at an angle of 45° clockwise, North East from the rotation 01. The orientation of the building was changed to 8° anti-clockwise from True North. At this point, an average energy consumption level of 267 kWh/m^2/yr was achieved which was again 9 kWh/m^2/yr lower than its previous rotation. The upper limit remained 1004 kWh/m^2/yr and lower 38 kWh/m^2/yr. ASHRAE 90.1 benchmark value is 301 kWh/m^2/yr as shown in figure 4.5.

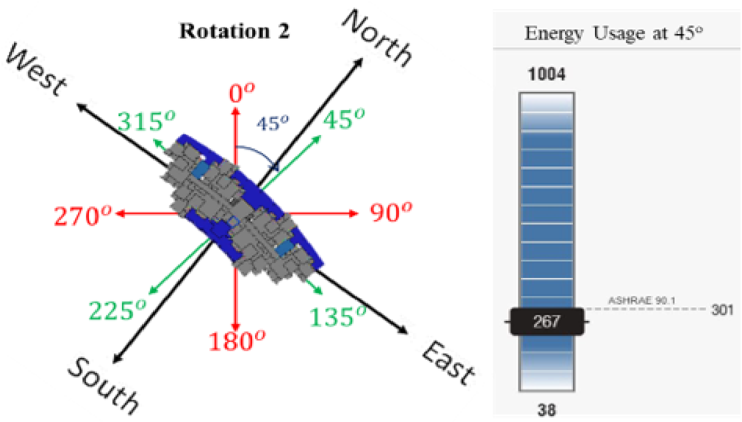


FIGURE 4.5: 45° Orientation

4.2.4 Rotation: 03

In rotation 03, the face of the building moved at an angle of 90° from zero orientation and faced the North Eastside. In this situation, an increase in annual energy consumption was observed from the previous rotation as the value changed to 271 kWh/m^2/yr. Figure 4.6 shows the ASHRAE 90.1 benchmark value is 298 kWh/m^2/yr with 39 and 1027 kWh/m^2/yr lower and upper limit respectively.

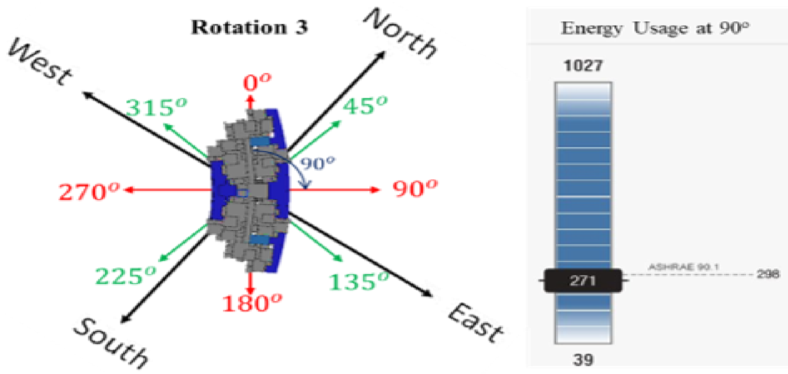


FIGURE 4.6: 90° Orientation

4.2.5 Rotation: 04

Interestingly, a further rotation toward the North East side by 45°, the annual energy consumption observed an upward trend. At this rotation, 283 kWh/m^2/yr is the average energy consumption with 57 and 998 kWh/m^2/yr lower and upper limit respectively. ASHRAE 90.1 benchmark value is 269 kWh/m^2/yr as illustrated in figure 4.7.

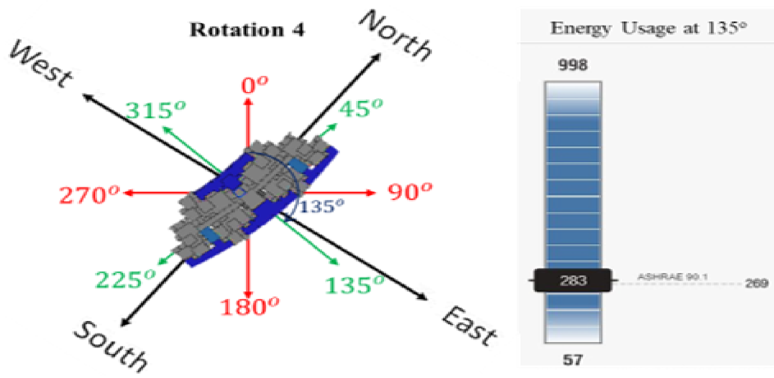


FIGURE 4.7: 135° Orientation

4.2.6 Rotation: 05

At this position, the face of the building becomes opposite to the situation at 0°. Now, the building faced the Southside. The trend shows the increase of annual energy consumption changed again as the energy decreased from 283 kWh/m^2/yr to 278 kWh/m^2/yr. 1020 and 50 kWh/m^2/yr upper and lower limit. ASHRAE 90.1 benchmark value is 282 kWh/m^2/yr as shown in figure 4.8.

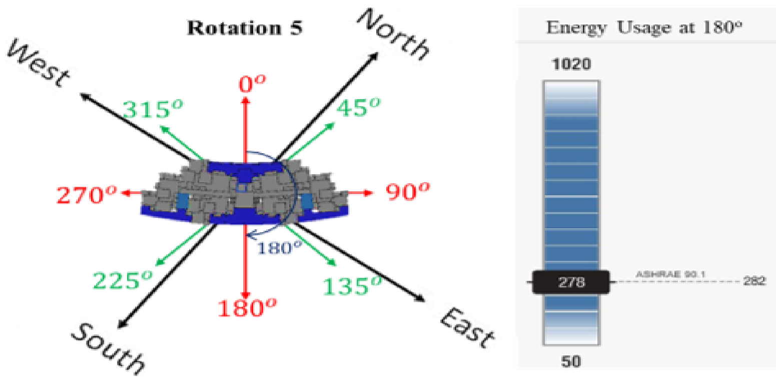


FIGURE 4.8: 180° Orientation

4.2.7 Rotation: 06

This orientation was Achieved by a further rotation towards the East-South side by an angle of 45°. The decreasing trend in energy consumption is maintained at this location also. The annual energy decreased by 9 kWh/m^2/yr with a value of 269 kWh/m^2/yr with 40 and 1027 kWh/m^2/yr lower and upper limit respectively. ASHRAE 90.1 benchmark value is 298 kWh/m^2/yr as shown in figure 4.9.

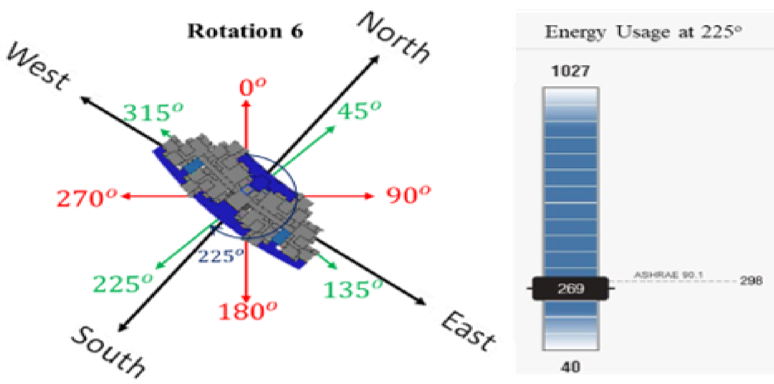


FIGURE 4.9: 225° Orientation

4.2.8 Rotation: 07

With further rotation, the building faced moved from the East-South zone to the South-West zone. However, in contrast to the East-South zone, the energy observed an increasing trend. This is the seventh orientation having ASHRAE 90.1 benchmark value is 294 kWh/m^2/yr. Figure 4.10 illustrates that 276 kWh/m^2/yr is the average energy consumption with 43 and 1032 kWh/m^2/yr lower and upper limit respectively.

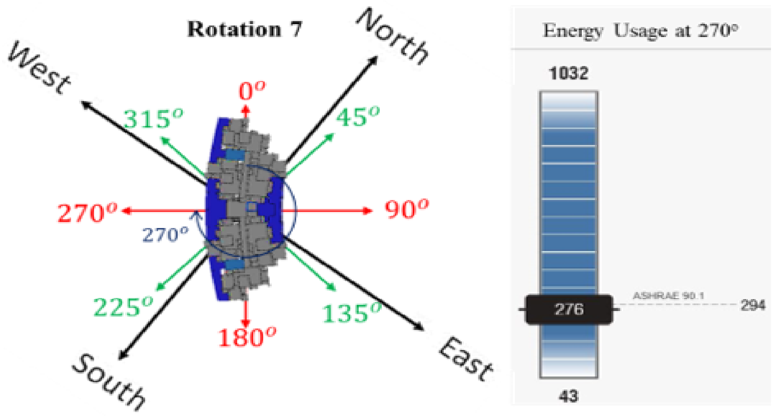


FIGURE 4.10: 270° Orientation

4.2.9 Rotation: 08

Eighth orientation is 315o, 284 kWh/m^2/yr is the average energy consumption with 58 and 977 kWh/m^2/yr lower and upper limit respectively. ASHRAE 90.1 benchmark value is 267 kWh/m^2/yr as shown in figure 4.11.

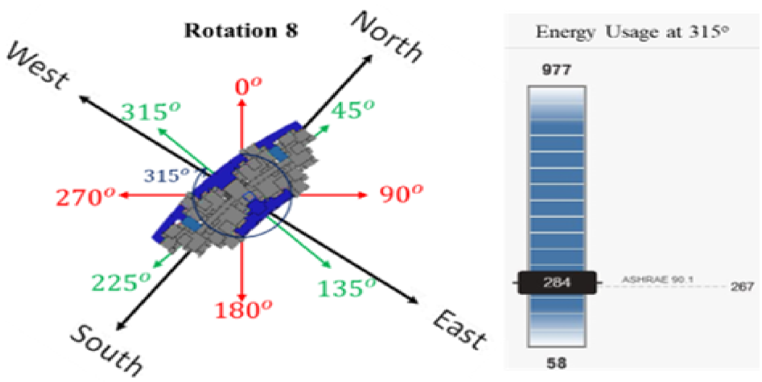


FIGURE 4.11: 315° Orientation

4.2.10 Critical Analysis

A critical analysis further revealed that the building orientation at both East-South side and West-North side showed a decreased annual energy trend whereas the North-East and South-West side resulted an upward trend in energy assumptions.

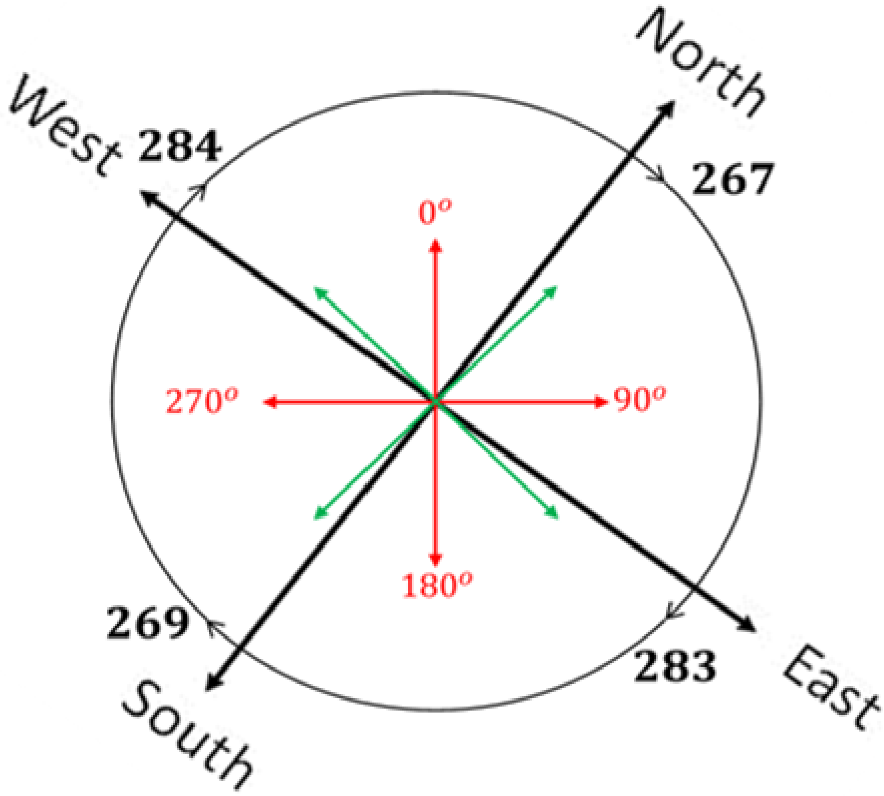


FIGURE 4.12: Energy Consumption Trend

4.3 Annual Energy Usage and Benchmark Comparison

Benchmark comparison measure and compare the performance against Architecture 2030 which is our main objective to be achieved. The energy cost range dial will update and change colors among red, orange, and green according to the benchmark value. Our goal is to achieve Architecture 2030 that represents the

'Green Color'. The major aim of the 2030 challenge is to carbon-neutralize all new buildings' construction and renovations by 2030 to avoid the disastrous effects of climate change and global warming due to the building industry. For this case study, ASHRAE 90.1 limit is 290 kWh/m^2/yr and Architecture 2030 limit is 115 kWh/m^2/yr as shown in figure 4.13. Color of the dial will be red if the value is higher than ASHRAE 90.1 limit, orange if the value is between ASHRAE 90.1 and Architecture 2030 limit, and green color is shown when the value is less than Architecture 2030 limit which is our ultimate goal.

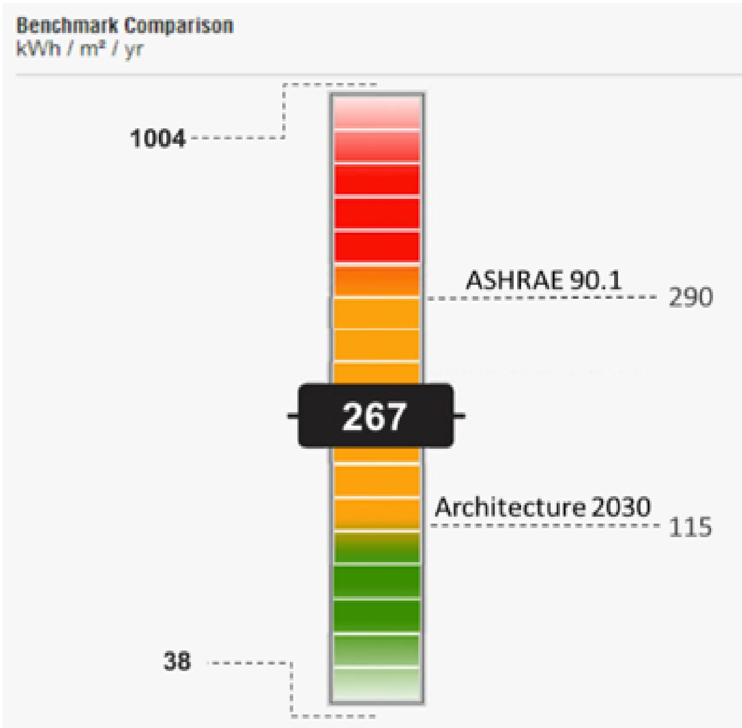


FIGURE 4.13: Benchmark Comparison before Energy Optimization

4.4 Comparative Analysis

Based upon the results achieved, a comparative analysis for a 360° rotation cycle has been performed, shown in table 4.1. On average, the energy consumption remained between a range of 267 kWh/m^2/yr to 284 kWh/m^2/yr. The highest consumption was achieving at rotation 08 (315°) and lowest at rotation 02 (45°) with respect to True North.

TABLE 4.1: Average Energy Consumption Statistics with 360° Rotation Cycle

Description/ Orientation	**Unit**	**True North Angle**	**Rotation No.**							
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
			0° or 360°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**
Average annual Energy		270	276	267	271	283	278	269	276	284
Upper Limit		974	1005	1004	1027	998	1020	1027	1032	977
Lower Limit	$kWh/m^2/yr$	47	45	38	39	57	50	40	43	58
Consecutive Variations			6	9	-4	-12	5	9	-7	-8
Variation w.r.t True North			6	15	11	-1	4	13	6	-2

The baseline location was observed to be at higher side of consumption level. Two different type of energy consumptions were performed. The first one among the consecutive rotations with each proceeding rotation and second one with baseline against each orientation.

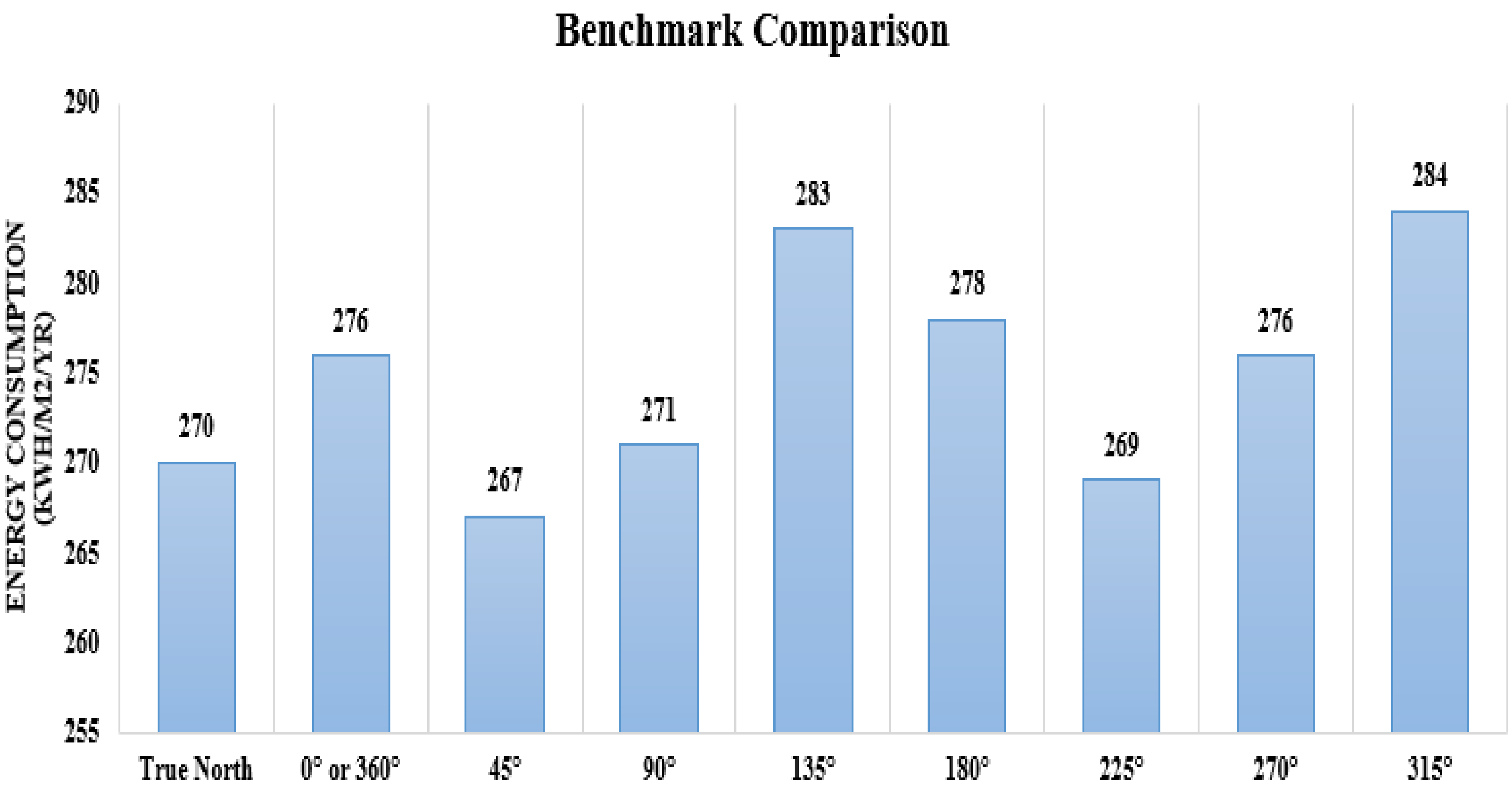


FIGURE 4.14: Benchmark Comparison

In the first case, the rotation 02 and 06 achieved the maximum saving of energy consumption among each consecutive rotation with a value of 9 $kWh/m^2/yr$. Interestingly, in the second comparison, the rotation 02, 45° from baseline, again was the highest in energy consumption saving of 3 $kWh/m^2/yr$. Figure 4.14 elaborates the comparative impact graphically, Based upon these findings, the rotation 02 at angle 45° presented the maximum opportunity to maximize the benefits of building orientation in energy consumption savings. So, this rotation has been selected to perform further optimization analysis. Figure 4.14 shows the benchmark comparison of each rotation.

4.5 Factors Affecting Energy Consumption

4.5.1 Window Wall Ratio

Window-to-wall ratio (WWR) which is also known as window area, is a vital variable that affects the energy usage and efficiency of a structure or building. The window to wall ratio affects the heating, cooling, and lighting of the building. It also plays an important role in the natural environment and access to daylight, ventilation in the building, and inner and outer views. It is calculated by the division of the total glass area of the building to the wall areas of the outer side or shell in terms of percentage area.

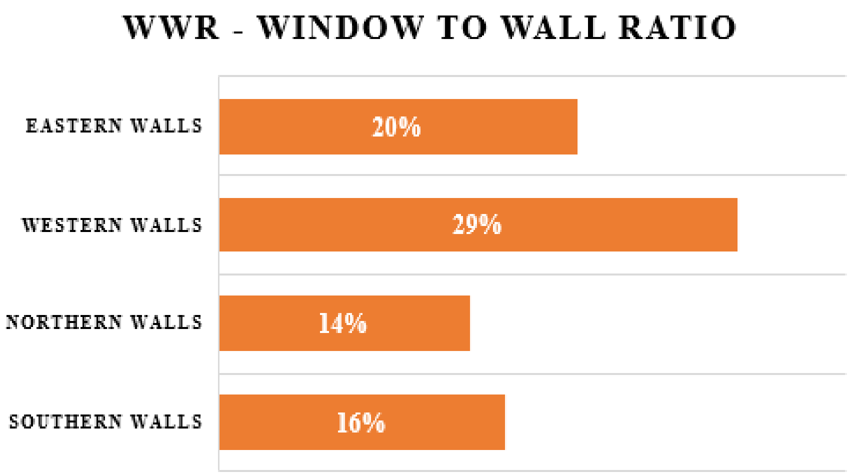


FIGURE 4.15: Window to Wall Ratio

In this case study, the western wall having a significant glazing area up to 29% as shown in figure 4.15. These results were calculated using INSIGHT360 using a cloud database. It interrelates with window properties to effect daylighting and HVAC or heating and cooling.

4.5.2 Window Shades

Window shades can decrease energy utilization for heating and cooling due to solar radiation which depends on factors like solar properties in terms of heat gain and size of the window. Some portion of sun radiation directly catch by the shade and reflected back from the window. Some shades are partially transparent so the radiations directly pass through them. Heat absorbed by the shades is mainly carried away from the window by airborne convection currents or radiation. In

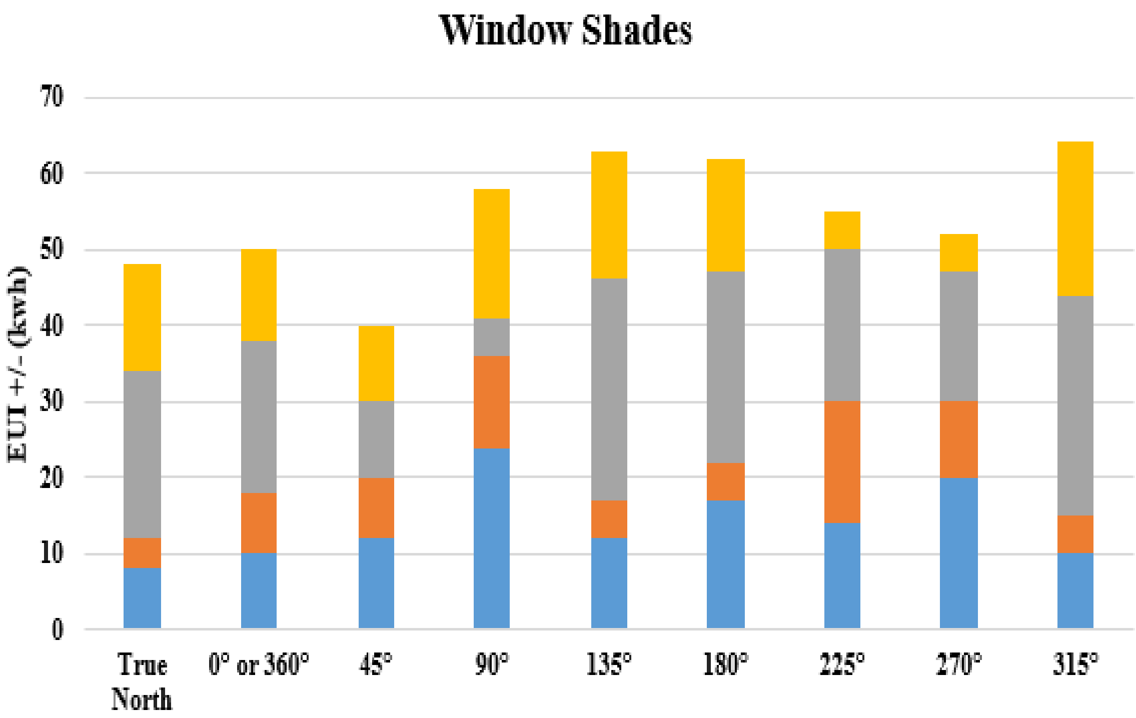


FIGURE 4.16: Window Shades

this case, the shade of 1/2 window height means that if the window is 8ft high from its sill to head, then the shade sticks out 4ft from the wall. 45° having the lowest window shades value as shown in figure 4.16.

4.5.3 Window Glass

The amount of daylight that enters a building along with heat transfer and gain is controlled by the glass properties, along with additional factors. External Windows usually made up of glass that is a transparent glazing material used in the building envelope.

4.5.4 Wall Construction

In energy analysis, the purpose of wall construction is strength and its overall ability for resistance towards heat gain and loss. In this case study, walls are made up of building blocks and plaster insulation and paint on them later on. Insulations in the wall significantly affect the internal environment of the building.

4.5.5 Roof Construction

In energy analysis, the purpose of roof construction is load-bearing and also its overall ability for resistance towards heat gain and loss. Typical Reinforced cement concrete roof is used in this building. Insulations of roof significantly affect the energy usage for heating and cooling.

4.5.6 Infiltration

The unintentional leaking of air into or out of conditioned spaces; Frequently because of gaps in the structure or building insulation. Leakage of air mostly through the cracks or gaps in the building envelope as well as the windows or doors used for passage. Building Porosity and magnitude of wind as well as temperature are the major factors on which the rate of air infiltration mainly depends on.

4.5.7 Lighting Efficiency

The definition of lighting efficiency is a representation of the energy-saving properties of the lighting appliances. The performance of LED light sources is measured by using its index value. It represents power or electricity usage of lighting and the internal heat gain per unit area.

4.5.8 Daylighting and Occupancy Control

This includes the advanced system used for automatic detection of the occupants with the help of sensors and dimming of daylight. Occupancy sensors automatically turn on and off lights to increase suitability, safety, long-term energy savings and decrease the fuel consumption. Daylight sensors worked with the help of the power provided by its batteries. They can save energy with the help of dimming and turning off the lights if there is enough daylight accessible. They also detect the light in the space and then adjust the lights to make the daylight better, thereby saving energy. Figure 4.17 illustrates that the value of energy-saving is increased as controls increased from no control to daylighting and occupancy control.

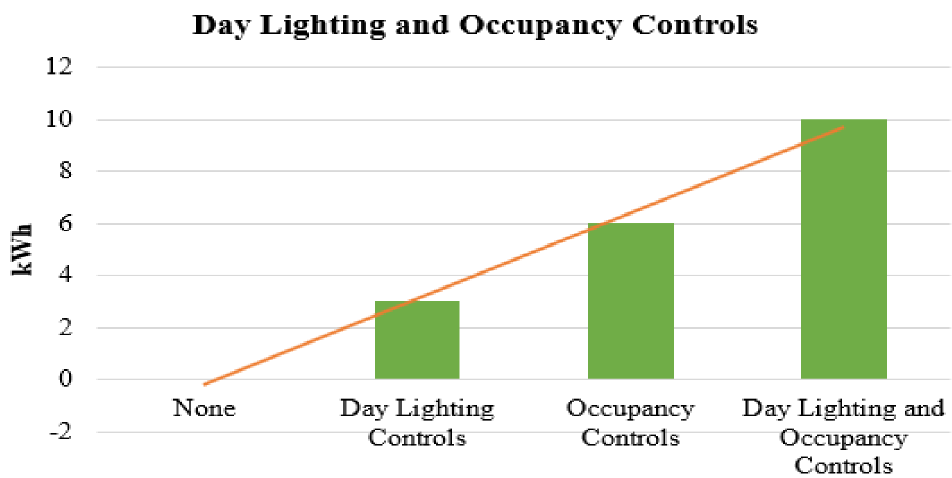


FIGURE 4.17: Day Lighting and Occupancy Control

4.5.9 Plug Load Efficiency

The plug load is the electricity or energy utilized by goods or appliances that gain power through plugs of electricity. Nowadays, Commercial buildings having height plug loads which are rapidly rising with time. In offices, they account for 15-20% of the electricity consumption in the office. Lighting, heating, and cooling equipment are not included in it. 6.46 w/m^2 is the plug load efficiency in this case study. This value is selected on the bases of most feasible values in the residential sector.

4.5.10 HVAC

The HVAC setup provides heating and cooling capacities for buildings. HVAC framework has become the requirement for the construction of new buildings nowadays. Different HVAC systems having different efficiency according to the type, location, and size of the building. Buildings having different HVAC systems according to needs. So, a range and its effect on total energy consumption are shown below. ASHRAE package terminal heat pump is selected due to less energy consumption among all HVAC types illustrated in figure 4.18.

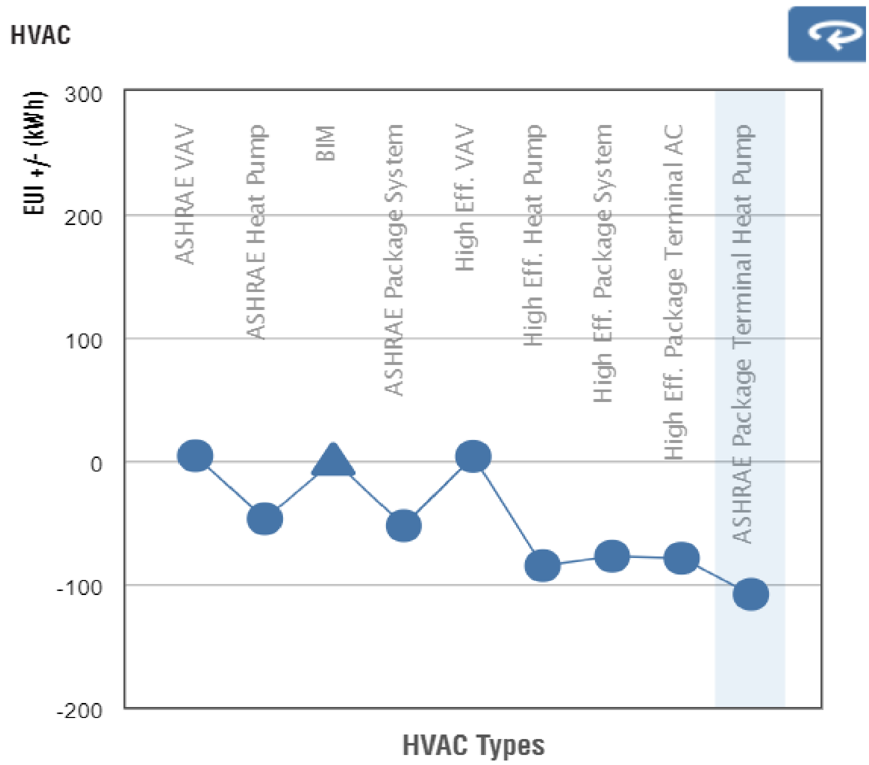


FIGURE 4.18: Energy Saving Trend Due Different HVAC Systems

4.5.11 Operating Schedule

It is the total utilization of energy consumption due to the building occupants' time spent in the building in terms of hours and days. In residential building, energy consumption is random according to occupants' energy usage patterns. So, the average value is considered for optimization. We can change this value according to the operating schedule of the building as shown in figure 4.19.

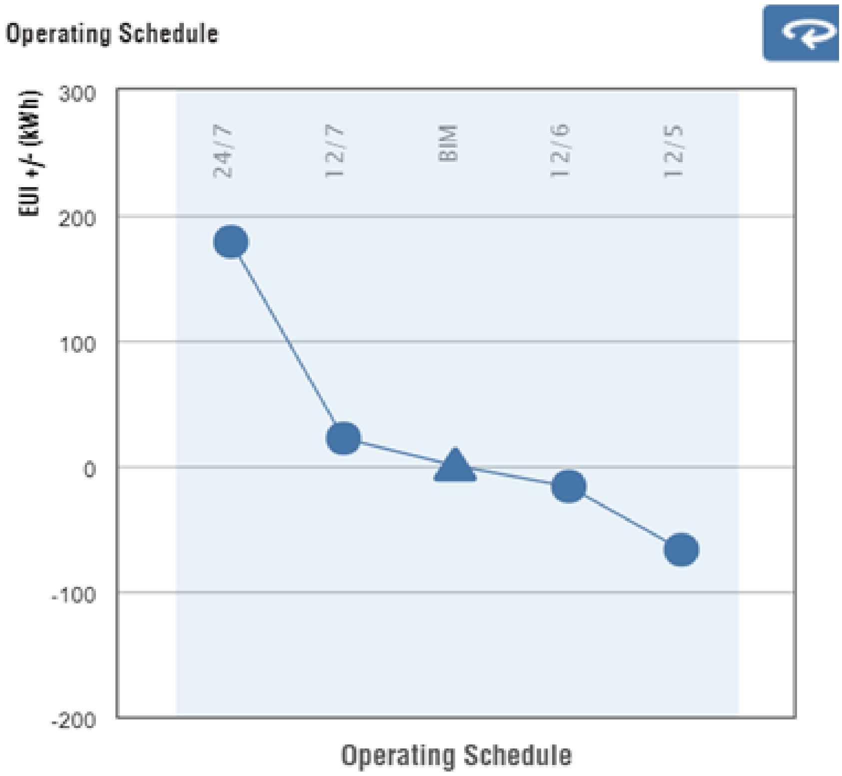


FIGURE 4.19: Operating Schedule

4.5.12 Photovoltaic Panel Efficiency

Photovoltaic panels are used to convert the energy from the sun's radiations into electricity. The panel having higher cost are more efficient and produce more energy by using the surface area. The efficiency of the panel is 16.8% in this case study. This value is selected from a given range because it gives the maximum energy savings.

4.5.13 Photovoltaic Surface Coverage

It is total areas that include the whole system and covered by the panels for the production of electricity or conversion of sunlight into energy in terms of electricity. In this case study, its value is 60%. This value is selected from a given range because it gives the maximum energy savings.

4.6 Energy Optimization

In the last step, 45° orientation was optimized on the bases of guidelines and factors mentioned earlier in table 3.3 of the methodology section. Figure 4.20 shows the optimized value of energy after the adoption of energy measures.

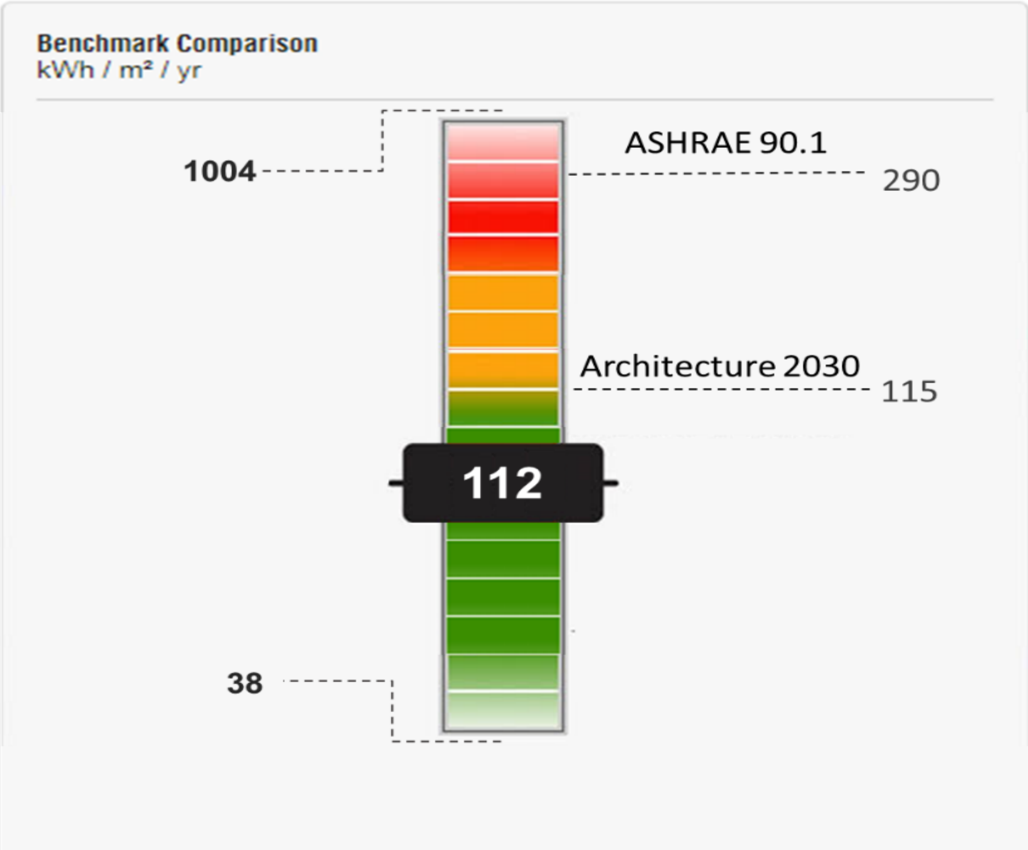
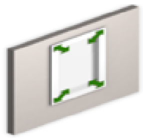
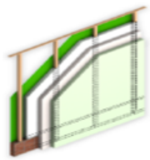


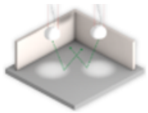
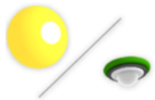
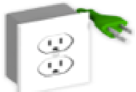
FIGURE 4.20: Benchmark Comparison After Energy Optimization

The most realistic values according to actual building features and specifications were selected to optimize from the given range as shown in table 4.2.

Table 4.2: Optimization Elements

Factors	**Pictorial View**	**Settings**	**Optimized Settings**
Benchmark		267 kWh / m^2 / yr	112 kWh / m^2 / yr
Orientation		45°	45°
WWR - Southern Walls WWR - Northern Walls WWR - Western Walls WWR - Eastern Walls		95% to 0%	16% 14% 29% 20%
Window Shades – South Window Shades – North Window Shades – West Window Shades - East		1/6 to 2/3 Win Height	1/2 Win Height
Wall Construction		Uninsulated to R13 + R10 Metal	BIM

Continued Table: 4.2

Roof Construction		Uninsulated to BIM	BIM
Infiltration		2.0 ACH to 0.17 ACH	0.285 ACH
Lighting Efficiency		20.45 W/m^2 to 3.23 W/m^2	7.53 W/m^2
Daylighting & Occupancy Controls		None - Daylighting & Occupancy Controls	Occupancy Controls
Plug Load Efficiency		29.99 W/m^2 to 6.46 W/m^2	6.46 W/m^2
Operating Schedule		24/7 to 12/5	BIM
PV - Panel Efficiency		16% to 20.4 %	18.60%
PV - Pay Back Limit		10 yr to 30 yr	30 yr
PV - Surface Coverage		0% to 90%	60%

45° orientation alignment was chosen for optimization due to the lowest energy utilization value. Actual Window to wall ration was chosen according to building design and drawings. For wall construction, BIM settings were applied which means that the actual wall that is made up of blocks and plaster on it was analyzed and chosen in optimization. The same case is for roof construction as usually used reinforced concrete cement slab. The infiltration rate according to actual openings of buildings was applied. Plug load efficiency is 6.46. Panel efficiency is 18.60% with the payback period of 30 years and surface coverage of 60%.

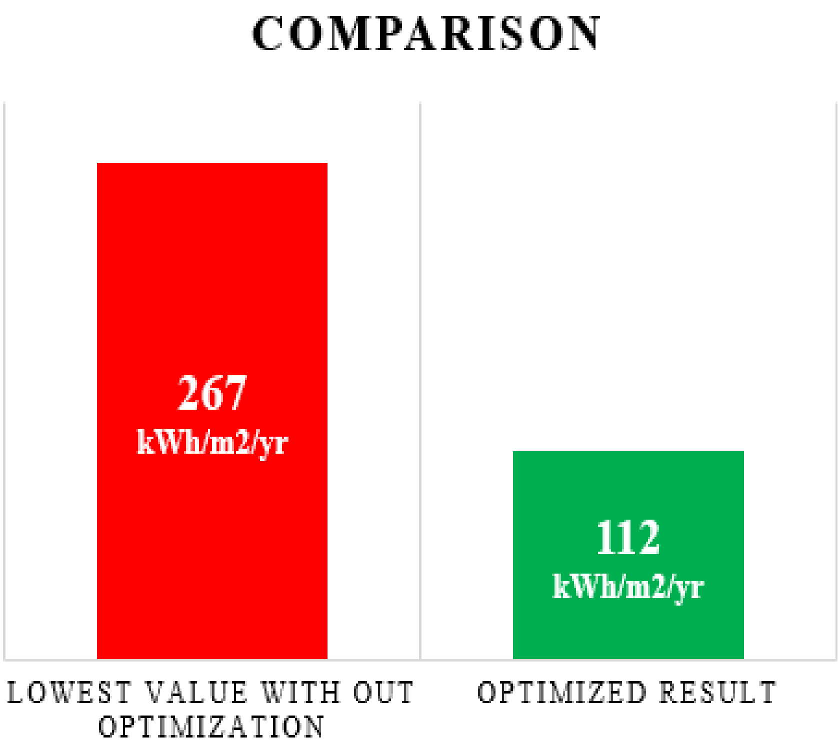


FIGURE 4.21: Comparison of Energy Consumption After Optimization

Figure 4.22 illustrated how average energy consumption is decreasing with the optimization of each factor. The highest optimization is achieved by the HVAC factor with the decreasing value of 39 kWh/m^2/yr in the overall energy consumption of the building. Other major factors are orientation, window to wall ratio, window shades, lighting efficiency, and operating schedule. Due to alignment or orientation adjustment, there is an 18 kWh/m^2/yr decrease in total value. Window to wall ratio of Eastern wall and window shades are collectively reducing the 30 kWh/m^2/yr.

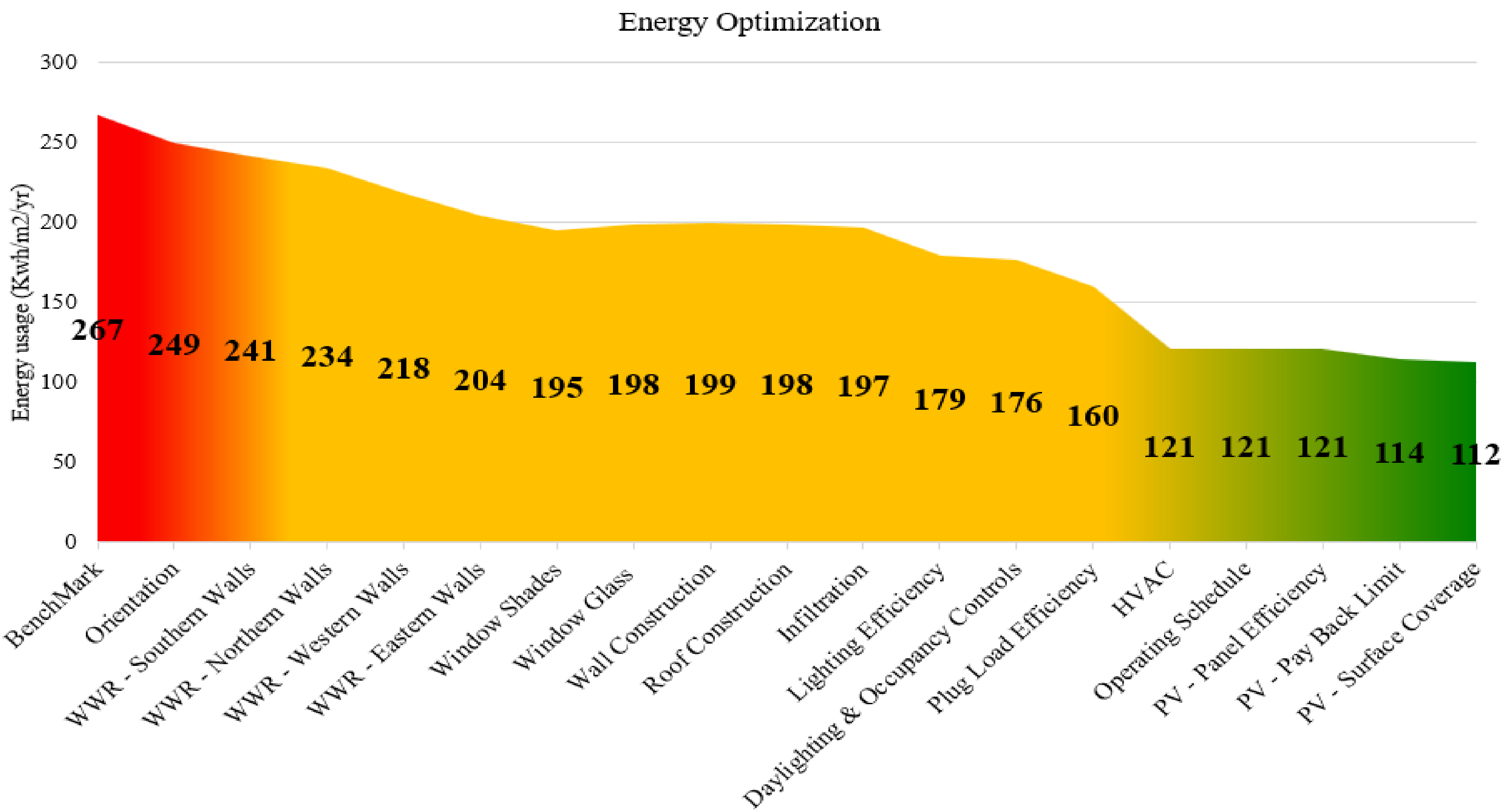


Figure 4.22: Energy Optimization by Each Factor

Electricity operating schedule is another major factor that can reduce energy consumption according to the usage hour. The peculiar behavior of the increase in value is shown on the window glass and roof construction values. This is due to the average values that were used initially by the cloud base analysis. Red color shows the values above the ASHRAE 90.1 benchmark, which has been optimized to 112 kWh/m^2/yr in the Green zone as shown in figure 4.21 and 4.22. Overall 155 kWh/m^2/yr energy saving is achieved by optimization.

Chapter 5

Conclusions and Recommendations

This chapter is comprising of the findings and conclusions of the energy analysis of building. Some future recommendations have also been given accordingly. This chapter is further divided into three parts, the first section is comprised of findings. The second part details the conclusion based on energy analysis and optimization whereas the third part consists of recommendations.
The scope of this research work was limited to the case study of residential building and only the operational phase was undertaken. The objective of the study was to optimize energy usage using INSIGHT360 for energy analysis. The energy analysis was performed on the building by rotating it in a circle with the lap interval of 45°. So, BIM models are valuable and proficient in this regard.

5.1 Findings

The findings of energy analysis and optimization are that:

- Building orientation has been observed as a vital fact to optimize the energy performance of the building up to 5%. Among eight different orientations, 45° is the most effective alignment with respect to True North. Rotation 08 at 315° is the alignment with the highest energy consumption.

- 112 kWh/m^2/yr is the optimized value of average energy utilization which is more than 50% reduction in overall usage and less than the Architecture 2030 challenge to go green for sustainability.
- The major factor to optimize energy in the building that collectively responsible for reducing 50% of total optimization, table 5.1 shows the percentage that can be optimized by each major factor.

TABLE 5.1: Major Optimizing Factors

Sr. N.	**Description / Factor**	**The Percentage that Can be Optimized**
1	Orientation	More than 6%
2	Window to Wall Ratio	More than 15%
3	Window Shades	Up to 5%
4	Lighting Efficiency	More than 5%
5	Type of HVAC system	Up to 15%

5.2 Conclusions

- East to South and West to Northside showed a declining trend in energy usage while North to East and South to Westside is vice versa.
- Up to 60% Energy consumption and 50% cost reduction can be possible by energy analysis and optimization using Insight in the early design phase. More than 20% of energy saving can be done in the existing building by optimizing the following factors i.e. Infiltration (Insulation), Lighting Efficiency, Daylighting & Occupancy Controls, PV - Panel Efficiency and payback period.
- As a result, the optimal energy consumption design will help to improve the development of sustainable buildings in terms of energy consumption.

- Designing energy-efficient buildings entails comprehending results from energy simulation to help the stakeholder in finalizing the design that uses optimum energy and promotes sustainability.

5.3 Recommendations

Based on the results, analysis, and conclusion of the work, it is recommended that

- A proper selection of various optimization factors in compliance with the ARCHITECTURE 2030 challenge can help to achieve a significant reduction in energy consumption and help to achieve optimized energy patterns using virtual technology at the early stage of the design phase.

- Pakistan is facing an energy crisis from the last four decays, this research will help to reduce energy usage in the building sector, in the early design phase as well as already constructed buildings in aspects of the HVAC system, insulations, daylighting and occupancy control and panel efficiency, etc. Therefore, early energy optimizations may be made a part of contractual requirements for new construction ventures.

- Cost is one of the vital aspects in achieving sustainable consumption patterns. Thus, to explore this relation, a comprehensive cost analysis for optimized energy saving should be performed.

- The trajectory of Sun, during different periods within a year, observes a significant impact on daylight, thus affecting the outdoor temperature. These seasonal variations impart a good impact on energy consumption patterns. A future study for energy analysis in combination with daylight and solar analysis may help to explore this phenomenon in a more comprehensive manner to achieve more collaborative results.

Bibliography

[1] Q. Tushar, M. Bhuiyan, M. Sandanayake, and G. Zhang, "Optimizing the energy consumption in a residential building at different climate zones: Towards sustainable decision making," *Journal of Cleaner Production*, vol. 233, pp. 634-649, June. 2019.

[2] R. Jin, B. Zhong, L. Ma, A. Hashemi, and L. Ding, "Integrating BIM with building performance analysis in project life-cycle", *Automation in Construction*, vol. 106, pp. 102861, June. 2019.

[3] M. Sandberg, J. Mukkavaara, F. Shadram, and T. Olofsson, "Multidisciplinary Optimization of Life-Cycle Energy and Cost Using a BIM-Based Master Model", *Sustainability*, vol. 11 no. 1, pp. 286, January. 2019.

[4] E. I. Samuel, E. Joseph-Akwara, and A. Richard, "Assessment of energy utilization and leakages in buildings with building information model energy", *Frontiers of Architectural Research*, vol. 6 no. 10, pp. 29-41, January. 2017.

[5] M. Hamdy, A. Hasan, and K. Siren, "A multi-stage optimization method for cost-optimal and nearly-zero-energy building solutions in line with the EPBD-recast 2010", *Energy and Buildings*, vol. 56, pp. 189-203. January. 2013.

[6] H. Gao, C. Koch, and Y. Wu, "Building information modelling based building energy modelling: A review. *Applied Energy*", vol. 238, pp. 320-343, January. 2019.

[7] M. Sohail, and M. D. Qureshi, "Energy-efficient buildings in Pakistan", *Science Vision*, vol. 17, pp. 27-38, December. 2011.

[8] Z. Tariq, "The Role of Renewables in the Energy Mix of Pakistan: A Study Based on Social, Economic, and Environmental Indicators" October. 2018.

[9] K. Mishra, and A. Goel, "Energy analysis of high rise building integrated with BIM", *Indian Journal of Science and Technology*, vol. 12, no. 6, pp. 1-10, February. 2019.

[10] N. M. Kumar, J. Vishnupriyan, and P. Sundaramoorthi, "Techno-economic optimization and real-time comparison of sun tracking photovoltaic system for rural healthcare building", *Journal of Renewable and Sustainable Energy*, vol. 11, pp. 015301, January. 2019.

[11] J. Park, J. Park, J. H. Kim, and J. Kim, "Building information modelling based energy performance assessment system: An assessment of the Energy Performance Index in Korea"; Construction Innovation: *Information, Process, Management*, vol.12, no. 3, pp. 335-354, July. 2012.

[12] A. F. Latif, N. A. Ahmad, M. R. Abdullah, A. Ismail, and A. A. A. Ghani, "A Review on Energy Performance in Malaysian Universities Through Building Information Modelling (BIM) Adaptation", *Earth and Environmental Science*, vol. 291, pp. 012033, June. 2019.

[13] G. Gourlis, and I. Kovacic, "Building Information Modelling for analysis of energy efficient industrial buildings – *A case study", Renewable and Sustainable Energy Reviews*, vol. 68, no. 2, pp. 953-963, February. 2017.

[14] B. Li, and R. Yao, "Urbanisation and its impact on building energy consumption and efficiency in China", *Renewable Energy*, vol. 34, no.9, pp. 1994-1998, September. 2009.

[15] J. U. Kim, O. A. Hadadi, H. Kim, and J. Kim, "Development of A BIM-Based Maintenance Decision-Making Framework for the Optimization between Energy Efficiency and Investment Costs", *Sustainability*, vol. 10, no. 7, pp. 2480, July. 2018.

[16] K. Zeb, S. M. Ali, B. Khan, C. A. Mehmood, N. Tareen, W. Din, U. Farid, and A. Haider, "A survey on waste heat recovery: Electric power generation and potential prospects within Pakistan", *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 1142-1155, August. 2017.

[17] A. Khan, and D. Ghadg, "Building Information Modelling (BIM) based Sustainability analysis for a construction project", *Proceedings of Sustainable Infrastructure Development & Management*, pp. 11, February. 2019.

[18] S. Maltese, L. C. Tagliabue, F. R. Cecconi, D. Pasini, M. Manfren, and A. L. C. Ciribini, "Sustainability Assessment through Green BIM for Environmental, Social and Economic Efficiency", *Procedia Engineering*, vol. 180, pp. 520-530, April. 2017.

[19] S. Eleftheriadis, D. Mumovic, and P. Greening, "Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities", *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 811-825, January. 2017.

[20] K. Negendahl, "Building performance simulation in the early design stage: An introduction to integrated dynamic models", *Automation in Construction*, vol. 54, pp. 39-53, June. 2015.

[21] M. R. Asl, S. Zarrinmehr, M. Bergin, and W. Yan, "BPOpt: A framework for BIM-based performance optimization", *Energy and Buildings*, vol. 108, pp. 401-412, December. 2015.

[22] T. Ramesh, R. Prakash, and K. K. Shukla, "Life cycle energy analysis of buildings: An overview", *Energy and Buildings*, vol. 42, no. 10, pp. 1592-1600, October. 2010.

[23] H. J. Kuo, S. H. Hsieh, R. C. Guo, and C.C. Chan, "A verification study for energy analysis of BIPV buildings with BIM", *Energy and Buildings*, vol. 130, pp. 676-691, October 2016.

[24] R. Evins, "A review of computational optimisation methods applied to sustainable building design", *Renewable and Sustainable Energy Reviews*, vol. 22, pp. 230-245, June. 2013.

[25] C. Zhang, R. S. Nizam, and L. Tian, "BIM-based investigation of total energy consumption in delivering building products", *Advanced Engineering Informatics*, vol. 38, pp. 370-380, October. 2018.

[26] M. Kamran, M. R. Fazal, and M. Mudassar, "Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis", *Renewable Energy*, vol. 146, pp. 543-558, February. 2020.

[27] M. Marzouk, and E. M. Abdlekader, "Architecture and Design: Breakthroughs in Research and Practice (2 Volumes): Minimizing Construction Emissions Using Building Information Modeling and Decision-Making Techniques" (Chapter 22), pp. 604-626, November. 2018.

[28] M. M. Ouf, and M. H. Issa, Energy consumption analysis of school buildings in Manitoba, Canada", *International Journal of Sustainable Built Environment*, vol. 6, no. 2, pp. 359-371, December. 2017.

[29] M. Sheikhkhoshkar, M. Khanzadi, and S. Banihashemi, "BIM Applications Toward Key Performance Indicators of Construction Projects in Iran", *International Journal of Construction Management*, June. 2018.

[30] S. Kim, P. A. Zadeh, S. S. French, T. Froese, and B. T. Cavka, "Assessment of the Impact of Window Size, Position and Orientation on Building Energy Load Using BIM", *Procedia Engineering*, vol. 145, pp. 1424-1431, 2016.

[31] L. D. Vilariño, S. Laguela, J. Armesto, and P. Arias, "As-built BIM with shades modeling for energy analysis", *18th International Conference on Virtual Systems and Multimedia*, 2012.

[32] C.S. Cho, D. Chen, and S. Woo, "Building information modeling (BIM) - Based design of energy efficient buildings", *Proceedings of the 28th International Symposium on Automation and Robotics in Construction*, pp. 1079-1084, 2011.

[33] F. Jalaei, and A. Jrade, "Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings", *Sustainable Cities and Society*, vol. 18, pp. 97-107, November. 2015.

[34] B. Keskin, and B. Salman, "Building Information Modeling (BIM) Implementation for Sustainability Analysis: A Mega Airport Project Case Study", *7th International Building Physics Conference*, pp.1343-1348. January. 2018.

[35] P. H. Shaikh, N. B. M. Nor, P. Nallagownden, I. Elamvazuthi, and T. Ibrahim, "A review on optimized control systems for building energy and comfort management of smart sustainable buildings", *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 409-429, June. 2014.

[36] J. B. Kim, W. S. Jeong, M. J. Clayton, J. S. Haberl, W. Yan, "Developing a physical BIM library for building thermal energy simulation", *Automation in Construction*, vol. 50, pp. 16-28, February. 2015.

[37] S. Lee, S. Tae, S. Roh, and T. Kim, "Green Template for Life Cycle Assessment of Buildings Based on Building Information Modeling: *Focus on Embodied Environmental Impact" Sustainability*, vol. 7, no. 12, pp. 16498-16512, December. 2015.

[38] S. Liu, X. Meng, and C. Tam, "Building information modeling based building design optimization for sustainability", *Energy and Buildings*, vol. 105, pp. 139-153, October. 2015.

[39] Y. Cho, T. Bode, and S. Alaskar, "BIM-Driven Energy Analysis For Zero Net Energy Test Home (ZNETH)", *6th International Conference on Construction Project Management*, May. 2009.

[40] A. Farzaneh, J. Carriere, D. Forgues, and D. Monfet, "Framework for Using Building Information Modeling to Create a Building Energy Model", *Journal of Architectural Engineering*, vol. 24, no. 2, June. 2018.

[41] M. Zanni, R. Soetanto, and K. Ruikar, "Towards a BIM-enabled sustainable building design process: roles, responsibilities, and requirements", *Architectural Engineering and Design Management*, pp. 1-29. August. 2016.

[42] M. Khanzadi, A. Kaveh, M. R. Moghaddam, and S. M. Pourbagheri "Optimization of Building Components with Sustainability Aspects in BIM Environment", *Periodica Polytechnica Civil Engineering*, November. 2018.

[43] C. Fu, G. Aouad, A. Lee, A. M. ponting, and S. Wu, "IFC model viewer to support nD model application", *Automation in Construction*, vol. 15, no. 2, pp. 178-185, 2006,

[44] B. Welle, J. Haymaker, and Z. Rogers, "ThermalOpt: A methodology for automated BIM-based multidisciplinary thermal simulation for use in optimization environments. *Building Simulation", Building Simulation*, vol. 4, no. 4, December. 2011.

[45] J. Basbagill, F. Flager, M. Lepech, and M. Fischer, "Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts", *Building and Environment*, vol. 60, pp. 81-92, February. 2013.

[46] Y. Ham, and M. Golparvar-Fard, "Mapping actual thermal properties to building elements in gbXML-based BIM for reliable building energy performance modeling".

[47] P. Singh, and A. Sadhu, "Multicomponent energy assessment of buildings using building information modeling", *Sustainable Cities and Society*, vol. 49, pp. 101603, 2019.

[48] E. Kamel, and A. M. Memari, "Review of BIM's application in energy simulation: Tools, issues, and solutions", *Automation in Construction*, vol. 97, pp. 164-180. January. 2019.

[49] N. Somboonwit, A. Boontore, and Y. Rugwongwan, "Obstacles to the Automation of Building Performance Simulation: Adaptive Building Integrated Photovoltaic (BIPV) design", *Environment-Behaviour Proceedings Journal*, vol. 2, pp. 343. March. 2017.

[50] J. Carvalho, K Ridder, L Bragança1 and R Mateus "Using BIM to optimise and assess the energy efficiency category of SBTool PT –H", *Earth and Environmental Science*, vol. 225, pp. 012072, 2019.

[51] A. Oti, and H. Abanda, "A Review of Systems for Information Modelling in the Built Environment", Data-Driven Modeling for Sustainable Engineering, pp. 161-174, January. 2020.

[52] A. T. Nguyen, S. Reiter, and P. Rigo, "A review on simulation-based optimization methods applied to building performance analysis", *Applied Energy*, vol. 113, pp. 1043-1058, January. 2014.

[53] T. Gerrish, K. Ruikar, M. Cook, M. Johnson, M. Phillip, and C. Lowry, "BIM application to building energy performance visualisation and management: *Challenges and potential", Energy and Buildings*, vol. 144, pp. 218-228, june. 2017.

[54] A. Saberi, O. Bakhshaei, and G. Ridolfi, "Computational BIPV Design : An energy optimization tool for solar facades", *Med Green Forum* 4, August. 2017.

[55] A. Farzaneh, D. Monfet, and D. Forgues, "Review of using Building Information Modeling for building energy modeling during the design process", *Journal of Building Engineering*, vol. 23, pp. 127-135. May. 2019.

[56] C. Treeck, R. Wimmer, and T. Maile, "BIM for Energy Analysis: Technology Foundations and Industry Practice", *Building Information Modeling*, pp. 337-347, September. 2018.

[57] X. Chen, H. Yang, and J. Peng, "Energy optimization of high-rise commercial buildings integrated with photovoltaic facades in urban context", *Energy*, vol. 172, pp. 1-17, April. 2019.

[58] M. Irfan, Z. Zhao, M. K. Panjwani, F. H. Mangi, H. Li, A. Jan, M. Ahmad, and A. Rehman, "Assessing the energy dynamics of Pakistan: Prospects of biomass energy. *Energy Reports"*, vol. 6 p. 80-93, November. 2020.

[59] A. Ghafoor, and A. Munir, "Design and economics analysis of an off-grid PV system for household electrification", *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 496-502, February. 2015.

[60] T. Hemsath, and K. A. Bandhosseini, "Energy Modeling in Architectural Design", August. 2017.