CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Development of Relationship between Cost and Transformation of Conventional Commercial Buildings to Net Zero Energy Buildings

by

Danyal Shuja

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Dedicated to my teachers who enlightened my soul and directed me towards the right path. Dedicated to my parents who always prayed for me and my sisters who have encouraged and supported me in every situation.

CERTIFICATE OF APPROVAL

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Abstract

With the advancement of the technology and expansion of urban population, construction industry is on the point where some serious steps must be taken to sustain the renewable energy resources. NZEB can play a vital role in minimizing the consumption of resources but it also depends on how NZE goals in buildings are achieved. The one big concern in this regard is the existing conventional buildings. This study enlightens the importance and possibility of the transformation of a conventional commercial building to NZEB and explains the causal relationship between the transformation and the additional cost that will be incurred in achieving that NZEB goal. In this research work a case study methodology has been applied on four commercial buildings from Islamabad, Pakistan. The 3d architectural models of these buildings were developed in BIM's platform, REVIT. These models were then subjected to the energy analysis process in the extension of REVIT, Insight360, which is a cloud-based software and provides multiple factors on which a building can be analysed. Two NZEB factors were considered from Insight360 i.e. Pv-Surface Coverage and Roof Construction. These factors were applied to each case study in four phases of energy analysis. The purpose of applying these factors in different phases was to recognize the most efficient parameters of the applied factors. The results of the energy and cost analysis show that 60% roof top surface covered with solar panels is more cost efficient than the 75% and 90% options also the difference in the energy usage reduction between 60% and 75%,90% is quite minimal which makes it even more efficient. The results also confirms that the thicker roof insulation doesn't necessarily gives the efficient results because in this study R38 insulation gave as much efficient results as R60 but R38 was found to be cheaper than R60 in the cost analysis section. Finally the payback periods of these NZEB components were estimated. Further research is required in investigating the performance of HVAC, Lighting Efficiency, Plug Load efficiency, wall insulation and windows glass. These factors were found to have high impact on energy performance of buildings.

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Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEM	Building Energy Modeling
BIM	Building Information Modeling
CAD	Computer-Aided Design
EEM	Energy Efficient Measures
EU	European Union
EUI	Energy Use Intensity
GHG	Greenhouse Gases
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
KWh	killo Watt Hour
LCC	Life cycle Cost
M	Meter
NZEB	Net Zero Energy Building
NZE	Net Zero Energy
PV	Photo Voltaics
R	Resistance
US	United States
WRT	With respect to
YR	Year
ZEB	Zero Energy Building

Chapter 1

Introduction

1.1 Background

With the ever-increasing demand of energy due to the expansion of urban population the world is now at the point where we need to make some serious measures to overcome the energy crises and come up with the solutions that will contribute to make sure the sustainable use of the renewable energy resources. In other words, such technologies should be introduced that contribute to make this earth a better place rather than vitiating it to the point where the survival of life becomes challanging. Technology is progressing perpetually in order to make the living standard better and better which in turn caused a substantial stress on the natural resources. According to Ibrahim et al. [1] and Ametepey & Ansah [2], Construction industry being a gigantic consumer of natural resources , posing serious impacts on the environment, energy, and the lives of the inhabitants. Such transformations are required in this industry that can have transformative effects on the society, the ways scarce materials are used, energy use, operational cost of buildings and overall economic progression. In order to make construction industry more feasible and efficient in terms of economy and its impact on the environment and society, we need to focus on how much energy do buildings utilize, how the efficiency of energy utilization can be improved and more importantly buildings should be made capable of generating enough energy to meet their own needs. The concept of Net Zero Energy Buildings (Net-ZEB) fulfills these criteria of being the self-sufficient and efficient consumer of energy.

According to Torcellini [3], the concept of “Net Zero Energy Building” NZEB is about the efficient use and on-site/off-site production of sufficient amount of energy through renewable sources to fulfill its own requirement. So basically, first of all, the energy requirement of the building is minimized by applying efficiency measures in the building and once the efficiency is achieved the next step is to fulfil the energy requirement of the building by using renewable energy source. It means, for achieving net zero energy in buildings, efficiency gains are indispensable. The renewable energy technologies are of two types i.e. On-site renewable energy and Off-site renewable energy. Technologies like solar collectors, solar water heating and wind turbines are considered as on-site renewable technologies. On-site renewable energy can be obtained by the effective use of biomass. Biofuels when combined with conventional fossil fuel can provide enough thermal energy to meet heating loads. Anyhow it is very important to consider the availability and cost effectiveness of the renewable source. The economic value of the systems should be evaluated according to their productive lifetimes. On the other hand offsite renewable energy sources are those in which the renewable sources such as solar collectors and wind turbines are installed at some dedicated separate space in case there is a limited space around the building facility. The principle of NZEB is widely applicable and feasible in building construction. Due to its energy, cost and environment related benefits it can be adopted in residential, industrial and commercial buildings. Further NZEB is not completely independent in terms of energy production and it initially requires some electrical energy from the grid for the on-site energy production system of the building to operate and then pay back the same amount of energy to the grid which balances the amount of energy taken and supplied back over any defined period of time. Grid connection is also necessary due to the limited energy storage system and to achieve the net zero energy balance. The Initiative of Net Zero Energy Commercial Building has been approved by The Energy Independence and Security Act of 2007 (EISA 2007) [4], USA to support the goal of net zero energy for all new commercial buildings by 2030. It further approves the net zero-energy goal for all U.S. commercial buildings by 2050. Moreover Nejat et al. [5], approved that the benefits of NZEB are not only limited to efficient energy utilization but also countless environmental and social advantages .

1.2 Research Motivation

Construction industry has numerous adverse effects on environment. Researches from past have authenticated the adverse impacts of construction industry on forests and trees, coral reefs, air quality, water, ozone, and the amount of land for agriculture. According to US Energy Information Administration (EIA 2005) [6], between 1980 and 2000 the commercial building sector have doubled its electrical energy consumption and it's probable that by 2025 it will escalate by an amount of half of the existing energy consumption. According to US Energy Information Administration (EIA 2010) [6], it's foreseeable that from the year 2007 to 2035 the energy utilized by commercial buildings in both developed and developing countries will expand up to 0.9 and 2.7%, respectively. Thus making the energy efficiency in commercial buildings inevitable. According to Global Status Report 2017 [7], by World Green Building Council, buildings are responsible for 36% of global final energy use which inturn contributes almost 39% to our carbon footprint and which is quite terrifying considering the global warming and other climatic and geological changes occurring in the world today. If the existing buildings are retrofitted to be net zero energy buildings (NZEB) and same practices are implemented for the future constructions, society's overall carbon footprint figures can be reduced substantially. Considering the environmental impacts of the conventional building type and its inefficient way of utilizing the renewable energy resources, the significance of the NZEB has become more of an obligation than just a possibility. Thus achieving net zero goals in building industry is not just a matter of efficiency but to provide a clean and livable environment for the inhabitants most affected by it and also for the future generations.

According to Pikas et al. 2017 [8], NZEBs have the potential to bring huge cost saving benefits to the owner and there has been a lot of research being carried out to determine the benefits of Net-ZEB in terms of cost saving. In Pakistan, the urban population is rapidly increasing which is causing immense pressure on the urban land and resources. The prices of houses are increasing day by day and to overcome the issue of large scale accommodation of people migrating from rural areas to urban areas, building contractors are now more inclined towards residential buildings because they provide affordable living space to masses. On the other hand, with the expansion of cities, new housing societies are now getting more popular among the business community as it's one of the worth-while area for investment nowadays which results in the abundance of commercial and residential buildings. Keeping in mind the inefficiency of the conventional buildings the burden on our energy generation is getting severe with every passing day as we have limited renewable energy production plants. NZEB can address most of the issues regarding energy crises and how can we utilize the available energy in more efficient way that will help to gain more cost related benefits.

1.3 Problem Statement

Daut et al. 2017 [9], confirmed that conventional buildings are inefficient and they are the main consumers of electrical energy due to their poor energy efficiency measures . This is one of the issue we face in achieving net zero goals because the number of both residential and commercial buildings has been significantly increased in past few years and it's constantly increasing. For achieving net zero energy goals the transformation of the conventional building to NZEB is inevitable. This transformation can be achieved in several ways as we know there are several parameters for NZEB. In order to transform the already existing conventional building to NZEB we have to consider those parameters that will emphasize on the greater efficiency with ample productivity. One big factor in such transformation is the extra cost for materials and putting them to function as required i.e. solar panels installation, enhancing the building envelope, improving the daylight and upgrading HVAC system for energy efficiency and it's also an essential aspect as cost is one of the most concerned area in such projects.

For that reason, there should be some technique that will allow us to estimate the total cost of transforming a conventional building to Net Zero Energy Building (Net-ZEB). Also it will help promoting the concept of net zero energy on large scale due to its long term benefits.

1.4 Research Objectives

As we know that Pakistan being a developing country is an energy deficient country. With the increase in energy demand every year, the electricity shortfall is increasing accordingly. The recent recorded shortfall is 9000mw which will cause the prolonged energy outage in many areas of the country. Load shedding is one of those issues that affects the masses in various ways especially during summer when the energy demand is higher as the climate gets very hot reaching up to 53 °C (127.4 °F) in some areas and the average temperature during the month of June is 38 °C (100 °F). In such conditions the net zero energy concept will contribute a lot to overcome the energy scarcity of the country. To achieve the net zero energy goals in buildings the methods of energy production and efficiency should be transformed in such a way that the buildings should be self-sufficient in energy area and also efficient enough to fulfill their energy requirement.
The objectives of this study are

- Investigating the aspects that can help achieving NZE energy goals in conventional buildings.

- Asses the relationship between the cost and transformation process of conventional buildings to Net Zero Energy Buildings.

1.5 Scope of Work

In this research work, the data which included drawing and floor plans of commercial buildings with maximum 5 floors including ground floor. The models of the buildings were analyzed only for summer season. The energy analysis of the models was carried out to assess the operational energy of the buildings in the form of EUI value using Insight360 that contributed toward estimating the number of solar panels for the on-site energy production. Insight360 produced results on the basis of different factors which can also be altered according to our needs from the slider given with each factor tile. Two factors i.e. Roof Construction and PV- Surface Coverage were considered for proposed NZEB model by altering their values. After a market survey, the solar panels chosen for this study are from LONGI, an international company having wattage output of 445w, dimensions of 2.13x1.22m, efficiency of 20% and are made from mono-crystalline silicon. The solar system considered is grid-connected/On-Grid system. In estimating the payback periods of the components that are meant to perform in a way such that NZE goals in the building models are achieved, the cost of saved energy was calculated.

The considered NZEB parameters for the energy analysis and Cost analysis are:

- Roof Construction
- Pv-Surface Coverage
- Panel Efficiency

Roof Construction is the only considered parameter related to the energy efficiency while *Pv- Surface Coverge* and *Panel Efficiency* are related to the on-site energy generation. In cost analysis, only the cost for civil works was taken from the BOQs of the respective buildings also the cost for the best possible option which provided greater energy efficiency was calculated.

1.6 Limitations of Study

- The study is only carried out for four and five storey buildings.
- The energy consumption of the building was calculated in the form of EUI value in energy simulations.
- The buildings are selected from Islamabad region only.
- The solar system being considered in this study is On-Grid system.
- The energy analysis was done for hot weather season only.
- The study is only carried out for commercial buildings.
- HVAC systems have not been considered due to non availibilty.
- The effect of only the considered factors was analysed, rest of the factors were not included.

The case studies of the commercial multi-storey buildings are not still reported and the need of analyzing the energy performance of the buildings in the context of Pakistan is still a grey area of research.

1.7 Brief Methodology

The different stages of this research work are elaborated in figure 1.1, starting from the literature review and defining the problem statement along with the research gap. The buildings were selected from different locations in Islamabad, Pakistan. Case studies were developed after that energy and cost analysis was carried out. On the basis of results from energy and cost analysis conclusions and recommendations are given

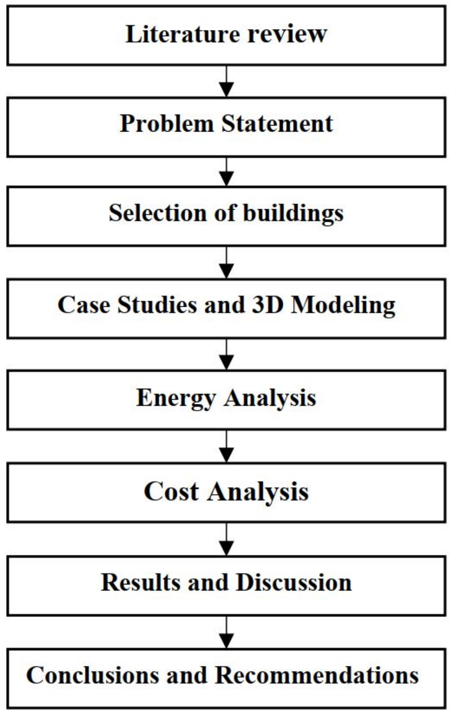


FIGURE 1.1: Methodology flowchart.

1.8 Thesis Layout

The thesis is comprised of five chapters and these are:

Chapter 1: This chapter gives the introduction of the thesis with the background of buildings energy consumptions, energy analysis and NZEBs.

Chapter 2: This chapter provides a critical literature review about the previous studies related to conventional buildings and their energy performance, BIM and energy analysis, NZEB development and NZE in existing buildings.

Chapter 3: It details the methodology, tools and methods being adopted in this study.

Chapter 4: It provides the fine points of the results and subsequent discussions.

Chapter 5: It provides conclusions and recommendations on the basis of the findings.

Chapter 2

Critical Literature Review

The current chapter provides an overview of the global energy consumption trends. It briefs the environmental concerns of these energy consumption trends and role of buildings in this regard. Then the concept of Net Zero Energy Buildings (NZEB) has been explored and how this concept manages the environmental inputs of the energy consumption patterns. The various innovations in development of Net Zero Energy Building has been elaborated. The last part of this chapter reviews the records of work that have been previously conducted on Net Zero Energy building and explore the research gap.

2.1 World-Wide Energy Consumption Trends

According to a report by Global Energy Review [10] the carbon emissions related to energy consumption remained stable at 33.2 Gigatons (GT) during the year 2019, following the increases in last two years. This stability in the carbon emissions is mainly because of the shift of developed economies towards the renewable energy sources such as wind and solar. In the developing economies the CO_2 emissions rose by 1.7% in 2019 which makes these economies account for two third of global CO_2 emissions. According to the report the emissions raise in 2019 is 2.2% which is relatively slower than the growth of 2.6% in 2018 since 2010. The report also states that the global electricity demand in 2019 raised by 1.4% which is a significant drop from 3.9% of increase every year in the previous years. This slow raise in the electricity demand can be linked with the growth of renewable energy sources which cut down the fossil fuel generation for the first time in four decades during the economic expansion. The use of renewable energy has amplified by 3.7% in the year 2019 which is slightly higher than 2018. The use of renewables for the electricity generation has accounted for most of the part of overall growth.

2.2 Environmental Concerns of the Energy Utilization

According to World Energy Outlook [11] buildings are the largest consumers of energy and already informed about the increase in urban population which indicates the continuous increase in energy use of urban buildings. According to World Bank, ("Carbon Emission Data," 2020) data, worlds CO2 emissions has been continuously increased from 24,935.6 kt in the year 2000 to 34,998.9 kt in the year 2016. Also the CO2 emissions of Pakistan has increased from 0.74 million tons per capita in the year 2000 to 0.988 million tons per capita in the year 2016.

2.3 Buildings as Consumer of Energy Resources

Lombard et al. [12], reviewed the energy consumption information of buildings and concluded that energy consumption by both commercial and residential buildings in developed countries is 20-40% of the total energy use and almost half of the energy is consumed by the HVAC system which makes 10-20% of the total energy. The study also reviewed the buildings energy consumption and concluded that commercial buildings offer great potential in reducing the energy consumption as the 7% of the world's energy is being consumed by commercial buildings. Khadilkar et al. [13], proposed a backup solution for an office building and concluded that load shedding is one of the key issues in developing countries due to which the reduction in energy consumption of commercial buildings is needed, as Saurav et al. [14], confirmed by proposing a framework to lower the energy costs of commercial buildings, that in developing countries, commercial buildings consume higher energy due to use of diesel generators during power disconnection. Santamouris. [15] presented the framework for present and future energy consumptions required for cooling and concluded that the cooling demand for the commercial buildings will increase by 275% by 2050. The study also confirmed that commercial buildings covered around 20 billion square meters in 2010 which is likely to increase up to 80 billion square meters by 2050. Cao et al.[16], studied the state-of-the-art technologies for ZEB and reported that the buildings in U.S. and E.U. consume 40% of the total energy and 27.3% in China.

2.4 Attributes of Net Zero Energy Building

Torcellini et al. [3], defined Net Zero Energy Building as a building with lower energy demand through greater energy efficiency measures that balances its energy requirement with the energy generated from renewable source. Pless & Torcellini. [17], gave different interpretations for NZEB based on the goals set by the owner, designer and the political goals of the certain region. The 4 different interpretations of NZEB definitions are, Net-zero site energy, Net-zero source energy, Net-zero energy cost, Net-zero emissions. All these definitions are achievable and present their respective merits and demerits. The study also classified NZEB in levels on the basis of renewable energy supply options where the most preferred ones are those that meet their energy requirement from the renewable sources within the building footprint. On the other the least preferred NZEBs use excess amount of the energy than being produced at the site and purchases energy credits from an off-site source. The study approves that no matter how complex is it to define NZEB and despite of having these classifications and interpretations the design rule of ‘energy efficiency before energy supply' will remain constant. However Crawley et al. [18], studied different aspects of getting Net Zero Energy in buildings. The study focusses on the realization of NZEB vision. It approves that out of various definitions of NZEB it's possible for a building to fulfill one or more definitions but may not behave like NZEB every year. A NZEB may partially fulfill the Net-ZEB parameters becoming a near NZEB due to unfavorable weather conditions. Mlecnik et al. [19], reviewed different definitions of NZEB for developing a definition for NZEB in Belgium and confirmed that the very first definition of NZEB was set by Belgium in 2009. The definitions are revised for the shortcomings every year. Marszal et al. [20], reviewed the definitions and calculation methodologies for ZEB (Zero Energy Buildings) and acknowledged that for a unified ZEB understanding it's important to ascertain the type of energy used along with the renewable energy supply in the energy balance. According to Sartori et al. [21], Zero Energy Building (ZEB) is a general term and commonly understood as a building that is energy efficient and meets its energy requirements by generating electrical energy or other energy carriers from renewable energy sources. This concept doesn't give the idea about the connection of the building facility to the energy infrastructure. For that reason the term NET ZEB is introduced that indicates the connection of the building facility with the grid. The term 'net' also points out to the balance between the borrowed energy and the energy to be supplied back to the grid. Zhao et al. [22], Pless & Torcellini. [17] approved and favored the time span in which the building achieves its Net zero energy criterion to be annual based. Sartori et al. [21], presented a consistent definition framework for NZEB by assessing the standards in the definition structure and selection of the related options to set NZEB definitions in methodical way and concluded that an internationally accepted definition of NZEB is still lacking and it is also possible to have different definitions of NZEB according to the purpose and the political objectives of the certain region. It's also suggested to incorporate operational energy uses in balance boundary for a verifiable definition of NZEB. Panagiotidou and Fuller [23], reviewed the common aspects in the definitions of ZEB and studied the related activities and policies and explained the difference between the autonomous ZEB, NZEB and Near-ZEB. The study indicated that ZEB is more of a general concept which doesn't include the energy balance with the local grid whereas the NZEB and Near- ZEB balance the energy taken with the energy supplied back to the grid over a period of a year. Apart from the other important parameters for the implementation of the NZEB the study enforced the consideration of user's attitude and cost criteria in the ZEBs definitions. Ascione et al. [24], analyzed a NZEB in Berlin, Germany, for one year, monitoring the performance of the building and concludes that the NZEB may not perform exactly as expected as the occupant behavior has been one of the main factors in NZEB performance.

2.5 NZEB Solutions

2.5.1 Solar Energy Systems

Torcellini et al. [3]; Voss and Musall [25]; Kapsalaki et al. [26], emphasized the correct use of energy generating method as they contribute to reach the Net Zero Energy goal. These studies favored Photovoltaics as one of the on-site renewable energy source whereas offsite renewable energy sources may include Biomass, wood pellets, wind turbines and also Photovoltaics. Scognamiglio and Rostvik [27], studied the challenges involved in the use of PV in ZEBs and conveyed that in order to catch people's attention, the design of PV "at-site" should be aesthetically pleasing and convenient in mounting. Yang and Lam [28], reviewed strategies for ZEB i.e. EEMs (Energy Efficient measures) and RETs (Renewable Energy and other technologies) and concluded that wide dissemination of PV may result in trade-off in quality of the existing power infrastructure and power instability. Also the design of the ZEB should be such that it doesn't put extra load on the existing power infrastructure. Gallo et al.[29], analyzed the NZEB in Spain by integrating photovoltaic and conferred that it can cover almost the whole energy demand of zero energy building and is more efficient in the areas with higher solar radiation availability. It's also been conferred that the integration of PV in NZEB is feasible today due to the significant reduction in the prices of PV panels. Pyloudi et al. [30], applied the energy efficient measures in combination with the renewable resources in their simulation-based study on a building of a university campus. They concluded that the best productive period for the PV panels is from March to September for that particular location. Tsalikis and Martinopoulos [31], studied the potential of solar energy systems and concluded that it has the ability to fulfill up to 76% of total energy demand and in certain cases 97% in residential NZEB. Good and Hestnes [32], carried out a comparative study on different solar energy solutions for a residential building in Norway and analyzed that only the high efficiency photo voltaic modules could made it possible to get closest to net zero energy balance in buildings. Albadry et al. [33], analyzed the existing buildings in Egypt to achieve net zero energy through retrofitting and found that its affordable to use photo voltaic panels and materials available in market for retrofitting. Alajmi et al. [34], worked out the performance of a house in US being transformed to a Net Zero Energy House and found that 4053kwh/year of electrical energy is produced by the photovoltaic panels covering area of $26m^2$. Wang et al. [35], conducted a simulation based study on a case building and achieved Zero-Energy by utilizing parking lots and 15% of rooftop area for PV panels installation with a payback period of 4.3 years. Asdrubali et al. [36] studied the retrofit strategies for Nearly-ZEB for their energy payback periods and approved that the payback periods for lightening and generation systems should be considered for short term prospect as having lower return periods while renewable energy generation systems such as solar systems having more potential to bring down the energy consumption and should be considered for long term prospect.

Spiegel et al. [37], demonstrated the demand side management potential of the grid-connected solar systems installed at different location across US and determined that the benefits of grid-connected system may exceed its cost of installation in certain applications. Abdullah et al. [38], assessed the practicality of grid/connected system for the Kuwaiti climate and noticed the cost saving of

\$1625 during the course of study. The study concludes that grid-connected system is more suitable for the Kuwaiti climate. Kirmani et al. [39], studied the effectiveness of grid connected solar system to power small commercial building and found that this system of solar electricity generation is best suited for small scale commercial buildings. Allouhi et al. [40] carried out the energy and environmental analysis of the On-grid PV system and found that installed 2kw system was able to cut down the CO2 emissions by 5.01 tons annually. Taherahmadi et al. [41], said that limited roof and facade space is one of the barriers in NZEB renewable energy generation system.

2.5.2 Roof Insulation

Florides et al. [42], carried out a research on the different measures to lessen the buildings energy consumption and conferred that among all the elements of the building envelope, roof plays the most important role in cutting down the energy consumption. According to S.P.F. Alliace. [43] ; Sartori and Hestnes [44] insulation reduces the energy requirement of the building by increasing the R-value i.e. resistance to the heat flow. Hence saving the primary energy use of the building and providing environmental benefits as CO_2 emissions are reduced. Tariku et al. [45], studied the effect of insulation thickness in the attic and found that the thicker insulation provides more cooling benefits during summer. Halwature and Jayasinghe [46], studied the thermal performance of roof insulations and concluded that concrete slabs have inferior thermal performance but a proper insulation system in roofs can provide significant improvement in tropical climate conditions. Ong. [47], studied the thermal performance of insulation in different roof designs and found out that insulation applied directly underneath the tile roof is more preferable that above the ceiling. Brito and Santos [48], studied the thermal performance of the roofs in subtropical climates with thermal insulation installed and conferred that the thermal insulation layer in the roof is the best energy saving option. Piselli et al. [49], presented the role of thermal insulation and conferred that buildings energy performance is greatly affected by varying insulation implemented to a standard roof without any external coating. Horvath. [50], studied the material properties of the Expanded Polystyrene (EPS) and found that EPS is has the ability to be used for thermal insulation due to its closed cell structure. Dombayci et al. [51], carried out a optimization based study on this thickness of insulation for walls and found EPS to be the most optimal insulation material. Kruger et al. [52], studied the thermal performance of the insulation sheets and recommended the use of EPS for thermal insulation due to its reduced thermal conductivity.

2.6 Net Zero Energy Buildings Developments

Zhao et al. [53], studied Net Zero Energy buildings for their operational energy in China. The study the lack of boundary conditions that results in the difference between actual consumption and the simulated results. Also the role of experts in managing the operations of NZEB is emphasized. Wells et al. [54], explored the existing NZEB models in Australian context and emphasized on the government policies to encourage Net Zero Energy targets. The study enlightens the lack of research for auditing the embodied energy of the materials and devices required for the on-site energy generation. The study also suggests to discuss the economic feasibility of NZEB as there is a little research on this factor. Harkouss et al. Wells et al. [54], reviewed various NZEBs located in different regions of the world and came to the conclusion that for the success of the NZEBs in any country is associated with their public acceptance and the response of their government towards this concept. The study also supports the lack of collective definition of NZEB. Mavrigiannaki et al. [54], concluded that policies and legislations should be developed for implementing NZE approach to buildings and also there must be flexibility in these policies to introduce new technologies. Lin et al. [55], presented a review on the research work done in the development of ZEBs and concluded that investment in the essential aspects of zero energy buildings should be increased to provide technical and theoretical support. Also the public awareness about energy conservation and new technologies should be increased to boost the impacts of

ZEBs. Market competition should be increased by developing the incentive policies and by providing subsidies.

2.7 Net Zero Energy and Existing Buildings

Marszal and Heiselberg [56], carried out an analysis by adopting LCC methodology for a multi-storey residential building in Denmark and deduced that it's crucial to minimize the energy use of the building before applying any renewable technology as the energy efficiency is more advantageous than investing on renewable technologies. Ma et al. [57], presented the methodology and the state of the art to determine the most appropriate and effective retrofits for the existing buildings and concluded that the rate at which the existing buildings are being retrofitted is low i.e. 2.2% per year only. Also with proper retrofits the energy and environmental performance of the buildings can be considerably improved. This study also suggests that risk assessment is also required since the investment in building retrofits has a high degree of uncertainty. Silva et al. [58], presented a prefabricated module solution for retrofitting of existing building and analyzed that 83% of reduction in total energy needs has been achieved in single-family retrofitted building and 76% of reduction in multi-family retrofitted building by implementing integrated retrofit strategy. Aksamija. [59], studied the retrofitting feasibility of the existing commercial building and presented that by applying passive design strategies such as day-lighting, improvement in building envelope and by the effective use of renewable energy sources the goal of Net Zero Energy in commercial building is achievable. Becchio et al. [60], studied the concept of Post-Carbon city and the role of NZEB in this transition and concluded that the transformation of an existing buildings to NZEB is a greater challenge than fabricating new NZEB. Kumar. [61], applied different strategies to a conventional building to convert it into a NZEB and analyzed 10% reduction in the energy consumption if low energy efficient electrical appliances are replaced with day lighting and high energy efficient appliances. Ferreira et al. [62], studied the cost effective solutions for net zero energy by analyzing a building in Portugal and concluded that nearly zero energy building with lowest cost is achievable if renewables with cost optimal levels are introduced. Alajmi et al. [63], examined three different scenarios for achieving net zero energy of existing building and reported that the payback period for EEMs (Energy Efficient Measures) ranges from 0.5 years to 3 years and for solar systems it ranges from 14.1 to 16.1 years making EEMs more cost efficient than solar systems. The study also presented EEMs to be more energy efficient than solar systems saving around 27% of the buildings consumption. Abugrain and Ali Baba [64], investigated an existing building for its potential of energy efficiency in order to achieve net zero energy. The study presented that with passive design strategies up to 30% of energy could be saved annually. Also that 11% of energy saving was achieved just by optimizing the lighting. Ballarini et al. [65], assessed the globally accepted refurbishment scenarios for transforming buildings to NZEB and said that remarkable results could be obtained from retrofit measures by optimizing the retrofitting procedures for adequate daylight delivery which also improves the visual comfort. Irfan et al. [66], concluded that the beliefs of the consumers about the economic aspect of renewable energy, negatively effects their intention to utilize them.

2.8 Energy Simulation and BIM

Ma et al. [57], reviewed the computational optimization methods for different fields of building design and presented that companies are realizing the importance of computational optimization due to effectiveness of such methods. The study also confirms that Building Information Management (BIM) will help integrating every aspect of the building design. Attia et al. [67], studied the need of simulation based performance optimization of buildings and approved this strategy to be effective to improve the energy performance of the building during design phase. Volk et al. [68], reviewed over 180 research papers from past and concluded that the usage of BIM in existing buildings is quite rare that that of the newly constructed structures. The study emphasized the implementation of

BIM in existing structures as it presents numerous advantages related to cost and sustainability requirements and also the energy performance of building is essential to predict in order to make the design of buildings more energy efficient with enhanced indoor environment at reasonable cost. Nguyen et al. [69], carried out a simulation based study by applying different optimization strategies to a building and approved that this approach of optimization can be effective to explore various cost optimal design strategies by taking least computing time. Ahmad et al. [70], carried out the simulation based study and estimated the energy consumption of a residential building at Islamabad after applying the energy efficient measure to windows, HVAC and space lightening and concluded that it costs additional PKR140210 for a two storied building with net area of $2352ft^2$ to integrate all these energy efficient measures with a payback period of three years. The study approved the reduction in energy consumption by 38% as compared to the standard building. Jalaei and Jrade [71], introduced a methodology to implement BIM (Building information Modeling) and energy analysis tools in the conceptual design stage of the building. The study confirms that the conceptual design stage allows the designers to choose the materials and items and use them in their energy and sustainability based design, making more room for modification in the early stages of design. Aksamija. [59] discussed the potential of retrofitting a commercial building to achieve net zero energy goal and presented that simulation and energy modeling are beneficial tools for retrofitting as they can help us analyzing the energy saving measures for their energy saving potential. Keskin et al. [72], showed how the retrofitting process on mega airport project improved by implementing BIM for energy analysis. The study confirmed that Autodesk Insight360 can be used to analyze building for total energy consumption on monthly and yearly basis. Moreover fast data input of these tools allows owners to ascertain the amount of energy produced by PV at the operational stage. Oti and Abanda [73], reviewed information modeling systems i.e: BIM, GIS, CEIM, in the key sectors of built environment. The study concluded that different information modeling systems can be incorporated in building sector for different purposes in order to improve efficiency and productivity of all the works involved in the process. The study also urged the stakeholders to pay attention to the ability of such systems to exchange and make use of information in the supply chain to decide which systems to choose for their specific purpose. Tatari and kucukvar [74], studied the cost premium of a leed certified building and reported that the improvement in the energy-efficiency technology has decreased the prices of renewable energy in US and UK. Kylili and Fokaides [75], studied the contribution of ZEBs in achieving smart cities in Europe and presented that it's possible to achieve smart cities with ZEBs if the related aspects of ZEB are fulfilled. The study also mentioned that if buildings reduce their energy consumption by two third of their current energy consumption, the transition of the buildings to ZEBs is possible. Soares et al. [76], studied the NZEB concept in urban context and concluded that the urban factors that can affect the performance of NZEB should be explored and the interaction between different urban factors and the benefits gained by this interaction should be understood. Harkouss et al. [77], carried out a simulation based optimization for multiple criterion of NZEB and concluded that finding the best possible combination of the energy efficient measures and renewable energy sources is one the challenges in NZEB that would cater for the energy related problems of a particular building. Abbasi and Noorzai [78], integrated BIM in studying the environmental impact of a building and concluded that too much thermal insulation should be avoided as it increases the total life cycle energy. Xu et al. [79] concluded that BIM is an effective tool for improving buildings energy performance due to its accurate energy estimation capability.

2.9 Economic Aspect of NZEB Transformation

Ferrari and Beccali [80], concluded that the cost of energy and discount rate are the main parameters to affect the economic performance of retrofit solution. Moran et al. [81], assessed the optimum retrofit packages to improve the buildings performance and concluded that for the identification of retrofit packages, cost optimal approach was found effective . Also it was suggested that cost optimal approach should be the part of design strategy to narrow down the retrofit sample sizes. Luca et al. [82], Studied the economic implications in the transformation of housing building type to NZEB and concluded that by improving energy policy the best tradeoff between energy efficiency and cost can be achieved. Salem et al. [83] carried out the cost analysis for NZEB retrofit of hotel and confirmed that EEMs with lower initial cost can reduce the global cost of retrofitting.

2.10 Energy Concerns In Pakistan

According to Pakistan Energy Yearbook by HDIP. [84], the 40% of the GHG (Global greenhouse Gas) emissions were from the electricity consumption of the country. Also according to Ministry of petroleum and natural resources. [85], the 67.2% of the world's electricity is being produced from fossil fuels which makes them a huge contributor to the GHG (Global greenhouse Gas) emissions. Qudrat-Ullah. [86], reviewed the energy policies implemented in Pakistan for the last two decades and confirmed that Pakistan is facing intense load shedding of 8 to 12 h in urban areas and upto 18 h in rural areas. Irfan et al. [87], studied the energy dynamics of Pakistan and concluded that high power demand-supply gap of 3000MW generally and 5000MW in summer season is causing GDP loss by 3%-6% to the country. 61% of the energy needs are fulfilled by fossil fuels and only 1.1% by renewable energy. According to Power system statistics. [88], the total number of commercial users in year 2018-19 were recorded to be 3,144,247. This report shows that the consumption of energy by commercial sector has increased by 33% from fiscal year 2010 to 2019.

2.11 Research Gap

In developing countries like Pakistan, the concept of NZEB is not much explored. Various factors that will help in the acceptance of this concept among the owners and designers still need to be addressed. In achieving net zero energy in building sector, the existing conventional buildings needs attention. The existing buildings can be transformed to the NZEB by applying the most feasible factors of NZEB. The main concern in the construction industry is the cost of project and to transform an existing conventional building to NZEB the additional cost of materials and systems installation should be anticipated according to the features of the buildings such as location, floors and area covered etc, so that arrangement could be made accordingly. In literature review the aspect of cost for the most optimum factors that will be implemented for this transformation is missing.

Chapter 3

Research Methodology

This chapter explains the methodology of the whole research process and the scientific methods applied in this study for accomplishing the desired objectives.

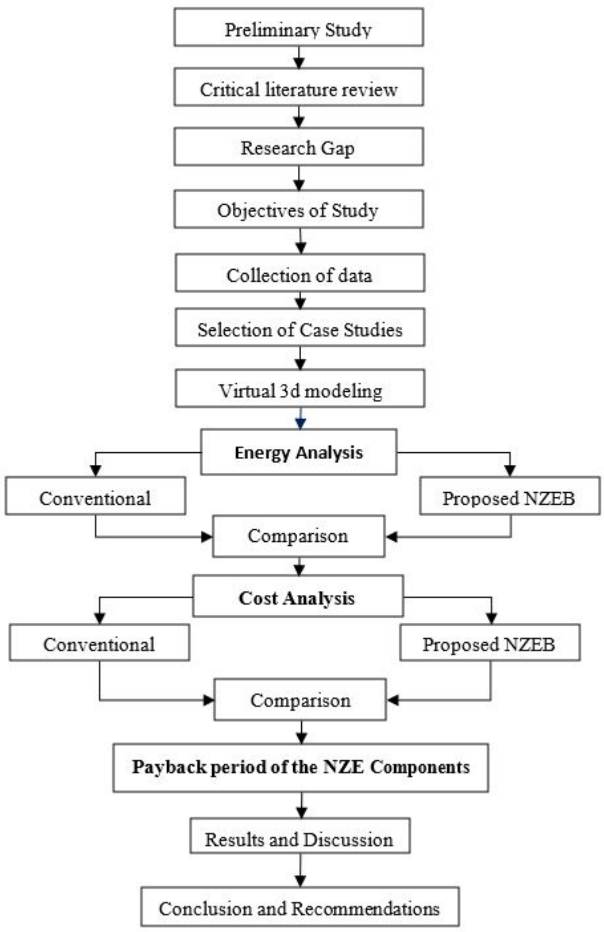


FIGURE 3.1: Methodology flowchart

The figure 3.1 shows the schematic diagram of the research processes. Preliminary study and literature review were carried out before the commencement of work. In literature review the aspect of cost for the most optimum factors that can be implemented for the transformation of conventional commercial building to NZEB, is missing. The literature review however remained continued till the whole process. In this study primary data has been collected from different construction companies. The data includes 2d AutoCAD drawings and the BOQs of the respective buildings.

Case Study strategy was adopted to carry out the study. Four commercial buildings were selected from Islamabad as case studies. Case Study 1 and Case Study 2 are four storeyed buildings and Case Study 3 and Case Study 4 are five storeyed buildings. All these buildings were constructed by conventional way of construction. Each of the building is supposed to be dependent on grid for its electricity supply. The construction costs of the buildings were taken from the BOQs of the respective buildings. Secondary data includes 3d models which were created on REVIT and energy analysis was carried out on each model in REVIT's extension, Insight360. Energy analysis generated the EUI (Energy Use Intensity) value for each building. With Insight 360 results were achieved by adopting alterable factors that can be adjusted according to the design needs. In this study, only three factors were chosen, two of them are related to solar energy i.e., Pv - Panel Efficiency, Pv – Surface Coverage and Roof Insulation. The number of solar panels were calculated by dividing the area of roof by the area of solar plate. The cost of the solar panels installation was confirmed from the market and in this study, cost for covering different percentages of the roof top as suggested by Surface Coverage factor, was determined. Similarly, for roof insulation the rate was taken from market and for each building the cost for roof insulation was calculated according to the area of the roof.

The existing conventional buildings can be converted into NZEB by applying the parameters of NZEB i.e., achieving energy efficiency and onsite/offsite energy generation system in buildings. One of the most important concern in every construction project is cost. Every client and builder is concerned about the cost of their buildings and in transforming an existing building to NZEB, cost is going to be one of the main concerns for this concept to be widely implemented. This research is mainly focused on the causal relationship between cost and transformation of an existing commercial building into NZEB and estimating the payback periods of the innovated NZE factors and their parameters.

3.1 Study Area

In most of the previous studies the energy analysis and performance of the buildings was monitored using different software. There were no such studies that were conducted for Pakistan even though the construction projects share many common characteristics but in order to analyse buildings for a specific country, the research must be conducted in detailed manner. The concept of NZEB development is still not discovered much in Pakistan.

In this research study, case study approach has been used to carry out the desired results. Case studies of Four commercial buildings were considered from different locations in Islamabad. The locations of the case studies are indicated in the figure 3.2. below.

Figure 3.2: Locations of Buildings

3.1.1 Building Information Modeling (BIM)

BIM is a process of analyzing a single building project by the architects, designers, clients and builders, Eadie et al. [89]. It allows us to step away from the conventional 2D drawings and plans and switch to 3D models which can be analyzed and optimized for energy performance, used for cost control and many other virtual reality benefits such as rendering and animations can be obtained. In this study 3D models were created for all the case studies from their respective 2D drawing on Revit. These architectural 3D models were then analyzed for their annual energy by Revit's extension Insight360 on the bases of the geometry of each building and the considered factors.

3.1.2 Designing Virtual 3-D Model

The 3-D virtual models of the case studies were created on REVIT. It's an intelligent software on which 3-D models of the buildings can be created and offers a wide range of parameters which allow users to set the required parameters of their building according to their requirement. The 3-D virtual models of the considered case study buildings were created in the architecture template of REVIT. With its great practicality and specifically the 3-D aspect of REVIT offers wide range of viewing angles and the components of the building can be added, removed, modified and be can viewed through different angles. In this study the 3-D virtual models of the considered case studies were created in the architecture template of the REVIT.

3.1.3 From 3D Models to Energy Models

The Building Energy Model (BEM) is generated from the architectural 3-D model of the specific building. This energy model allows us to examine the model elements in browser and review element properties without going back to the original model which makes the work easier. In this research, the BEMs were generated using Insight360 for each case study building from their respective BIM models. The BEMs were generated on a basis of some considerations, as shown in the table 3.1 below, that need to be set before submitting the architectural model to the cloud-based energy analysis platform. These considerations are required by the software itself. The location of all the case study buildings were set to Islamabad in the energy setting interface. The steps involved in the energy analysis in BIM are illustrated in the figure 3.3. This figure demonstrates the whole process right from the design of 3d models to implementation of the considered NZEB factors and adjusting the parameters to obtain the efficient results. The identification of NZE factors was done by comparing the results of energy analysis with different parameters which led to the selection of only those parameters of the selected factors which gave the most optimal results.

Table 3.1: Inputs for Generating Building Energy Model

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

3.2 Energy Analysis Procedures

The energy analysis has been performed in four phases with different parameters of the considered NZEB factors. The schematic diagram in figure 3.4 shows the energy analysis process adopted in this study. In BIM, the energy analysis can be performed on the architectural 3-D model of a building when it's completed. It allows the architects and designers to have an idea about the energy performance of the building during the design stage in virtual reality. This allows them to make the necessary modifications to the building in order to make it more energy efficient and improve the energy performance of a particular building. The energy analysis is performed on the architectural models of all the case study buildings. The

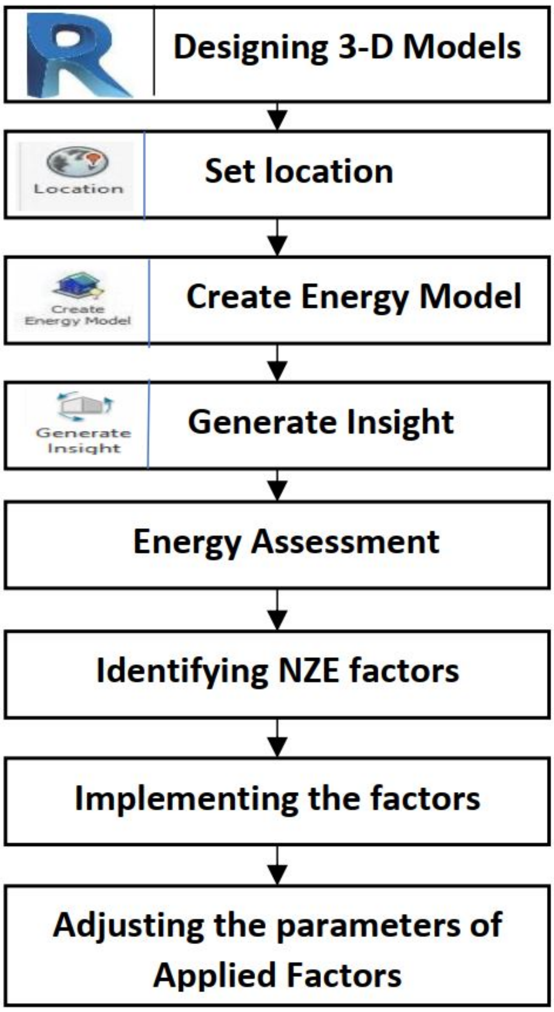


FIGURE 3.3: BIM Workflow

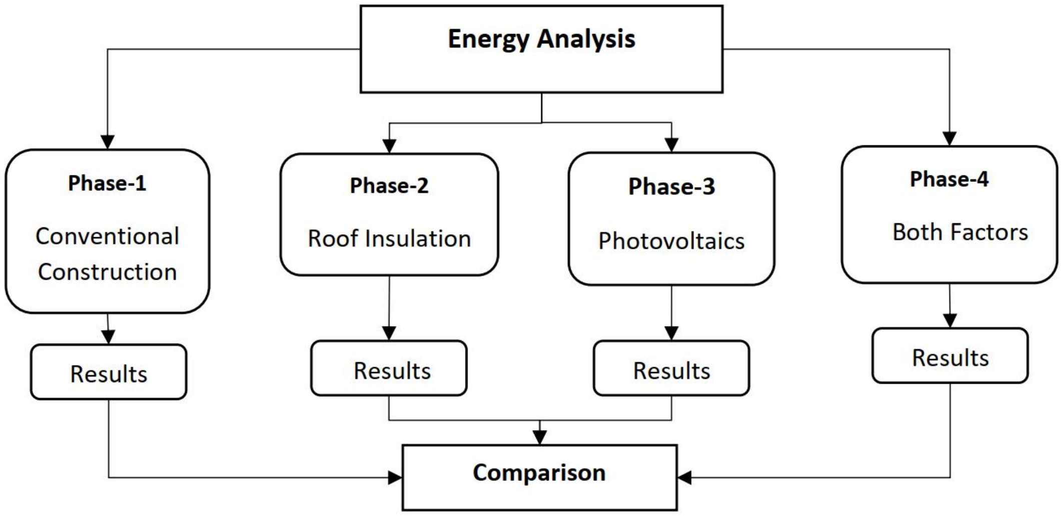


FIGURE 3.4: Schematic diagram of Energy Analysis process

selected factors are provided by Insight360 after the energy analysis is completed. These factors also serve the purpose of NZEB parameters.

The factor Panel Efficiency was considered to be 20.4% for each phase as the solar panels being considered for this study have efficiency given by their manufacturer to be up to 20.9%. The factors selected from the various other factors of NZEB provided by the cloud-based software along with their purpose and their limitation for application in this study is shown in the table 3.2. The selected parameters

TABLE 3.2: Selected Factors and adapted parameters

Factors	**Adapted Parameters**
Roof Construction	R38, R60
Pv-Surface Coverage	0%, 60%, 75%, 90%
Panel Efficiency	20.4%

were then applied on the case studies in four phases.

3.2.1 Phase-I (Conventional Construction)

To assess the improvement in the energy performance of the building with the application of the selected NZEB parameters, it was necessary to carry out the energy analysis of the base building model which is also considered as conventional type building. This phase of energy analysis was meant to be carried out on a conventional building model, hence the considered parameters "Roof Construction" and PV-Surface Coverage were not taken into account. These factors are presented in the table 3.3.

TABLE 3.3: Parameters selected for Phase-I

Factors	**Parameters**
Roof Construction	Nill
Pv-Surface Coverage	Nill
Panel Efficiency	Nill

3.2.2 Phase-II

To assess the improvement in the energy performance of the building with only roof insulation. The factor Roof Construction was applied with R38 and R60 parameters to the energy models of the case studies. The Table 3.4 shows these factors along with their setting considered for this study.

TABLE 3.4: Parameters selected for Phase-II

Factors	**Parameters**
Roof Construction	R38, R60
Pv-Surface Coverage	Nill
Panel Efficiency	Nill

In this phase of energy analysis, the considered NZEB factor Roof Construction was meant to be applied within the scope of this study. Hence this energy analysis was carried out by considering the parameters for the Roof Construction to be R38 and R60 type insulation. The factor Pv-Surface Coverage and Panel Efficiency were not applicable in this case.

3.2.3 Phase-III

The table 3.5 shows the factors and their respective parameters chosen for this phase. In the third phase of energy analysis the case study buildings were analyzed by considering the Pv-Surface Coverage factor only. This factor allows us to select different percentages of roof area coverage to determine the most suitable option for the particular purpose. The 0% option was analyzed in the first phase and the 60%, 75%, 90% options were analyzed in this phase. In this phase, panel efficiency of the solar panels was considered due to application of PV-Surface Coverage factor. Panel efficiency was taken to be 20.4%.

Table 3.5: Parameters selected for Phase-III

Factors	**Parameters**
Roof Construction	Nill
Pv-Surface Coverage	60%, 75%, 90%
Panel Efficiency	20.4%

3.2.4 Phase-IV

The fourth phase of energy analysis was carried out to see the combined effect of the both NZEB factors on the case study buildings. The factors were applied on the basis of the energy and cost effciency which were determined by the results of the energy and cost analysis carried out on the case studies. The parameters for Phase-IV are shown in the table 3.6

Table 3.6: Parameters selected for Phase-IV

Factors	**Parameters**
Roof Construction	Decided on the basis of Phase-II results
Pv-Surface Coverage	Decided on the basis of Phase-III results
Panel Efficiency	20.4%

3.3 Energy Analysis Comparison

In order to perceive the effectiveness of the NZEB factors, a comparison was carried out between the results of first phase of energy analysis with the rest of the phases. The comparison was done to determine the improvement in the energy performance of the case study buildings after considering the NZEB factors and evaluating them for different parameters and obtaining the best possible option. This comparison was done on the basis of the following factors and their respective parameters.

- Conventional VS Proposed Insulation
- Conventional VS Proposed Coverage

The comparison was done between the results of the performed simulations to see how only roof insulation improves the buildings energy performance. The comparison between the Pv- surface coverage options was also carried out. In this case the 0% option was compared to the option with most efficient option.

3.4 Cost Analysis Procedures

The schematic diagram of the cost analysis process is shown in the figure 3.5. The diagram explains the cost evaluating process for the components that will be analyzed for their performance in cloud-based energy analysis platform.

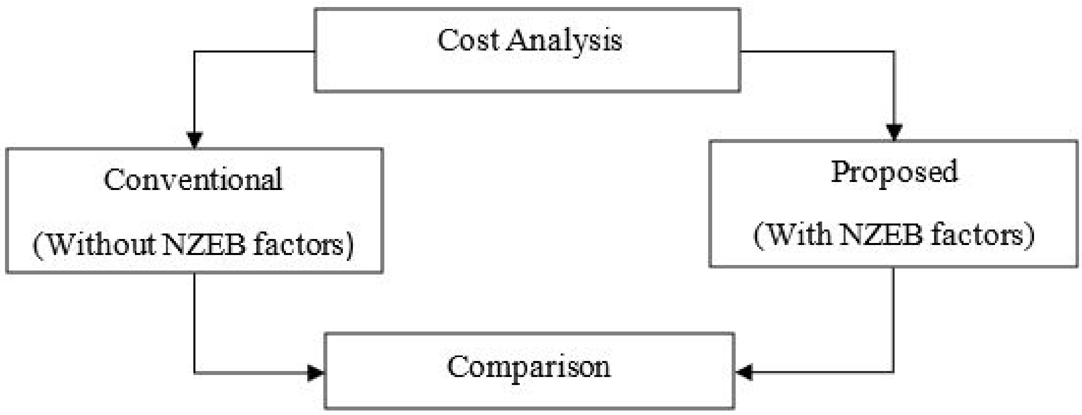


FIGURE 3.5: Schematic diagram of Cost Analysis process

The cost analysis process includes

- The determination of the cost of the buildings without any NZEB factors (Conventional Building)
- The cost of the buildings after applying Roof Insulation.
- The cost of the buildings after PV Installation

- The analysis of cost increase after application of both considered NZEB factors.

3.5 Cost Analysis Comparison

The comparison between the results of the cost analysis performed in different phases was carried out to

- Determine the variation in the original cost of buildings with roof insulation.
- Determine the increase in cost of buildings with PV.
- Determine the increase in cost with both Roof Insulation and PV.

3.6 Materials

3.6.1 Roof Insulation

The material selected for roof insulation in this study is Expanded Polystyrene (EPS). The cross section of EPS is shown in the figure 3.6.

FIGURE 3.6: Cross section of EPS

The cost for the insulation material is calculated in terms of R value per inch for $1ft^2$ of the specimen. R value is the measure of thermal resistance. it tells us what quantity of heat (Btu) will transfer through a $1ft^2$ section of a 1-inch-thick specimen of a homogeneous material. it is an imperial system of units which is mostly used for the thermal insulating materials and its unit is F.ft^2.h/Btu. The material for roof insulation chosen in this study is Expanded Polystyrene (EPS). The material has been selected on the bases of the availability in the local market and efficiency. EPS is one of the widely used roof insulation material in Pakistan.

3.6.2 Pv-Panels

The solar panels being considered for this study are from International Brand, Longi. Each plate has a power of 445w and area of 28ft^2(2.6m2). The efficiency of the panels was given by the manufacturer which is 20.5%Ȯn the basis of the results and the comparison between the different phases of energy and cost analysis, the payback period of the installed components was estimated.

Chapter 4

Results and Discussions

This chapter presents the results obtained from the energy analysis and cost analysis and discusses these results in the light of different factors. The energy analysis and cost analysis on the selected case studies were completed and comprehensive comparative analysis has been performed. The considered NZEB factors for these analyses have also been discussed and the most energy and cost-efficient model has been suggested.

4.1 Case Studies

The table 4.1 shows the considered case studies and their respective characteristics. Four commercial type buildings were being selected as case studies from Islamabad, Pakistan. BLDG-1 and BLDG-2 are four storeyed buildings and BLDG-3 and BLDG-4 are five storeyed buildings as these are the most common designs being adopted by the majority of the builders in Islamabad. The reason for selecting 4 and 5 storeyed buildings is to address the issue of inefficiency in the buildings of this size because with the urban expansion in Islamabad, commercial building is being constructed on a large scale and majority of the buildings don't go more than 5 floors. The selected buildings are frame structures built by conventional methods of construction. Wooden doors, aluminum windows are installed in each

TABLE 4.1: Characteristics of the selected buildings for case studies

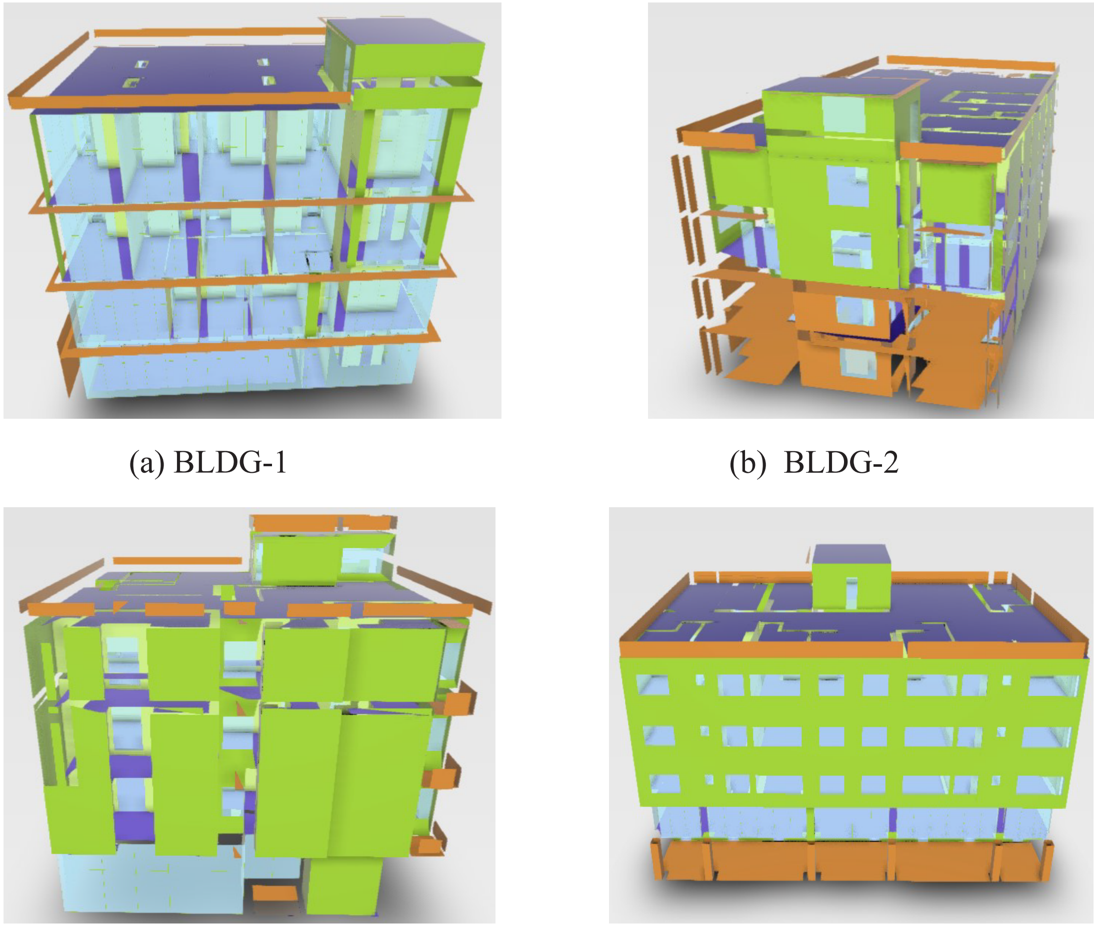
S.no	Building Code	Area (m^2)	No. of Floors	Building Type	Structure Type	Location
1	BLDG -1	1746	G+3	Commercial	Frame	Islamabad
2	BLDG -2	1013	G+3	Commercial	Frame	Islamabad
3	BLDG -3	1115	G+4	Commercial	Frame	Islamabad
4	BLDG -4	3110	G+4	Commercial	Frame	Islamabad

building. Concrete filled columns and outside walls are made up of concrete blocks while on the inside walls, brick masonry is used. The rendered images of the case study buildings can be seen in the figure 4.1(a),(b),(c),(d) given below.

FIGURE 4.1: Revit 3D Models

4.2 Building Energy Models (BEM)

The figure 4.2(a),(b),(c),(d) show the perspective views of the BEMs of buildings selected as case studies in this research. These energy models are developed from the architectural models of the buildings by considering some inputs given in table 3.1 from chapter 3. These energy models allow the user to see which places have been selected from the entire building for which the software will calculate the annual energy usage of the building.



(a) BLDG-1 (b) BLDG-2

(c) BLDG-3 (d) BLDG-4

FIGURE 4.2: BEMs of the building models

The above figure elaborates the energy analysis process where the selected factors were applied to the building energy models with certain parameters and the results were obtained. The results were obtained by varying the parameters and repeating the energy analysis process.

4.3 Energy Analysis

Energy analysis of the buildings was performed on the extension of REVIT, insight360. The energy patterns of the building's models were studied from their respective energy models.

- Phase-I - Analysis was performed on the case studies without applying any parameter to the selected factors
- Phase-II - only the factor Roof Construction was considered
- Phase-III- only the factor Pv-Surface Coverage was considered.
- Phase-IV - both the factors Roof Construction and PV-Surface Coverage were Integrated in the models.

For the research study, this energy analysis cycle has been elaborated in the figure 4.3.

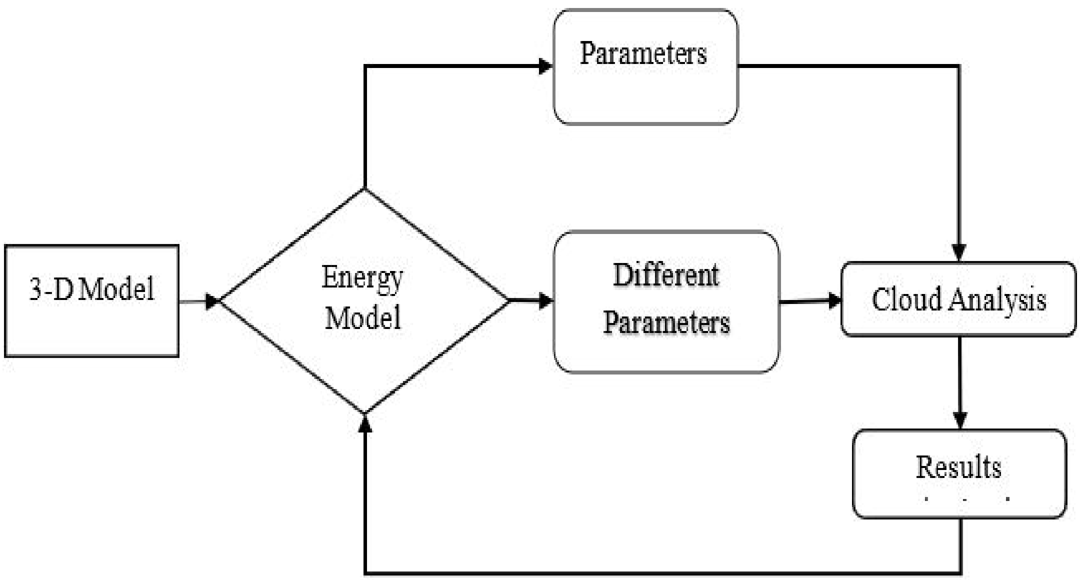


FIGURE 4.3: Energy Analysis Cycle

4.3.1 Energy Analysis – Phase I

In this phase, the selected case study buildings were meant to be analyzed without considering the selected NZEB factors. In other words, the buildings were supposed to be conventional. The factors and their settings in cloud analysis are shows in the figure 4.4.

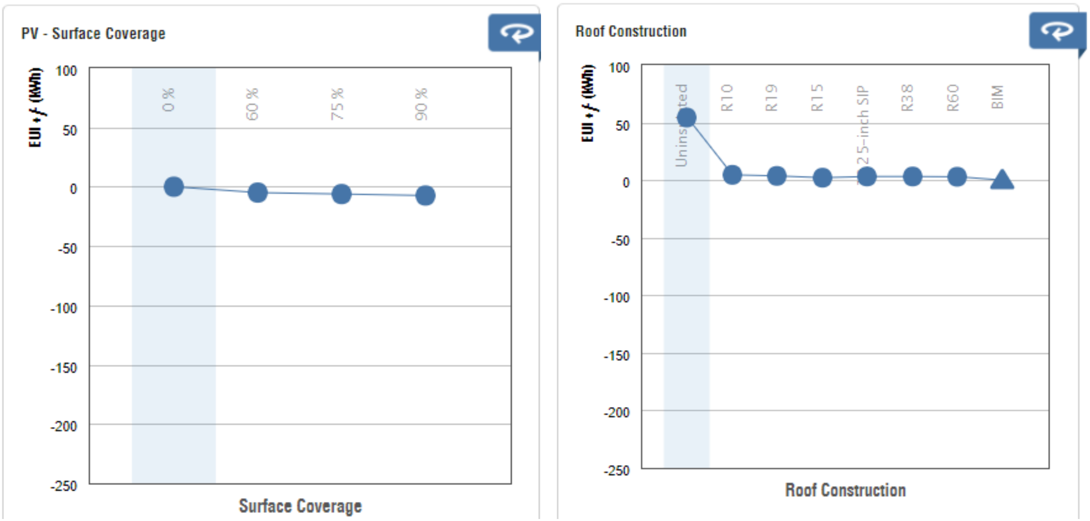


FIGURE 4.4: Parameters for Surface Coverage and Roof Construction

It can be seen in the figure 4.4 that Pv-Surface Coverage is set to 0%, which means no solar panels installed on the roof. Similarly Roof Construction has been set to uninsulated. First phase of energy analysis is performed on the case study buildings and the results from Insight360 are shown in the figures 4.5 (a), (b), (c), (d) for each building model . The ASHRAE 90.1 becnchmark values can be seen in the figures. ASHRAE 90.1 has been a standard benchmark for the commercial buildings all over the world since 30 years. This standard provides minimum requirements for the energy efficient design of commercial building. It offers the minimum energy efficiency requirements for design and construction of new buildings and new portions of buildings along with their systems and new equipment and systems in existing buildings, as well as criteria for determining whether the additional components are in compliance with the requirements. It is an essential reference used by engineers and professionals of others fields that are involved in building systems.

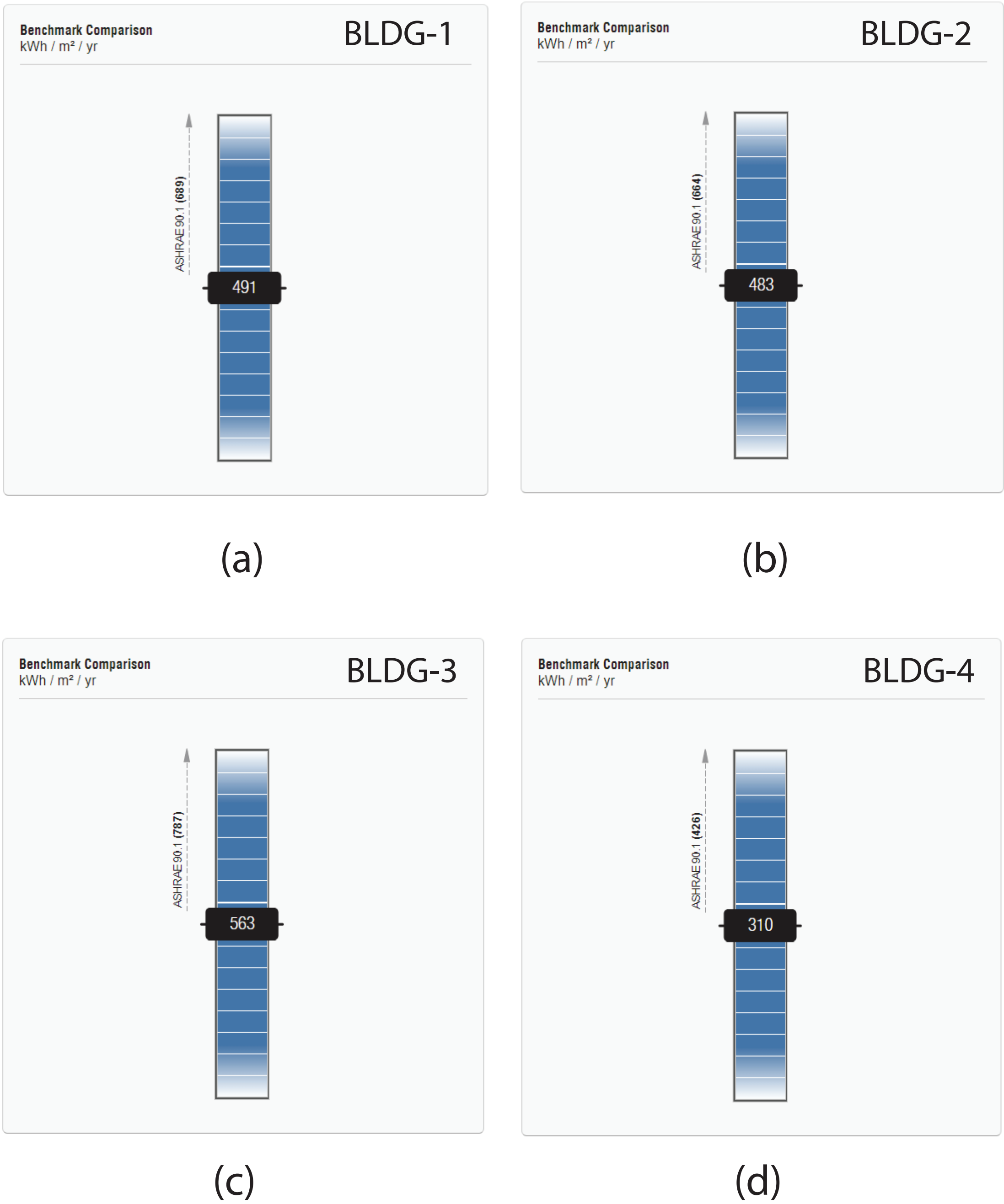


FIGURE 4.5: Annual energy usage of BLDG-1, BLDG-2, BLDG-3, and BLDG-4

The above results provided by insight360 are displayed in the tabulated form in the table 4.2. the energy usage in Kwh/m2/yr are shown along with the ASHRAE 90.1 benchmark values for each case study.

Table 4.2: Results of first phase of energy analysis

Case Study	Energy Usage (Kwh/m^2/yr)	Ashrae 90.1 (Kwh/m^2/yr)
BLDG-1	491	689
BLDG -2	483	664
BLDG -3	563	787
BLDG -4	310	426

4.3.2 Energy Analysis – Phase II

In this phase of energy analysis, Roof Insulation was considered. The energy analysis was carried out for two types of insulations i.e. R38 and R60 as shown in the figure 4.6. Both of these insulation types are recommended for roofs. The factor Roof Construction from the interface of the cloud-based energy analysis was set to R38 and R60 type insulation as shown in the figure below.

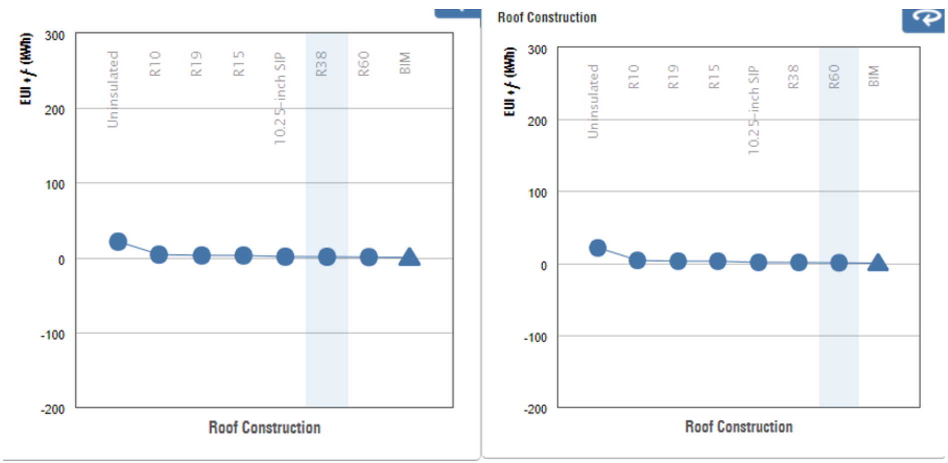


Figure 4.6: Parameters for Roof Construction

The factor Pv-Surface Coverage was set to 0%. Panel Efficiency was set to 20.4% as default setting and all other factors were set to BIM which is actually the baseline settings for the energy analysis in Insight360. the Insulation materials are available in wide varieties with their respective installation costs and thermal properties. The insulation material considered for this study is selected on the bases of market availability and trend which lead to the selection of expanded polystyrene. The results obtained from the Insight360 are presented for each case study building below.

4.3.2.1 BLDG – 1

The energy usage of BLDG-1 is shown in the figure 4.7 which shows the energy usage with R38 and R60 type insulation. With R38 the energy usage was reduced to 470 kwh/m2yr and with R60, the energy usage reduced to 471 kwh/m^2yr.

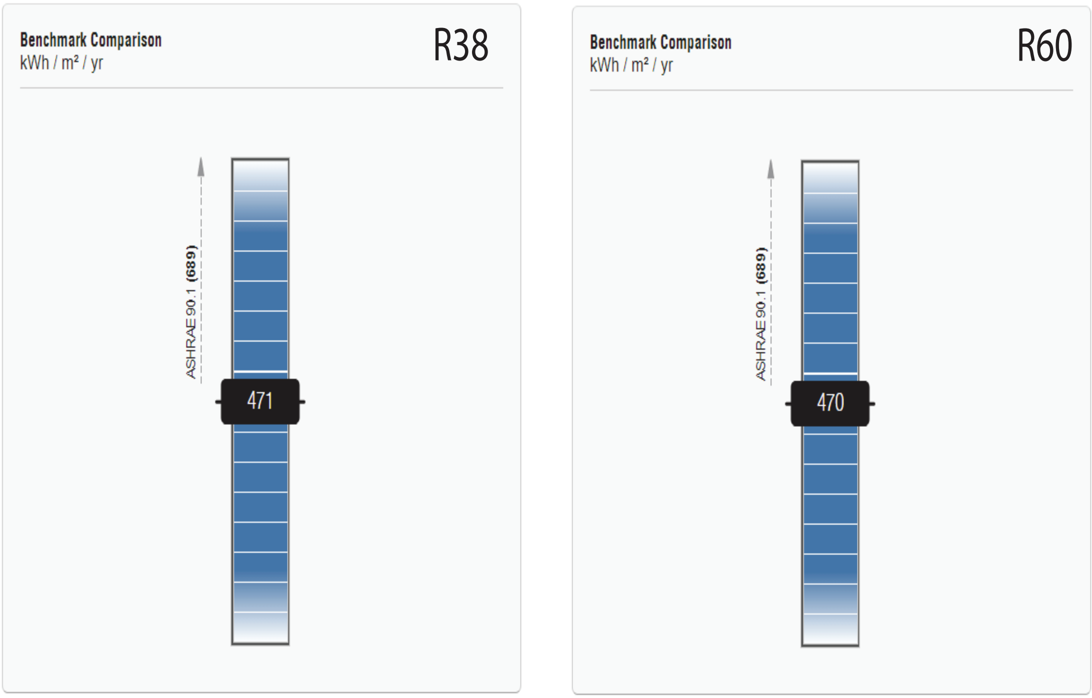


FIGURE 4.7: Energy Usage of BLDG-1 with roof Insulations

4.3.2.2 BLDG – 2

The energy usage of BLDG-2 is shown in the figure 4.8 which shows the energy usage with R38 and R60 type insulation. No difference was found between the energy usage of the buildings with both R38 and R60 type insulation. Both were able to reduce the energy usage to 462 kwh/m^2/yr.

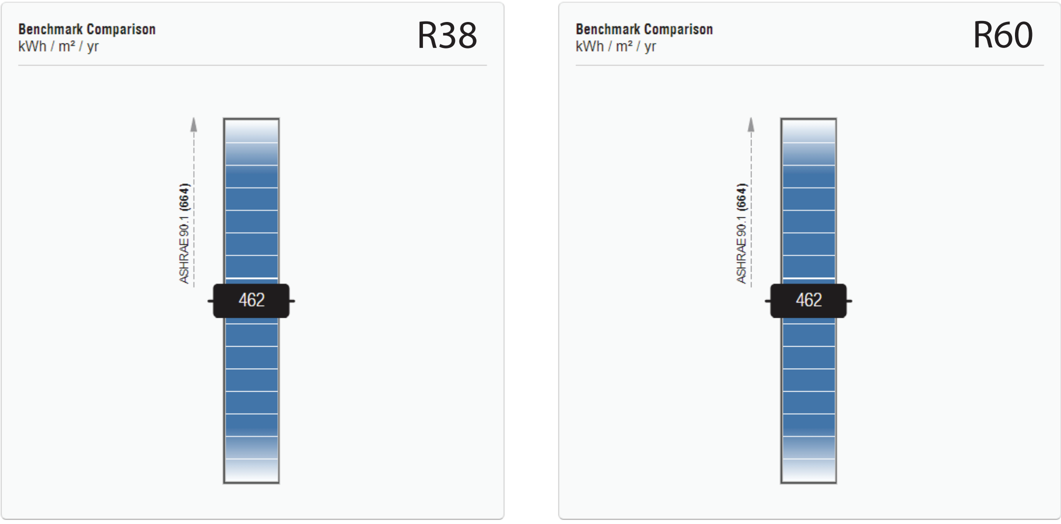


FIGURE 4.8: Energy Usage of BLDG-2 with roof Insulations

4.3.2.3 BLDG – 3

The energy usage of BLDG-3 is shown in the figure 4.9 which shows the energy usage with R38 and R60 type insulation. No difference was found between the energy usage of the buildings with both R38 and R60 type insulation. Both type of insulations performed equally in reducing the energy usage of the building.

FIGURE 4.9: Energy Usage of BLDG-3 with roof Insulations

4.3.2.4 BLDG – 4

The energy usage of BLDG-4 is shown in the figure 4.10 which shows the energy usage with R38 and R60 type insulation. Both R38 and R60 type insulations were able to reduce the energy usage to 307 kwh/m^2/yr.

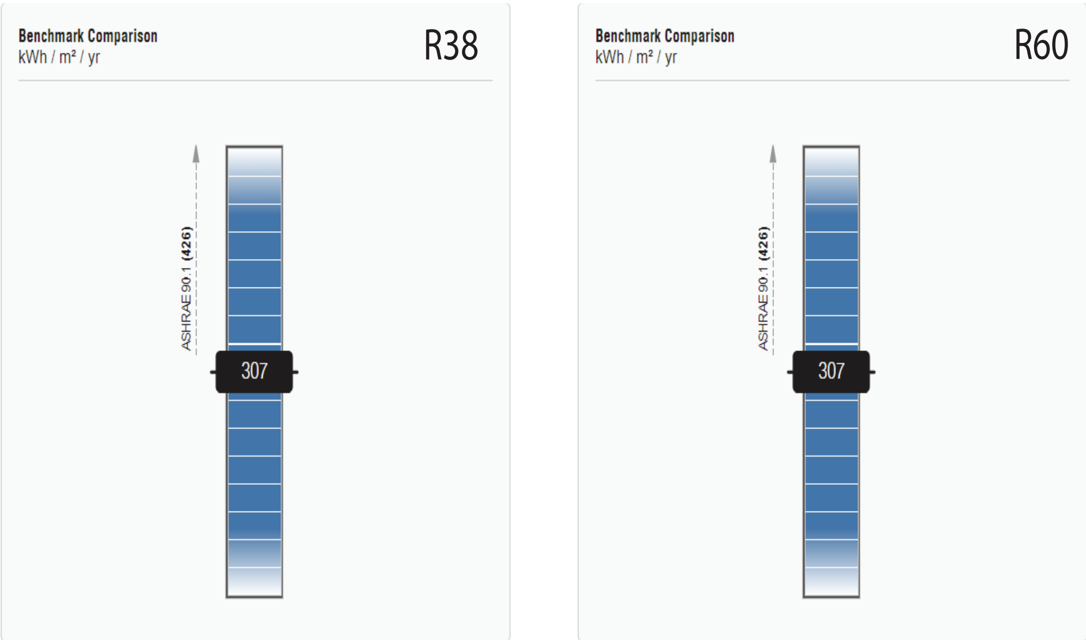


FIGURE 4.10: Energy Usage of BLDG-4 with roof Insulations

The above results of the Phase-II energy analysis are shown in the table 4.3. The table also shows the energy usage with uninsulated building models and also the difference caused by the considered insulations.

TABLE 4.3: Results of Second phase of energy analysis

Case Studies	**Uninsulated (Kwh/m^2/yr)**	**R38 Insulation (Kwh/m^2/yr)**	**R60 Insulation (Kwh/m^2/yr)**	**Difference w.r.t Uninsulated (%age)**	
				R38	**R60**
BLDG-1	491	471	470	4.07	4.2
BLDG-2	483	462	462	4.3	4.3
BLDG-3	563	556	556	1.25	1.25
BLDG-4	310	307	307	0.96	0.96

A reduction in the annual energy usage of the buildings was observed with both type of insulation with a minor difference. The table 4.3 shows the results for R38 and R60 type insulation and also the difference with respect to the uninsulated models is also shown.

4.3.3 Energy Analysis – Phase III

In this phase of energy analysis, Roof Insulation was considered. The energy analysis was carried out for two types of insulations i.e. R38 and R60 as shown in the figure 4.15. Both of these insulation types are recommended for roofs. The factor Roof Construction from the interface of the cloud-based energy analysis was set to R38 and R60 type insulation as shown in the figure 4.11.

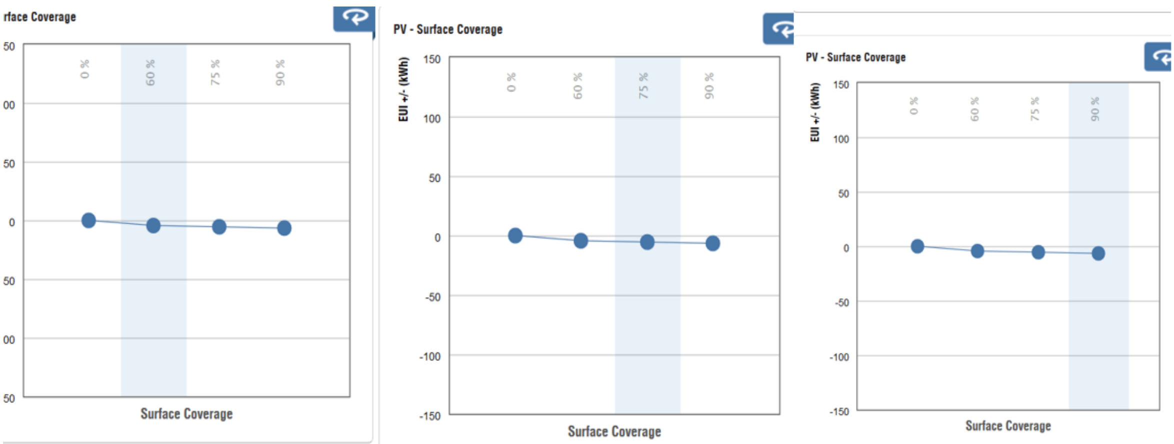


FIGURE 4.11: Parameters for Pv Surface coverage for Phase-III

The results from the cloud-based software for Phase-III of energy analysis are presented below for BLDG-1, BLDG-2, BLDG-3 and BLDG-4 respectively.

4.3.3.1 BLDG – 1

The results of energy analysis for 60%, 75% and 90% for BLDG-1 are shown in figure 4.12 as presented by the cloud-based software. The energy usage of BLDG-1 was not significantly improved with 75% and 90% options with the difference of 2Kwh/m^2/yr and 4 Kwh/m^2/yr respectively with respect to 60% option.

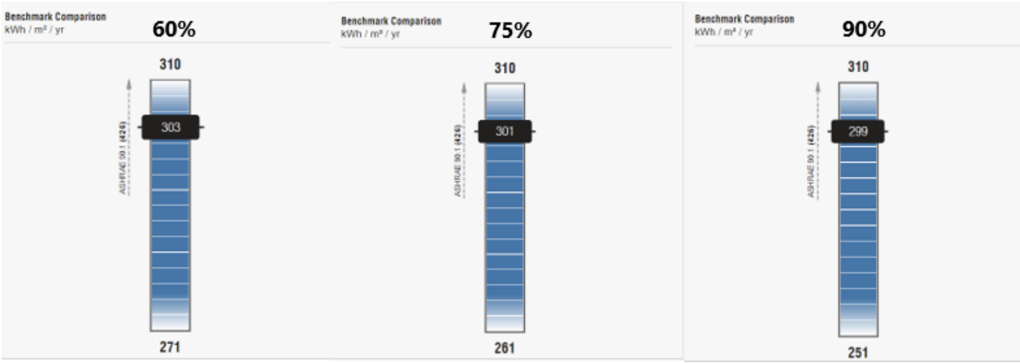


FIGURE 4.12: Results of phase-III of energy analysis for BLDG – 1

4.3.3.2 BLDG – 2

The results of energy analysis for 60%, 75% and 90% for BLDG-2 are presented in figure 4.13 which presents the results of Phase-III of energy analysis for BLDG-2 with the consideration of Pv-Sruface Coverage factor and its parameters. It can be seen that the difference between the 60%, 75% and 90% options of surface coverage is quite minimal. The 75% and 90% only lowered the energy usage of building by 2 Kwh/m2/yr and 4Kwh/m2/yr respectively with respect to 60% option as provided by the cloud-based software. In this case, the energy usage of building was not significantly improved with the 75% and 90% options exhibiting the difference of 2 Kwh/m^2/yr and 4Kwh/m^2/yr respectively with respect to 60% option.

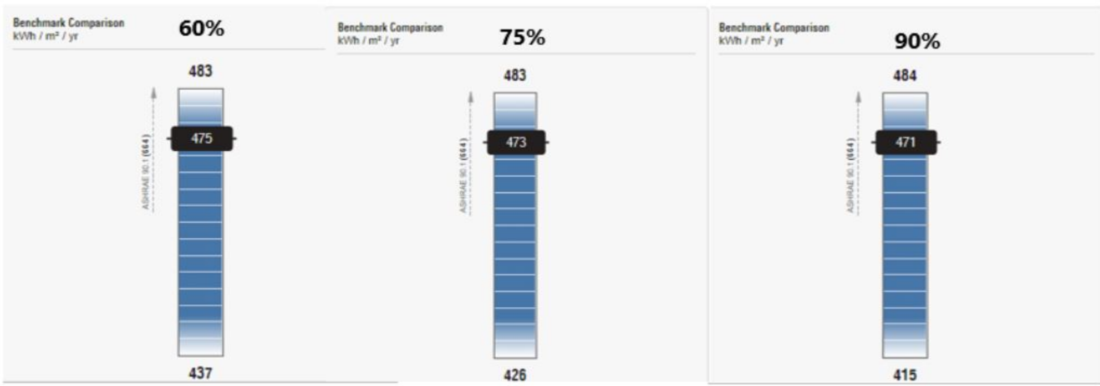


FIGURE 4.13: Results of phase-III of energy analysis for BLDG – 2

4.3.3.3 BLDG – 3

Figure 4.14 presents the results of Phase-III of energy analysis for BLDG-3 with the consideration of Pv-Sruface Coverage factor and its parameters. It can be seen that the difference between the 60%, 75% and 90% options of surface coverage is quite minimal. The 75% and 90% only lowered the energy usage of building by 2 Kwh/m2/yr and 4Kwh/m2/yr respectively with respect to 60% option.

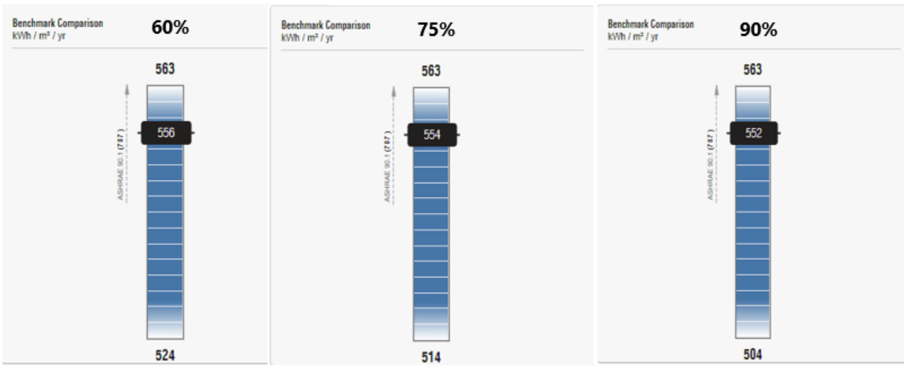


FIGURE 4.14: Results of phase-III of energy analysis for BLDG – 3

4.3.3.4 BLDG – 4

Figure 4.15 presents the results of Phase-III of energy analysis for BLDG-4 with the consideration of Pv-Sruface Coverage factor and its parameters. It can be seen that the difference between the 60%, 75% and 90% options of surface coverage is quite minimal. The 75% and 90% only lowered the energy usage of building by 2 Kwh/m2/yr and 4Kwh/m2/yr respectively with respect to 60% option.

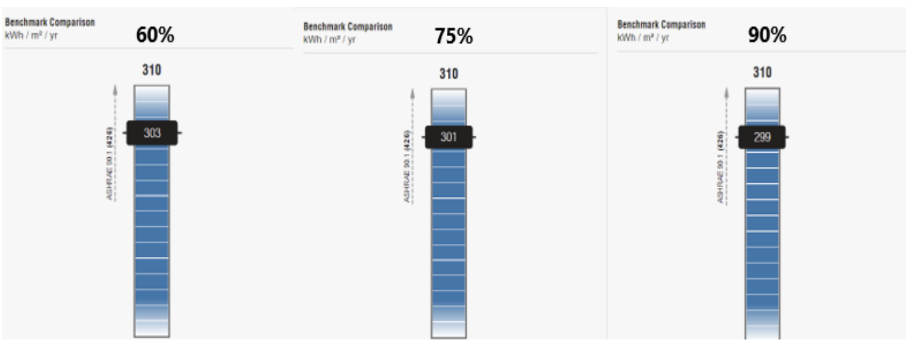


FIGURE 4.15: Results of phase-III of energy analysis for BLDG–4

From the above results it is evident that the most energy efficient results were obtained with 60% roof top surface coverage. With 75% and 90% surface coverages the results were not impressive as the energy usage reduced by very small amount and also the cost for larger areas is more. Hence the most efficient option was found to be 60%. The result of Phase-III are presented in table 4.4

Table 4.4: Results of Third phase of energy analysis

Case Study	EUI with 0% Surface coverage ($Kwh/m^2/yr$)	EUI with 60% Surface coverage ($Kwh/m^2/yr$)	EUI with 75% Surface coverage ($Kwh/m^2/yr$)	EUI with 90% Surface coverage ($Kwh/m^2/yr$)	Variation w.r.t 0% Surface coverage (%age)		
					60%	75%	90%
BLDG-1	491	483	481	479	1.62	2.0	2.4
BLDG-2	483	475	473	471	1.65	2.0	2.5
BLDG-3	563	556	554	552	1.24	1.6	1.95
BLDG-4	310	303	301	300	2.25	2.9	3.2

4.4 Costing of Roof insulation and Pv-Panels

Before moving to the fourth phase of energy analysis, it was necessary to ascertain the parameters for the selected factors. In above energy analyses results, the performance of each parameter was examined. The cost of implication of these parameters was also necessary and is determined in this section. The ones with minimum cost were chosen for the fourth phase of energy analysis.

4.4.1 Cost estimation R38 and R60 type Insulation

In order to select the insulation material for roofs of case studies on the bases of R values, the costing of both R38 and R60 type insulation was carried out to see which type of insulation will be more economical to be used in this study. The cost has been calculated for Expanded polystyrene sheets. The table 4.5 shows the type of insulation along with their thicknesses to achieve the respective R value.

TABLE 4.5: Cost of Insulation

Type of Insulation	**Required Thickness (Inches)**	**Cost per m^2**
R38	7	2,268
R60	11	3,564

From table it is evident that in order to achieve R60 insulation in Expanded polystyrene, the thickness of the material needed to be increased which also increases the cost of the material. In table, the cost per m^2 of R60 type insulation is higher than that of R38 by Rs1,296. Hence the R38 type insulation was considered for the combined energy and cost analysis in this study as it was more economical and gave identical results to that of R60.

4.4.2 Cost Estimation of Pv-Panels

The cost of solar panels installation on the give percentages of roof top surfaces in Insight360 was carried out to find out the most economical and energy efficient option as shown in the table 4.6.

TABLE 4.6: Costing of PV Installation

Case Studies	**Cost for 60% (PKR)**	**Cost for 75% (PKR)**	**Cost for 90% (PKR)**
BLDG-1	3,55,0000	4,50,0000	5,30,0000
BLDG-2	2,80,0000	3,50,0000	4,20,0000
BLDG-3	2,40,0000	2,85,0000	3,45,0000
BLDG-4	5,75,0000	7,15,0000	8,55,0000

This cost was calculated to determine the difference between the costs for applying Pv to the given percentages of roof top coverage. In third phase of energy analysis, it was confirmed that the difference between the energy results of 60% and 75%, 90% option was minimal. Hence 60% option was considered for the rest of the analysis for its better efficiency.

4.5 Fourth Phase of Energy Analysis

This phase of energy analysis was carried out by considering both the NZEB factors and were applied to the models. The parameters for this phase are shown in the figure 4.16

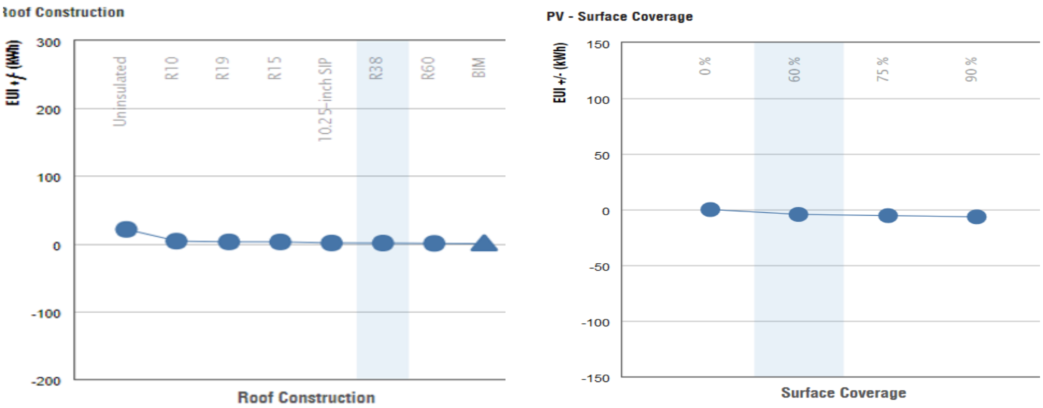


FIGURE 4.16: Parameters for Phase-IV

In Roof Construction factor, R38 type insulation was selected for each case study. When the cost analysis was done the R38 type insulation was found to be cheaper than R60 due to its less thickness than R60. The factor Pv-Surface Coverage was set to 60% as from the results of energy analysis in Phase 3 it was evident that the 60% coverage of roof surface with solar panels provides maximum energy and cost efficiency because the difference between the results of 60%, 75% and 90% was minimal and also 60% option required lesser additional cost of installation than 75% and 90% coverage options. The results provided by Insight360 for each case study are presented below in figure 4.17. The results of this phase of energy analysis are also presented in table 4.7 . The table shows the energy usage of each case study building during Phase-IV of energy analysis and also the difference between the Phase-I (Conventional) and Phase-IV (Innovated NZEB) is also presented.

FIGURE 4.17: Results for Phase-IV

TABLE 4.7: Results of Phase-IV of Energy Analysis

Case Study	**Energy Usage of conventional model (Kwh/m^2/yr)**	**Energy usage of innovated NZEB (Kwh/m^2/yr)**	**Difference (Kwh/m^2/yr)**	**Percentage Decrease (%)**
BLDG -1	491	463	28	5.7
BLDG -2	483	453	30	6.2
BLDG -3	563	549	14	2.5
BLDG -4	310	299	11	3.5

4.6 Comparative Energy Analysis – Case Study based

A comparison was done in order to show the difference between the energy usage in each phase of energy analysis. To represent the difference, bar graphs were created for the case study buildings which show the energy usage in Kwh/m^2/yr for each phase for each case study.

4.6.1 BLDG-1

The energy usage of the BLDG-1 for each phase of energy analysis is shown in the figure 4.18. The energy usage during phase I, II, III and IV are 491 Kwh/m2/yr, 471 Kwh/m^2/yr, 483 Kwh/m^2/yr, 463 Kwh/m^2/yr. It can be seen in the figure that in phase 2, the annual energy usage of the building reduced by 20 Kwh/m^2/yr which is more than that of the phase 3 where the energy usage reduced by 8 Kwh/m^2/yr. The combined application of both the factors reduced the energy usage of BLDG-1 by 28 Kwh/m^2/yr.

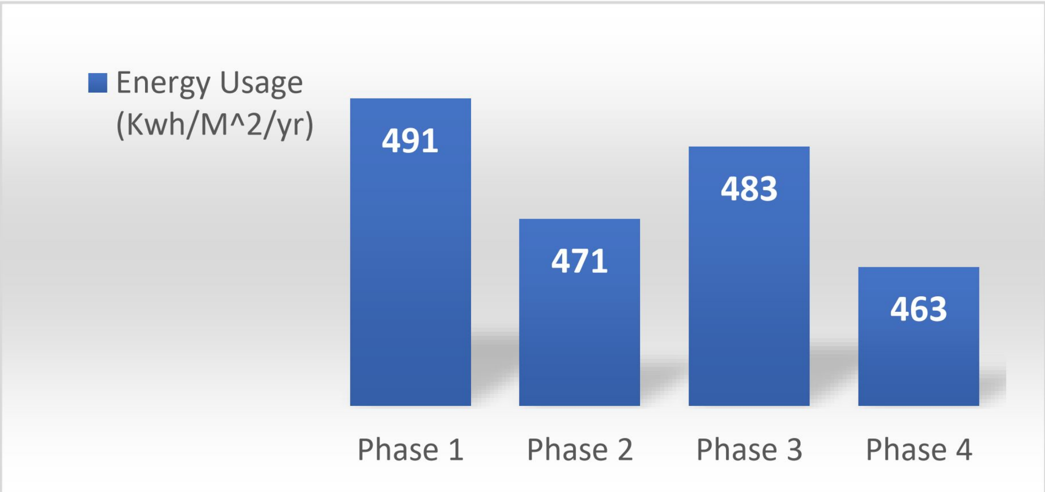


FIGURE 4.18: Energy Usage of BLDG-1 for each phase of energy analysis

4.6.2 BLDG-2

The energy usage of the BLDG-2 building for each phase of energy analysis is shown in the figure 4.19. the energy usage during phase I, II, III and IV are 483 Kwh/m^2/yr, 462 Kwh/m^2/yr, 475 Kwh/m^2/yr, 453 Kwh/m^2/yr. It can be seen in the figure that in phase 2, the annual energy usage of the building reduced by 21 Kwh/m^2/yr which is more than that of the phase 3 where the energy usage reduced by 8 Kwh/m^2/yr. In this case also the Roof Construction factor is more dominant than the PV Surface Coverage in terms of energy efficiency. The combined application of both the factors reduced the energy usage of BLDG-2 by 30 Kwh/m^2/yr.

4.6.3 BLDG-3

The energy usage of the BLDG-3 building for each phase of energy analysis is shown in the figure 4.20. the energy usage during phase I, II, III and IV are 563 Kwh/m^2/yr, 556 Kwh/m^2/yr, 556 Kwh/m^2/yr, 549 Kwh/m^2/yr. It can be seen in the figure that in phase-II and also in phase 3 the annual energy usage of the building reduced by 7 Kwh/m^2/yr. In this case the effect of both NZEB factors was identical. The combined application of both the factors reduced the energy usage of BLDG-3 by 14 Kwh/m^2/yr.

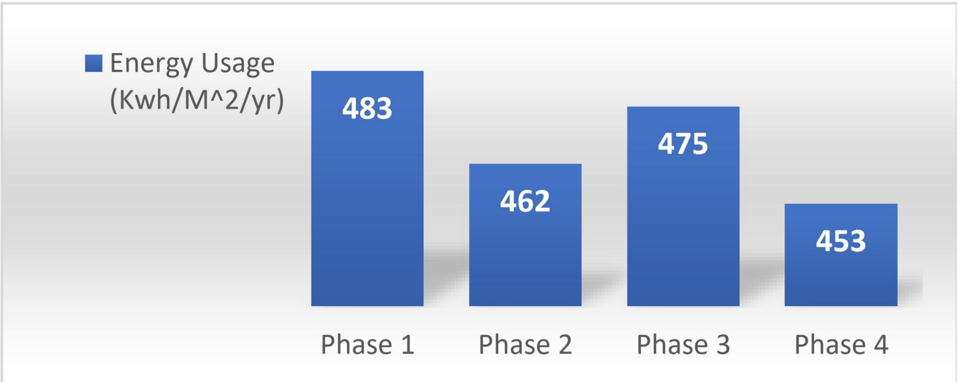


FIGURE 4.19: Energy Usage of BLDG-2 for each phase of energy analysis

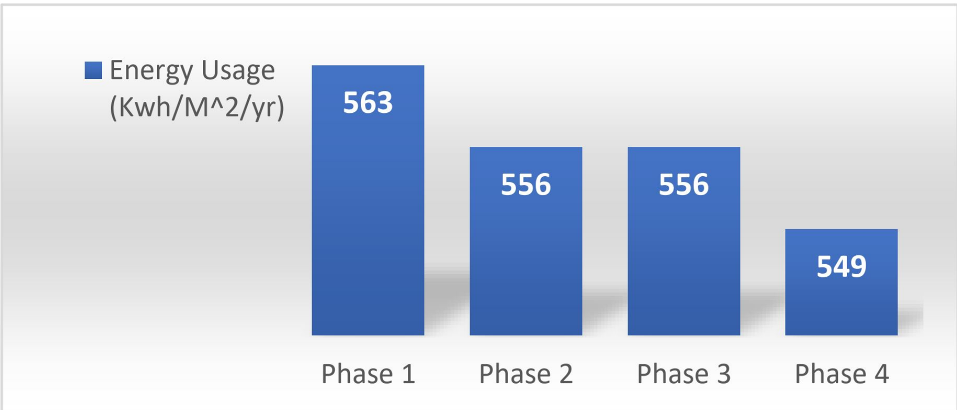


FIGURE 4.20: Energy Usage of BLDG-3 for each phase of energy analysis

4.6.4 BLDG-4

The energy usage of the BLDG-4 building for each phase of energy analysis is shown in the figure 4.21. The energy usage during phase I, II, III and IV are 310 Kwh/m^2/yr, 307 Kwh/m^2/yr, 303 Kwh/m^2/yr, 299 Kwh/m^2/yr. It can be seen in the figure that in phase 2 when only R38 type insulation was considered and also in phase 3 when Pv-Surface Coverage was considered the annual energy usage of the building reduced by 3Kwh/m2/yr and 7 Kwh/m^2/yr. Only in this case the factor Pv-Surface Coverage is dominant in energy efficiency. The combined application of both the factors reduced the energy usage of BLDG-4 by 11Kwh/m^2/yr.

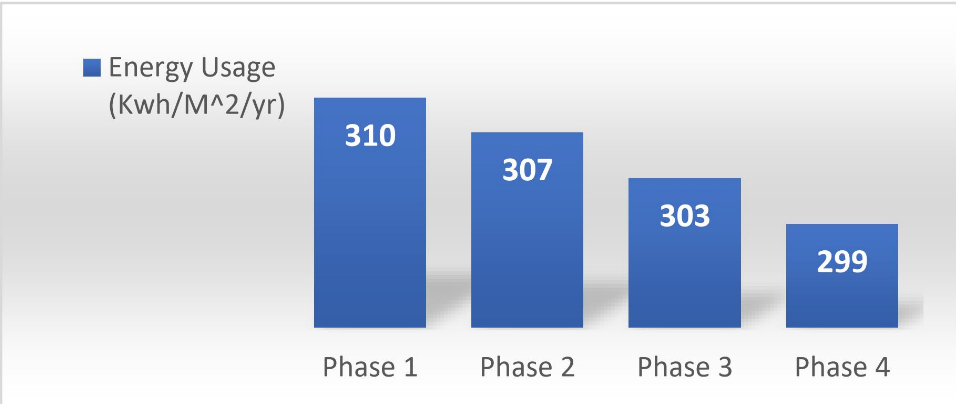


FIGURE 4.21: Energy Usage of BLDG-4 for each phase of energy analysis

4.7 Cost Analysis

The cost analysis of the NZEB transformation is one of the most important concerns in this whole study. Hence a detailed cost analysis was carried out for the parameters of NZEB factors that were finalized for this study. The average cost was taken due to variation in the cost of installation depending on the location of the site. The main objective of this study is to determine the cost of implementing the most suitable and efficient combination of factors and their parameters. In the energy analysis section, the case study buildings were subjected to a cloud-based energy analysis process and the whole purpose of this energy analysis was to apply different combinations of factors and their parameters on the case studies and then determine the most energy efficient option so that the estimated cost of implementing that option can be determined.

The cost analysis process was done in four steps.

- Without implementing any NZEB factor. (conventional Building)
- With R38 type Insulation
- With 60% of the roof top covered with PV panels.
- With both R38 insulation and 60% of roof top covered with PV panels.

4.7.1 Cost of Conventional Buildings

Cost of conventional building was determined, as we needed a baseline cost to which the additional cost of transformation will be added so that the estimated additional cost could be determined. The data from the BOQs of the case studies has been represented in the Table 4.8 below.

TABLE 4.8: Original Cost of Case Studies

Case Studies	Cost from BOQs (PKR)
BLDG-1	48,726,810
BLDG-2	30,033,915
BLDG-3	19,224,041
BLDG-4	43,000,218

4.7.2 Cost of Roof Insulation Installation

In second phase of energy analysis, the Roof Construction Factor was considered. The cost of roof insulation material and its installation was determined by market survey. Expanded Polystyrene was selected as insulation material due to its availability and effectiveness in the sub-tropical climate of Islamabad. The cost of installing the expanded polystyrene on each of the case study building has been determined and shown in the table 4.9.

TABLE 4.9: Total cost of buildings with Roof Insulation

Properties	**Case Studies**			
	BLDG-1	**BLDG-2**	**BLDG-3**	**BLDG-4**
Original Cost of the Building (PKR)	48,726,810	30,033,915	19,224,041	43,000,218
Cost of insulation material (Per m^2/per inch) (PKR)	324	324	324	324
Required Thickness (inches)	7	7	7	7
Roof top Area (m^2)	335.06	264	215	546
Cost for the Insulation for the given roof top area (PKR)	759,780	598,752	487,620	1,238,328
Total cost of the building with roof insulation (PKR)	49,486,590	30,632,667	19,711,733	44,238,909
Increase in cost (%)	1.5	1.95	2.4	2.8

4.7.3 Cost Analysis with PV-Panels Installed

In third phase of energy analysis, the roof Construction factor was considered. as the 60% option gave the most efficient results hence the cost analysis for all the case study buildings was carried out for only 60% surface coverage option. The additional cost of installing PV panels on each case study building has been calculated and mentioned in the table 4.10 along with the total cost of building after PV installation and percentage increase in cost. The minimum increase in cost is 6.7% for BLDG-1 and maximum is 11.7% for BLDG-4.

Table 4.10: Total Cost of Buildings with PV Installed

Properties	Case Studies			
	BLDG-1	**BLDG-2**	**BLDG-3**	**BLDG-4**
Original Cost of the Building (PKR)	48,726,810	30,033,915	19,224,041	43,000,218
Cost Of Pv Installation (PKR)	3,55,0000	2,800,000	2,400,000	5,75,0000
Total cost with Pv Panels (PKR)	52,276,810	32,833,915	21,624,045	48,750,218
Increase in cost (%)	6.7	8.5	11	11.7

4.7.4 Cost with PV Panels and Roof Insulation

In fourth phase of energy analysis, both the factors were analyzed for each case study building. The cost of installing both Pv Panels and Roof Insulation in each case study building has been calculated in the earlier phases. The table 4.11 shows the total cost of the buildings after applying these factors which was calculated by adding the cost of PV panels installation and roof insulation into the original cost of the buildings. The percentage increase in the original cost of each case study building is also given.

Table 4.11: Total Cost of buildings with Pv and Roof Insulation

Properties	Case Studies			
	BLDG-1	**BLDG-2**	**BLDG-3**	**BLDG-4**
Original Cost of the Building (PKR)	48,726,810	30,033,915	19,224,041	43,000,218
Cost Of PV Installation (PKR)	3,55,0000	2,800,000	2,400,000	5,75,0000
Cost of roof Insulation (PKR)	759,780	598,752	487,620	1,238,328
Total cost of building (PKR)	53,036,590	33,432,667	22,111,733	49,988,909
Increase in cost (%)	8	10	13	14

4.8 Comparative Cost Analysis-Case Study Based

In order to have to have almost accurate idea of the cost that will incur in the application of NZEB factors, the comparison was done to represent the rise in cost with the addition of each factor. The difference in the cost of case studies according to the phases of energy analysis is presented in graphical form below.

4.8.1 BLDG-1

The variation in the original cost of BLDG-1 with the addition of NZEB factors is represented in graphical form and can be seen in the figure 4.22. The total cost of the buildings increased from 48.7 million to 53 million which makes almost 8% of increase in the original cost of the building.

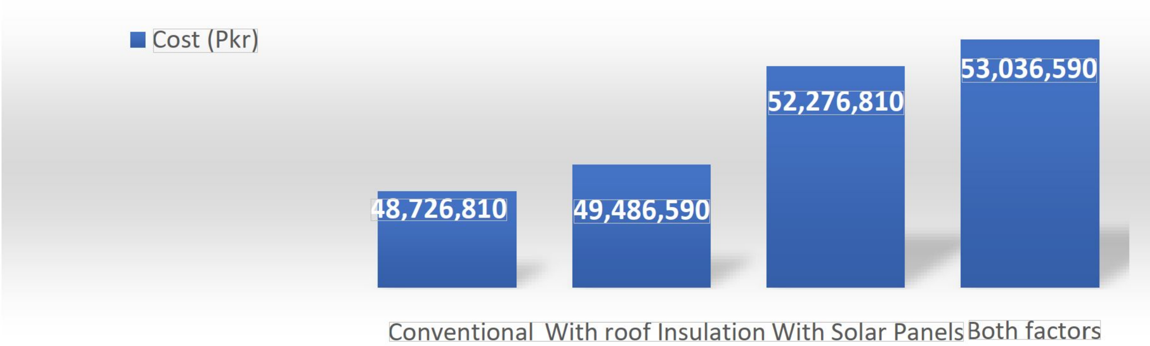


FIGURE 4.22: Cost of BLDG-1 during each phase of energy analysis

4.8.2 BLDG-2

The variation in the original cost of case study 2 with the addition of roof insulation, solar panels and their combined application is represented in graphical form and can be seen in the figure 4.23. the total cost of the buildings increased from 30 million to 33.4 million with the addition of both NZEB factors making almost 10% increase in the original cost.

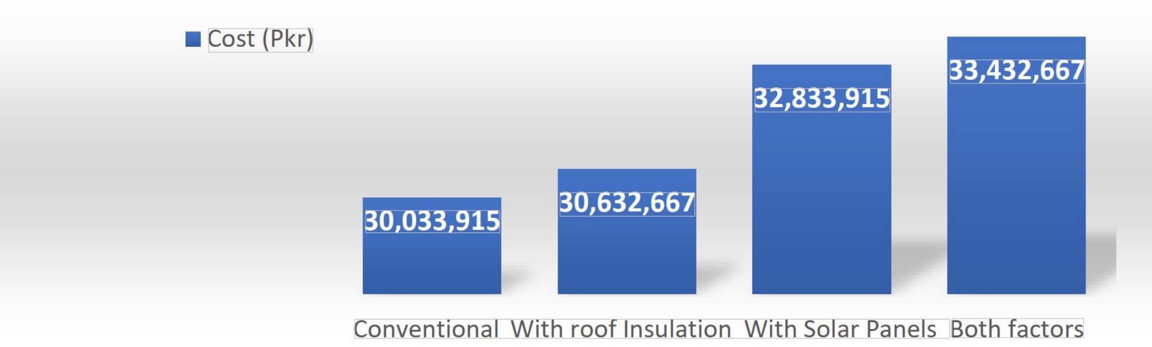


FIGURE 4.23: Cost of BLDG-2 during each phase of energy analysis

4.8.3 BLDG-3

The variation in the original cost of case study 3 with the addition of roof insulation, solar panels and their combined application is represented in graphical form and can be seen in the figure 4.24. The total cost of the buildings increased from 19.2 million to 22.1 million with the addition of both NZEB factors making almost 13% increase in the original cost.

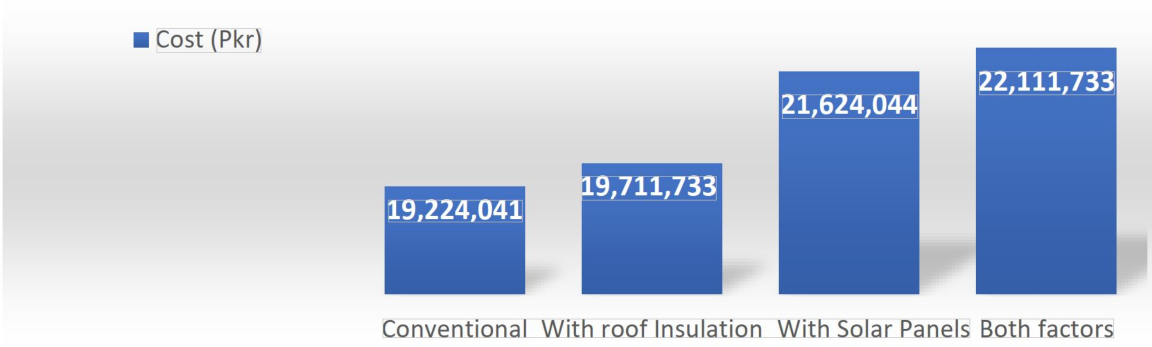


FIGURE 4.24: Cost of BLDG-3 during each phase of energy analysis

4.8.4 BLDG-4

The variation in the original cost of case study 4 with the addition of roof insulation, solar panels and their combined application is represented in graphical form and can be seen in the figure 4.25. The total cost of the buildings increased from 43 million to 49.9 million with the addition of both NZEB factors making almost 14% increase in the original cost.

FIGURE 4.25: Cost of BLDG-4 during each phase of energy analysis

4.9 Payback period

From the energy analysis of the case studies, the cost analysis of the energy reduced and the components installed for NZEB factors, the final objective of the study is to determine the payback periods of the additional components for each case study building. The details of payback period calculation for all buildings have been provided in the appendix A. In table 4.12 the payback periods of each case study building is prsented.

TABLE 4.12: Payback Periods of NZEB Parameters

Case Studies	**Total Area m^2**	**Roof top Area (m^2)**	**Payback Period of NZEB parameters (Yrs)**
BLDG-1	1746	335	3.5
BLDG-2	1013	264	4.5
BLDG-3	1115	215	4
BLDG-4	3110	546	9

4.10 Relationship of Cost and NZEB transformation

The relationship between cost and areas of buildings with NZEB factors is shown in the figure 4.26. The cost is represented in percentage and area in m^2. BLDG-1 has the lowest increase in cost of 8% while the BLDG-4 has the highest increase in cost of 14%.

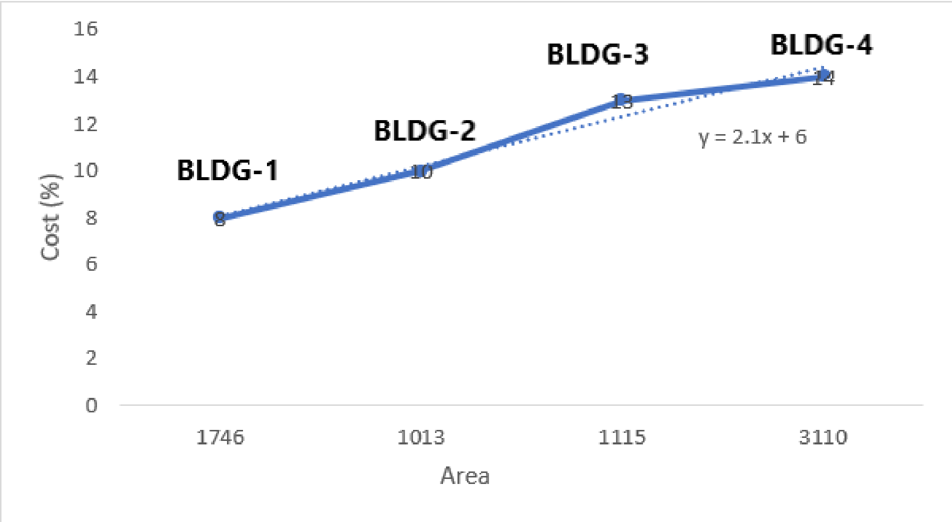


FIGURE 4.26: Relationship between Cost and Areas of NZEBs

The relationship between the cost and areas of the innovated NZEBs is defined by the following equation.

$$Y = 2.1x + 6$$

Chapter 5

Conclusions and Recommendations

This chapter is comprised of the findings and accomplishments of this research study. Also, the future recommendations regarding the NZEB concept in existing buildings are also described. This chapter further consists of three sections. The first section describes the findings of this study, second section presents the conclusions based on the energy and cost analysis and the third section discusses the future recommendations regarding NZEB concept.

5.1 Findings

The findings from the energy and cost analysis in this study are:

- From energy Analysis, R38 type insulation for roof was found to be more feasible due to its lesser cost and energy saving.
- The 60% roof top surface coverage was found to be economical due to energy efficiency and lesser cost.
- The incorporation of Roof Insulation and Pv panels on the 60% roof top area reduced the annual energy usage by 5.7 Kwh/m^2/yr, 6.2 Kwh/m^2/yr,

2.5 Kwh/m^2/yr and 3.5 Kwh/m^2/yr for BLDG-1, BLDG-2, BLDG-3 and BLDG-4 respectively.

- The increase in cost with both factors for BLDG-1, BLDG-2, BLDG-3 and BLDG-4 was found to be 8%, 10%, 13% and 14% respectively.
- Payback periods for BLDG-1, BLDG-2, BLDG-3 and BLDG-4 were estimated to be 3.5 yrs. 4.5 yrs, 4 yrs and 9 yrs respectively.

5.1.1 Conclusions

- In this study, a cloud-based software Insight360 was used for energy analysis of the building models developed In BIM which affirms the feasibility and authenticity of Insight360 to be taken into practical use in building projects for designing and monitoring the energy patterns of the buildings.
- NZEB concept requires to make buildings energy efficient first and then design a energy generation system according to the requirement. In this study only one energy efficient measure was incorporated in the models i.e., Roof Insulation. It means that to achieve NZE goals in buildings the factors that affect the energy performance of the buildings can be added according to the requirements of the building located at certain location.
- Before deciding the NZEB factors for the conventional building, the available resources, residents behaviour and environment should be considered
- From energy analysis it was established that extra thick roof insulation material doesn't give any benefits rather it will cost more. In this study it was found that R38 type insulation works as good as R60 type in Islamabad region.
- From energy analysis and cost analysis comparisons carried out for the four phases, it was established that the 60% roof surface coverage option is more economical than 75% and 90% options due to less additional cost and significant energy saving.

- The payback periods of the installed components were estimated for each case study where the minimum payback period was estimated to be 3.5 years for BLDG-1 which is 4 storey building and maximum of 9 years was estimated for the BLDG-4 which is a five storey building.

- The methodology adopted in this study is very practical and useful and can be very benificial in achieving NZE goals in buildings on larger scale. However, the adoption of factors and parameters remains dependant upon local conditions.

- The payback period depends on the roof top area and energy consumption patterns, which indirectly depends on number of floors and Area/floor.

- The relationship of cost and areas of innovated NZEB shows that the NZEB cost of the buildings raises with area of building and roof top area. Orientation of the building also plays role in the energy performance of the building.

5.1.2 Recommendations

The recommendations for the future research works are given on the basis of findings and conclusions presented in this study.

- Higher buildings with different specifications should also be analysed.

- The effect of only one energy efficiency factor i.e. *Roof Insulation* was discovered in this study, there are other factors that play an important role in the energy performance of a building. These factors include walls insulation, plug load efficiency, windows glass, HVAC, lighting efficiency. These factors need to be discovered in the future studies. However, proper design parameters would be required.

- The cost analysis should be performed for the other NZEB factors too and their causal relationship with the transformation of a conventional building to NZEB should also be discovered along with payback periods.

- Results shown that NZEB provides energy saving with considerable payback periods, hence governments should design such policies to support NZEB concept.

- Insulation and PVs are easily incorporable in residential construction. Governments should implement proper legislation to manage energy demand through these factors. Also the parameters for NZEB should be subsidezed to promote the trend.

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Appendix A

TABLE 1: Payback Period of applied NZEB factors for BLDG-1

Symbols	Properties	Formula	Value
A	No. of floors of BLDG-1		4
B	Total Area of BLDG-1 (m^2)		1745.5
C	Roof top Area (m^2)		335
D	Cost of one commercial electricity unit (Pkr)		25.65
E	Annual EUI reduced with R38 insulation (kwh/m^2/yr)		20
F	Annual EUI reduced with 60% option (kwh/m^2/yr)		8
G	Total Annual EUI reduced with both factors (kwh/m^2/yr)	E+F	28
H	Total energy reduced with both factors (kwh/yr)	B*G	48,876
I	Cost of reduced energy with both factors (PKR/yr)	D*H	1,253,855
J	Cost of R38 Insulation for BLDG-1 (PKR)		759,780
K	Cost of 60% roof top coverage with PV (PKR)		3,550,000
L	Total cost of NZEB factors (PKR)	J+K	4,309,780
	Payback Period (yrs)	L/I	3.5

Table 2: Payback Period of applied NZEB factors for BLDG-2

Symbols	Properties	Formula	Value
A	No. of floors of BLDG-2		4
B	Total Area of BLDG-1 (m^2)		1012.7
C	Roof top Area (m^2)		264
D	Cost of one commercial unit (Pkr)		25.65
E	Annual EUI reduced with R38 insulation (kwh/m^2/yr)		21
F	Annual EUI reduced with 60% option (kwh/m2/yr)		8
G	Total Annual EUI reduced with both factors (kwh/m^2/yr)	E+F	29
H	Total energy reduced with both factors (kwh/yr)	B*G	29,369
I	Cost of reduced energy with both factors (PKR/yr)	D*H	753,315
J	Cost of R38 Insulation for BLDG-1 (PKR)		598,752
K	Cost of 60% roof top coverage with PV (PKR)		2,800,000
L	Total cost of NZEB factors (PKR)	J+K	3,398,752
	Payback Period (yrs)	L/I	4.5

Table 3: Payback Period of applied NZEB factors for BLDG-3

Symbols	Properties	Formula	Value
A	No. of floors of BLDG-3		5
B	Total Area of BLDG-1 (m^2)		1115
C	Roof top Area (m^2)		215
D	Cost of one commercial unit (PKR)		25.65
E	Annual EUI reduced with R38 insulation (kwh/m^2/yr)		7
F	Annual EUI reduced with 60% option (kwh/m^2/yr)		7
G	Total Annual EUI reduced with both factors (kwh/m^2/yr)	E+F	14
H	Total energy reduced with both factors (kwh/yr)	B*G	31,220
I	Cost of reduced energy with both factors (PKR/yr)	D*H	800,793
J	Cost of R38 Insulation for BLDG-1 (PKR)		487,620
K	Cost of 60% roof top coverage with PV (PKR)		2,400,000
L	Total cost of NZEB factors (PKR)	J+K	3,200,793
	Payback Period (yrs)	L/I	4

Table 4: Payback Period of applied NZEB factors for BLDG-4

Symbols	**Properties**	**Formula**	**Value**
A	No. of floors of BLDG-4		5
B	Total Area of BLDG-1 (m^2)		3110
C	Roof top Area (m^2)		546
D	Cost of one commercial unit (PKR)		25.65
E	Annual EUI reduced with R38 insulation ($kwh/m^2/yr$)		3
F	Annual EUI reduced with 60% option ($kwh/m^2/yr$)		7
G	Total Annual EUI reduced with both factors ($kwh/m^2/yr$)	E+F	10
H	Total energy reduced with both factors (kwh/yr)	B*G	31,100
I	Cost of reduced energy with both factors (PKR/yr)	D*H	797,715
J	Cost of R38 Insulation for BLDG-4 (PKR)		1,238,328
K	Cost of 60% roof top coverage with PV (PKR)		5,750,000
L	Total cost of NZEB factors (PKR)	J+K	6,988,328
	Payback Period (yrs)	L/I	9

Appendix B

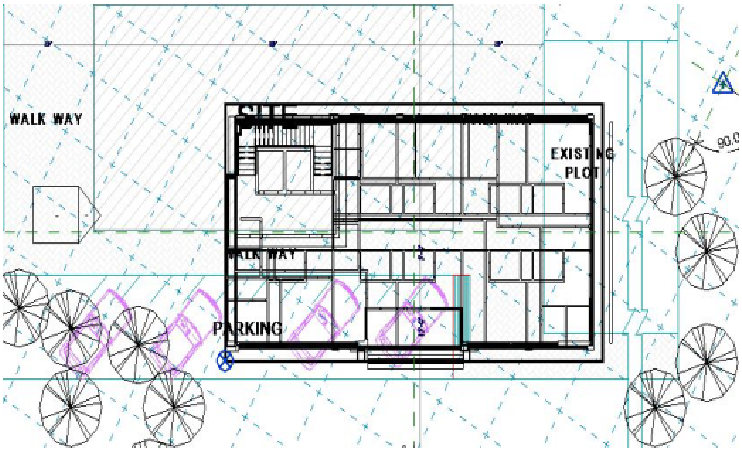

FIGURE 1: Layout of BLDG-1

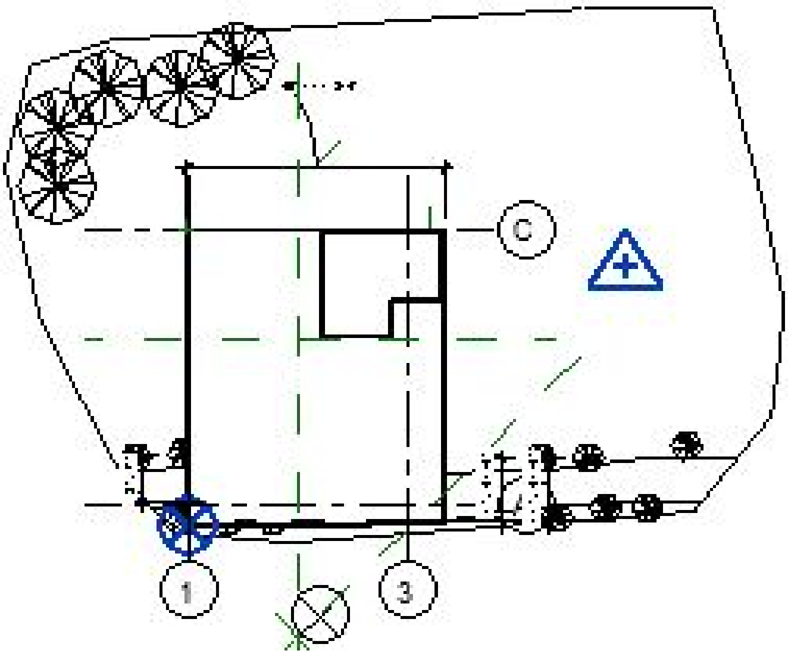

FIGURE 3: Layout of BLDG-3

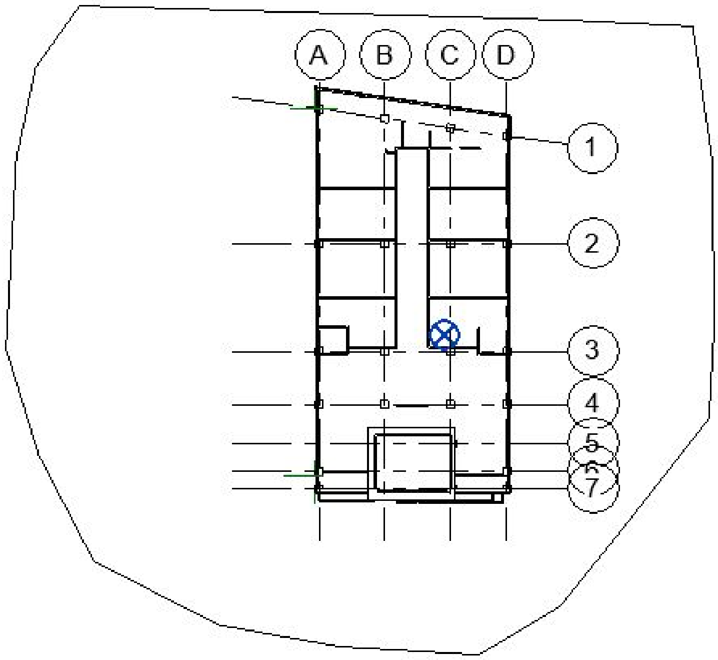

Figure 2: Layout of BLDG-2

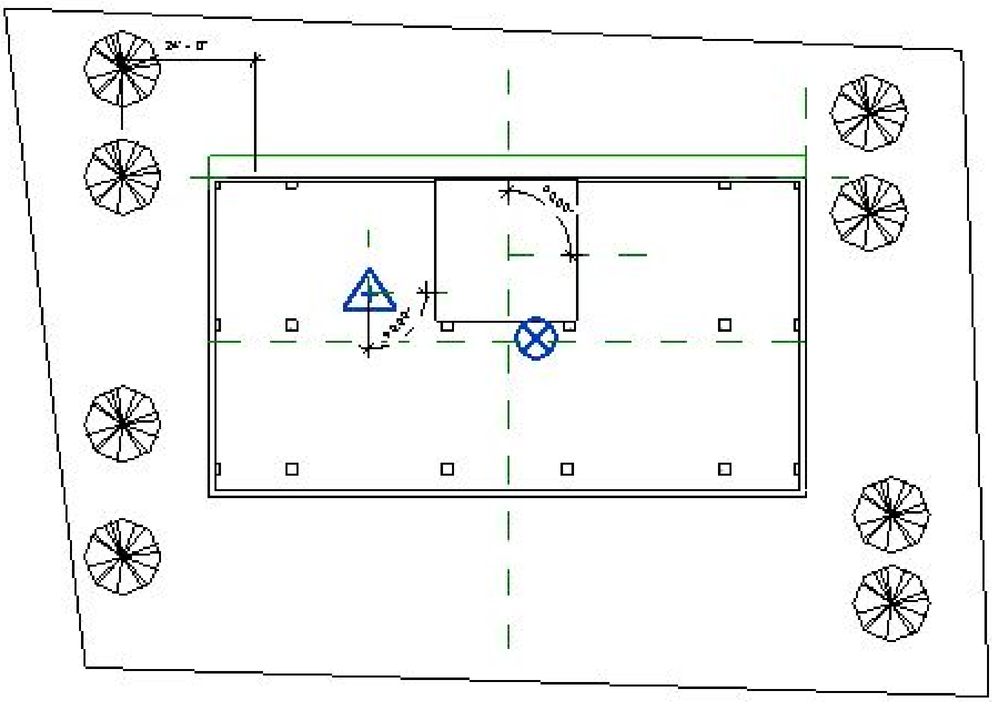

Figure 4: Layout of BLDG-4