GREEN RETROFITTING OF BUILDING VIA BIM-BASED SUSTAINABILITY OPTIMIZATION USING DESIGN BUILDER - A CASE STUDY

A thesis submitted by

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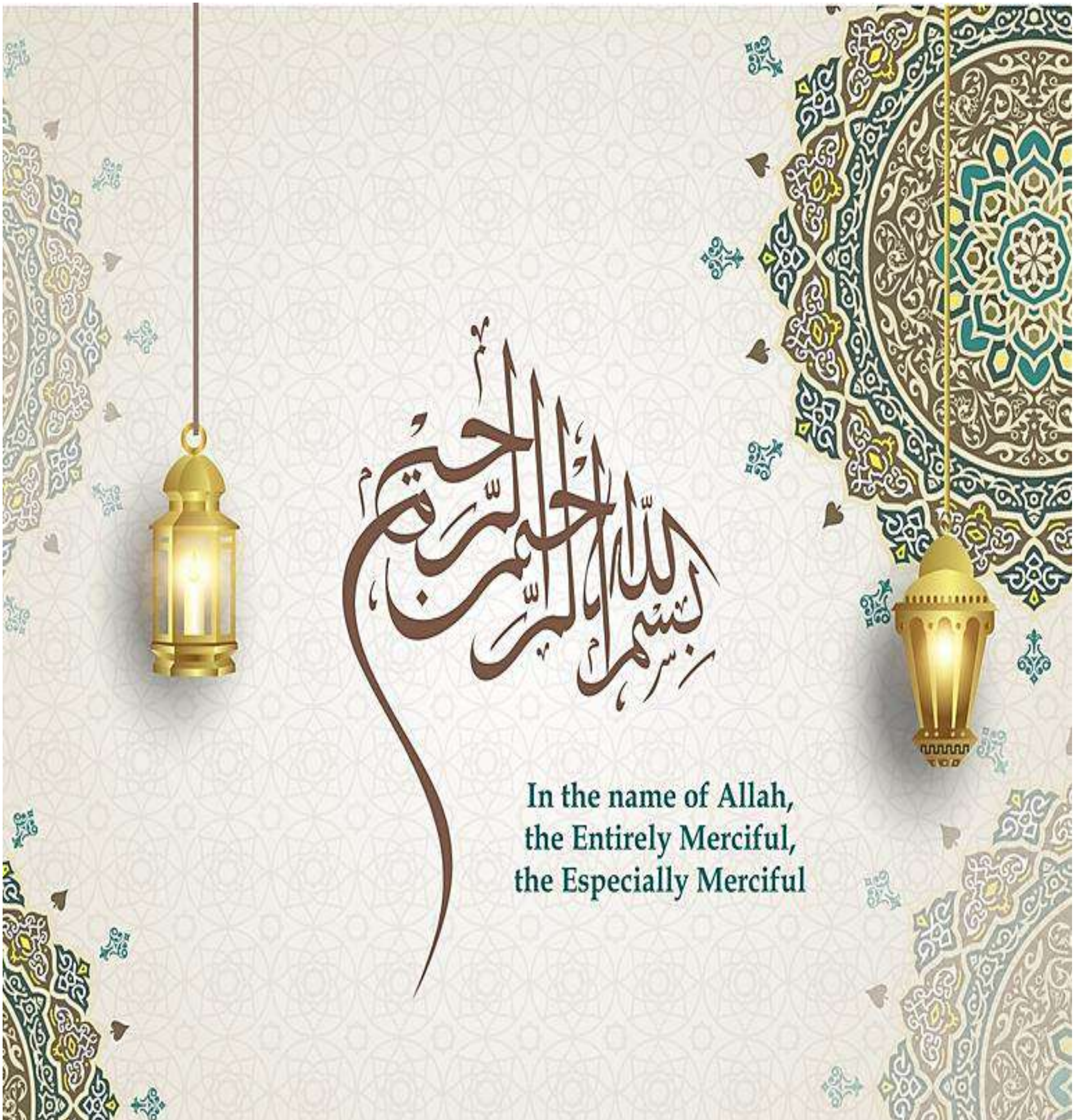
MEHRAN UNIVERSITY OF ENGINEERING & TECHNOLOGY,

JAMSHORO

October 2022


بسم الله الرحمن الرحيم
In the name of Allah,
the Entirely Merciful,
the Especially Merciful

CERTIFICATE

This is to certify that "Final Year Project-II Report on, Green Retrofitting of Building via BIM-based Optimization using DesignBuilder - A case study" is submitted in partial fulfilment of the requirement for the degree of Bachelor of Civil Engineering by the following students:

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ACKNOWLEDGEMENT

First and foremost, we would like to express our deepest, sincerest and warmest thanks to **ALLAH Almighty** who blessed us with that strength and courage to successfully complete this research work.

We would like to express special gratitude to our Worthy Supervisor **Prof. Dr. Tauha Hussain Ali** for his brilliant guidance, encouragement and utmost support throughout our research study.

Next, we would like to deeply acknowledge our Co-Supervisor **Dr. Ali Raza Khoso** for imparting significant knowledge and expertise in research writing. His continuous and unwavering support, encouragement and guidance throughout the final year carried us through all stages of research writing very effectively.

Besides, we are highly indebted to the Postgraduate Student **Engr. Sameer Ahmed** from Mehran University of Engineering & Technology for his constant guidance regarding the important tools and functions of Autodesk Revit which led us to the preparation of a perfect model of our case study.

Moreover, we are highly obliged to Researcher & PhD Student **Jack Morewood** from Cardiff University, United Kingdom for the considerate endorsement and highly professional & cooperative response to all queries solicited in this study specially in DesignBuilder.

Finally, we would like to thank our teachers, families and friends for their consistent support and motivation to carry out our study in best professional and social settings. Special acknowledgements are due to well-wishers who have always supported us during the university life.

ABSTRACT

Green Retrofitting is a major development in the achievement of UN Sustainable Development Goals (SDGs 3, 7, 9, 11, 12 and 13) in the construction sector. The construction industry consumes around 55 percent of Pakistan's annual energy and is the country's most energy-intensive sector. It is, therefore, significant to devise a novel and effective model which aims to optimize energy consumption to promote sustainable structures. To effectively meet diversified climatic concerns, current buildings must be retrofitted or refurbished, especially with the advent of digital building solutions like Building Information Modelling (BIM). This research aims to reform the existing building by modifying the design parameters for an inefficient building envelope based on obtained simulation results to optimize the overall energy consumption. The existing building is investigated for case study purpose. BIM tools, such as Autodesk Revit and DesignBuilder have been used for the development of the building model, running energy simulations, and evaluation of the optimized energy-efficient design by comparing different design alternatives. This research has attempted to prevent the flaws associated with the adoption of traditional techniques used in design and construction and has come up with a list of 'green' solutions i.e., optimal designs with the help of BIM tools which possess advanced algorithms for an effective optimization process. After a detailed analysis, this research has concluded that the existing building is consuming a high amount of annual energy and the proposed optimal design suggests the least annual energy consumption, hence saving 46% of energy in total. The novelty associated with this research is that the design variables selection was fulfilled according to the local environment sustainability. Hence, the procedure involved in previous studies have been tried to improve in a way to come up with a realistic retrofit solution for the building. The implication of this research is the provision of more accurate energy usage guidelines during the maintenance or renovation of the building.

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List of Abbreviations

AEC: Architecture, Engineering, and Construction

BIM: Building Information Modeling

GDP: Gross Domestic Product

AQI: Air Quality Index

GHG: Green House Gas

PEC: Pakistan Engineering Council

NEECA: National Energy Efficiency and Conservation Authority

PGBC: Pakistan Green Building Council

SEED: Sustainability in Energy and Environmental Development

HVAC: Heating, Ventilation and Air-Conditioning

LED: Light Emitting Diode

PV: Photo-Voltaic

PEB: Plus Energy Building

MATLAB: Matrix Laboratory

MPC: Model Predictive Control

SH: Supply Heating

AHU: Air-Handling Units

GA: Green Associate

PMV: Predicted Mean Vote

IoT: Internet of Things

EAM: Energy Analytical Model

Chapter-1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Pakistan is Asia's fastest urbanizing country in recent years. The construction sector of Pakistan is playing a major role in the country's economic progress as it is the largest employer and shares between 2.3% and 2.85% of Gross Domestic Product (GDP) in the last five fiscal years according to the Pakistan Economic Survey 2020 [1]. The buildings play a vital role and have a significant portion of Pakistan's construction sector. In comparison to developed countries such as the United States (39%), Canada (27%), and China (20%), Pakistan has the biggest share of electricity usage (55%) [2]. This sector calls for a sustainable transformation as the country's population continues to expand at increasingly higher rates. Over 40 million people are predicted to reside in Pakistan's cities and towns by 2023 [3]. The high rate of urbanization results in an ever-increasing demand for housing and construction. Consequently, high energy consumption, environmental degradation, and abrupt climatic changes have been faced by the country at considerable levels.

According to a recent study, Pakistan remained the second most polluted country in 2020 after Bangladesh, having a mean Air Quality Index (AQI) of 153 [4]. Air quality data collected in cities indicated the presence of significant concentrations of suspended pollutants such as carbon dioxide, methane, and nitrogen oxides in the air. Not limited to this, but also the poor electricity consumption in the residential and commercial buildings for heating, cooling, or lighting leads to needless fossil-fuel burning, thus contributing to greenhouse-gas emissions i.e., GHGs. Pakistan's share of GHGs and hence, that of global warming is bound to rise as the country proceeds in climbing the development ladder.

Building envelope codes have been improved globally over time. Similarly, with the assistance of the Pakistan Engineering Council (PEC), the National Energy Efficiency and Conservation Authority (NEECA) drafted the Pakistan Building Code (Energy Measures-2011), which includes provisions promoting energy efficiency in the country's construction sector [3]. The formation of the Pakistan Green Building Council (PGBC) is also a positive move towards increased energy efficiency in the construction industry.

Green building rating techniques have been introduced in most nations and are based on social, environmental, and economic factors. The Pakistan Green Building Council used a similar strategy, publishing the inaugural edition of Sustainability in Energy and Environmental Development (SEED) in October 2016 [5]. SEED is a tool for evaluating how buildings and communities are planned, built, monitored, and operated that is both sustainable and socially beneficial [5]. A SEED-rating system, as shown in Fig 1.1, has been devised in order to assess building sustainability. Location and transportation, eco-friendly sites, energy and the environment, water efficiency and indoor air quality are some of the parameters included in the rating system. However, SEED is based on the rating criteria of developed western nations, which do not take into account Pakistan's unique environment, particularly from a cultural and governmental standpoint. The SEED tool solely measures environmental, social, and economic sustainability [6]. Nevertheless, the methods utilized to design and construct buildings will have a substantial impact on future generations, as well as on current patterns of energy use and environmental degradation [7].

Fig.1.1: SEED-Rating System Parameters [5]

According to US Green Building Council, green retrofitting is “any sort of modification to an existing buildings, that are completely or partially occupied, to improve energy efficiency, reduce water usage, and increase overall comfort in terms of natural lighting, air quality, and noise, all while benefiting the client's wallet [8]. Higher labour productivity provides the major potential savings, much more than energy or water savings [9].

A green retrofit can range from simple tasks such as replacing heating, ventilating, and air-conditioning components or putting solar panels on a roof to more involved tasks such as many complex modifications to both the interior and exterior facades of a structure. While some buildings may complete the retrofit in one go, others may finish it in stages, such as by first improving the lighting system, then adding window layers, and ultimately upgrading the heating, ventilation, and air conditioning (HVAC) system [8].

According to researchers, green retrofit is a technique for implementing the "three R's" (reduce, reuse, recycle) by extending the life of a structure and lowering the cost of dismantling and purchasing new construction materials. Simply expressed, it is illogical to demolish a building when it is possible to rehabilitate it into a more environmentally friendly one [8].

Following are some of the measures commonly taken to alter the building components' configurations that lead to effective and green retrofitting of buildings.

- Many commercial buildings lack energy-efficient lighting, and retrofit procedures show that replacing light fittings can boost illuminance while reducing energy use by up to 70%, leading to substantial savings. Some options include replacing obsolete fluorescent lighting fixtures with Energy Star-certified or LED lighting, adding timers or sensors on fixtures that are only used periodically, or installing photo-sensors on fixtures that change the light output during the day to prevent unwanted illumination [8].
- Regular maintenance and adjustments can improve the HVAC system's efficiency, resulting in better occupant comfort and reduced environmental impact. Cleaning ventilators, exhaust fans, geysers, boiler tubes, and other HVAC equipment is required [8].
- Building heating and cooling systems consume a lot of energy. As a result, reducing the need for heating and cooling will result in a significant reduction in energy use. Good insulation helps in this scenario by retaining heat in the winter and trapping cool air inside during the summer.

    - Insulated windows effectively insulate the building. The best technique to improve window insulation is to replace existing windows with low-U-factor windows and provide weather-stripping to prevent air dissipation. Single-pane windows are replaced with double-pane windows, and low-emissivity coatings are applied to the windows to limit heat transmission from the interior to the outside.
    - Insulated walls also help to reduce the amount of energy required to heat and cool a building. On the other hand, due to its high cost, an insulation retrofit for walls is uncommon. Painting walls in brighter, light-reflective colors is a cost-effective way to reduce heat absorption [8].
- Water conservation is crucial since many areas lack water, especially drinking water. The main goal is to use as little water as possible. The following water saving techniques are beneficial: placing aerators and occupancy sensors on lavatory faucets, which regulate the rate of water flow through the taps by mixing air and water while retaining pressure; recycling water for irrigation, flushing toilets, and other building purposes; and collecting rainfall [8].
- Fossil fuels, on which we rely largely today to generate energy, are a limited resource, therefore finding sustainable alternatives is vital. Solar photovoltaics (PV) and solar thermal (a less expensive alternative to PV) are becoming increasingly popular. Wind turbines are also becoming more affordable and accessible, allowing for more energy-efficient renovations. Although geothermal energy is less expensive than solar energy, it is not widely available in different parts of the world. Finally, location and daily weather circumstances such as sunshine intensity, wind pressure, humidity, cloudiness, and daily particle concentration in the air influence the optimum choice of energy renewable adoption [8].
- Retrofitting with a building automation system is also a viable alternative, as it centralizes control of all operational systems, including the HVAC system, lighting, and appliances, among others, cutting utility costs and increasing user comfort. For example, the system can keep the temperature, air circulation, and lighting levels within a specified range and according to pre-programmed schedules within the facility. Additionally, the device can precisely track and record energy consumption.

Additionally, it aids in the detection and localization of a problem in the event of unusual energy use or a power outage [8].

BIM (Building Information Modeling) has evolved as a promising technology for increasing the level of automation in architectural, engineering, and construction (AEC) operations. By definition, it is referred to as “a set of interlinked processes and tools that allows applying an intellectual strategy to assemble, simulate and manage the critical data of a project throughout the project's lifecycle in a digital format”.[10] It is not only used to create models of the structure, but its wider functions also include analyzing and communicating the models in a broader perspective. [11] BIM has been used extensively by engineers for green retrofitting of buildings in the past. In this study, a systematic approach to create a building information model of an existing building has been employed and then it is utilized for the purpose of retrofitting or refurbishment.

1.2. PROBLEM STATEMENT

Building and construction activities are using approximately 36% of global energy and generating 39% of overall energy-related emissions of carbon dioxide [12]. The energy required to maintain inhabitants' thermal comfort levels accounts for a considerable portion of the total energy demand for buildings. In Southeast Asia, building cooling systems account for about half of all energy consumed in the construction industry [13]. In spite of numerous improvements in building energy efficiency standards around the world, analysts predict that energy consumption in building industry will increase by 50% by 2050 if no additional effort is made to improve building energy efficiency [13].

During the winter and summer seasons, Pakistan experiences intense cold and heat. As the middle and upper classes' living standards rise, so do their expectations for comfort. Power demand in Pakistan fluctuates between 8000 MW in the winter and 25000 MW in the summer [14]. The construction sector consumes 55 percent of Pakistan's annual energy and is the country's most energy-intensive sector. Fossil fuels, such as oil and natural gas are the two major elements of Pakistan's present energy balance, accounting for around 62 percent of the country's electrical needs, with hydropower plants accounting for 34 percent and nuclear power plants accounting for the remaining 4% [15]. Continually exhausting the non-renewable energy sources of the country, in the form of precious crude oil and natural gas, is not only wasting our revenue, but also impacting the environment and posing health hazards to our country.

Most of the buildings still use room level units for thermal comfort, such as Split Air conditioning system, space heaters, ceiling, and ventilation fans, due to the delayed adoption of efficient thermal comfort solutions (HVAC) in these locations. Given housing demands, budgetary restraints, and nature conservation, these structures will be monitored for several years, with at least 80% of them estimated to last beyond 2050 [16]. The difficulty is exacerbated by the continental climate of most cities of the country, which is typified by substantial daily and seasonal temperature changes. As a result, this harsh environment necessitates enormous energy consumption [17].

Excessive power consumption in buildings using non-efficient HVAC fixtures further leads to increased carbon footprint and green-house gas emissions of the building, thus making a major contribution towards changes in climatic conditions, depletion of ozone layer and global warming. In a nutshell, alteration in global climate further induces a long-term modification in the weather patterns and the cycle goes on.

Green building envelope retrofitting has a considerable positive influence on the structure's overall energy demand. As a result, an optimum combination of building materials and window layouts is required to green retrofit a building envelope for acceptable thermal performance and energy efficiency [13]. Current buildings must be retrofitted or refurbished to properly address a variety of climate challenges, especially with the emergence of digital building solutions such as Building Information Modelling.

1.3 AIMS AND OBJECTIVES

1.3.1 Aim of study

The aim of this research is to modify the design parameters for an effective building envelope based on simulation results in order to reduce the reliance on active mechanical systems, thereby improving the building's overall energy consumption and transforming it into a more green, sustainable structure.

1.3.1 Objectives

To achieve the aforementioned aim, the following objectives have been established:

1. To assess the energy performance of the existing building envelope.
2. To compare various design parameter alternatives using DesignBuilder Optimization process.
3. To propose a sustainable, green-retrofitted model of the building with optimum energy efficiency and minimum carbon emissions.

1.4. SCOPE OF STUDY

The scope of this study encompasses detailed assessment and analysis of the energy consumption of the existing building due to the heat gains from external walls, roof and glazing, natural ventilation, lightning and HVAC system and orientation of the building.

However, some factors contributing to the overall sustainability of the building such as structural performance, solar and wind analysis, daylighting, water conservation and building waste analysis are out of the scope of this study.

1.4.1 SITE SELECTION

Fig 1.2: Proposed Site Image from Google Earth

Fig 1.3: Front view of the building

The site that we selected for our project was “New Extension Building Block-1 of Industrial Engineering Department from Mehran UET situated behind the Department of Industrial Engineering as shown in Fig 1.2 and Fig 1.3. The building has 2 floors, both having different working plans.

1.5. SIGNIFICANCE OF WORK

This research would be a turning point to come up with the closest green and energy-efficient structure from an old building. The ultimate benefits of this study include:

1. Effective heat insulation in the building to minimize internal heat gains and maximize thermal comfort.
2. A building that is orientated in such a way that maximum amount of natural ventilation is achieved with reduced reliance on mechanical ventilation.
3. Minimum energy consumption with use of energy-efficient materials and fixtures, thus cutting down annual energy costs.
4. Lowest possible carbon emissions from a building, therefore causing a reduction in ozone depletion and global warming.

Chapter-2

LITERATURE REVIEW

2.1. INTRODUCTION

This chapter examines in depth various past research that focused on the central concerns of this thesis, namely, Sustainable Green Building Approach, Use of BIM in Green Retrofitting, Thermal Comfort and Energy-Efficiency Optimization in Buildings.

2.2. GREEN BUILDING APPROACH

A green building is generally defined as a carefully collaborated design strategy that significantly reduces energy consumption, maximizes natural light, improves interior environmental quality and thermal comfort, reuses materials and utilizes recycled materials, conserves water, minimizes site disturbances while maintaining occupant comfort [18]. A green building comprises the practice of implementing environmentally friendly and resource-efficient construction practices, from sustainable design to operation, maintenance, dismantling, and retrofitting. Green buildings use solar illumination, wind energy, roof ponds, rainwater harvesting, and green roofs and facades to mitigate thermal impacts to reduce energy consumption for lighting and comfort as shown in Fig 2.1 [19].

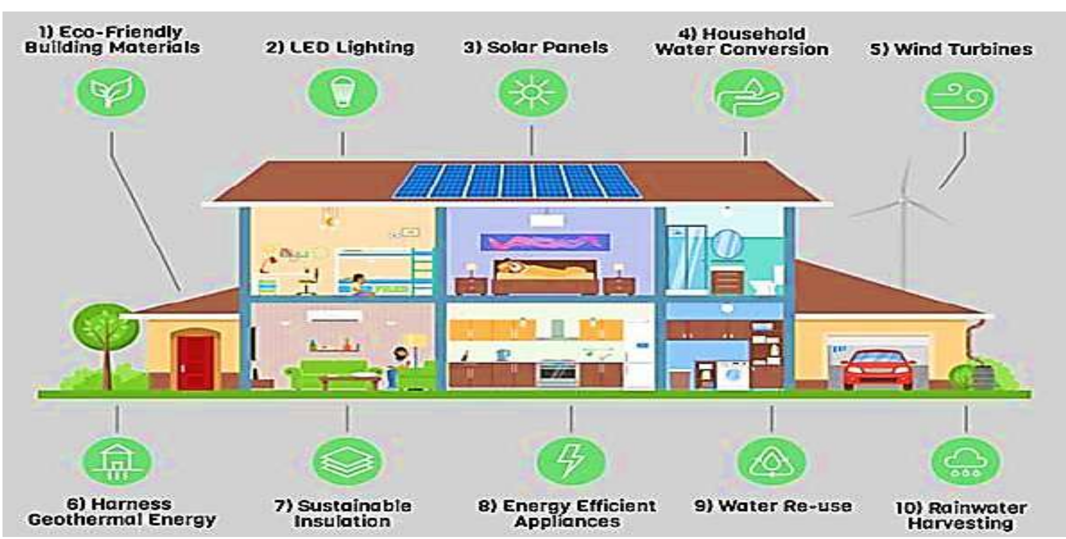


Fig 2.1: Goals in a Green Building [20]

2.2.1. BENEFITS OF GREEN CONSTRUCTION

Green buildings, according to various studies, have a major benefit over non-green ones. They aim to improve people's lives in a variety of ways, including the environment, cost, health, and community.

2.2.1.1. Environmental Benefits

The environmental benefits of green buildings are well known. Green buildings aim to promote urban biodiversity and protect the ecology through sustainable land use [21]. Clean air and water, less waste, conservation of natural resources and restoration of ecosystems are just some of the environmental benefits associated with green building [22].

2.2.1.2. Economic Benefits

For its cost-cutting qualities, green construction has become well-known. Investing in green building projects should begin during the planning phase, as this will save cost of construction. If an investor invests 3% more in the design phase, the cost of construction can be decreased by 10%. Over the life of the structure, a 2% rise of investment in green building design could save the 20% of construction phase expenses, which will be around ten times greater than the starting expenditure [23]. Although the initial cost of a green building may be higher than that of typical construction, the savings created by lower energy, health, and water use costs provide a quick payback and a positive revenue effect. Green buildings are more valuable than non-green buildings because their owners and developers may charge higher rents and have higher rental rates [23]. Reduced operating costs, the formation, expansion, and structuring of markets for green products and services, increased occupant productivity, and optimised economic performance during the building's lifetime are all economic benefits of green building [22].

2.2.1.3. Thermal Comfort

Thermal comfort, which largely depends upon temperature and humidity, is closely connected to building user contentment [21]. It refers to less air temperatures and balanced humidity inside the building. The green building lowers heat gain from a thermal standpoint. This is due to the fact that the structure has east-west orientation and most of the windows face north-south. The building is also designed to maximize natural light. This allows for passive sun shielding [23].

2.2.1.4. Internal Air Quality

One of the most important components of the human advantages associated with sustainable buildings is interior air quality, which indicates the absence of VOC emissions and other contaminants. Green buildings have been shown in research to have achieved a greater stage of interior air quality than traditional structures, which benefits occupants' health and productivity. As a result, occupants have greater degree of contentment. In fact, consumers of green buildings are more tolerant relating to internal air quality than users of conventional buildings [21].

2.2.1.5. Social and Government Perspective

The green building program has provided extra job opportunities for the local populace in terms of social and communal development. Because the building includes so many functions, there will be plenty of work openings for everyone from top management to the lowest level of employment. Current employees will be trained to be more productive and to operate the new building system more efficiently. Employees and corporations can provide the government with greater tax money. The government can also profit from the green building initiative that will be implemented throughout the country [23]. Aside from that, minimized strain on local infrastructure, increased inhabitant comfort and health, as well as aesthetic appeal, have been regarded as some of the societal benefits connected with green construction [22].

2.2.1.6. Advantages for the Market and the Industry

Green construction has a tendency to generate its own value in the markets, thus, as the number of people working in green buildings grows, their higher levels of contentment with their surroundings will inspire a desire for comparable environments from their colleagues in the industry [22]. As a result, a positive feedback mechanism will emerge in the marketplace, boosting the monetary, ecological, and health benefits [22].

Other advantages of green construction in the market include: enhancing project outcomes; enabling tech-innovation to play a role in the green building approach; emerging of more trained, educated, and qualified professionals; assisting in the creation and expansion of work opportunities, as well as permitting grant eligibility for sectors other than the construction industry that profit from new prospects and the list goes on [22]. The summary of potential benefits associated with green construction are shown in Table 2-1 below:

Table 2-1: Potential benefits associated with Green Construction

Environmental Benefits	Protects ecosystem and enhances biodiversity. Cuts down wastage. Enhances water and air quality. Preserve and regenerate natural resources.
Economic Benefits	Minimize operating costs with a little more investment in designing. Expansion of markets for green materials and services. Optimize life-cycle monetary performance.
Indoor Air and Thermal Quality	Less surrounding temperatures and balanced humidity. Minimal thermal conduction. Environment which is free of toxic VOC gases and other contaminated emissions. Improved consumer behaviours.
Communal and Industrial Advantages	Enhanced user health and hygiene. Aesthetically appealing structures. Greater employment oppurtunities and placements. Tax generation increased as the government profits more from green structures. Minimize burden on local infrastructure Successful Project completion Increased competition in building industry. Introduction of innovative technologies in market.

2.4. ENERGY-EFFICIENCY MAXIMIZATION

Energy-efficient buildings are created or renovated to extract the maximum amount of work from the energy supplied by taking steps to minimize energy loss. They are becoming more crucial as energy becomes a significant economic problem as a result of increased demand and unsustainable energy supplies [24]. Moreover, they lessen interior pollution problems by providing cleaner combustion and more ventilation compared to conventional constructions. They contribute to the reduction of external pollution by reducing the overall fossil fuel usage in power generation, as they consume less energy [25].

Oil, coal, and natural gas account for a large portion of the present global energy mix. Not only they largely contribute in toxic emissions of Green-House Gases (GHGs), these resources are non-renewable, meaning that their amounts are scarce or that they cannot be restored at the same speed as they are utilized. The existing reliance on non-renewable sources of energy is clearly unsustainable, since it includes more damaging extraction procedures, unpredictable supply, soaring market pricing, and public security vulnerabilities. [26].

Attia et al. [27] conducted a cost-benefit analysis of single-family dwelling energy execution in 2019. The primary objective of this research was to develop Plus Energy Buildings (PEB) requirements for Poland. Warm separator components, ventilation frameworks, and warming frameworks have all been associated with energy efficiency and renewable energy alternatives. The document included important proposals for new laws to be applied in 2021, which require that the yearly energy demand for non-renewable essential energy – which includes heating, ventilation, cooling, home hot water planning, and lighting – should not exceed 70 kWh/m2.year.

The Adaptive Sparrow Search Optimization Algorithm is a novel multiple-objective optimization technique proposed by Bo Liu and Dragan Rodriguez in their publication [28]. In the MATLAB environment, the optimization parameters are coded. Additionally, the energy operation of the building is evaluated using an analysis method created by Energy Plus. As a result, an optimization approach based on simulation is presented for optimizing the energy efficiency of building envelopes and HVAC systems. Its objective is to reduce energy consumption and improve the indoor thermal comfort of a building.

JuanHou et al. [29] proposed an MPC (Model Predictive Control) for the optimum monitoring of building energy, including cost efficiency and better thermal comfort, by including anticipated disruptions, electricity rates, energy needs, and the building performance model into the controller. The MPC idea is being used to regulate the space heating system in structures. A radiator system and a mechanical ventilation system make up the SH system. The radiator system is in charge of mitigate for heat loss to the atmosphere via building envelopes as well as heat inbound cooler air through air infiltration. The mechanical ventilation ventilation system, which is made up of many air-handling units (AHUs), is in charge of warming cold air coming from mechanical ventilation and distributing warm and fresh air to the building's inhabitants. The MPC (Model Predictive Control) controller utilized for monitoring and control in this study and seeks to optimize the (Supply Heating) SH system's designated supply water temperature

and its discharge rate [29].

2.5. THERMAL COMFORT OPTIMIZATION

Building energy usage and environmental comfort are frequently at odds in building design. When inhabitants are uncomfortable in an indoor setting, they will use air conditioning and lighting systems for longer periods of time, resulting in increased energy consumption.

Table 2-2: Past Study of Energy Efficiency Maximization in Buildings

S No.	Author	Title	Year	Methodology	Findings
1	Attia et al.	Energy efficiency in the polish residential building stock: A literature review	2022	Cost optimality consideration on single-family dwelling energy execution, analysing performance of ventilation and warming frameworks	The annual energy demand for non-renewable essential energy – including heating, ventilation, cooling, household hot water planning, and lighting – should not exceed 70 kWh/m^2.year
2	JuanHou et al.	Model predictive control under weather forecast uncertainty for HVAC systems in university buildings	2022	MPC (Model Predictive Control) controller utilized for monitoring by including anticipated disruptions, electricity rates, energy needs, and the building performance model into the controller.	This study attempts to optimize the (Supply Heating) SH system's designated supply water temperature and its discharge rate to increase building energy efficiency.
3	Lui B et al.	Renewable energy systems optimization by a new multi-objective optimization technique: A residential building	2021	In the MATLAB environment, the optimization parameters for Adaptive Sparrow Search Optimization Algorithm are coded. The building's energy operation is also assessed using a simulation approach developed by Energy Plus.	Simulation-based optimization approach for optimising the energy efficiency of building envelopes and HVAC systems is provided.

Limiting energy use and enhancing thermal comfort benefits not just the environment but also the productivity of the occupants. A considerable proportion of existing structures, particularly those in the hot summer and cold winter climate zones, have insufficient insulation [30]. Czopka et al. [31] suggested sustainable insulation materials in buildings as follows:

- cellulose – provides continuous insulation for any thickness of assembly, properly isolates due to its porous nature, strong fire prevention due to adequate adhesion, high absorption capabilities, and the tendency to remove excess moisture,
- mineral wool – Basalt rock and reclaimed slag make up this substance. Anti-in flammability and fire durability, as well as vapour penetration and thermal and sound insulation, are all characteristics of this material,
- cotton – Cotton is retrieved from jeans and other sources. Chemical elements are found less in these sources,
- agricultural products – for instance sugar cane, soybean, corn etc. These could include spray foam or stiff boards,
- sheep's wool – outstanding thermal insulator, has absorbent characteristics that have no significant effect on the health of users,
- cement – It has a high porosity when water is added and curdled with air, which boosts its heat shielding and capability to "breathe." The material is antimicrobial and moisture resistant.

To aid in the selection of appropriate thermally comfortable retrofit solutions, optimization methodologies and simulation tools have been offered. Sghiouri et al. [32], for example, aimed to reduce building overheating by installing shading devices, which is among the greatest ways for limiting building overheating caused by solar heat gains via the clear building envelope. They presented a way for integrating a GA optimization tool with a building energy simulation programme. The concept is then applied to a simple instance involving enhancing the thermal comfort of residents in an existing Moroccan residence [32].

Stazi et al. [33] suggested a flexible and controlled algorithm-driven automated operating mechanism for windows after examining influencing factors for opening and closing system of windows, that may ensure healthier and thermally friendly interiors in classrooms by incorporating temperature and carbon dioxide levels inputs. They chose two neighbouring classrooms for their experiment to examine the effects of two control techniques managing windows opening: users' manual control and automated mechanic control. In order to assess the effectiveness of the various settings in terms of thermal comfort and perspectives of the occupants, quantitative and qualitative outcomes from the two experimental set-ups were compared. They discovered that the key driving parameters for both window opening and shutting behaviors were interior and exterior temperatures, whereas CO_2 level in the air was not a cause [33].

To achieve a temperature that is both energy efficient and comfortable for the occupants, Zahid et al. [34] offered an optimization approach called 'Dynamic PMV' that integrates BIM (Building Information and Modeling) with IoT(Internet of Things) sensors. This combination enables maximizing indoor thermal comfort by coupling the geometric and functional complexity of BIM models with real-time registering of meteorological data (humidity, temperature, etc.) via IoT sensors. Initially, considering the parametric data from the BIM model, interpolation of IoT data is carried out according to a typical 3D grid while incorporating heat transfers between rooms. Next, Dynamic PMV enables for real-time 3D representation of thermal comfort, employing the Predicted Mean Vote (PMV) index. Eventually, the best temperature for sustaining indoor climate is determined [34]. The past studies related to thermal comfort optimization are summarized in Table 2-3.

Table 2-3: Past Study of Thermal Comfort Optimization

S No.	Author	Title	Year	Methodology	Findings
3	Zahid et al.	Dynamic Predicted Mean Vote: An IoT-BIM integrated approach for indoor thermal comfort optimization.	2021	Real-time registering of meteorological data via IoT sensors, then interpolation of IoT data carried out according to a typical 3D grid.	Predicted Mean Vote (PMV) index
1	Sghiouri et al.	Shading devices optimization to enhance thermal comfort and energy performance of a residential building in Morocco.	2018	Evaluating the effect of installing shading devices by integrating GA optimizing tool with energy simulations.	It is the greatest way for limiting building overheating caused by solar heat gains via the clear building envelope.
2	Stazi et al.	Indoor air quality and thermal comfort optimization in classrooms developing an automatic system for windows opening and closing	2017	Examining and comparing the effects of two control techniques managing windows opening: users' manual control and automated mechanic control.	Interior and exterior temperatures are key influencing factors for window opening and closing.

2.6. POTENTIAL OF BIM ADOPTION

BIM is rather a well-integrated procedure utilized in a project life cycle than simply a bunch of softwares. BIM models serve in the optimization of time, costs, and quality throughout the designing and construction stages, and aid in the smooth management of the facility during the operation stage [35]. Controlling and managing the construction process at every step of its development with the coordination of all the parties concerned, as well as automatic detection of clashes and faults, obtaining accurate cost estimates and collaboration among all stakeholders in the asset allocation process, are just a few of the benefits of adopting BIM [11]. Global experts in design, engineering and construction are leaning towards BIM for an effective structure and growth of the building industry. The growth of global BIM market in subsequent years can be seen in Fig 2.2.

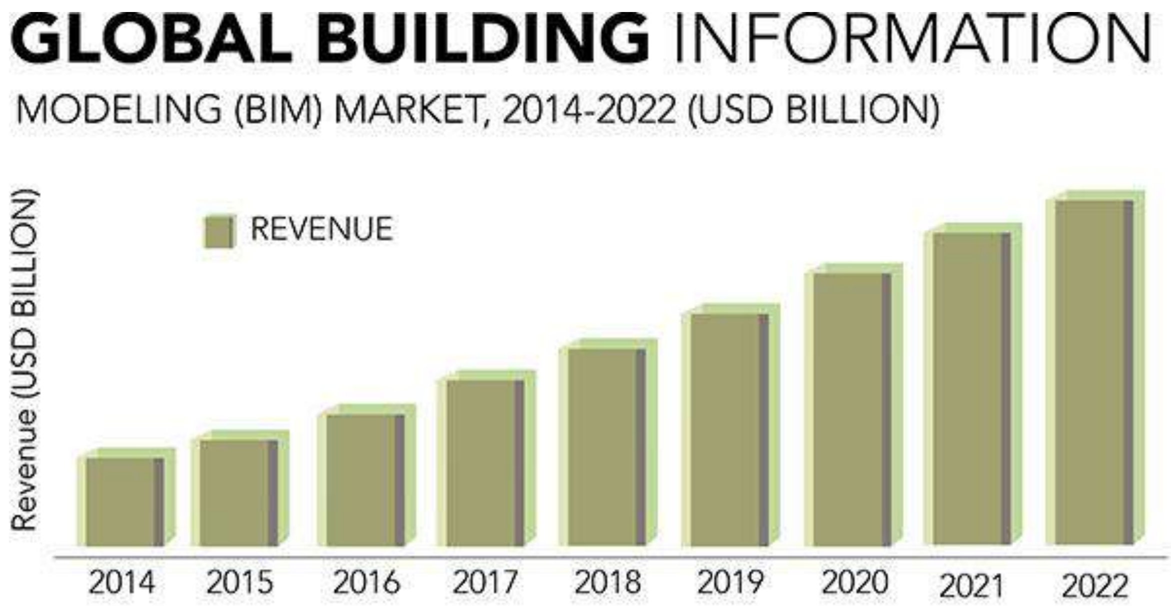


Fig 2.2: The projected growth of the global BIM market [36]

In terms of technical improvements, Pakistan lags in the global construction market. The construction industry of Pakistan has been criticized for its poor reputation for completing projects on time, on budget, and with quality. This is due to the implementation of conventional management practices, which may be readily reduced with the adoption of innovative technologies such as Building Information Modeling (BIM) [37]. The construction industry's degree of maturity and performance in terms of BIM adoption is considerably low since upgrades to traditional models to allow for improvements in technology have been made to a lower extent.

The adoption of BIM in Pakistan is only at 11% [11]. This trend had been recently employed in some newly-developed towns, such as DHA City and Bahria Town Karachi [19]. Although construction industry experts and some multinational companies in Pakistan are utilizing BIM in their projects, its actual use is limited due to a lack of skills and expertise in this technology [11].

Inadequate design, change in scope, not preparing drawings in the allocated time, delayed approvals, design conflicts, inaccurate estimates, lack of planning, insufficient coordination linkages between stakeholders, and unhealthy contract management are the main reasons for time and expense overruns in projects. All of the building methods used are traditional, primarily relying on 2D CAD designs. The CAD-based designing functions as a barrier to the integrated engagement of various project stakeholders, such as clients, contractors, designers, engineers and project managers. Every stakeholder represents and shapes the data in his unique way. This causes a slew of disputes, which lead to serious challenges throughout the planning and building phases. These approaches eventually lead to the failure of projects [11].

The construction costs of adopting a 'green building approach' are the same as existing building procedures; however, the government must educate the public and encourage energy conservation through incentives and refunds for those who utilise these methods [19].

2.7. THE NEED FOR 'GREEN BIM'

Pakistan's construction industry has made a significant contribution to the escalating worrisome issues harming the environment, either directly or indirectly. These issues include, but are not limited to, air, land, and water pollution, soil erosion, sudden climate and weather changes, global warming, deforestation and depletion of valuable energy sources such as minerals and fossil fuels, major health concerns, and loss of ecosystems and diversity. To address these issues, the construction industry is working to divert its attention towards environmentally friendly techniques and to develop greener building approaches that lead to sustainable buildings [38].

The AEC industry has seen two key developments emerging in the last few years: green building construction and the usage of BIM workflow. Despite the fact that these trends developed independently and stood distinct in the construction sector, industrialists recognized an extraordinary combo between them. An integrated design approach is excellent for green design, and BIM is best known for implementing it. Through its visualization technology and virtual prototyping and because of the advancements made possible by BIM in green buildings, we now have new tools for assessing construction's environmental impact and managing it. In this regard, consistent efforts are being made to investigate a variety of BIM processes that can be used to support green building, such as energy simulation, thermal analysis, lightning and airflow analyses, demolition waste analysis, and so on [39].

2.8. ANALYSIS OF BIM IN PAST RETROFITTING STUDIES

Architects are increasingly using the abbreviation BIM (Building Information Modeling). The majority of offices and professionals have already migrated or aim to migrate to this system, which digitally reflects the physical and functional qualities of a building while combining varied information about all project components. It is feasible to digitally produce one or more exact virtual models of a building using BIM software, which allows for better cost management and efficiency in the construction process. It is also feasible to model the building in order to better understand its behaviour prior to construction and to support the project throughout its life cycle, including after construction, disassembly, and demolition.

Despite the fact that their approaches differ, the strategies adopted by many researchers are basically the same. According to R. J. Scherer et al. [40], there are a number of different ways to go about retrofitting a building: anamnesis and diagnosis are two of the most common. Anamnesis is the process of gathering information about a building's structure and performance while diagnosis is the analysis and interpretation of that information to prepare for the retrofitting model.

BIMification refers to the use of BIM in retrofitting. It is expected to bring significant benefits in terms of behavioural building system identification, reliable planning of retrofitting measures both in terms of energy performance and costs, and, last but not least, measurable contributions in terms of the creation of building models of existing buildings by enabling sound and well-structured BIM creation [40]. BIMification can be used for more than simply retrofitting in terms of energy analysis; it can also be used to rehab bridge structures, airports, and other infrastructure.

L. Sanhudo et al. [41] employed a three-step strategy: data acquisition, which included developing an energy model for the building; data transfer, which included moving the model to energy analysis software; and finally, identification of critical issues encountered along the way.

Liu Q, Wang Z [42] stated that water supply and drainage system energy conservation, as well as HVAC system energy conservation, can be used in conjunction with passive energy-saving technology to help control building energy consumption and improve indoor comfort in large-scale university buildings such as libraries, sports, and sports/event venues.

According to Y. Lu, Z. Wu, et al. [43], green buildings are classified using "project stages" and "green qualities." The "project phases" dimension depicts the lifecycle of a project. Before a green project is demolished, it goes through a lifetime process that begins with project design and continues through construction, operation, and maintenance. Energy, thermal comfort, carbon emissions, water, material waste, daylighting, natural ventilation, and acoustics analysis are just a few of the areas where BIM software can be beneficial.

Table 2-4: Past Study of BIM in Green Retrofitting

Sr.No	Authors	Title	Year	Findings
1	Liu Q, Wang Z	Green BIM-based study on the green performance of university buildings in northern China	2022	According to the findings, this optimization technique can reduce annual loads by roughly 47.4%, which is in line with national energy efficiency guidelines for public buildings. The heating demand was lowered by 59.1 percent, while the cooling load was reduced by 21.5 percent.
2	Scherer R, Katranuschkov P	BIMification: How to create and use BIM for retrofitting	2018	BIM can be used in retrofitting by following the stages below: simulation, result evaluation, and result comparison.
3	Sanhudo L, Ramos N, Et al.	Building information modeling for energy retrofitting – A review	2018	Heat flux measurement, interior comfort, CO2, and other testing using laser scanning and BIM findings.
4	Lu Y, Wu Z, Li Y, et al.	Building Information Modeling (BIM) for green buildings: A critical review and future directions	2017	Green BIM applications, according to this research, could improve GBA in a variety of ways, including predicting GBA scores, handling application documents, and increasing the speed of the GBA process.

Chapter-3

DESIGN AND METHODOLOGY

3.1. INTRODUCTION

Research methodology refers to how a researcher plans a study adopting a systematic approach to guarantee that the results are accurate and reliable and that they fulfill the study goals and objectives. This chapter discusses what data was obtained about the building in question, how it was acquired, and how it was processed or analyzed in a structured manner to meet the target objectives of this study. The chapter is organized into the following sections that discuss the chronological workflow of this research.

3.2. RESEARCH DESIGN

Research design is essentially a structural framework for numerous research methodologies and procedures that are used by researchers in their studies, guaranteeing that the research problem is adequately addressed. It entails the systematic collection, measurement, and analysis of data in order to produce useful results, as depicted for our study in Fig 3.1.

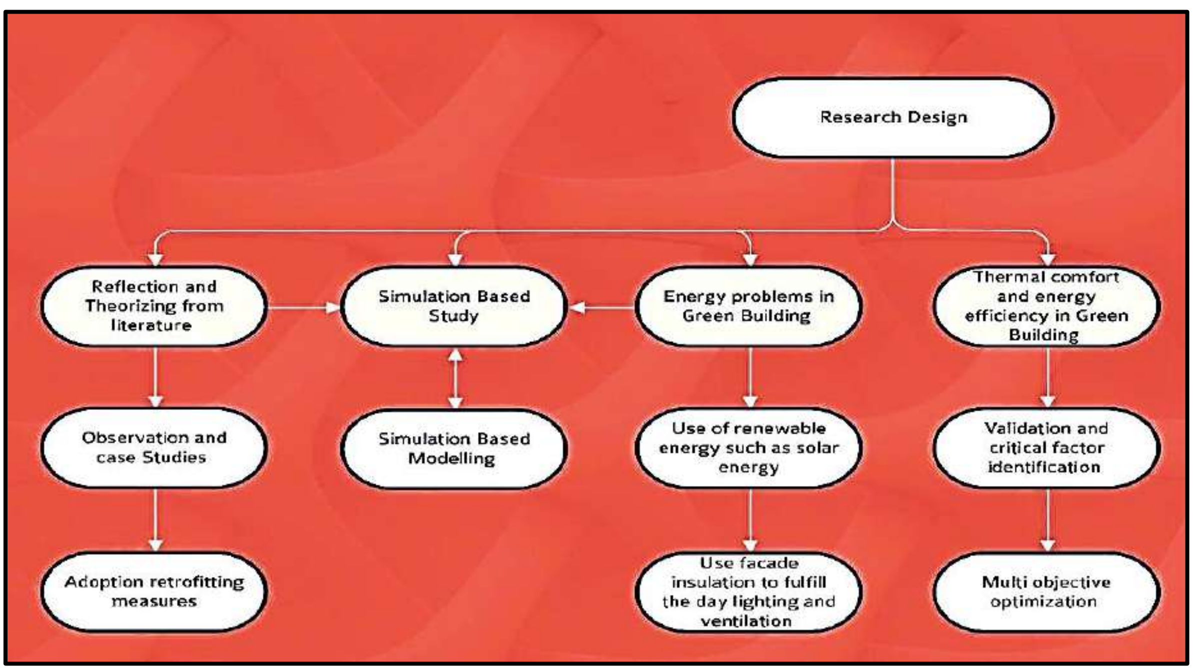


Fig 3.1: Research Design Flow

3.2.1 Reflection and theorizing from literature

The procedure of the use of background knowledge from the scientific field is referred to as a literature review. Almost all studies include a more or less detailed literature evaluation of previous research as part of their research methodology. Simulation studies as well as various theoretical investigations were employed for literature review in our research.

3.2.2 Case study and observations

A case study is a comprehensive examination of a particular event in a real - life setting. A suitable building for our study has been chosen in the Mehran University premises, named "Research and Development Enclave Block-1", constructed recently as an extension for Department of Industrial Engineering. The building is two-storey with different working plans for both storeys.

3.2.3 Identification of energy problems and thermal flaws

Problems will be noted down to be addressed in our study after carrying out a detailed on-site investigation. The energy problems and thermal flaws in the building will remain our focus.

3.3.4 Simulation-based modelling

Simulation-based modeling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the actual world. Simulation software creates a dynamic environment in which computer models or prototypes can be analysed.

We used Autodesk Revit for our simulation work, which is a three-dimensional design software that enables users to create their models using two-dimensional drafting elements and obtain building data from the building model's database. Prototyping and scheduling are made easier by the software, which provides insights into the projects. An integrated 3D model that includes all architectural, structural, mechanical/electrical/plumbing designs may be created, making it easier for the engineers and architects to collaborate on the design and building of structures.

The optimization parameters were applied to the existing energy model to convert it into green retrofitted model in the Design builder. It is a versatile, Energy Plus based software tool used for energy, carbon, lighting and comfort measurement and control. Design Builder is developed to ease up the building simulation process. Design Builder is used for comparing alternative building designs by using function and performance-based method of comparison results by the various analyses in a quick and economic manner.

Following optimization analysis, Design Builder presents us with a collection of ideal solutions on the "Pareto Front" that may be further numerically and graphically analysed to decide which designs best meet the priorities stated for the employed objectives. This strategy ultimately led to the selection of the most efficient, environmentally friendly alternative for our model with the lowest energy usage and lowest cost.

3.3. RESEARCH METHODOLOGY

This section goes over the research process employed in depth, which consists of a set of procedures that must be followed in order to do research efficiently. Fig 3.3 summarizes the research methodology in a flowchart.

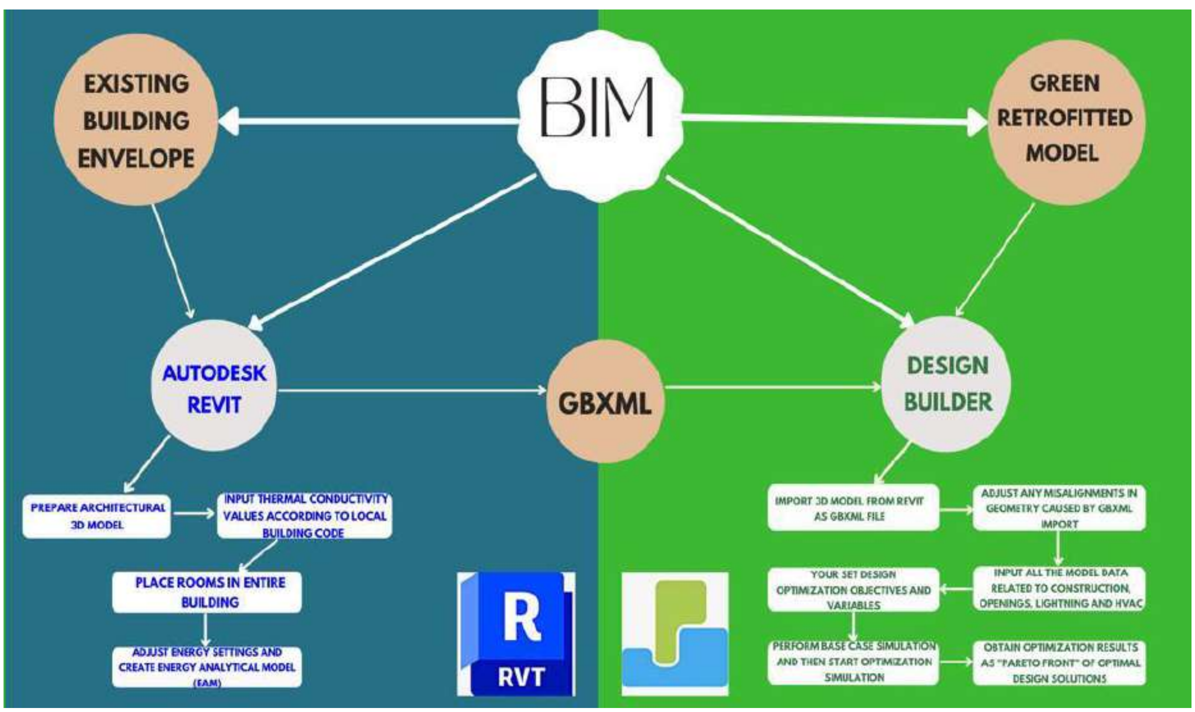


Fig 3.2: Research Methodology

3.3.1. LITERATURE REVIEW

Reading, organising, and summarising information from academic materials such as books, conference proceedings, postgraduate theses and peer-reviewed journals are all part of the process of doing a literature review. The purpose of a literature review is to compare our findings to those of other researchers who have previously published work on the same subject. The typical process of carrying out literature review for our research is shown in Fig 3.4.

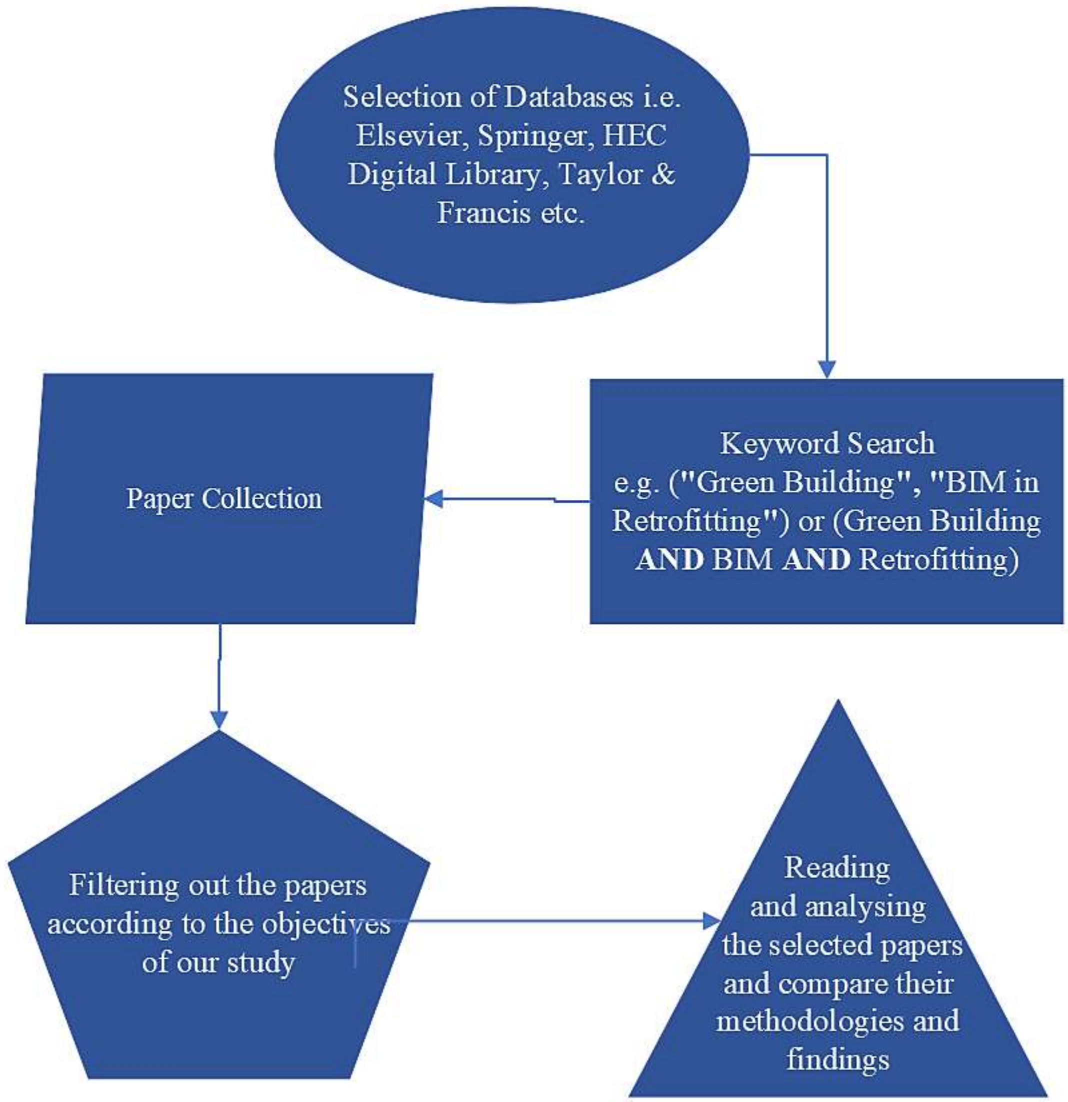


Fig 3.3: Method adopted in Review of Literature

3.3.2. DATA COLLECTION

On-site investigation of the chosen building **'Research and Development Enclave Block-1'** was done. The building has a total of 4 floors. Our team chose this building as it was newly built as an extension of Industrial Engineering Department and its full data was available in the Administration Department.

Secondary data collection was carried out by gathering qualitative and quantitative data from the Administration Department for the building as follows:

- Ground floor CAD working plans for 2 floors showing all dimensions of the building
- Construction materials used in the building
- Thickness of material layers used in walls
- Thermal conductivity (U-value) of materials

3.3.3. DATA ANALYSIS

The use of logical processes in a systematic manner for the aim of describing and showing, condensing and recapitulating, and assessing data is referred to as data analysis. The data acquired in our research is examined using the following processes:

3.3.3.1 Methodology for Analysis of Existing Building Envelope in Autodesk Revit

4. A realistic and accurate architectural building information model of the site, along with all the structure's materials and their thermal conductivities, was created using Autodesk Revit 2022.
5. After the model's geometry is complete, "Rooms" were allocated to each unique space, and the proper energy settings were produced.
6. The entire architectural model was then converted by Revit into an Energy Analytical Model (EAM), which contains the thermal characteristics of building components such walls, doors, windows, ceilings, and roofs.
7. The Green Building Extensible Markup Language (gbXML) file format, which is supported by DesignBuilder, was used to export the EAM.
8. Before moving on to the optimization analysis, the gbxml model was imported into DesignBuilder and any unneeded omissions or additions are corrected there.

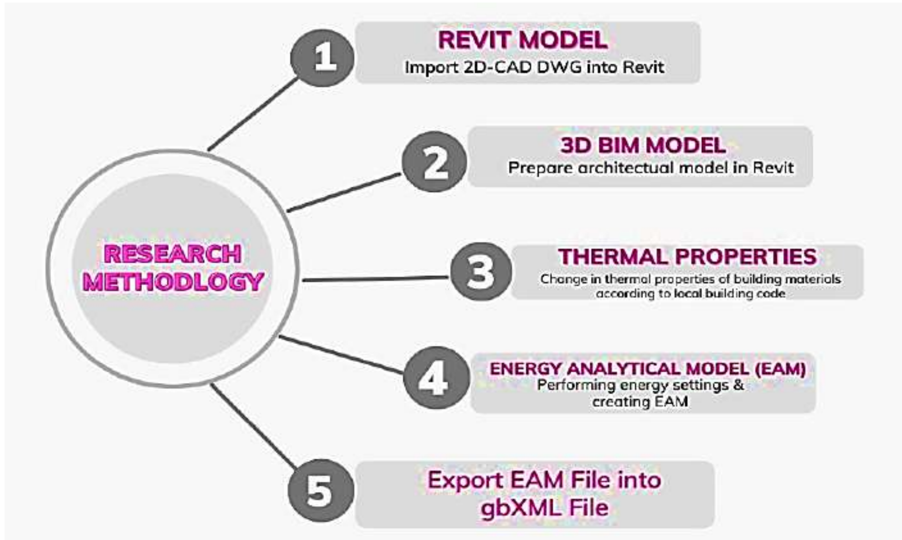


Fig 3.4: Process in Autodesk Revit

3.3.3.2. Methodology for Applying Various Strategies of Green Retrofitting in Design Builder

- It was confirmed that any construction assignments made in Revit are passed over to Design Builder after making the necessary geometry adjustments. These construction assignments can only be created if the building and all its layers of thermally conductive materials were accurately described in Revit and exported from it.
- The design objectives were specified in the optimization settings dialogue. In this study, the balance between net energy consumption and total cost of the building was optimized.
- The design factors that best suited our objectives were selected as below:
    1. Window to Wall ratio (%)
    2. External wall construction
    3. Internal glazing (%)
    4. Glazing type
    5. Flat roof construction
    6. Lighting template
    7. Local shading type
    8. Cooling setpoint temperature
    9. Natural ventilation rate

10. Site orientation

- To assist in achieving the design goals, Design Builder's Optimization module employs cutting-edge evolutionary algorithms through a natural selection process based on enhancing building performance. As seen in the following graphic, the process was repeated until the ideal designs had been found, passing on the best traits to subsequent iterations:

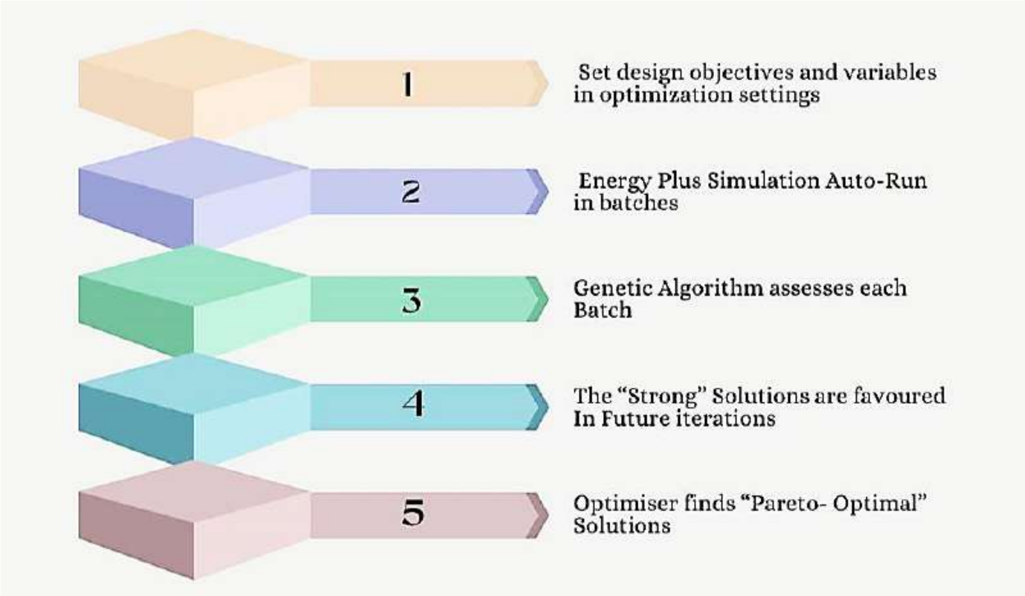


Fig 3.5: Optimization process in DesignBuilder

- The set of suggested solutions on the "Pareto front" was further visually and mathematically analysed to determine which designs best satisfy the design priorities defined on the employed objectives.

- On the local high-performance computer, multiple designs were evaluated concurrently.

- Energy-optimization findings were obtained, and the best or 'optimal' design solution was selected based on minimum energy usage and lowest cost.

3.3. SUMMARY

By using BIM technologies to simulate the study, we performed the retrofit the existing "Research and Development Enclave-1" building with sustainable green features. An architectural model of the building was created using Autodesk Revit, and by modifying the model's energy settings, an Energy Analytical Model (EAM) was produced. The output file format for this model is gbXML. Following that, we imported a gbXML file to Design Builder. It was made sure that any errors in geometry of building are adjusted and any construction assignments and thermal values generated in Revit are there in Design Builder. Then, after choosing the Optimize option, we will select the design variables that best suit our goals. Using advanced evolutionary Design Builder algorithms, several iterations were achieved based on various locally accessible materials, and the process will continue until the best or 'optimal' designs have been found. After the analysis, Design Builder eventually provided us with a set of optimal solutions on the "Pareto Front" that can be further analysed numerically and visually through the graphical outputs to determine which designs best satisfy the priorities established for the objectives being employed. The most effective, green-retrofitted option for our model with the least energy consumption and minimum cost was ultimately chosen using this method.

Chapter-4

RESULTS AND DISCUSSION

4.1. INTRODUCTION

This chapter discusses the modeling and analysis of the concerned building, comparison of design alternatives achieved in the optimization study and the design parameters of the most optimal design in detail.

4.2. MODELING AND ENERGY ANALYSIS OF EXISTING BUILDING

i. The CAD plans for both the ground and first floor were imported from AutoCAD as shown in Fig 4.1.

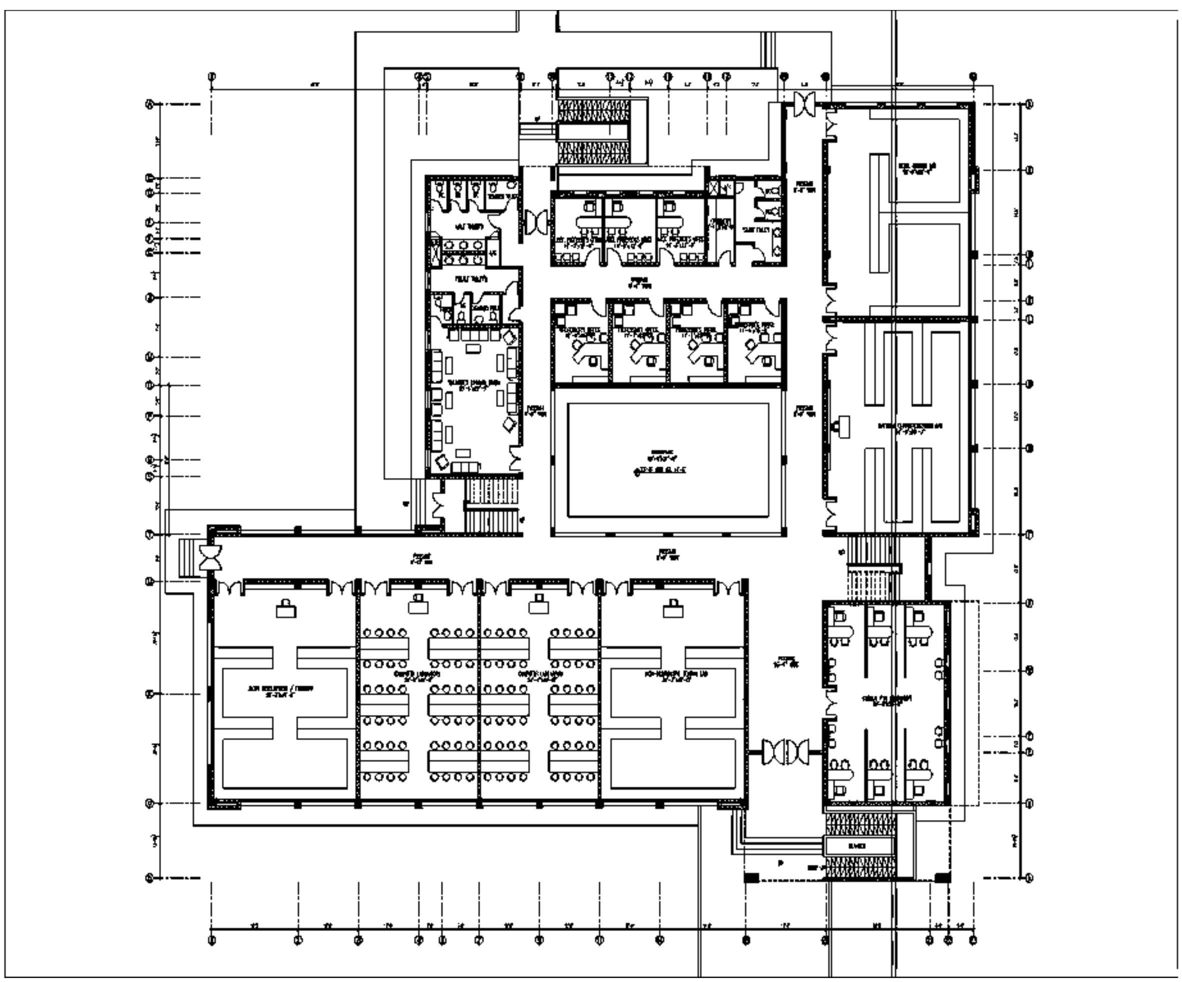


Figure 4.1: Ground floor plan of the building

ii. The model preparation was begun which included placing the required components of the structure i.e., walls, windows, floors, roofs, beams and columns on both ground floor and first floor plans as shown in Fig 4.2, Fig 4.3, Fig 4.4 and Fig 4.5.

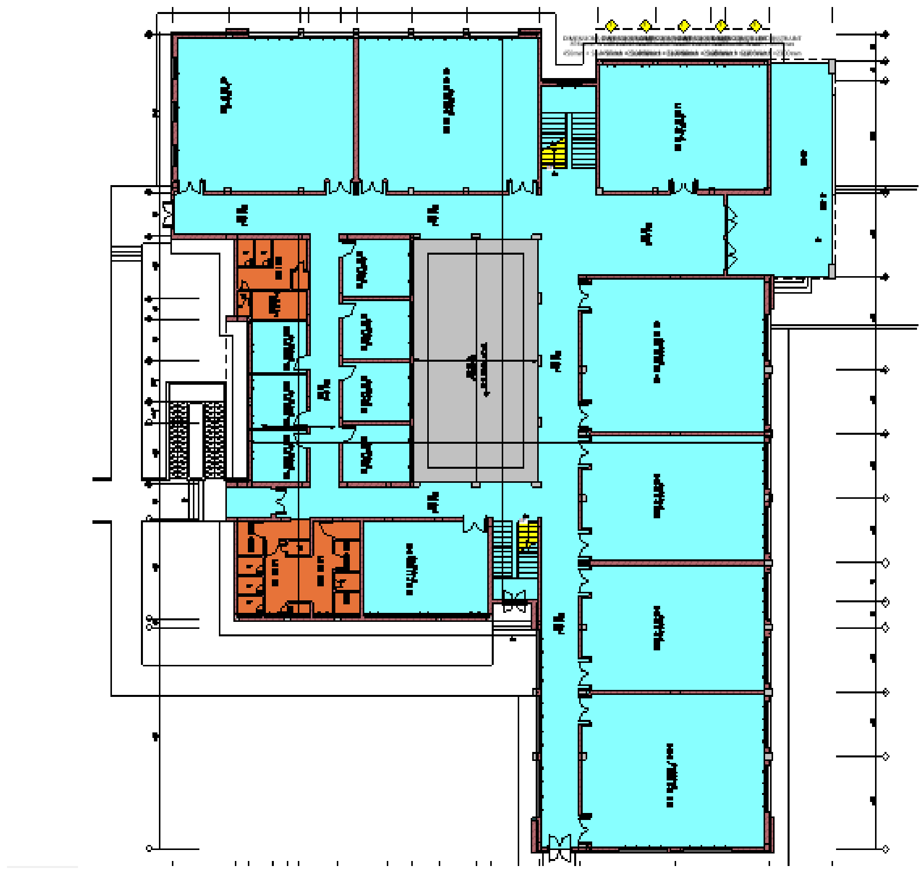


Fig 4.2: Ground floor plan after model placement

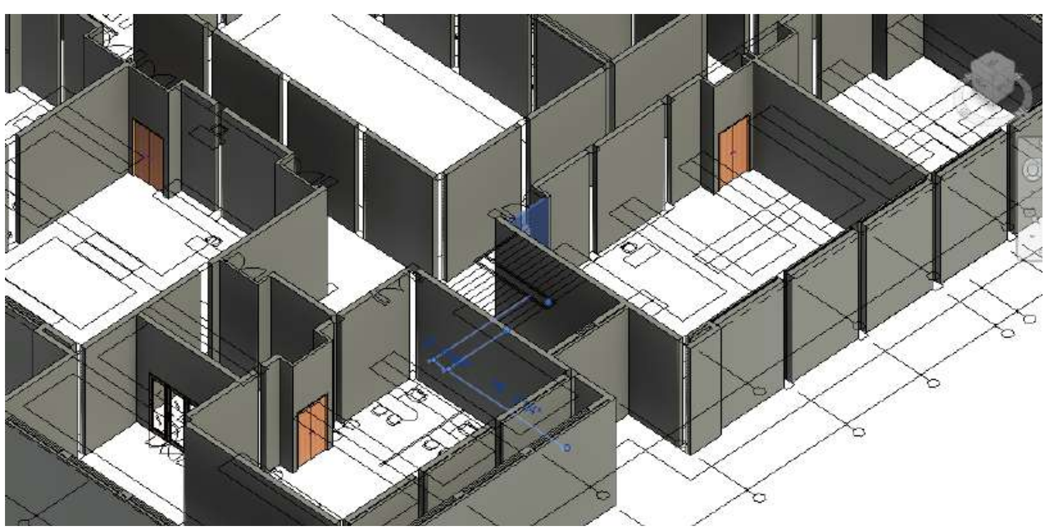


Fig 4.3: Placement of walls and doors in 3D

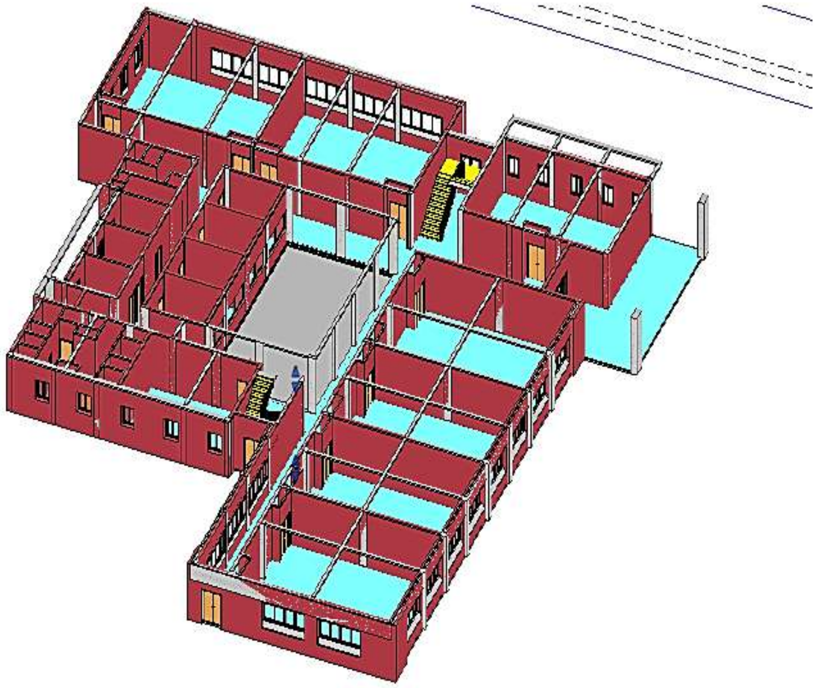


Figure 4.4: Ground floor section of the building

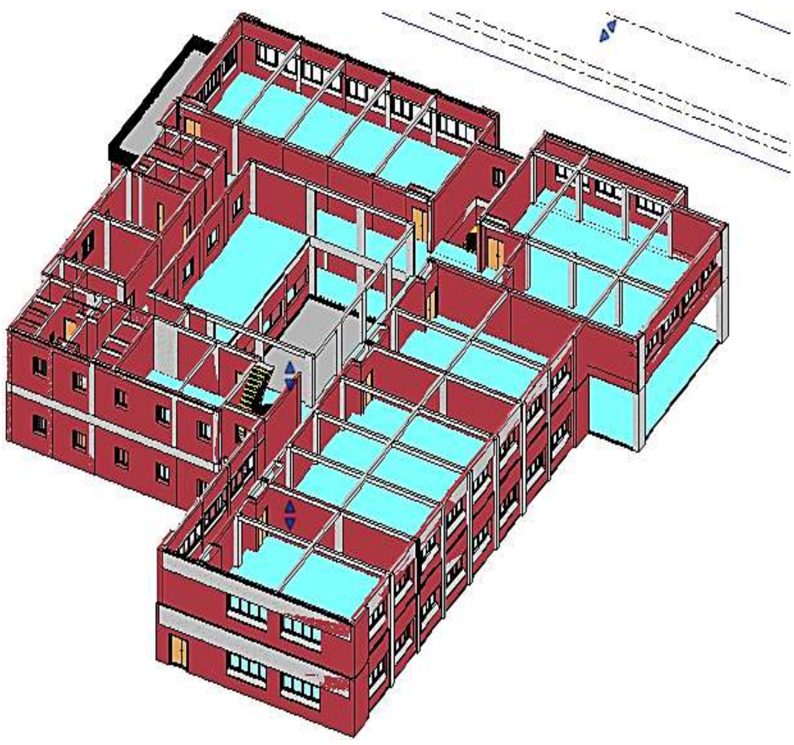


Figure 4.5: First floor section of the building

iii. The final 3D architectural model was prepared as shown in Fig 4.6. The sun path on a date of peak summers for the building is shown in Fig 4.7.

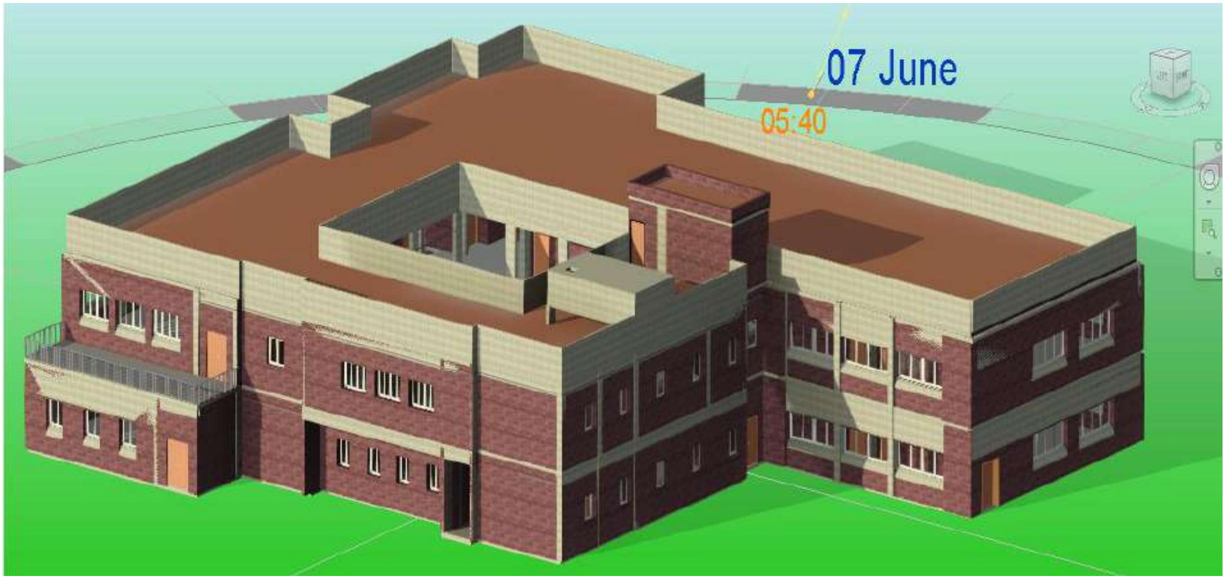


Fig 4.6: Three-dimensional model of building in Autodesk Revit

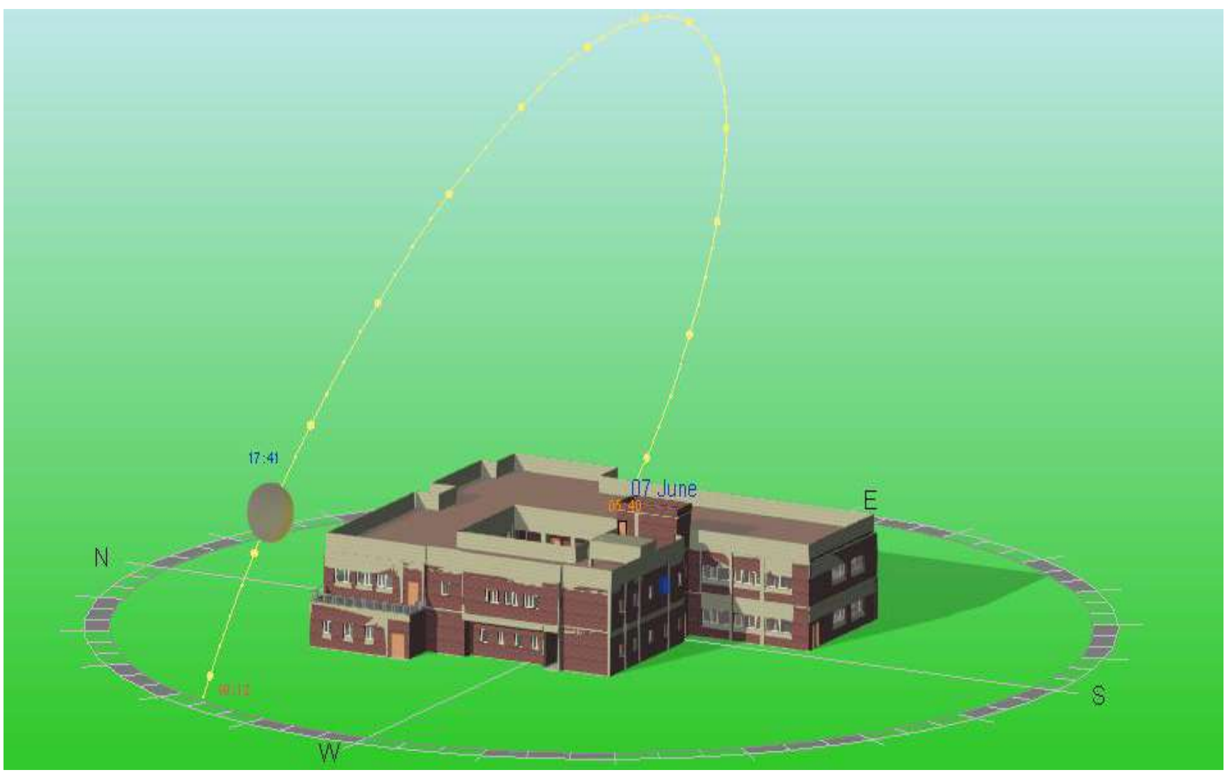
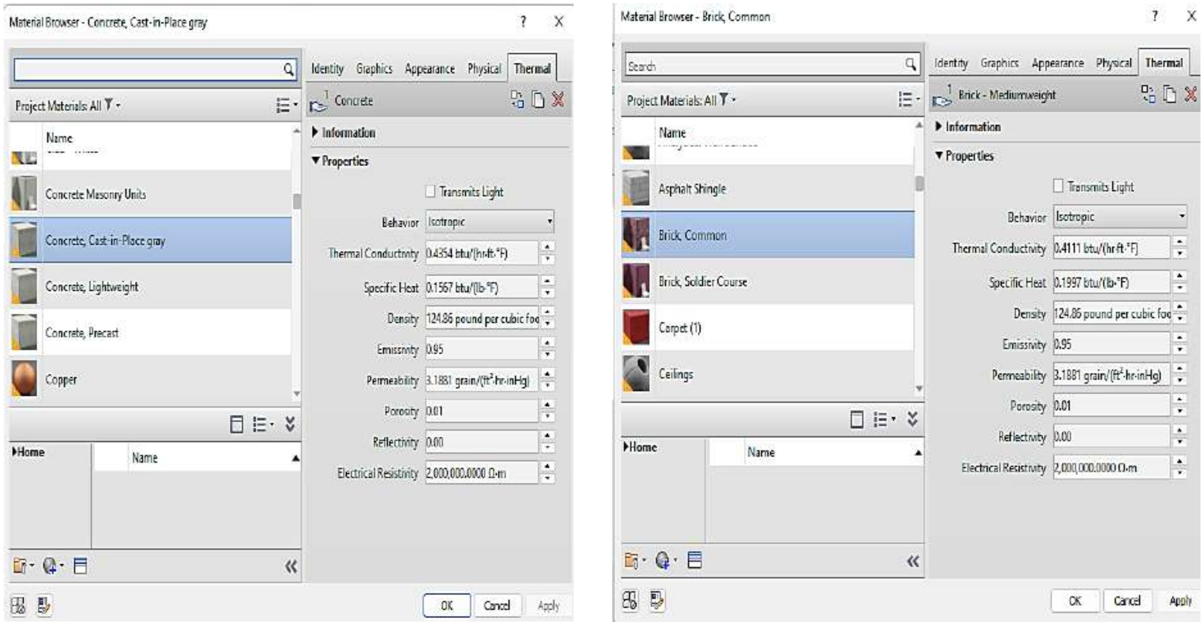


Fig 4.7: The sun path over the building on peak summer day

iv. The thermal conductivity and specific heat values for each material used in the building were modified in reference to the local building code and taken from a past study [44].



v. Rooms were placed in each room shown in plan, which are read by Revit as spaces in the model.

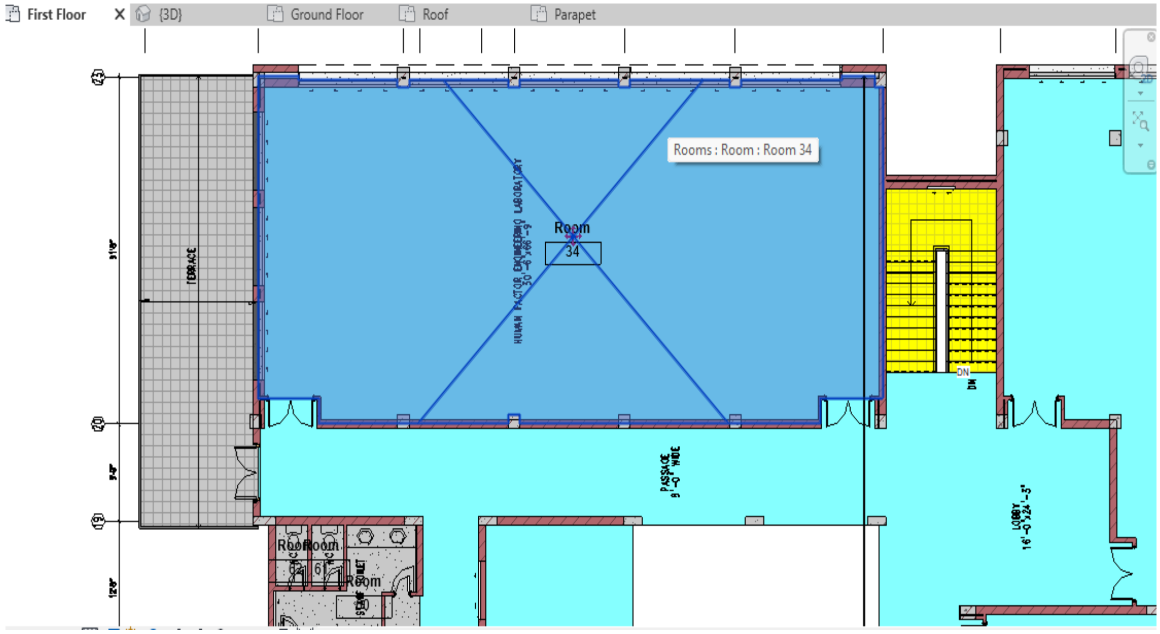


Fig 4.8: Rooms placement in model

vi. The rooms were aligned in section view such that the top of the rooms of ground floor coincided with the bottom of the rooms of first floor to avoid any gaps between the rooms as shown in Fig 4.9 below:

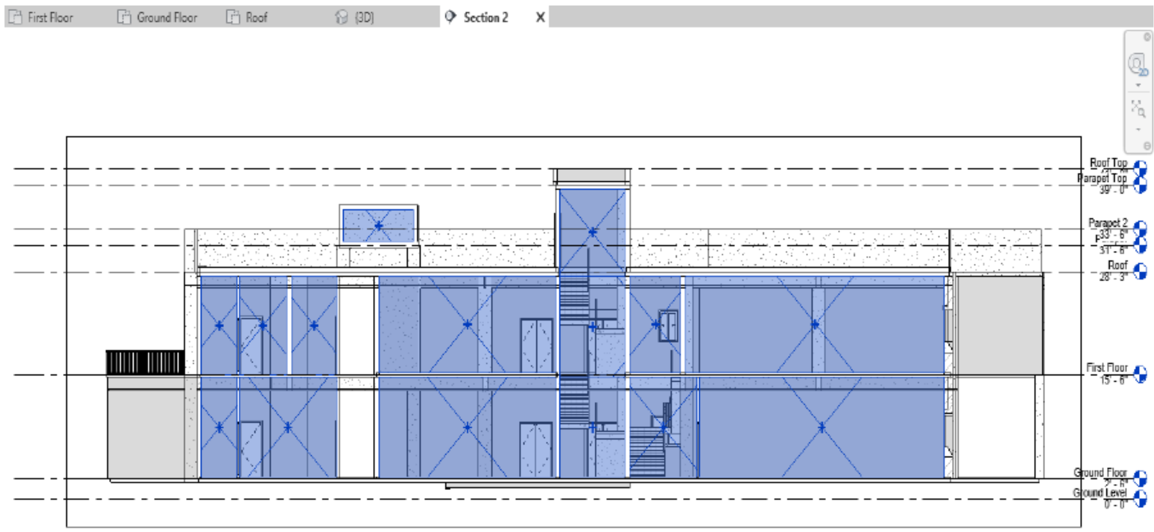


Fig 4.9: Rooms adjustment in model

vii. The energy settings were adjusted such that the mode for creating Energy Analytical Model (EAM) for the building was chosen as "Use Rooms or Spaces", export complexity as "Simple with shading surfaces" and for material thermal properties, "Detailed Elements" box was checked as shown in Fig 4.10 below:

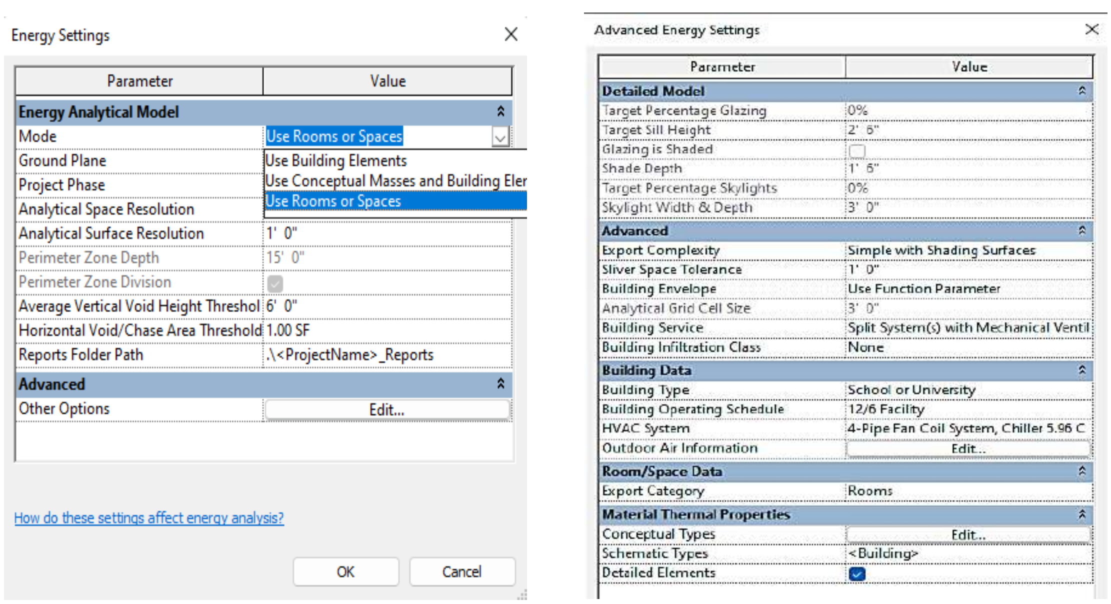


Fig 4.10: Rooms adjustment in model

viii. The Energy Analytical Model (EAM) was created and then exported to 'Green Building eXtensible Markup Language' or gbxml format as shown in Fig 4.11.

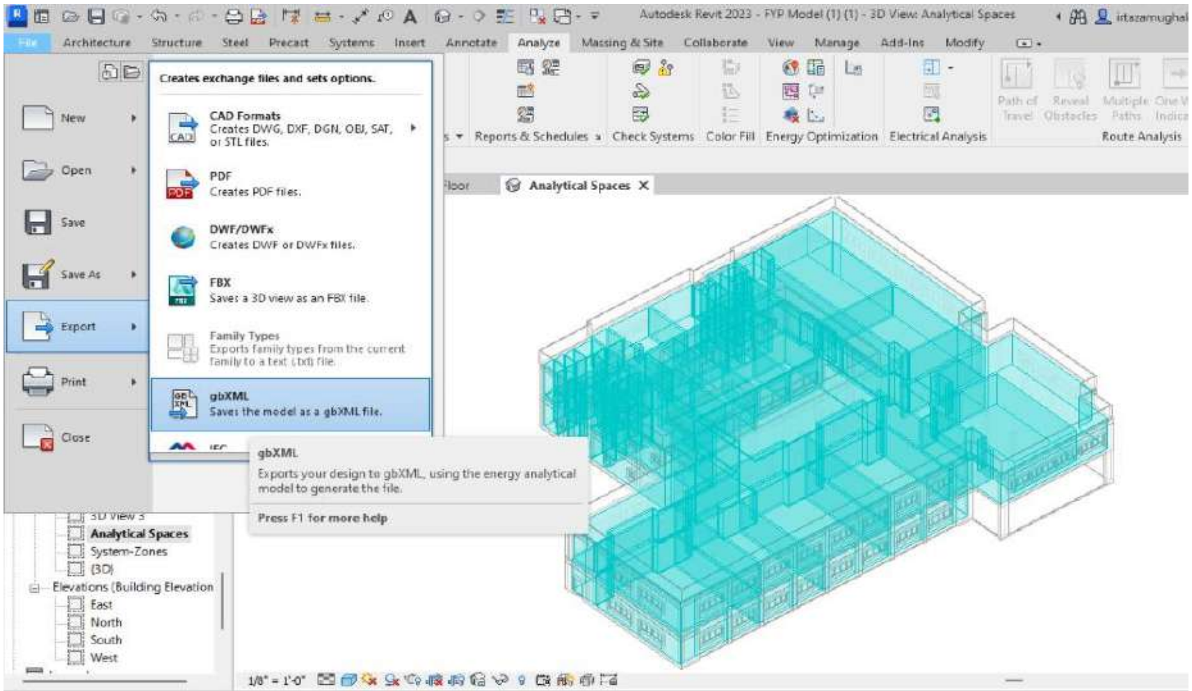


Fig 4.11: Export of Energy Analytical Model into gbxml

ix. A new file was opened in DesignBuilder, the location was set and the gbxml file was imported as shown in Fig 4.12.

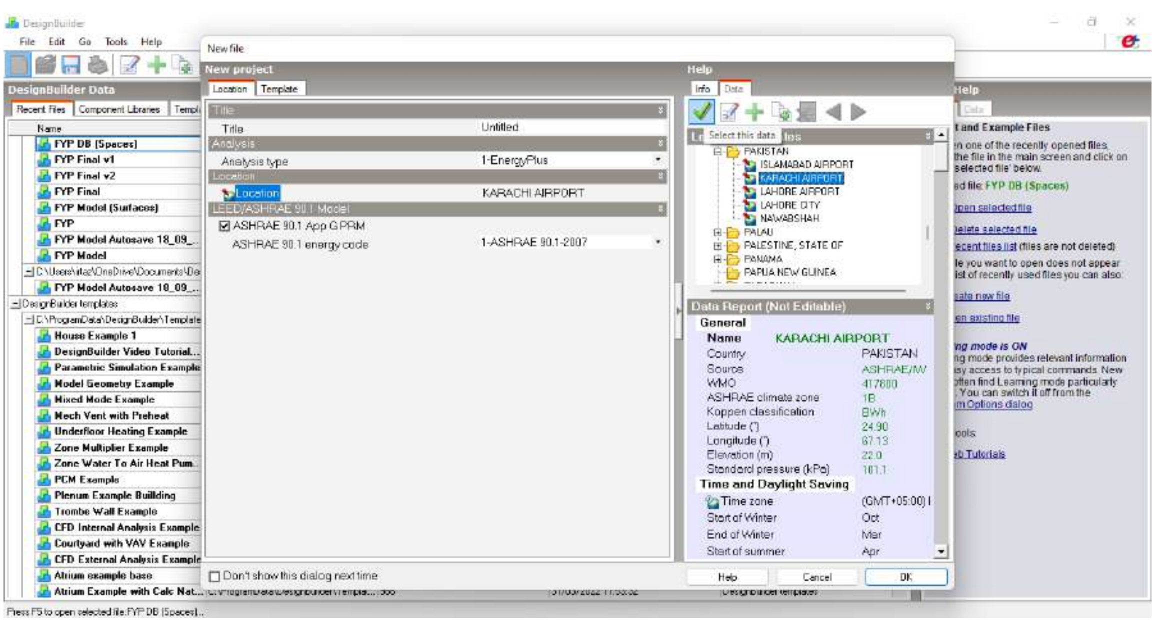


Fig 4.12: Import of gbxml in DesignBuilder

x. The model imported is divided into zones with rooms having similar heat flow and ventilation as shown in Fig 4.14 on the left bar. The model checked for any errors in geometry i.e., any omissions or additions to components of the building. All the gaps are filled properly to allow heat transfer. The final rendered view of the building along with sun path is shown in Fig 4.13 and Fig 4.15.

Figure 4.13: Revit Model imported into Design Builder

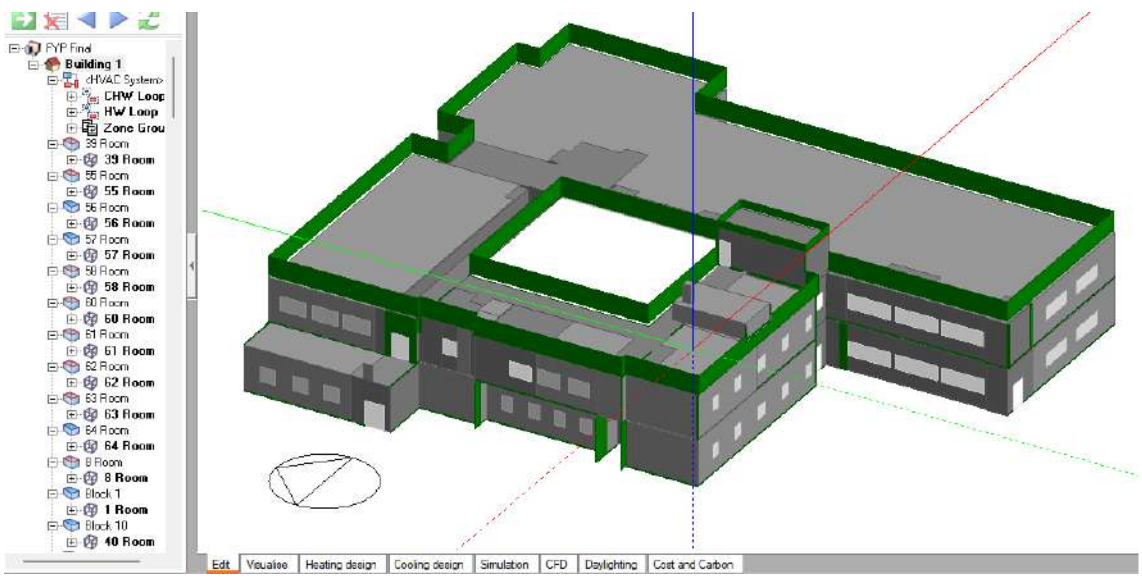


Fig 4.14: Model geometry adjustment

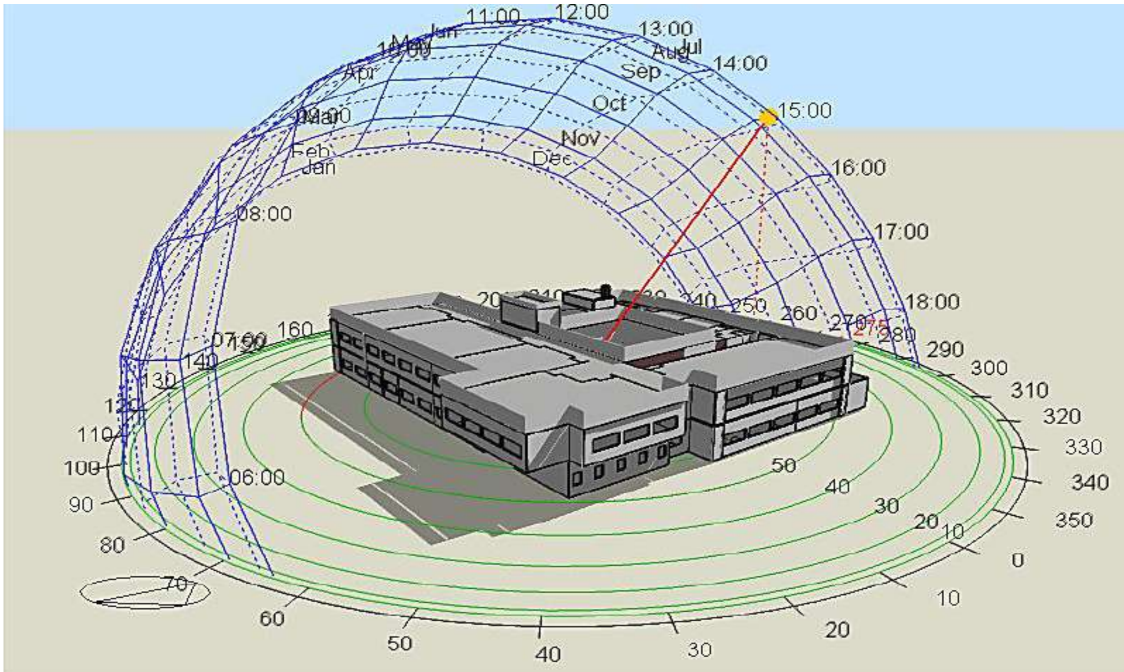
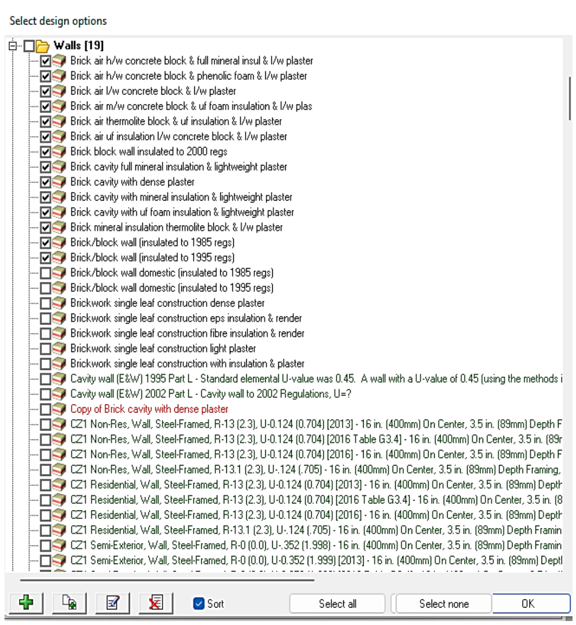


Fig 4.14: Rendered view of three-dimensional model in DesignBuilder

xi. All the model data for constructions, openings, lighting, and HVAC system was modified from the available design options in library data. To change the properties according to local requirements, copies of the selected options were made and then properties such as thickness of layers could be altered as shown in the figures below.



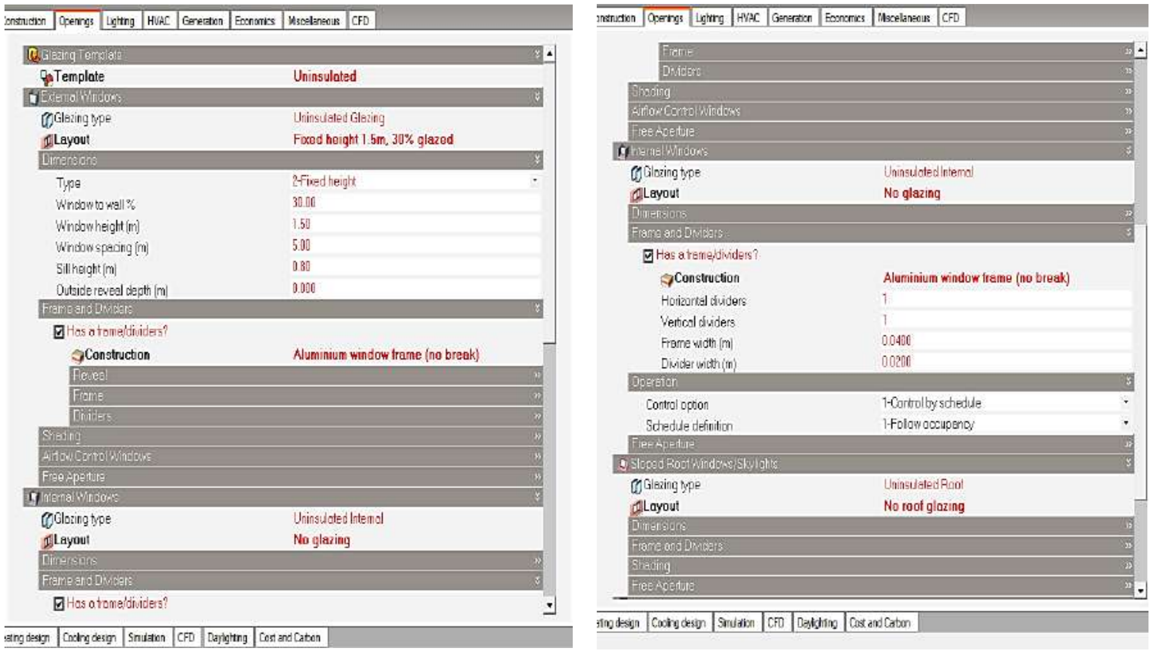


Fig 4.15: Model data input

xii. HVAC template was selected as "Fan Coil Unit, Air-cooled Chiller".

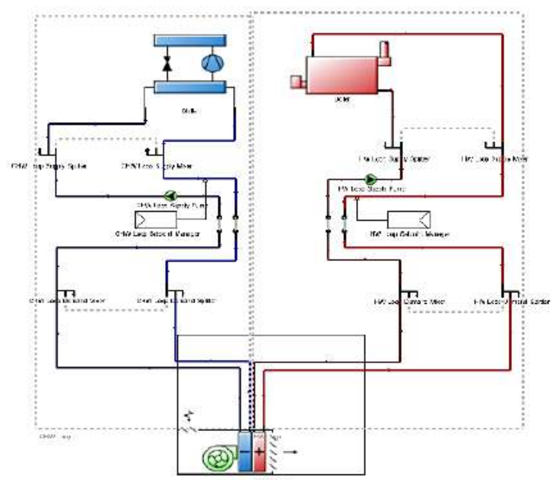


Fig 4.16: Assignment of HVAC system

xiii. In the ‘Simulation’ tab, simulation for the base case is run via integrated Energy Plus simulation engine. A graph showing the annual temperature distribution, heat gains and energy consumption for the building is obtained as shown in Figure 4.17 below.

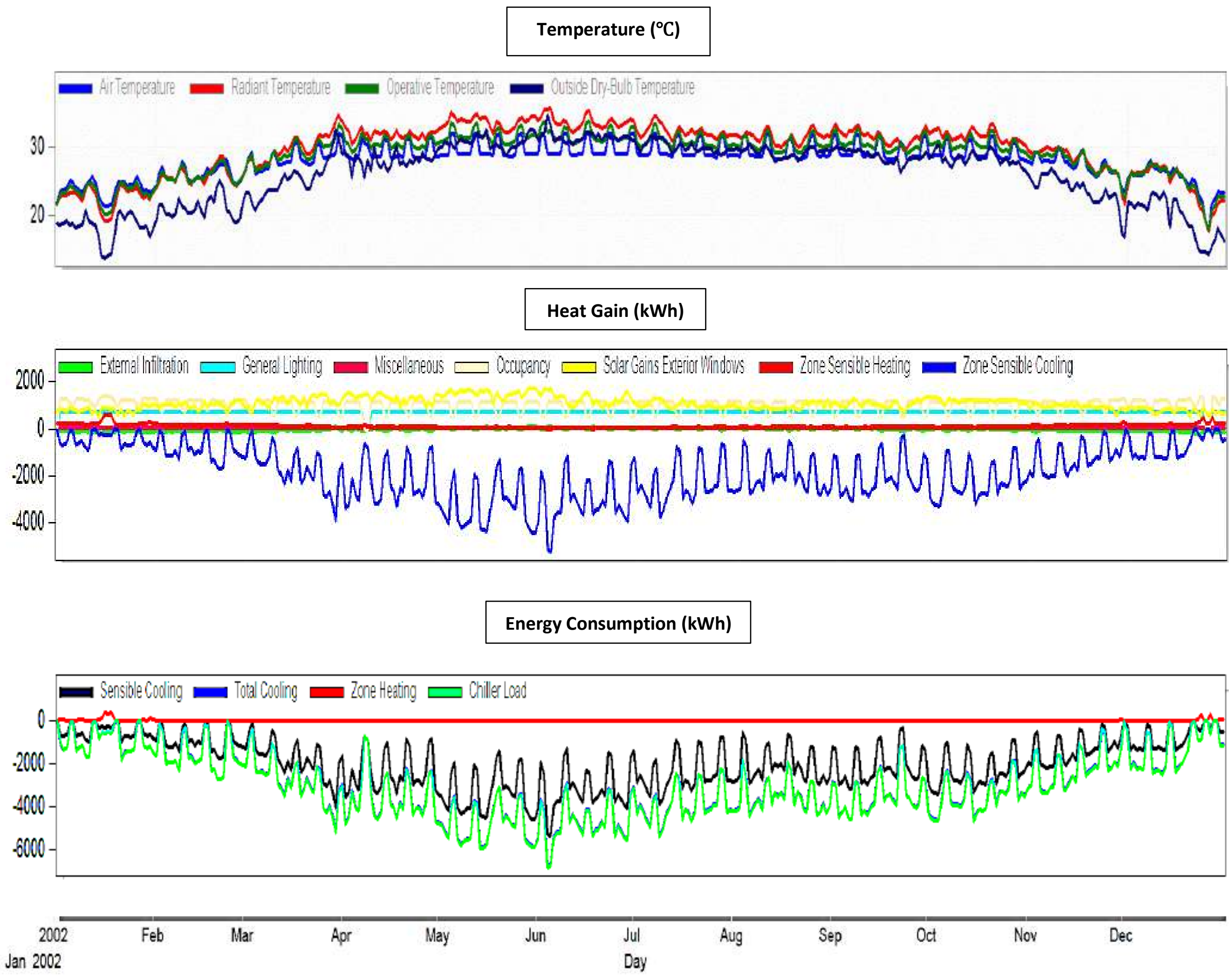


Fig 4.17: Temperature distribution, heat gain and system loads of existing building

a. The first graph above show that solar radiation, air and operative temperatures as high as 40-45°C are observed with periodic fluctuations at 30°C in peak summers from April to September while in peak winter, temperatures as low as 17-20°C are observed. The outside dry bulb temperature is around 27-32°C in peak summer months and drops to as low as 3°C in peak winters in January.

b. The second graph shows the heat gain inside the building, which is the highest through exterior windows and due to occupancy around 1000 kWh throughout the year with periodic fluctuations. It is constant at 600 kWh throughout the year due to lighting and zero for zone sensible heating as no heating system have been installed in the building. For zone sensible cooling, the heat loss of 4900 kWh is observed in the building in the peak summer month of June in which the use of chillers is the highest. It reduces to 2000 kWh in August with many periodic fluctuations in between and rises again to 2500 kWh in October with a slight fall in September. It falls to zero in peak winter month January as there is no need of cooling in winters.

c. The third graph shows the energy consumption of the building throughout the year. It is zero for zone heating as no heating system has been installed in the building. For cooling or chiller load, it is as high as 7000 kWh for the peak summer month of June but in other summer months from April to October, the average energy consumption is 4000 kWh. In peak month of winter in January, it steadily falls to zero with periodic fluctuations as cooling system or chillers do not operate in winters.

xiv. The Reporting tool in DesignBuilder generated the LEED (Leadership in Energy and Environmental Design) report for the building which displays the energy-use for different building systems and for the building as whole as shown in the Table 4.1.

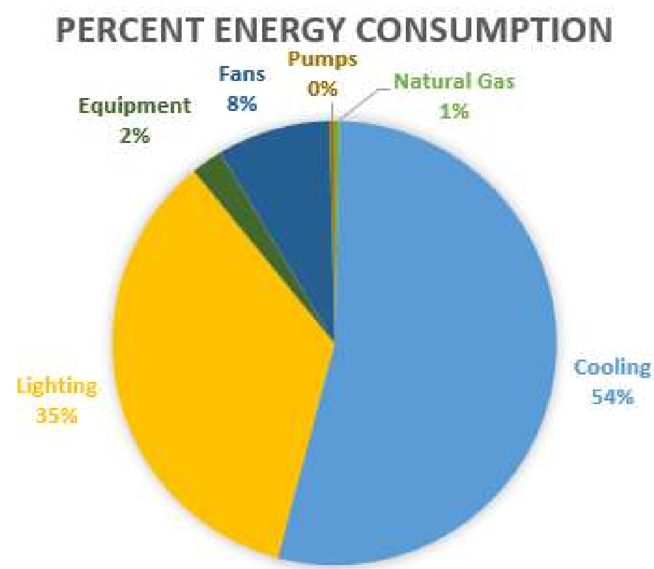


Fig 4.18: Percent energy consumed by individual systems according to LEED Report

EAp2-6. Energy Use Summary

	Process Subtotal [kWh]	Total Energy Use [kWh]
Electricity	17092.72	743942.55
Natural Gas	0.00	2914.58
Additional	0.00	0.00
Total	17092.72	746857.13

EAp2-7. Energy Cost Summary

	Process Subtotal [$]	Total Energy Cost [$]
Electricity	0.00	
Natural Gas	0.00	
Additional	0.00	
Total	0.00	

Process energy cost based on ratio of process to total energy.

L-1. Renewable Energy Source Summary

	Rated Capacity [kW]	Annual Energy Generated [kWh]
Photovoltaic	0.00	0.00
Wind	0.00	0.00

EAp2-17a. Energy Use Intensity - Electricity

	Electricty [kWh/m2]
Interior Lighting (All)	96.29
Space Heating	0.00
Space Cooling	147.96
Fans (All)	22.70
Service Water Heating	0.00
Receptacle Equipment	6.30
Miscellaneous (All)	274.23
Subtotal	274.23

	Electricity Energy Use [kWh]
Heating — General	0.00
Heating — Boiler	0.00
Heating — Boiler Parasitic	0.17
Cooling — General	401389.16
Interior Lighting — General	261223.49
Exterior Lighting — Not Subdivided	0.00
Interior Equipment — General	17092.72
Exterior Equipment — Not Subdivided	0.00
Fans — General	61570.48
Pumps — General	2666.54
Heat Rejection — General	0.00
Humidification — Not Subdivided	0.00
Heat Recovery — Not Subdivided	0.00

EAp2-18. End Use Percentage

	Percent [%]
Interior Lighting (All)	34.98
Space Heating	0.39
Space Cooling	53.74
Fans (All)	8.24
Service Water Heating	0.00
Receptacle Equipment	2.29
Miscellaneous	0.36

Figure 4.19: LEED Report of existing building

4.3 OPTIMIZATION & GENERATION OF DESIGN ALTERNATIVES

i. Optimization settings were edited by selecting optimization type, objectives i.e., minimum energy consumption and minimum cost, and design variables i.e., walls, roof, glazing type, lighting, orientation, natural ventilation, internal glazing and window to wall ratio, cooling setpoint temperature and shading as shown in Fig 4.20 below.

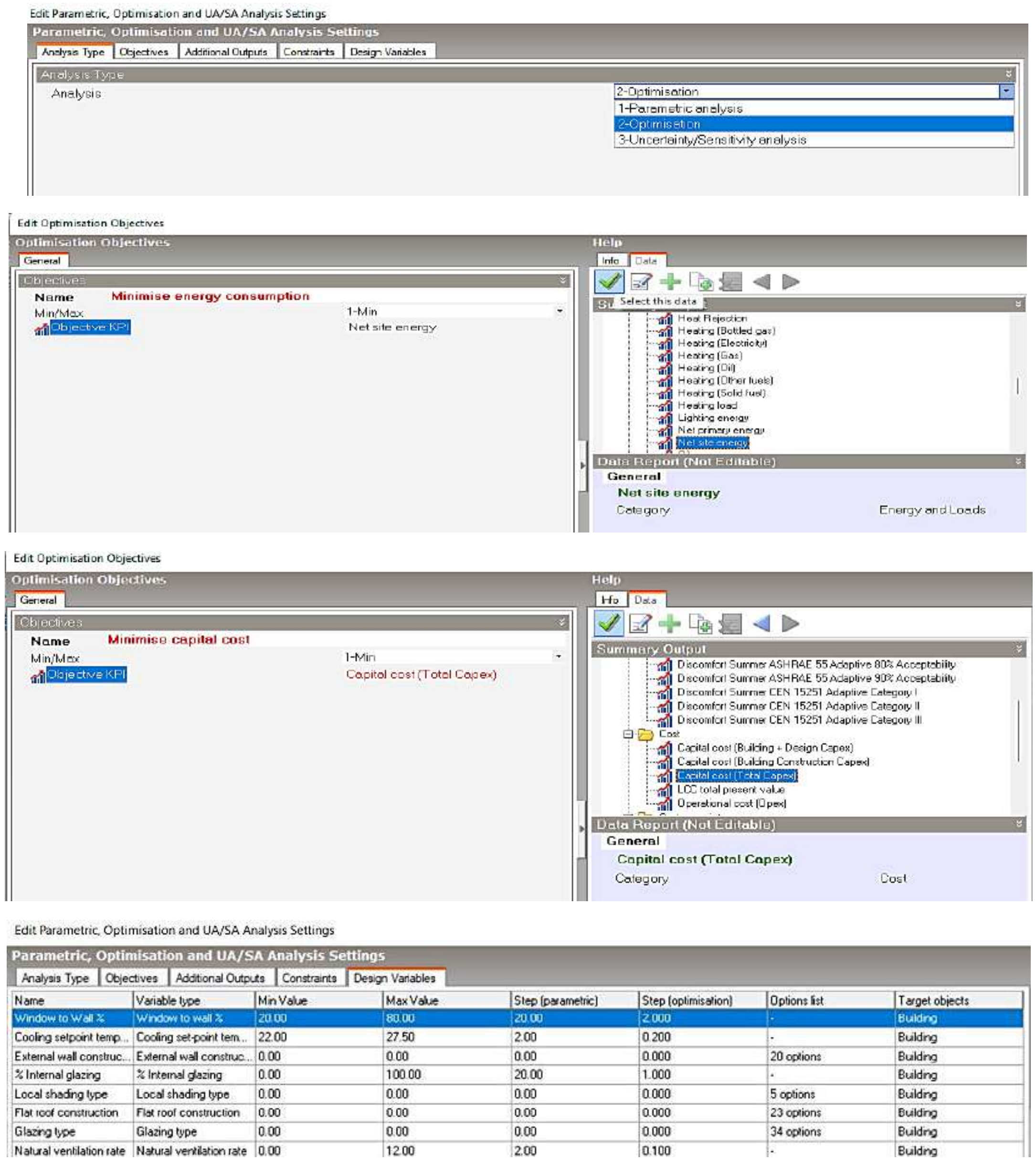


Fig 4.20: Optimization settings

ii. The optimization simulation was started on high performance of computer. After generating 306 iterations of design alternatives, the simulation was stopped. A graph of optimization analysis was obtained as shown in Fig 4.21 below, which clearly displays the "Pareto Front" of optimal design solutions constituting all red dots. All other iterations which are not optimal are registered as previous generations with grey dots.

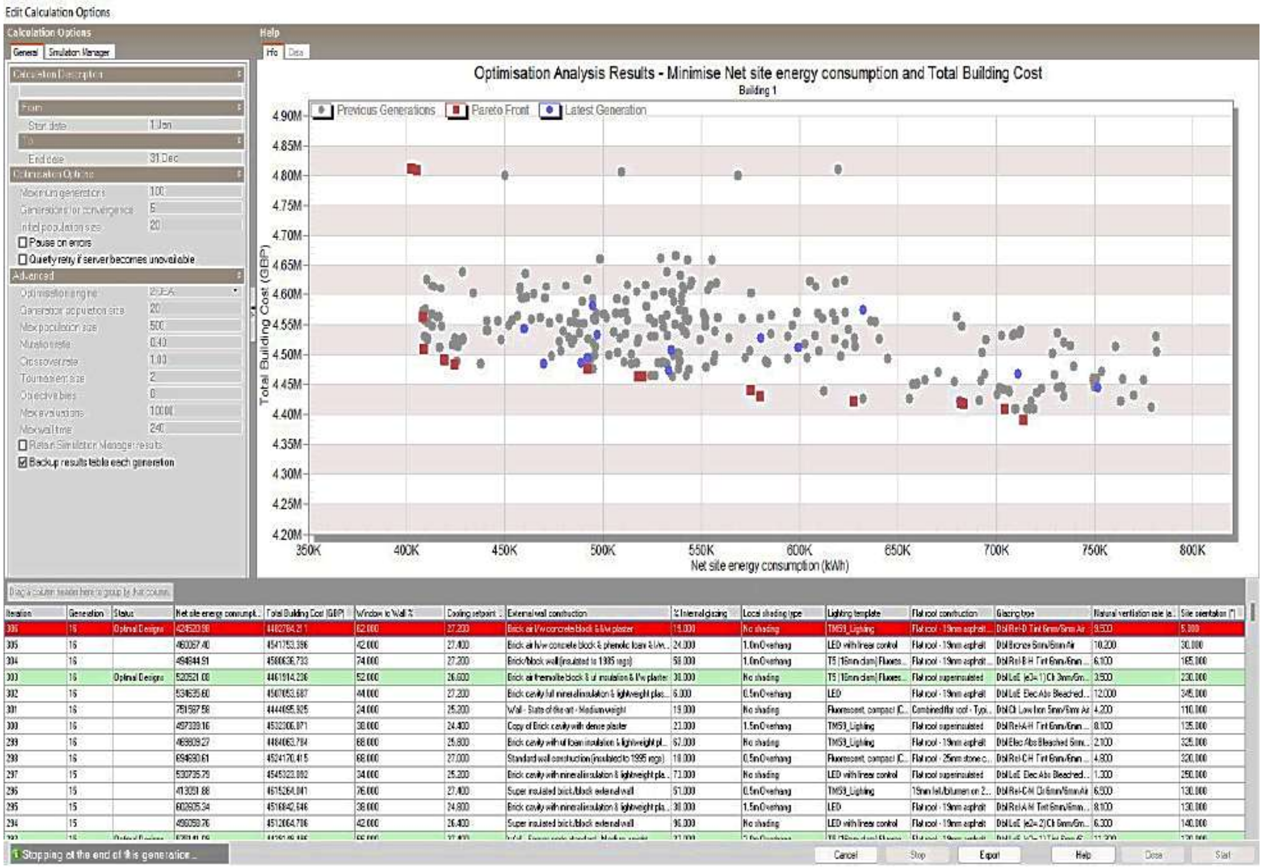


Fig 4.21: Optimization Analysis Results

The table of all potential design alternatives is exported to excel and is shown in Table A-1.

4.4 SELECTION OF THE OPTIMAL DESIGN AS GREEN-RETROFITTED MODEL

i. The set of suggested solutions on the "Pareto front" as shown in Fig 4.22 was further visually and mathematically analysed to determine which designs best satisfy the design priorities defined on the employed objectives.

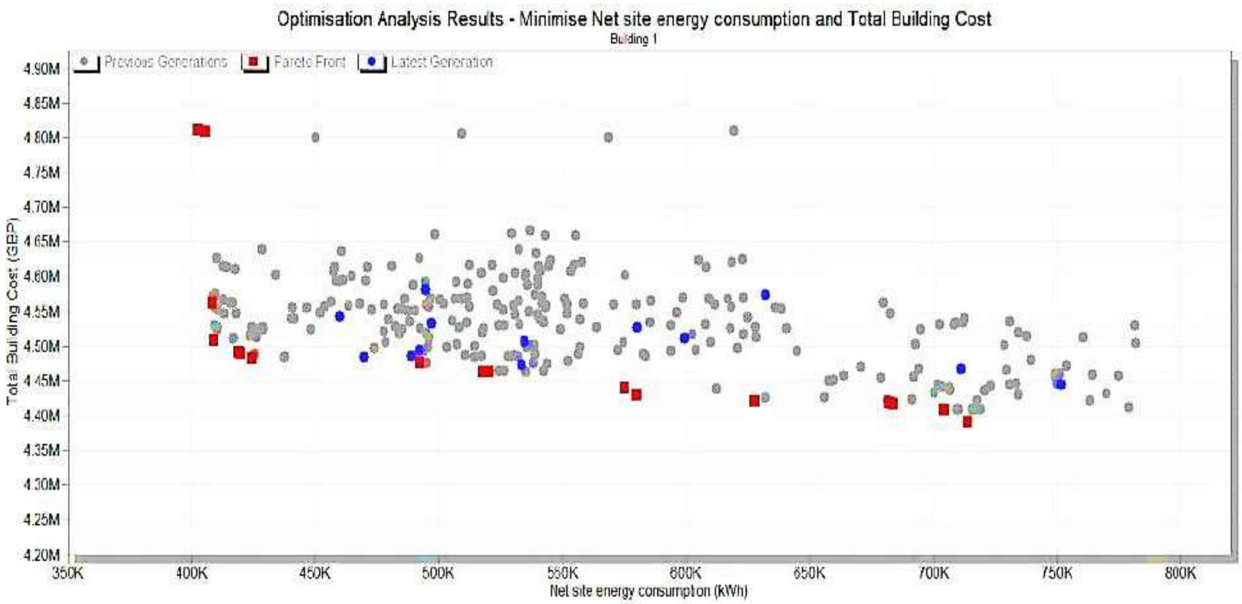


Fig 4.22: Graph showing the "Pareto Front" in red

ii. The table displaying all 17 optimal design solutions obtained is as shown as Table A-2. The graph showing the energy-cost analysis of the optimal designs is shown in Fig 4.23.

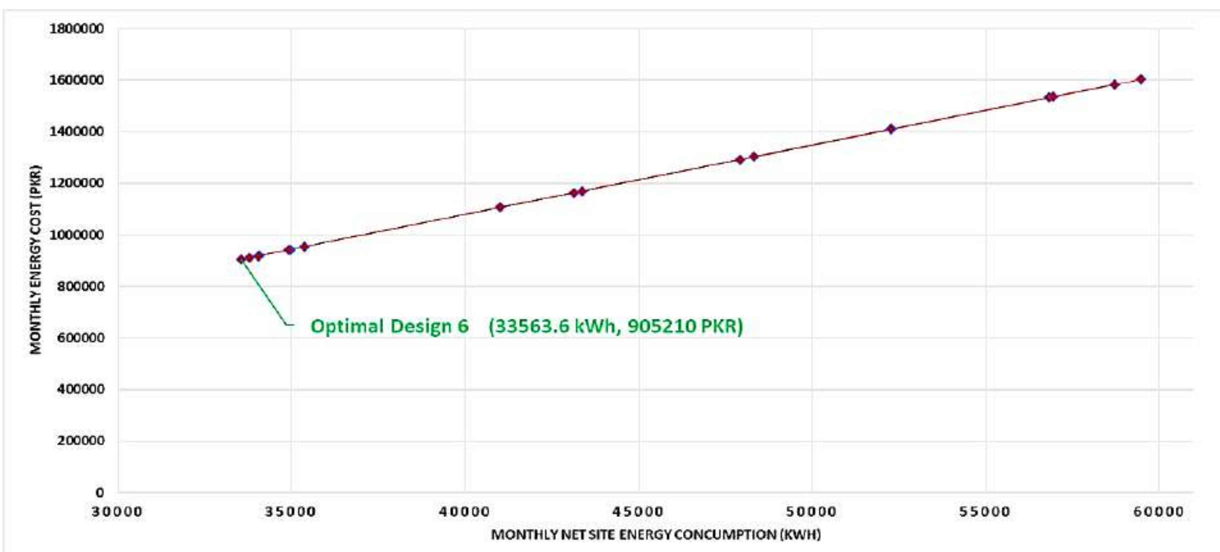


Fig 4.23: Energy vs Cost graph of optimal designs

iii. Fig 4.24 displays the energy consumption achieved with all possible optimal design alternatives obtained. It can be clearly seen that 'optimal design 6' is the most energy-efficient and economical optimal design solution achieved in the optimization analysis.

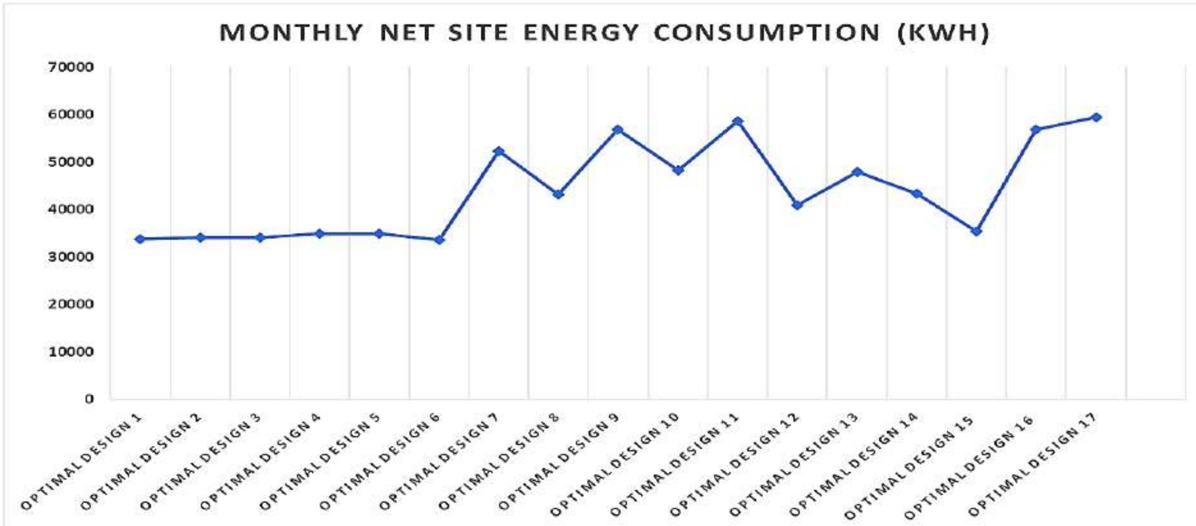


Figure 4.24: Energy Consumption by Optimal Designs

iv. The energy savings achieved by all the optimal designs are displayed in Fig 4.25 below. By adopting the 6th optimal design, 46% of energy saving has been achieved with reference to the energy consumption of the existing building as shown in the LEED Report in Table 4-1.

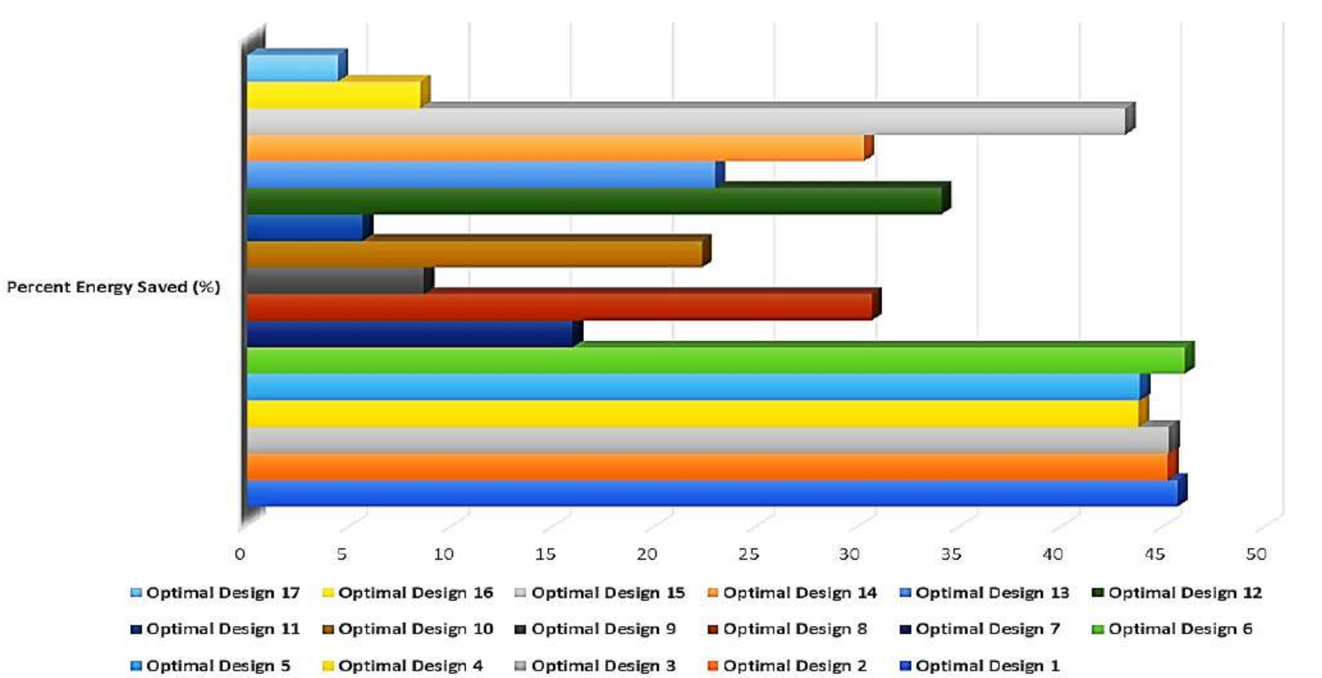


Figure 4.25: Energy Savings by Optimal Designs

4.4.1 PROPOSED 'OPTIMAL DESIGN 6' PARAMETERS

The optimal design achieved in this study is further analysed and compared with the design parameters of the existing building in terms of all the design variables selected in this study and the energy saving obtained by adopting this design. The comparison of retrofitted design with the existing design is as discussed below:

1. **Window to Wall Ratio (%)**

   The existing building's window area relative to the total exterior wall area is 30% while the proposed optimal design suggested a window area of 80% relative to the total exterior wall area as shown in Fig 4.26.

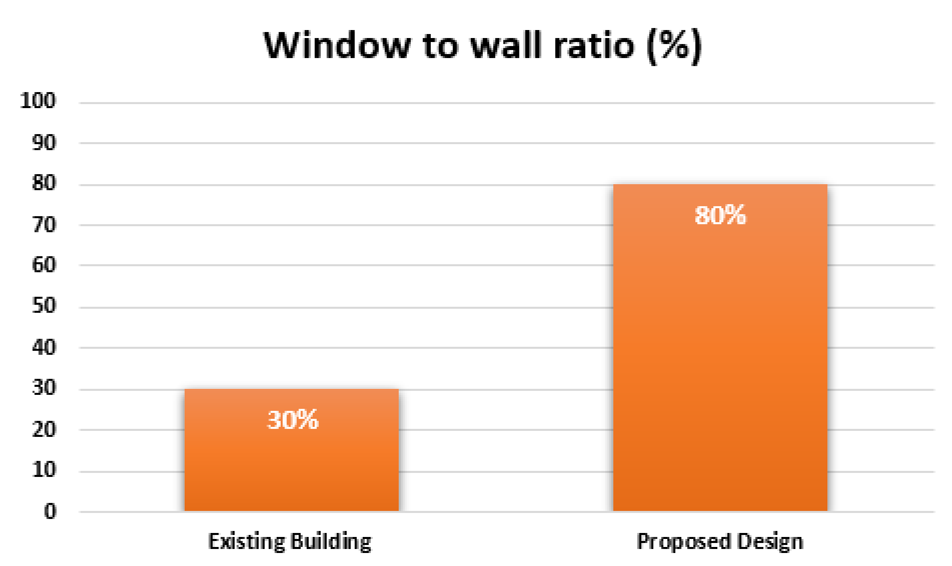


Figure 4.26: Window to wall ratio of existing vs proposed design

2. **Cooling set-point temperature** (℃)

   The cooling set-point temperature is the target temperature which the cooling system of the building attempts to maintain inside the building. The existing cooling system has a cooling setpoint temperature of 26℃ while the proposed design has suggested a cooling set-point temperature of 27.4℃. This reduces the energy consumption due to cooling drastically as shown in Fig 4.22.

3. **External wall construction**

   The existing building has a brick cavity wall with ordinary plaster as shown in Fig 4.27 having a U-value of 1.255 W/m2-K, while the proposed design has suggested a double layer wall with gypsum plastering and without cavity having a U-value of 2.071 W/m2-K as shown in Fig 4.28.

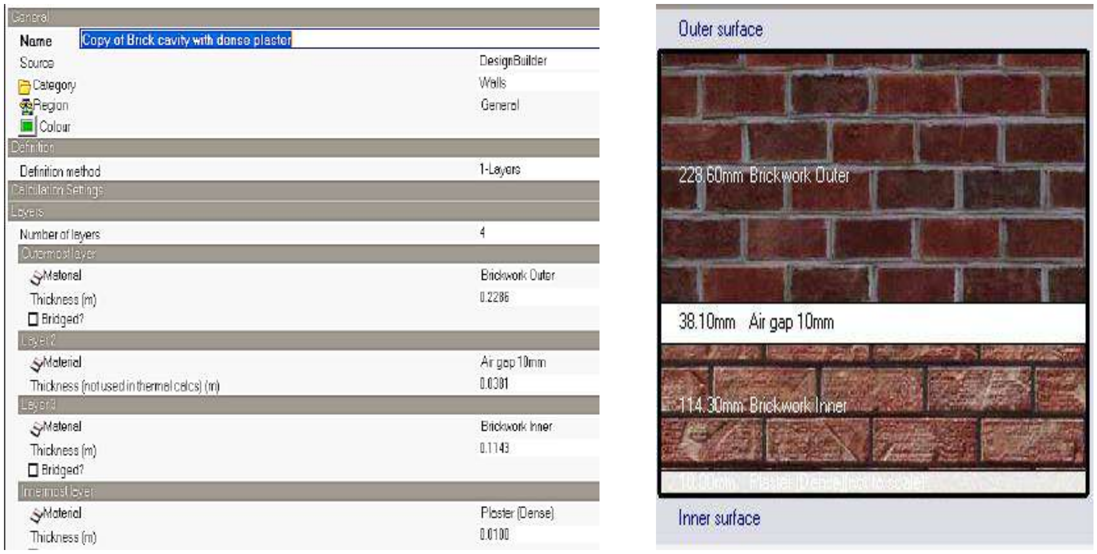


Figure 4.27: External wall construction in existing building

Figure 4.28: External wall construction in proposed building

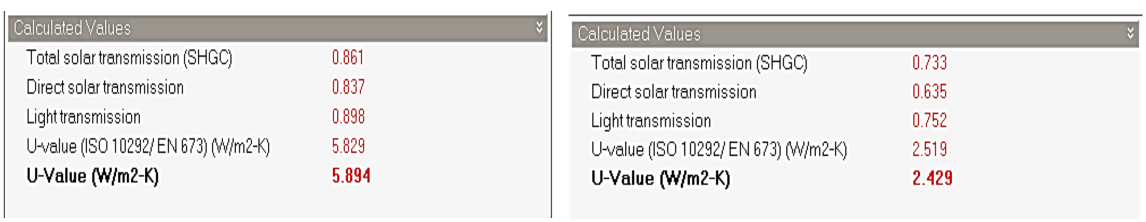
4. Flat roof construction

The flat roof construction remained unchanged for the proposed design with a U-value of 2.805 W/m2-K as shown in Fig 4.29 below.

Figure 4.29: Flat roof construction in existing and proposed building

5. **Glazing type**

The glazing type proposed over the single glazing of U-value 5.894 W/m2-K in the existing building was double glazing low emission Elec Abs Bleached with 6mm of glass and 6mm of air in between two panels with a U-value of 2.429 W/m2-K. The comparison of total solar transmission, light transmission and U-value is shown in Fig 4.30. The significant reduction of solar transmission, light transmission, and U-value in proposed glazing highlights that a high amount of internal heat gain can be prevented which is shown in Fig 4.17.



Calculated Values	
Total solar transmission (SHGC)	0.861
Direct solar transmission	0.837
Light transmission	0.898
U-value (ISO 10292/ EN 673) (W/m2-K)	5.829
U-Value (W/m2-K)	**5.894**

Calculated Values	
Total solar transmission (SHGC)	0.733
Direct solar transmission	0.635
Light transmission	0.752
U-value (ISO 10292/ EN 673) (W/m2-K)	2.519
U-Value (W/m2-K)	**2.429**

Figure 4.30: Comparison between the existing and proposed glazing

6. **Internal Glazing (%)**

Internal glazing provides an interior glazing system to designate space-saving, transparent internal walls in place of brick walls. The existing building has 30% internal glazing whereas the proposed design suggested 94% of internal glazing as shown in Fig 4.31.

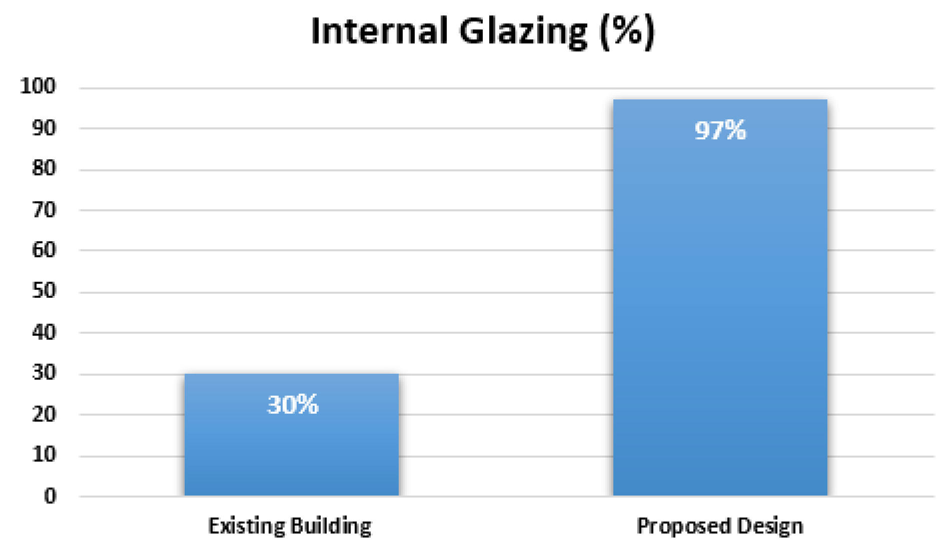


Figure 4.31: Internal glazing of existing vs proposed design

7. **Local shading type**

   The existing building has no shading over exterior windows, while the proposed design recommends 1.0 m of overhang shading above the exterior windows which considerably reduces the internal heat gains in the existing building as shown in Fig 4.17.

8. **Site orientation**

   The existing building has been oriented at North at 0° as shown in Fig 4.14. However, the optimal design suggests an orientation of 140° with the north. This orientation gives optimum natural ventilation and daylight, hence cutting a huge amount of energy costs.

9. **Natural Ventilation Rate**

   The natural ventilation rate is measured in units of air changes per hour. It is almost equal for existing building and proposed design i.e., 5.00 ac/h and 4.90 ac/h respectively.

Chapter-4

CONCLUSION AND FUTURE RECOMMENDATIONS

5.1. INTRODUCTION

This chapter recapitulates all the steps involved in the research process, summarizes the research outcomes, recommends the most appropriate design solution for the existing building, presents an overview concerning the reliability of the research in terms of novelty and contribution to the well-being of community and finally gives recommendation to the future researchers in this field.

5.2. SUMMARY OF RESEARCH FINDINGS

This research was carried out in parts and their findings are summarized below:

1. The first part included the preparation of the 3D model of the existing building in Autodesk Revit with the help of building CAD drawings imported from AutoCAD. After the thermal properties' assignment to the various building materials and placing rooms in the model appropriately, an energy analytical model was created which was exported to gbxml file format.
2. The second part then involved exporting the gbxml file into DesignBuilder software and then adjusting the model for any errors, omissions, or additions in geometry. All the model data is modified according to the real parameters of the existing building and the HVAC system is assigned.
3. The third part of the thesis attempted to simulate and assess the energy performance of the existing building. It was found from the LEED report that total annual energy consumption for the building was 746857.13 kWh from which 401389.16 kWh was consumed in cooling, 261223.49 kWh in lighting, 17092.72 kWh in interior equipments, 61570.48 kWh in fans, 2666.54 kWh in pumps and 2914.58 kWh in natural gas.
4. The fourth part consisted of adjusting optimization settings by defining design variables according to the objectives of this study. The optimization simulation was carried out and almost 306 design alternatives were generated, which were then filtered out with reference to optimal designs only. Hence, 17 optimal designs were obtained which were

then analyzed very deeply to find that the ‘optimal design 6’ was the optimum design achieved in this study which saved up to 46% of building energy consumption.

5.3. CONCLUSION

The construction of conventional buildings in Pakistan have been with many drawbacks, for instance, they have focused more on the structural performance of the structure and the project cost and delivery time rather than the energy performance and efficiency of the buildings. With the advent of Building Information Modeling (BIM) technology, it has become feasible and convenient to design and retrofit sustainable and energy-efficient buildings with optimized comfort and least carbon emissions. This research has attempted to prevent the flaws associated with the adoption of traditional techniques used in design and construction and has come up with a list of ‘green’ solutions i.e., optimal designs with the help of BIM tools which possess advanced algorithms for an effective optimization process. After a detailed analysis, this research has concluded that the existing building is consuming a high amount of annual energy and the proposed optimal design suggests the least annual energy consumption, hence saving 46% of energy in total.

5.4. RECOMMENDATIONS

A green-retrofitted sustainable solution for the existing building which saves up to 46% of total energy consumption and having the following design properties was recommended:

1) Window to wall ratio of 80%
2) Cooling setpoint temperature of 27.4℃
3) Double layer external brick wall with gypsum plastering
4) Internal glazing of 94%
5) Flat roof with 5 succeeding layers:
    i. Tile
    ii. Cast Concrete
    iii. Polyethene
    iv. Earth
    v. RCC Slab
6) Overhang shading of 1.0 m over exterior windows

7) Double glazing low emission bleached outer panel and 6mm air
8) Site orientation of 140° relative to north
9) Natural ventilation rate of 4.90 ac/h

5.5. NOVELTY AND INNOVATION

In previous studies on energy and thermal retrofitting, default parameters of the Building Information Modelling (BIM) tools have been used and established conventions have intervened in the reliability of optimum results. Previously, researchers have considered by-default thermal conductivity values in but in this research, researchers adopted a very premiere strategy in terms of selecting parameters according to societal requirement.

The innovation adopted in this work is that it has proposed realistic, green-retrofit alternatives based on locally manufactured building materials as mentioned in the Building Code of Pakistan. Furthermore, the design variables selection was fulfilled according to the local environment sustainability. Hence, the procedure involved in previous studies have been tried to improve in a way to come up with a realistic retrofit solution for the building.

5.6. CONTRIBUTION OF RESEARCH

Currently, the country is facing an alarming rise in energy crisis and causing a highly adverse impact on the country's environment as well as economy. In this study, the main aim of the researchers was to control the high energy consumption in the existing buildings to save fuel as well as cut costs as far as possible. Making targets for energy and emissions reduction., all while minimizing the expenditure requires innovative strategy which has been effectively adopted in this research. It has contributed to the overall well-being of the community by the provision of more accurate energy usage guidelines during the maintenance and renovation of the building. The local community would come to know which design parameters must be devised or modified while designing new constructions or renovating existing structures respectively.

5.7. FUTURE RECOMMENDATIONS

This study was circumscribed to scrutinizing the energy performance for the existing and proposed green-retrofitted sustainable building. In future studies, a green-building retrofit can be carried out by analysis and optimization of further building design parameters for achieving overall sustainability of building which satisfy all the Sustainable Development Goals (SDGs) as stated below:

- ✓ Daylighting Analysis
- ✓ Thermal Comfort Analysis
- ✓ Carbon Emission Analysis
- ✓ Computational Fluid Dynamics (CFD) Modelling (which calculates the wind impact of a building and its footprint on the environment)
- ✓ Solar Photovoltaic (PV) Analysis
- ✓ Structural Performance Analysis
- ✓ Water Conservation
- ✓ Building Waste Analysis

Furthermore, this study was basically based upon whole building retrofitting. However, in further studies, every design parameter can be optimized separately specific to individual zones in the existing building.

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APPENDIX

Table A-1: List of all design alternatives and their properties

Table A-2: List of optimal designs and their properties