Design and Techno-Economic Analysis of Net Zero Energy Buildings using Energy Simulations

Author

Shoaib Ahmed

Regn Number

00000326847

Supervisor

Dr Zaib Ali

DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

ISLAMABAD

OCTOBER, 2023

Design and Techno-Economic Analysis of Net Zero Energy Buildings using Energy Simulations

Author

Shoaib Ahmed

Regn. Number

00000326847

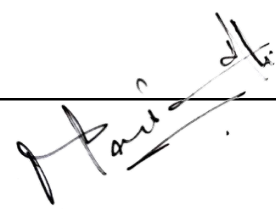
A thesis submitted in partial fulfillment of the requirements for the degree of

MS Mechanical Engineering

Thesis Supervisor:

Dr Zaib Ali

Thesis Supervisor's Signature: ____



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY, ISLAMABAD

OCTOBER, 2023

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by **Regn No. 00000326847 Shoaib Ahmed** of **School of Mechanical & Manufacturing Engineering (SMME) (SMME)** has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis titled. **Design and techno-economic analysis of net zero energy buildings using energy simulations**

Signature: 

Name (Supervisor): Zaib Ali

Date: 03 - Oct - 2023

Signature (HOD): 

Date: 03 - Oct - 2023

Signature (DEAN): 

Date: 03 - Oct - 2023

Certificate for Plagiarism

It is certified that MS Thesis Titled: Design and Techno-Economic Analysis of Net Zero Energy Buildings using Energy Samulations by Shoaib Ahmed (326847) has been examined by me. I undertake the follows:

a. Thesis has significant new work/knowledge as compared already published or are under consideration to be published elsewhere. No sentence, equation, diagram, table, paragraph, or section has been copied verbatim from previous work unless it is placed under quotation marks and duly referenced.

b. The work presented is original and own work of the author (i.e., there is no plagiarism). No ideas, processes, results, or words of others have been presented as Author own work.

c. There is no fabrication of data or results which have been compiled/analyzed.

d. There is no falsification by manipulating research materials, equipment, or processes, or changing or omitting data or results such that the research is not accurately represented in the research record.

e. The thesis has been checked using TURNITIN (copy of originality report attached) and found within limits as per HEC plagiarism Policy and instructions issued from time to time.

Name & Signature of Supervisor

Dr Zaib Ali

Signature:

DR. ZAIB ALI
Associate Professor
NUST School of Mechanical &
Manufacturing Engineering
(SMME), NUST, Islamabad

Declaration

I certify that this research work titled *"Design and Techno-Economic Analysis of Net Zero Energy Buildings using Energy Simulations"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

Shoaib Ahmed

2020-NUST-MS-Mech-326847

Copyright Statement

Acknowledgements

I am thankful to my Creator Allah Subhana-Watala to has guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed, I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me throughout in every department of my life.

I would also like to express special thanks to my supervisor Dr Zaib Ali for his help throughout my thesis. Each time I got stuck in something; he came up with the solution. Without his help I wouldn’t have been able to complete my thesis. I appreciate his patience and guidance throughout the whole thesis.

Finally, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment.

Abstract

The increasing demand for electricity is straining our natural resources. To secure a sustainable future, a transition to renewable energy sources is underway aimed at reducing resource depletion and environmental harm. During the last few years, the evolution of solar industry has made it possible to use it on domestic scale also. Development of structures that are more sustainable and eco-friendlier is the imperative of the time. Phase change materials (PCM's) and Photovoltaics (PVs) have emerged as a promising technology with potential to revolutionize the building sector.

In the past although PCM's and solar panels integration has been studied but none of the study incorporated the climatic condition of Pakistan. The outcomes of this study offer valuable insights into the viability of PCM-enhanced BIPV (Building Integrated Photovoltaics) systems as an effective and economically feasible approach for creating energy-efficient buildings. These findings also enhance our comprehension of the economic practicality and real-world application of such technologies within the construction sector. For this purpose, a common residential unit in Pakistan is selected which is then analyzed in various climatic conditions across the country.

With the inclusion of PCMs demand of energy is decreased by 7-12% in different climatic conditions with maximum decrease is observed 12.25% in case of Lahore, cooling demand of the building is decreased by 10-17% whereas maximum decrease is observed in Murree by 17.75% and heating demand reduced by 12-20%. BIPV system increased the solar production overall by 50.03% and net zero energy target is achieved. The knowledge derived from this research holds significant value for policymakers, architects, and engineers, empowering them to make informed decisions when considering the implementation of PCM-enhanced BIPV systems. Such decisions can play a pivotal role in advancing the creation of environmentally sustainable and energy-efficient buildings.

Key Words:

Net Zero Energy, Building Integrated Photovoltaics, Phase Change Materials, Life Cycle Assessment

Abbreviations

NZEB	Net Zero Energy Building
BIPV	Building Integrated Photovoltaics
GHG	Green House Gases
PCAM	Passive Climate Change Adaptation Measures
PCM	Phase Change Material
EPW	EnergyPlus Weather
TMY	Typical Meteorological Year
NV	Natural Ventilation
ATC	Annual Total Consumption
LPD	Light Power Density
EPD	Equipment Power Density
HVAC	Heat Ventilation and Air Conditioning
ESC	Energy Storage Capacity

Table of Contents

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

The path to Nearly Zero Energy Buildings and ultimately zero energy districts is Building Integrated Photovoltaics (BIPV). BIPV surfaces can be used on facades and roofs and their performance, productivity and effectiveness are influenced by factors such as shading, direction with respect to solar incident rays, and surface reflections. Energy Plus simulations are used to examine the building's performance while taking into account a reference building with several thermal zones that is situated in a neighborhood with comparable features. In this instance, the annual NZED criteria are met by harvesting solar energy on 60% of rooftops and 60% of the overall area of the façades, with an 11% loss in energy production per PV unit area due to shadows and darkening effect of nearby buildings. [1]

1.1 NZEB

Buildings that are self-sufficient means generations and consumption of buildings are equal or in other words building demand is less than the energy generation are termed as Net Zero Energy Building (NZEB). These are designed to use energy as low as possible by using passive energy methods, better building envelope and state of the art heating and cooling mechanisms with efficient energy consumptions. [2] These buildings have significant less carbon footprints than a traditional building. They are also more comfortable and cost effective to operate making them an attractive and economical sustainable option for both residential and commercial applications.

1.2 BIPV

Building integrated photovoltaics incorporates the photovoltaics cells on building roofs, façade and walls to generate electricity. BIPV systems can power multiple building systems such as lighting, heating, and cooling, leading to a substantial reduction in energy consumption and greenhouse gas emissions. BIPV essentials helps in achieving NZEB by increasing the energy conversion area for a building. Other than roof tops, the added façade and walls BIPV helps to achieve green zero energy goal. [3]

1.3 PCMs

Phase change materials (PCM) are considered as smart materials that are implemented as thermal regulators for buildings because it helps to link the gap between 'when the energy is available' and 'when it is required for cooling, heating, and enhancing the comfort & quality of the residential spaces [20]. Numerous research has taken place to study the impact of phase change materials (PCMs) on buildings roofs. [4-7]. Saxena et al. investigated the effect of embedding PCM materials into bricks to improve the indoor environment of the buildings. Experimental testing was conducted during peak summertime when temperatures exceeded 45^{o} C during a normal day. The results indicated that the temperature got reduced between 5~ 9.5°C across the embedded bricks with PCMs as against to the ordinary bricks without embedded phase change materials. [8]. Also, Eddhanak-Ouni et al. research resonated with the previous study which had deduced that Phase Change Material incorporated in the cementitious materials boosted the thermal qualities of the building [9]. Yoo et al. surveyed the thermal performance of bio-composites formed by mixing coffee wastes with PCM materials. The findings revealed that the usage of Biocompatible PCM by-products enhanced the thermal properties of the residence and was ecologically friendly. [10].

1.4 Climate Change

Climate change can adversely impact the thermal comfort and energy efficiency of the buildings stock. The South Asian countries are particularly vulnerable to the adverse impacts of climate change specially in the form of rising temperatures and increasing frequency of heat waves. The passive building design measures can be useful in mitigating and adapting to the climate change by increasing energy efficiency and reducing greenhouse gas (GHG) emissions. In this study various passive climate change adaptation measures (PCAMs) have been used individually and in form of combinations in order to analyze their impact on the energy efficacy of residential buildings in Pakistan. [11] It has been found that the natural ventilation and front green wall are the most efficient options for reducing the overall energy consumption. By implementation of these PCAMs, cooling demand can be decreased by 27.75% while heating demand can be reduced by 35%. Secondly, the prospect of net zero-energy building and reduced CO2 emissions are also studied. It has been shown that building can achieve net-zero energy on an annual basis at every orientation and it can attain the status of nearly zero-energy building on a monthly basis. Moreover, emitted CO_2 can be reduced by 31% by using the renewable energy. [12]

1.5 Design Builder

Design Builder is software used by architects, engineers, and building scientists to design and analyze the energy performance of buildings. It is used to design the 3D models and stimulate the building for energy analysis. Existing infrastructure can be modeled or retrofitted to analysis energy demands and to use state of the art techniques including passive and phase change materials to optimize the energy demand. It is a popular tool among professionals in the building industry and is widely used in the design and analysis of NZEB (Nearly Zero Energy Building) projects.

1.6 Building Carbon Footprints

Buildings consume 30%–40% of the yearly primary energy in developed countries, and approximately 15%–25% in developing countries [13]. Approximately 40% of primary energy consumption in the United States is attributed to buildings, which also account for around 40% of the total U.S. CO_2 emissions and 7.4% of global CO_2 emissions. Specifically, residential buildings contribute to 21% of U.S. energy consumption and around 20% of total U.S. CO_2 emissions. By reducing energy usage in homes, it would significantly decrease energy consumption and greenhouse gas emissions. [14] As a result, there is a growing global focus on net-zero energy buildings (NZEBs) to decrease emissions. In this paper NZEBs are defined as buildings that generate at least as much energy as they consume on an annual basis when tracked at the building site [15]. The United Kingdom was the 1st country to mandate NZEBs on a large scale, with the goal of producing zero-carbon homes by 2016 [16]. The European Union parliament has introduced a directive regulating that all new buildings constructed starting January 2021 should be "nearly zero-energy" buildings. France has set ambitious targets for energy-positive houses by 2020 [17].

The U.S. Department of Energy (DOE) has targeted "marketable zero-energy homes in 2020 and commercial zero energy buildings in 2025" [8]. California will require all new residences to be net-zero by 2020, and all commercial buildings by 2030 [18]. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) set a goal of market-viable NZEBs by 2030 [19]. Many other countries have also set long-term goals to implement NZEBs. [20]

There are many approaches to realize residential NZEBs, either through minimized building energy demand (via improved building designs and/or occupant behaviors) or increasing renewable energy generation. There is a lack of systematic literature review focused on recent progress in residential NZEBs. A systematic review and professional perspective can greatly contribute to broader and better implementation of residential NZEBs towards a sustainable future. Therefore, this paper gives an overview of the public literature covering the methods and recent developments (≈last 10 years) in residential NZEBs across the world. Although there have been other review papers on NE. [21]

According to the European Commission's report in 2010, buildings in the EU are accountable for 40% of energy consumption and 36% of CO_2 emissions. These numbers prove that the building sector represents a significant energy and CO_2 emissions savings potential. To achieve EU climate and energy objectives, improving buildings in terms of energy consumption is necessary.

1.7 Fossil Fuels

One of the regulations set forth in this directive is the limitation of the consumption of fossil

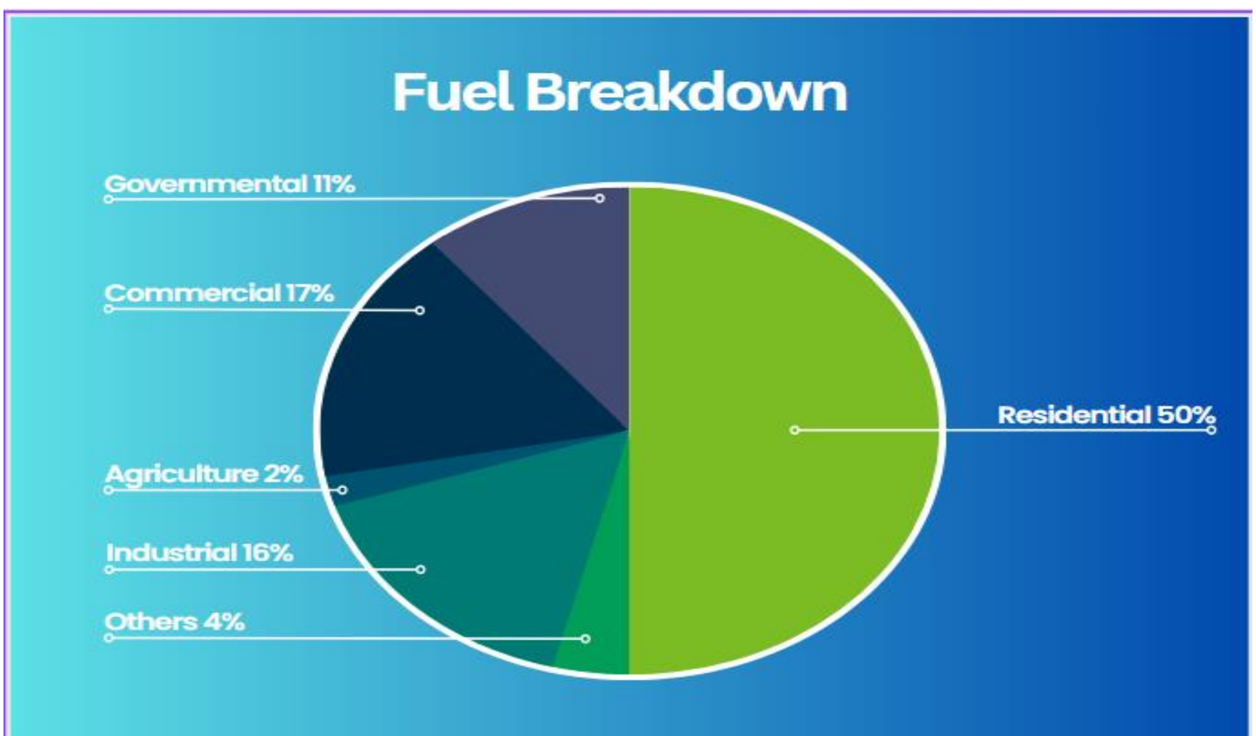


Figure 1.1: Fuel Breakdowns

fuels and energy. Ecological benefits that result from this investment, there are also significant financial implications: initial investment cost, maintenance costs, energy consumption savings, grants. In order to stimulate people to build as energy-efficient as possible, and at the same time utilize the full potential of energy savings in the building sector, both the environmental and the economical aspect of energy efficiency should be considered. [22] Not only is it important that people realize that energy-efficient building is necessary for the environment, the economical aspect of this should support people in making this decision. The requirement that all new buildings should be nearly zero-energy-buildings (nZEB) in EU from 2020 onwards is a key element to achieve the longer-term objectives of the EPBD and EPB (Buildings Performance Institute Europe.

1.8 Fossil Fuel to Green Energy Transition

Ensuring the energy transition from fossil fuel to renewable energies is amid the biggest challenges of the 21st century. The actual energy situation and the future previsions are very alarming because of the increase of energy demand does not satisfy the sustainability objectives. Indeed, according to the International Energy Agency (IEA), the world demand of energy was estimated to be 12 Giga-ton equivalent of petroleum (GTEP) in 2010 with a 13% use of renewable energies. In 2035, the world energy demand is estimated to increase to 17 GTEP with an 18% use of renewable energy [23]. Morocco has to face the same energy challenges and to become less dependent on fossil fuels. In fact, crude oil, oil products and coal accounted for 81.7% of its energy source in 2013 [24]. It is in this context that Morocco launched a national strategy to reduce its dependency on external energy resources. Morocco aims at producing 52% of its energy from renewable sources by the end of 2030.

1.9 Energy Demand

In the electrical power system, load demand plays an important role of maintaining the stability of the system. A good proportionality between demand (consumption) and supply (generation) should hold in order to avoid generation disturbances which later introduces negative effects in technical, economic and social areas (Davda, Desai, and Parekh, 2011). The rapid rise of energy needs has made electric utility companies to expand generation plants with respects to peak demand rather than average power in order to meet the consumer's demand (Goyal, and Shimi, 2017). This approach, unfortunately, renders power systems highly underutilized and customers' consumption patterns increasingly irresponsible. [25] Additionally, it has spurred electric utility companies to make substantial, long-term investments in new power plants, primarily reliant on traditional energy sources. These power plants, in addition to being costly to build, contribute to heightened emissions of Greenhouse Gases (GHG), with profound impacts on the Earth's climate, weather patterns, sea levels, and land use, as documented by Swathi, Balasubramanian, and Veluchamy in 2016 [26]. To improve the efficiency of existing power plants without necessitating the construction of new facilities, it is crucial to make optimal use of their generation capabilities, as emphasized by Abaravicius in 2007 and Won and Song in 2013 [27].

In today's global context, load management is widely acknowledged as a straightforward, safe, and cost-effective approach to achieving a better synchronization between electricity generation and demand. This involves implementing practices on the consumer side, such as reducing demand and adjusting load profiles. Typically, these load management practices aim to shift electricity consumption from peak to off-peak periods, thereby reshaping the load profile and reducing the overall cost of electricity. Through research and emphasis on energy management, electrical engineers can reduce the operational costs of power systems by optimizing the utilization of the available generation capacity [28].

Progress in the development of residential net-zero energy buildings (NZEBs) holds great promise for significantly reducing energy consumption and curbing greenhouse gas emissions. These advancements fall under three main categories: energy infrastructure connections, renewable energy sources, and energy-efficiency measures. Remarkably, there has been a notable absence of a systematic literature review focused on recent advancements in residential NZEBs. To address this gap, this work offers an in-depth overview of each of these categories, with a specific emphasis on the latest developments over the past decade. Its primary objective is to provide valuable references and support for the broader and more successful adoption of residential NZEBs on a global scale. In the domain of energy infrastructure connections, this discussion encompasses electrical grids, district heating/cooling networks, and various energy storage options, including vehicle-to-home and hydrogen storage. When it comes to renewable energy sources, the focus is on solar photovoltaic and solar thermal systems, wind energy, and biomass, which includes micro combined heat and power (CHP) systems. The final category delves into energy-efficiency measures, which include improvements in building envelope designs, more efficient HVAC (heating, ventilation, and air conditioning) systems, upgrades in domestic hot water systems, and the integration of phase change materials. These categories offer a wide array of technological options, which can make selecting the optimal configuration a complex task. However, this diversity also grants flexibility in design, allowing for adaptation to local climates and other considerations such as building codes, available energy resources, and cost constraints. The ultimate aim of this paper is to provide references and highlight various technology choices that can be harnessed to realize the concept of residential NZEBs worldwide.

1.10 Climatic Condition of Pakistan

Today world is facing climate change and Pakistan is vulnerable to climate change. Particularly vulnerable to this issue is the building industry since increased ambient temperatures would increase the need for cooling in structures to maintain occupant comfort. In addition to interfering with residents' thermal comfort, the gradual temperature rise brought on by climate change, it is also possible that more energy will be consumed in an effort to maintain it.

Pakistan's climate can be classified as a continental type, marked by extreme temperature fluctuations on a daily and seasonal basis. Positioned in the temperate zone, Pakistan's climate is as varied as its topography [29]. The climate ranges from dry and hot conditions near the coastal areas and along the lowland plain of the Indus River to progressively cooler climates in the northern uplands and Himalayas. It can be described as a four-season country with the following seasons: 1) Winter, which is cool and dry from December to February; 2) Spring, characterized by mild, hot, and dry conditions from March through May; 3) Summer, known as the rainy season or southwest monsoon period, occurring from June to September; and 4) Autumn, marking the retreating monsoons and extending from October to November. The country generally receives limited rainfall, except for the northern regions where monsoons bring up to 200 mm of rain per month from July to September. Inter-annual variations in rainfall are significant, often leading to a cycle of successive floods and droughts. [30]

Over a decade, the peak demand for electricity of buildings has increased by 83% to touch around 25GW. [24]. The residence sector consumes about 50% of electricity in which air conditioning is accountable for over 45% of total energy consumption [31]. Owing to the ever-increasing population and extreme temperatures conditions, Pakistan has planned to expand the electric generation to 50 GW by 2025. This will, in turn, cause expansion of air conditioning usage in buildings leading to (a) higher energy consumption (b) peak energy demand increase (c) environmental related issues especially global warming and depletion of the ozone layer. (d) indoor air quality problems [32]. As a result, passive adaptation measures are necessary to lessen energy consumption and maintain indoor comfort.

The effect of climate change not only involves rising temperature but also rising sea levels, extreme weather occasions, shifting of wildlife populations and habitats to different locations and a range of other negative impacts which includes: (i) cooling and heating energy demand for buildings (ii) energy efficiency and thermal comfort for the building stock. [33]

To cater to these heating and energy cooling demands and subsequent residents' thermal comfort, it would become imperative to install more active cooling and heating systems. However, this will further increase the climate change hazards as more burning of fossil fuels, excessive carbon dioxide emissions would take place. Therefore, to overcome unpredictable temperatures and climate change impacts, effective policies and strategies are required to be employed across the globe to get a better eco-friendly environment for thermal comfort for the residents.

1.11 Passive Adaptive Measures

Santamouris et al. [28] showed that the application of green roofs lessened the average overall ambient temperature from 0.4~2.8. ° C. An experiment study conducted by Peng et.al recorded a maximum daily temperature decline of around 5 °C and cooling load savings of 0.89 kWh/m^2 on a sunny day and 0.55~0.57 kWh/m^2 on a normal cloudy day. [24]. In an experiment by Hodo-Abalo et al., a green roof was implemented for energy savings and concluded that by varying (changing) the Leaf Area Index (LAI), solar penetration flux was reduced & in the summers the indoor conditions got cooler [35].

Luo, M et al. [31] analyzed the positive effect of implementing natural ventilation to improve the thermal comfort of the building. Much research has been conducted where the mixed mode of ventilation i.e., combination of natural ventilation from operable windows (automatically controlled or manually controlled) and Heating, Ventilation and Air Conditioning Systems (HVAC). In these research, natural ventilation strategies coupled with schedules for these HVAC systems were designed in such a way to ensure thermal comfort, better air quality and minimization of energy consumption due to the mechanical cooling. [36]. In similar research by

[37,38], it is apparent that the energy consumption of a residential or commercial building can be lessened through the implementation of passive climate adaptation means.

Akbari et al. [39-41] revealed that the application of white paint on buildings roofs does increase the emissivity & reflectivity of the roof's surface, which resulted in a lower surface temperate as compared to general roof surfaces. He also concluded that these types of roofs are quite effective at cooling in the summer conditions since these roofs abate solar heat gain. However, they increase the heating load in winters causing a negative effect for this passive measure.

The term "net zero" denotes achieving a balance between the production and removal of greenhouse gases from the atmosphere. In the realm of Net Zero Energy Buildings (NZEBs), these structures are distinguished by their nearly negligible net energy consumption. This means that the total energy utilized by the building over the course of a year is approximately equal to the total renewable energy generated on-site. The concept of NZEBs has transitioned from a theoretical study to practical implementation. While there are currently only a limited number of highly productive builders in this field, the construction of NZEBs is becoming increasingly feasible, thanks to advancements in building technology, renewable energy systems, and academic research.

Determining the very first NZEB is challenging because this concept might not be entirely novel but rather a modern term for energy-efficient buildings [42]. However, there were a few publications in the late 1970s and early 1980s that used phrases like "zero energy home," "autonomous energy house," or "energy-independent house." This time period coincided with the oil crisis, which brought attention to issues related to fossil fuel sources and energy consumption, sparking discussions about sustainable building practices.

CHAPTER 2: METHODOLOGY

In current research a residential double story house is used located in Rawalpindi the twin city of Islamabad the capital of Pakistan. After the validation of results the on-site energy demand is decreased using the passive techniques. For this purpose, the phase change materials are used to decrease the cooling demand in summer season and winter heating demand. Due to geographical location the roof top is insufficient to fulfill the energy demand as there is not enough room for solar panels installation. [43] This research creates a novelty by in lining the building integrated photovoltaics along with the use of PCM's to make a building a net zero energy. For the purpose the software used in this study is Design Builder which is state of the art well reputed and recognized as the most comprehensive and powerful graphical user interface for EnergyPlus.

Design Builder is software used by architects, engineers, and building scientists to design and analyze the energy performance of buildings. It is used to design the 3D models and stimulate the building for energy analysis. Existing infrastructure can be modeled or retrofitted to analysis energy demands and to use state of the art techniques including passive and phase change materials to optimize the energy demand. It is a popular tool among professionals in the building industry and is widely used in the design and analysis of NZEB (Nearly Zero Energy Building) projects.

Design Builder in-built dynamic simulation engine that helps in generating performance data. The use of Building-Integrated Photovoltaics (BIPV) and Net Zero Energy Buildings (NZEB) has grown significantly in the construction sector. BIPV refers to a form of renewable energy system that uses solar panels to produce electricity from sunlight. On the other hand, NZEBs are structures that are built to produce the same amount of energy they consume over the course of a year. This combination of technologies offers an effective solution for both commercial and residential properties to minimize their carbon footprint, save on energy costs, and play a role in a more sustainable future. [44] BIPV technology operates by transforming sunlight into direct current electricity that can be utilized right away or stored in batteries for later use. These systems are typically placed on rooftops or walls, where they are integrated with traditional building materials such as glass or metal panels. This integration not only enhances the appearance of the building but also provides added insulation due to their thermal mass properties. Another advantage of BIPV is that they do not necessitate any extra wiring, other than connection to the existing electrical system, making installation less complicated compared to traditional PV systems that may require more extensive renovations. [45]

In summary, investing in either one or both of these technologies, depending on individual needs and preferences, can bring long-term economic and environmental benefits while also helping society move towards global sustainability goals set by international organizations and governments worldwide. By producing enough clean energy over the course of a year to offset the need for energy from external sources, NZEBs provide a way to reduce carbon footprint and save money on monthly utility bills. [46] Additionally, with many countries offering incentives for NZEB construction, they are an attractive option for both financially and environmentally conscious individuals. Meanwhile, BIPV has its own unique benefits, such as the ease of installation and its ability to blend seamlessly into existing building structures, making it an ideal solution for those looking to reduce their reliance on traditional fossil fuels for energy generation.

2.1 Design Builder Software:

To model the energy consumption of buildings in this research, DesignBuilder (Version 6.1.6.008) simulation software was utilized, which boasts a highly user-friendly and intuitive interface with extensive performance data. This software provides information such as annual energy consumption, temperature fluctuations over the year, and HVAC component properties. [47] DesignBuilder emphasizes four types of energy simulations, including cooling systems, heating systems, energy performance indicators, and real weather data simulations.

The Design Builder and EnergyPlus simulation approach is an effective method for enhancing the energy efficiency of homes. This approach offers a comprehensive solution for designing and evaluating the performance of residential buildings, from the earliest stages of design to the final outcome. The methodology provides architects, engineers, and homeowners with valuable insights into the thermal comfort and energy consumption of a building, which they can use to optimize the design for maximum energy efficiency. [48] This integrated set of tools makes it simple to improve the energy efficiency of homes and reduces the carbon footprint of these structures, making it a crucial tool for building environmentally friendly and sustainable homes.

In the initial phase, the residential house under examination was created in Design Builder using various construction and simulation parameters. The weather data for one of the city of Pakistan was chosen and used in the software simulations. The comparison between the actual energy consumption of a residential house in Rawalpindi, Pakistan and the energy output from the simulation was conducted to validate the software's results. [49]

The simulation engine, EnergyPlus, is integrated within DesignBuilder and performs all necessary calculations related to the energy model of any type of building stock, with results presented within the DesignBuilder interface. [50]

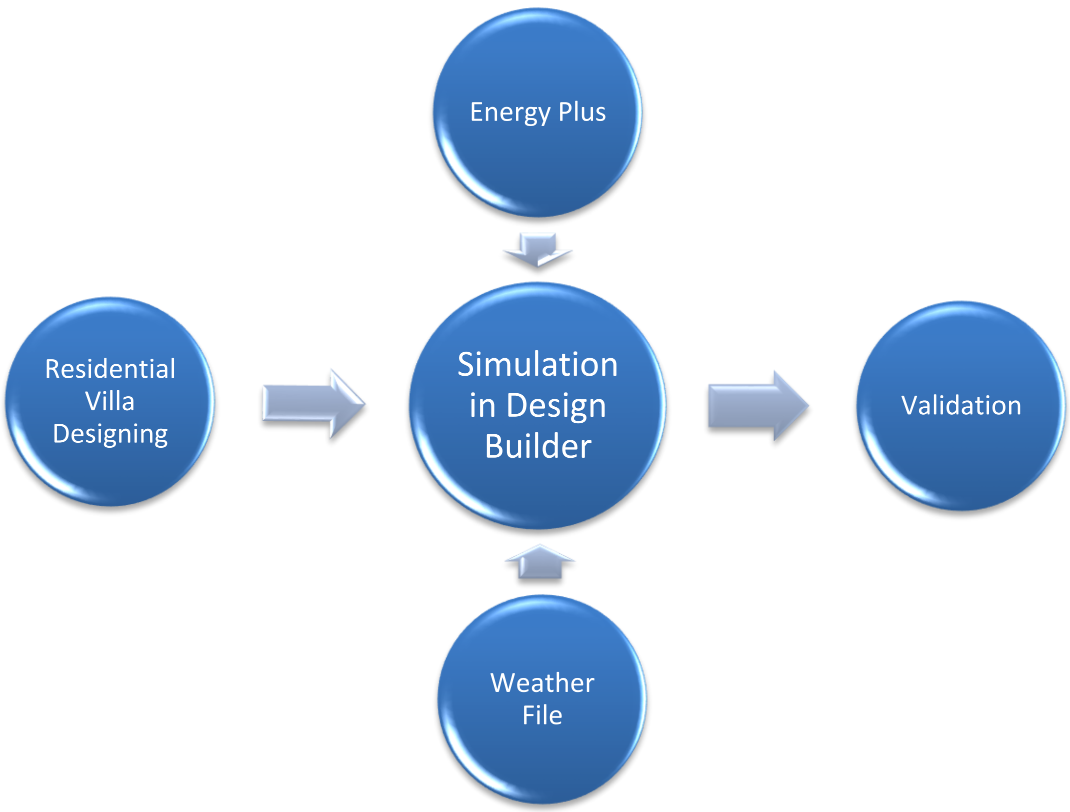


Figure 2.1: Flow Chart

2.2 Construction and Simulation Parameters:

Table-1 gives an overview of various input parameters for the construction of this residential building having 2 floors. The total floor area was 204m^2. The walls of the house consisted of 3 layers. The outer layer which was exposed to the outside ambient condition was 12 mm plaster. The middle layer was a 90 mm brick and the inside was 12 mm plaster. Similarly, the roof was constructed with an outside layer of 10 mm build-up roofing with 200 mm concrete roof slab and 13 mm plaster inside. Window-to-Wall (WWR) ratio was kept to 12%.

Split AC was the HVAC system with thermostat settings of 75.0 ^{0}F (23.8 ^{0}C) for heating and 76 ^{0}F (24.4 ^{0}C). In this type of HVAC, the compressor and condenser are placed outside the building while the evaporator and fans are positioned inside. Air Infiltration value was kept at 0.8 ACH (Air Changes per Hour). This house is occupied by 4 people. The age and sex of the occupants do not affect the outcome of the results. Lighting Power Density (LPD) was kept at 3.5 W/m^2 and Equipment Power Destiny (EPD) was 2.1 W/m$^{2.}$ LPD denotes the load consumed by any type of lighting equipment in a defined boundary area or watts per square meter of the lighting equipment. By dividing the total lighting load by the concerned area, LPD can be calculated. Similarly, EPD represents the load consumed by any equipment/appliance in any defined boundary area or watts per square meter of any appliance. It can be obtained by dividing the total equipment load by the respective area. After the validation of the results PCMs are installed in walls and roof of the house to reduce the energy demand of the residential unit.

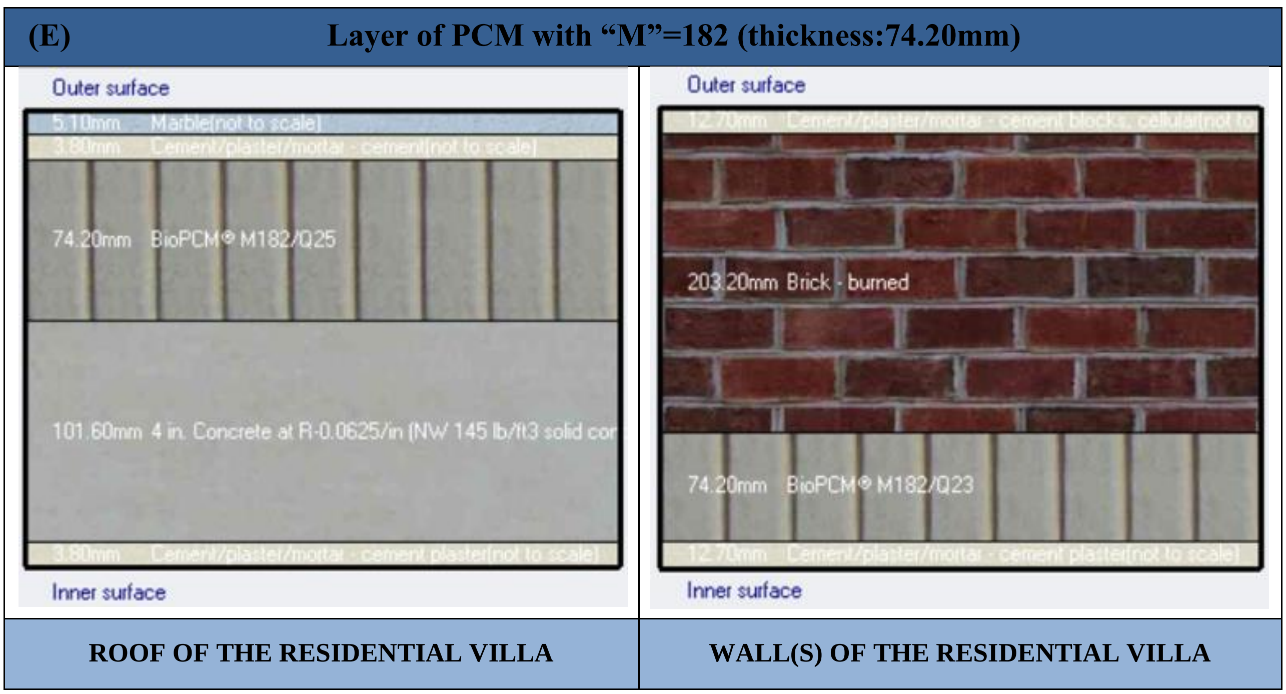


Figure 2.2: PCMs composition for roof and walls of residential house

Figure 2.2 shows the PCM wall and PCM roof composition. Wall consists of 12.7 mm inner and outer side plaster with 74.2 mm PCM layer on the inner side and 203.2 mm of burned brick. Whereas the roof consists of RCC slab having 101 mm of concrete with top layer of 74 mm of PCM and screed of 3.8 mm with marble finishings.

The presence of the occupants in the unit was maintained through a 24hrs schedule which is presented in Table-2. Likewise, the same duration schedule for Lighting and appliances are also given in the same table. Occupancy (1-8 hrs, WD-100%, WEH-100%) is described as all occupants were present in the house from 1 am to 8 am on weekdays (Sunday-Thursday) and on weekends (Friday-Saturday). Similarly, Lighting (8-14 hrs, WD- 20%, WEH- 20%) means that from 0800 to 1400 hrs, 20% of Lighting was consumed in the weekdays and weekends. Also, Appliances (22-24 hrs, WD- 10%, WEH- 10%) is defined as 10 % of all the appliance are being used from 2200 hrs to 2400 hrs in weekdays and weekends.

Table 2-1: Specifications for the Building Construction

Model	**House**
Number of Floors	2
Total Floor Area	204 m^2
Wall Construction	12 mm plaster outside + 203 mm brick + 12 mm plaster inside
Roof Construction	10 mm build-up roofing + 200 mm concrete roof slab + 13 mm plaster inside
Glazing	Single Clear with Wood Frames
Window-to-Wall Ratio (WWR)	12 %
Air Infiltration	0.85 ACH
Number of Occupants	4
Lighting Power Density	3.5 W/m^2
Equipment Power Density	2.1 W/m^2
Cooling Set Point	75.0 F (23.8 ^oC) for heating and 76 F (24.4 ^oC) for cooling
HVAC System	Split AC of 1.5 ton capacity
Energy Efficiency Ratio (EER)	4.5
Heating & Cooling Period	4 h/day

Table 2-2: Typical Schedule for Occupancy, Lightning and Appliances

Typical Schedules	Hours	WD (Mon-Fri)	WEH (Sat-Sun)
Occupancy	1-8	100%	100%
	8-15	20%	80%
	54-22	80%	80%
	22-24	100%	100%
Lighting	1-8	5%	5%
	8-14	20%	20%
	14-22	40%	50%
	22-24	5%	5%
Appliances	1-8	10%	15%
	8-14	30%	30%
	14-22	50%	60%
	22-24	15%	10%

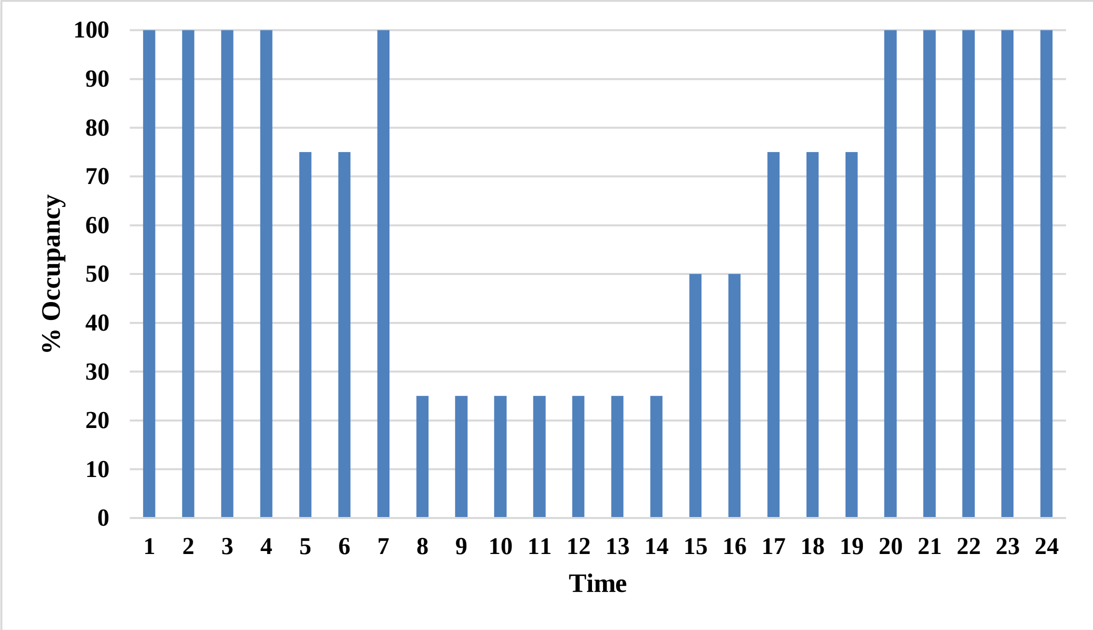


Figure 2.3: Occupancy Schedule, Weekdays Schedule

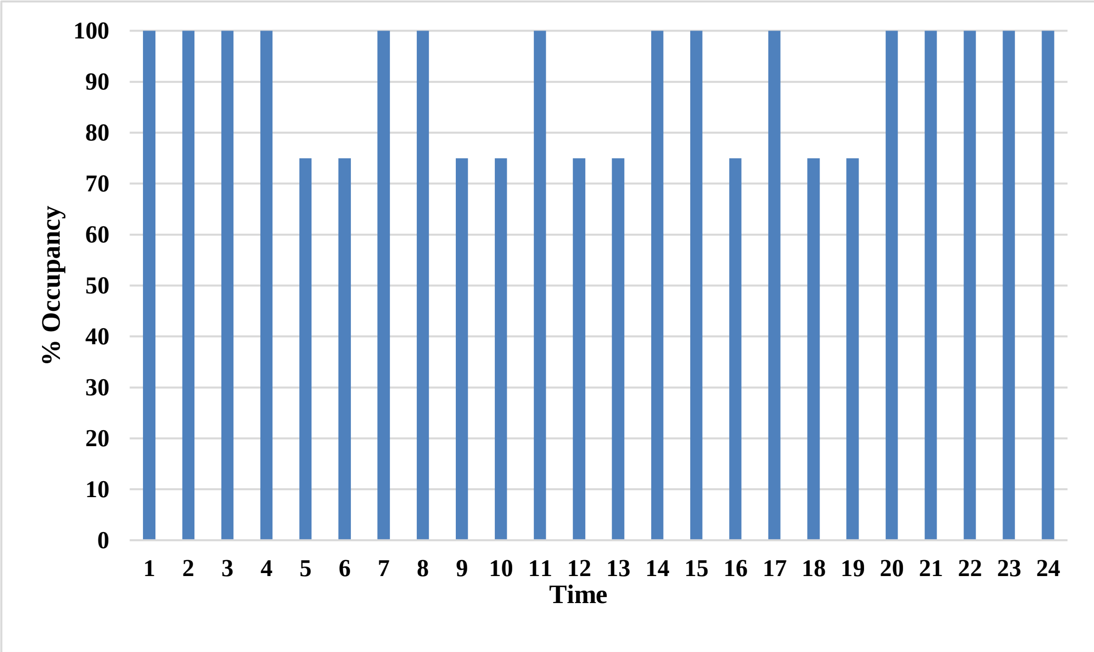


Figure 2.4: Occupancy Schedule, Weekends

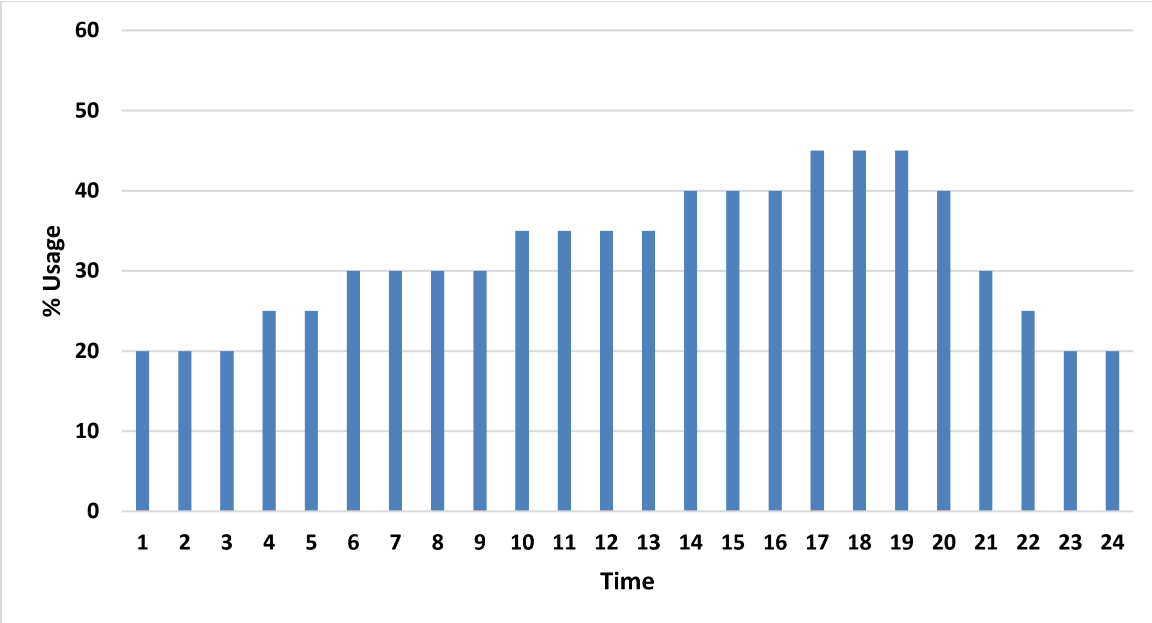


Figure 2.5: Appliance Schedule, Weekdays

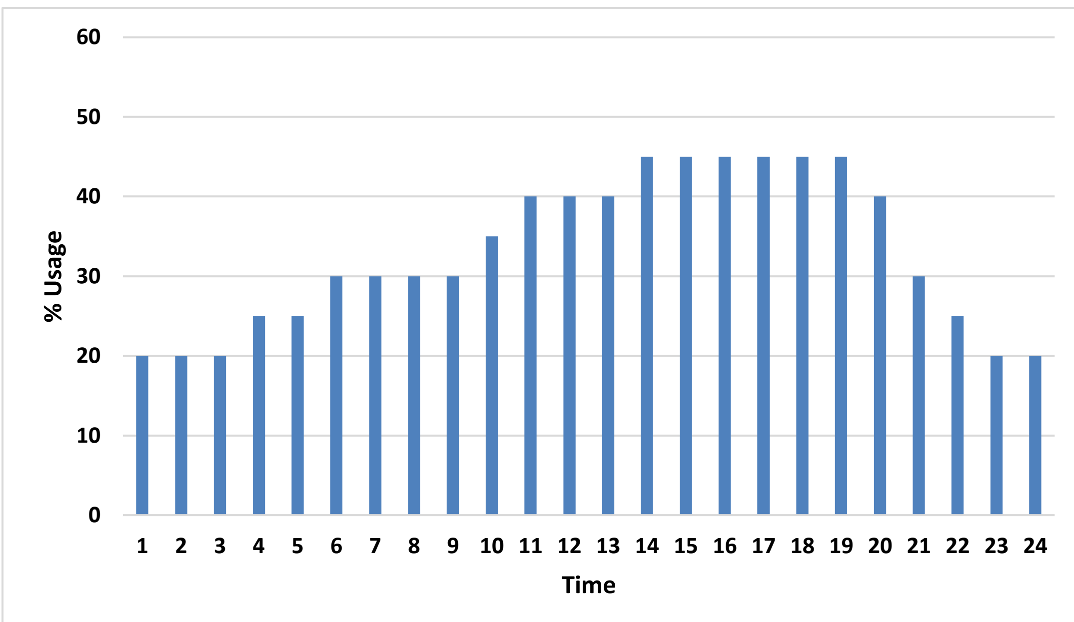


Figure 2.6: Appliances Schedule, Weekends

2.2.1 Floor Plans of Residential Building:

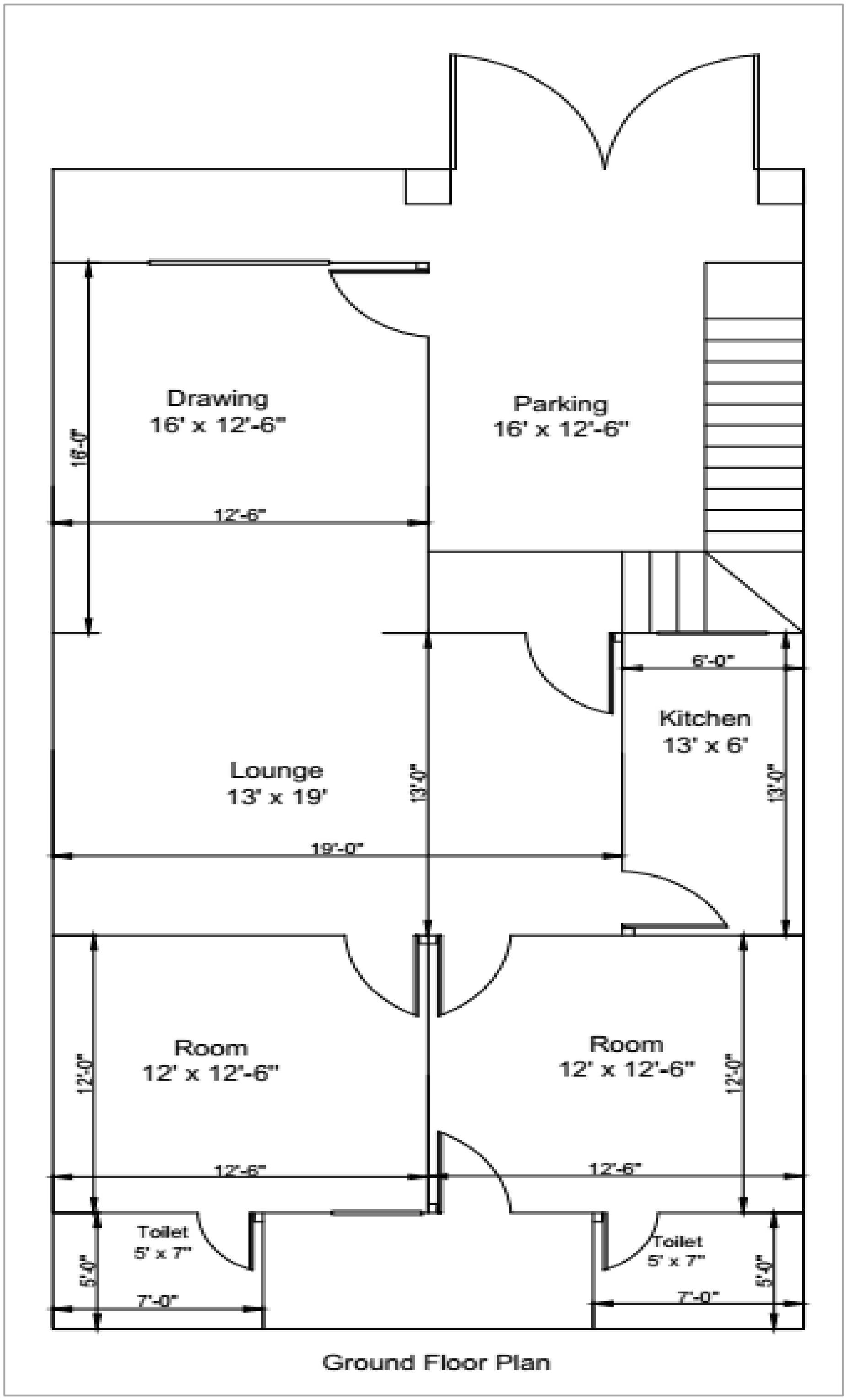


Figure 2.7: Ground Floor Plan of Residential Building

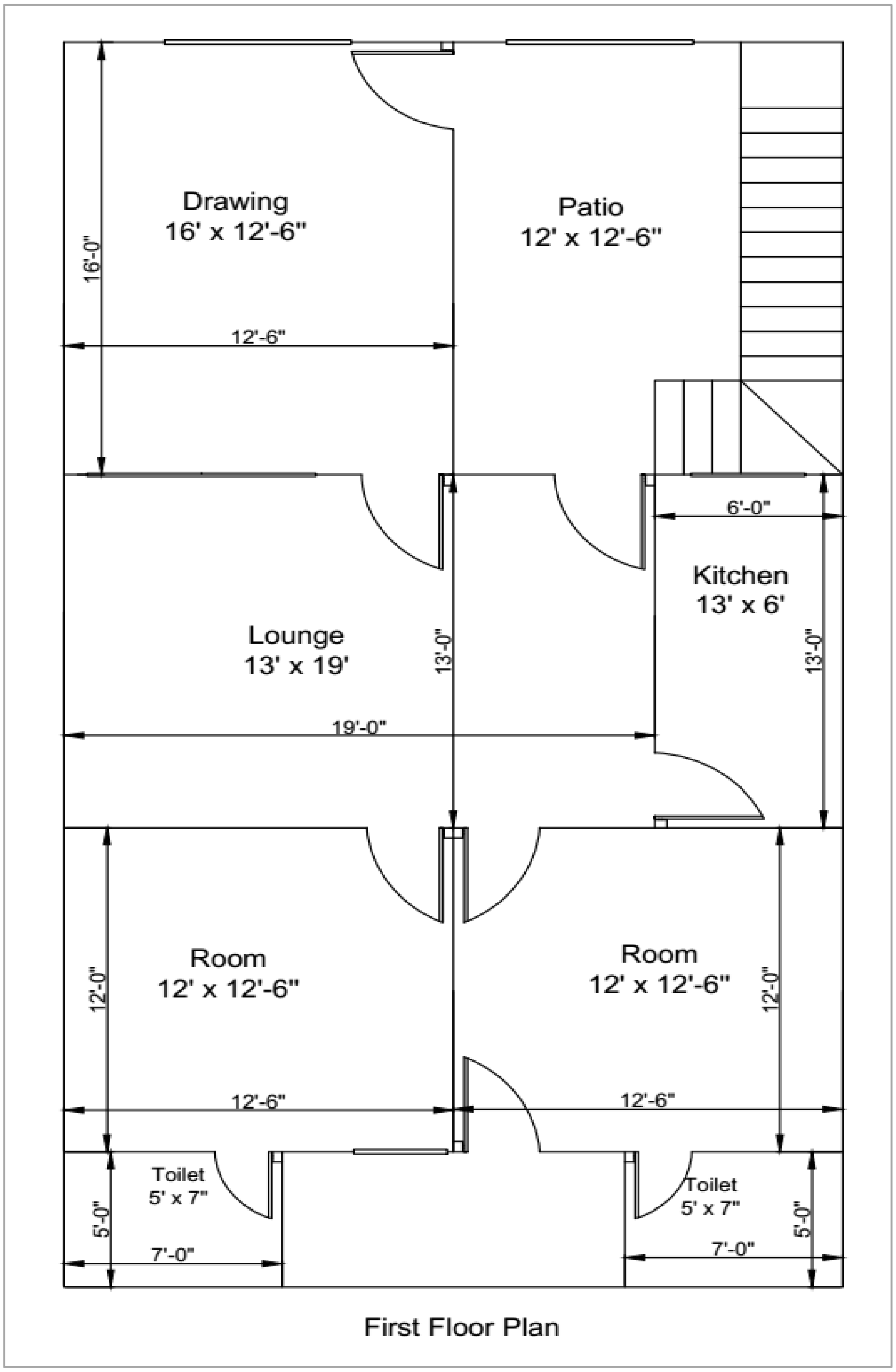


Figure 2.8: First Floor Plans for the residential villa

CHAPTER 3: ANALYTICAL MOEDEL

This chapter focuses on the methods used to calculate the energy demand and microgeneration necessary to meet that demand, as well as the economic indicators associated with each design option. The energy uses typical of residential buildings, such as space heating and cooling, water heating, lighting, cooking, refrigeration, and appliances (dishwasher, oven/cooker, TV, PC, and clothes dryer), are taken into account when calculating the building's energy needs. The energy requirements for cooking, lighting, refrigeration, and appliances are estimated based on the average power of the equipment and the assumed usage profile on a weekly and yearly basis.

After the validation of simulation results in the initial stage, passive measures will be implemented on the base case. The first passive measure involved the macro encapsulation of Phase Change Material (PCM) with varying Melting Points and thickness. After this measure was applied, energy simulations were conducted once more to determine the impact on cooling load, heating load, and overall energy consumption.

3.1 Energy uses in Residential Buildings

When evaluating the energy demand of a residential building, the initial step is to pinpoint the specific energy end uses that come into play. As per the fourth assessment report from the Intergovernmental Panel on Climate Change (IPCC), the major energy end uses in the residential sector can be categorized into the following groups: space heating and cooling, water heating, refrigeration, cooking, and lighting.

3.2 Building Simulation:

There are five main categories of building simulations. The first one concentrates on the building's envelope and its thermal properties, the second one focuses on thermal comfort, the third one pertains to internal gains and the behavior of the occupants, the fourth one revolves around daylighting, and the fifth and final category pertains to building service systems, which include heating, ventilation, domestic hot water systems, and renewable energy sources. For building simulations, typical simulation periods are utilized, which include an annual simulation from January 1st to December 31st, a winter design week from February 10th to February 16th, and a summer design week from August 3rd to August 9th. To enhance the accuracy of the calculations, the calculation option is set to 30-time steps per hour. The output data interval is set to an hourly frequency.

The process of determining the amount of heat lost by the building was carried out both before and after the energy retrofitting (as shown in Figure 10), with identical indoor and outdoor boundary conditions. The indoor air temperature averaged 19.6°C, while the average outside dry-bulb temperature was -9.9°C. On average, the building's total heat loss decreased from 3.05 kW to 1.03 kW after the retrofitting, which is approximately a 66% reduction.

3.3 Weather Data File:

The energy simulation employs an Energy Plus Weather (EPW) data file that utilizes the Typical Meteorological Year (TMY) based on a collection of specific weather data for a given location, such as Karachi and Islamabad, that details hourly values of temperature, humidity, precipitation, sunshine, wind velocity, and air pressure for a year. The TMY model relies on the Filkenstein-Schafer (FS) method [50], a statistical approach that selects twelve months of weather data that meet certain criteria for each month of the year. The TMY typically records weather data for 30 years to produce the EPW weather file [54].

3.4 Design Builder Software:

To model the energy consumption of buildings in this research, DesignBuilder (Version 6.1.6.008) simulation software was utilized, which boasts a highly user-friendly and intuitive interface with extensive performance data. This software provides information such as annual energy consumption, temperature fluctuations over the year, and HVAC component properties. DesignBuilder emphasizes four types of energy simulations, including cooling systems, heating systems, energy performance indicators, and real weather data simulations. The simulation engine, EnergyPlus, is integrated within DesignBuilder and performs all necessary calculations related to the energy model of any type of building stock, with results presented within the DesignBuilder interface.

The DesignBuilder software's user interface provides access to various types of templates, including construction templates and schedule templates.

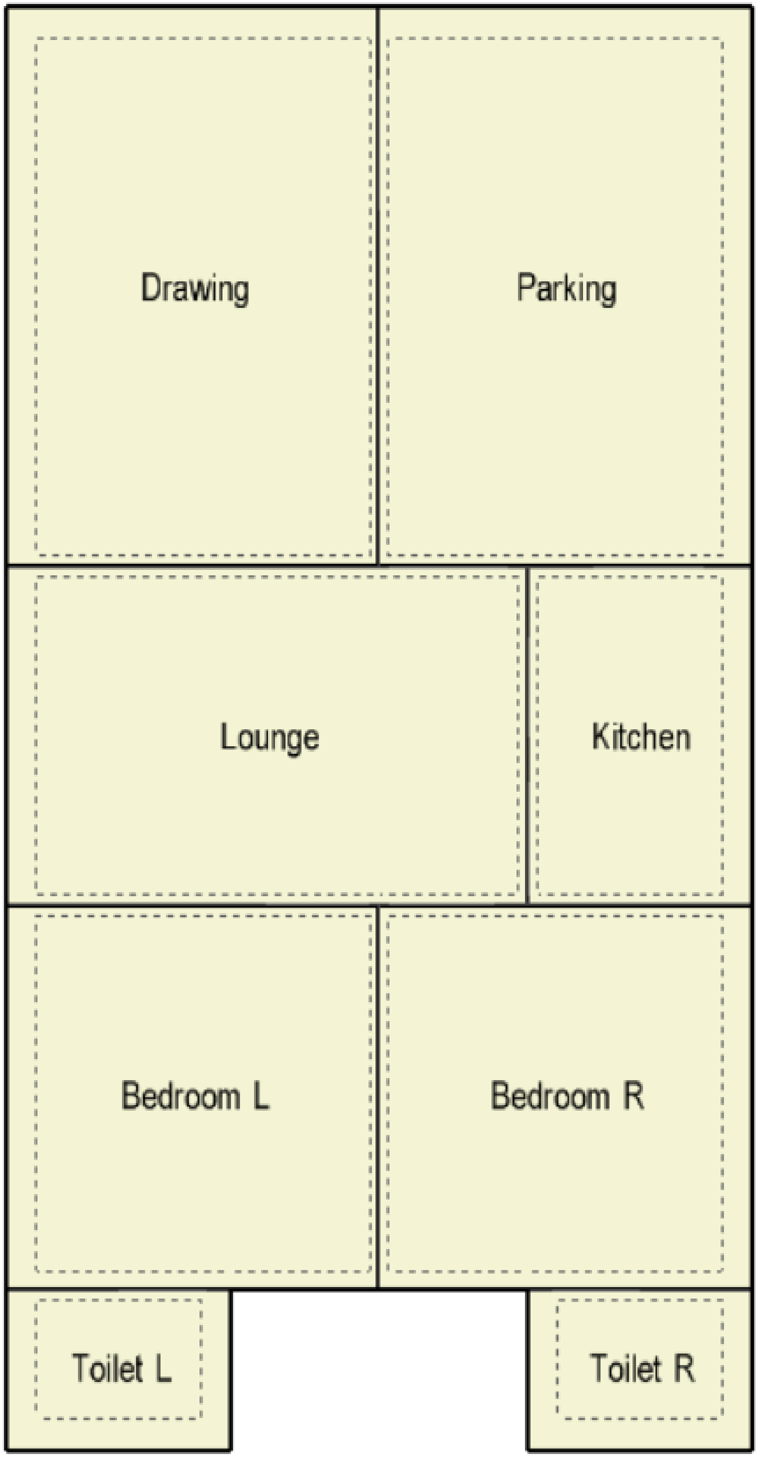


Figure 3.1: Ground Floor Plan - DesignBuilder

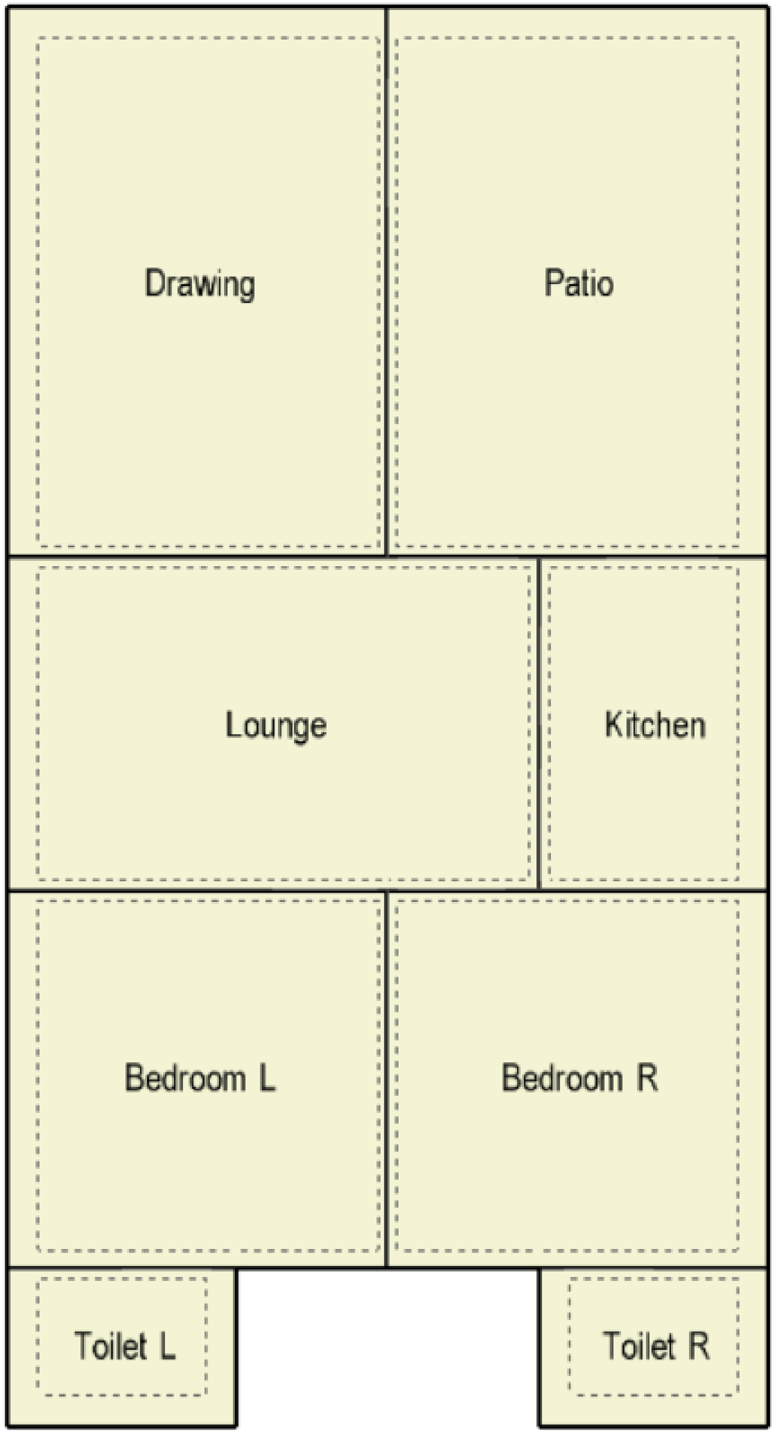


Figure 3.2: First Floor Plan - DesignBuilder

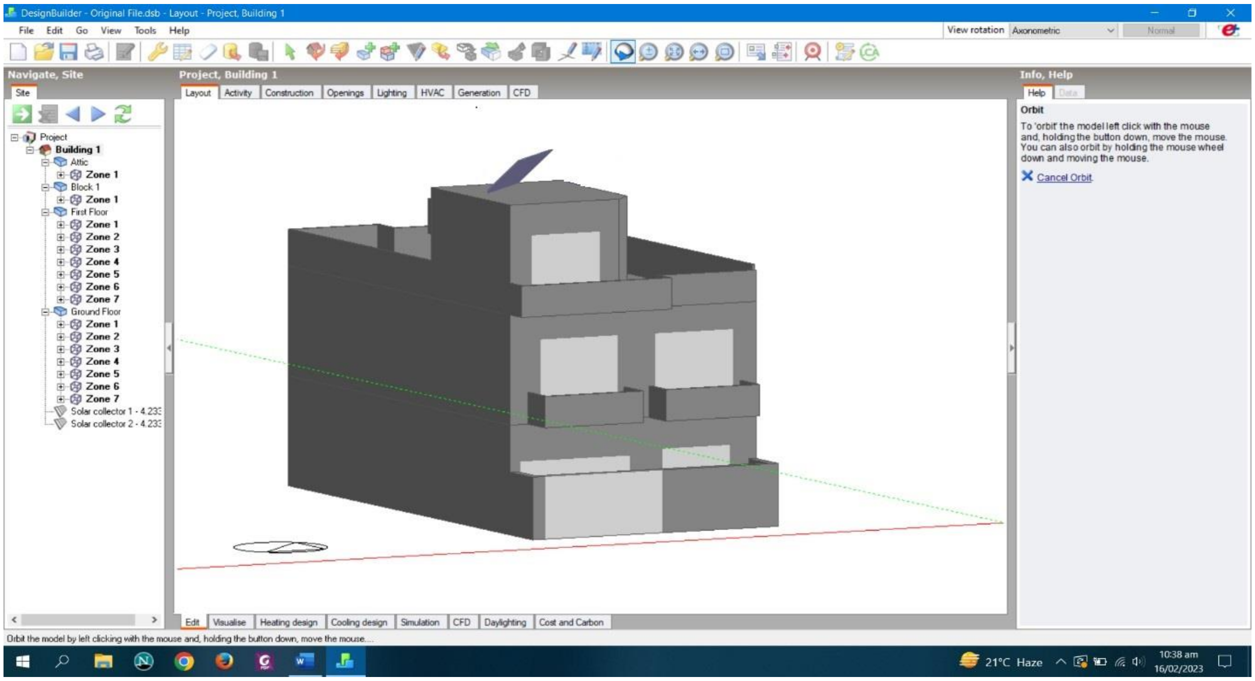


Figure 3.3: Residential building front view in DesignBuilder

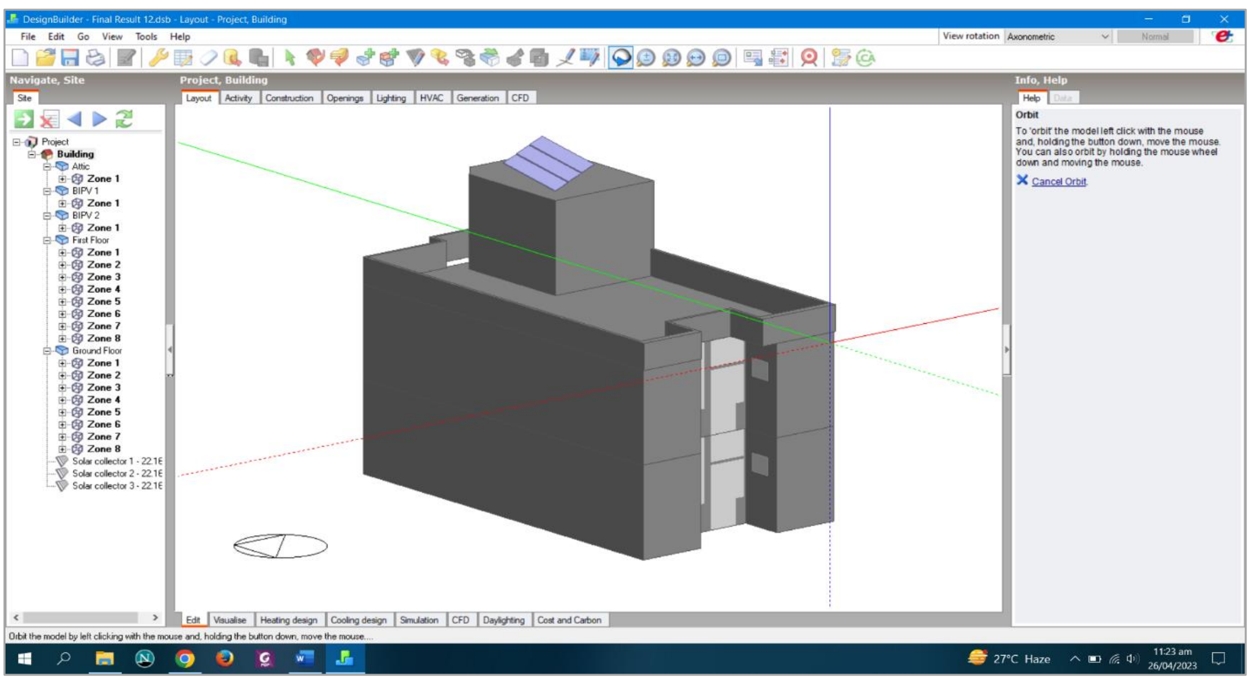


Figure 3.4: Residential Building Rear View in DesignBuilder

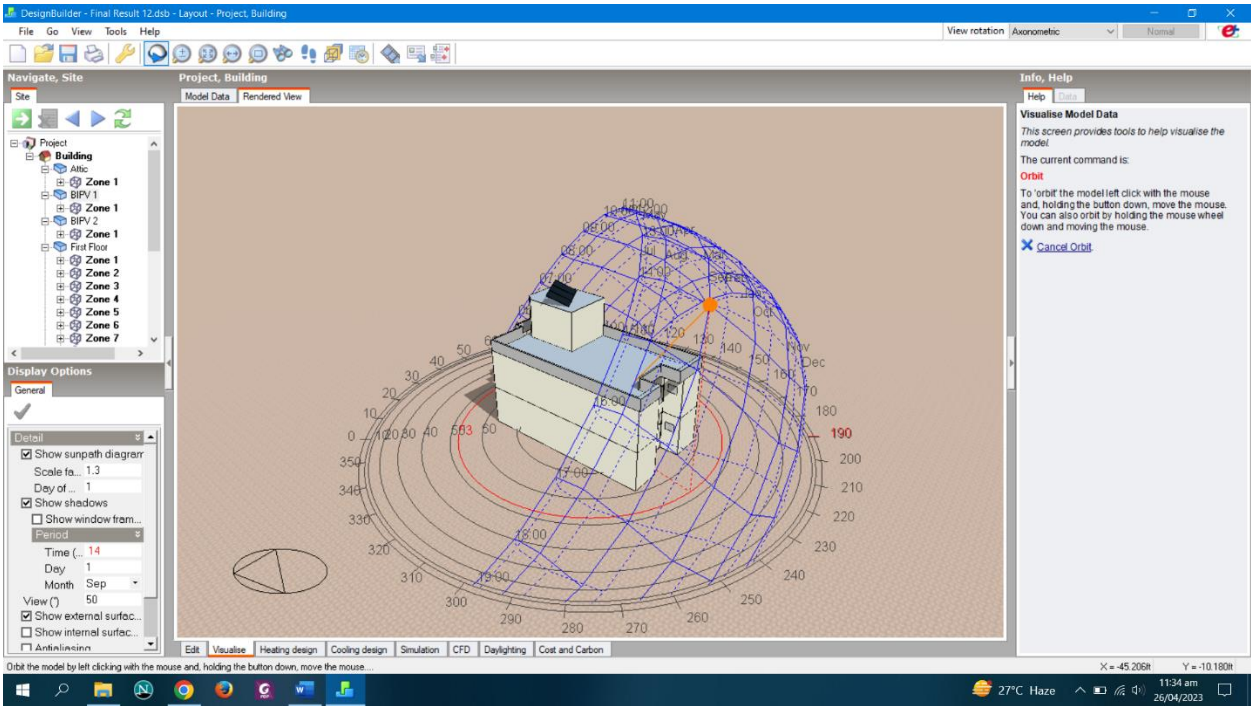


Figure 3.5: Rendered front view of house

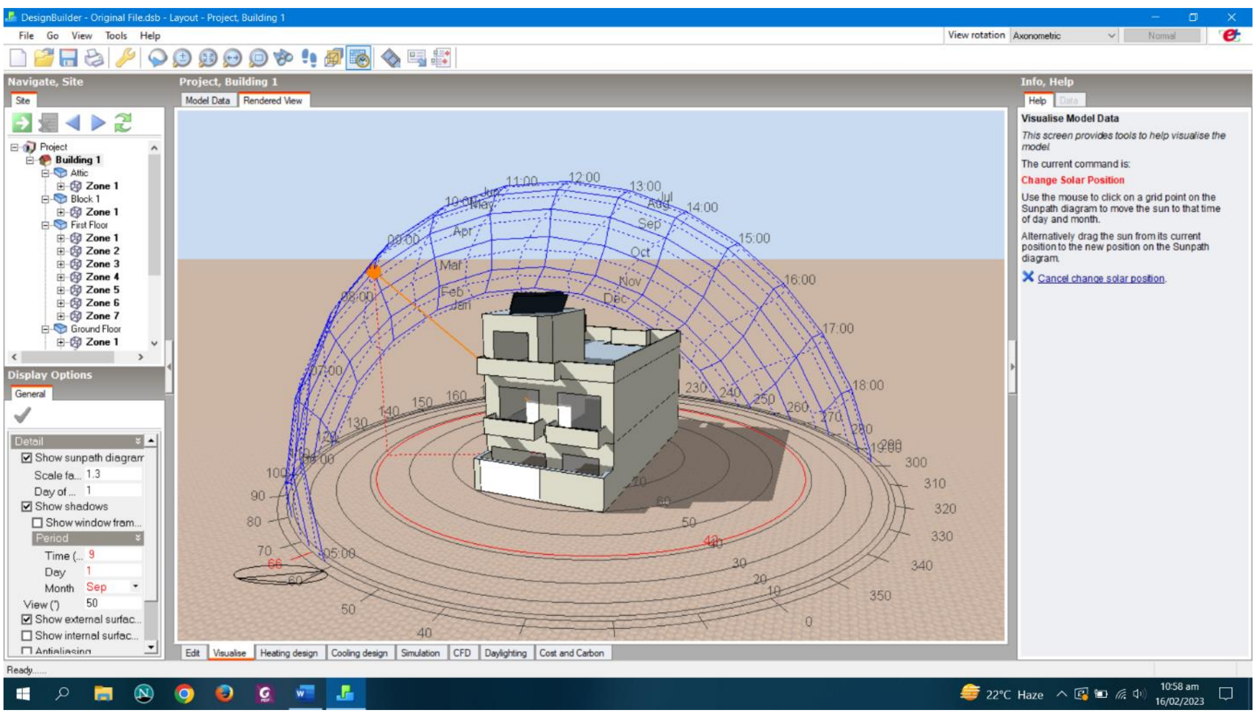


Figure 3.6: Rendered rear view of house

CHAPTER 4: RESULTS AND DISCUSSION

The selected residential building is simulated for energy demand around the year, simulated resulted are found in compliance with the original results. Maximum difference found was less than 3%. Energy demand was found minimum during the winter season heating demand is found during chilling winter season. Maximum demand of electricity is found in summer season with the peak found in September season due to high cooling demand because of high moisture content in atmosphere during the monsoon season. Following table numerically compares the actual consumption and simulated electricity demand.

Table 4-1: Simulated Energy Results for Residential Building

Month	Actual Consumption (kWh)	Simulation (Electricity) (kWh)	Difference (%)
January	79	77	2.5
February	85	83	2.4
March	150	148	0.5
April	198	197	0.5
May	239	247	-3.3
June	287	297	-3.5
July	345	343	0.9
August	331	327	1.2
September	310	315	-0.3
October	255	254	0.4
November	168	164	2.4
December	102	101	1.0

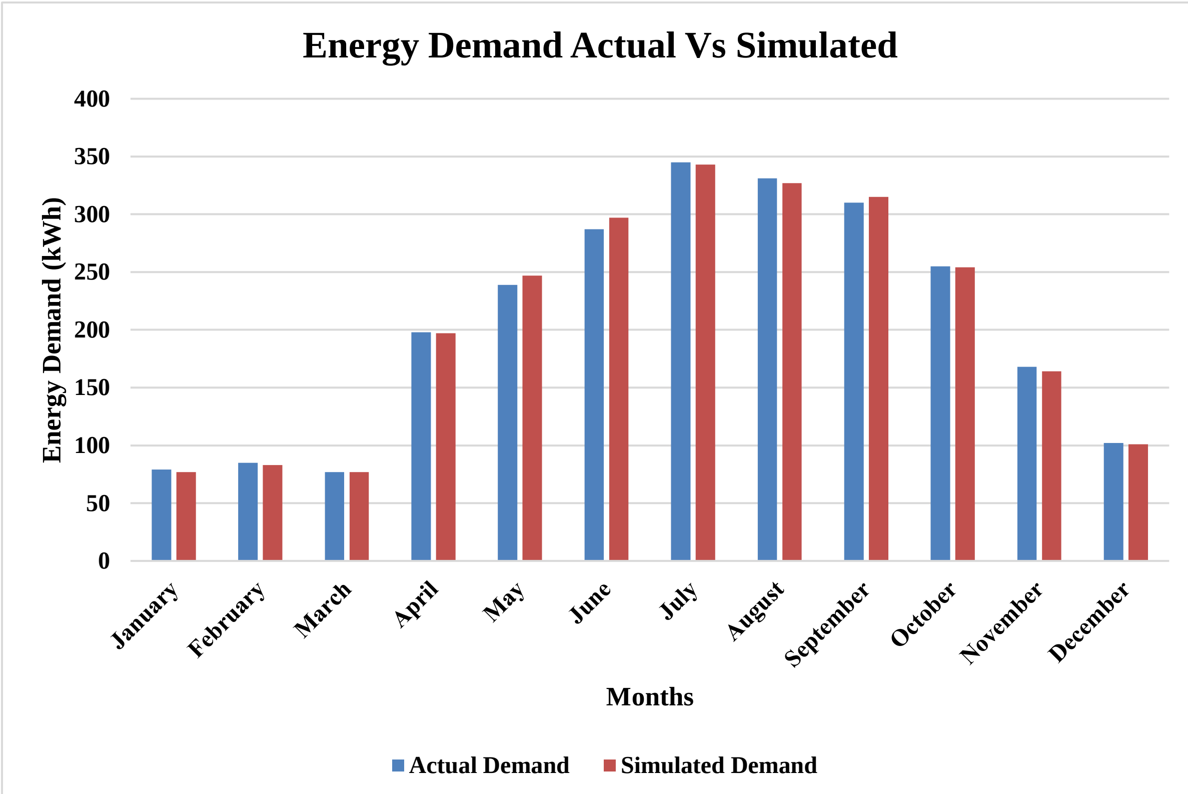


Figure 4.1: Actual and Simulated Energy Demand of Residential Building

4.1 Effect of PCMs

Energy demand in further decreased using the PCMs. Simulated resulted that are found in correspondence with the actual results are further added with PCMs. For this purpose, the PCM used for simulation is M182/Q25 in roofing and outer walls of building to develop a better energy barrier and in order to reduce the energy demand of the building. Rigips Alba Balance 25 (plasterboards with microcapsules of PCM is used for simulation. In this study, macro-encapsulated Bio PCMS are used in a sheet and then incorporated in walls and roofs of the residential building. M182/Q25 used for this purpose where Q25 representing the melting point of 25°C and M182 with its relevant Energy Storage Capacity (ESC) 182 BTU/ft2 in SI units 2066.89 kJ/m2 and thickness of 74.2mm. 182 BTU of energy stored in 1 ft2. Definitely higher the value of M, the higher would be its thickness.

Table 4-2: Simulated Results with PCMs Incorporation and Energy Savings

Month	Simulation (Electricity) (kWh)	Simulation PCM (M182/Q25) (kWh)	Energy Saving (kWh)
January	**77**	74	3
February	83	80	3
March	148	133	10
April	197	167	30
May	247	221	26
June	297	271	26
July	343	304	39
August	327	301	26
September	315	287	28
October	254	229	25
November	164	159	5
December	101	97	4

With the addition of PCMs energy demand of the building is decreased, especially the cooling demand of the building is found decreasing during the summer days because of better energy conservation and temperature barrier along with integrated building envelope with PCM. M182/Q25 is used because of its performance as found in research conducted on comparison of different PCMs impact on indoor comfort in an energy positive building.

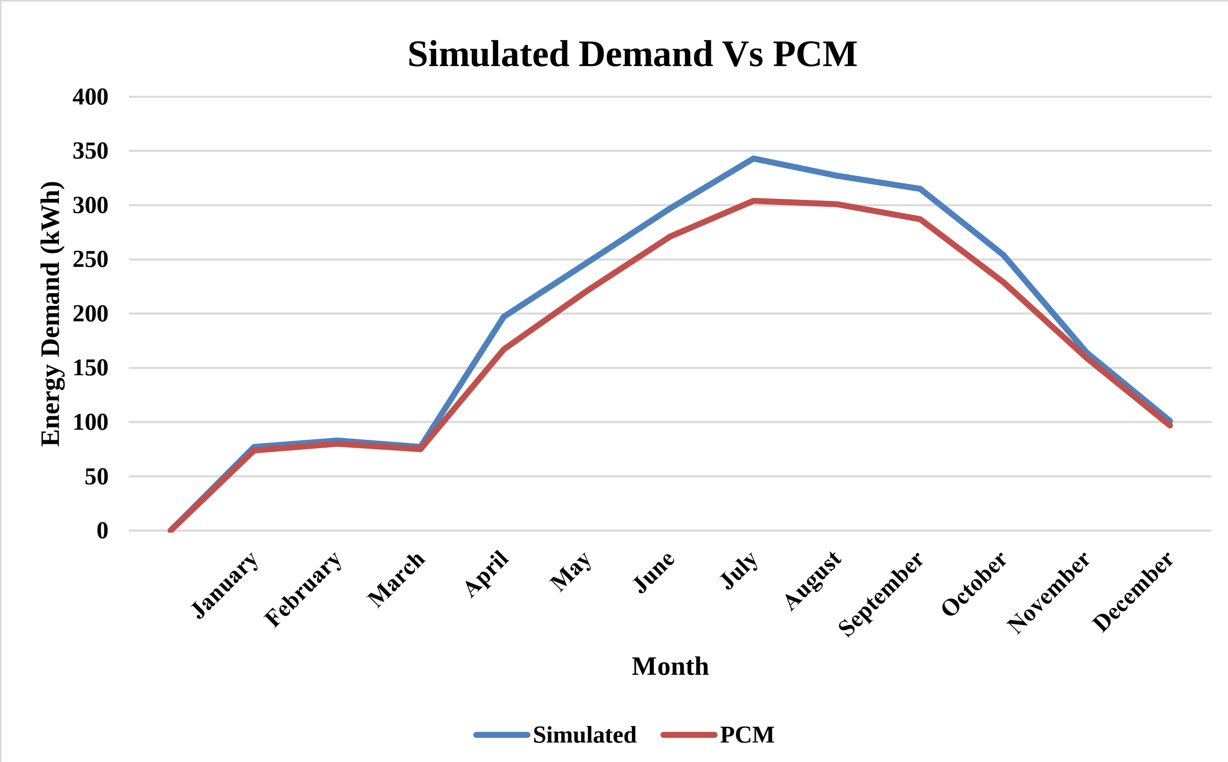


Figure 4.2: Actual energy demand vs PCMs results

Figure 4.2 shows the trend of actual simulated energy demand of the building in comparison with the energy demand of the building after installation of PCM. Energy demand during summer season is decreased much more because of the better temperature management with PCM.

With the installed PCMs, the decreased energy demand is achieved and for a sustainable solution of the net zero building, generation plants are installed. Distributed energy generation facility of 6m2 approximate is installed on roof top. Traditional photovoltaics with Mono PERC half cut technology is installed in standardized structure. The energy generation is listed in below table.

Table 4-3: Simulated Energy Demand and On-site Energy Generation with Traditional PV System

Month	Simulation with PCM (Electricity) (kWh)	Electricity Generation (With Traditional PV System)
January	74	119
February	80	135
March	133	141
April	167	153
May	221	166
June	271	158
July	304	149
August	301	146
September	287	131
October	229	127
November	159	119
December	97	114
Total	*2323*	**1628**

Month wise energy generation shows the optimum output during spring and start of summer season and during end of summer. The increased energy generation shows the daylight duration and also weather favorable conditions. During hot summer energy generation decreased due to higher temperature of solar panels.

Figure 18 shows the graph between electric consumption and solar generation. Higher energy demands and lower solar generations are observed and un sufficient solar generation shows contradiction with net zero energy building.

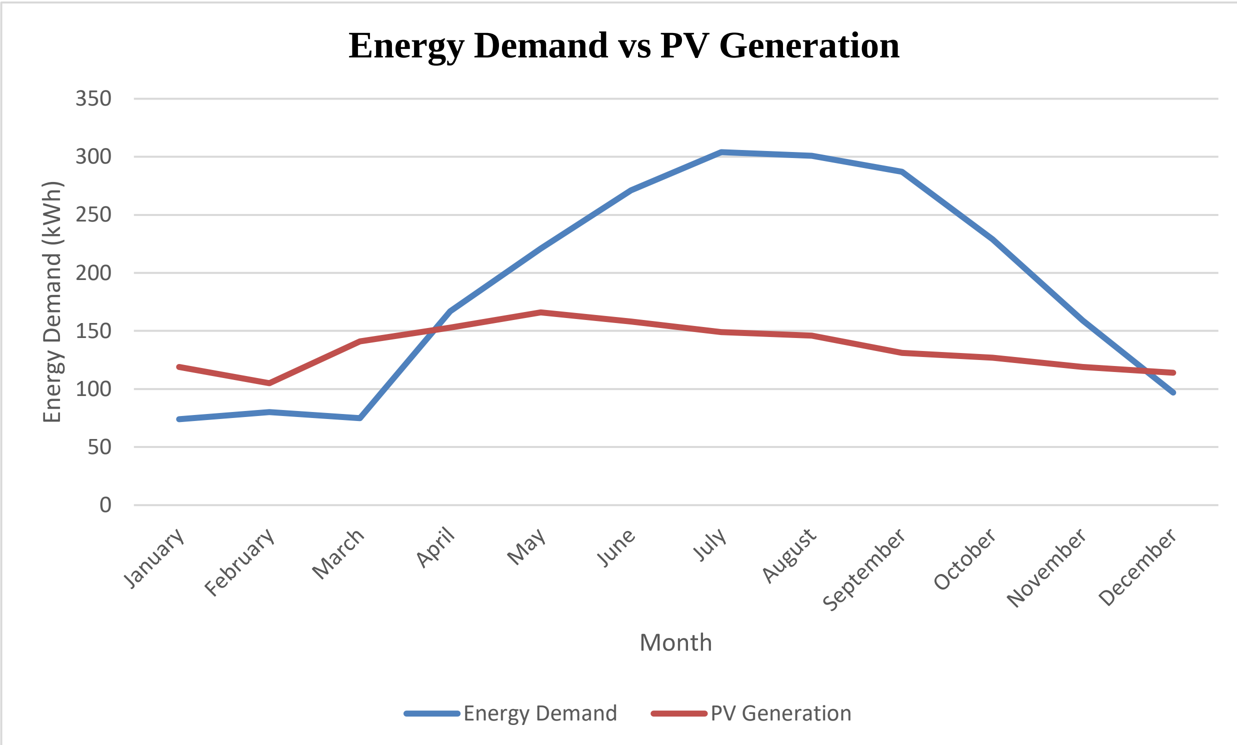


Figure 4.3: Simulated results with PCMs incorporation

Overall available space of rooftop is unable to achieve net zero target. For this purpose, building integrated photovoltaics is used. Results obtained with BIPV are listed below.

Table 4-4: Simulated Energy Demand and Solar Generation Including BIPV

Month	Simulation with PCM (Electricity) (kWh)	Electricity Generation	Electricity Generation with BIPV
January	74	119	246
February	80	135	254
March	133	141	285
April	167	153	308
May	221	166	334
June	271	158	320
July	304	149	282
August	301	146	274

September	287	131	263
October	229	127	259
November	159	119	255
December	97	114	239
Total	*2323*	**1658**	***3319***

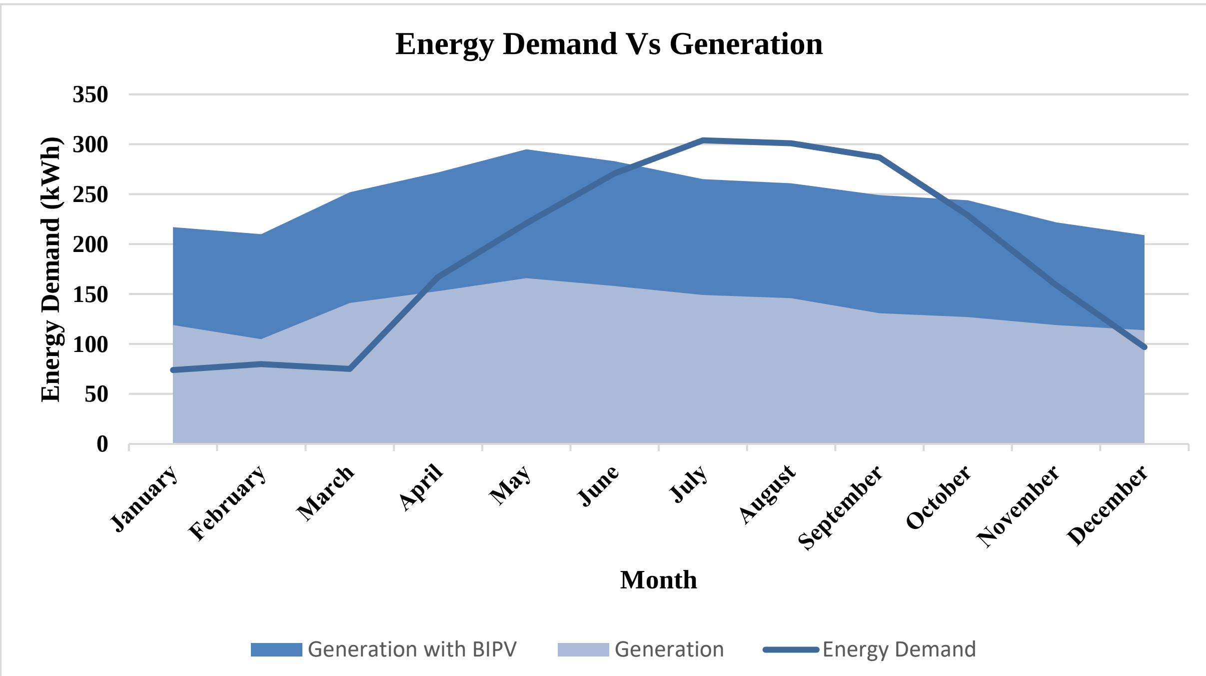


Figure 4.4: Simulated Results with PCMs Incorporation

Results obtained from BIPV generation along with standardized solar panel mounting shows target of net zero energy can be achieved. With the integration of BIPVs overall solar generation is increased by 45% then the demand of residential unit throughout the year. On deeper insight the target of net zero energy month wise is still pending because of demand of electricity is higher in monsoon season but generation is less. Firstly, increasing the BIPV's to achieve net zero in these months not only increases the capital expenses and make it less profitable, also in the cyclic fashion of net zero calculation as already practiced in Pakistan makes it net zero on cumulative energy demand and generation.

Photovoltaics generation fulfills the demand of electricity, moreover if losses are considered then electricity generation still fulfills the energy demand. Table below enlists the electricity generation considering losses shows the demand of electricity still fulfilled. Generation as well as transportation losses are considered 12%.

Table 4-5: Electricity Solar Generation considering Losses

Month	Electricity Generation with BIPV	Electricity Generation considering losses
January	246	209
February	254	216
March	285	242
April	308	262
May	334	283
June	320	272
July	282	240
August	274	233
September	263	223
October	259	220
November	255	217
December	239	203
Total	***3319***	**2821**

From the table, it is visible that electricity generation is enough to fulfill the demand of green building.

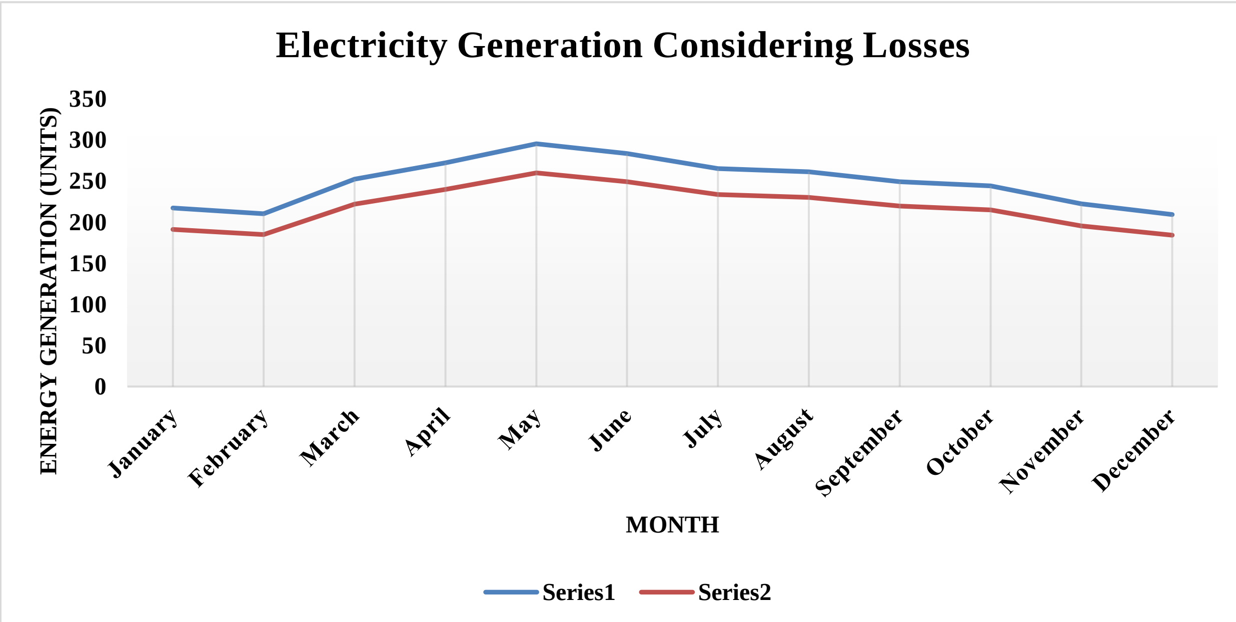


Figure 4.5: Electricity generation considering losses

Final results obtained are listed in table below, actual energy demand along with simulated energy demand is listed. With the inclusion of phase change materials, the energy demand is minimized. Finally, photovoltaics is used for energy generation, initially standard PV system is used but lack of available space is insufficient to fulfill the demand of energy, the target of net zero building cannot be achieved with standard PV system. To achieve the target of net zero BIPV system is used, inclusion of BIPV panels fulfills energy demand and generations and make it NZEB.

Table 4-6: Energy Demand and Generation

Month	Actual kW	Simulated kW	PCM	Electricity Generation
January	79	77	74	246
February	85	83	80	254
March	150	148	133	285
April	198	197	167	308
May	239	247	221	334
June	287	297	271	320

July	345	343	304	282
August	331	327	301	274
September	310	315	287	263
October	255	254	229	259
November	168	164	159	255
December	102	101	97	239
Total	**2549**	**2553**	**2323**	**3319**

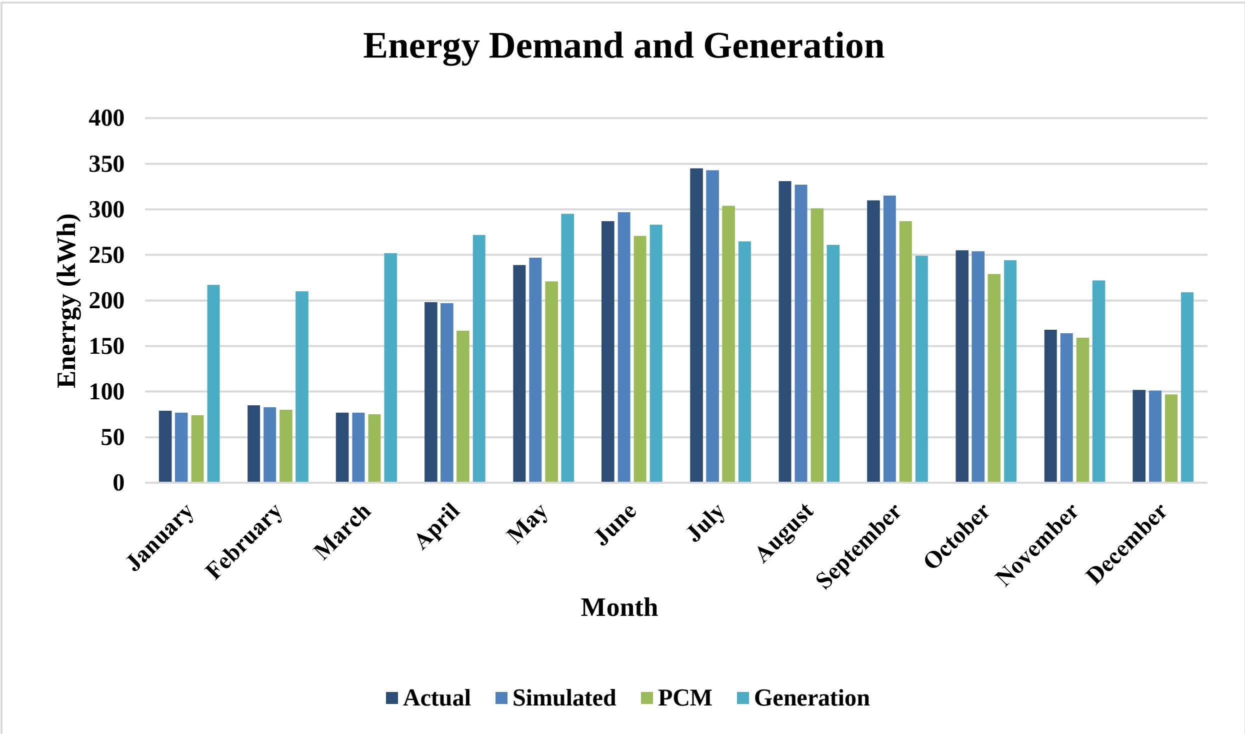


Figure 4.6: Electricity Generation Considering Losses

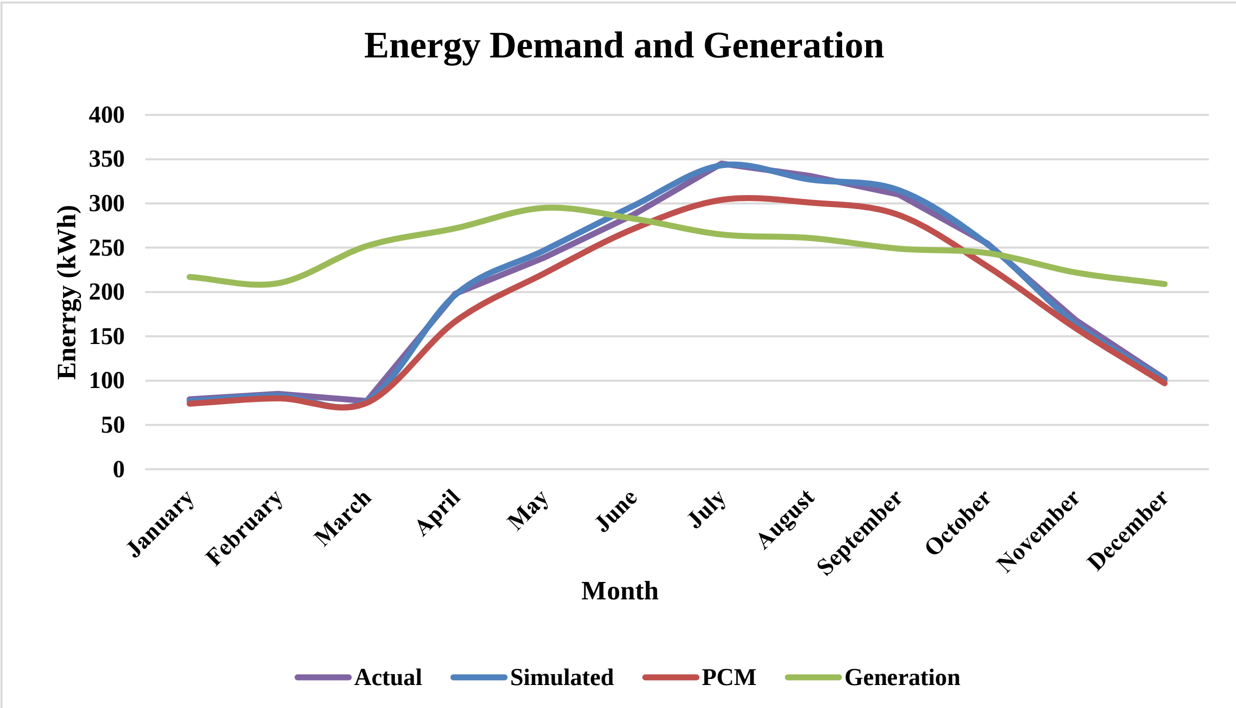


Figure 4.7: Overall Electricity Consumption and Generation

4.2 Cooling and Heating Effect:

Table 4-7: Cooling and Heating Effect of Residential Unit

Month	Simulated	PCM	Cooling Demand		Heating Demand		Generation
			Without PCM	PCM	Without PCM	PCM	
January	77	74	0	0	15	12	246
February	83	80	0	0	7	4	254
March	148	133	0	0	0	0	285
April	197	167	48	23	0	0	308
May	247	221	160	137	0	0	334
June	297	271	219	196	0	0	320
July	343	304	254	224	0	0	282

August	327	301	247	198	0	0	274
September	315	287	210	170	0	0	263
October	254	229	152	134	0	0	259
November	164	159	0	0	5	3	255
December	101	97	0	0	13	11	239
Total	**2553**	**2323**	**1290**	**1082**	**40**	**30**	**3319**

Final results obtained are further elaborated by bifurcating the heating and cooling demand of the residential house. With the inclusion of PCMs the demand of energy is decreased by 8.38%. The lighting load has no effect of PCM's whereas significant decrease in demand can be seen in cooling and heating demand of the building. During the summer season the cooling demand of the building is decreased by 14.83%, also during the winter season the heating demand of the building is decreased by 25%.

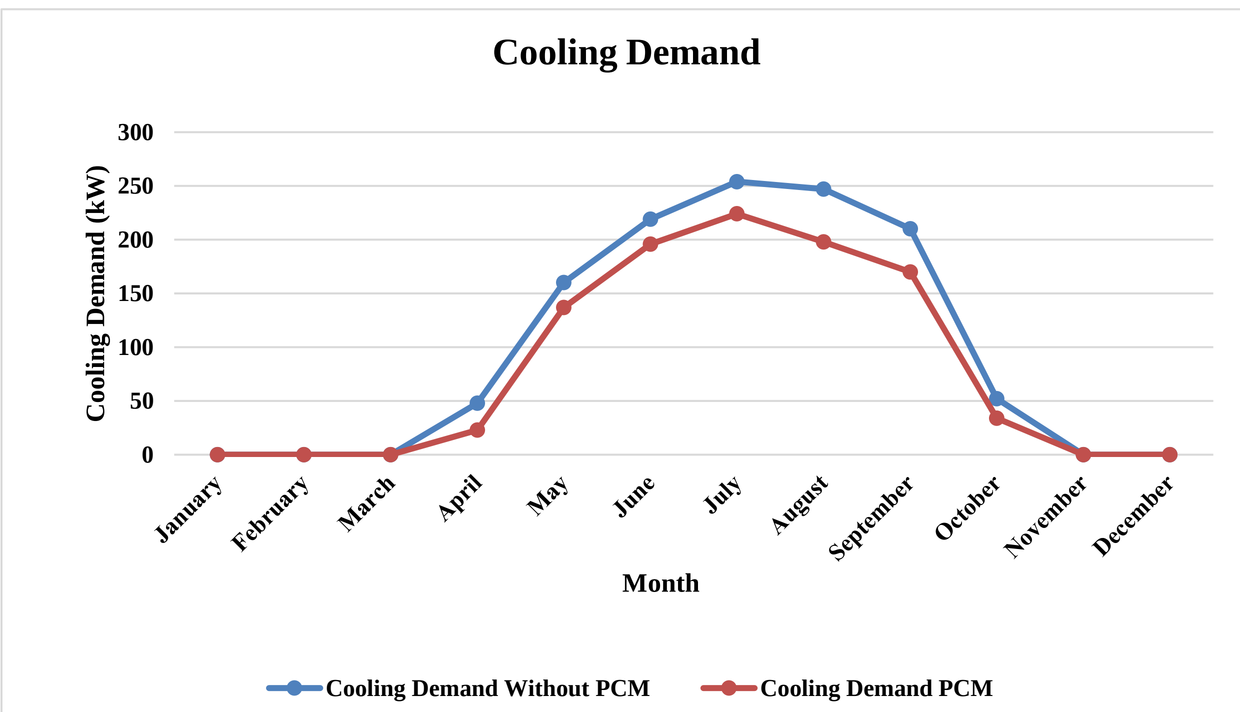


Figure 4.8: Cooling Demand with PCM

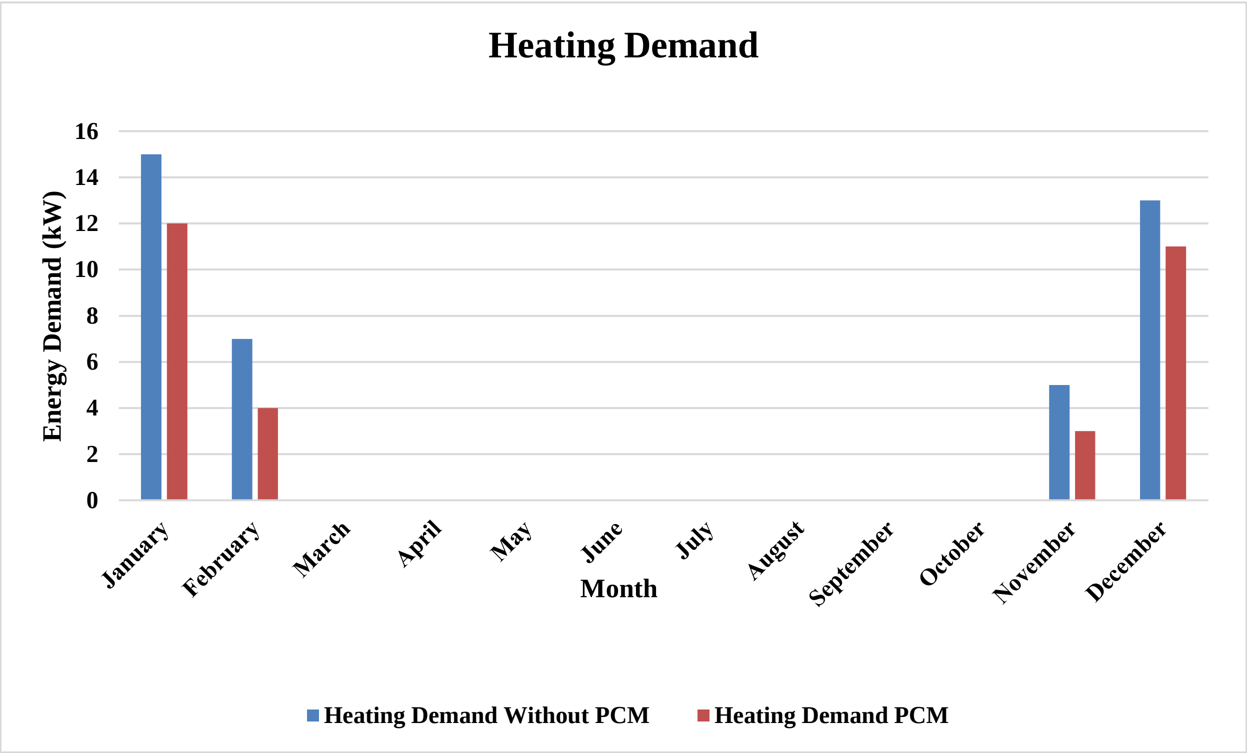


Figure 4.9: Heating Demand with PCMs

4.3 Other Climatic Conditions of Pakistan

To get overview of the same installed setup at different climatic conditions, simulations have been carried out in Design Builder in different cities of Pakistan. For this purpose, different cities are selected based on their geographical locations and different climatic conditions.

4.3.1 Lahore

Lahore displays a five-season semi-arid climate, designated as Köppen climate classification BSh, which closely borders a humid subtropical climate. The city goes through distinct seasonal variations: a foggy winter occurring from 30th November to 15th February, accompanied by occasional western disturbances causing rainfall; a pleasant spring from 16th February to 15th April; a hot summer with dust, rain storms, and heat waves from 15th April to 30th June; a monsoon period with rain from 1st July to 16th September; and a dry autumn spanning from 16th September to 14th November.

Although primarily classified as semi-arid, Lahore can also be partially characterized as having a humid subtropical climate (Cwa) due to its well-defined seasons and adequate precipitation. At times, it experiences long and heavy monsoons, which are typical of a humid subtropical climate.

Table 4-8: Electricity demand and generation for Lahore

Month	Simulated	PCM	Cooling Demand		Heating Demand		Generation
			Without PCM	PCM	Without PCM	PCM	
January	77	74	0	0	5	3	242
February	84	79	1	0	0	0	295
March	175	145	12	2	0	0	311
April	273	236	123	93	0	0	318
May	309	273	221	189	0	0	330
June	346	315	268	239	0	0	310
July	422	375	385	343	0	0	295
August	377	343	253	224	0	0	284
September	351	322	317	289	0	0	276
October	303	271	100	76	0	0	268
November	169	159	0	0	4	2	260
December	100	96	0	0	6	4	254
Total	**2986**	**2620**	**1680**	**1455**	**15**	**9**	3442

Following results are originated for Lahore.

From the result obtained it is visible that sample residential unit is performing equally well in Lahore climatic condition. Energy demand of residential unit is increased because of change in climate and relatively hot conditions in Lahore. Energy demand is increased by 16% whereas the generation is only increased by 1.79%. The reason is high temperature of panels decrease the production output but overall, in the scenario goal of NZEB is still achieved. Heating requirement in Lahore is minimum compared to Rawalpindi. However cooling requirement is increased and further incorporation of PCMs help in thermal management of residential unit which results in lower energy demand during summer season.

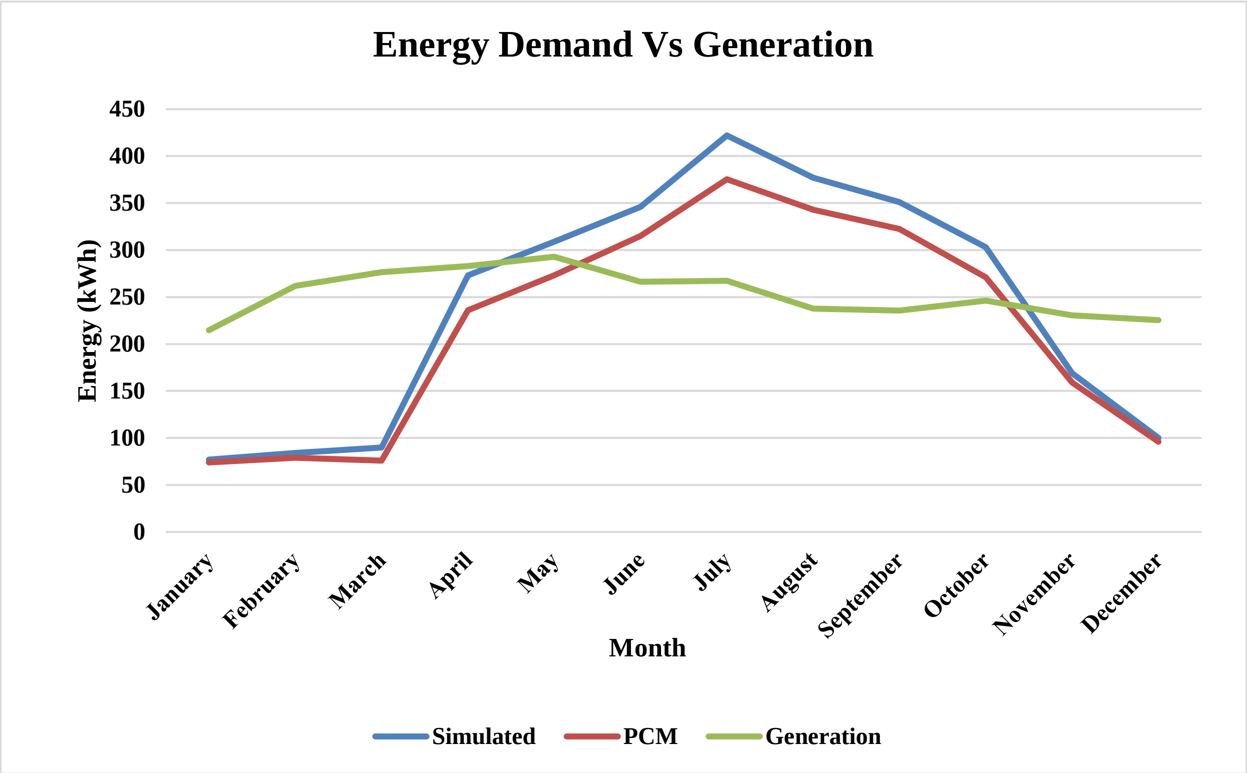


Figure 4.10: Energy demand vs PV Generation for Lahore

4.3.2 Karachi

Karachi, situated on the coast along the Arabian Sea, experiences an arid climate, although it can be considered a more moderate version of this type. Despite its location just above the Tropic of Cancer, the city falls within the monsoon region of Pakistan, giving it a tropical climate. The overall climate in Karachi is relatively mild. However, in recent years, there has been a notable increase in rainfall. At times, Karachi may even be classified as semi-arid (BSh) due to its mild climate, featuring a brief but well-defined wet season followed by a longer dry season.

Indeed, the city of Karachi undergoes high humidity, but the intensity of the heat is mitigated to some extent by the cooling sea breezes. Throughout the summer season, temperatures commonly vary between 78°F (26°C) and 95°F (35°C). On the other hand, during the winter months of December and January, the climate turns delightful, making it an ideal time to visit Karachi, as temperatures range from 52°F (11°C) to 81°F (27°C).

Table 4-9: Energy Demand and Generation for Karachi

Month	Simulated	PCM	Cooling Demand		Heating Demand		Generation
			Without PCM	PCM	Without PCM	PCM	
January	77	75	0	0	0	0	228
February	98	79	0	0	0	0	265
March	210	185	77	65	0	0	274
April	272	240	225	198	0	0	285
May	314	279	256	211	0	0	309
June	354	324	301	267	0	0	315
July	412	356	348	299	0	0	311
August	374	321	312	268	0	0	284
September	298	267	254	221	0	0	276
October	278	258	187	154	0	0	268
November	179	158	19	4	0	0	235
December	102	98	0	0	0	0	227
Total	2968	2640	1979	1687	0	0	**3277**

From the result obtained it is visible that energy demand of Karachi is higher compared to Rawalpindi but solar production is less compared to Rawalpindi. Moreover, Karachi has higher cooling demand but heating demand in terms of equipment not required.

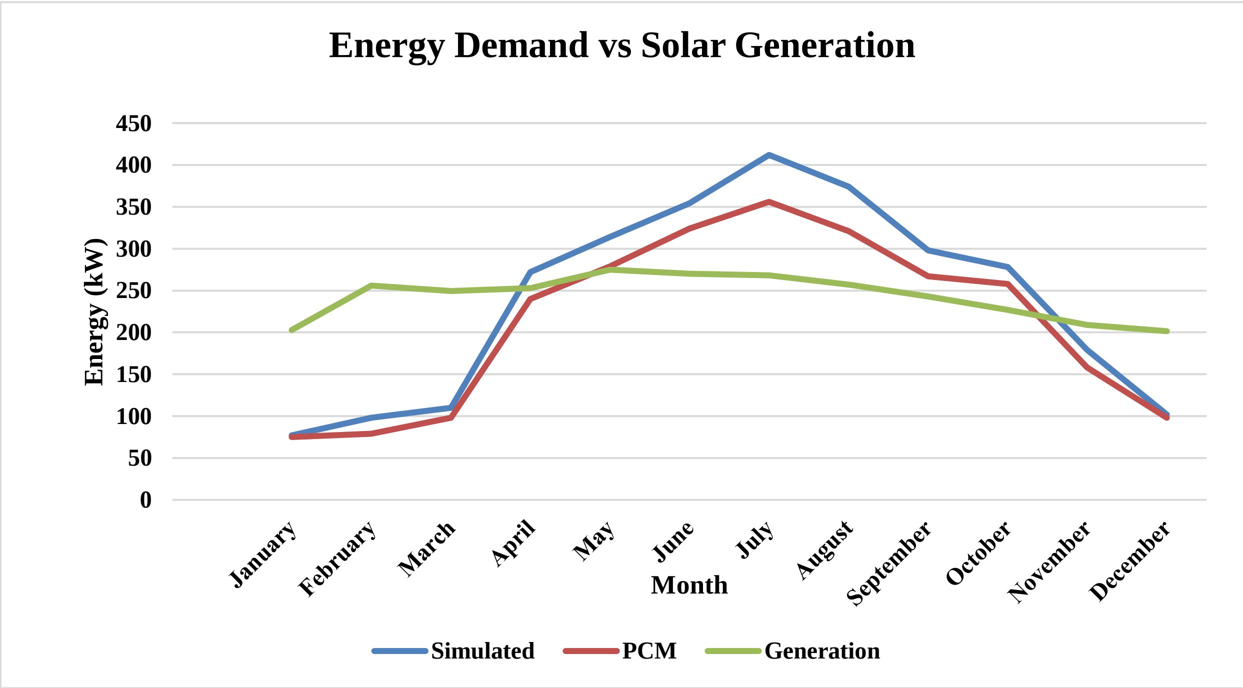


Figure 4.11: Energy demand vs PV Generation for Karachi

4.3.3 Peshawar

Peshawar boasts a subtropical climate characterized by mild winters and scorching summers. This city, located in northern Pakistan, serves as the capital of Khyber Pakhtunkhwa and is situated at an elevation of 330 meters (1,080 feet) above sea level, positioned at 34 degrees north latitude. Nestled in the northernmost lowland region of Pakistan and surrounded by mountains, Peshawar lies about 50 km (30 mi) to the northwest of the Khyber Pass, which marks the border with Afghanistan. In the winter and spring months, Peshawar occasionally experiences rainfall due to disturbances originating from the Mediterranean, a phenomenon more frequent compared to the south-central regions of Pakistan. Consequently, March stands out as the wettest month in the city's annual weather cycle.

From December to February, and sometimes extending into November and March, Peshawar encounters cold nights, with temperatures occasionally dropping to or just below freezing.

Moreover, fog tends to form from November to February, primarily during the nighttime and early morning hours. Although the fog typically dissipates during the day, during specific periods, particularly from mid-December to mid-January, daytime temperatures can remain quite cool, with maximum temperatures hovering around 8/10 °C (46/50 °F). In January 2013 and December 2019, there were even days when the maximum temperature reached as low as 5 °C (41 °F). Conversely, from April to early July, before the monsoon season. Peshawar experiences intense heat. During the hottest periods, temperatures can soar to or exceed 45 °C (113 °F), although they generally do not reach the extreme highs observed in south-central Pakistan. From July to September, which coincides with the Indian monsoon period, temperatures decrease while humidity levels rise.

Table 4-10: Energy Demand and Generation for Peshawar

Month	Simulated	PCM	Cooling Demand		Heating Demand		Generation
			Without PCM	PCM	Without PCM	PCM	
January	77	74	0	0	10	8	223
February	83	80	0	0	0	0	247
March	151	130	1	0	0	0	271
April	212	184	63	40	0	0	301
May	272	241	185	158	0	0	342
June	321	309	278	244	0	0	310
July	351	324	284	267	0	0	295
August	356	329	292	267	0	0	284
September	340	317	276	243	0	0	276
October	249	228	47	34	0	0	268
November	165	159	0	0	0	0	249
December	101	97	0	0	8	6	225
Total	2606	2417	1426	1175	18	14	3291

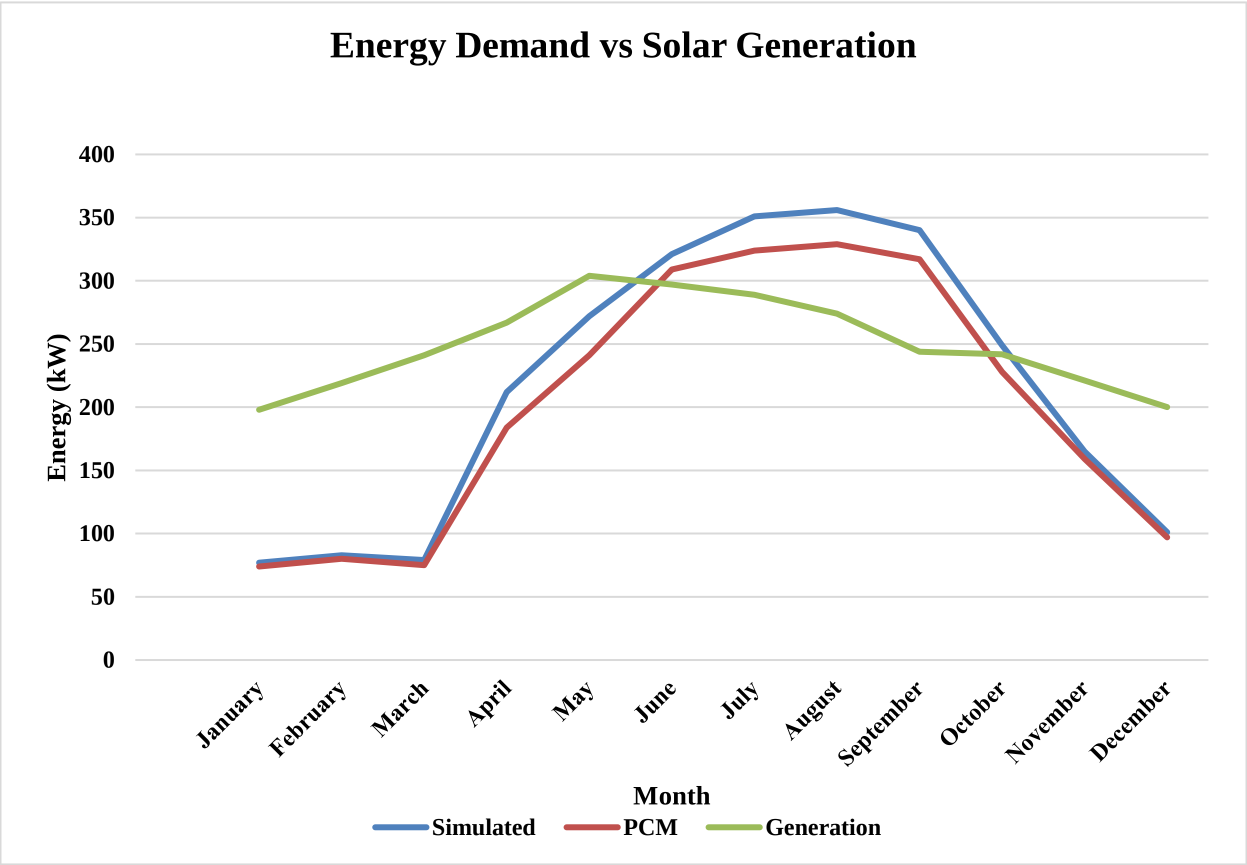


Figure 4.12: Energy demand vs PV Generation for Peshawar

Promising results obtained for the city of Peshawar, a similar trend to that of Rawalpindi can be seen with the demand of electricity increased in summer and less cooling requirements in winter. Moreover, solar generation is almost comparable with Rawalpindi also.

4.3.4 Gawadar

Gwadar is known for its dry and hot arid climate, situated at an elevation ranging from 0 meters (0 ft) to 300 meters (984 ft) above sea level. The nearby ocean significantly influences the temperature, causing it to be lower during the summer and higher during the winter. In June, which is the hottest month, the average temperature varies between 31 °C (88 °F) and 32 °C (90 °F). In contrast, January, the coldest month, experiences mean temperatures ranging from 18 °C (64 °F) to 19 °C (66 °F).

A distinctive feature of the coastal region in Balochistan, including Gwadar, is the consistent temperature throughout the year. Although occasional cold spells may occur when winds descend from the Balochistan plateau, the winters are generally pleasant. Notably, the winter season is briefer when compared to the summer in this area. Gwadar's weather closely resembles that of the Middle East, with the majority of rainfall occurring from December to January.

Table 4-11: Electricity demand and generation for Gawadar

Month	Simulated	PCM	Cooling Demand		Heating Demand		Generation
			Without PCM	PCM	Without PCM	PCM	
January	87	84	0	0	0	0	235
February	94	79	0	0	0	0	264
March	201	168	14	2	0	0	295
April	272	243	234	200	0	0	308
May	305	277	266	231	0	0	365
June	379	346	312	286	0	0	335
July	365	327	301	286	0	0	298
August	343	315	297	279	0	0	285
September	321	278	276	260	0	0	276
October	289	267	129	103	0	0	268
November	181	161	18	4	0	0	259
December	99	95	0	0	0	0	233
Total	**2936**	**2640**	**1847**	**1651**	**0**	**0**	**3421**

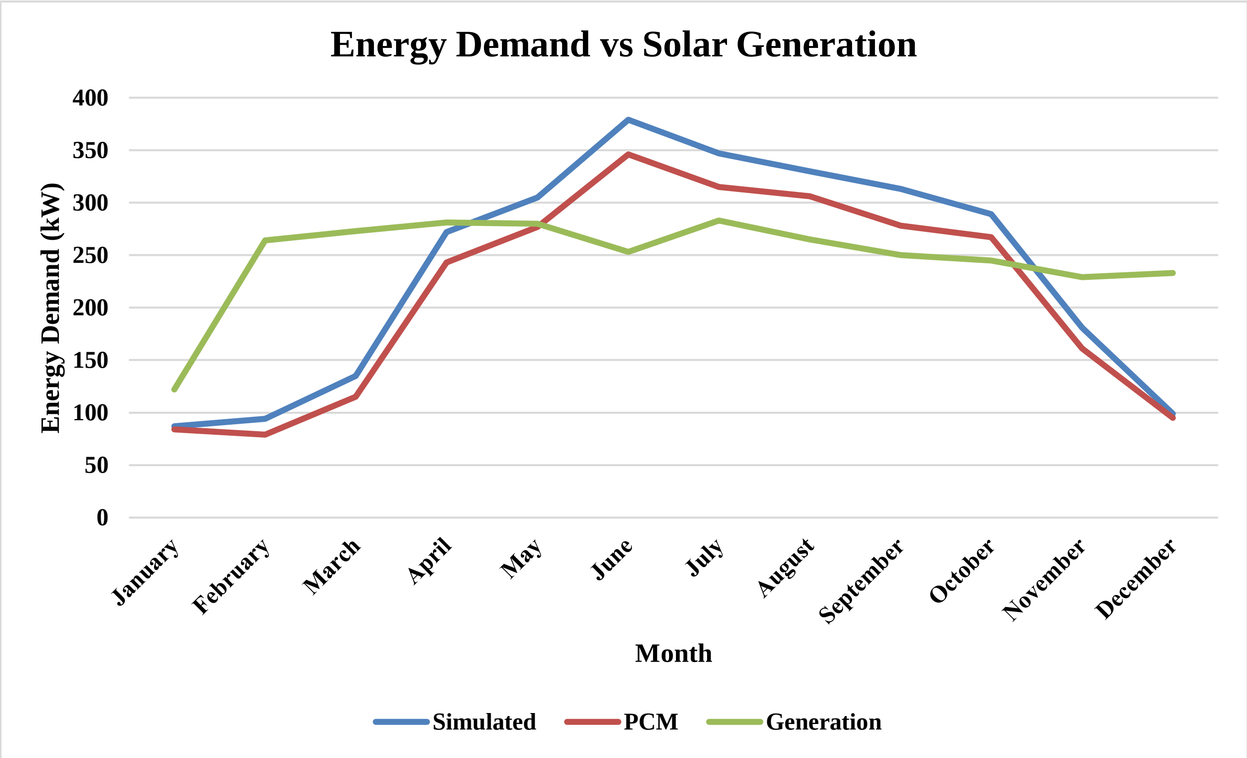


Figure 4.13: Energy demand vs PV Generation for Gawadar

4.3.5 Murree

The town of Murree is situated at an elevation of around 2,291 meters (7,516 feet) above sea level, and this high altitude plays a significant role in creating its enjoyable climate, particularly during the summer season. As a result, it becomes a popular destination for numerous visitors seeking relief from the heat experienced in the nearby regions. The town enjoys a mild and pleasant climate throughout the year, with an average annual temperature of 14.8 °C.| 58.6 °F. The significant amount of precipitation, approximately 1616 mm | 63.6 inches of rainfall annually, ensures that the area remains lush and green. Murree experiences four distinct seasons, with summer attracting many visitors due to its warm weather, which lasts from late June to September. In contrast, winters can be cold and chilly, with occasional snowfall and sub-zero temperatures. The ample rainfall contributes to the natural beauty of Murree's landscape.

Table 4-12: Electricity demand and generation for Murree

Month	Simulated	PCM	Cooling Demand		Heating Demand		Generation
			Without PCM	PCM	Without PCM	PCM	
January	148	138	0	0	70	72	244
February	130	115	0	0	46	47	259
March	148	121	0	0	19	17	279
April	156	127	4	1	3	2	305
May	166	147	46	37	0	0	325
June	198	186	120	95	0	0	310
July	203	175	124	101	0	0	295
August	212	191	90	81	0	0	284
September	195	168	47	41	0	0	276
October	190	161	3	1	2	1	268
November	186	155	0	0	20	20	248
December	157	143	0	0	55	58	235
Total	**1968**	**1827**	**434**	**357**	**218**	**217**	**3090**

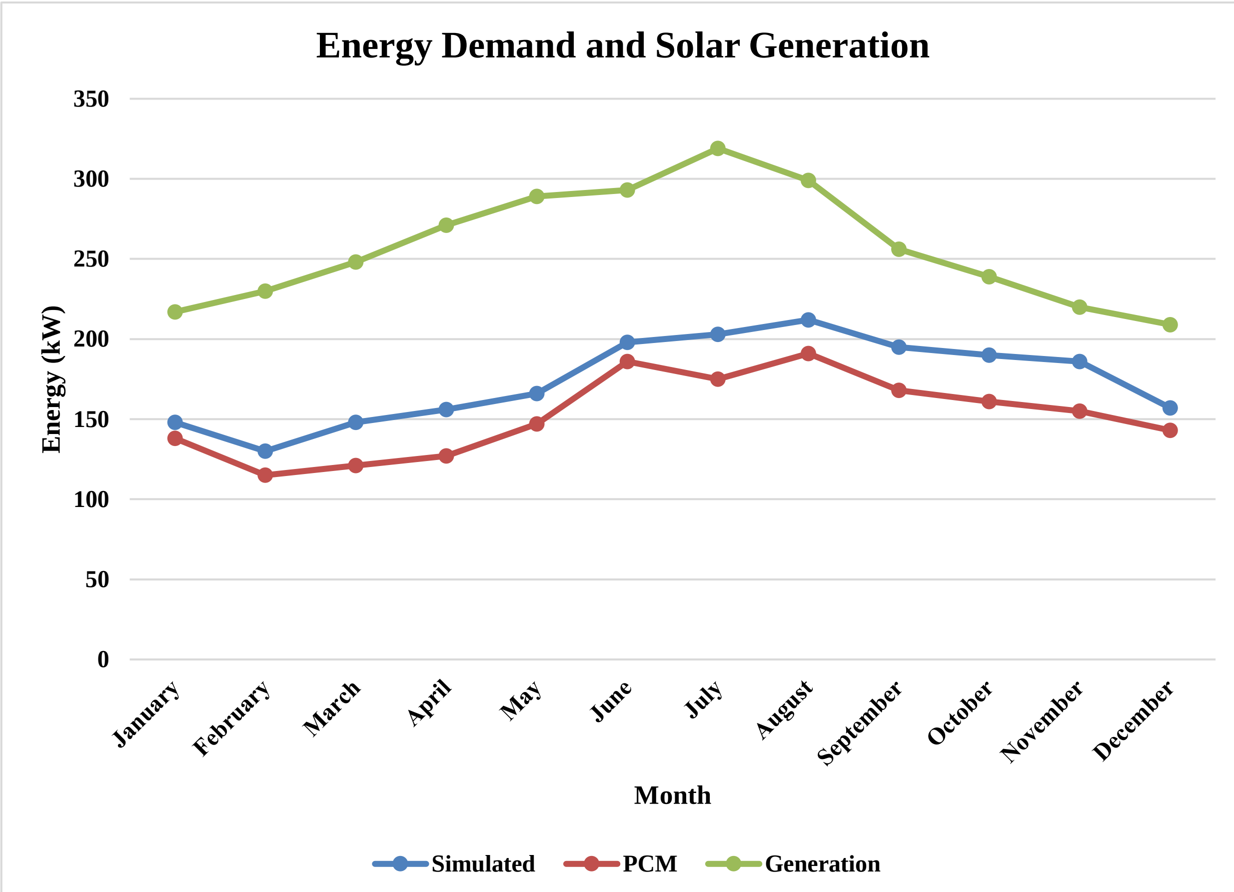


Figure 4.14: Energy demand vs PV Generation for Murree

CHAPTER 5: TECHNO ECONOMIC ANALYSIS

Nowadays, many green building designs include a combination of renewable energy (RE) and energy efficiency (EE) technologies to generate on-site energy. As the costs of hardware, software, and O&M have decreased due to economies of scale and research and development (R&D) activities, the demand for these technologies has increased. However, choosing the optimal mix of RE and EE technologies to maximize cost efficiency and meet energy resiliency targets for a building design can be a difficult decision for consumers. Currently, most energy asset modeling tools require the homeowner to specify the system/technology size, which can significantly impact the economic viability of the system if the performance analysis is based on suboptimal system sizes.

For economic analysis of the system, initially, phase change materials are implemented then solar system is installed to produce green energy and to equalize the energy demand and generation to make it net zero energy building. After that their net present value (NPV) and discounted payback period (DPP) are computed. The NPV represents the total of all future cash flows over the designated period, discounted to their present value. A positive NPV at the conclusion of the period signifies that the investment is financially beneficial and can be pursued. To determine the cash flows, the following equation is employed.

$$CF = R - C = \frac{(R - C)}{(1+r)^t}$$

- CF is the net cash flow (i.e., revenues minus costs) at a given time t,
- r is the real interest rate, and
- t is the time of the cash flow, usually expressed in years.
- The term (1+r) -t is known as the discount factor, DF(t)

The formula calculates the cash flow at a particular time, denoted as CFt, which is the difference between the revenue and cost. The real interest rate is represented by r, while t denotes the duration of the cash flow, typically expressed in years. The discount factor, DF(t), is the result of (1+r) -t.

Finally, the NPV can be calculated using the following formula.

$$NPV = \sum_{t=0}^{n} \frac{CFt}{(1+r)^{t}}$$

The discounted payback period (DPP) refers to the duration when the investment equates to the revenue, indicating that the system has achieved equilibrium. At this point, the NPV equals zero. In the case of passive measures, it is mandatory to have a DPP of 30 years, while for chillers/coolers, the period is 20 years, and for PV technology, it is 15 years. Every energy efficiency measure (EEM) will undergo scrutiny based on its NPV and DPP.

The techno-economic assessment of the system indicates that the system is expected to have a lifespan of around 25 years. The initial investment for the system, which covers the cost of phase change materials (PCM), photovoltaic panels (PVs), and system installation, is estimated to be Rs 1.47 million. Additionally, the operating and maintenance costs are minimal.

The return on investment is calculated to be achieved in 7 years, meaning that the system is expected to generate enough income to cover the initial investment within this period. Over the course of its expected 25-year lifespan, the system is projected to yield a net present value (NPV) of Rs 9.1 million at the end of its operational life.

Furthermore, the analysis is detailed in a table that presents the system's performance data for a ten-year period. In summary, this analysis assesses the economic feasibility of the system, taking into account its initial costs, payback period, and the anticipated financial benefits over its lifetime. The table provides a more detailed breakdown of its performance over the first decade of operation.

Table 5-1: NPV of the System

Cash Flows	YEARS											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Inflows (increment @ 10%)		150,000	183,000	223,260	272,377	332,300	405,406	494,596	603,407	736,156	898,110	1,055,280
Maintenance Cost							-32,210					-51,875
PAT		150,000	183,000	223,260	272,377	332,300	373,196	494,596	603,407	736,156	898,110	1,003,405
Initial Outlay	- 1,470,000											
	- 1,470,000	150,000	183,000	223,260	272,377	332,300	373,196	494,596	603,407	736,156	898,110	1,003,405
Discount Factor @ 10%	1.00	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35
Net Present Value	- 1,470,000	136,364	151,240	167,739	186,037	206,332	210,659	253,806	281,494	312,202	346,260	351,687
Cummulative CF	-1,470,000	- 1,333,636	- 1,182,397	- 1,014,658	- 828,621	- 622,289	- 411,629	- 157,823	123,670	435,872	782,133	1,133,820

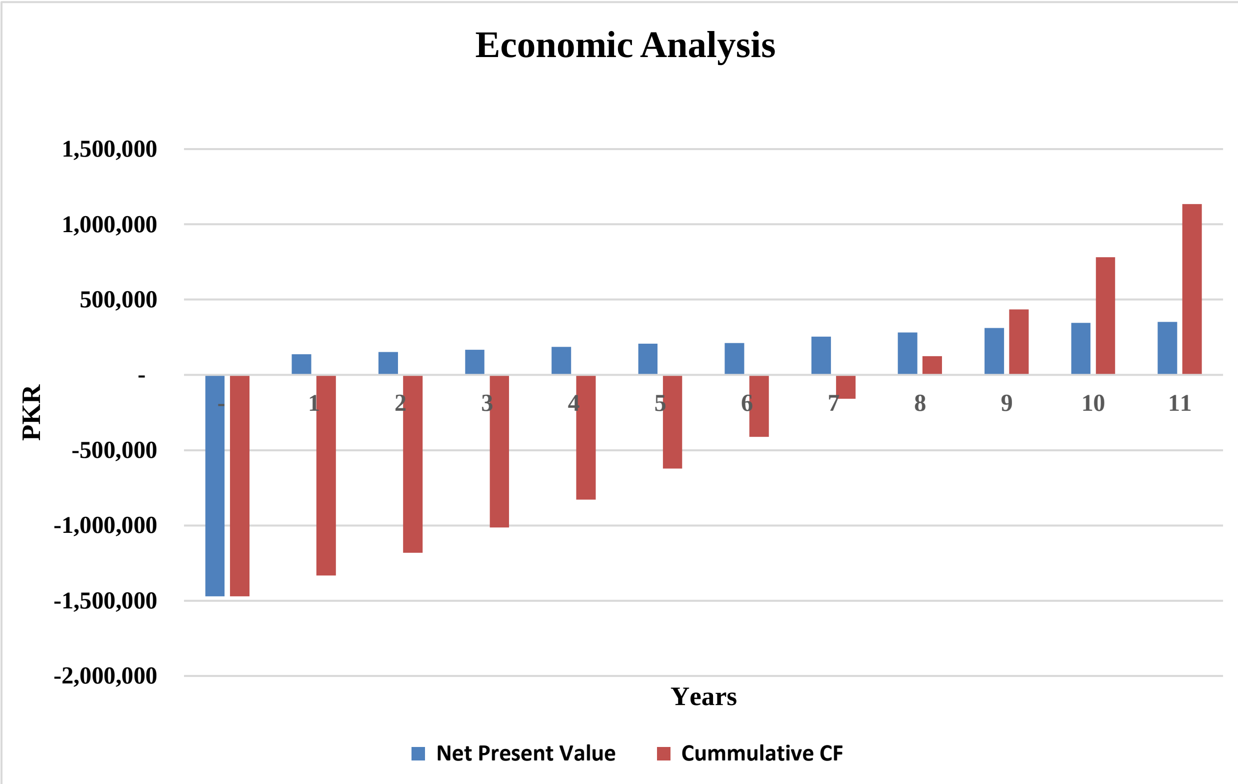


Figure 5.1: Life Cycle Assessment of System

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

PCM and BIPV Technology: Phase Change Materials (PCMs) and Building-Integrated Photovoltaics (BIPV) have emerged as promising technologies with the potential to revolutionize the building sector. The integration of these technologies in building design holds the promise of enhancing energy efficiency and reducing reliance on traditional energy sources. It is noteworthy that, despite the extensive research on PCM and solar panel integration, no previous study has considered the unique climatic conditions of Pakistan. This research addresses this critical gap by examining the feasibility and effectiveness of PCM-enhanced BIPV systems in Pakistan's diverse climates.

The research findings indicate that the inclusion of Phase Change Materials (PCMs) in building design leads to a reduction in energy demand of 7-12% across various climatic conditions in Pakistan. The most significant decrease in energy demand, amounting to 12.25%, is observed in the case of Lahore. Furthermore, the cooling demand of buildings is reduced by 10-17%, with the maximum reduction observed in Murree at 17.75%. Heating demand is also notably reduced by 12-20%. Building-Integrated Photovoltaics (BIPV) systems significantly enhance solar energy production by 50.03% in the overall context. This increase in solar energy generation is instrumental in achieving net-zero energy targets for the selected residential unit. The knowledge generated by this research holds substantial value for policymakers, architects, and engineers. It empowers them to make informed decisions regarding the adoption of PCM-enhanced BIPV systems in building design. These informed decisions can play a pivotal role in advancing the creation of environmentally sustainable and energy-efficient buildings across Pakistan.

The research explored in this thesis addresses the increasing strain on natural resources due to the surging demand for electricity. This urgency has driven the need for more sustainable energy sources to secure a better future for forthcoming generations. Consequently, there has been a global pivot towards renewable energy alternatives, notably solar power, which has seen significant advancements in its industry, enabling its adoption at the residential level.

To foster environmentally conscious structures, two technologies have garnered attention: Phase Change Materials (PCMs) and Photovoltaic (PV) systems. These innovations hold the potential to bring about substantial improvements in energy efficiency within the construction sector.

However, prior investigations into combining PCMs and solar panels have generally disregarded the distinct climate of Pakistan.

The practical ramifications of this research extend to multiple stakeholders, encompassing policy makers, architects, and engineers. By contemplating the incorporation of PCM-enhanced BIPV systems, these professionals can make more informed decisions when strategizing and executing energy-efficient and ecologically sustainable building initiatives. Ultimately, these decisions culminate in propelling the evolution of sustainable construction practices and contribute to the reduction of both energy usage and carbon emissions.

The research conducted in the study demonstrated the importance of using both theoretical and experimental methods to validate the design and operation of a building. The building energy model, created during the design stage, was verified through in-situ monitoring of the building's operation. This approach confirmed the research objectives, methodology, and goals of the study, which aimed to develop a nearly zero-energy building retrofitting method for single-family houses.

REFERENCES

[1] M. Irfan, N. Abas, and M. S. Saleem, “Net Zero Energy Buildings (NZEB): A Case Study of Net Zero Energy Home in Pakistan,” in *2018 International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET)*, Islamabad, Pakistan, Sep. 2018, pp. 1–6. doi: 10.1109/PGSRET.2018.8685970. [

[2] J. M. Santos-Herrero, J. M. Lopez-Guede, and I. Flores-Abascal, “Modeling, simulation and control tools for nZEB: A state-of-the-art review,” *Renew. Sustain. Energy Rev.*, vol. 142, p. 110851, May 2021, doi: 10.1016/j.rser.2021.110851.

[3] P. Aparicio-Ruiz, J. Guadix-Martín, E. Barbadilla-Martín, and J. Muñuzuri-Sanz, “Applying Renewable Energy Technologies in an Integrated Optimization Method for Residential Building’s Design,” *Appl. Sci.*, vol. 9, no. 3, p. 453, Jan. 2019, doi: 10.3390/app9030453.

[4] A. Rehman, H. Ma, M. Ahmad, M. Irfan, O. Traore, and A. A. Chandio, “Towards environmental Sustainability: Devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan,” *Ecol. Indic.*, vol. 125, p. 107460, Jun. 2021, doi: 10.1016/j.ecolind.2021.107460.

[5] K. Ahmed, S. Shahid, and N. Nawaz, “Impacts of climate variability and change on seasonal drought characteristics of Pakistan,” *Atmospheric Res.*, vol. 214, pp. 364–374, Dec. 2018, doi: 10.1016/j.atmosres.2018.08.020.

[6] Alrashed, F. and Asif, M., 2012. Prospects of renewable energy to promote zero-energy residential buildings in the KSA. Energy Procedia, 18, pp.1096-1105.

[7] Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P. and Dubash, N.K., 2014. Climate change 2014: synthesis report. Contribution of Working Groups I. II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, 151.

[8] Wuebbles, D.J., Fahey, D.W. and Hibbard, K.A., 2017. Climate science special report: fourth national climate assessment, volume I.

[9] van Hooff, T., Blocken, B., Timmermans, H.J.P. and Hensen, J.L.M., 2016. Analysis of the predicted effect of passive climate adaptation measures on energy demand for cooling and heating in a residential building. Energy, 94, pp.811-820.

[10] van Hooff, T., Blocken, B., Hensen, J.L.M. and Timmermans, H.J.P., 2014. On the predicted effectiveness of climate adaptation measures for residential buildings. Building and Environment, 82, pp.300-316.

[11] Aldossary, N.A., Rezgui, Y. and Kwan, A., 2017. Establishing domestic low energy consumption reference levels for Saudi Arabia and the Wider Middle Eastern Region. Sustainable cities and society, 28, pp.265-276.

[12] Krarti, M., Dubey, K. and Howarth, N., 2017. Evaluation of building energy efficiency investment options for the Kingdom of Saudi Arabia. Energy, 134, pp.595-610.

[13] Alyami, S.H., Rezgui, Y. and Kwan, A., 2013. Developing sustainable building assessment scheme for Saudi Arabia: Delphi consultation approach. Renewable and Sustainable Energy Reviews, 27, pp.43-54.

[14] Santamouris, M., 2007. Advances in Passive Cooling, Buildings. Radiative Cooling, Energy and Solar Technology Series.

[15] Alaidroos, A. and Krarti, M., 2015. Optimal design of residential building envelope systems in the Kingdom of Saudi Arabia. Energy and Buildings, 86, pp.104-117.

[16] Alrashed, F. and Asif, M., 2012. Prospects of renewable energy to promote zero-energy residential buildings in the KSA. Energy Procedia, 18, pp.1096-1105.

[17] Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P. and Dubash, N.K., 2014. Climate change 2014: synthesis report. Contribution of Working Groups I. II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, 151.

[18] Wuebbles, D.J., Fahey, D.W. and Hibbard, K.A., 2017. Climate science special report: fourth national climate assessment, volume I.

[19] van Hooff, T., Blocken, B., Timmermans, H.J.P. and Hensen, J.L.M., 2016. Analysis of the predicted effect of passive climate adaptation measures on energy demand for cooling and heating in a residential building. Energy, 94, pp.811-820.

[20] van Hooff, T., Blocken, B., Hensen, J.L.M. and Timmermans, H.J.P., 2014. On the predicted effectiveness of climate adaptation measures for residential buildings. Building and Environment, 82, pp.300-316.

[21] Aldossary, N.A., Rezgui, Y. and Kwan, A., 2017. Establishing domestic low energy consumption reference levels for Saudi Arabia and the Wider Middle Eastern Region. Sustainable cities and society, 28, pp.265-276.

[22] Ahmad, A., 2004. ENERGY SIMULATION FOR A TYPICAL HOUSE BUILT WITH DIFFERENT TYPES OF MASONRY BUILDING MATERIALS. Arabian Journal for Science & Engineering (Springer Science & Business Media BV), 29.

[23] Al-Sanea, S.A., Zedan, M.F. and Al-Hussain, S.N., 2012. Effect of thermal mass on performance of insulated building walls and the concept of energy savings potential. Applied Energy, 89(1), pp.430-442.

[24] Harland, A., MacKay, C. and Vale, B., 2010. Phase change materials in architecture. Victoria University of Wellington, 11.

[25] Li, D., Zheng, Y., Liu, C. and Wu, G., 2015. Numerical analysis on thermal performance of roof contained PCM of a single residential building. Energy conversion and management, 100, pp.147-156.

[26] Izquierdo-Barrientos, M.A., Belmonte, J.F., Rodríguez-Sánchez, D., Molina, A.E. and Almendros-Ibáñez, J.A., 2012. A numerical study of external building walls containing phase change materials (PCM). Applied Thermal Engineering, 47, pp.73-85.

[27] Saffari, M., de Gracia, A., Ushak, S. and Cabeza, L.F., 2017. Passive cooling of buildings with phase change materials using whole-building energy simulation tools: A review. Renewable and Sustainable Energy Reviews, 80, pp.1239-1255.

[28] E. Meng, H. Yu, and B. Zhou, "Study of the thermal behavior of the composite phase change material (PCM) room in summer and winter," Applied 5ermal Engineering, vol. 126, pp. 212–225, 2017.

[29] Eddhahak-Ouni, A., Drissi, S., Colin, J., Neji, J. and Care, S., 2014. Experimental and multi-scale analysis of the thermal properties of Portland cement concretes embedded with microencapsulated Phase Change Materials (PCMs). Applied Thermal Engineering, 64(1-2), pp.32-39.

[30] Al-Sanea, S.A., Zedan, M.F. and Al-Hussain, S.N., 2013. Effect of masonry material and surface absorptivity on critical thermal mass in insulated building walls. Applied energy, 102, pp.1063-1070.

[31] Mujeebu, M.A. and Alshamrani, O.S., 2016. Prospects of energy conservation and management in buildings–The Saudi Arabian scenario versus global trends. Renewable and Sustainable Energy Reviews, 58, pp.1647-1663.

[32] Al-Ajlan, S.A., 2009. Energy Audit and Potential Energy Saving in an Office Building in Riyadh, Saudi Arabia. Journal of King Saud University-Engineering Sciences, 21(2), pp.65-74.

[33] Abdou, A.A. and Budaiwi, I.M., 2005. Comparison of thermal conductivity measurements of building insulation materials under various operating temperatures. Journal of building physics, 29(2), pp.171-184.

[34] Yoo, J., Chang, S.J., Wi, S. and Kim, S., 2019. Spent coffee grounds as supporting materials to produce bio-composite PCM with natural waxes. Chemosphere, 235, pp.626-635.

[35] Chou, H.M., Chen, C.R. and Nguyen, V.L., 2013. A new design of metal-sheet cool roof using PCM. Energy and Buildings, 57, pp.42-50

[36] Santamouris, M., 2014. Cooling the cities–a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar energy, 103, pp.682-703.

[37] Jim, C.Y. and Peng, L.L., 2012. Weather effect on thermal and energy performance of an extensive tropical green roof. Urban Forestry & Urban Greening, 11(1), pp.73-85.

[38] Hodo-Abalo, S., Banna, M. and Zeghmati, B., 2012. Performance analysis of a planted roof as a passive cooling technique in hot-humid tropics. Renewable Energy, 39(1), pp.140-148.

[39] Luo, M., Cao, B., Damiens, J., Lin, B. and Zhu, Y., 2015. Evaluating thermal comfort in mixed-mode buildings: A field study in a subtropical climate. Building and environment, 88, pp.46-54.

[40] Salcido, J.C., Raheem, A.A. and Issa, R.R., 2016. From simulation to monitoring: Evaluating the potential of mixed-mode ventilation (MMV) systems for integrating

natural ventilation in office buildings through a comprehensive literature review. Energy and Buildings, 127, pp.1008-1018.
[41] Rees, S.J. and Ezzeldin, S., 2013. The potential for office buildings with mixed-mode ventilation and low energy cooling systems in arid climates.
[42] Chen, J., Augenbroe, G. and Song, X., 2018. Evaluating the potential of hybrid ventilation for small to medium sized office buildings with different intelligent controls and uncertainties in US climates. Energy and Buildings, 158, pp.1648-1661.
[43] Feng, H. and Hewage, K., 2014. Energy saving performance of green vegetation on LEED certified buildings. Energy and buildings, 75, pp.281-289.
[44] Barbosa, R., Vicente, R. and Santos, R., 2015. Climate change and thermal comfort in Southern Europe housing: A case study from Lisbon. Building and Environment, 92, pp.440-451.
[45] Liang, X., Wang, Y., Royapoor, M., Wu, Q. and Roskilly, T., 2017. Comparison of building performance between Conventional House and Passive House in the UK. Energy Procedia, 142, pp.1823-1828.
[46] Liang, X., Wang, Y., Zhang, Y., Jiang, J., Chen, H., Zhang, X., Guo, H. and Roskilly, T., 2017. Analysis and optimization on energy performance of a rural house in northern China using passive retrofitting. Energy Procedia, 105, pp.3023-3030.
[47] Ran, J. and Tang, M., 2017. Effect of green roofs combined with ventilation on indoor cooling and energy consumption. Energy Procedia, 141, pp.260-266.
[48] Cascone, S., Catania, F., Gagliano, A. and Sciuto, G., 2018. A comprehensive study on green roof performance for retrofitting existing buildings. Building and Environment, 136, pp.227-239.
[49] Levinson, R. and Akbari, H., 2010. Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency, 3(1), p.53.
[50] Finkelstein, J.M. and Schafer, R.E., 1971. Improved goodness-of-fit tests. Biometrika, 58(3), pp.641-645.
[51] Lawrie Linda K, D.B., Crawley. Development of Global Typical Meteorological Years (TMYx). 2019; Available from: http://climate.onebuilding.org
[52] DesignBuilder documentation (2019) retrieved from DesignBuilder website: http://www.designbuilder.co.uk
[53] Al-Baldawi, M.T., 2015. Application of Smart Materials in the interior design of smart houses. Civil and Environmental Research, ISSN, pp.2224-5790.
[54] Mohamed, A.S.Y., 2017. Smart materials innovative technologies in architecture; towards innovative design paradigm. Energy Procedia, 115, pp.139-154.
[55] Hasnain, S.M., 1998. Review on sustainable thermal energy storage technologies, Part I: heat storage materials and techniques. Energy conversion and management, 39(11), pp.1127-1138.

[56] Halawa, E., Bruno, F. and Saman, W., 2005. Numerical analysis of a PCM thermal storage system with varying wall temperature. Energy Conversion and Management, 46(15-16), pp.2592-2604.

[57] Liu, Z. and Ma, C., 2002. Numerical analysis of melting with constant heat flux heating in a thermal energy storage system. Energy conversion and management, 43(18), pp.2521-2538.