Modelling and Energy Consumption Analysis of an Industrial Building and passive techniques to reduce energy consumption, A case study in Pakistan

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Abstract:

The continuous expansion in modern building effects the consumption of energy directly. Specially, in growing countries like Pakistan this expansion becomes more evident. Due to high growth rate, there is a major need of hospitals, industries, educational buildings and IT parks thus, increasing the carbon emission and energy consumption, specifically electrical energy consumption. Several techniques were implemented by different organizations to reduce energy consumption. This research investigates time pack of face change materials online energy consumption of an industrial building located in Sialkot, Pakistan. The study utilizes building energy simulation software, DesignBuilder, to model the building and assess its energy consumption under present climate conditions. The research findings reveal that the implementation of energy efficient techniques (EETs) has a significant influence on the energy utilization of industrial buildings. The application of EETs resulted in a remarkable reduction up to 20-30% in the total energy consumption of the building. Furthermore, the heating and cooling demand during winter and summer was reduced to approximately 10-20%. These findings highlight the positive impact of EETs on energy efficiency in industrial buildings, presenting an opportunity for sustainable energy savings and environmental benefits. The results of this research contribute to the body of knowledge on sustainable building design and provide valuable insight for architects, engineers, and building owners seeking effective strategies to optimize energy performance and mitigate climate impact.

Chapter 1

1. Introduction

1.1. Background

The International Panel on Climate Change (IPCC) has issued reports on global climate change, warning of increasing temperatures throughout the 21st century. Hong Kong, a city with a humid subtropical climate, is vulnerable to overheating and higher energy demands if buildings are not designed for warmer weather. Unfortunately, the building sector is the largest contributor to carbon emissions, accounting for 92.7% of locally generated electricity. The effects of anthropogenic climate change are apparent in the rising temperature records in Hong Kong, resulting in greater per capita electricity consumption in residential buildings. As building lifespans extend, it is crucial to design both new and existing buildings to withstand worsening climate conditions. Passive design strategies, including solar shading, fenestration systems, and natural ventilation, are effective in reducing energy consumption in hot and humid climates. Understanding the effectiveness of these passive design strategies under changing climate conditions is crucial to maximize indoor thermal comfort and minimize energy demand. These strategies have significant energy-saving potential in urban areas with hot summers and warm winters, where the increased use of air conditioning could worsen the micro-climate through anthropogenic heat release[1].

1.2. Scope and motivation

The topic of climate change is complex and has substantial repercussions on a number of fronts, including the environment, public health, and the economy. The occurrence of unexpected and extreme meteorological events, particularly during heat waves with temperatures that are higher than 35 degrees Celsius, has significantly increased in both frequency and intensity. This phenomenon has an effect not only on the temperature but also on precipitation, humidity, wind speed, and the irradiance of the sun. Buildings are particularly vulnerable to the effects of climate change because of their interaction with both the outdoors and the indoors. The consequences include disruptions in the equilibrium between the amount of energy used for heating and cooling, an increase in the emissions of greenhouse gases, flooding, structural problems, and adverse impacts on the occupants' comfort, health, and possibly even death. The fundamental objective of this research is to investigate the connection between climate change and buildings, with a particular focus on Nearly Zero Energy Buildings (NZEBs), which are required by law in the EU as of the year 2021. The goals of this project are to investigate the weather datasets that are most frequently used in building simulations and to produce weather files that look into the future in order to simulate how buildings will react to an evolving environment. The impacts of these changes on the energy loads of buildings, the selection of efficiency measures in nearly zero energy buildings (NZEBs), photovoltaic generation, and the influence of electrical energy storage are investigated in this paper. The climates of Europe are the primary focus of this research; nonetheless, the conclusions are relevant to climates everywhere[2].

1.3. Climate Change Impacts

Buildings are extremely vulnerable to the adverse effects of climate change, such as excessive heat, heatwaves, and flooding, which can have a negative impact on the well-being and health of building inhabitants. Buildings contribute a significant amount to the global CO_2 emissions, and they are also extremely vulnerable to these adverse effects. It is essential to have an accurate prediction of the climatic conditions of the future in order to appreciate the impact that climate change will have on the demand for energy in buildings. It is vital to reduce emissions of greenhouse gases in order to battle climate change, and there is a growing emphasis being placed on renewable and sustainable energy resources, in addition to improvements in energy efficiency. Many studies, covering global, regional, and urban dimensions as well as diverse climatic zones, have investigated the impact that climate change will have on the future energy requirements of buildings [1].

1.4. NZEBs:

Buildings are vital to the achievement of the European Union's energy and climate goals because of the significant contribution that they make to the consumption of energy, the production of CO2 emissions, and the utilization of power. The European Union (EU) has taken steps to decarbonize the energy sector, including the construction of buildings with almost zero energy consumption. These steps are being taken in order to reduce emissions of greenhouse gases, improve energy efficiency, and encourage the use of renewable energy sources (NZEBs). NZEBs strive to have strong energy performance while consuming a low amount of energy and getting the majority of their power from renewable sources. Previous study has shown that thermal efficiency measures, equipment, appliances, and renewables can achieve the NZEB goal using a strategy that is cost-optimal. Despite the fact that there is debate among nations regarding the NZEB criteria, this research has been shown. The recently implemented Renovation Wave program has the goal of enhancing both NZEBs and building restoration in order to achieve the climate plan that has been outlined. This study investigates how the consequences of climate change will influence the construction of new buildings and the renovation of existing ones in the future. Simulations of a building's energy use are an essential component of building design, as are projections of the facility's energy performance and activities related to energy policy. Despite this, the precision of the conclusions may be affected by uncertainties connected to the simulation, such as databases of weather conditions. When outdated meteorological records are used, this might result in an increase in the amount of energy that is consumed, as well as additional costs and inadequate heating and cooling systems. Because of the consequences of climate change, it is essential to make use of meteorological datasets that correspond to the conditions that are expected to be present in the future. For the purpose of producing energy simulations, the "morphed" meteorological datasets that have been downscaled to correspond with IPCC scenarios is the methodology that is recommended[2].

1.5. The impact of climate change

Because buildings are such an important component of overall energy consumption, a great number of research projects have been carried out all over the world to investigate the effects that climate change will have on the amount of energy that is used in buildings. These international studies study the influence that climate change has on the energy requirements for residential and commercial buildings in terms of both heating and cooling, as well as the carbon emissions that result from those energy demands. More research is required in order to gain an understanding of the impact that future climate change will have on the patterns of energy use in the building sector, notably in the United States. It is of the utmost importance to have a solid understanding of the potential repercussions, particularly in light of the fact that climate change may occur in the future and that its effects may vary depending on location. Therefore, more research needs to be done to investigate this subject in more depth[3].

1.6. Meteorological year weather data

Accurately predicting a building's long-term energy performance is crucial, and the use of typical meteorological year (TMY) weather data in building energy simulations is common. However, deviations have been observed between energy performance simulated with TMY weather files and that measured under long-term actual weather conditions. As a result, various methods have been developed to generate TMY data, and the subjectivity involved in attributing weighting factors has been investigated. Researchers have conducted several studies on the effects of using these weather files in building energy simulation for different climates and the impact of various generation methods on simulated building performance. To enhance the accuracy of TMY weather data, the development of generation methods to consider the urban heat island effect has been proposed. This approach is particularly relevant due to the increasing number of urban areas worldwide characterized by higher temperatures than surrounding rural areas as a result of human activities and urbanization[3].

1.7. Building energy simulation

The effects of climate change have been significant in Canada, which has warmed at a rate that is twice as fast as the average rate for the rest of the world. This is especially true in the north, where the warming rate has been three times the normal rate for the rest of the world. According to a study conducted in Canada, the average annual temperatures in 16 of the country's most populous cities increased by anywhere from 0.5 degrees Celsius to 4 degrees Celsius between the years 1900 and 2013. This rise in temperature contributed to a 0.85 degree Celsius increase in the average global temperature from 1880 to 2012. In an effort to forestall the potentially catastrophic repercussions that could result from continued global warming, architects and engineers are increasingly integrating sustainable design practices into the building design process. The simulation of building energy use is necessary for the evaluation of building energy performance; however, the accurate creation of future weather data is required in order to accurately represent future energy demand. This requirement extends to the representation of extreme weather events such as heatwaves. The use of climate change data in building energy modeling raises a number of challenges that need to be addressed. For energy simulation, several different types of weather files are used to evaluate both typical and extreme weather situations[3].

1.8. Renewable Energy Resources

The depletion of traditional energy sources has made it necessary to search for other sources of energy that are also sustainable. Academics are hard at work coming up with innovative ideas, performing economic analyses of energy systems, and optimizing future projects as a result of the fact that renewable energy sources have emerged as the most practical alternative for solving the current global energy dilemma. In order to better understand how normal irradiance and incidence angle affect the thermodynamic performance of a solar-powered, high-temperature steam electrolyzer system, researchers are examining the relationship between the two variables. In addition to the production of hydrogen, researchers are investigating other potential sources of renewable energy, such as solar ponds, geothermal sources, and PEM fuel cells. In addition, there has been a rise in interest in the concept of "virtually zero energy buildings," also known as "NZEBs," and significant strides have been made in the construction industry as well as in academic research to develop techniques that can convert conventional buildings into structures that use no energy at all. Researchers have investigated the functionality and effectiveness of NZEBs in a wide range of climatic conditions, in addition to the sizing of PV systems that are able to function on their own. The development of sustainable and renewable energy sources, as well as the design and construction of buildings that use zero net energy, are essential milestones in the fight against climate change and the reduction of carbon emissions[4].

1.9. Objectives of study

Because of the impact that climate change is having on the modeling of building energy, it has become necessary to develop new methods for the creation of weather files. This paper discusses a number of the issues that are related with this attempt. One of the challenges that must be overcome in order to guarantee the reliability of meteorological data is to eliminate any potential biases that may be present in general circulation models (GCMs). Another challenge is the use of general circulation models (GCMs) with a low resolution, which, in order to collect data on a local scale, need to be downscaled to specific regions. In addition to this, the modeling of a building's energy use requires the conversion of daily data into an hourly format. This paper presents a standardized workflow that utilizes a hybrid machine learning method that combines weather classification and regression models to handle climate change data for the purpose of building energy simulation. This is done in order to address the limitations that were mentioned earlier. It is possible that the proposed method will provide numerous future hourly weather data, year by year, for various climate change scenarios. This data can then be utilized by engineers, architects, and building energy modelers in order to maximize the performance of buildings and energy systems. This approach applies to both global climate model (GCM) and regional climate model (RCM) data. A supplementary regression model has been introduced in order to tackle challenges related with the downscaling of GCM data in order to improve the quality of future weather files and enable more precise building energy simulation[5].

1.10. Centralized Electricity Supply

It is impossible to ignore the impact that buildings have on global energy consumption because of the significant role they play in the production of greenhouse gases and the accelerating rate of climate change. Heating, cooling, lighting, and ventilation all require enormous quantities of fossil fuels. The building and construction industry is responsible for 39 percent of the world's CO2 emissions and 36 percent of the world's energy usage. Developing countries such as Pakistan are witnessing a surge in the amount of energy used for building construction as a direct result of improved access to centralized electrical supply. The widespread use of personalized heating and cooling technologies that have low energy efficiency ratios has a considerable negative influence on the environment in these countries. Building envelope improvements, such as retrofitting existing structures with thermal mass, thermal insulation, and high-efficiency windows, are examples of passive energy efficiency measures (PEEMs) that are currently being researched by scientists all over the world as a means of combating this issue. Passive energy efficiency measures can reduce the demand for electricity used for heating or cooling by as much as 20%. Globally, building envelope codes and policies have been improved in order to further encourage the saving of energy. One example of this is Pakistan's Building Code of Pakistan (Energy Provisions-2011), which was implemented by the Pakistan Green Building Council (PGBC). Yet, since 2006, Pakistan's energy regulations have not encouraged the construction of energy-efficient buildings, which has led to a massive economic disaster in the country. Illegal power grid connections, a lack of interest on the part of the government in designing energy-efficient structures, and electricity use in buildings that exceeds the maximum system capacity are all factors that contribute to this problem. It is imperative that energy-efficient buildings be given priority and that PEEMs be encouraged in order to reduce the adverse effects that man-made structures have on the environment and the economy[6].

1.11. Scope of work

On a global basis, there has been substantial progress made in the development of new building constructions that are both environmentally friendly and energy efficient, as well as in the upgrading of energy-efficient technical equipment for the operations of buildings. Older buildings in Pakistan have low thermal performance and are responsible for two-thirds of the country's overall energy consumption. By the process of retrofitting, already-existing structures have the potential to be renovated into projects that are better for the environment and consume less energy. According to a study, the energy efficiency of existing buildings can be improved by undergoing renovations. This is particularly important in Pakistan, where the energy efficiency of existing buildings is rather poor. A number of studies have also looked into potential energy-saving measures that could be implemented in Pakistan's current buildings. A college building in Mianwali, Pakistan, was selected for the purpose of conducting a pilot project to researchenergy-efficient strategies. One of the strategies under investigation was the usage of solar renewable energy sources for the generation of power. In addition, a study was conducted in Multan, Pakistan, to examine the application of passive cooling, indoor environmental quality, user comfort, and energy efficiency in public buildings. The researchers came to the conclusion that the incorporation of passive measures in the building envelope could result in significant savings on energy consumption. No research has been done on the topic of decreasing the indoor temperature and the energy demand for cooling in educational buildings in Karachi, Pakistan through the building envelope and passive energy efficiency measures. While a number of studies in Pakistan have investigated the relationship between indoor environmental quality, thermal comfort, and passive design measures, no research has been done on the topic of reducing the indoor temperature. This research identifies various building envelope compositions as passive energy efficiency measures for an existing exemplary architectural campus building in Karachi, Pakistan, with the intention of determining the cooling energy demand reduction potential of specific methods. The building in question serves as an example of architectural campus design in Pakistan. Developing alternative building envelope compositions as passive energy efficiency measures is one of the objectives of this research, along with assessing the possibilities of reducing the cooling energy demand through specific processes[6].

1.12. Research Aim:

The aim of the dissertation project is to decrease the energy consumption of an industrial building that already exists. To achieve this goal, an in-depth analysis of the industrial building has been conducted, which takes into account its specific characteristics and functions. In order to evaluate the energy usage of the structure, the simulation software DesignBuilder has been chosen. This software allows for a detailed and accurate assessment of the building's energy consumption, which can then be used to identify areas for improvement.

In order to reduce the energy usage of the industrial building, passive climate adaptation strategies are being employed. These strategies involve the use of natural resources and techniques to regulate the internal temperature and humidity of the building, such as shading, insulation, and ventilation. The effectiveness of these strategies is being evaluated using the DesignBuilder modelling software, which allows for the comparison of energy usage before and after their implementation.

Through the comparison of the energy consumption data gathered before and after the implementation of passive climate adaptation strategies, valuable insights can be gained into their effectiveness in reducing energy usage in industrial buildings. This information can then be used to make informed decisions regarding the implementation of energy-saving measures in similar buildings in the future. Overall, this dissertation work is a significant contribution to the field of energy conservation in industrial buildings and can help to promote sustainable practices in the industrial sector.

1.13. Objectives:

The primary objective of this research is to establish a conceptual framework that can bridge the gap between actual and expected energy demands in multi-functional areas of buildings. This framework will incorporate the use of DesignBuilder tools for energy projections. Energy modelers will be able to utilize this framework to enhance the accuracy of energy estimates in multi-functional settings, both in existing and newly constructed buildings.

To achieve this overarching goal, several specific objectives have been identified. Firstly, the current state of energy demand estimation in multi-functional buildings will be analyzed, with a focus on identifying the existing gaps in knowledge and practice. This will be followed by a review of the existing literature on energy modeling and projection tools, with a particular emphasis on DesignBuilder. Next, the proposed conceptual framework will be developed, based on the insights gained from the previous stages of research. The framework will take into account the unique characteristics of multi-functional spaces, such as varying occupancy levels and usage patterns. It will also incorporate the latest developments in energy modeling and projection tools, in order to ensure its effectiveness. The final stage of this study will involve the testing and validation of the proposed framework. This will be accomplished through the use of case studies, in which energy modelers will apply the framework to real-world multi-functional buildings. The accuracy of the resulting energy projections will be compared with the actual energy usage data, in order to determine the effectiveness of the framework. By achieving these objectives, this research will make a significant contribution to the field of energy modeling and projection in multi-functional buildings. It will provide energy modelers with a robust and effective tool for estimating energy demand, which can be used to improve the energy efficiency of buildings and reduce their environmental impact.

The aim of this research is to model and simulate the energy consumption of a building, as well as to analyze its heating and cooling design and passive climate adaptive measures. To accomplish this, a detailed 3D building design has been created using DesignBuilder software, with measurements taken from all sections of the building. Simulation has been performed to calculate the total energy usage of the building, providing valuable insights into its energy efficiency.

1. In addition to modeling and simulating the building's energy consumption, this research also seeks to analyze its heating and cooling design. This analysis will involve an examination of how the existing building structure behaves under different climatic conditions, and how this impacts its energy usage. By gaining a deeper understanding of the heating and cooling design of the building, energy-saving measures can be implemented to reduce its overall energy consumption.

2. Passive climate adaptive measures are another area of focus for this research. Specifically, the use of Green Roof, Green Walls, and Window double Glazing will be studied as separate cases, in order to determine their effectiveness in reducing energy

usage. The analysis of these measures will involve a comparison of their energy-saving potential, as well as an assessment of their feasibility and cost-effectiveness.

3. Overall, this research represents an important contribution to the field of energy conservation in buildings. By providing a detailed analysis of the building's energy consumption, heating and cooling design, and passive climate adaptive measures, valuable insights can be gained into the most effective ways to reduce energy usage in buildings. These findings can then be used to inform the development of sustainable building practices, helping to promote a more environmentally friendly built environment.

Chapter 1 of this thesis outlines the goals and objectives of the research, as well as the main structure of the thesis. The purpose of the research is to analyze building energy consumption and investigate the effectiveness of passive climate adaptation measures in reducing energy usage. The chapter provides an overview of the research methodology and highlights the key contributions of the research.

Chapter 2 provides a comprehensive review of the existing literature on building energy consumption analysis. This chapter examines the different approaches and tools used for energy analysis, as well as the factors that influence building energy consumption. The chapter also highlights the gaps and limitations in the existing literature, which the research aims to address.

Chapter 3 describes the buildings that were selected as case studies for this research and the methodology used to analyze their energy consumption. The chapter provides details on the data collection process and the tools used for building energy simulations.

Chapter 4 presents the results of the model validation process. The chapter examines the accuracy of the energy simulation models used in the research, highlighting any discrepancies or issues that were identified during the validation process.

Chapter 5 is devoted to the results and discussion of the building energy simulations. The chapter examines the energy consumption patterns of the case study buildings, as well as the factors that contribute to energy usage. The chapter also discusses the effectiveness of different energy-saving measures, such as building insulation and lighting upgrades.

Chapter 6 presents the results of implementing passive climate adaptation measures on the case study buildings. The chapter examines the cost and payback time associated with different measures, such as green roofs and double glazing. The chapter also discusses the potential impact of these measures on building energy consumption.

Chapter 7 provides the concluding remarks of the thesis, summarizing the main findings and highlighting their significance. The chapter also identifies areas for future research, such as the development of more accurate energy simulation models and the evaluation of the long-term impact of passive climate adaptation measures on building energy consumption.

CHAPTER 2

2. Literature Review

Energy is an essential component of human life, and it is critical for socioeconomic progress. Over the period, energy consumption has increased due to continues increase in the world's population and economic growth. Access to reliable and consistent power and energy supply is considered a basic human right. The availability of energy is essential in maintaining a fair living standard and supporting the ecosystem as the world continues to advance (IEA, 2020).

However, due to the surge in global population, which is currently growing at a rate of 3.4% per year, the population is projected to exceed 9 billion by 2040. During the same period, global energy demand is expected to increase by 30% (UN, 2020).

Global Climate Change:

Due to the industrial revolution, the world is facing several environmental and energy issues. These include global warming, depletion of natural resources, energy insecurity and increasing energy demand. One of these major issues is global warming which is not only responsible to sea level rise but drastic climate change. To deal with climate change more energy is being consumed. Energy extracted from fossil fuel is being utilized for heating, illuminating, ventilation and refrigeration that ultimately cause environmental changes. Thus, the challenge of meeting energy demand while reducing carbon emissions and mitigating climate change cannot be overstated. According to an estimate, buildings consume one-third of the total energy worldwide. The World Green Council mentioned in research that 32% of the world's natural resources, 40 % of energy is used by the buildings directly and as a result 36% of Green House Gas are emitted. Therefore, the effects of climate change could result in an increase in cooling energy needs of up to 72% in the coming years[7].

Sustainable Buildings:

One of the most promising solutions to address this challenge is to design sustainable buildings. There are certain requirements based on which any building is referred to sustainable that includes efficient use of water and other resources, reduction of environmental degradation and wellbeing of occupants. One of the latest possible methods is the implementation of NZEBs.

Industrial Sector:

Industrial buildings play a vital role in economic development. The total energy consumed by industrial building is the sum of energy consumed during the lifetime. Best practices for the implementation of NZEBs in the industrial sector include the integration of renewable energy systems, the use of energy-efficient building materials and systems, and the adoption of building automation systems to monitor and control energy usage. In conclusion, the implementation of NZEBs in the industrial sector is a promising solution to address the challenge of meeting energy demand while reducing carbon emissions and mitigating climate change. The existing literature provides evidence of the success of NZEBs in various countries, and best practices have been identified to ensure their successful implementation. By adopting NZEBs, the industrial sector can reduce energy consumption and operating costs while improving indoor environmental quality and employee productivity.

Need of Reforms for Industrial sector:

Human population is increasing rapidly due to which energy demand has also increased all over the world. A major portion of energy (40%) is consumed by the building sector as shown in figure.

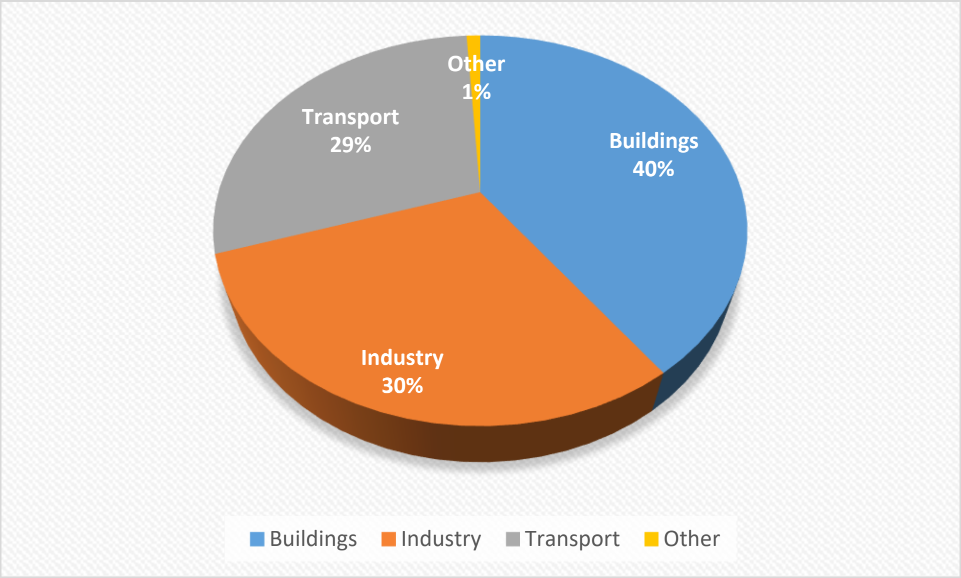

Figure 1: Energy Consumption by Different Sectors in Pakistan

Energy Needs in Pakistan:

When considering global energy and environmental policy, it is important to consider the energy mix and consumption patterns of India, Pakistan, and Bangladesh (IPB), the three largest South Asian countries in terms of population, geographical area, and GDP. The building industry is the most energy-intensive in all three countries, even though renewable energy resources have a great deal of potential in all three. Human and economic progress has been stymied in many countries due to insufficient policies surrounding renewable energy. This research examines the regulatory and technical constraints that prevent the widespread deployment of renewable technology and presents a critical analysis of the major performance indicators from 1970 to 2017. The results of this research are relevant for all low-income countries[8].

IPB's energy usage has skyrocketed since 1970, with fossil fuels continuing to provide the bulk of that demand. The consumption of coal is increasing at a greater rate than that of any other fossil fuel. More than 30 percent of all energy used in IPB is used by the construction industry, making it the most energy-intensive sector. As private automobiles and motorcycles are commonplace in the area, transportation also contributes significantly to energy consumption. Although solar, wind, and hydropower all have the potential to significantly increase IPB's total energy composition, they currently contribute very little. Inadequate renewable energy regulations, institutional arrangements, and market structures impede the deployment of renewable energy technology in IPB. Lack of a level playing field and unfavorable regulatory and legislative frameworks have stymied the expansion of renewable energy in these countries. The growth of renewable energy in the region has been delayed by a lack of necessary infrastructure, such as transmission and distribution networks. The report suggests long-term strategies for decreasing IPB's per-capita energy use. Among these suggestions are the development of a strong institutional framework, the encouragement of public-private partnerships, the adoption of market-oriented approaches to renewable energy, and the creation of a complete and integrated energy policy framework. The research also recommends using alternative funding methods like green bonds to help advance renewable energy. In conclusion, there are significant implications for international energy and environmental policies resulting from IPB's energy composition and consumption. The industry is the most energy-intensive in all three countries, even though renewable energy resources have a great deal of potential in all three. The research examines the regulatory and technical constraints that prevent the widespread use of renewable technology, and it presents a critical analysis of the major performance metrics from 1970 to 2017. The research's conclusions can help other developing countries around the world improve their own energy and sustainable development[8].

Passive Climate Adaptation Measures:

The thermal comfort and energy efficiency of buildings are gravely threatened by global warming. South Asian nations must take preventative measures to mitigate the effects of climate change and acclimate to the new normal. Energy efficiency and reduced greenhouse gas emissions are two primary objectives of passive building design. This study's objective is to investigate the effects of PCAMs (passive climate adaptation measures) on the energy efficiency of Pakistani industry.

Methods adopted for creating energy efficient industrial buildings varies from industry to industry. Even the requirement for energy efficient industry in the same building varies. Hence, the effective design for industrial building cannot be generalized. Natural ventilation and front green walls were found to be the two PCAMs with the greatest potential for lowering Pakistani residential buildings' total energy consumption. There is a 27.75% drop in heating needs and a 35% drop in cooling needs. Shading devices, roof gardens, and insulated building wall are some of the other efficient techniques for decreasing energy usage. The research highlights the significant role that PCAMs can play in lowering building energy use and combating climate change.

Ventilation:

Considering energy efficient design and environmental control, industrial buildings are divided into two main categories. In first category, no intense pollution or heat is generated. All the energy is utilized either for heating or cooling purposes. The design principle for this type of buildings is to reduce energy utilized for heating purposes in winter while cooling in summer. This can be done by heat preservation and insulating the structure. In second type of building, intense pollution and heat is generated hence, energy is consumed throughout the year. The principle for such buildings is to minimize the energy utilization of the ventilation system, heating and air conditioning. Certain methods such as insulating the structure, natural ventilation, heat preservation and mechanical ventilation system can be adopted to attain energy efficiency. Industrial buildings that include rolling process and metal smelting represent such buildings. In industrial buildings, efficient ventilation is very necessary.

Green roof or green wall:

Green roofs and walls are also known as Vegetated roofs and walls. An extra layer of grass or plants is placed to the roof and walls for insulation purposes. It is quite beneficial for improving overall energy performance. To avoid overloading the roof, it should be maintained light in weight. This passive measure not only saves energy but also has environmental benefits [38]. Green infrastructure, such as roof gardens and wall plantings, can improve wildlife habitat connections and hence boost urban biodiversity. The authors evaluate green roofs and walls from an ecological and technical standpoint using factors such as patch size, quality, quantity, and isolation. The analysis shows that green roofs and walls are not very effective as wildlife corridors due to their small patch sizes, lack of diversity in habitat quality, and lack of redundancy in patch quality throughout the terrain. More research is needed, the authors argue, to determine whether green walls can serve as vertical corridors for wildlife and whether it is possible to integrate the biotic and abiotic characteristics of green buildings so that they more closely resemble open green spaces. A sustainable method of urban development, this strategy has the potential to improve biodiversity in cities and increase landscape connectedness [22].

Green roofs are often classified into two types: extensive green roofs and intensive green roofs. Green roofs are lighter in weight than grass and require minimal care. Intensive green roofs, on the other hand, are heavier in weight, such as tiny trees, and are placed at a deeper level.

A research [9] was conducted to assess the performance of green roofs on existing structures. The study was conducted at the Mediterranean city of Catania, Italy, where several types of green roofs were used to determine the load limit for existing buildings and compared to prior studies. The load limit of integrating green roof for existing building was found to be 1.46 kN/m^2. This method reduced cooling and heating energy usage by 31 to 35% and 2 to 10%, respectively. Another study [10] was carried out to check the performance of green walls on buildings. Green wall was attached to the building vertically as a passive climate adaptation method. Both experimentation and simulation were performed to analyze the energy performance in hot arid region of Jordan.

It was discovered that installing a vertical green wall reduced outside wall surface temperatures by 6 to 11 °C. [11] investigated the impact of green roofs on residential buildings in another study. The effect of green roofs on heat transfer was observed and compared to conventional roofs. This research was carried out in various Iranian climate cities using the DesignBuilder software. Only in the city of Rasht was it discovered that green roofs might prevent heat transfer between the months of April and July.

Numerous school buildings located in various cities of Egypt were investigated to assess the effect of a green roof on cooling energy usage. Different green roofs were installed and investigated. For each type of green roof, cost analysis was also performed in order to choose the best affordable green roof. By using green roofs, energy consumption was reduced up to 39.74%. It was advised that the 0.1 m soil depth can be used to save energy. A 4°C decrease in average temperature was also observed in hot desert locations with green roofs.

Cooling potential from green roofs and solar thermal shading in buildings is calculated using a mathematical model. The model uses Newton's iterative process to simulate the physical properties of the green canopy, soil, and support layer separately. The model is tested and its accuracy in forecasting changes in canopy air temperature and indoor-air temperature is determined using experimental data from a similar green roof-top garden. The results show that green roofs and sun shading can significantly lower inside temperatures, which in turn reduces the need for cooling energy. Important to building design and energy saving efforts is the model's ability to estimate the performance of green roofs paired with solar shading. The model is useful for architects and engineers since it can be used with a wide variety of greenhouse and building simulation systems[12].

Shading:

An efficient method to reduce heat gain via windows is shading. This will also reduce the overall energy consumption. Different elements can be installed to provide shade that includes louvers, side fins, overhangs and blinds. Overhangs, louvers and fins are installed outside. To find the relation between energy consumed and window shading, a study was conducted using simulation software. It was found that overhangs and side fins were useful when placed on north and west facing windows. When overhangs and side fins are placed on the east facing windows energy consumption almost remain the same.

Glazing:

The usage of glass in modern structures is increasing, which will eventually contribute to heat gain. To maintain the comfort level, the building's energy requirement rises. Glazing is a key component of windows. Glazing is classified as:

1. single glazing
2. double glazing
3. triple glazing
4. quadruple glazing

The majority of solar radiation passes through window glass. If the proper type of glass is utilized for the windows, it will result in energy savings by lowering the overall cooling energy consumption [50].

Different types of glazing were investigated for four different cities of India. It includes clear glass, green glass, bronze reflective glass and bronze glass. All façades were simulated 64 times in this study. The south-facing windows were found to be more efficient. The window with bronze reflecting glass was found to be more efficient.

Photovoltaic Technology:

As the communities are developing world widely so as human activities is increasing. A rise of 0.6 ^{0}C in temperature is observed due to continues emission of carbon dioxide that is causing global warming. If no action is taken, an increase of 1.4 to 5.8^{0}C in surface temperature could be observed in upcoming times. This abrupt change in temperature can disturb the whole eco system. Hence, it is important to shift from traditional methods of energy extraction to renewable energy. Sun is providing 10,000 times more energy as compared to need of the earth each day. The simplest and easiest technology to convert available solar energy into electric energy is PV (photovoltaic). It can easily be installed in any place. It is still expensive but ecofriendly and low maintenance source of energy. The technology was first introduced in 1839. Further development in solar technology is described in table:

The PV system comprises of silicon cells that are assembled in the form of modules. These modules are highly resistant to water, hail impact, abrasion and other environmental factors. There are two types of PV cells: mono-crystalline cells and poly-crystalline cells. Out of these mono-crystalline system is most commonly used and cost-effective system. It uses crystalline Si p-n junctions.

Comparison between industrial and non-industrial buildings:

Researchers and practitioners may get a deeper understanding of, and find solutions to, building energy use by focusing on these knowledge gaps, which will in turn lead to more efficient building designs and policies. This article provides a concise overview of the literature on the topic of building energy use and demand, as well as suggestions for further research. The report highlights the need to combine quantitative and qualitative research findings into energy simulation tools and the need to examine the influence of occupant behavior on the energy performance of buildings [12].

The urban thermal environment, often known as the UTE, is an essential part of urban ecosystems that has an impact on the well-being and comfort of people living in cities. The urbanization process, changes in land use and land cover (also known as LULC), and environmental circumstances all have a significant impact on the urbanization process. This study aims to investigate the relationship between UTE and a wide range of important elements as well as ecological circumstances by employing indices that are derived from remote sensing (RS). According to the findings of the study, the amount of land that is covered with vegetation in Faisalabad has shrunk as a result of the growth of the city. In addition, urbanization has been responsible for both a rise in land surface temperature (LST) and a worsening of ecological conditions in all urban buffers. In addition, the research establishes a positive association between LST and Normal Difference Built-up Index (NDBI), which indicates that regions with a high built-up density have a bigger LST. This is because locations with a higher built-up density have more people living in them. In contrast, the Normal Difference Vegetation Index (NDVI) exhibits a negative connection with LST, which indicates that areas with greater vegetation cover experience lower LST. This may be deduced from the fact that the NDVI is negatively correlated with LST.

This research highlights the need to protect ecological conditions in urban areas and the impacts of urbanization on the UTE. The results suggest that green spaces and vegetation cover should be considered in urban development to lessen the impact of UTE. The study's use of RS-based indicators provides a helpful instrument for monitoring and analyzing UTE in urban settings, which can aid in the creation of effective urban planning initiatives[13].

The review also highlights various open research questions, including the integration of quantitative and qualitative research findings into energy simulation tools, as well as urban analysis, interior design, psychological and cognitive behavioral methodologies, and more.

The accuracy and scope of building energy evaluations are sometimes compromised by the need to make assumptions about building features and tenant behavior. An open-source, wireless sensor network has been created to deal with this matter. Air temperature, humidity, heat flux, luminosity, oil flow, and CO2 concentration are just some of the parameters that may be measured by this sensor network, which is easily programmable, adaptable, and deployable. Improve the accuracy and completeness of energy evaluations with the help of real-time data streaming to an online database for monitoring. Furthermore, the sensor network's adaptability allows for additional sensors to be added at any time. The cost and efficiency of the sensor network are on par with existing systems, with a battery life of up to a year and an average installation time of 7 minutes per sensor node. Co-location tests and deployment in an occupied building are discussed, together with their resulting hardware and software architectures, costs, and outcomes. This wireless, open-source sensor network holds great potential as a tool for conducting more accurate and comprehensive energy audits of commercial structures.

This paragraph investigates the significance of thermal performance within the context of environmental building assessment. In addition, it describes a simulation investigation conducted on a module located in a university building in Australia's south-eastern region in order to assess its cooling burden. The analysis of the cooling load reveals that the module located at the northwest corner of the building's roof has the greatest cooling demand. The research evaluated various modifications in materials, construction methods, and design principles relative to a baseline scenario and identified significant variables that affect thermal efficiency. The final configuration, which included a hypocaust slab mechanism atop the office module, was anticipated to reduce annual energy consumption for heating and cooling by 72% and 77%, respectively. The significance of employing sophisticated modeling and simulation techniques during the design phase to improve the thermal performance of buildings is highlighted by the present research[14].

The utilization of building energy simulation tools is crucial to the evaluation of a building's performance in terms of energy efficiency. Selecting precise and dependable instruments is essential for accurate evaluation. The current study proposes a methodology for evaluating simulation outcomes using artificial neural networks (ANN) for the purpose of predicting the energy efficiency of buildings. In order to train and evaluate the artificial neural network (ANN), the researchers utilized energy consumption data from a specific building known as the Solar

House. The Artificial Neural Network (ANN) forecasted building energy performance with a mean absolute error of 0.9%, demonstrating its high level of accuracy. The study compared the results produced by four distinct building simulation tools, namely Energy_10, the Green Building Studio web tool, quest, and Energy Plus, with the energy consumption predicted by an Artificial Neural Network. The study revealed that simulation tools with a higher level of detail demonstrated superior simulation performance, as demonstrated by the heating and cooling electricity consumption being within 3% of the mean absolute error.

These findings highlight the need for using accurate and trustworthy building energy modeling software for a thorough evaluation of a building's efficiency. It has been proposed that artificial neural networks be used to evaluate simulation results as a helpful method for determining a building's energy efficiency [26]. Numerous factors, such as climate, building materials, and resident behavior, contribute significantly to buildings' overall energy consumption. Accurately estimating a building's energy performance is essential for lowering energy use and meeting sustainability targets. Engineering models, statistical models, and AI models are only some of the models developed to take on this problem [26].

Energy efficiency predictions for buildings can be made using several different modeling approaches. The work provides a thorough overview of the research done on these models in the academic literature and how they have been applied in the real world. Engineering models replicate a building's energy consumption by applying the first principles of physics and mathematical equations. Models are constructed using statistical methods to examine the relationship between building energy usage and other variables, such as weather and occupancy rates. Artificial intelligence models use machine learning algorithms to predict future energy use in buildings by studying existing data.

The above assessment assesses the strengths and weaknesses of several models, as well as their applicability in predicting building energy consumption. study gaps are highlighted, and possible future study directions are suggested. The use of big data and Internet of Things (IoT) technologies, as well as the creation of hybrid models that combine the best features of several modeling methodologies, are all possibilities for improving the accuracy of building energy forecast. In conclusion, reducing energy consumption and achieving sustainability goals relies heavily on accurate predictions of building energy efficiency. More research is needed in this area to improve the accuracy of building energy forecasting, but the critical evaluation of different modeling methodologies provides valuable perspectives on their respective benefits and drawbacks [27].

The global energy consumption of buildings is substantial, which has increased interest in models of building energy consumption. These models are renowned for their ability to support energy management, conservation efforts, and the detection of malfunctioning building systems. This article provides an overview of the numerous techniques used to construct building energy simulations. These methods are separated into four distinct categories: data-driven, physics-based, large-scale building energy forecasting, and hybrid approaches. The focus of this article is on methodologies that utilize data analysis and predictive models to estimate the energy consumption of large structures. Four distinct subcategories constitute the classification of data-driven methodologies: artificial neural network-based, clustering-based, statistical and machine learning-based, and support vector machine-based. Utilizing historical data to anticipate building energy consumption patterns is a valuable strategy for both energy consumption prediction and energy management optimization.

White-box, black-box, and grey-box are the three distinct approaches that can be used to predict building energy on a large scale. The aforementioned techniques were developed specifically to predict energy consumption across vast temporal and spatial domains, making them extremely advantageous for government decision-makers and city planners. White-box methodologies employ models based on fundamental principles and are particularly applicable to the improvement of energy efficiency. Black-box approaches rely on empirical data, which proves useful for forecasting energy consumption patterns across diverse building types and end-uses. Grey-box approaches are characterized by the incorporation of features from both black-box and white-box approaches, which prove to be extremely advantageous in the transition from building-specific models to urban-scale models.

The article describes the advantages and disadvantages of each methodology, along with their intended purposes and practical applications. Several topics pertaining to energy performance metrics, the use of various building types, numerous levels of granularity, and urban and rural scales are examined in depth. The development of models for building energy consumption is crucial for improving energy management, preserving building systems, and detecting malfunctions. This article provides an overview of the various methodologies that can be used to construct energy simulations, as well as an analysis of the advantages and disadvantages of each technique. More research is required to develop more precise and reliable models for predicting the energy consumption of buildings [28].

The impact of climate change on the energy consumption of buildings in the United States is becoming more evident. Academic: The integration of global climate models and conventional meteorological year weather files has been achieved through a newly devised technique called "morphing" by researchers. This method enables the prediction of local hourly weather data. The data previously mentioned was employed to predict forthcoming trends in energy consumption for both residential and commercial structures in four representative American urban areas. The study's findings indicate that energy consumption will be significantly affected by climate change. The expected fluctuations are estimated to fall within the range of -1.64% to 14.07% for residential edifices and -3.27% to -0.17% for commercial edifices. The findings of the study suggest that the utilization of lighting and fans has resulted in a reduction in energy consumption. It is expected that in the upcoming years, there will be a surge in the maximum electricity requirement during the cooling seasons, leading to an augmented burden on the power grid. The aforementioned findings underscore the necessity for the construction sector to adopt efficient strategies to alleviate and adjust to the impacts of climate change [29]. This article examines the effects of climate change on a residential building of moderate height in Turkey. It evaluates numerous scenarios to determine the building's energy requirements, CO2 emissions, and thermal comfort for occupants. This study investigates four distinct Turkish cities with distinct climatic characteristics. The study evaluates three distinct scenarios, ranging from natural ventilation to complete air conditioning. On the basis of the outcomes of the energy simulations, it can be concluded that the potential for future overheating will have a significant impact on the consumption of cooling energy and the comfort of occupants. As a means of mitigating the effects of climate change, the research indicates the necessity of implementing measures to adapt to climate change and minimizing carbon emissions in the electricity sector. These findings may serve as a basis for future research on the retrofitting of buildings in Turkey in response to climate change [30].

In response to the growing demand for countermeasures to renovate building envelopes as a consequence of climate change, a study was conducted utilizing the morphing method to generate future hourly weather years in order to forecast building energy consumption. To determine the operational status of air conditioning during the hours of occupancy in a standard residential building, an adaptive comfort model was implemented. The Energy Plus software was utilized to conduct simulations, which revealed a time-dependent, dynamic increase in cooling energy consumption. The study proposed five passive design strategies for the renovation of buildings with the objective of preventing the escalation of cooling energy consumption. The study revealed that the implementation of a single strategy is insufficient to curb the increase in cooling energy consumption. However, multiple passive strategies can effectively mitigate the effect of climate change on cooling energy consumption. To reduce energy consumption in buildings, passive strategies such as green roofs, shading devices, insulation, natural ventilation, and thermal mass are employed. This study highlights the importance of employing passive techniques during building renovation to mitigate the effects of climate change on energy consumption [31].

It is impossible to overstate the importance of energy efficacy in the design of school buildings, as it has a direct impact on the indoor environment and the comfort of students. This study highlights a zero-energy educational facility in Greece that serves as a model for achieving significant reductions in energy consumption while concurrently enhancing thermal comfort. The educational institution utilizes advanced energy technologies, such as a high-performance building envelope, a geothermal heat exchanger, and a solar photovoltaic array, to generate sustainable electricity. By integrating these technologies, the educational institution reduces its energy consumption by nearly 68% compared to a conventional school building, resulting in substantial financial savings and environmental benefits. The article emphasizes the importance of enhancing the interior environmental quality of educational facilities, particularly through the implementation of optimized ventilation and lighting systems. This is essential for providing students with a wholesome and comfortable learning environment. The paper presents a case study of a zero-energy school, illustrating the successful application of sustainable design principles in the education sector. The study emphasizes the advantages of energy efficiency and enhanced indoor environmental quality as a result of such practices [33].

The rising demand for residential cooling systems presents a formidable barrier to the pursuit of decarbonizing energy systems. In Switzerland, the use of cooling equipment and the effects of climate change necessitate innovative strategies to reduce cooling needs. This study examines the viability of employing passive cooling techniques, such as night ventilation and window shading, to reduce cooling energy consumption. The methodology employs a physical bottom-up approach to model the cooling needs of residential buildings, taking into consideration factors such as the age and construction characteristics of the Swiss building stock, regional climatic conditions, urban design, and occupant behavior. The results indicate that the combination of window shading and night ventilation has the potential to reduce the cooling demand by 84%. Notable is the fact that half of the current cooling energy demand is attributable to buildings constructed after the year 2000. The findings indicate that passive cooling techniques have the potential to mitigate the effects of climate change in Switzerland, promoting sustainability and enhancing the durability of residential cooling [32].

DesignBuilder was used to simulate a four-story institution in subtropical Queensland, Australia, in order to evaluate the effectiveness of various energy conservation measures (ECMs). The energy consumption profiles of existing systems were analyzed, and the results were confirmed through on-site measurements. We compared ECMs that received substantial investment, moderate investment, and no investment whatsoever. The study found that the evaluated ECMs could reduce energy consumption by up to 41.87 percent without compromising occupant comfort. In addition, the significance of establishing energy efficiency benchmarks for commercial buildings is emphasized. The majority of benchmarking models rely on a simple percentile table of energy consumption; this study presents a benchmarking method that uses multiple regression analysis to establish a correlation between energy-use intensity and explanatory factors. This enables the standardization of EUIs by removing the influence of variation in key explanatory factors, resulting in a comparison matrix that takes into account all significant contributors to energy consumption. To demonstrate the utility of this strategy, we will use grocery stores as an example [19].

This study evaluates the energy efficiency of a structure and investigates the effectiveness of energy-saving innovations. The Electrical Engineering Building at the Industrial University of Santander in Bucaramanga, Colombia, served as the pilot site for this study. The researchers utilized the software DesignBuilder to model a number of variables, including air temperature, humidity, air velocity, daylighting, and energy consumption. In the analysis, the thermal burden and energy consumption of the building were utilized to identify critical areas. After calibration and validation, the virtual model achieved an error rate of less than 5%. According to the simulations, the installation of green roofs resulted in a 31% reduction in internal heat accumulation. In addition, the use of solar pipes was found to enhance the amount of daylight by 33%. The building's estimated annual energy consumption was 69,283 kilowatt hours. The research highlights the potential benefits of energy-saving technologies and stresses the importance of examining and evaluating the energy efficiency of buildings [23]. This paragraph describes a benchmarking model that evaluates the energy consumption of ventilation systems in air-conditioned office spaces, with an emphasis on indoor air quality. The current model is based on psychrometric analysis conducted under Hong Kong's standard office design conditions. The research indicates a strong correlation between the annual energy consumption per unit floor area of a ventilation system and the concentration of carbon dioxide (CO2) in the environment, as opposed to the air temperature setting. The benchmarking model demonstrates that energy conservation can be achieved while maintaining acceptable internal air quality. Assessing the energy efficiency of ventilation systems in air-conditioned office spaces is facilitated by the aforementioned model, which has the potential to improve their efficacy [24].

In addition, the study assesses the potential for lowering carbon dioxide emissions by the utilization of renewable energy sources and realizing a net-zero energy building. Using renewable energy sources, structures can reduce their carbon footprint by 31% per year and by nearly half monthly. The potential of renewable energy to produce energy-efficient, greenhouse gas-reducing buildings is highlighted by these findings.

The study continues by emphasizing the significance of climate change to indoor thermal comfort and energy efficiency, with special reference to the vulnerable countries of South Asia. By improving energy efficiency and lowering greenhouse gas emissions, passive building design strategies are crucial for combating and adapting to climate change. The research compares the effectiveness of PCAMs both singly and in combination to determine their overall effect on the energy efficiency of Pakistani homes. The potential for zero-energy buildings is highlighted, as is the possibility of reducing carbon dioxide emissions by switching to renewable power sources [10].

Chapter 3

3. Methodology:

The methodology employed for this research commenced with inputting the weather file of the industrial city Sialkot, 51310 Pakistan, into the DesignBuilder software. Subsequently, constructional records and measurements were collected to create a building model in the desired orientation within the software. The industrial building was then examined in detail, with the assistance of the building's maintenance and operation staff, to gather information on occupancy, HVAC, lighting, machinery, operating schedules, and office equipment. Power densities of the equipment were calculated, and all parameters were inputted into the DesignBuilder software for simulation. The model was validated using the building's electricity bill. Finally, passive climate adaptive measures were implemented in the office spaces as two different cases, along with an economic analysis and assessment of payback time.

3.1. Summary of Building Features and Study Parameters:

The industrial building is in Small Industrial Estate (S.I.E), Sialkot 51310, in the Punjab region of Pakistan. It comprises of offices and workshops, with the offices being fully air-conditioned, while the workshops utilize ceiling fabs for ventilation. The construction of the building consists of locally standard walls made of double both sides. In the offices, the roof features suspended 10 mm Gypsum ceiling panels, whereas in the workshops, a standard concrete roof plastered on both sides is used. The design takes into account both inner and outer shading, considering the actual conditions of the site. The information base for the study included architectural documents of the building, weather data, occupancy details, lighting factor data, machinery specifications, inner consumption data, and air conditioning requirements. Table 1 presents a summary of the industrial building system being investigated, including its working plan and orientation. The specific details of the building under study are as follows:

- Location: Small Industrial Estate (S.I.E), Sialkot 51310, Punjab, Pakistan
- Building Components: Offices and workshops
- Office Features: Fully air-conditioned
- Workshops Features: Ceiling fans for ventilation
- Wall Construction: Double brick walls plastered on both sides.

- Office Roof: Suspended 10 mm Gypsum ceiling panels.
- Workshop Roof: Standard concrete roof plastered on both sides.
- Shading: Inner and outer shading considered in the design
- Data Sources: Building architectural documents, weather data, occupancy details, lighting factors data, machinery specifications, inner consumption data, and air conditioning requirements.

Table 1: Industrial Building Design Characteristics

Sr. No.	Building Features	Parameters
1	Size	Double story flat roof, almost rectangular geometric with opening on the earth floor.
2	Working Plan	8:00 to 18:00 [6 days/week]
3	Walls	Two-fold Brick Plaster on both sides.
4	Roof Ceiling	Concrete and Gypsum board.
5	Floors	Concrete slab with carpet
6	Internal Partitions	Single Brick Plaster on both side
7	Component Block	Bricks
8	Roof	150mm thickness concrete.
9	Orientation	North-East
10	City	Sialkot, 51310
11	Country	Pakistan
12	Coordinates	32°29'10.0"N 74°31'06.7"E
13	Width	50 m
14	Length	78 m
15	Total Height	7 m
16	Number of Storeys	2
17	Window height	1.5 m
18	Window width	1.5 m
19	Windows to Wall %	10
20	Kind of Window	6mm Glass single Glazed with overhang.
21	Occupancy	1.2 people/m^2
22	Air infiltration	10L/s/person
23	Internal Shading of window	Blinds (medium Reflectivity Stats)
24	Local Shading Type	0.5m Overhang
25	Lighting Type	LED
26	Luminaire Type	Surface Mount and Suspended
27	Mean Density of	15 W/m^2

	Lighting	
28	Cooling (in offices)	Split Air conditioning in Offices
29	Cooling (in Workshops)	Natural and Mechanical Ventilation.
30	Cooling System (Fuel)	Electricity from Grid

3.2. Data Collection and Analysis:

In order to gather comprehensive information on the thermal characteristics and specification of the under-study building, an extensive examination was conducted in every area of the site, with the invaluable assistance all the maintenance and operation stop. The investigation focused on building occupancy, office equipment, machinery, HVAC systems, and lighting. Additionally, the constructional and engineering sketches of the modelled building word thoroughly reviewed.

The analysis encompasses determining the total number of machinery and office devices in use, as well as assessing the lighting features of each area within the industrial building. Energy concentrations of the machinery and office devices were calculated in accordance with the requirements specified by DesignBuilder data pertaining to the air conditioning systems were collected from appliances tags and supplemented by information provided by the buildings operational staff.

3.3. Building Model Creation:

The design model of the industrial building was developed by incorporating various structures such as roots, slabs, floors, and walls, which collectively form that steer of the building. The interior of the building was divided into thermal zones to accurately represent the different areas within the model. To create the model in DesignBuilder, 2D blueprints of the industrial building in .dxf format were imported, align for the visualization and sketching of building blocks and zones.

The comprehensive model was meticulously aligned with the orientation of the existing industrial building. Component blocks, serving as primary mathematical profiles, were utilized to construct a precise 3D model that replicated the actual building. These building blocks were assembled to form non air flow zones, and DesignBuilder requires the thermal properties of various elements, such as roofs, walls, partitions, and floors, to accurately calculate energy consumption.

Thermal masses were appropriately grouped together for each area and integrated into the design model within DesignBuilder. The resulting model consisted of 35 distinct zones, representing offices, workshops, packing halls, reception areas, toilets, storerooms, mosques, and other spaces present within the industrial building. The design model in DesignBuilder faithfully reflected the site orientation and maintained the same special arrangement as the actual building, ensuring A comprehensive representation of the building's information.

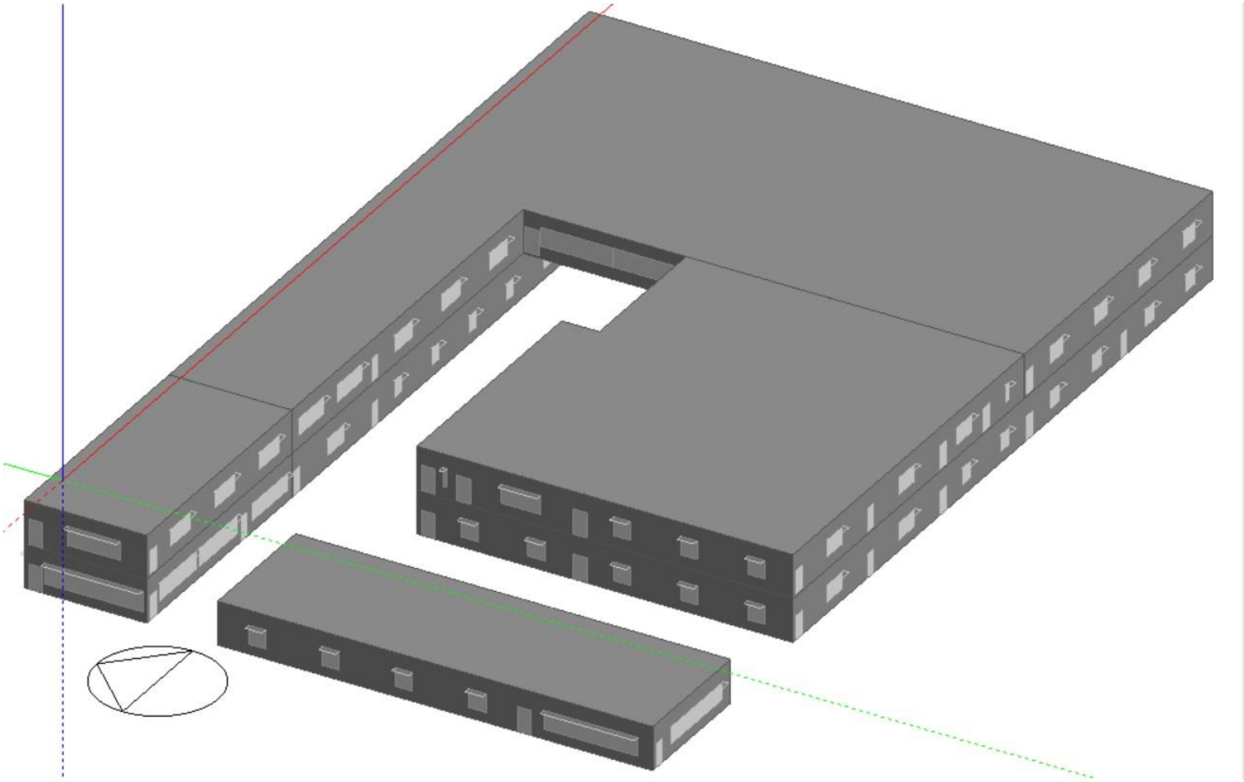

Figure 2: 3D model of Industrial Building designed using DesignBuilder Software

3.4. Building Construction Details:

Within the scope of building construction, Table 2 provides an overview of the constructional component blocks used in DesignBuilder for computational purposes, including their average thickness. The industrial structure was designed with various construction elements such as roofs, slabs, walls, and floors, which constitute the exterior skin of the building. These elements were internally divided to accurately model the thermal zones within the building.

Table 2: Constructional details related to the Industrial Building

Building Components	Material Layers	Thickness (m)
External Walls	Plaster (Dense)	0.013
	Bricks	0.22
	Plaster (Dense)	0.013
Partition Walls	Plaster (Dense)	0.013
	Bricks	0.1016
	Plaster (Dense)	0.013
Roof (Workshops)	Mortar/Plaster/Cement	0.05
	Concrete	0.1524
	Mortar/Plaster/Cement	0.013
Roof (Offices)	Mortar/Plaster/Cement	0.05
	Concrete	0.1524
	Air Gap	0.013
	Gypsum Plaster Boards	0.01
Floor	Mortar/Plaster/Cement	0.05
	Concrete	0.07
	Earth Grewal	0.1524

3.5. Working Profiles of building Sections:

Table 3 presents the working profiles of different sections within the building, including their respective areas. The work profile indicates the utilization of specific building sections throughout the week.

Table 3: Working Profiles of different sections of the Industrial Building Building Section Area (m^2)
Working Profiles

		(No. of day in week)
1 Reception	114.79	6
18 Offices	995.99	6
Milling Shop	185.1	6
Press Shop	300	6
Injection Molding	71.98	6
Setting Shop	134.65	6
Vibrators Shop	312.29	6
Tempering Area	110.29	6
Grinding Shop	194.91	6
Passivation Area	182	7
Mosque	180.46	7
Compressor Room	66.13	6
Sand Hall	182.23	6

Canteen	109.56	7
CNC Machine Shop	250.45	6
Packing Hall 1	225.36	7
Packing Hall 2	290.95	7
Packing Hall 3	274.39	7
Cutting and Grinding Shop	71.98	6
Guards Room	98.74	7
Storerooms	389.94	6

3.6. Heating and Cooling Setpoint Temperatures:

To facilitate computational calculations in DesignBuilder, predefined heating and cooling set point temperatures were established, asked for the actual activation and deactivation of active measures are subject to the occupants' actions. Table four displays the heating and cooling setpoint temperatures, as well as the setback temperatures, utilized for the DesignBuilder computations.

Table 4: Heating and Cooling Setpoint Temperatures for different zones of the IndustrialBuilding

Zone	**Heating**		**Cooling**	
	Set Point	Set Back	Set Point	Set Back
Offices	18	12	25	28
Workshops	18	12	25	28

3.7. Activity, People Density, and Operating Hours:

Table 5 provides details regarding the density of people, their activities, and the operating schedule for different zones within the building. These parameters, along with the working profiles (number of days per week), are utilized in DesignBuilder for simulation purposes.

Table 5: Activity Template, Density of People, Operating Hours of working personal inIndustrial Building

Sr. No.	**Activity**	**Density (People /m^2)**	**Schedule (Hours)**	**Activity Template**	**Metabolic Factor**	**Working Profiles (Day in a week)**	**DHW**
1	Reception	0.11	9:00-18:00	Standing/ walking	0.9	6	OFF

2	Offices	0.12	9:00-18:00	Light Office work/Standing/Walking	0.9	6	OFF
3	Milling Shop	0.1	8:00-17:00	Performance/industrial Process	0.9	6	OFF
4	Press Shop	0.07	8:00-17:00	Performance/industrial Process	0.9	6	OFF
5	Injection Molding	0.12	8:00-17:00	Performance/industrial Process	0.9	6	OFF
6	Setting Shop	0.12	8:00-17:00	Light Manual work (Industrial)	0.9	6	OFF
7	Vibrators Shop	0.05	8:00-17:00	Performance/industrial Process	0.9	6	OFF
8	Tempering Area	0.05	8:00-17:00	Heavy industrial Process	1	6	OFF
9	Grinding Shop	0.2	8:00-17:00	Sawing (Table Saw)	0.9	6	OFF
10	Passivation Area	0.2	8:00-22:00	Performance/industrial Process	0.9	7	OFF
11	Mosque Area	0.15	8:00-17:00	Reading/Seating	0.9	7	ON
12	Compressor Room	1.2	12:00-21:00	Walking	0.9	6	OFF
13	Sand Hall	1.5	8:00-20:00	Performance/industrial Process	0.9	6	OFF
14	Canteen	0.02	8:00-17:00	Cooking/Eating/Drinking	0.9	7	OFF
15	CNC Machine Shop	0.05	8:00-17:00	Performance/industrial Process	0.9	6	ON
16	Packing Hall 1	0.15	8:00-22:00	Light Manual Work	0.9	7	OFF
17	Packing Hall 2	0.2	8:00-22:00	Light Manual Work	0.9	7	OFF
18	Packing Hall 3	0.3	8:00-22:00	Light Manual Work	0.9	7	OFF
19	Cutting and Grinding Shop	0.12	8:00-17:00	Sawing (Table Saw)	0.9	6	OFF
20	Guards Room	0.1	24hr	Rest Room	0.9	7	OFF
21	Storerooms	0.01	8:00-17:00	Light Manual Work/Standing/Walking	0.9	6	OFF
22	Toilets	0.1238	8:00-18:00	Standing/Walking	0.9	6	OFF

23	Stairs	0.1238	8:00-18:00	Walking	0.9	6	OFF
24	Corridor	0.1238	8:00-18:00	Walking	0.9	6	OFF
25	Parking	0.0053	8:00-18:00	Parking/Standing/ Walking	0.9	6	OFF

3.8. Thermal Transmittance within Building Structure:

The thermal transmittance of a building structure refers to the rate of heat transfer through materials. It is typically represented by a U-value, which quantifies the thermal transmittance of a material or assembly. Table 6 presents the average thermal transmittance details of the industrial building structure, which are used during the DesignBuilder simulation.

Table 6: Thermal Transmittance of different Structural Components of the IndustrialBuilding

Sr.	Component	Material Layers	U-value (W/(m2·K))
1	External Walls	Cement Plaster, Bricks, Cement Plaster	2.067
2	Internal Walls	Cement Plaster, Bricks, Cement Plaster	1.959
3	Ground Floor	Earth Grewal, Concrete, Mortar	1.463
4	Internal Floor	Cement plaster, Concrete, Cement Plaster	2.93
5	Roof	Cement plaster Concrete, Cement Plaster	1.96
6	Window Single Glazing	Glass 6mm	5.778
7	Window Double Glazing	Glass 6mm, Air Gap 6mm, Glass 6mm	2.883

3.9. Factors Affecting Energy Consumption:

The consumption of a building is influenced by various elements, some of which are discussed below:

3.9.1. Window to Wall Percentage:

The window to wall percentage, also known as windows space, plays a significant role in the energy consumption and efficiency of a structure. It affects heating, cooling, and lighting within the building. This value is derived by multiplying the total glass surface area of the structure by the percentage area of the exterior shell walls.

3.9.2. Window Shading:

Window shading can effectively reduce energy consumption for cooling and heating purposes by mitigating solar radiation. The type and size of the window, as well as solar qualities associated with heat gain, determine the impact of window shading. Shades can either absorb and reflect solar rays or allow partial light transmission while dissipating absorbed heat through convection currents or radiation.

3.9.3. Window Glass:

The properties of window glass, along with other factors, regulate the amount of sunlight and heat that enters a building. Glass, as a clear glazed material, is commonly used in external windows to form part of the building envelope.

3.9.4. Wall Construction:

The construction of walls plays a crucial role in energy analysis, focusing on strength and resistance to heat gain and loss. In this research, walls are constructed using basic building elements and plaster insulation, which significantly influence the indoor environment and energy performance.

3.9.5. Roof Construction:

The construction of the roof aims to provide load bearing capacity and overall resistance to heat absorption and loss. In this research, a regular reinforced cement concrete roof is employed. Roof insulation has a substantial impact on the energy consumption of air conditioning systems.

3.9.6. Infiltration:

Infiltration refers to unplanned air leakage into air-conditioned spaces, often resulting from structural or architectural insulation deficiencies. Common sources of air leakage include defects or openings in the building envelope, such as doors and windows. Factors such as porosity, wind in intensity, and temperature primarily determine the amount of air infiltration.

3.9.7. Lighting Efficiency:

Lighting efficiency represents the energy saving properties of lighting fixtures, particularly the effectiveness of LED light sources. It considers both electricity consumption for illumination and the amount of inner thermal gain per square meter of area.

3.9.8. HVAC:

The heating, ventilation, and air conditioning system provides the heating and cooling capabilities for buildings. Depending on the project's type, location, and size, different HVAC systems exhibit varying levels of efficiency. The industrial building in this research utilizes split type air conditioning.

3.9.9. Operating Schedules:

The total energy consumption is influenced by the hours and days of occupancy within the building. Operating schedules are typically regulated in industrial buildings, although they may vary across different zones. Mean values are considered when calculating energy consumption, taking into account the energy use patterns of the occupants. Unknown factors that impact energy consumption may exist but are not currently accounted for in energy simulation software, although they may be considered in future developments of such software.

Chapter 4

4. Verification and Validation:

4.1. Integration and Simulation Process:

In this step, all a for mentioned parameters is incorporated into the DesignBuilder software. Default values for activities, occupancy, working profiles, and schedules are replaced with customized input collected specifically for the industrial building. Subsequently, a year-long simulation is conducted to analyze the performance and energy consumption of the building.

The accuracy of the building energy estimates heavily relies on the quality of the primary input provided to the energy model. This input encompasses various aspects such as the buildings characteristics, equipment, location, weather data, and occupant behavior. Ensuring the accuracy and reliability of these inputs is crucial for obtaining resize energy estimates and assessments.

While historical climate data is utilized for the simulation of building energy, it is important to acknowledge that anthropogenic global warming and other environmental factors continually influence outdoor temperature, humidity, precipitation, and other climatic variables. These dynamic changes in environmental conditions should be considered when interpreting the simulation results. Moreover, it is worth noting that specific parameters related to the building's location are often overlooked in sustainable building simulations, and this omission should be taken into account when analyzing the results.

4.2. Integration and Validation of Building Energy Efficiency:

The energy efficiency of a building is influenced by the integration of various systems and the design considerations made regarding energy efficiency. The design of the building envelope, including walls, windows, and roofs, plays a crucial role in ensuring thermal comfort and visual satisfaction for occupants, as well as meeting other operational requirements. DesignBuilder software offers numerous data templates for different building simulation inputs, such as envelop construction assemblies, lighting systems, and occupancy schedules.

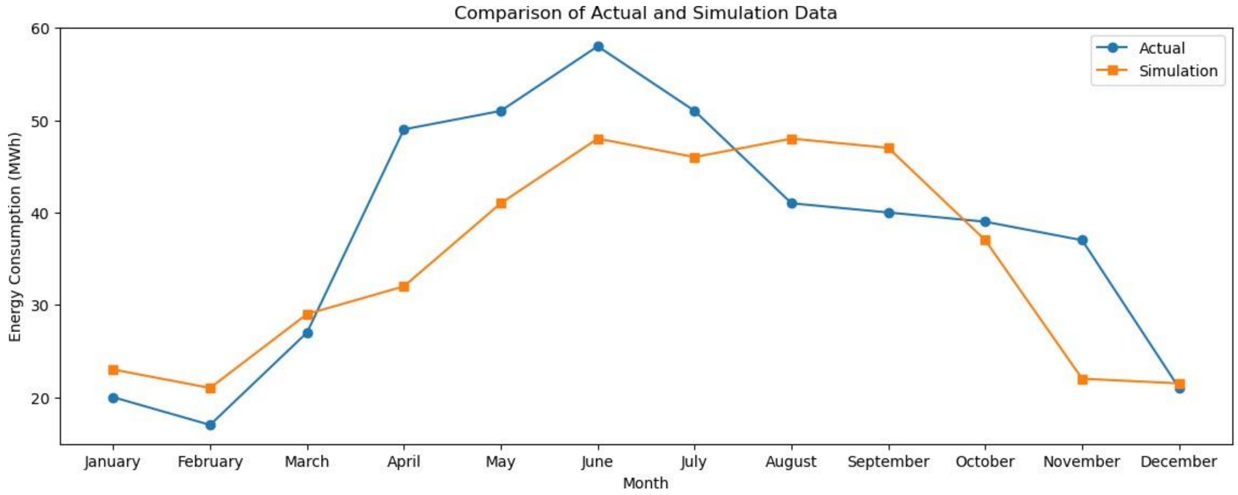

Figure 3: Validation of Industrial Building Model based on Monthly Energy Consumption

The validation in our case is done with the actual energy consumption of the industrial building using the data from the monthly electricity bills and the simulation model designed using DesignBuilder is carried out. The results of the simulation were compared with the actual data based on both yearly and monthly energy consumption of the house. To establish acceptable levels of accuracy, Kaplan and Canner recommend that the annual difference between simulation and metered data should be less than 10%. On a monthly basis, a difference of up to 15% to 25% is acceptable, with a slightly higher tolerance of 25% to 35% for air-conditioning simulations. In our case, the annual difference is less than 5% and the monthly difference is less than 10%, as seen from Figure 3 and 4. However, it is important to note that there is often a significant variation between the actual and expected energy usage in buildings, as observed in various studies.

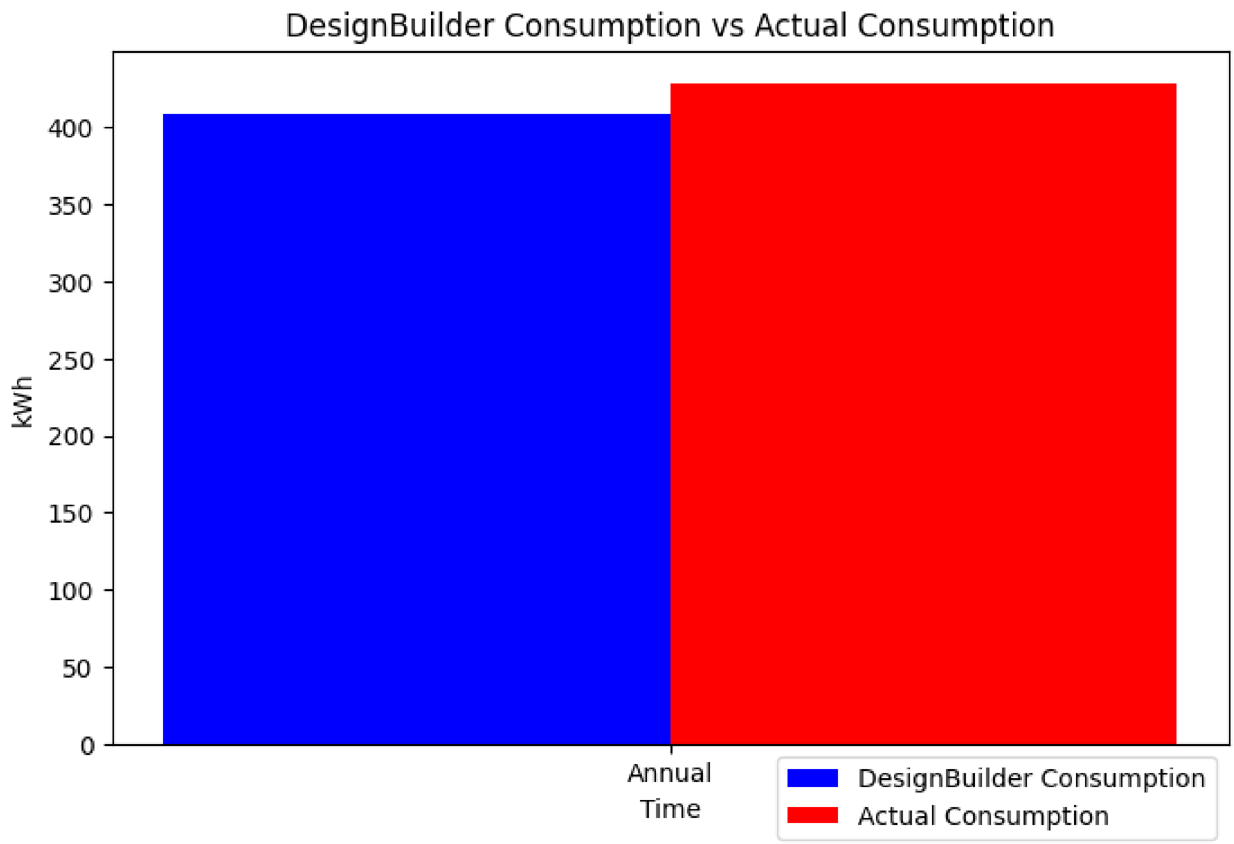

Figure 4: Validation of Annual Energy Consumption of the Selected Industrial Building

Chapter 5

5. Results & Discussion:

Green Walls:

The room energy profile in terms of light consumption over one year is presented in Figure 5. From the results of the simulation, it is evident that the temperature profile of the selected industrial building is maintained within the human comfort range for the summer as well as the winter season. However, the addition of green walls to the building leads to a significant reduction in lighting energy consumption. This is because green walls help to regulate the temperature inside the building, which leads to a decrease in the need for artificial lighting. Additionally, green walls can help to improve the air quality inside the building, which leads to a decrease in the need for artificial lighting.

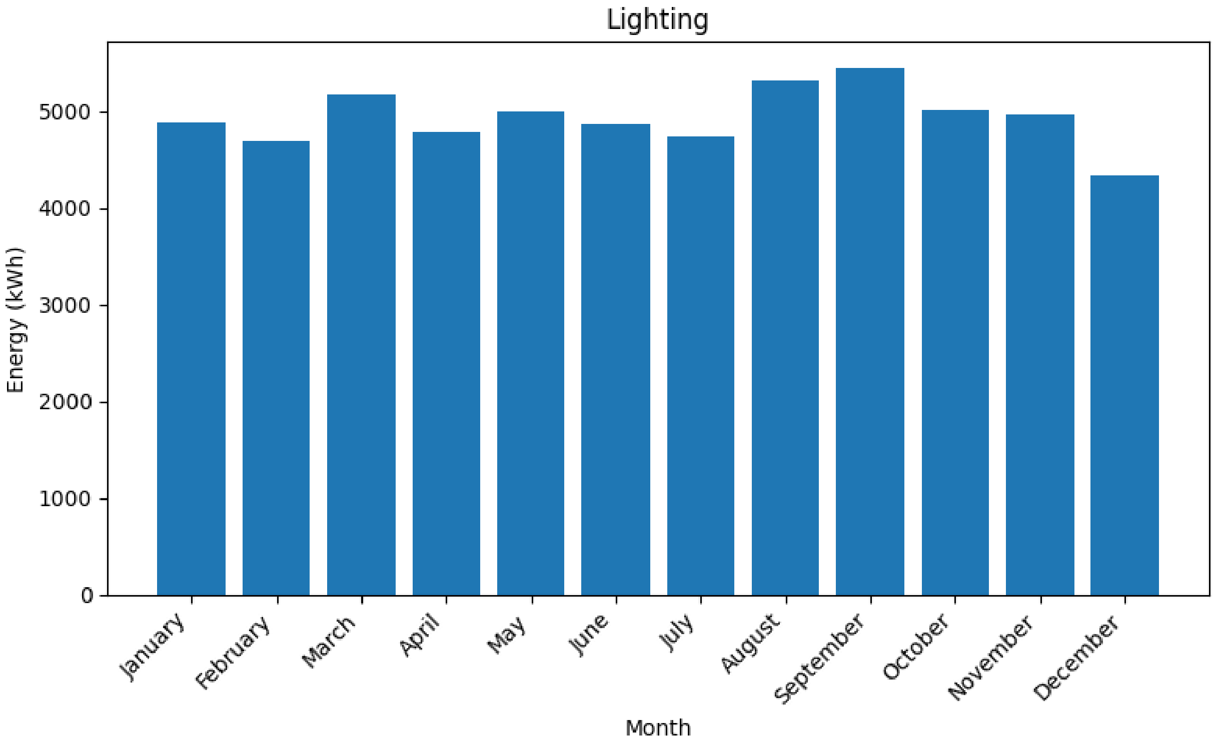

Figure 5: Building Lighting Consumption with Green Roofs

Figure 6 depicts the monthly energy consumption of the selected industrial building, revealing a significant decrease when green walls are implemented. The average energy consumption of the industrial building has decreased from 31181.95 kWh to 23511.96 kWh (i.e., approximate 24.6% decrease in energy consumption) with the green walls. This reduction can be attributed to the diminished heating and cooling demands throughout the building. Green walls mitigate energy usage primarily by moderating temperature fluctuations and maintaining a more suitable internal environment. Consequently, the need for heating and cooling is reduced, leading to substantial energy saving. By harnessing the natural cooling and heating properties of plants, industrial building benefits from improved thermal regulations, resulting in lower energy consumption. This decrease in energy usage stems from the efficient management of thermal dynamics, ultimately enhancing the buildings overall energy efficiency and sustainability.

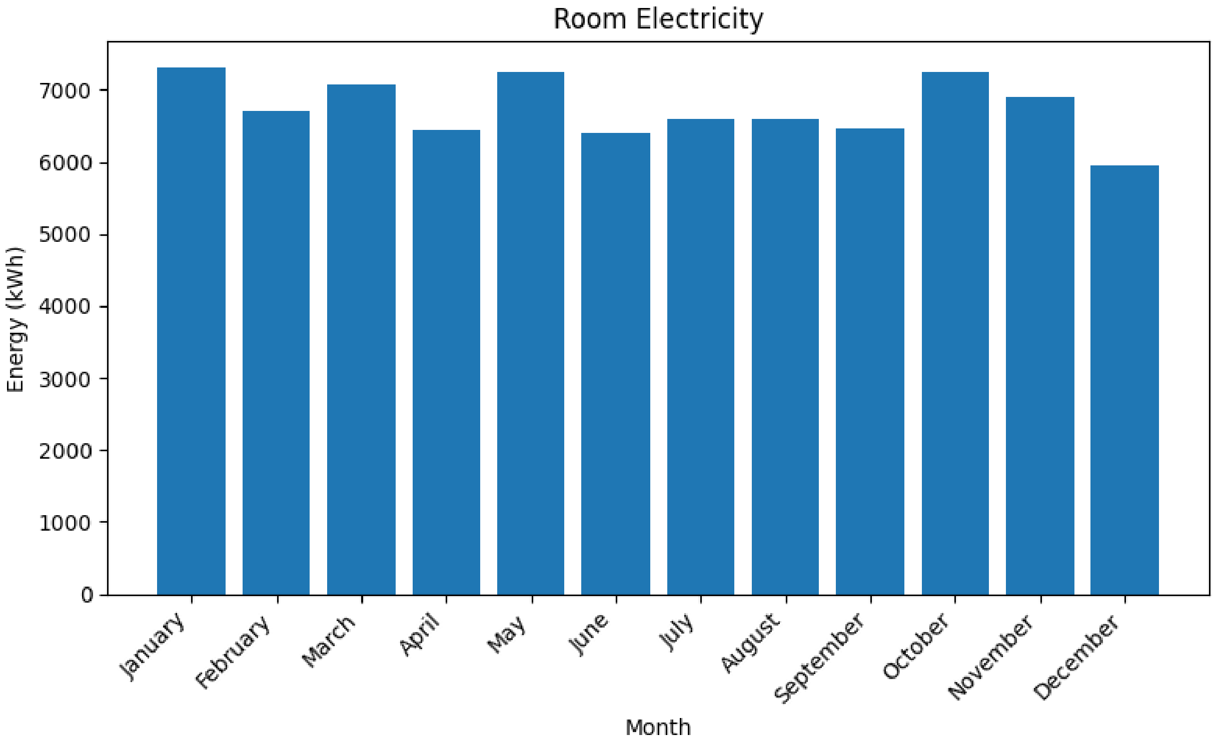

Figure 6: Building Electricity Consumption with Green Roofs

Figure 7 depicts the impact of green was on heating energy consumption in the selected industrial building. The analysis of the results indicates a substantial decrease (i.e., our decrease of about 27.4266%) in heat energy when green walls are integrated into the building thermal management system. This reduction can be attributed to the remarkable thermal properties of plants, which facilitate efficient heat absorption and release. By leveraging green walls’ capacity to stabilize temperature fluctuations, the buildings' heating system trades more efficiently, resulting in significant energy savings.

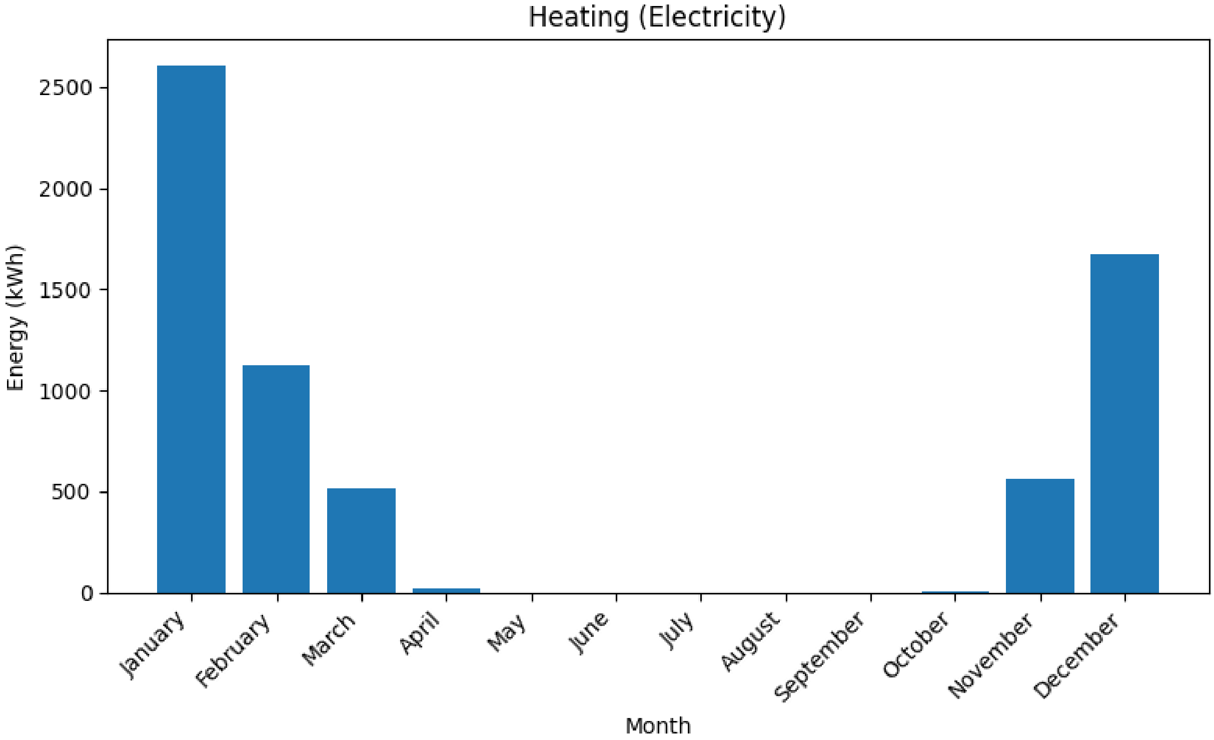

Figure 7: Heating Consumption of the Selected Industrial Building with Green Roofs

Figure 8 illustrates the impact of incorporating green walls on cooling energy consumption in the selected industrial building. The comparison of data reveals a noticeable decrease (i.e., a decrease of about 27.1%) in cooling energy consumption when green walls are utilized. This reduction can be attributed to the thermal properties of plants, which enable efficient energy absorption and release during the cooling cycle. Green walls act as a thermal buffer, effectively moderating temperature fluctuations and reducing the energy required for cooling. By leveraging the green wall's heat storage capabilities, the industrial building achieves impressive thermal regulation and adds enhanced energy efficiency. The findings also emphasize the potential of green walls as a viable solution for optimizing cooling energy consumption in the selected industrial building, contributing two sustainability and the pursuit of energy-efficient building practices.

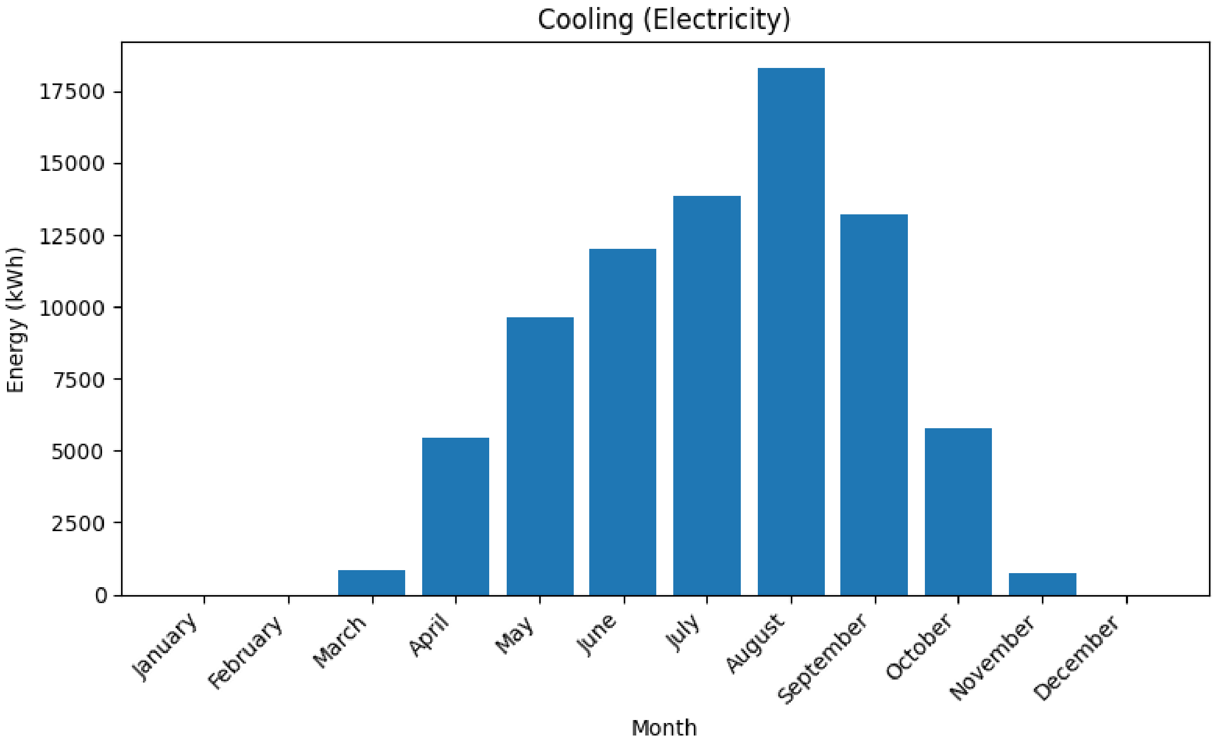

Figure 8: Cooling Consumption of the Selected Industrial Building with Green Roofs

Figure 9 showcases the influence of integrated green walls on domestic hot water energy consumption in the selected industrial building. The comparison of the data reveals a decrease (i.e., a decrease of about 21.2%) in DHW energy consumption when green walls are implemented. This reduction can be attributed to the thermal properties of plants, which contribute to improved heat retention and distribution in the DHW system. By effectively storing and releasing thermal energy, green walls minimize heat losses and optimize the efficiency of the DHW system. It also signifies the potential of green walls as a viable solution for reducing DHW energy consumption in the selected industrial building, supporting sustainable and energy-efficient practices in the domain of hot water supply.

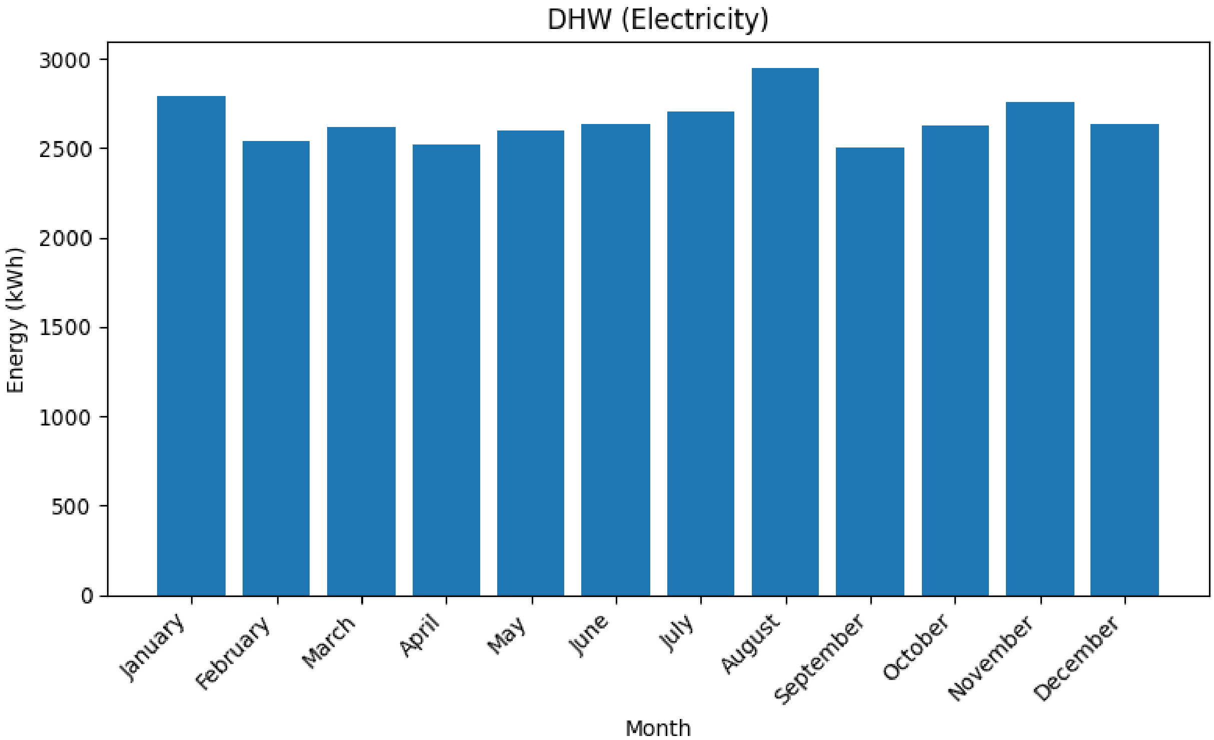

Figure 9: DHW Consumption of the Selected Industrial building with Green Roofs

Green Roofs:

Figure 10 illustrates the monthly room electricity consumption with green walls. The average room electricity consumption decreased from **31181.95** kWh to **24932.51** kWh, a decrease of 21.5%. This is because green walls help to regulate the temperature inside the building, which leads to a decrease in the need for artificial lighting. Additionally, green walls can help to improve the air quality inside the building, which leads to a decrease in the need for artificial lighting.

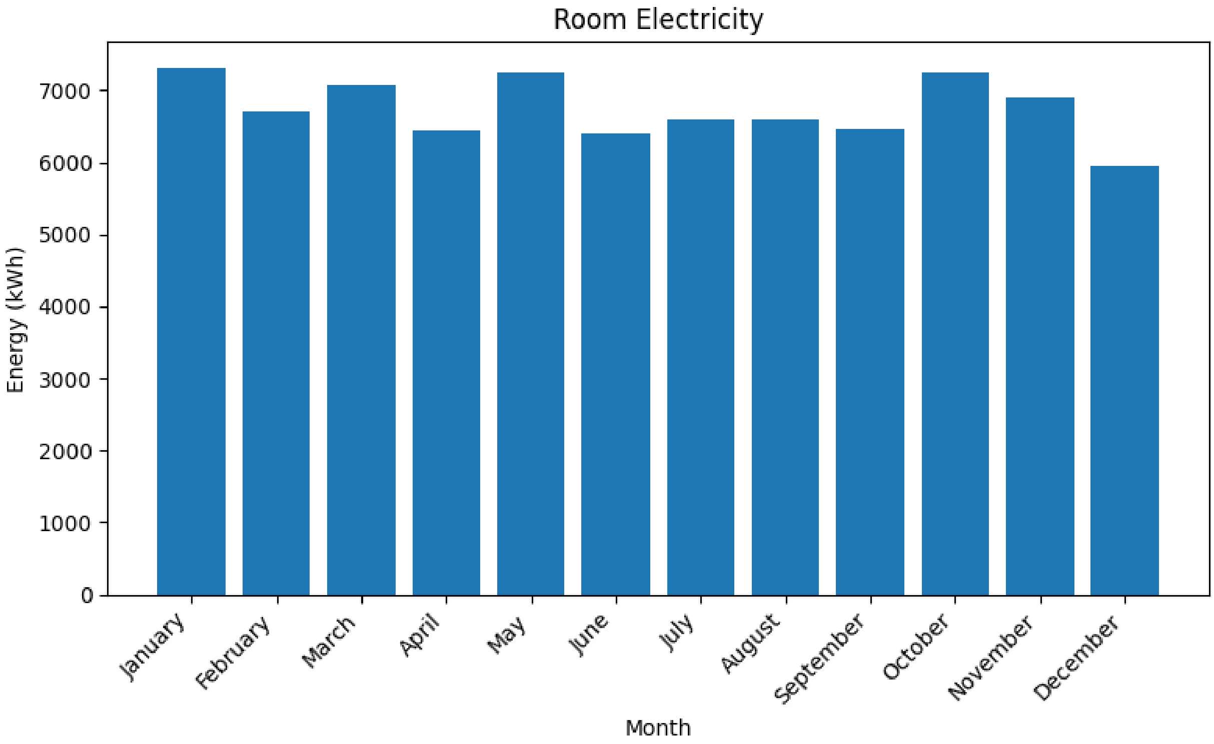

Figure 10: Building Lighting Consumption with Green Walls

Figure 11 showcases the monthly light electricity consumption with green walls. The average light electricity consumption decreased from 23586.38 kWh to 16647.96 kWh, a decrease of 30.6%. This is because green walls help to provide natural lighting to the building, which produces the need for artificial lighting. Additionally, green walls can help to improve the air quality inside the building, which leads to a decrease in the need for artificial lighting.

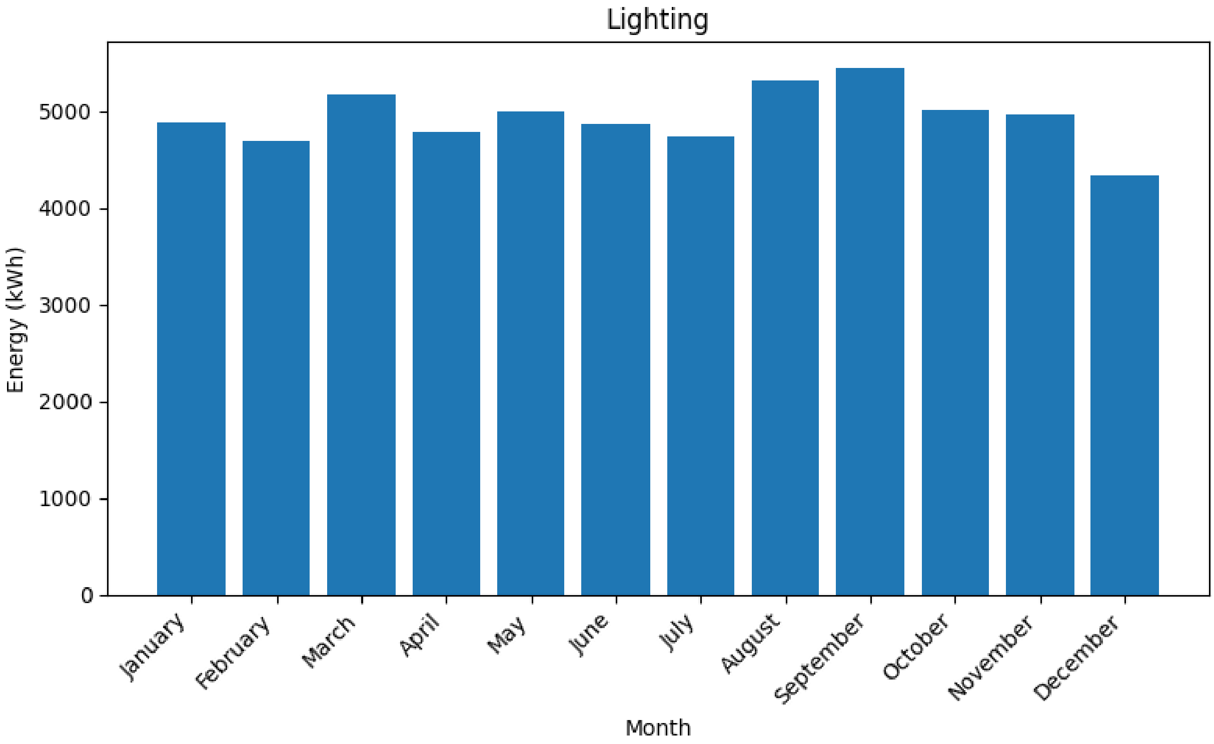

Figure 11: Building Electricity Consumption with Green Walls

Figure 12 demonstrates the monthly heating electricity consumption with green walls. The average heating electricity consumption decreased from 12497.35 kWh to 8887.77 kWh, a decrease of 28.4%. This is because green walls help to moderate temperature fluctuations and maintain a more suitable internal environment. Consequently, the need for heating is reduced, leading to substantial energy savings. By harnessing the natural cooling and heating properties of plants, industrial building benefits from improved thermal regulations, resulting in lower energy consumption. This decrease in energy usage stems from the efficient management of thermal dynamics, ultimately enhancing the building’s overall energy efficiency and sustainability.

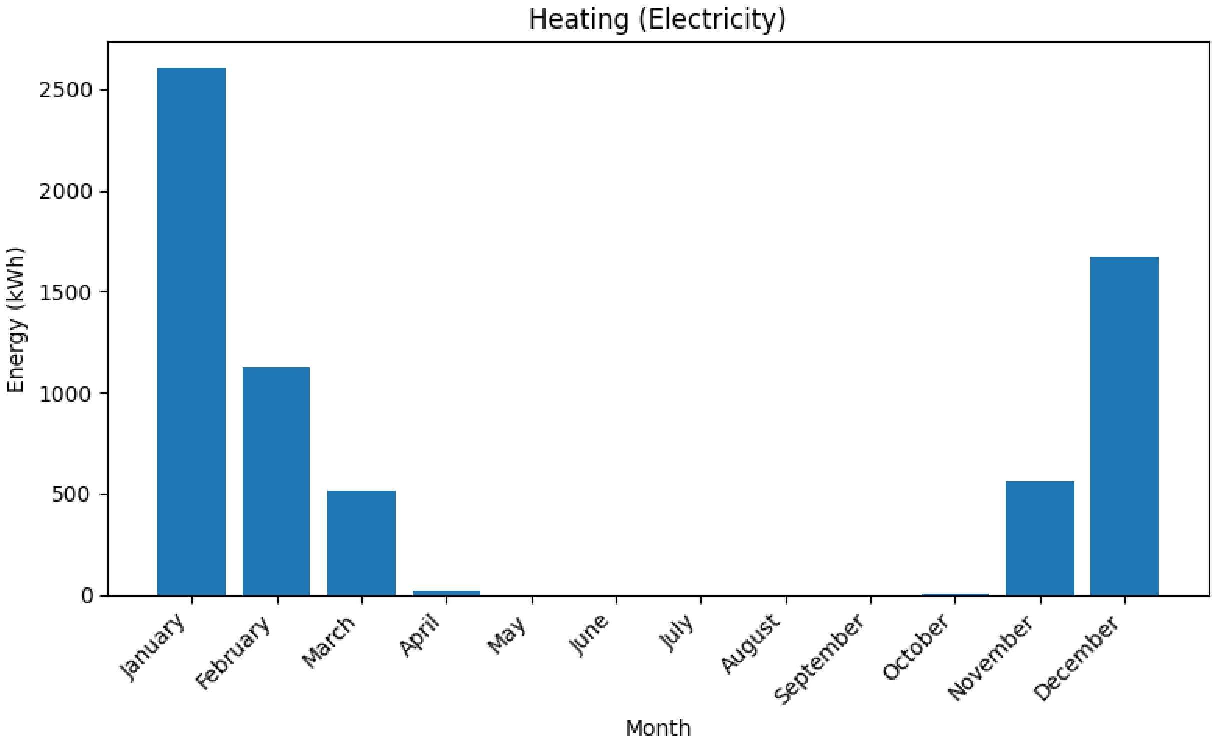

Figure 12: Heating Consumption of the Selected Industrial Building with Green Walls

Figure 13 represents the monthly cooling electricity consumption with the green walls. The average cooling electricity consumption decreased from **x kWh to y kWh**, are decrease of 100%. This is because green walls help to act as a thermal buffer effectively moderating temperature fluctuations and reducing the energy required for cooling. By leveraging the green walls' heat storage capabilities, the industrial building achieves impressive thermal regulations and adds enhance energy efficiency. The findings also emphasize the potential of green walls as a viable solution for optimizing cooling energy consumption in industrial buildings, contributing to sustainability and the pursuit of energy-efficient building practices.

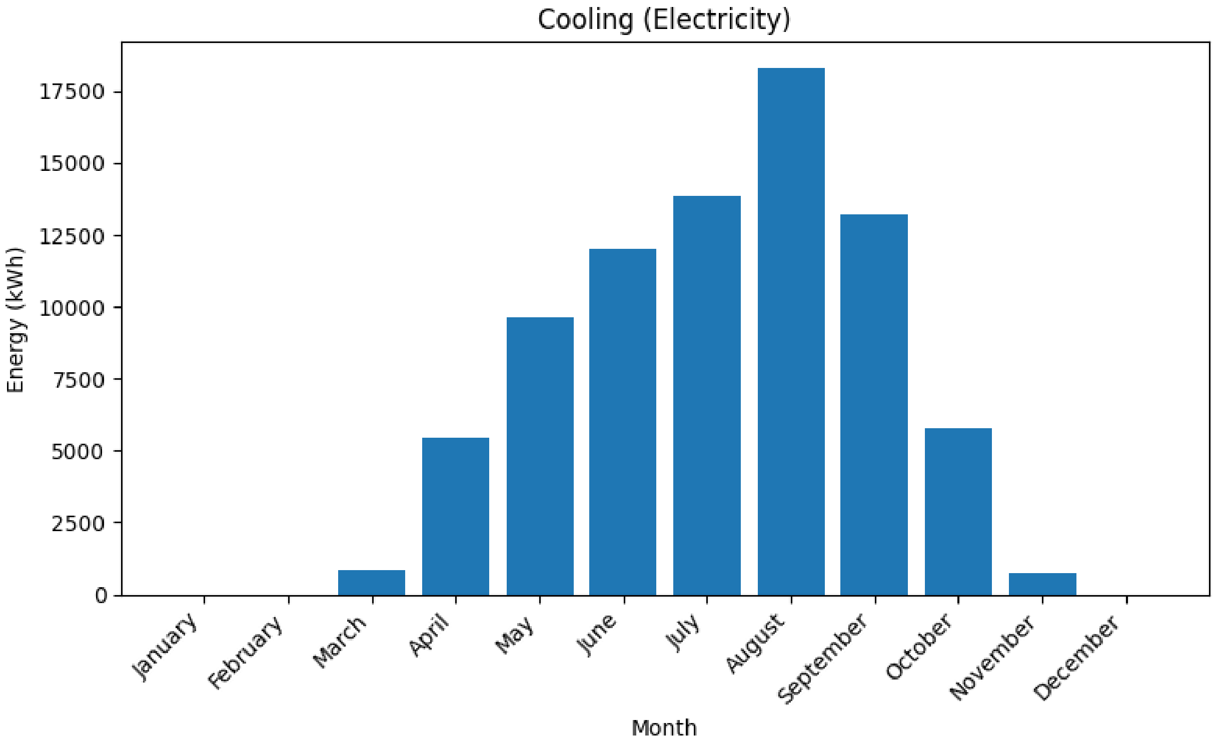

Figure 13: Cooling Consumption of the Selected Industrial Building with Green Walls

Figure 14 showcases the monthly DHW electricity consumption with green walls. The average DHW electricity consumption decreased from 12578.19 kWh to 9538.8 kWh, a decrease of 23.6%. This is because green walls help to improve the insulation of the buildings which reduces the heat loss from the hot water system. Additionally, green walls can help to provide shade to the building, which reduces the need for cooling water.

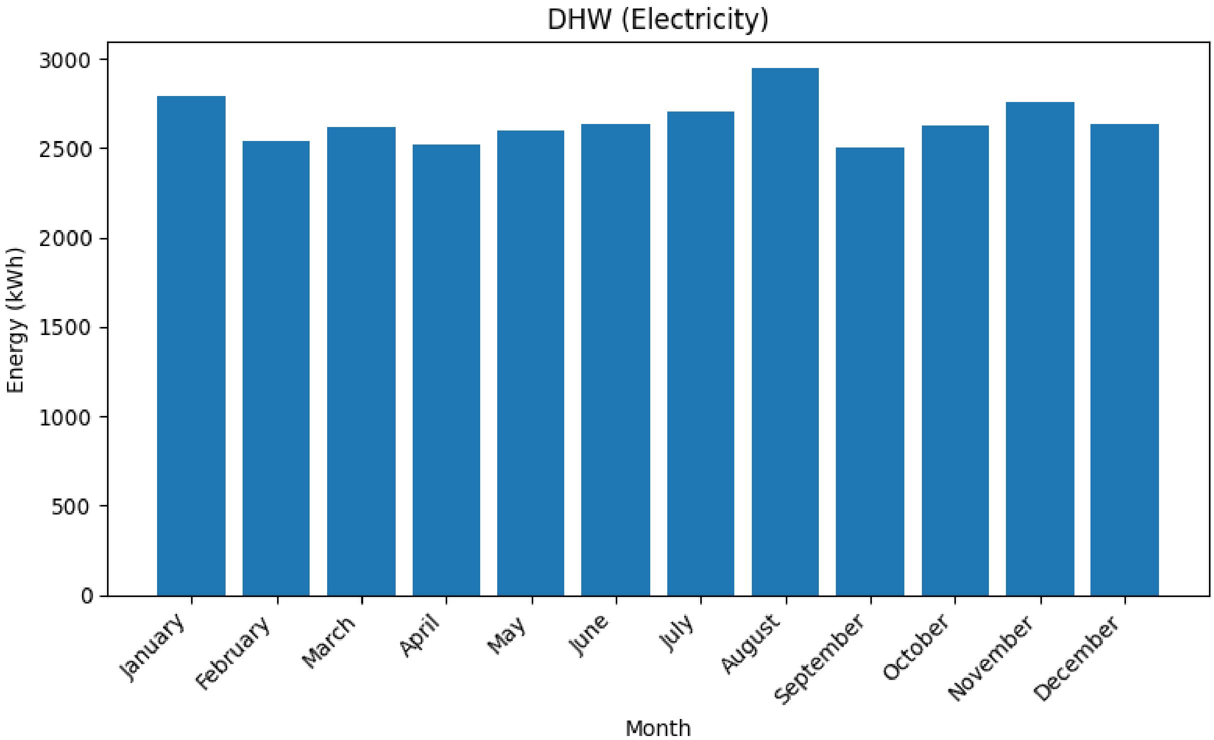

Figure 14: DHW Consumption of the Selected Industrial building with Green Walls

WALL + ROOF + Double Glazed Windows + PV Panels:

Additionally, the combination of green walls, green roofs, double-glazed windows, and PV panels was also applied to the selected industrial building. The combination of these technologies can lead to a significant reduction in energy consumption. These techniques help to regulate temperature, improve air quality, provide insulation, and generate renewable energy. Green walls and green roofs help to moderate temperature fluctuation and maintain a more suitable internal environment. This can lead to a significant reduction in the need for heating and cooling, as well as a decrease in electricity demand, as seen in Figure 15. Additionally, green walls and green roofs can help to improve air quality by absorbing pollutants and releasing oxygen. Double-glazed windows help to reduce the heat loss from the building, which can further reduce the demand for heating and cooling. Additionally, double-glazed windows can help to improve air quality by reducing the infiltration of pollutants from outside. PV panels generate renewable energy, which can be used to offset the electricity consumption of the building. This can help to reduce the building's reliance on fossil fuels and lower its carbon footprint. The energy generation from the PV panels in the figure meets the requirement of the industrial building. The average monthly energy consumption of the building is 30097.32 kWh, and the average monthly energy generation from the PV panels is 32004.9 kWh. This means that the PV panel generates enough electricity to meet the needs of the building and even provides a surplus.

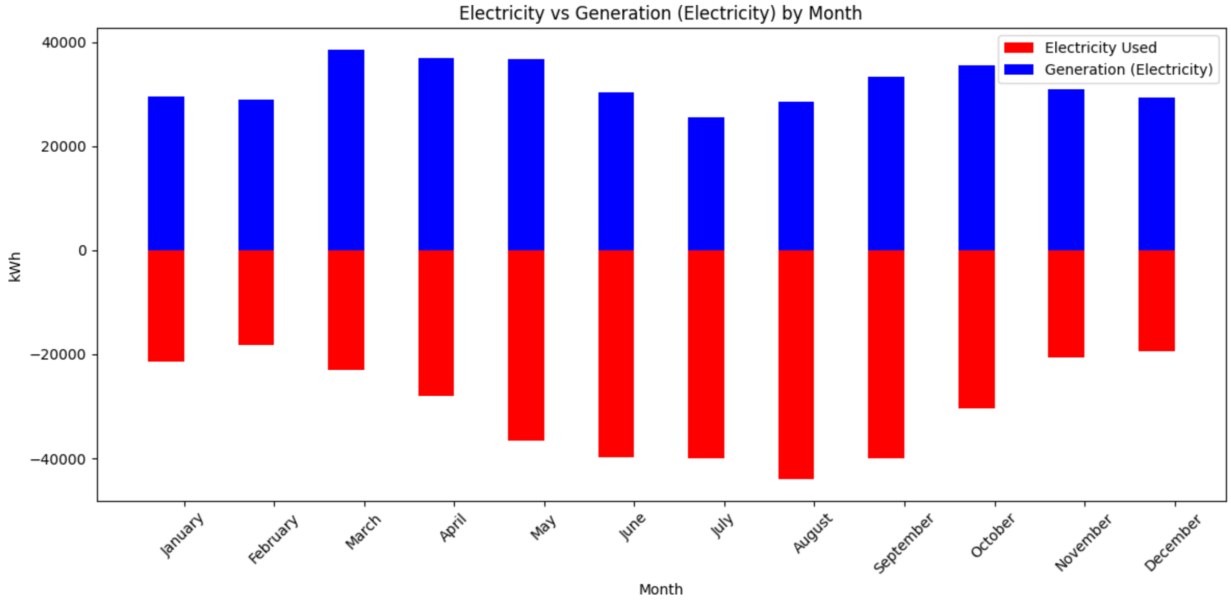

Figure 15: Monthly Electricity Consumption and Generation for the Selected IndustrialBuilding when EETs are applied.

Assessment of Payback Time:

Sunlit areas within building spaces are selectively chosen for the implementation of green wall vegetation. The cost per square foot is determined based on a comprehensive analysis conducted on local providers of green roofs and green wall installations in Pakistan.

Green Roofs:

Total Area for Green Roofs = $745m^2$ =8019.11 ft^2

Cost of Green System = $3/ft^2

Total Start-up Cost per square foot = 8019.11 × $3/ft^2

Total Cost for Green Roof= $24057.33

Green Walls:

Total Area for Green Roofs = $745m2$ =8019.11 ft^2

Cost of Green System = $3/$ft^2$

Total Start-up Cost per square foot = 8019.11 × $\$3/ft^2$

Total Cost for Green Roof= $24057.33

Window Double Glazing:

Cost per square feet with installation = $\$10/ft^2$

Total area for windows = $110m2$ = 1184.03 ft^2

Total Cost for double Glazed windows = 1184.03 × $10

Total Cost for double Glazed windows = $11840.3

WALL + ROOF + Double Glazed Windows + PV Panels:

Total Cost: $24057.33 + $11840.3 = $35897.63

Annual HVAC Cost = $21326.326

Annual 13.11% energy Saving Cost = $2797.4505

Payback Period = $35897.63/$2797.4505

Payback Period = 12 Years

Chapter 6

6. Conclusion:

In conclusion, the integration of energy-efficient techniques (EETs) in the selected industrial building has demonstrated significant benefits in terms of energy efficiency and thermal management. The temperature profile analysis revealed that the EETs effectively maintain room temperature within the human comfort range throughout the year, providing a consistent and comfortable indoor environment. The utilization of EETs leads to a notable reduction in heating, cooling, and domestic hot water energy consumption. In addition to the energy-saving benefits, the integration of energy-efficient techniques in the industrial building offers potential advantages in terms of peak log management due to their efficient thermal management abilities, EETs helped to reduce the strain on the electrical grid and mitigate the artist of power outages. The thermal buffering effect provided by EETs contributes to a more stable and balanced energy consumption pattern, improving the overall resilience of the building's energy systems.

EETs' thermal properties enable efficient heat absorption and release, moderating temperature fluctuations and reducing the overall energy demand for heating and cooling systems. This efficient management of thermal dynamics improves the building's energy efficiency and sustainability. Furthermore, EETs' ability to store and release thermal energy optimizes the efficiency of DHW systems, resulting in reduced energy consumption. Furthermore, EETs' long lifespan and durability make it a reliable and cost-effective solution for energy management in industrial buildings. The passive nature of EETS systems requires minimal maintenance and operational interventions, resulting in lower operating costs over the lifespan of the building. This combination of energy efficiency, peak load management, and cost-effectiveness positions EETS as a promising technology for achieving sustainable and economically viable industrial buildings.

The findings underscore the potential of EETs as a viable solution for enhancing energy efficiency and promoting sustainable practices in industrial buildings. The successful integration of EETs can contribute to the development of more sustainable and environmentally friendly building environments. Furthermore, research and implementation efforts in this area can drive advancement in building design and energy management practices, leading to a more sustainable future. In conclusion, the integration of EETs in industrial buildings offers a comprehensive solution for optimizing energy consumption, enhancing thermal comfort, and promoting sustainability. As the field of EETs continues to advance, further research, technological innovations, and implementation efforts are necessary to fully unlock its potential and drive widespread adoption. By harnessing the benefit of EETs, industrial buildings can significantly reduce their environmental footprint while improving operational efficiency and occupant comfort.

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