ANKARA YILDIRIM BEYAZIT UNIVERSITY

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TECHNO-ECONOMICAL FEASIBILITY ANALYSIS OF NEARLY ZERO ENERGY BUILDING (NZEB) STRATEGIES FOR RESIDENTIAL BUILDINGS IN KIRKUK, IRAQ

M.Sc. Thesis by

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"TECHNO-ECONOMICAL FEASIBILITY ANALYSIS OF NEARLY ZERO ENERGY BUILDING (NZEB) STRATEGIES FOR RESIDENTIAL BUILDINGS IN KIRKUK, IRAQ."** completed by **Mohammed Waleed Ismael Ismael under the supervision of PROF. DR. BÜLENT YEŞİLATA** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Date: July, 2025 **Mohammed Waleed Ismael Ismael**

TECHNO-ECONOMICAL FEASIBILITY ANALYSIS OF NEARLY ZERO ENERGY BUILDING (NZEB) STRATEGIES FOR RESIDENTIAL BUILDINGS IN KIRKUK, IRAQ

ABSTRACT

Global warming and climate change have emerged as significant challenges in recent decades, with fossil fuel consumption being a major contributor. The burning of fossil fuels leads to CO_2 emissions, which exacerbate these issues. Consequently, buildings must be designed using new strategies focused on low energy consumption and high energy efficiency. To reduce a building's dependence on fossil fuel energy, the concept of nearly-zero energy buildings (nZEB) has been developed. It is essential that the definition of near zero energy buildings integrates renewable energy sources and efficiency measures.

This study presents design strategies aimed at reducing building energy demand as well as annual costs, in an extremely hot climate like Kirkuk, Iraq. Including the use of low conductivity materials, the installation of low energy devices, and the incorporation of renewable energy systems. These strategies are evaluated through a case study of an example residential building. The results demonstrate that achieving a near zero energy building is feasible through various approaches. Cutting annual costs as well as achieving a more efficient and environmentally friendly building.

Keywords: Carbon-free Energy, Sustainable Energy, Environmental impact**.**

KERKÜK, IRAK'TAKİ KONUTLAR İÇİN NEREDEYSE SIFIR ENERJİLİ BİNA (NSEB) STRATEJİLERİNİN TEKNOLOJİK VE EKONOMİK UYGUNLUK ANALİZİ

ÖZET

Küresel ısınma ve iklim değişikliği, son birkaç on yılda önemli bir sorun olarak ortaya çıkmış olup, fosil yakıt tüketimi bu sorunlara büyük katkı sağlamaktadır. Fosil yakıtların yakılması, bu sorunları şiddetlendiren CO_2 emisyonlarına yol açmaktadır. Bu nedenle, binaların düşük enerji tüketimi ve yüksek enerji verimliliğine odaklanan yeni stratejilerle tasarlanması gerekmektedir. Bir binanın fosil yakıt enerjisine olan bağımlılığını azaltmak amacıyla, neredeyse sıfır enerji binaları (nZEB) kavramı geliştirilmiştir. Yakın sıfır enerji binalarının tanımının, yenilenebilir enerji kaynakları ve verimlilik önlemlerini içermesi çok önemlidir.

Bu çalışma, Irak'ın Kirkuk gibi son derece sıcak bir ikliminde, bina enerji talebini ve yıllık maliyetleri azaltmaya yönelik tasarım stratejilerini sunmaktadır. Düşük iletkenliğe sahip malzemelerin kullanılması, düşük enerjili cihazların kurulumu ve yenilenebilir enerji sistemlerinin entegrasyonu gibi unsurlar bu stratejiler arasında yer almaktadır. Bu stratejiler, bir örnek konut binası üzerinden yapılan bir vaka çalışmasıyla değerlendirilmektedir. Sonuçlar, çeşitli yaklaşımlar aracılığıyla neredeyse sıfır enerji binasına ulaşmanın mümkün olduğunu ve yıllık maliyetlerin düşürülmesiyle daha verimli ve çevre dostu bir bina elde edilebileceğini göstermektedir.

Anahtar Kelimeler: Karbonsuz Enerji, Sürdürülebilir Enerji, Çevresel Etki

CONTENTS

M.Sc. THESIS EXAMINATION RESULT FORM iii
ETHICAL DECLARATION iv
ACKNOWLEDGMENTS v
ABSTRACT vi
ÖZET vii
CONTENTS viii
NOMENCLATURE x
LIST OF TABLES xi
LIST OF FIGURES xii

CHAPTER 1 - INTRODUCTION 1

CHAPTER 2 - OVERVIEW OF HVAC SYSTEMS 4
2.1 Energy Efficiency in Buildings 4
2.2 Nearly zero energy buildings 6
2.3 Thermal insulation. 8
2.4 Solar Systems 9
2.5 Recent Developments and Research 10
2.6 Gaps in Existing Research 12

CHAPTER 3 - RESEARCH DESIGN 15
3.1. Reducing Greenhouse Gases (GHG) 15
3.2 Core fundamentals for a building's energy consumption. 16
3.3 Passive Design Optimization 18
3.3.1 Building Orientation 19
3.3.2 Shading & Overhangs 20

3.3.3 Natural Ventilation and infiltration effects 22

3.3.4 Effects of Insulation and U values 22

3.3.5 Effects of Lighting use 25

3.3.6 Utilization of PV Solar Panels as renewable energy. 27

CHAPTER 4 - ENERGY SUPPLY AND USE 29

4.1. Increasing efficiency 30

4.2 The Data for the Sample Building. 31

CHAPTER 5 - RESULTS 35

5.1 Improvements to the Building Under Various Scenarios 36

5.1.1 Building orientation and Windows Adjustments 36

5.1.2 Adjustments to construction of the building. 36

5.1.3 Adjustments of Lighting and Power 38

5.1.4 HVAC System 39

5.1.5 PV System 40

5.1.5 Evaluation of every strategy 41

5.2 Monthly EUI Comparison 42

5.3 Economic Factor 43

CHAPTER 6 - CONCLUSIONS 46

REFERENCES 48

NOMENCLATURE

Roman Letter Symbols

ACH	Air Changes per Hour
AFUE	Annual Fuel Utilization Efficiency
AI	Artificial Intelligence
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEMS	Building Energy Management System
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DHW	Domestic Hot Water
EUI	Energy Use Intensity
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IoT	Internet of Things
LED	Light-Emitting Diode
nZEB	Nearly Zero Energy Building
PV	Photovoltaic
PV/T	Photovoltaic/Thermal
SEER	Seasonal Energy Efficiency Ratio

LIST OF TABLES

Table 3.1 Thermal properties of Iraq's local insulation materials…….24
Table 4.1 Overview of the selected HVAC systems……..29
Table 4.2 Overview of HVAC systems……..30
Table 4.3 Room Dimensions for 100m² House……..34

LIST OF FIGURES

Figure 3.1 Passive solar effect on a building…….20
Figure 3.2 Effects of window overhangs on a building……...……..21
Figure 3.3 Insulation combinations……25
Figure 3.4 Extra cost per unit reduction of heat flow……25
Figure 3.5 Percentage of energy consumption in a residential building…..……..26
Figure 3.6 PV solar panel operation……...……....28
Figure 4.1 the sample building from Autodesk Revit……32
Figure 4.2 The residential building's location and climatic conditions in Kirkuk, Iraq……..33
Figure 4.3 Rooms distribution of the residential building…….33
Figure 5.1 Illustration of EUI for the residential building…….35
Figure 5.2 ASHRAE 90.1 comparison for the building…….35
Figure 5.3 The used wall construction materials effect on the EUI……...37
Figure 5.4 The used roof construction materials effect on EUI…….37
Figure 5.5 Lighting Efficiency……...38
Figure 5.6 Plug load efficiency……..39
Figure 5.7 Optimal HVAC Types and their effect……39
Figure 5.8 Relationship Between Surface Coverage Ratio and Cost for the PV System……..…...40
Figure 5.9 Efficiency of the Photovoltaic panels……...40
Figure 5.10 Evaluation of each strategy……41
Figure 5.11 ASHRAE 90.1 comparison after the proposed solutions are implemented…….....42
Figure 5.12 EUI per month before and after improvements……..42
Figure 5.13 Economic comparison……45
Figure 5.14 Formula used for calculating the simple payback period……...45

CHAPTER 1

INTRODUCTION

Two of the most pressing issues in recent decades are global warming and climate change which are mainly caused by the high reliance on fossil fuel. The use of fossil fuel causes an increase in CO_2 emissions and both commercial and residential buildings, contribute significantly to the overall energy consumption in the world. Due to the constant energy requirement of buildings, which is often in the form of electricity, it is often generated from fossil fuels. Therefore, approximately 40% of the world's total energy consumption and 36% of the CO_2 emissions are from buildings which leads to the realization that it is important to design buildings that require low energy consumption and emphasize high energy efficiency using innovative strategies and the strategies utilized should offer integrated solutions that aim at energy savings, environmental protection, and CO_2 emissions reduction in the building sector and to address this challenge, the near-zero energy buildings (nZEB) emerged to solve the problem and limit the reliance of buildings on fossil fuel as their main energy sources.

However, while the utilization of these strategies can have significant environmental benefits, it is essential to consider the economic factors of the process as well. One notable point is that with the implementation of energy-efficient technologies and renewable energy systems there are higher initial costs alongside them which lead to financial concerns for owners of buildings and their developers. However, it is evident that such investments have long-term savings in the operational costs which makes them good options financially when these buildings' lifecycles are taken into consideration. Consequently, achieving balance between the environmental goals set and the economic considerations of these options is important to reach a widespread adoption of sustainable building practices. [1] Moreover, the reduction of energy consumption and an increase in the utilization of renewable energy sources in buildings are significant steps in the process of decreasing energy dependence and lowering greenhouse gas emissions and it is important to note that the possibility of emission reduction in buildings is noteworthy high and that through the principles of

integrated design, the potentially saved operation costs can reach up to 80% in standard new buildings.

Additionally, it is important to note that these savings are usually reached with little to no additional cost over the lifespan of the measures because building's energy consumption primarily consists of the development of laws and regulations, and certain standards aiming at improving the energy efficiency which includes improving the performance of different building subsystems and equipment like thermal insulation, heating and ventilation, air conditioning (HVAC), lighting.. etc. This study is going to address a number of specific energy consumption requirements of residential buildings in the city of Kirkuk, Iraq which is a region known for the harsh climate of very hot and dry summers and cold winters that it has. The key considerations in this study are the inclusions of the automatic operation of HVAC systems and the specific regional climate energy demands. However, the framework used currently to improve energy efficiency is expected to face some significant adaptations with the widespread usage of artificial intelligence in the current world because like all other fields, AI has obtained a critical role in the process of energy usage optimization. [2] Through internet-based applications, it has been observed that the energy consumption of data center buildings can be reduced by up to 15%. Energy consumption control allows for more efficient use of air conditioners, fans, and windows. Beyond directly improving energy efficiency, the use of Artificial Intelligence (AI) also contributes to a reduction in the carbon emissions of buildings. The primary factor driving this improvement is the integration of Internet of Things (IoT) technology, which enables the connection of sensors to the network, allowing for real-time monitoring and optimization of energy use. [3] [4] A critical step in the advancement of smart building technologies is the process of data collection and management using cloud technologies in an IoT environment. This process allows for real-time monitoring of the systems of buildings and more efficient management which contributes to the improvement of energy efficiency and the systems general operational performance. [5]

Kirkuk, Iraq, due to its harsh climate with extreme heat in summers and cold winters, is a valuable case study of energy efficiency and sustainable building practices. The

city’s geographical location makes it face difficulties in maintaining a comfortable environment indoors while managing energy consumption at the same time making it rely heavily on energy intensive HVAC systems. This heavy dependency makes the city rely on fossil fuels to generate electricity almost entirely with more than 98% of the energy need of the country of Iraq being supplied by non-renewable sources. [6] Hence, it has increased resource depletion and the carbon footprint of the region. However, these challenges present an opportunity for the integration of renewable energy systems and adopting nearly zero-energy building (nZEB) systems in the country’s buildings that are both environmentally and economically more viable alternatives. By reducing energy consumption building owners can be relieved of financial burdens and benefit from sustainable development. It is important to note that achieving nZEB standards in the city of Kirkuk comes with several adjustment requirements such as optimizing building orientation, improving thermal insulation, upgrading HVAC systems, and incorporating renewable technologies such as photovoltaic panels. This study is a case study of a building in Kirkuk investigating and evaluating energy efficient strategies by focusing on enhanced insulation, renewable energy through the utilization of PV and more through the utilization of simulation tools like Autodesk Revit with Autodesk insight to evaluate energy efficient strategies. The aim is to highlight the way these measures allow for more cost effective and sustainable buildings that accommodate the region's unique challenges and contribute to global environmental goals. The study emphasizes the the region’s energy challenges and its need for nZEB principles by advocating for new holistic approach of building designs that combine standards such as technological innovation, environmental consideration, and economic feasibility seeking to provide more efficient methods for regions with similar climates and energy profiles to embrace sustainable building practices.

CHAPTER 2

OVERVIEW OF HVAC SYSTEMS

Heating and cooling systems possess significant roles in ensuring thermal comfort and the quality of indoor air of buildings. These systems encompass a range of technologies: heating systems, such as furnaces, boilers, heat pumps, and electric heaters, serve to generate or transfer heat to indoor environments. On the other hand, we have cooling systems, including air conditioners, chillers, and evaporative coolers, function to reduce indoor temperatures by extracting heat from the air. Furthermore, essential components like thermostats, ductwork, pumps, fans, and filters are integral in regulating temperature and promoting air circulation. Significantly, but more modern systems prioritize energy efficiency, incorporating advanced technologies like variable speed drives and smart thermostats to enhance performance while minimizing energy consumption [7]. HVAC systems can be categorized into four primary types. First, All-Air Systems rely exclusively on air for both heating and cooling, encompassing single duct, dual duct, and variable air volume (VAV) configurations. Next, All-Water Systems use water as the heating or cooling medium, featuring 2-pipe systems for either function individually, or 4-pipe systems that enable simultaneous heating and cooling. Additionally, Air-Water Systems integrate both air and water distribution, providing greater flexibility in temperature control. Finally, Unitary Systems consist of standalone units, ideal for low-cost and low-load scenarios. Each system type is tailored for specific applications, offering unique advantages aligned with varying environmental requirements [8].

2.1 Energy Efficiency in Buildings

Improving building's energy efficiency is a key priority for global energy policies, supported by directives and standards like ISO. This involves balancing various factors, including environmental, energy, financial, and social aspects. The decision-making process for this is a multi-objective optimization problem, typically addressed through simulation or multicriteria decision-making methods [9]. Several of the reviewed

projects illustrate that information campaigns have the potential to reduce energy consumption; however, their effectiveness varies significantly, with reported savings ranging from 10% to instances of increased electricity usage. Consequently, the uncertainty surrounding the long-term impacts of these campaigns often results in a preference for more definitive technological solutions. Furthermore, human factors play a crucial role in shaping the outcomes of energy efficiency initiatives, which complicate data analysis. Although continuous reminders and educational efforts can enhance and extend the effectiveness of behavior-based energy savings, financial incentives frequently act as a more compelling motivator for consumers. Additionally, clear and comprehensible electricity bills can further bolster sustained energy efficiency by providing consumers with ongoing feedback [10]. And some of the factors that influence energy efficiency in building design, categorizing them into three main areas: building characteristics, energy-efficient technologies, and occupant behaviors. While considerable research has been dedicated to optimizing building design and advancing technologies, challenges related to cost-effectiveness and practical feasibility persist. In contrast, interventions aimed at modifying occupant behavior present a cost-effective and easily implementable solution that is applicable to both new and existing buildings. Recent trends suggest a notable shift from an exclusive focus on technological upgrades to a more comprehensive approach that includes building management and occupant behavior. Furthermore, some studies advocate for a systematic approach to understand the interactions among various design measures and highlight the necessity of benchmarking energy performance in both occupant behavior interventions and technological advancements [11]. The traditional HVAC systems have the disadvantage of heavy dependence on fossil fuels, which are facing rapid depletion. This situation, accompanied by the high and increasing demand for cost-effective infrastructure demonstrates the need for energy efficiency enhancement with new installations and substantial upgrades in buildings to parallelly support environmental sustainability [12]. Several strategies can be employed to address these challenges. For example, advanced control systems can increase efficiency by approximately 30% and evaporative cooling systems similarly can decrease energy consumption by about 50%. Additionally, the use of thermal energy storage is another approach that can shift energy consumption to off-peak hours.

Moreover, combining different air conditioning technologies and retrofitting existing systems with innovative solutions have the potential of providing significant improvement in their efficiency, with potential energy savings ranging from 20% to 40%. The methods mentioned are crucial for developing HVAC systems that adhere to modern energy efficiency standards [13].

2.2 Nearly zero energy buildings

Major contributors to energy consumption are conventional buildings that account for nearly 40% of primary energy usage and 36% of greenhouse gas emissions in Europe, with some member States exceeding 45%. It is worth noting that space heating is the primary energy end-use in residential buildings which accounts for about 70% of total energy consumption and depends predominantly on fossil fuels. Meanwhile, Nearly Zero Energy Buildings (NZEBs) are characterized by structures demonstrating very high energy performance, where the supplement of nearly zero or very low energy is largely provided by renewable sources generated on-site or in neighboring areas.

To mitigate energy consumption and greenhouse gas emissions in the building sector, it is crucial to use the concept of NZEBs which plays a vital role in the process and is responsible for a substantial portion of energy use in Europe [14] [15] [16]. Conventional buildings are the buildings that most commonly demonstrate high energy consumption with an average of approximately 280 kWh/m² and a considerable reliance on fossil fuels for space heating that accounts for about 70% of the total energy usage. In contrast, Nearly Zero Energy Buildings (NZEBs) are designed with the aim of achieving very high energy performance and their energy requirements are predominantly provided by renewable sources generated on-site or in close proximity. This transition towards NZEBs is diminishing reliance on non-renewable energy significantly which contributes to a reduction in greenhouse gas emissions and overall environmental impact. Moreover, the implementation of NZEBs is increasingly indorsed by regulatory flameworks which are promoting energy efficiency and sustainability within the building sector. In conclusion, NZEBs represent a transformative approach to building design which emphasizes the minimization of energy consumption and maximization of the utilization of renewable energy sources

[17] [18] [19]. The technologies and features nZEBs around Europe that concentrate on buildings' construction and renovation in relation to varying climate conditions emphasize the reality that climate does in fact influence the adoption of renewable technologies, and that the overall technology package essential to achieve nZEB targets stays unaffected by climatic variations. The analysis is based on a sample of 411 high-energy performance buildings collected through the EU IEE ZEBRA2020 project which's findings revealed that national minimum requirements for thermal transmittance were consistent across Europe and resulted in comparable heating demands irrespective of climate. Ultimately, the study aspires to provide design guidelines and identify best practices to facilitate the broader adoption of nZEBs throughout Europe [20]. The development of zero-energy buildings (ZEBs) faces several challenges, including high energy demands and inefficient architectural designs that frequently contribute to energy waste. To address these issues, an integrated design approach is essential, necessitating collaboration among architects, engineers, and energy experts from the initial stages to optimize overall building performance. Furthermore, occupant behavior significantly influences energy efficiency, underscoring the importance of education and awareness initiatives to encourage responsible energy usage. Effective load matching between energy demand and renewable supply is also critical, requiring advanced management systems to align building operations with real-time energy availability. Additionally, achieving ZEB status can be particularly complex in commercial buildings due to varying usage patterns, which may lead to substantial discrepancies between predicted and actual energy performance [21]. The implementation of Nearly Zero Energy Buildings (nZEBs) in Southern Europe encounters considerable challenges due to geographical and climatic factors, such as elevated summer temperatures and urban heat. The decline in design and construction skills associated with bioclimatic design further complicates efforts to effectively address summer comfort. Moreover, the absence of a skilled workforce and inadequate national or regional strategies undermine the human infrastructure essential for the successful execution of nZEB projects. Current construction practices frequently depend on outdated calculation methods, resulting in discrepancies between anticipated and actual building performance. Ultimately, there

is an urgent need for a supportive legislative and industrial framework to facilitate the transition to high-performance nZEBs throughout the Southern European region [22].

2.3 Thermal insulation

Many scholars have studied the way different design characteristics of massive exterior walls that include some insulation, impact heating and cooling demands in both commercial and residential buildings. When it comes to walls with multiple layers, three main configurations were analyzed: insulation placed inside the massive layer, outside the massive layer, and between two massive layers. The findings provided by extensive parametric analysis clearly demonstrated that walls with insulation on the outside consistently performed better than those with insulation on the inside [23] [24]. How insulation is placed plays a crucial role in determining the thermal performance of building walls and walls with exterior insulation consistently demonstrate better thermal effectiveness than those with interior insulation. Moreover, this configuration improves the building's capacity that helps minimize interior temperature fluctuations, enhance thermal stability and lower energy requirements for heating and cooling. The analysis of one source indicates that the best thermal performance is achieved when massive material layers are positioned nearest to the interior that allow for improved heat retention and reduced energy use and generally, the study highlights how significance the insulation placement is in creating energy-efficient building designs across different climate conditions [25].

Additionally, in places like Adana in Turkey, thermal insulation significantly reduces cooling loads and energy consumption in hot and humid regions because insulated buildings in these places experienced up to a 33% reduction in cooling load which led to around 25-33% savings in energy costs for air-conditioning systems which was shown in economic analysis that proved that insulated buildings had lower initial and operational costs compared to non-insulated ones. Moreover, thermal insulation is particularly effective in regions with long cooling seasons for their greater energy efficiency and cost savings compared to regions where heating is more critical [26] and for a comprehensive comparative analysis of various insulation materials, including polyisocyanurate, recycled glass fiber, vacuum insulation panels (VIPs),

aerogels, cellulose, kenaf fiber, cork, stone wool, and mineralized wood fiber [27]. It is important to note that each material is evaluated depending on its thermal conductivity, thermal transmittance, and environmental impact [28]. For example, polyisocyanurate is noted for its low thermal conductivity which makes it effective in winter, while recycled glass fiber demonstrates versatility with good performance in both winter and summer conditions [29]. Additionally, VIPs and aerogels offer exceptional insulation properties but may face practical limitations in thickness for certain applications [30] and mineralized wood fiber also demonstrate promise with low periodic thermal transmittance values [31]. However, for dry high-temperature environments with long summers, recycled glass fiber is regarded as the best option due to its effective heat management capabilities and its overall performance in varying conditions [27].

2.4 Solar Systems

The research [32] investigated the efficiency of solar systems for heating and cooling buildings through a design study concentrating on a virtual hotel examining the energy performance of solar heating and cooling systems under various climatic conditions and highlighting the role of solar thermal collectors and thermally driven cooling cycles. It assessed the achievable solar fractions and primary energy savings in comparison to conventional systems that use fossil fuels for heating and domestic hot water production [32]. In the study, a detailed analysis is conducted for a specific location which is Malta, a place where the primary energy savings and costs of the solar system are compared to those of a conventional reference system and the results indicated that the solar thermal solution led to significant primary energy savings accompanied by extensive simulations evaluating different system configurations including variations in solar collector size and buffer storage volume [32]. The results also suggested that optimizing these components can improve the overall efficiency of solar heating and cooling systems in buildings by examining three types of solar energy systems: solar thermal, photovoltaic (PV), and hybrid photovoltaic-thermal (PV/T) systems, each with distinct characteristics and applications [33]. Solar thermal systems are designed to capture and convert solar energy into heat which is done primarily for space heating and domestic hot water, but they do not generate electricity.

In contrast, traditional PV systems focus solely on converting sunlight into electricity, achieving efficiencies of over 20%, but they lack thermal energy production capabilities [34]. PV/T systems combine the functionalities of both technologies, generating electricity and heat simultaneously, which can enhance overall efficiency and reduce space requirements on building rooftops [33].

However, although PV/T systems can improve the thermal management of PV cells by dissipating waste heat, they generally exhibit lower efficiencies compared to dedicated PV modules [35]. The market for PV/T technology is still emerging and facing challenges regarding availability and performance compared to the more established solar thermal and PV systems [28]. Additionally, the integration of PV/T systems may introduce complexity and higher costs due to the need for hydronic systems [34]. In conclusion, the choice between these technologies relies on specific building energy requirements, available space, and the desired balance between electricity and heat generation [33] [35]. The study by [36] investigated the optimal use of photovoltaic solar panels in urban residential buildings by analyzing three scenarios: grid-connected systems with batteries, without batteries, and full feed-in and findings indicated that the GCPVS without batteries is the most effective option, maximizing energy efficiency while minimizing costs and environmental impacts. The researchers highlighted the need for improved electricity pricing mechanisms to encourage investment in renewable energy sources without burdening low-income households [37].

2.5 Recent Developments and Research

This research [38] examines how renewable energy and smart design can create ultra-efficient buildings in hot climates as the country of Oman. The results show that solar panels can cover 60–80% of a building’s energy needs, while simple fixes like better insulation and shading cut cooling demands by nearly half. Though solar systems cost more upfront, they pay for themselves in 7–10 years thanks to lower energy bills. The study also highlights that government support and smart building materials are crucial to making these solutions work in extreme heat. These findings could help similar

regions, like Iraq, Kirkuk design more environmentally friendly and more affordable buildings.

Yet another research [39] shows findings as solar-powered cooling systems as a sustainable solution for buildings in hot climates. Key findings show these systems can reduce conventional AC electricity use by 40-60%, with a return on investment within 5-8 years. The research highlights that performance is optimized when integrated with proper building insulation and system sizing, making it particularly effective in sunny regions with high cooling demands. The results demonstrate solar cooling's potential as both an environmentally friendly and economically viable alternative to traditional air conditioning in warm climates.

And another research [40] evaluated hybrid solar cooling systems for buildings in warm climates, finding they can reduce conventional electricity use for cooling by 50-70%. While also requiring higher initial investment, these systems become cost-effective within 4-7 years through energy savings. The study also emphasized that success depends on proper system sizing and local solar conditions, with best results in areas receiving strong, consistent sunlight. Importantly, the technology cuts associated CO_2 emissions by 60-80% compared to standard air conditioning. These findings position solar-assisted cooling as both an environmentally and economically viable option for sustainable building design in sun-rich regions.

As we can see, renewable energy systems like solar PV and hybrid cooling can meet 60-80% of building energy needs in hot climates while cutting cooling demand by 40-70%. With payback periods of 4-10 years approximately and significant CO_2 reductions, these solutions offer both economic and environmental benefits for regions like Kirkuk facing extreme heat challenges especially during summer seasons.

Another recent study [75] conducted in 2024 overviewed literature on ZEBs Over the past ten years finding that research ZEBs has usually been centered on three strategies that are related with each other and that being improving energy efficiency, optimizing both passive and active HVAC systems, and the use of renewable energy technologies to help improve the energy efficiency. However, few investigations have noticed how cultural, social, economic, as well as climatic factors affect real world implementation

and results, especially in traditional or high-density urban areas. Although photovoltaics remains the leading choice for renewable energy, wind and geothermal options show potential but face challenges like space, cost, and performance related issues. But importantly, we notice that the literature lacks detailed economic analyses concerning high costs initially and the roles of public versus private investment, as future works must address these financial, social, and spatial challenges to make ZEBs practically achievable at a large scale.

And this study [76] which was also conducted in 2024 also reviewed practical strategies and ways for achieving Net-Zero Energy and Net-Zero Carbon Buildings. And it found that combining efficient design, renewable energy systems, and life cycle assessment helps reduce both energy use and carbon emissions to the environment. As real world examples have shown how material choices, insulation, and solar panels can lower not only environmental impact but also energy savings. The study concludes that focusing on both operational and embodied carbon is essential, and that future work should aim to balance energy performance, cost, and sustainability in real building projects.

And internationally nearly zero-energy homes typically have a payback period of 3 to 8 years, while full zero-energy homes with solar systems pay back in about 7.8 to 13.8 years. Though upfront costs are higher, long-term energy savings make them cost-effective [77].

And a study on payack period of a nearly zero-energy building (nZEB) was designed for Yazd, Iran a hot and dry climate using passive strategies and solar panels. The results showed significant reductions in energy use and emissions. The payback period for the additional investment was estimated at approximately 5.5 years, making the nZEB approach financially feasible for residential use in such climates [78].

2.6 Gaps in Existing Research

To the current knowledge of the researcher, there has been only one study that investigated the optimal form and orientation of multi-story buildings in Kirkuk, Iraq, to enhance energy efficiency and the T-shaped model emerged as the most efficient

design by achieving the lowest energy consumption of 40,495 kWh annually at a rotation angle of 285° and resulting in costs of $964. Additionally, the U-shaped model exhibited the highest energy utilization at 73,880 kWh and a cost of $1,758 when oriented at 270°. That study highlighted that building orientation significantly impacts energy efficiency and emphasized the necessity for thoughtful design choices. Moreover, the findings showed the importance of integrating sustainable architectural practices in response to Kirkuk's growing energy demands and contributed valuable insights into optimizing building designs for energy conservation in urban settings [33]. Additionally, another paper investigated the strategies needed for enhancing thermal comfort and reducing energy consumption in educational buildings, specifically focusing on the College of Education for Pure Sciences at the University of Kirkuk and the key findings revealed that optimal building orientation significantly lowered thermal loads, with a recommended adjustment of 30 degrees counterclockwise from the existing position and the use of thermal insulation materials on exposed facades was shown to decrease energy expenditures and operational costs. The study also highlighted the effectiveness of simulation software, such as Autodesk Revit with Autodesk Insight, in predicting thermal performance and facilitating informed design decisions. Moreover, the research also emphasized the necessity of adapting architectural strategies to local climatic conditions to enhance energy efficiency [39]. Building upon these previous studies, this study aims to address the gap by focusing specifically on residential buildings in Kirkuk and its unique climate conditions. By doing so, it will investigate and evaluate the effectiveness of adding insulation to walls and roofs, integrating photovoltaic (PV) solar panels for renewable energy generation, optimizing building orientation and other strategies to minimize overall energy consumption and operational costs. This study aims to enhance the thermal performance of residential structures while capitalizing on the region’s high solar irradiation potential by combining these strategies.

This study is particularly important for a climate such as the city of Kirkuk’s, where extreme temperatures can cause increased reliance on heating and cooling systems which in its turn results in placing significant strain on local energy supplies and creating significant CO2 emissions. Additionally, improved insulation levels help in reducing heat loss in winter and limit heat gain in summer leading to the reduction of

the energy needed for space conditioning. Meanwhile, the PV solar panels offer a cleaner and more cost-effective power source capable of giving aid to the local grid's demand. Moreover, the consideration of building orientation capitalizes on passive solar gains and natural ventilation opportunities and by systematically examining and implementing these measures in residential buildings, this study will offer practical design guidelines and technology recommendations for architects, planners, and homeowners in Kirkuk which ultimately contributes to a more sustainable and economically built environment.

CHAPTER 3

RESEARCH DESIGN

This study relies on simulated case study based research design in the process of evaluating and improving the efficiency of energy in a residential house building. The simulation based method was selected due to its suitability for early stage building design analysis, as it allowed for rapid iteration and and performance predictions that were quantifiable under numerous design scenarios [43] By using This research examines in a systematic manner how modifications to the building's envelope, orientation, fenestration, and other architectural features have a crucial role in the overall energy consumption by using Autodesk Revit for 3D modeling and the integrated Autodesk Insight plugin for part of performance simulations and it contributed significantly since Autodesk insight uses advanced energy simulation engines like EnergyPlus in its calculations of energy use, daylighting, and thermal comfort metrics [44] This study, using iterative modeling and analysis, examines different design parameters such as wall insulation levels, glazing ratios, shading strategies and more in the process of identifying configurations that are optimal for energy performance. Additionally, the focal objectives are to provide crucial insights in the field of residential building designs that can minimize operational energy demands that can simultaneously maintain comfort and functionality. Therefore, by using a combination of parametric design approach with provided validation to the simulation tools, this method combined and addressed both quantitative performance data and qualitative design considerations that ensured that the final recommendations were grounded in real-world conditions and practical constraints [43]

3.1. Reducing Greenhouse Gases (GHG)

The need for a definition that is clear and consistent and supports energy and reduction of CO2 emission is one of the important implications of nearly Zero Energy Buildings (nZEBs). The building's minimum energy performance standards should use an energy metric that accurately reflects both its energy consumption and CO2 emissions, as

reduced energy use should directly lead to lower CO2 emissions. A building's primary energy consumption provides a reliable measure of fossil fuel depletion and is generally proportional to its CO2 emissions, except when nuclear energy is involved. If a single metric is applied, it should focus on primary energy consumption, as outlined in the current Energy Performance of Buildings Directive (EPBD), while CO2 emissions should also be included as supplementary information to reflect the building's climate impact. To align nZEB standards with EU climate targets for 2050, new buildings must aim for nearly zero carbon emissions, keeping emissions below approximately 3kgCO2/m² per year. [19]

3.2 Core fundamentals for a building's energy consumption

Core Definitions and Measurements of Residential Building Energy Demand One of the most common methods of addressing a house's energy use is by using the concept of overall demand which explains how much electricity or fuel a household requires to stay comfortable and functional. To simplify it further, it is the total energy that a house consumes to maintain and sustain lighting, heating, cooling, hot water, and power for appliances and one of the commonly used metrics is the Energy Use Intensity (EUI) that shows the amount of energy used (usually in kWh) per square meter (or square foot) of floor area per year [45] and it assists researchers and homeowners in comparing performances across different properties. It is also possible to see demand being measured in terms of the Home Energy Rating System (HERS) Index in the United States, which is a and index that compares a home's efficiency with a standard reference house [46]. It is important to note that a lower HERS Index demonstrates the existence of a better energy performance. Another concept is the building's envelope efficiency, which measures how effectively walls, windows, roofs, and insulation keep indoor temperatures stable. In simpler terms, it's basically how well the "skin" of the house keeps warm or cool air inside without letting it leak out. Moreover, one of the key measurements is air infiltration which shows how much outside air gets into the house through its cracks, gaps, and poorly sealed doors or windows and depending on the measurement of air changes per hour (ACH), a lower infiltration rate normally indicates a greater efficiency since less conditioned air escapes [47].

Considerations and Efforts to Reduce Energy Consumption Insulation is one of the primary considerations for lowering energy consumption. Insulations that are thick and of high-quality in the walls and roof, significantly reduce heat loss in the cold seasons and heat gain in the warm seasons. Additionally, window glazing is another important factor which refers to double or triple-glazed windows that maintain more heat and keep out cold air better than single-pane types which means that layering windows is like putting on additional coats in winter which makes the windows hold in warmth more effectively. Other major roles go to Efficient Heating, Ventilation, and Air Conditioning (HVAC) systems. The HVAC units that have higher Seasonal Energy Efficiency Ratio (SEER) ratings utilize less electricity to cool and furnaces with higher Annual Fuel Utilization Efficiency (AFUE) ratings at the same time which uses less fuel for hearing [48]. It is noteworthy that regular maintenance of these systems such as changing their filters and checking their ducts can prevent energy wastage. It is also important to address that appliances and lighting play significant roles too. However, they are often overlooked. One fact is that LED lights use significantly less electricity than older incandescent bulbs while ENERGY STAR-rated refrigerators, dishwashers, and washing machines are also modernly designed to require less power and water for operating without compromising their performances [45]. Occupant behavior matters a lot, too. Simply turning off lights and electronics when not in use or adjusting thermostats by a few degrees can lead to noticeable reductions.

Lastly, integrating renewable energy systems, like rooftop solar panels, can reduce reliance on the grid. In simpler language, making use of free sunshine to generate electricity at home can bring down monthly bills and environmental impact. All of these definitions, measurements, and strategies such as EUI, HERS Index, airtightness, insulation, and efficient appliances fit together to create a picture of how a house uses energy and how we can make it use less. In short, residential buildings benefit from a mix of better design, technology, maintenance, and user awareness to keep energy demand as low as possible. In a hot, semi-arid location like Kirkuk, reducing excessive heat gain during summer days and minimizing heat loss during cooler evenings is essential for residential energy efficiency. A high level of thermal insulation in the walls and roof addresses this issue by keeping the indoor temperature stable, lessening the need for continuous air conditioning or heating [50]. Some objects can block harsh

sunlight such as shading devices like overhangs, and well-placed trees [52]. Additionally, windows that are well-sealed and doors can prevent the unwanted infiltration of hot outdoor air, which reduces the cooling load on HVAC systems [51]. Another option to improve general comfort and energy consumption is using double- or triple-glazed windows which curb the transfer of heat. Moreover, since Kirkuk gets ample sunlight, the incorporation of solar panels or solar water heaters assist significantly in the decreasing of reliance on grid electricity and the trimming of monthly utility costs simultaneously [49]. However, small daily routines are important as well such as increasing the thermostat a few degrees in summer and using curtains to prevent sunlight during peak daylight hours which both provide considerable saving of energy over time.

3.3 Passive Design Optimization

Passive Design Optimization refers to the designs of buildings that are constructed in a way that that prioritizes natural elements like solar radiation, shading, and ventilation to regulate indoor temperatures for example, and reduces reliance on active mechanical systems [53]. In a location like the city of Kirkuk, where summers are extremely hot, the goal is to achieve minimization in excessive heat gain while maintaining an adequate amount of daylighting and ventilation.

Common Types of Passive Design Strategies:

1. Building Orientation: it refers to positioning buildings relative to the sun, prioritizing winds to maximize solar gain, cross-ventilation, and daylight.
2. Shading and Glazing: refers to the usage of overhangs, louvers, or screens on façades, with the placement of windows strategically or low-emissivity glazing which helps in controlling solar heat gain.
3. Natural Ventilation: refers to the integration of openings or wind-catchers to help exploiting dominant breezes and improving indoor airflow which are very important in hot climates like Kirkuk’s.

3.3.1 Building orientation

One of the critical aspects of passive design for residential structures in Kirkuk is building orientation since kirkuk is a place where summers are extremely hot, and winters are milder but still can benefit from strategic solar gain. By placing the house in a way that minimizes direct exposure to the intense afternoon sun, designers decrease internal heat buildup and hence, a decrease in the reliance on air-conditioning systems is achieved [53]. Additionally, orienting houses in a way that makes them capture dominant winds can foster natural ventilation which allows for cooler outdoor air to circulate through interior spaces and expel excess heat and this approach is specifically of significance in hot regions since it can prevent indoor temperatures from increasing to uncomfortable levels without depending only on mechanical cooling methods [54]. Moreover, it can be beneficial in climates with strong solar radiation to adjust the main facades to face north and south because this configuration is helpful in controlling the amount of sunlight entering the interior, and in the reduction of harsh and low-angled sun in the early morning and late afternoon. For example, a south-facing facade can maximize wintertime solar gain that allows the warmth of the sun to enter the living spaces when there is a high heating demand [55]. Additionally, a shading strategy that is well designed like extended overhangs or vertical fins also block high-angle sun rays and allow ambient light to diffuse indoors at the same time and this careful organization of sunlight, combined with the natural cooling breezes common in the climatic pattern of Kirkuk can offer incredible energy savings that cut down on mechanical heating and cooling needs [53]. However, beyond heat management, to reduce the reliance on artificial lighting and create visually relaxing interiors, it is necessary to orient living areas making them receive balanced levels of daylight. In the context of Kirkuk, illumination is provided by early morning sun from the east, while extreme westward sun in the late afternoon can be managed using shading devices or narrower window designs. By orienting windows strategically and with insulation and high-performance glazing, we can limit unwanted flow of heat and ensure that indoor spaces stay comfortable even during the hottest periods of the year [54]. While at the same time is the capture of adequate sunlight in the cool months helps in avoiding extensive reliance on electrical heating which in its turn increases energy efficiency and occupant well-being [56].

In a broad view, a residential building in Kirkuk that is carefully oriented can reduce cooling pressure significantly in summer and enhance passive solar heating potential in winter while the alignment of the structure to dominant winds, enhancing the façade placement, and the implementation of appropriate shading systems are important in lowering energy consumption and maintaining interior comfortably. The employment of these principles of passive design orientation, architects and planners assist the development process d sustainable solutions specified to the city's climate, while improving the livability and decreasing the environmental impact at the same time [53].

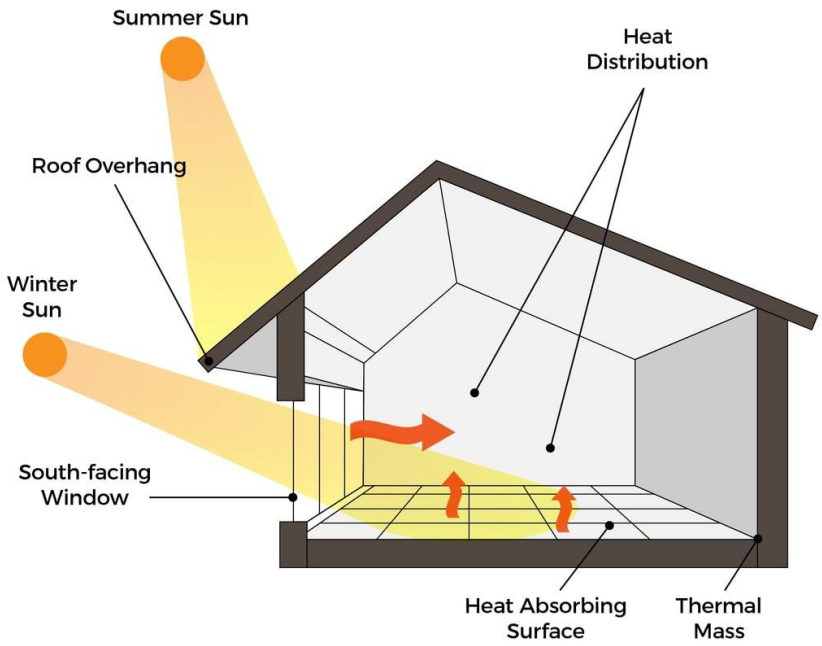

Figure 3.1 Passive solar effect on a building

3.3.2 Shading & overhangs

Two of the essential passive design solutions that help minimize unwanted heat from the sun are shading and overhangs and they work by blocking intense, high-angle sunlight before entering the interior part of a building. In the city of kirkuk where the climate is characterized by hot summers and a lot of sunlight case of a residential building can benefit from correctly sized overhangs that have the potential of

mitigating indoor temperatures and reducing the need for mechanical cooling which is due to their ability in preventing hot rays of the sun from penetrating directly into the living spaces, hence maintaining a cooler and more comfortable atmosphere. Additionally, shading devices also reduce glare from direct sunlight by controlling the path of the sun which also improves visual comfort inside the residence and as mentioned above, overhangs that are strategically planned and that are usually laced above windows and glazed openings help in the obstructions of the higher-angle summer sun responsible for the bulk of heat gain during warmer periods which also allow lower-angle winter sun to enter indoors which ultimately lead to the facilitation of passive heating during the cold seasons. This strategic approach to the management of daylight ensures that interior spaces benefit from natural illumination without causing any incurring to excessive heat or unpleasant brightness.

It is worth reiterating the fact that shading and overhangs work on balancing indoor environment which is achieved by reducing direct solar radiation and glare leading not only to the alleviation of reliance on air conditioning but also fostering a more comfortable atmosphere for residents. [53] states that the dimensions and proportions of overhangs need to be derived from local sun-path data and orientation considerations. [57] similarly highlights the significance of sizing overhangs in accordance to climatic conditions in order to improve both thermal comfort and energy efficiency. In other words, climate-appropriate shading does not assist only in blocking the sun it but it also actively moderates temperatures indoors while preserving desirable levels of daylighting at the same time.

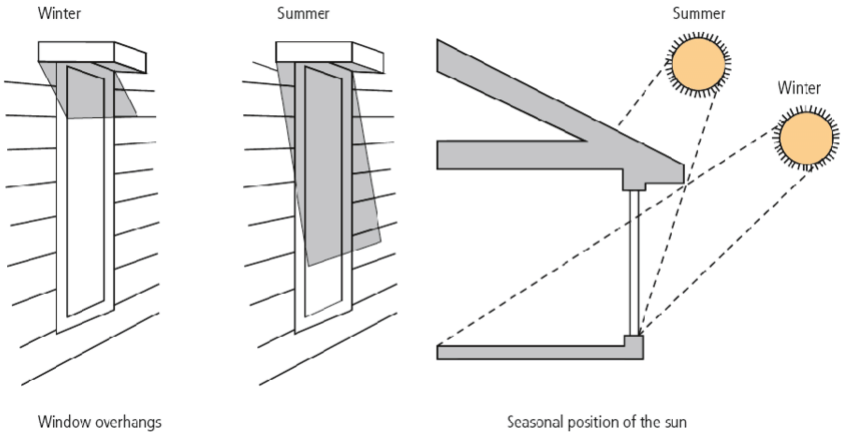

Figure 3.2 Effects of window overhangs on a building

3.3.3 Natural ventilation and infiltration effects

Natural ventilation and infiltration both significantly influence indoor air quality, comfort, and energy consumption in residential buildings, particularly in a hot, arid environment like Kirkuk. Natural ventilation involves the strategic placement of openings such as windows, vents, and louvers that allow fresh outdoor air to enter and stale indoor air to exit [58]. This technique can effectively reduce indoor temperatures, especially if cooler nighttime or early-morning air is harnessed. Reiterating this point is important: drawing in cooler air at specific hours lowers reliance on air conditioners or mechanical systems, conserving energy by minimizing daytime cooling demands [59]. At the same time, some infiltration unintentional air movement through cracks and gaps around doors, windows, or the building envelope can help with natural ventilation by introducing fresh air [60]. Yet, excessive infiltration forces HVAC systems to work harder to maintain comfortable indoor conditions, causing higher energy use in both summer (to combat unwanted heat gain) and winter (to offset heat loss). It is worth repeating that sealing unnecessary gaps and maintaining an airtight building envelope remain crucial to preventing excessive energy bills. However, preserving a degree of controlled air exchange is essential to ensure occupants enjoy good indoor air quality.

Thus, carefully merging natural ventilation strategies with controlled infiltration levels enables residential buildings in Kirkuk to optimize occupant comfort and energy efficiency. In other words, allowing a deliberate flow of fresh outdoor air at cooler times of the day, while limiting unplanned leakage during peak heat, strikes a balance between providing sufficient ventilation and reducing heating or cooling loads [58]. Repeating for emphasis: by managing both natural ventilation and infiltration judiciously, homeowners can achieve lower energy consumption, healthier indoor environments, and more comfortable living spaces.

3.3.4 Effects of insulation and U values

As previously noted, a significant portion of energy used in buildings is for heating and cooling. Thus, effective heat management in buildings is essential. To ensure high indoor comfort levels, building components exposed to the air entering from external

sources must be shielded from external temperature fluctuations. Heat loss indoors primarily occurs through the building envelope, distributed as follows: in approximation of 10% through floors of the house, 15-25% from windows, around 25% through roofs, roughly 20% through walls, and somewhere between 20% and 50% at thermal bridges. Effective control of temperatures and general heating in residential buildings is achieved through reliable constant, effective quality thermal insulation in the residential building, airtight windows and walls of the residential building, making sure thermal bridges aren't disturbing the flow, and high-performance windows. As we aim to improve the thermal resistance in the materials used for building and control heat loss more, insulation materials with a low thermal conductivity coefficient are recommended. Insulation materials can be applied in walls, roofs, floors, and even installation systems. Additionally, well-crafted windows and insulated glass units are crucial for maintaining thermal efficiency.

When selecting thermal insulation materials, it is important to understand their properties, including:

- Low thermal conductivity,
- Lightweight,
- Lack of odor,
- Moisture resistance,
- Resistance to bacteria and pests,
- Durability against decay,
- Stability of insulating properties over time,
- Fire resistance,
- Long lifespan,
- Ease of handling and safety for human health,
- Affordability and availability.

Examples of insulation materials and their thermal conductivity values:

- Polyurethane Foam: 0.046 W/mK
- Extruded Polystyrene (XPS): 0.025 W/mK

- Expanded Polystyrene (EPS): 0.033 W/mK
- Glass wool: 0.042 W/mK

In passive house construction, insulation materials are critical for maintaining U-values between 0.1-0.15 W/m²K. Apart from the thermal conductivity of materials, their thickness also plays a key role in achieving these U-values. [61]

When considering the costs, thermal insulation systems do require an initial investment. However, the energy savings they provide allow the building to recover these costs within 2 to 3 years. Additionally, insulation helps mitigate the impact of rising fuel costs driven by increasing energy demands. [62] Experiments with different wall configurations showed that increasing wall thickness by 50% reduced heat gain by 20%, while using local insulation materials like cane mat, wood sawdust, and cork grains further reduced heat gain by 50%, 44%, and 40%, respectively, with cane mat being the most effective [63].

Table 3.1 Thermal properties of Iraq's local insulation materials.

Material	Thermal conductivity K (W/m.k)	Density ρ (kg/m^3)	Specific heat capacity C_P (kJ/kg.k)
Local cane mat	0.11	400	0.52
Wood sawdust	0.15	750	1.7
Cork grains	0.13	26	0.77

A separate analysis of roof insulation revealed that while insulation could reduce heat transfer by up to 98%, higher costs were involved. The most cost-effective combination was found to be a mix of air, cork, and concrete. These findings emphasize the potential for energy savings through optimized insulation techniques using locally sourced materials [64] [65].

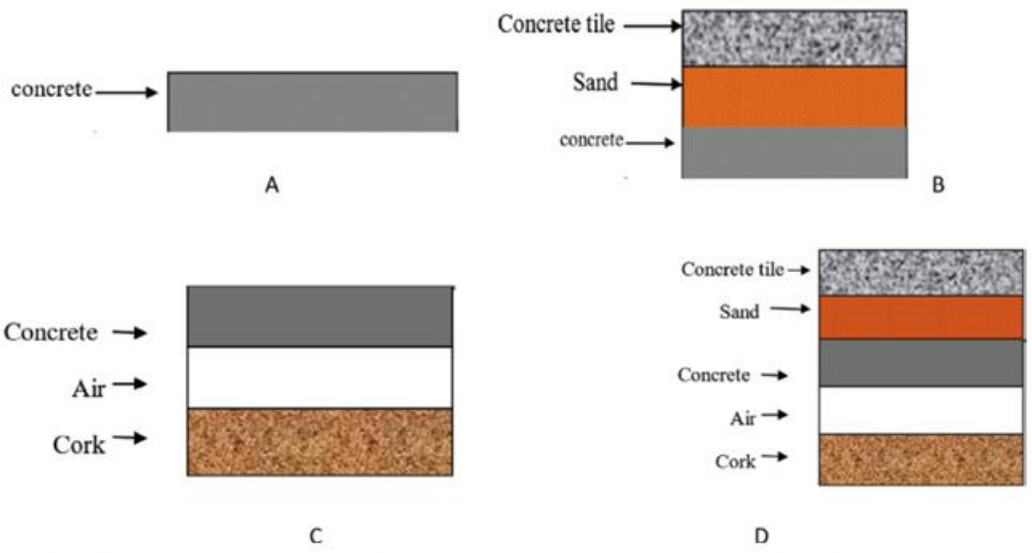

Figure 3.3 Insulation combinations

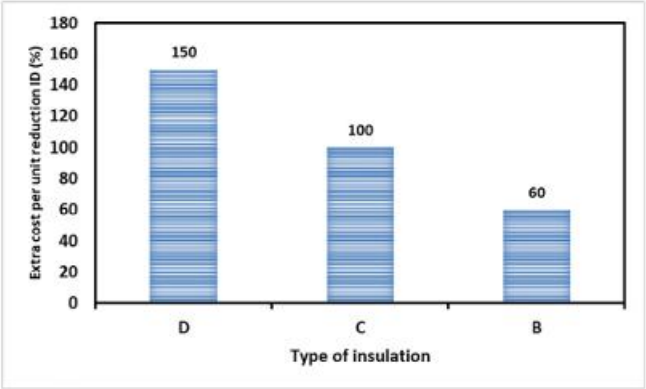

Figure 3.4 Extra cost per unit reduction of heat flow

3.3.5 Effects of lighting use

Lighting is a critical aspect of any building and its energy consumption, whether it involves artificial sources or natural daylight. It must be taken into important consideration in its role in building's design when having energy consumption in mind and combining artificial lighting with daylight can enhance the overall comfort of a space. Elements like glass and skylights can also contribute to creating a pleasant aesthetic while maximizing natural light. Although lighting can be incorporated into every area, relying heavily on artificial lighting increases electricity consumption and

can produce excess heat. Research by a lighting company suggests that adopting efficient lighting strategies such as updated fixtures, sources with more energy efficiency and controls of the use of lighting can help reduce energy consumption by around 60% to 75%, be it either indoors or outdoors. [66]

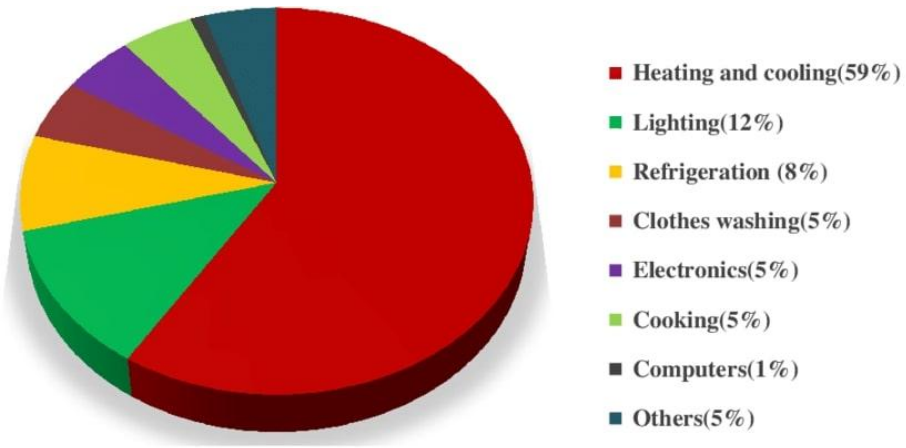

Figure 3.5 Percentage of energy consumption in a residential building

Fluorescent lighting is the most commercially available as well as used type of artificial lighting, as it offers significantly more efficient performance compared to incandescent bulbs. Additionally, incorporating sensors in areas with infrequent use can further reduce electricity consumption by automatically controlling the lighting. Taking advantage of the availability of natural daylight in buildings can help decrease the consumption of energy as the need for artificial lighting, thereby reducing energy consumption. However, daylight is not always available or feasible in certain architectural designs. And for such instances the most effective approach is to combine natural lighting with artificial lighting. Incorporating windows and skylights can help minimize the need for artificial lighting, reducing its overall energy load. [67] The placement of windows plays an important role in a building's design and its effectiveness to utilize natural light. It is one of the most important considerations for creating an environmentally friendly building.

3.3.6 Utilization of PV Solar Panels as renewable energy

The creation of an energy efficient building requires the use of renewable energy sources that fulfill its energy needs. Therefore, the utilization of PV solar panels in residential buildings in Kirkuk will result in noticeable improvement of energy efficiency by catering to the city's high solar irradiance. According to the International Renewable Energy Agency [68], the city of Kirkuk receives abundant sunlight which creates an ideal location for the usage of the solar energy and reduction of reliance on conventional electricity sources. The ample solar potential in Kirkuk provides a prime opportunity for homeowners and researchers to advocate for renewable energy that will reduce monthly utility costs and minimize environmental impacts [68]. the United States Department of Energy [66] noted that the cornerstone of an efficient and well-sized PV system is matching daily energy consumption patterns with predicted solar power output. Moreover, the analysis of actual household consumption data with Kirkuk's abundant sunshine creates the basis for the selection of the right solar panel capacity [69]. During the time that the data is collected, simulation tools like Autodesk Revit with Autodesk Insight are utilized to model numerous configurations and panel orientations. The European Commission [70] emphasized that these software solutions assist in optimizing the panel tilt angle, spacing, and layout which maximize electricity generation throughout the year. This constant emphasis on adequate layout and simulation highlights how even slight adjustments in panel positioning have the potential of significantly affecting the system's overall performance [70].

Lastly, the regular monitoring and maintenance of these devices assist in guaranteeing that the system operates at maximum efficiency. Moreover, property owners can address problems such as dirt accumulation and wiring issues before any escalation by tracking power output, panel temperature, and any performance fluctuations. The International Renewable Energy Agency [71] emphasizes that creating a routine inspection schedule helps in preserving the long-term gains of a PV system which ensures that the building continues to benefit from energy savings and reduced carbon emissions. Additionally, accurately sizing the system through detailed data collection, leveraging simulation tools to enhance design, and conducting continuous monitoring are important steps in forming a residential building that is energy efficient due to the

usage of PV systems. These steps create the way for a truly energy efficient building that does not merely benefit its residents financially but additionally contributes to a more sustainable environment [71].

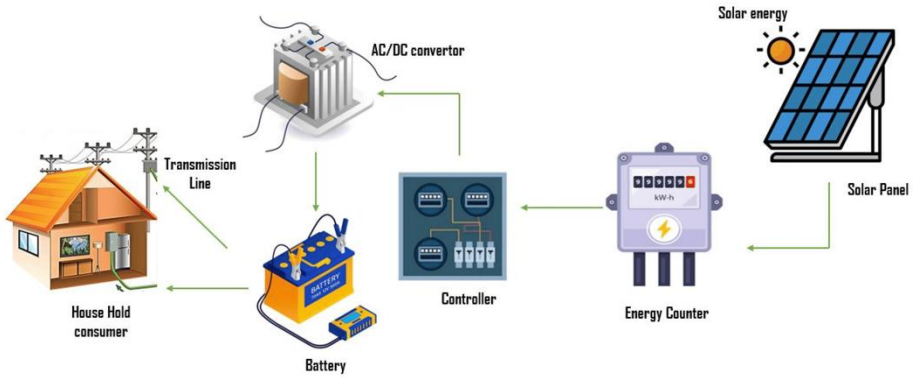

Figure 3.6 PV solar panel operation

CHAPTER 4

ENERGY SUPPLY AND USE

Buildings require primary energy for services such as heating, cooling, domestic hot water (DHW), and lighting. A variety of systems can be used to meet these demands, including air and brine source heat pumps, biomass and gas condensing boilers, and micro-CHP (Combined Heat and Power) units powered by gas or biomass. Multi-split cooling units for residential settings, central cooling systems for offices, heat pumps with heat recovery, photovoltaic (PV) setups, and rooftop installations are additional options for optimizing a building's energy needs.

Table 4.1 Overview of the selected HVAC systems

	Efficiency Heating/Cooling (annual weighted average)	Efficiency Hot water (annual weighted average)
Air Source Heat Pump (SEER)	3.5-4.1*	3.6 – 4.3*
Brine Source Heat pump (SEER)	4.6- 5.4*	3.6 – 4.2*
Biomass Boiler	0.9	0.9
Gas Condensing Boiler	1	0.9
District heating	0.95	0.95
(Micro-) CHP Gas	0.63/0.32**	0.63/0.32**
(Micro-) CHP Biomass	0.63/0.32**	0.63/0.32**
(Multi-)Split cooling units for residential (COP)	3.5	3.5
Central cooling system for office	5.0	5.0

In the case of a building in Kirkuk, Iraq, the primary energy demand for heating and domestic hot water (DHW) would largely be met through fossil fuels. According to the International Energy Agency (IEA), in 2022, Iraq depended on fossil fuels for 98% of its electricity generation. Of this, natural gas contributed 57.3%, and oil accounted for 36.7%. But the IEA also highlights that less than 3% of Iraq's electricity comes from hydroelectric power, and 1% is generated from solar and wind, underscoring the country's heavy reliance on fossil fuels for its energy production. [72]

Recent efforts to boost Iraq's renewable energy capacity are gaining momentum. A key development is QatarEnergy's acquisition of a 50% stake in TotalEnergies' 1.25-gigawatt solar project in Iraq. This project is designed to improve the country's electricity supply and help reduce its reliance on fossil fuels. [73]

According to these energy providers, a significant portion of the energy supply comes from fossil fuels. And fossil-based energy sources emit higher levels of CO2 and are not suitable for the nZEB (Nearly Zero Energy Building) concept, as present in Table 4.2. As a result, renewable energy sources such as photovoltaic (PV) systems and insulation materials are used to meet the nZEB standards.

Table 4.2 Overview of HVAC systems.

	Off-site, grid electricity	Off-site, grid 'Green' electricity	Natural gas	Biomass	District heating	On-site electricity*
CO_2 factor** [kg/kWh]	0.252	0.0	0.202	0.0	0.107	0.0
Renewable share*** [%]	35	100	0.0	100	54	100
Primary energy factor*** [-]	2.0	0.0	1.1	0.2	0.61	0.0

4.1. Increasing Efficiency

Techniques aimed at reducing energy demands, increasing the share of renewable energy, and improving efficiency include the following:

1. Glazing: Argon-filled double or triple-glazed windows to enhance thermal insulation.
2. Insulation: Increased thickness of XPS-EPS insulation materials for better energy retention.
3. Solar Collectors: Use of vacuum tube solar thermal collectors for renewable energy heating.
4. Electric Heating: Electrical radiators powered by photovoltaic (PV) systems.
5. Ventilation: Hygro-sensible ventilation systems for improved indoor air quality and human comfort.
6. Air Tightness: Windows designed to prevent heat loss.

7. Water Efficiency: Energy-efficient taps and showers.

Building Energy Management Systems (BEMS):

- Benefits include energy, cost, and maintenance savings.
- Functions:
- Monitoring building status and environmental conditions (e.g., temperature).
- Providing energy management data and remote-control capabilities.
- Optimizing building operations for efficiency.
- For example, Cloud-based BEMS solutions to help save 10–25% of energy consumption.

4.2 The Data for the Sample Building

We analyzed the energy needs of a 100 m² single-family house with a simple design over a year. We will take a look at a house built using standard materials in Iraq Kirkuk. We looked at how the house would perform if upgraded with certain changes to meet zero-energy building (ZEB) standards. These upgrades are explained in detail in the following section. Different software methods as well as tools were used to calculate and compare the energy consumption performance before and after the improvements.

In this particular case study, a single family residential building is shown in the following Figure below which is optimized for demonstration and energy analysis through the programs Autodesk Revit with the extension of Autodesk Insight.

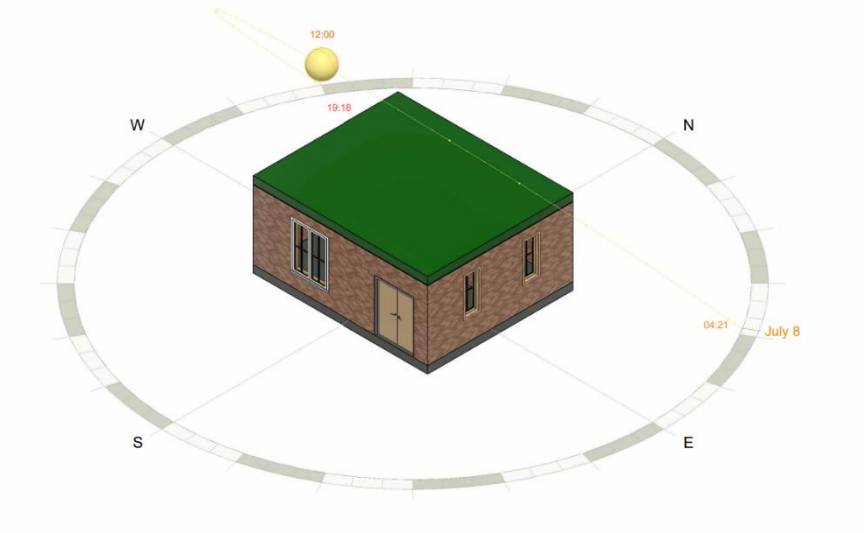

Figure4.1 The sample building from Autodesk Revit

The residential building which is found in Kirkuk, Iraq. It is designed and set up with the energy analysis calculation aligning with the design specifications as:

In the winter season as outdoors temperature: 0°C

In the summer the outdoors the dry bulb temperature is taken as 43°C and a wet bulb temperature of 24°C, as the daily temperature change is around 15°C.

Kirkuk Latitude: 35.47° N

Kirkuk Longitude: 44.39° E

Kirkuk's height above Sea level: 350m high

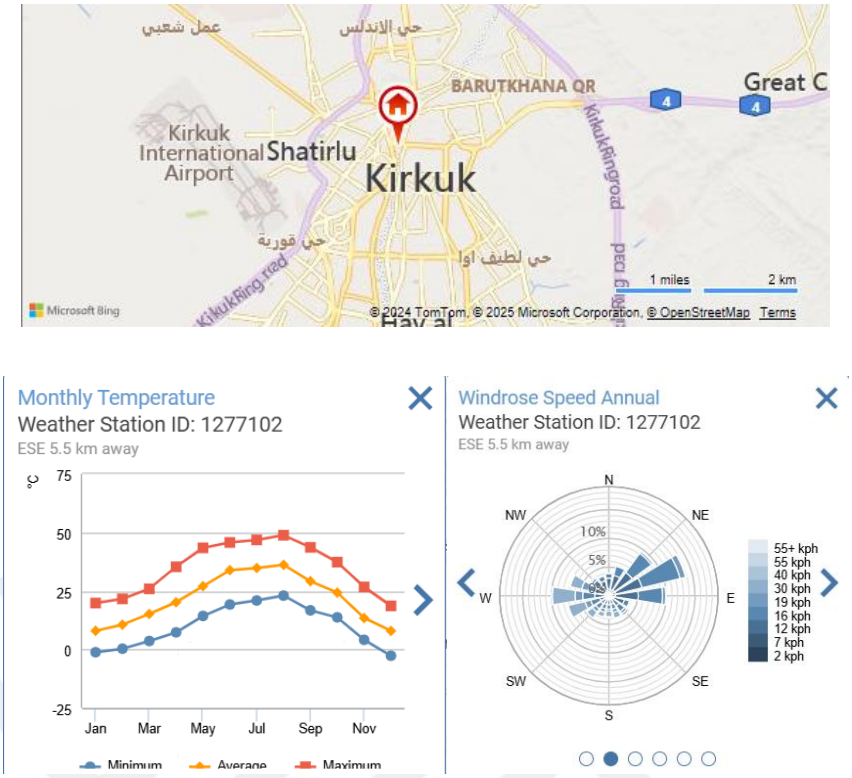

Figure 4.2 The residential building's location and climatic conditions in Kirkuk, Iraq

Indoor temperatures are kept at approximately 22°C in winter and around 30°C in summer, with the analysis conducted based on these set conditions.

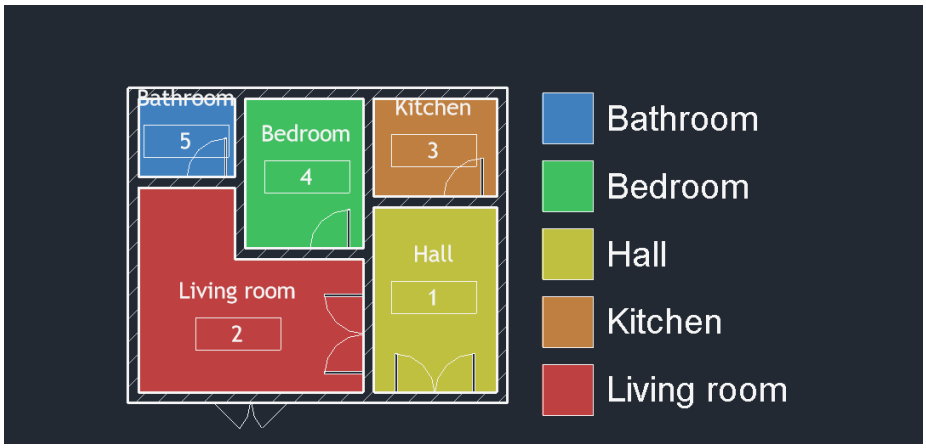

Figure 4.3 Rooms distribution of the residential building

In line with the 2019 ASHRAE Fundamentals Handbook, occupant heat gains are estimated at 80 W of sensible heat and 60 W of latent heat per person. For lighting and

power loads, kitchens typically use 15 W/m² for lighting and 25 W/m² for equipment, whereas living areas often have 10 W/m² for lighting and 15 W/m² for equipment. These values serve as a guide for calculating space heat gains in buildings located in Kirkuk, Iraq.

Table 4.3 Room Dimensions for 100m² House

Room	Dimension (m²)
Living Room	30
Hall	15
Bedroom	20
Kitchen	15
Bathroom	10
Total	100

CHAPTER 5

RESULTS

The sample residential building's energy use intensity (EUI) is 421 kWh/m² per year as shown in the following Fig. 5.1.

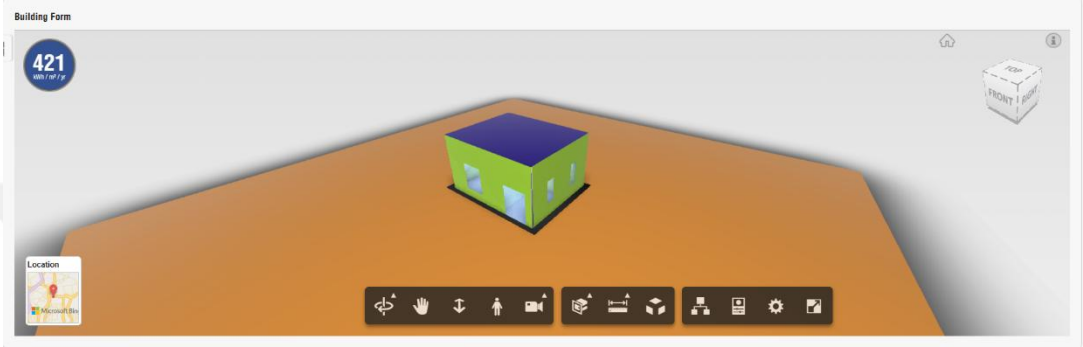

Figure 5.1 Illustration of EUI for the residential building

Based on the given information with ASHRAE 90.1, we can conclude that the energy use intensity (EUI) for the sample residential building should not exceed 320 kWh/m² per year, as illustrated in Fig. 5.2. However, the sample results reveal that the design conditions fail to comply with the ASHRAE 90.1 standards.

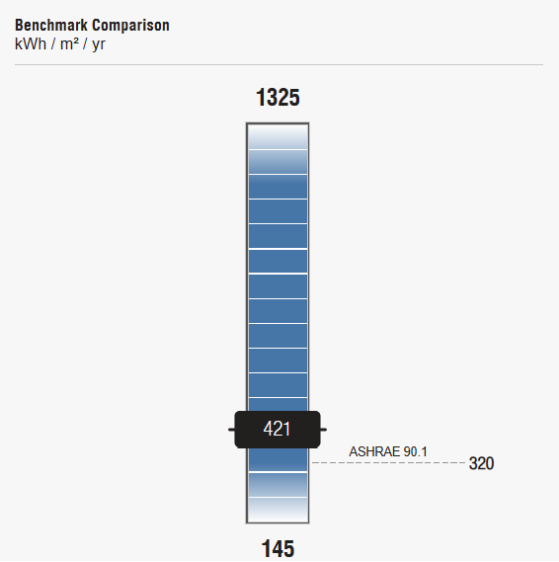

Figure 5.2 ASHRAE 90.1 comparison for the building

5.1 Improvements to the Building Under Various Scenarios

To lower the energy use intensity (EUI) and in order to make the sample residential building in Kirkuk achieve a nearly zero-energy level, various scenarios need to be implemented. In this case, we explored energy-efficient strategies including adjustments to the window-to-wall ratio, incorporation of window shades, selection of high performance window glass, optimization of building construction, reduction of infiltration, enhancements in lighting and power efficiency, improvements in the HVAC system, and the integration of renewable energy solutions through the installation of photovoltaic (PV) panels. As displayed in several charts in the upcoming sections, as the vertical axis per chart represents changes in energy use intensity and the horizontal axis shows the options for improvement and the highlighted selection shows the chosen criteria to best improve the system.

5.1.1 Building orientation and windows adjustments

The energy use intensity (EUI) of buildings is influenced by various factors, with building orientation being a key parameter. Orientation plays a crucial role in solar heat gains and losses, heavily influenced by wind direction. To optimize energy efficiency, we opted for windows being strategically designed by adjusting the window to wall ratio and modifying shading configurations. Enhancements may include upgrading to high performance glazing or incorporating external shading as well as elements that blend with the architectural design.

The initial energy use intensity (EUI) being 421 kWh/m² per year. Following the building orientation adjustment scenario, the EUI reduced to 416 kWh/m² per year. However, after implementing window glass adjustments, the EUI dropped further to 328 kWh/m² per year.

5.1.2 Adjustments to construction of the building

Insulation within any building always plays a significant role in determining energy use intensity (EUI). which influences heat transfer values from for example the roof, external walls, floor, as well as infiltration.

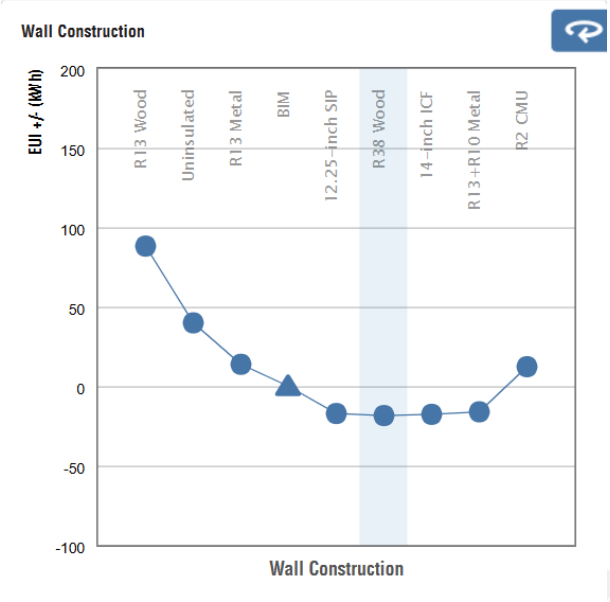

Figure 5.3 The used wall construction materials effect on the EUI

R38 wood material was selected with U value which is 0.16 W/m².K leading to a reduction of 18.4 kWh/m² per year in the energy use intensity (EUI) from the initial value, as shown in Figure 5-3.

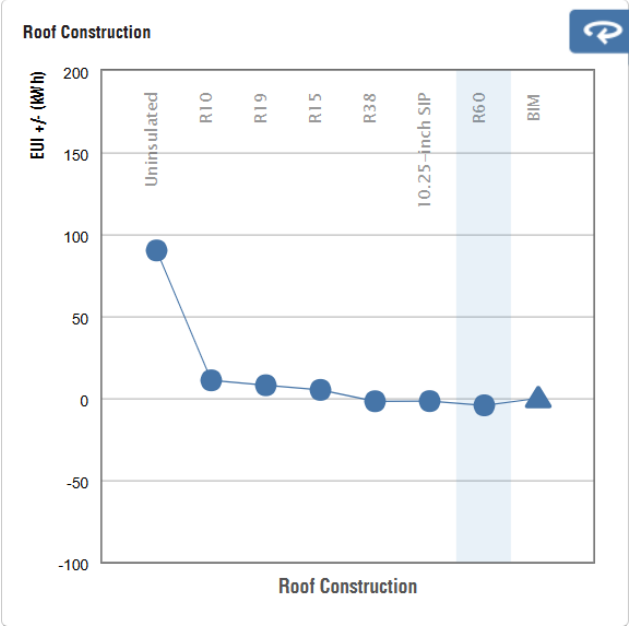

Figure 5.4 The used roof construction materials effect on EUI

The R60 material, with a U-value of 0.10 W/m²·K, was selected to further reduce the energy use intensity (EUI), as shown in Figure 5-4. Following this scenario, the EUI decreased from 328 kWh/m² per year to 287 kWh/m² per year.

5.1.3 Adjustments of lighting and power

The design criteria set for the lighting load is at 10-15 W/m² and the power load at 15-25 W/m². and so to meet net zero energy requirements, these loads must be made more efficient. As shown in the following figure below, the lighting and power load per area values have undergone optimization for improved efficiency in the sample residential building.

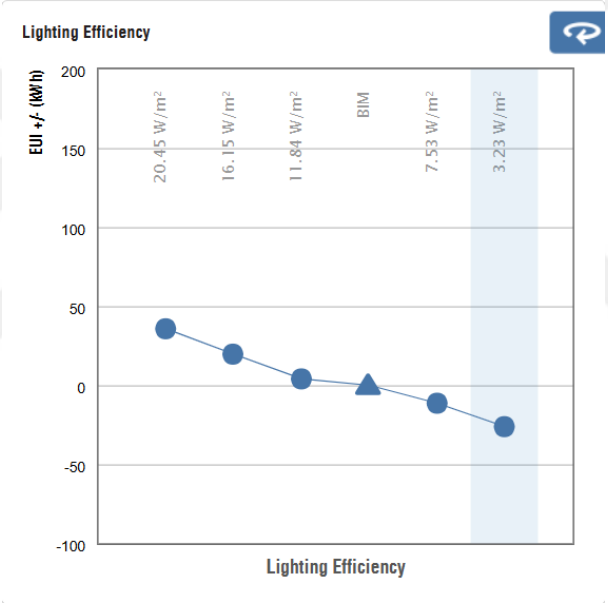

Figure 5.5 Lighting Efficiency

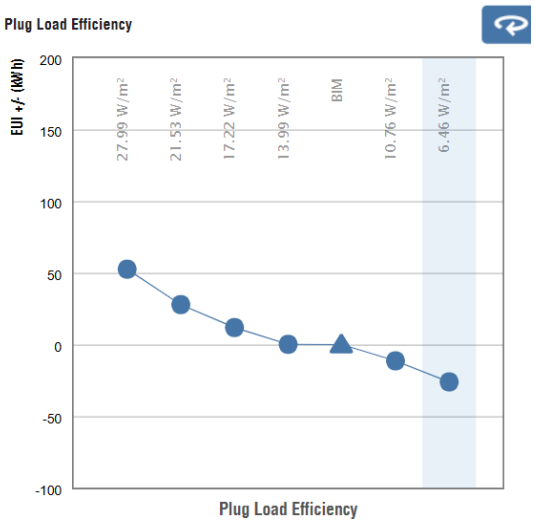

Figure 5.6 Plug load efficiency

Through the optimization of lighting and power load per area, the energy use intensity (EUI) decreased from 287 kWh/m² per year to 226 kWh/m² per year.

5.1.4 HVAC System

The HVAC system is critical for heating, cooling, and ventilation. In the initial design, a split air conditioner system was selected. But to further improve the energy consumption the ASHRAE package terminal heat pump was chosen to increase the energy efficiency, as shown in the following Figure 5-7.

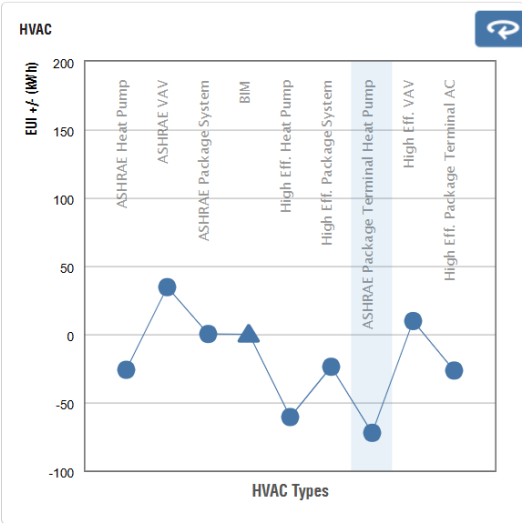

Figure 5.7 Optimal HVAC Types and their effect

As we can notice after implementing these adjustments, the energy use intensity (EUI) gets reduced from 226 kWh/m² per year to 185 kWh/m² per year.

5.1.5 PV System

To determine the size and capacity of the photovoltaic (PV) system that we chose to be installed, we used the surface coverage and cost graph that is shown in the of Figure 5-8. As a 90% coverage ratio was chosen, making use of nearly the entire roof area for installing the PV panels as well as setting it at the optimal annual slope for the city of Kirkuk's location. Additionally, the PV panels have an efficiency of 20.4%.

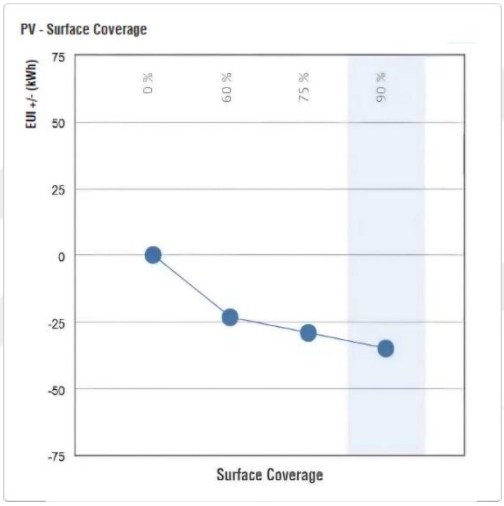

Figure 5.8 Relationship Between Surface Coverage Ratio and Cost for the PV System

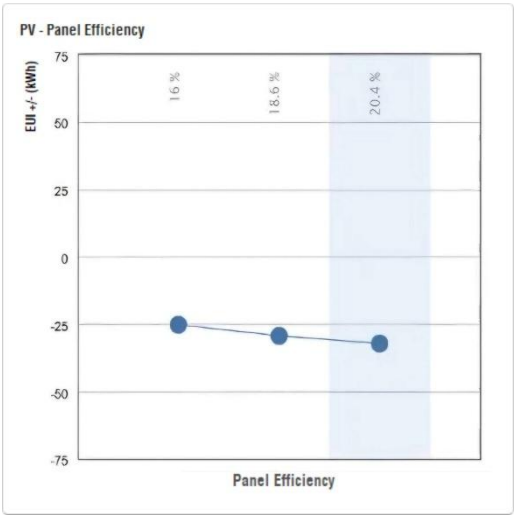

Figure 5.9 Efficiency of the Photovoltaic panels

After implementing this scenario, the energy use intensity (EUI) decreased from 185 kWh/m² per year to 145 kWh/m² per year.

5.1.5 Evaluation of every strategy

The following Figure 5-10 below illustrates the impact and effects of the implementation of each and every one of these strategies on the sample residential building's energy efficiency.

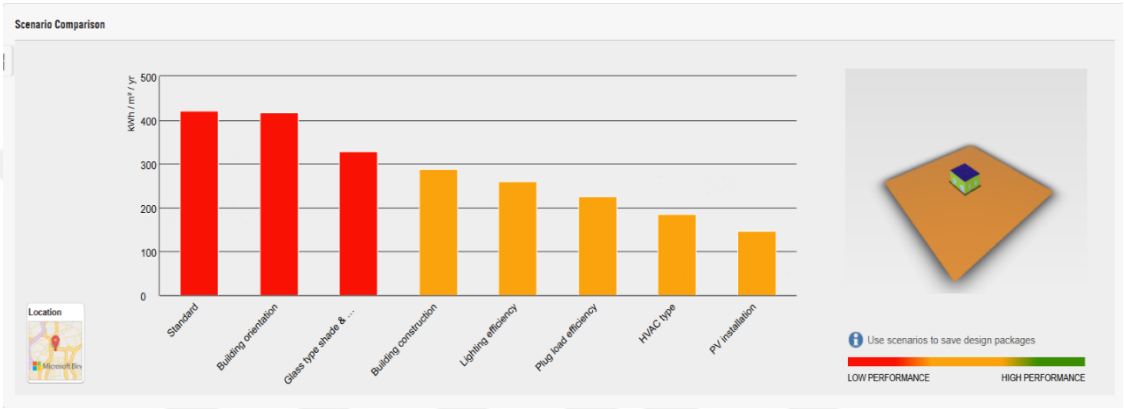

Figure 5.10 Evaluation of each strategy

As a result of implementing these scenarios, the energy use intensity (EUI) was originally at 421 kWh/m² per year and was strategically lowered to as low as 145 kWh/m² per year, as shown in Figure 5-12. This represents a 65.56% reduction in the EUI, leading to direct decreases in operational costs as well as CO2 emission rates into the environment. These outcomes demonstrate that the solutions applied are effective steps toward achieving a nearly zero-energy building (nZEB) design.

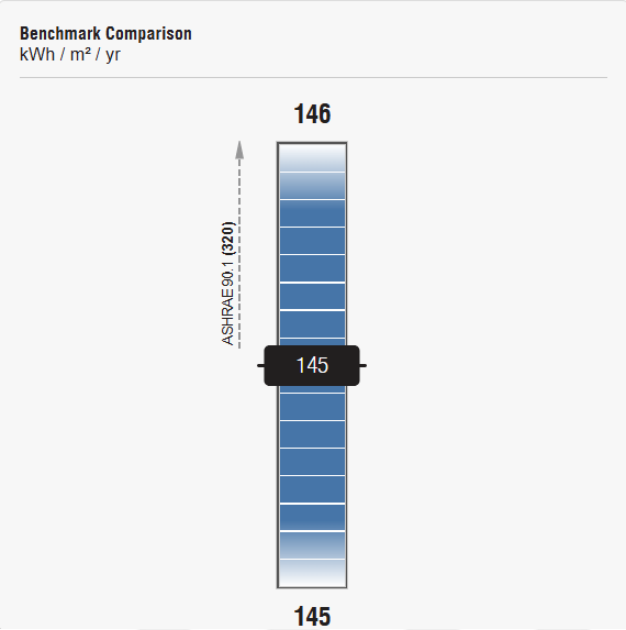

Figure 5.11 ASHRAE 90.1 comparison after the proposed solutions are implemented.

5.2 Monthly EUI Comparison

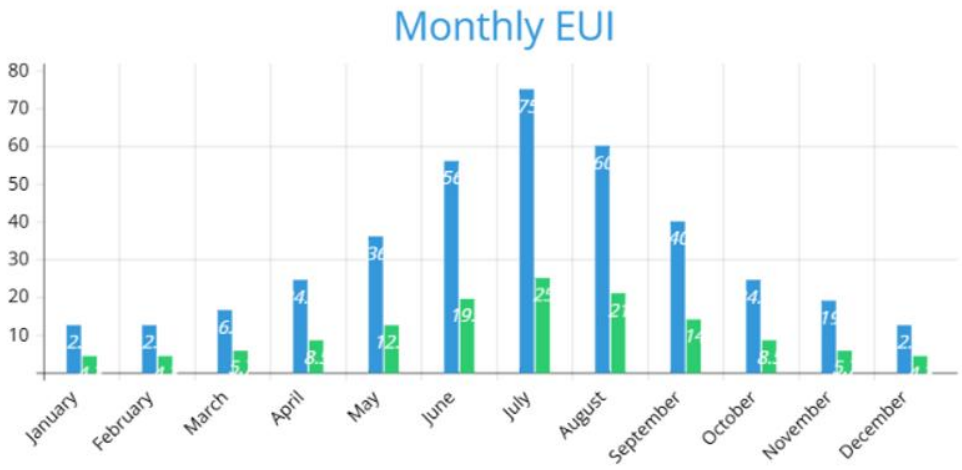

Figure 5.12 EUI per month before and after improvements

As we can notice in this chart as it compares monthly energy use intensity (EUI) for the sample residential building in Kirkuk, Iraq, before and after implementing energy efficient improvements. The data shows significant reductions across all months, with

total annual EUI dropping by 65.6% (from 421 to 145 kWh/m²). As the largest savings occurred during the July and August months, where extreme summer heat historically drove high cooling demands. Upgrades like improved insulation, high-efficiency HVAC systems, and solar panels reduced July's EUI by 67% from a significant 75 kWh/m² to a more reasonable 25 kWh/m² and August's by 65% also from a similar 60 kWh/m² to 21 kWh/m². Even mildly colder months like January saw quite the improvements (66% reduction), highlighting the year-round impact of airtight construction and renewable energy integration. The results emphasize how strategic improvements particularly those targeting cooling loads in arid climates, can achieve dramatic energy savings while maintaining good comfort levels. This study demonstrates the viability of near-zero energy building strategies in regions with harsh climates like Kirkuk.

5.3 Economic Factor

In our analysis of the sample building, we have not only focused on reducing energy use intensity (EUI) but also on the economic implications of these improvements. The initial EUI was 421 kWh/m² per year, leading to significant operational costs. With the implementation of various energy-efficient strategies, the EUI was reduced to 145 kWh/m² per year. Considering the cost is 0.015USD per kWh For residential buildings in March 2024 [74].

An initial calculation estimated the building's energy consumption expenses at 4.7 USD per square meter annually. Multiple energy efficiency measures led to cutting the building's energy cost to 1.5 USD per square meter per year. The building achieved sustainable performance through a series of incremental energy improvements that each focused on certain aspects of energy consumption, Orientation of the building towards maximum solar gain and wind exposure during the initial upgrade reduced annual energy costs per square meter from 4.7 USD to 3.6 USD. By optimizing the building's orientation the structure required less artificial heating and cooling which led to significant reductions in overall energy usage. then, The installation of improved window glass and adjustment of the window to wall ratio reduced annual costs from 3.6 USD to 3.5 USD per square meter. The upgraded window glass material enhanced

insulation properties to limit window heat transfer and lowered energy requirements for maintaining interior temperatures. As well as Increasing the building's insulation led to further cost reductions. The cost of energy per square meter per year decreased from 3.5 USD to 3.3 USD because enhanced insulation in walls and roofs reduced energy consumption for heating and cooling. The substantial enhancement involved optimizing lighting systems alongside power consumption. And quite significantly the shift to energy efficient lighting systems and more efficient appliances resulted in a decrease in energy costs from 3.3 USD to 2.1 USD per square meter annually. This initiative significantly decreased electrical usage which led to reduced operational costs without compromising the building occupants access to sufficient lighting and overall power.

A subsequent change involved upgrading the HVAC system to a more efficient ASHRAE package terminal heat pump. This refinement brought the cost down even further from 2.1 USD to 1.9 USD per square meter per year by delivering a similar quality level of heating, cooling, and ventilation with lower energy demand.

Finally, the installation of photovoltaic (PV) panels helped decrease reliance on external energy sources, reducing the building’s energy cost from 1.9 USD to 1.5 USD per square meter per year. Generating renewable energy on site not only cut costs but also aligned the building with sustainability objectives, as illustrated in Figure 5-13.

Overall, these phased improvements ranging from orientation adjustments and better insulation to upgrades in lighting, HVAC, and on site renewable energy resulted in a noticeable decrease in the building’s annual energy cost, taking it from 4.7 USD all the way down to 1.5 USD per square meter per year.

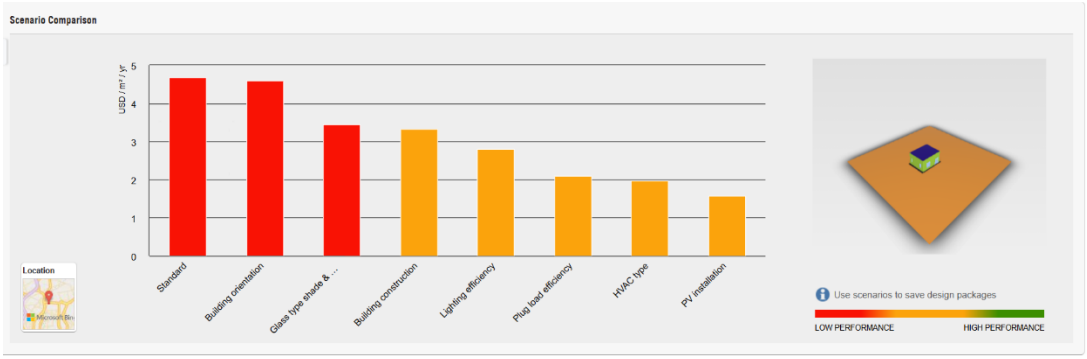

Figure 5.13 Economic comparison

As for the payback periods, when we look at the economic part of the improvements, the building's energy cost went from 4.7 USD per square meter per year to 1.5 USD, so that's a saving of about 3.2 USD per square meter every year. This is a big drop, and it shows that the changes worked well. Even though the total upfront investment cost wasn't exactly calculated due to price discrepancies in Iraq, based on similar studies and typical prices, it's estimated to be around 25 to 30 USD per square meter. If we take that as a number, then the payback period would be between 8 and 9 years. That means after that time, the savings will basically cover the cost of the improvements. Also, this result matches what other studies have found in hot, dry places many of them say the payback for nZEB homes is usually somewhere between 7 to 10 years. So, these upgrades are not just good for saving energy, but they're also smart economically in the long run [79].

$$\text{Payback Period} = \frac{\text{Cost of Investment}}{\text{Average Annual Cash Flow}}$$

Figure 5.14 Formula used for calculating the simple payback period.

CHAPTER 6

CONCLUSION

The primary energy consumption of a building is directly tied to the depletion of fossil fuels and the rise in CO_2 emissions. While renewable energy solutions, such as photovoltaic (PV) systems, are effective at reducing emissions, their high costs often make them less financially viable compared to energy efficiency measures that provide similar environmental benefits. In this study, high-efficiency PV panels (20.4%) were integrated, covering 90% of the roof's surface, but the analysis also emphasized the critical need for energy efficiency improvements to achieve sustainability goals.

Initially, the building's energy use intensity (EUI) was recorded at 421 kWh/m² per year, which exceeds the ASHRAE 90.1 benchmark of 320 kWh/m² per year. By implementing a comprehensive set of strategies including optimizing the window to wall ratio, enhancing insulation, upgrading the HVAC system, and incorporating PV panels the EUI was successfully reduced to 145 kWh/m² per year. This marked reduction not only meets nearly zero-energy building standards but also delivers substantial benefits in terms of lower operational costs as the initial cost of the building's energy use was 4.7 USD per m² per year and got reduced to 1.5USD per m² per year as well as reduced carbon emissions.

The findings highlight the importance of a holistic approach to building design and renovation, where the integration of energy efficiency measures and renewable energy technologies provides both economic and environmental advantages.

The analyses carried out in this thesis were conducted in accordance with the established standards and assumptions outlined within its scope. However, these results may not fully represent actual operating conditions due to the inherent limitations of modeling and simulation environments. To ensure further reliability and accuracy of the findings, it is necessary to validate the results through the use of alternative software tools other than Autodesk Revit and Insight, not only that but also the practical testing under real world conditions should also be conducted to confirm

the outcomes and address any discrepancies that may arise between theoretical predictions of the simulation and real time performance.

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