REPUBLIC OF TÜRKİYE

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Mechanical Engineering

EMPLOYING INNOVATIVE ENERGY-SAVING AND OPTIMIZATION TECHNIQUES FOR A ZERO -ENERGY CONSUMPTION BUILDING

Baraa Mwafaq Ayesh AYESH

Master's Thesis

Supervisor

Asst. Prof. Dr. Yaser ALAIWI

Istanbul, 2023

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The thesis titled EMPLOYING INNOVATIVE ENERGY-SAVING AND OPTIMIZATION TECHNIQUES FOR A ZERO-ENERGY CONSUMPTION BUILDING prepared by BARAA MWAFAQ AYESH AYESH and submitted on 08/08/2023 has been **accepted unanimously** for the degree of Master of Science in Mechanical Engineering.

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I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Baraa Mwafaq Ayesh AYESH

Signature

DEDICATION

I would like to dedicate my work on energy-efficient buildings and energy-saving methods in facilities to my great father, who offered me much support and energy to carry out this thesis. Further, I dedicate my research to my beloved mother. My mother provided much love and care to complete my work and reach this stage. On the other hand, I would like to dedicate this study to my supervisor, who supported me through his valuable time and advice, helping me achieve my research outputs. Moreover, I dedicate this study to the academic staff for their vital tips and beneficial consultation to improve the findings of my thesis. Without their helpful knowledge and experience, I could not attain high-quality outcomes of this work.

ACKNOWLEDGEMENT

I would like to thank Allah for providing me with the perseverance and strength to complete my Master of Science. I would also like to thank the Mechanical Engineering Department and the doctors who helped me develop the skills and knowledge I needed to write and defend my thesis. I would also like to thank my supervisor, Asst. Prof. Dr. Yaser ALAIWI, from the bottom of my heart, without his guidance, encouragement, and patience, I would never have finished this project. I am hoping that after reading this thesis, my adviser will have a great sense of accomplishment. In addition, I appreciate everyone on the review board for their insightful comments and for standing up for my paper. Also, I want to express my gratitude to every faculty member and staff member of Altinbas University for their unwavering support.

ABSTRACT

EMPLOYING INNOVATIVE ENERGY-SAVING AND OPTIMIZATION TECHNIQUES FOR A ZERO-ENERGY CONSUMPTION

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Date: 08/2023
Pages: 65

This master's thesis was guided to determine the critical contributions and essential benefits of various energy-saving strategies and optimization approaches to help achieve zero-energy consumption facilities that are more sustainable and energy-efficient. To accomplish this goal, the energy performance, profitability analysis, and thermal behavior were assessed and evaluated for a building in Turkey investigated as a case study. Extensive simulations and comparative explorations were carried out via the Python software package. Based on the mathematical simulations and numerical modeling research, it was found that using innovative insulating materials, passive cooling and heating techniques, and advanced energy-efficiency strategies could help improve the Turkish residential building's energy performance in terms of energy efficiency, occupants' comfort, and cost-effectiveness. Furthermore, the results revealed that the Turkish facility's thermal behavior was significantly fostered by the employment of those active energy-saving methods. Besides, relative humidity, interior temperature, cooling and heating loads, and the overall annual energy consumption linked to cooling and heating loads, were alleviated and effectively minimized, fulfilling promoted economic feasibility. According to these findings, this master's research offers valuable advice for different building designers and engineers to help attain boosted energy efficiency in residential buildings.

Keywords: Energy-saving, Optimization, Zero-Energy, Consumption, Construction, Thermal Insulation, Modern Materials.

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ABBREVIATIONS

ANNs	:	Artificial Neural Networks
BIPV	:	Building Integrated Photovoltaic
CLF	:	Cooling Load Factor
CLTD	:	Cooling Load Temperature Difference
EPBD	:	Energy Performance of Buildings Directive
ESR	:	Energy Saving Ratio
EUI	:	Energy Use Intensity
GHGs	:	Greenhouse Gases
HVAC	:	Heating, Ventilation, and Air Conditioning
NCACC	:	Natural Convection Air-Cooled Condenser
NNZEB	:	Nearly Net Zero Energy Building
NSA	:	Numerical Simulation Analysis
NZEBs	:	Nearly-Zero Energy Buildings
PCMs	:	Phase Change Materials
PEE	:	Primary Energy of Electricity
PENG	:	Primary Energy of Natural Gas
PV	:	Photovoltaic
RE	:	Renewable Energy
SC	:	Shading Coefficient
SHGF-Max	:	The Maximum Solar Heat Gain Factor
TPE	:	Total Primary Energy
ZEBs	:	Zero Energy Buildings

1. INTRODUCTION

1.1 RESEARCH BACKGROUND

Around the world, there has been a significant increase in the use of sophisticated mechanisms and creative strategies for energy conservation, such as (A) passive lighting techniques (such as light shelves, mirrors, light tubes, transparent doors, skylights, and employment of reflective surfaces and light colors in roofs, ceilings, and walls) [1]–[8], (B) thermal losses mitigation techniques (such as double and triple-pane windows, thermal insulation material), and (C) lighting controls. [9]–[11] Using smart Renewable Energy (RE) generating techniques in houses, such as the Photovoltaic (PV) systems illustrated in Figure 2, geothermal heat pumps illustrated in Figure 3, as well as solar collectors (such as SECTs [12]–[14] or a straightforward flat plate). It's also important to note that the creation of new materials (such as Phase Change Materials (PCMs) [15]–[18], smart materials, nanoparticles, graphene, advanced composites, and other technologies) has led to a sharp decline in the price and budget associated with using those new techniques. These innovative materials can rely on clever, affordable, and energy-efficient principles to provide cost-effective, profitable, energy-feasible, longer lifespans, and significant resistance to mold, humidity issues, fire, and heat transfer [19]–[22]. Examples of such concepts include a texture with a high degree of porosity and the use of silver and white for their superior heat and radiation reflection. The development of unique, useful materials that consider environmental sustainability and alternative manufacturing methods that may rely on the recycling, reuse, recovery, and reduction (4R) principles has also received significant attention from academics in recent years [23], [24].

According to [25]–[30], those unique materials include bio-based materials, environmentally friendly compounds, and nature-derived polymers that are significant to give some positive attributes and critical contributions to the environment :

a. Reducing pollution,
b. Minimizing waste of used materials and ended-lifespan substances thrown in land and sea, contributing to negative influences of wildlife and marine creatures,
c. Saving colossal mass and amount of metals and other materials that cannot be easily recycled or recovered, or renewed in future.

d. Treating some very long lifespan materials (like plastics) that may not be degraded or decay unless the prolonged period of years is exceeded. Examples of those active techniques include the utilization of microplastics, nano-plastics, biomaterials in construction and biodiesel for heat production.

The use of excellent vegetation and trees for shade, such as egg crates, vertical and horizontal louvers, and overhangs, as well as clever architectural design and an adequate building envelope, may also reduce significant cooling and heating loads required in different seasons [31]–[36]. Additionally, the so-called energy auditing approach, which is effective at reducing energy usage in many small and large-scale facilities, was notably used to reduce the high electricity bills in houses, factories, hotels, and industrial buildings [37]–[48]. In this method, mechanical, electrical, and architectural engineers can conduct a thorough examination of the structure, looking for and identifying various mechanisms and workable solutions to get rid of extraneous cooling or heating in the structure and provide passive energy and RE generation methods without compromising occupant comfort. This practical method might assist owners achieve more sustainability and economic viability over the long run while saving significant amounts of money that would otherwise be spent on a monthly or annual basis.

Figure 1.1: Examples of Common and Practical Insulation Materials Employed in the Market: (a) Rock Wool, (b) Fiberglass, (c) Polyethene Rolls, and (d) Cellulose Insulation Materials [49]–[52].

Figure 1.2: Using Modern PV On-Grid Systems to Cover the Electrical Demand of the Whole Home [53].

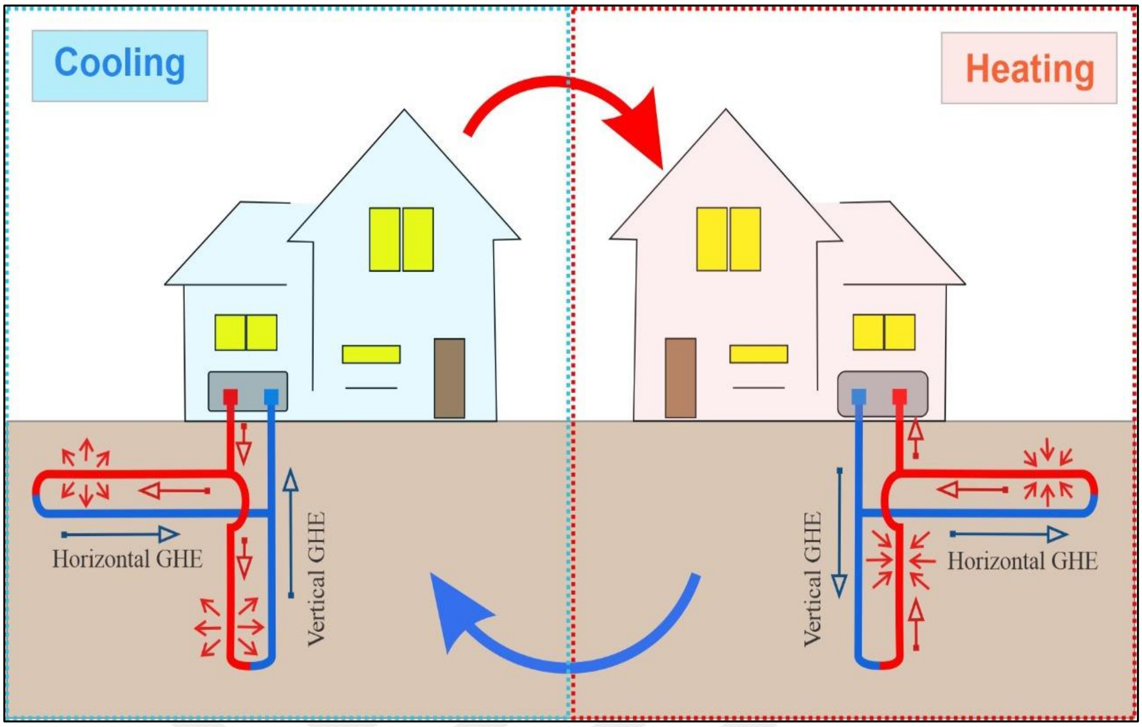

Figure 1.3: Geothermal Heat Pump to Cover the Heating and Cooling Loads in Homes [54].

1.2 PROBLEM STATEMENT

Over the last decades, the construction industry witnessed the implementation, development, design, and evolution of various state-of-the-art approaches and intelligent techniques characterized by their significant energy efficiency, beneficial mechanical properties, and valuable thermal effectiveness, helping mitigate the considerable demand for cooling and heating loads during summer and winter, respectively, alleviate the extensive dependence on electrical power (that relies on fossil fuels for generation), reduce Greenhouse Gas Emissions (GHGs), and minimize different adverse impacts of conventional construction materials and obsolete methods of energy provision for dwellers in various commercial and residential buildings that may influence the environment and result in harmful effects on nature [55]–[58]. It is highly advised and popular in Turkey to use these efficient energy consumption mitigation techniques in homes and other facilities to help owners save major budgets and expenses incurred for cooling, heating, and other thermal functions. The Zero-Energy Consumption Building (ZECB) is another smart and sensible idea that has lately been widely accepted by several experienced engineers and facility owners across the world [59].

This notation shows that the entire facility could rely entirely on energy-efficient heating, cooling, hot water, and other requirements based on solar energy, wind energy, passive cooling and heating techniques, and practicable insulation materials to reduce any type of energy losses or waste during the day and night. This research will be directed to examine and categorize the significant contributions and positive impacts of using this novel concept for a case study representing a building in Turkey, illuminating potential energy consumption optimization methods and thermal losses alleviation strategies to help the building approach a ZECB. Numerical Simulation Analysis (NSA) will be adopted in this research via the MATLAB® software package to achieve the goal of this study, assessing the thermal comfort, thermal loss elements, and factors that influence the degrees of emissions and energy consumption in this building.

1.3 RESEARCH MAJOR AND MINOR OBJECTIVES

The goal of the research is to evaluate and analyze the crucial role that contemporary energy-saving methods and sustainable energy consumption strategies (such as the use of thermal insulation) play in reducing the need for cooling and heating as well as other thermal requirements in buildings for the best possible thermal comfort. Therefore, it is essential to develop a set of precise (small) goals that aid in ensuring the effective completion of this activity.

These secondary goals include the following elements:

a. To illuminate and examine novel processes and modern practices used to improve the facilities' energy performance and thermal comfort while taking steps to reduce energy use and electricity costs.

b. To draw attention to current innovations and key notations used to improve energy usage, with an emphasis on ZECB and numerical simulations of this issue.

c. To choose a case study that represents a building in Turkey and utilize an energy auditing method that identifies, determines, and employs cutting-edge and useful energy-saving techniques.

d. To carry out numerical simulations to assess and analyze this building in terms of GHG emissions, thermal comfort and effectiveness, and thermal losses with the help of the MATLAB® software tool.
e. To validate, verify, and modify the research findings depending on construction professionals and high-knowledge energy specialists and simulation experts.

1.4 RESEARCH QUESTIONS

Using the previously mentioned major and minor aims as a guide, the study questions may be divided into the following categories:

a. General Question: Could the employment of innovative insulation materials and recent energy efficiency strategies reduce the electrical bill and optimize the energy consumption of buildings?
b. Specific Questions:
    i. Would utilizing innovative passive lighting provide a sufficient illumination amount for zones in the building without depending on the electrical network?
    ii. Would using double or triple-pane windows offer adequate thermal stability and better thermal performance in the building?
    iii. Does using RE systems reduce the heavy electrical power demand of the building, maintaining optimum and appropriate thermal comfort?
    iv. Could using various passive lighting methods and alternative heating and cooling systems help accomplish a ZECB?
    v. Can the implementation of energy auditing techniques in the building optimize the thermal losses and save much amount of cooling and heating energy wasted in all seasons?
    vi. Do modern thermal insulation materials and finishing materials provide significant rates of sustainability and cost-effectiveness, taking into account the thermal comfort aspects for residents in the building?
    vii. Would the adoption of modern intelligent, and sustainable construction materials alleviate the GHG emissions, paying attention to the thermal performance fundamentals of the facility?

1.5 SIGNIFICANCE OF THE STUDY

The major contributions of this research consist of two main relevances. These critical significances are (i) Theoretical significance and (ii) Practical significance. More information about these three significances is provided in the paragraphs that follow.

1.5.1 Theoretical Significance

The theoretical importance of this work is demonstrated by shedding light on new materials used for various construction purposes, such as insulation, finishing, protection, decor, and thermal comfort. These materials are distinguished by their higher performance, more effectiveness in achieving better thermal stability, and cost-effectiveness in terms of their price compared to conventional and outdated materials. Additionally, this master's research aims to identify and categorize the crucial positive effects of those modern construction materials in lowering buildings' high electrical costs and energy requirements for cooling and heating in the summer and winter while maintaining the best possible thermal conditions for building occupants. It is important to note that there are just a few peer-reviewed studies and fewer current research publications that address the crucial importance of those contemporary, workable, and innovative materials in providing residents with the proper thermal needs. This remark was made for a reason connected to the fact that the worldwide market and the building industry make extensive use of many new material categories that have lately been created and manufactured. However, as the present literature lacks these numerical analysis features, there is a need to give further validation, verification, and confirmation of the key functions, crucial merits, and considerable qualities of those materials based on numerical analysis, modelling, and simulation work. This study is being done in an effort to fill all of those research gaps.

1.5.2 Practical Significance

Additionally, this study is being conducted to offer some useful insights to the mechanical engineering community, specialists in insulating materials, project managers, construction consultants, and thermal analysis engineers for the Turkish and international building industries. In order to provide better thermal comfort, significant cost-effectiveness, and a reduction in thermal losses to reduce the electrical bill and the heating and cooling energy requirements of the facility, this work will first offer a set of substantial guidelines and critical aspects for decision-makers in the construction sector. Chief mechanical engineers can use these guidelines to adopt and consider the employment of modern construction materials in various buildings and projects. Additionally, the numerical outcomes and simulation outputs that will be produced by the BEM approach will assist researchers and academics who are interested in assessing and evaluating the mechanical characteristics and thermal performance of modern construction materials that can be used for insulation, finishing, and other purposes while maintaining low installation and maintenance costs and resisting various issues over their lifespan, such as thermal losses, fire, and mold.

1.6 RESEARCH HYPOTHESIS

In order to improve the thermal stability and comfort of occupants in buildings, as well as to decrease thermal losses and enormous electricity bill budgets, high-thermal performance techniques and new sustainable tools are being investigated and evaluated in this study. The numerical analysis from this study will be used to confirm or refute the research hypothesis. The following sentences can present these theories:

a. Null Hypothesis, H_o – which considers that: "Buildings' electrical bills and energy consumption may still be not managed or optimized in case cutting-edge insulating materials and innovative energy efficiency approaches are applied."
b. Sub-Alternative Hypothesis, $H_{a,1}$ – which suggests that: "Utilizing innovative passive lighting provides a sufficient illumination amount for zones in the building without depending on the electrical network."
c. Sub-Alternative Hypothesis, $H_{a,2}$ – which assumes that: "Using double or triple-pane windows offers adequate thermal stability and better thermal performance in the building."
d. Sub-Alternative Hypothesis, $H_{a,3}$ – which considers that: "Implementing RE systems reduces the heavy electrical power demand of the building, maintaining optimum and appropriate thermal comfort."
e. Sub-Alternative Hypothesis, $H_{a,4}$ – which suggests that: "Utilizing

f. Sub-Alternative Hypothesis, $H_{a,5}$ – which suggests that: “Using various passive lighting methods and alternative heating and cooling systems help accomplish a ZECB.”

g. Sub-Alternative Hypothesis, $H_{a,6}$ – which suggests that: “The implementation of energy auditing techniques in the building optimizes the thermal losses and saves much amount of cooling and heating energy wasted in all seasons.”

h. Sub-Alternative Hypothesis, $H_{a,7}$ – which suggests that: “Modern insulation materials and finishing materials provide significant rates of sustainability and cost-effectiveness, taking into account the thermal comfort aspects for residents in the building.”

i. Sub-Alternative Hypothesis, $H_{a,8}$ – which suggests that: “The adoption of modern intelligent and sustainable construction materials alleviate the GHG emissions, paying attention to the thermal performance fundamentals of the facility.”

1.7 RESEARCH METHODOLOGY

The study process will begin with a thorough literature evaluation, which will discuss and identify significant contributions as well as the crucial importance of modern building materials and energy-saving techniques. Additionally, a thorough evaluation of the literature is necessary for categorizing important BEM tools and numerical modeling and simulation techniques in order to address and evaluate building thermal performance, heat stability, and thermal loss issues. Following this phase, a case study of a building in Turkey will be selected and analyzed. Then, the MATLAB® software package will be used to make accurate inspection and analysis associated with the thermal effectiveness and some critical thermal parameters of the building. Following this, the numerical findings and simulation results will be validated and verified in light of the opinions of mechanical engineers, building experts, and numerical thermal analysis consultants regarding the crucial elements and beneficial factors that should be considered for the best reduction of thermal losses and energy costs. The research approach is shown in Figure 1.4, which summarizes the study steps.

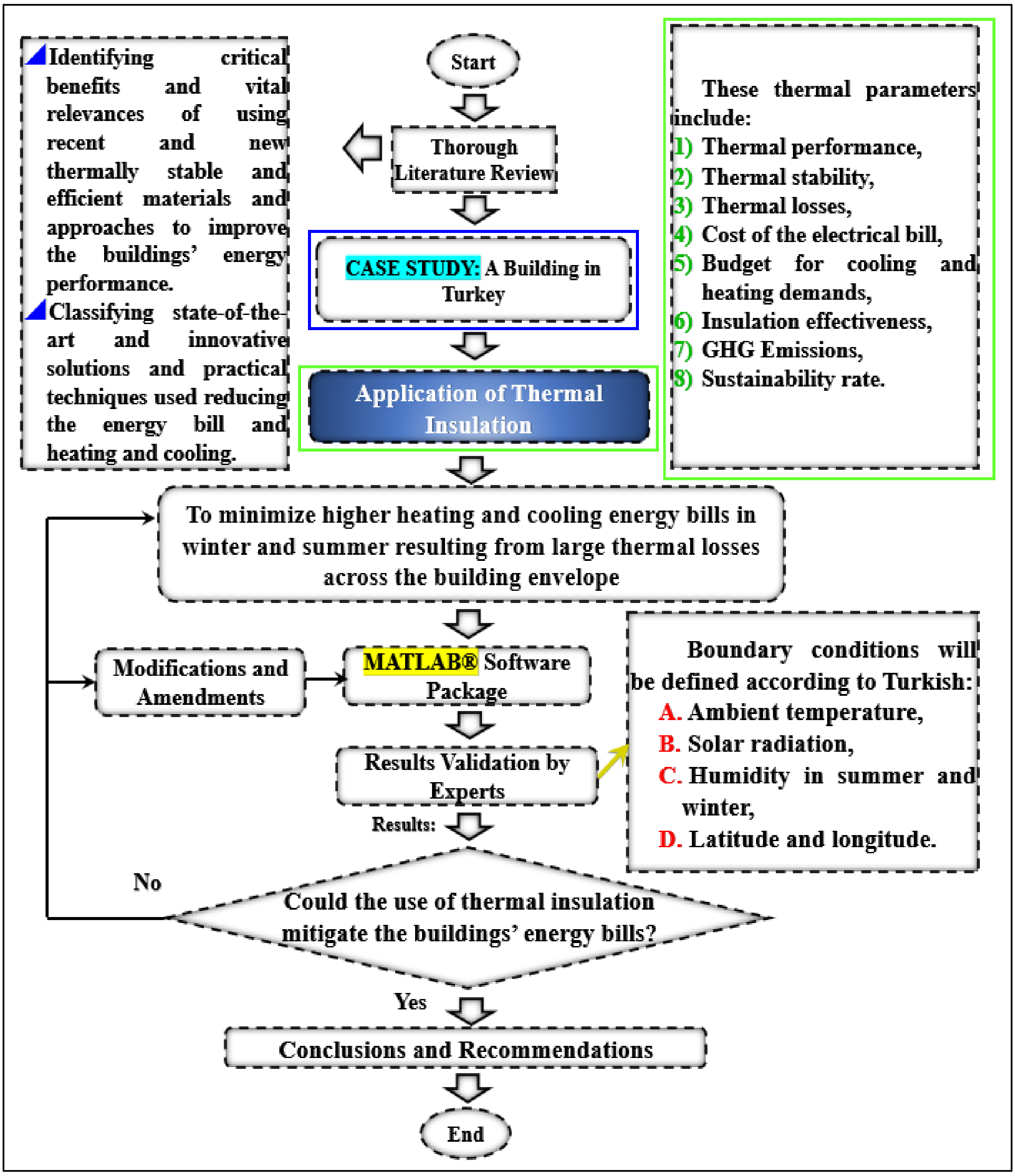

Figure 1.4: The Research Methodology Flowchart [59].

Last but not least, crucial conclusions and recommendations will be provided to help mechanical engineers, engineering consultants, numerical modeling and thermal analysis experts employ modern energy-saving approaches to avoid thermal losses or efficiency declines in diverse buildings.

2. LITERATURE REVIEW

2.1 INTRODUCTION

In order to make the building more energy-efficient, this chapter will highlight the key contributions and positive effects of cutting-edge energy-saving techniques and energy usage optimization strategies. By reducing the amount of electrical bills and cooling and heating requirements in the summer and winter, better economic feasibility and cost-effectiveness can be achieved.

2.2 BENEFICIAL IMPACTS OF IMPLEMENTING INNOVATIVE ENERGY-SAVING APPROACHES

Nearly Zero-energy residential structures have drawn a lot of interest because of their superior energy-saving potential. To achieve balance between energy demand and supply in residential constructions, RE usage was essential [60]. Their study optimized typical zero-energy public buildings in hot summer and cold winter settings using the concepts of passive priority, active optimization, and 100% RE supply guarantee. The significance of passive energy-saving techniques, such as heating, shading, and heat recovery; consideration of the conditions of local resources; analysis of building RE utilization systems, such as solar energy and air energy; and recommendation of the most cutting-edge building energy system. According to the simulation findings, if the criteria for zero-energy buildings are satisfied, the 8.9 kW building solar system could produce 36.4 kWh/m2 of electricity yearly, and the annual energy consumption index per unit area would be 37.6 kWh/m2.

Dissemination of education is crucial, especially in emerging countries like Turkey. It is also vital to promote understanding and make optimum use of energy resources. In order to achieve the aim of a zero-energy building, RE sources should be used when energy is in short supply [61]. Furthermore, the development of smart technology has the potential to lower the energy consumption of educational facilities. The authors said that their paper tried to examine RE sources to minimize energy consumption and achieve the goal of a building requiring nearly no energy by applying a variety of energy-efficient retrofitting scenarios. The retrofitting choices for a school building in Ankara, Turkey, were provided by a Building Energy Simulation Tool, Design Builder Software, and were based on RE sources. In order to construct an accurate model, monitoring educational institutions and calibrating the model were done. The installation of wind turbines, solar collectors, and PV panels to provide power was one of several energy-efficient retrofitting scenarios that followed.

Building electrification and energy efficiency would both be successfully increased by nearly-Zero Energy Buildings (NZEBs). [62] the scholars assessed the impact of NZEB standards to carbon emission targets in the metropolitan area of China by 2060 using a bottom-up mid- to long-term energy consumption model combined with a carbon emission model. Three scenarios—BAU, stable development (S1), and high-speed development (S2)—were established. By 2040, BAU's total carbon emissions would peak at 1.94 Gt CO_2. According to S1, by 2030, overall building carbon emissions would peak at 1.72 Gt CO_2. According to the S2 scenario, 1.64 Gt CO_2 would be the peak amount of carbon emissions by 2025. The carbon emission peak would be reached in 2030 if the S1 scenario was implemented, which included periodic improvements to building energy-efficiency regulations and conformity with NZEB market development. By 2060, upgrading building energy standards to NZEB would contribute 50.1% toward achieving carbon neutrality, while zero-carbon power would provide 49.9%. The study's findings supported the possibility of setting the mandatory enforcement years for NZEBs and ZEBs at 2025, 2030, and 2035, respectively.

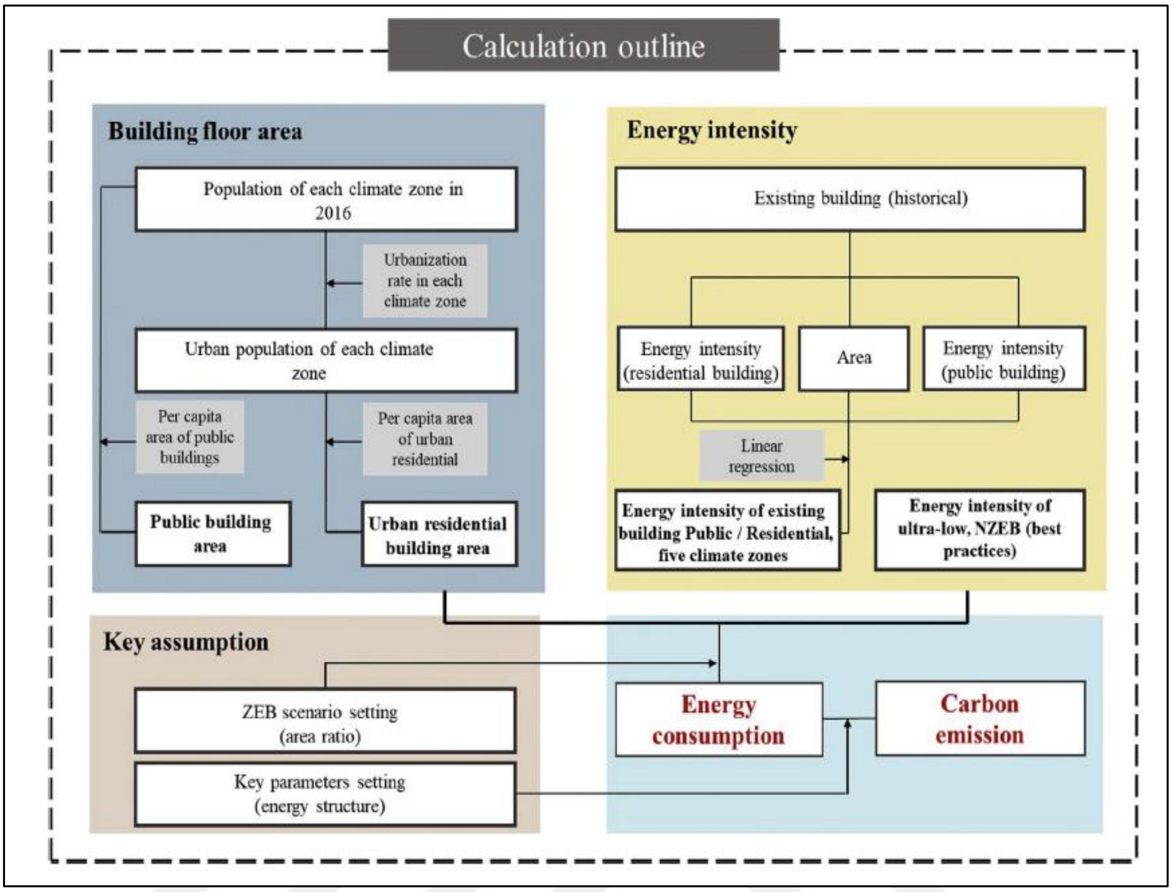

Figure 2.1: A Model for Calculating the Carbon Emissions and Energy Consumption of Urban Buildings Using NZEB [62].

Due to declining prices for photovoltaics (PV) and lithium-ion batteries, off-grid Zero Energy Buildings (ZEBs) were expanding rapidly. The bulk of academics have focused their writing on on-site, grid-connected ZEBs. Their literature review concentrated on off-grid ZEBs created in factories [63]. Currently, there are three challenges facing ZEB buildings: excessive investment costs, poor construction, and problems operating ZEB. Through the automated mass manufacture of continually improved, standardized modules, their study investigated solutions to such problems. A shipping container served as the modular unit, utilizing the existing transportation system. Due to the narrow width, there was a higher chance of utilising daylight than in traditional buildings. Off-grid ZEBs must be completed in real-world operation, including plug loads, by the user. The users' interest in RE was probably sparked by the local energy production. Plug loads were frequently ignored in ZEB criteria even though they were the biggest energy consumers in buildings. The conditions for exporting container structures to the important markets in Asia and

Africa were increasing as a result of the Belt and Road Initiative and governmental incentives to promote China's industrialized expansion.

In their study [64], the authors looked at how the functioning of a 2247 m2 residential structure in several coastal Anatolian sites is impacted by Building Integrated Photovoltaic (BIPV) technologies. We chose the lowest, highest, and average cities based on their solar heat gain. Hourly performances were calculated using the DOE's Energyplus tool, and the installed peak PV output was found to be 84.2 kW. The annual energy usage for heating and cooling at the three locations varied between 1.44 kWh/m2 and 9.12 kWh/m2 and 22.2 kWh/m2 and 56.9 kWh/m2, respectively, according to their preliminary findings. The demand for cooling was (as would be expected) far larger than the demand for heating in these Anatolian coastal locations. The results revealed that an 84.2 kWp PV could easily fulfill the maximum demand of 56.9 kWh/m2 for the three cities. Those early results might be managed within 20 kW of the indicated limitations depending on the solar cell type and the orientation of the building façade.

The experts said that their publication [65] outlined the methods for creating zero energy structures in new towns. To mimic that subject, two programs were used: TRNSYS 16.0 and Energy Plus. The building materials, window size, and window direction were all taken into consideration while constructing the building facade using the Energy Plus software simulation. On the other hand, TRNSYS 16.0 software has been used to research the design of zero energy buildings that use solar water heating systems and high efficiency heating systems under the new climatic circumstances of Binalood. The goal of their study was to examine several design philosophies and select the most effective one for house design and energy system decisions.

2.3 THE FUNCTIONAL MERITS AND ACTIVE USES OF OPTIMIZATION TECHNIQUES FOR A ZERO-ENERGY CONSUMPTION

There is still uncertainty over the updated building energy regulations in China's future development path. No research have looked at how Zero Energy Buildings (ZEBs) affect medium- to long-term building energy use [66]. By reviewing the development and enforcement of building energy codes in China over the last 30 years (1986-2016), as well as the analysis of energy consumption of ultra-low energy buildings and nearly-zero energy buildings (nearly-ZEB) demonstrators, the researchers reported that their study proposed a three-definition hierarchy of ultra-low energy buildings, nearly-zero energy buildings (nearly-ZEB), and ZEB as the successive building energy codes upgrading goals towards 2050. Six scenarios have been created, ranging from BAU to leapfrog scenarios, to examine the building energy usage from 2025 to 2050. The results showed that the peak of a building's energy usage decreases over time. In general, the ultra-low energy building, nearly-ZEB, and ZEB account for more than 50% of the total floor area before the building's energy consumption begins to fall. In the most likely scenario of moderate development, the peak would occur in 2035 with a total of 567 million tce. The overall amount of fossil fuels conserved up to 2050 might be reduced by up to 9380 million tce in the leapfrog scenario compared to the BAU scenario, which was what contributed most to climate change mitigation.

The improvement of building energy efficiency has been a cornerstone of energy policies [67]. The primary goal was to lower power usage in order to decrease the carbon imprint of dwellings. This objective was accomplished by lowering design criteria for component and raw material quality, as well as by using sustainable energy sources. These particulars formed the basis for the creation of zero-energy buildings (ZEB). The marketing and continued development of this novel technology have faced several obstacles. As a result, both the obstacles to the commercialization of zero energy buildings and their current state as a whole were evaluated and analyzed. A number of suggestions for new technologies that the sector may adopt to complement existing ones were also presented in the study. The investigation also investigated how the occupant's personality influenced zero energy constructions. Policies like tax exemptions and government subsidies were offered to encourage more investors into the sector. Last but not least, effective public education might help to dispel the myth that green buildings are more expensive than traditional ones.

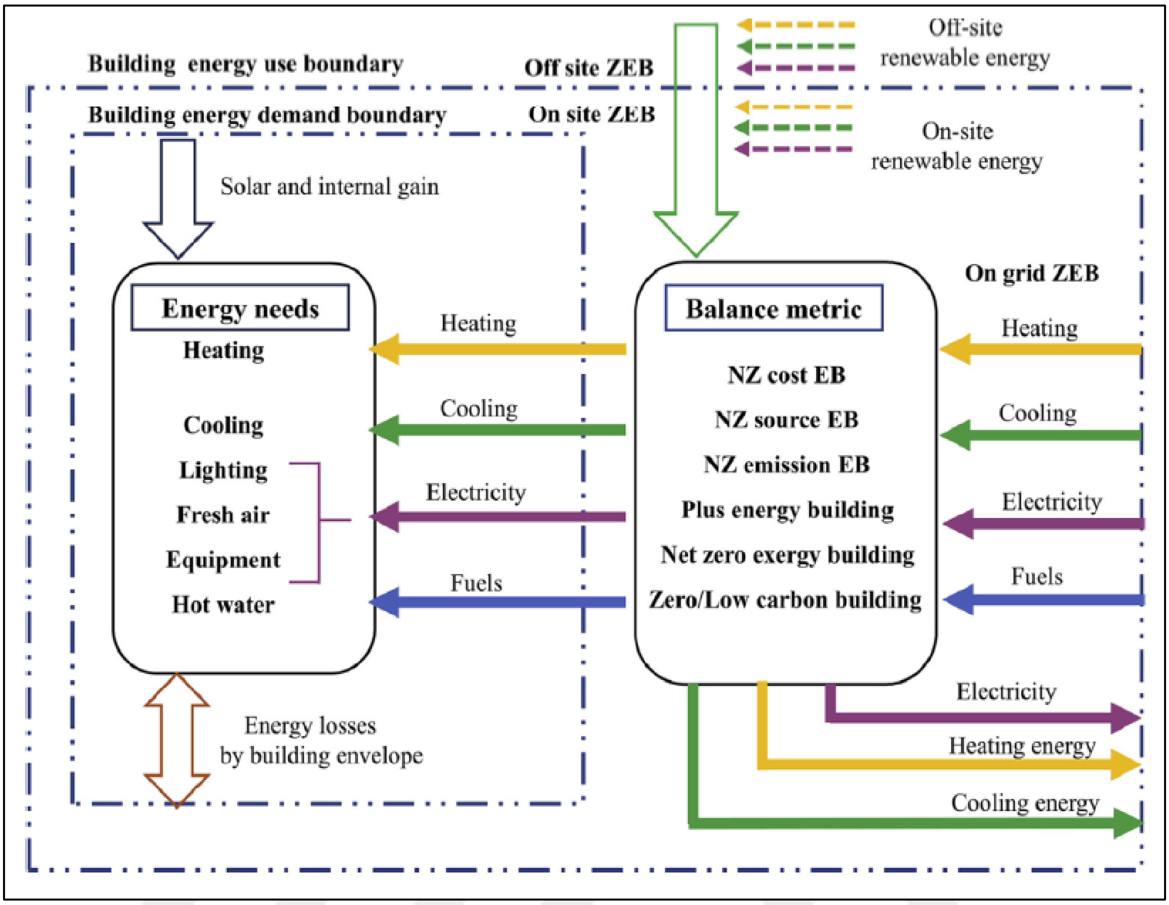

Figure 2.2: Specifications of the Appropriate Concepts' Boundaries [67].

By optimizing important factors with energy consumption as the control goal, the amount of heating and cooling needed for buildings might be decreased [68]. The forecasting of energy consumption for virtually Zero energy buildings (nZEBs) and the design optimization of performance parameter were the main topics of the authors' research, they stated. The optimal ratio of various performance attributes and the Energy Saving Ratio (ESR) was looked into using a sizable quantity of simulation data. Artificial Neural Networks (ANNs) were used to forecast yearly electrical energy usage in a building in Shenyang, China, that is almost entirely energy-free. The information on the energy consumption for our test was collected using tools for building simulation. The findings showed that the test almost zero energy building's heating energy demand was 17.42 KWh/(m^2a). The most obvious consideration was the Energy Saving Ratio of window-to-wall ratio optimization, which was followed by window thermal performance parameters and then insulation thickness. When employing an artificial neural network model to predict energy use, the maximum relative error for buildings was 6.46%. The development of that prediction approach made it possible for architects to quickly and precisely determine a building's energy usage during the design stage.

In order to lessen the demand for buildings in the retrofitting toward the nearly Zero Energy Building standard, a Mixed-Integer Linear Programming model for the design of the energy renovation of existing buildings was proposed in their paper [69]. This model takes into account both Energy Supply Systems and the adoption of Energy Saving Measures. The technique was used to an existing building in the northern Spanish city of Bilbao to determine the best design or one with a lower yearly net cost given different restrictions on the usage of principal non-RE. A straightforward mechanism was developed to distribute the specific demand drop caused by the energy saving measures in the reference days. The input for such demand decrease came from dynamic simulations that had already been verified. This simple approach that employs degree-days might be used to establish reference days by utilizing a base temperature based on an Energy Saving Measure. These reference days account for the weather, usage, and the relationship between the thermal characteristics and the distribution of demand. The optimization technique was used to produce designs for various restrictions, such as financial, spatial, etc., and to deliver the design selection and operation strategy for upgrading buildings to conform to various non-renewable primary energy consumption limits.

The investigation of zero-energy buildings included a wide variety of topics, however the conventional ideal method had limitations. On the physic and energy balancing boundaries of zero-energy buildings in various locations emphasized by various architectural attributions, more investigation and confirmation were required. The data showed that extra components and installation expenses required to be added to zero-energy buildings [70]. They undertook their research in response to buildings' rising energy usage, which resulted in the creation of a ground-breaking global multiple-criteria optimization approach for zero-energy buildings. They included a thorough review method to their concept. The model was optimized using the Grey numerous-Level Complete Evaluation technique, which took into account social and economic factors, the efficacy of solar energy implementation, and numerous optimization design approaches for RE structures. When it comes to energy optimal models and prices, this was done utilizing the Improved Red Fox Optimization Algorithm on the basic design. The global optimal model recommended the best course of action based on the selected choice. The engineer might construct useful buildings using the solution. In order to get the optimal design outcome, a multi-objective optimum framework for a case study based in Beijing, China, was suggested. They found that designers might apply the proposed approach to get at sensible conclusions. In the applications that were considered to be practical, their design was straightforward to use.

2.4 VARIOUS CASE STUDIES OF ENERGY-SAVING BUILDINGS IN TURKEY AND OTHER COUNTRIES

Around the world, buildings utilize a rising quantity of resources and energy. High-performance buildings, also known as near zero-energy structures, have recently incorporated energy-saving strategies into their design in response to rising standards of living, population increase, and global warming. This was particularly true for Egypt, where energy use has expanded at an unprecedented rate over the previous 10 years, particularly in the building industry, where the percentage of electricity consumed may vary from 66% to 74%. Therefore, it was logical for Egypt to decide to update its building construction code by demanding energy reduction. The researchers said that for a non-residential construction in Egypt, the effects of energy rationalization were looked at in their study. Using the Mechanical Engineering Department building on the Faculty of Engineering Campus of Ain Shams University as a case study, EnergyPlus was utilized to model a typical educational institution. Numerous retrofitting strategies and energy-saving methods have been compared and assessed (energy rationalization) in order to create the best building envelope with the least amount of energy needed. The retrofitting of the building walls significantly (>20%) increased energy savings. The energy consumption of the building was reduced by more than (>36%) by combining different building envelope retrofitting technologies. Additionally, employing energy-saving techniques by replacing the mechanical HVAC systems used to cool and heat the retrofitted building resulted in energy savings of over 50% and a reduction in system capacity of over 65%. The sample building with a yearly Energy Use Intensity (EUI) of 230 kWh/m2 was then converted into a nearly zero-energy building with an EUI of 106 kWh/m2 by sizing a solar PV system to satisfy these rationalized energy needs with a payback period of 4-5 years [71].

Nearly zero energy buildings (NZEB) have been successfully used as a climate change mitigation technique in the building sector [72]. By the end of 2020, China originally set a NZEB goal of 10 million m2. The NZEB floor area rose from practically nothing to 12 million m2 as a result of a series of incentive programs implemented at the provincial level. However, it was still uncertain how NZEB laws will affect buildings in the medium to long term or how they would affect the decrease of energy peaks. According to the authors, they gathered 47 current rules and looked at how they influenced how much energy buildings utilized. The total construction energy consumption of representative provinces in China's cold region from 2020 to 2050 was calculated using a policy-driven model with conservative, moderate, and aggressive scenarios. The findings show that compared to a conservative scenario, a moderate scenario with 100% NZEB market penetration in 2050 and a "30-30-30" mid-term objective by 2030 may cut energy demand by 13% by 2030 and by 60% by 2050. The pushing scenario suggests that the government should choose 2025, 2030, and 2035 as the enforcement years for ultra-low energy buildings, also known as NZEB and ZEB, in response to China's carbon emission target.

Residential structures accounted for 23% of Jordan's total energy demand, a significant component of the nation's overall energy usage. In Jordan, where it accounted for about 43% of all power use in 2016, it was the industry with the highest electricity usage. As a result, improving the energy efficiency of existing residences in Jordan was probably going to lead to decreased energy consumption (getting closer to net zero energy) and would be a strategy to reduce the nation's use of power [73]. A typical Irbid house type was selected as a case study for the near zero energy design and conserving energy aims. The authors' study examined the economic and computational potential of various integrated active and passive design systems for the Jordanian residential sector by focusing on a number of parameters, such as orientation, layout, type of insulation, type of windows, shading system, and type of ventilation system, which used a comprehensive and thorough model of the Natural Convection Air-Cooled Condenser (NCACC) integrated to stack as a new efficient ventilation method. Their project used three building energy analysis approaches to construct a nearly Net Zero Energy Building (nNZEB) in Irbid, Jordan. There are two approaches that might be used to identify building performance analysis: computational or analytical. A dynamic building energy modeling and simulation program with different climatic conditions was utilized to identify the best building energy model. A suitable economic assessment criterion was used to determine the payback period for each of the deployed systems.

According to [74], their study concentrated on the multi-objective optimization of building envelope characteristics in order to enhance the energy and financial performance of structures. Their research was separated into cooling- and heating-dominant zones according to the climates. All feasible solution scenarios—more than 13 million—including those that may occur in actual practice—were considered during the optimization process. Two opposing objectives were pursued: decreasing the building envelope's initial investment costs and lowering the total thermal energy demand. With the use of produced code in the Matlab environment, the NSGA-II genetic algorithm's convergence time was sped up. The two Turkish provinces of Osmaniye and Erzurum were given Pareto-Front choices after the envelope optimization process, and the life cycle costs of each option were compared. The results unmistakably showed that careful selection of the building envelope features at the basic design stage might significantly reduce life cycle costs in addition to providing superior solution possibilities for zero-energy buildings.

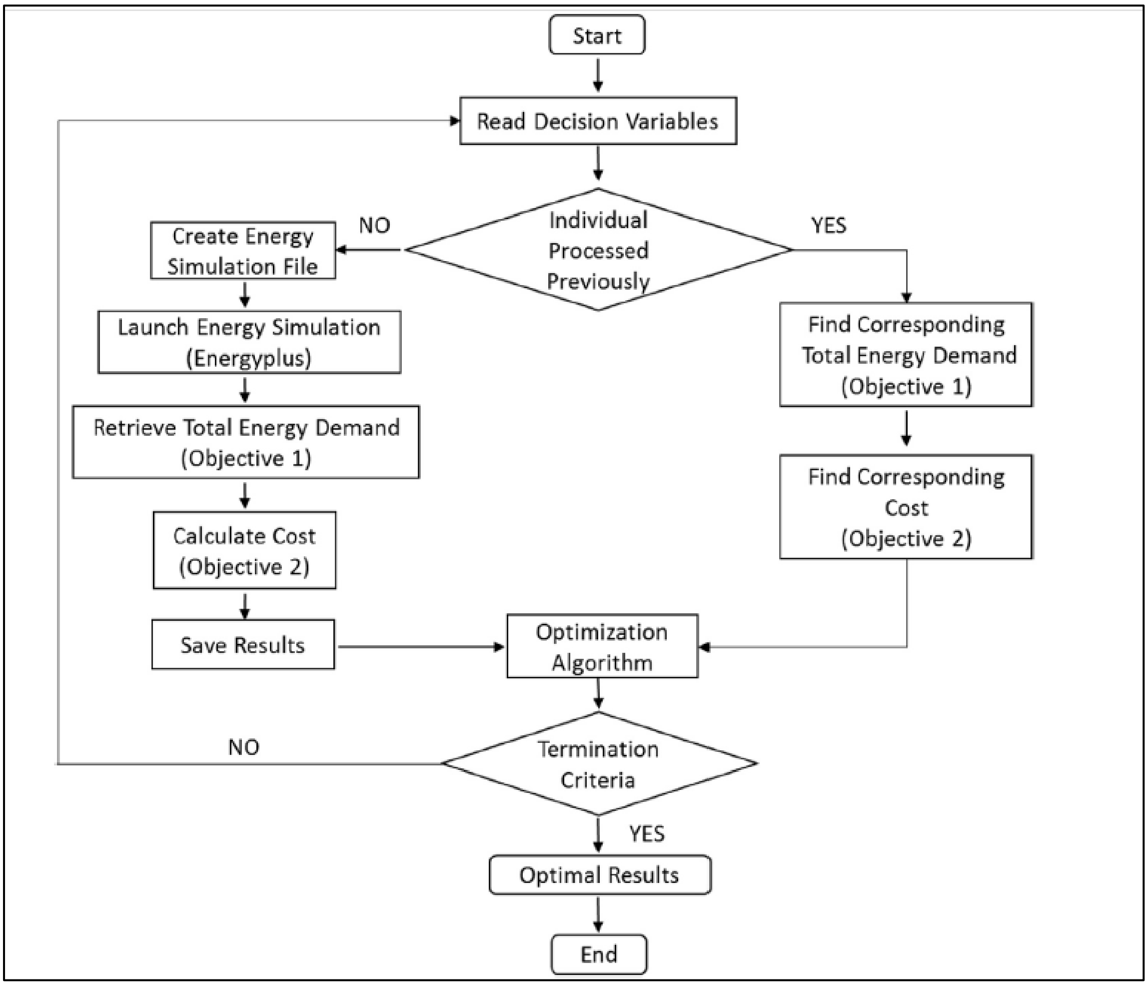

Figure 2.3: Matlab-Energyplus Connection [74].

RE systems offer long-term solutions to the world's energy issues. For remote off-grid households without a grid connection, alternatives like hybrid systems were offered. In their study, they looked at the size of an islanded wind-solar-battery power system for a zero-energy residence in Afyon, Turkey, without a grid connection. This remote home needed a constant power source, thus the system that was developed had to guarantee that the house would get a steady, uninterrupted supply of electricity. An off-grid wind-solar-battery hybrid system would require a different minimum number of batteries to fulfill the requirements for an uninterrupted continuous power supply if different-rated wind turbines and/or a different number of solar panels were used. In practice, it commonly happened that mismatched hybrid system components caused consumers to endure brief power outages. They conducted a size study for a hybrid wind-solar-battery power system in their work using information on the home's power usage as well as real wind and solar measurement data from the Afyon site. For a sizing study, calculations using real small-time interval data were essential to ensure dependable continuous power from a hybrid system [75].

The building industry was essential to address the previous global concerns of urbanization, climate change, and environmental pollution. Analysis of a building's performance was crucial in terms of energy use, comfort, and carbon emissions. Numerous paradigms, including bioclimatic, sustainable, green, and carbon-neutral architecture, have been studied for a long time. Since 2016, the regenerative paradigm has been a crucial issue for examining positive effect architecture to move past neutral impact. To analyze a method for obtaining an energy-efficient school building toward zero energy, [76] conducted their research aiming to assess the current state of a school building in Istanbul, Turkey. The research methodology was focused on creating an energy model of the school and running simulations with the software programs Design Builder and Energy Plus. The validated simulation was used to examine the retrofit packages for the school building's efficiency and discuss the alternatives, which were divided into two types of insulation layer alternatives, three types of glazing alternatives, two types of lighting system alternatives, and five types of HVAC system alternatives. 111 retrofit packages were examined. Due to the integration of RE systems, the P102 scenario has the lowest Primary Energy results for Electricity (PEE), Natural Gas (PENG), and Total Primary Energy (TPE). Those results were 1.84 kWh/m^2, 1.51 kWh/m^2, and 3.35 kWh/m^2, respectively, compared to the case study school building's existing conditions of 29.99, 63.05, and 93.05 kWh/m^2. As a result, to achieve a zero-energy school building, it was important to consider retrofit scenarios that focus on combining a RE system with an advanced HVAC system, as well as integrating proper insulation thickness, efficient glazing, and the right kind of lighting. The research's options and component parts could serve as a blueprint for next study phases and related research to advance school buildings' building stock toward zero energy use.

The energy needs of residential structures in Turkey account for about 31% of total energy consumption. Residential buildings therefore play a significant part in lowering energy requirements and greenhouse gas emissions. The scholars mentioned that their study presented a method for calculating the ideal thermal insulation thickness to be applied to the outside walls, columns, floors, and roofs of residential buildings using the required energy for heating and cooling. The ideal thermal insulation thicknesses were used to calculate the heating and cooling loads, as well as the energy costs, for various constructions. The Turkish Thermal Insulation Standard divided Turkey into four climate zones based on the average temperature degree-days of heating. By contrasting four insulation materials for 20 various energy demand scenarios for four different cities, each of which represented a different climatic zone of Turkey, the methodology was applied to a residential building as a case study. Following the acquisition of the Life Cycle Assessment-based global warming potential and cost indicators, eco-efficiency graphs were used to illustrate the analysis of each scenario's environmental impact [77].

Hotel buildings in Turkey account for 35% of all building energy usage, according to TUK Sectoral Energy usage Statistics from 2006. Depending on the building's typology, different energy requirements and consumption patterns apply. In order to improve energy and cost efficiency, to lessen the detrimental impacts on the environment and the economy, the Energy Performance of Buildings Directive (EPBD) has been modified to the conditions in Turkey. In an existing hotel building, various scenarios for energy use and total cost were explored. When the literature review about the issue detailed in the previous works was evaluated in detail, [78] their paper was exceptional in its capacity to deliver the best solution through comparison by evaluating energy and cost efficiency at the same time taking into account sectoral, climatic, technological, and economic national conditions. To determine the energy and cost efficiency, all findings were compared concurrently under various climatic conditions of the seasonal and yearly working conditions of the chosen test hotel. The best improvement scenario, in terms of cost and energy efficiency, was found to be S18, the scenario with the maximum energy efficiency. In that instance, it was possible to bend the kind of glass, the thickness of the insulation material, and both in order to increase energy efficiency by 25.7%.

2.5 CHAPTER SUMMARY

After reviewing different peer-reviewed articles and recent academic publications in the available literature, it can be observed that the last decades witnessed the development and innovation of various novel energy-efficient approaches and modern energy-saving methods whose adoption in facilities and buildings helped achieved significant cost-effectiveness in the energy usage and reasonable consumption of the electrical power needed for cooling and heating energy demands. Building on this thorough review, the third chapter in this thesis is represented to highlight further data and investigate the critical role of innovative energy-saving methods and mathematical optimization mechanisms in minimizing the energy usage of a building in Turkey.

3. METHODOLOGY

3.1 INTRODUCTION

This chapter tries to give a thorough review of the tools and research techniques used in this study. This chapter's main purpose is to defend the selected research methodology and outline how it helps to accomplish the study's goals. The study methodology, data-gathering strategies, and data analysis approaches will all be described in this chapter. Additionally, it will go into the ethical issues that were taken into account when conducting the research.

3.2 CASE STUDY DESCRIPTION

A domestic residence in Istanbul, Turkey, is the structure chosen for this case study. This single-story home has a total surface area of around 240 square meters and is a good example of traditional Turkish domestic construction. The house's layout, as seen in Figure 3.1, is intended to comfortably house a family of seven.

There are both private and public areas in the residence. The common areas include the living room, dining room, and kitchen, while the private spaces are the bedrooms and baths. The home also has outside areas like a front yard and a backyard, which are essential components of the living space.

The building's design and building materials are regionally typical, with an emphasis on sustainability and energy efficiency. Fiberglass and rock wool are used as insulation for the walls, floors, and ceilings, and the windows are double-glazed to improve thermal performance.

Istanbul's climate affects the building's thermal performance, thus the placement of the home there is important. Istanbul has a moderate oceanic climate, which includes hot, muggy summers and chilly, rainy winters. This climatic information is essential to our study since it affects how well the energy efficiency strategies we will be examining work.

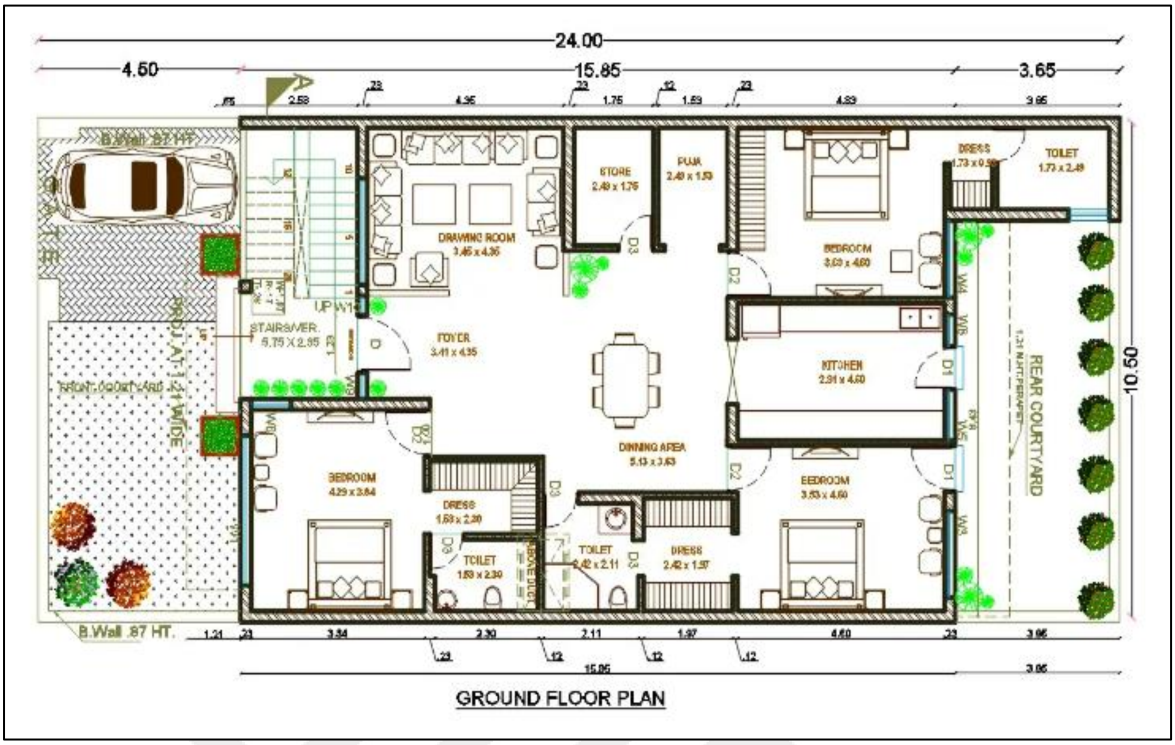

Figure 3.1: Details on the Single-Floor Apartment's Plan (240 M^2) of the Case Study Considered in This Work [79].

The house that was chosen for this case study has a floor size of around 240 square meters. This one-story building is planned with a layout that maximizes space usage and supports a cozy living space for its residents.

The house's design is carefully thought out to provide both private and community living areas. Each renter has their own private space thanks to the several bedrooms and bathrooms in the private areas. A sizable living room, a dining area, and a fully furnished kitchen make up the shared areas. These common areas provide locations for family activities including meals, entertainment, and leisure in order to promote family engagement.

A family of seven people may reside in the house without discomfort. This number of tenants gives our study a realistic base because it is common for a family house in this area. Our research must take into account the inhabitants' lifestyle, daily routines, and energy use patterns because they have a substantial impact on the building's energy use and thermal efficiency.

The house has both interior and outdoor living spaces, including a front yard and a backyard. These outdoor areas contribute to the overall thermal performance of the building in addition to improving the living environment.

The house is a perfect case study for our research on energy saving methods since its layout, size, and occupancy are typical of residential buildings in Istanbul.

The residential building under study is situated in Istanbul, a city that straddles the Bosphorus strait in northwestern Turkey. Istanbul's unique geographical location, bridging Europe and Asia, contributes to its diverse climate and architectural styles.

Istanbul experiences a temperate oceanic climate, characterized by hot, humid summers and cold, wet winters. The city's climate significantly influences the thermal performance of buildings and the effectiveness of various energy efficiency techniques.

Climate records show that February, when 78% of the year's maximum relative humidity rates are recorded, is the month with the highest relative humidity levels. In contrast, June and July have the lowest percentage of relative humidity, which is 67%. The thermal comfort inside the building and the amount of energy used for heating and cooling are both impacted by the year-round variability in humidity levels.

The city has seasonal variations in average temperatures, with summer highs frequently surpassing 30 degrees Celsius and lows in the winter below 5 degrees Celsius. These temperature changes also have an impact on how well the investigated energy efficiency strategies work and how much energy is used in the building.

In order to improve the efficacy of the energy efficiency measures and the potential for energy savings, it is essential for our study to have a thorough understanding of the local climate.

The monthly sun irradiation profile for Istanbul, Turkey is shown in Figure 3.2. The results clearly show that the sun irradiation reaches its greatest in July, peaking at 178.38 kWh/m2. On the other hand, December has the lowest sun irradiation levels, with 46.87 kWh/m2. When evaluating the potential for solar energy usage in the building, the variation in sun irradiation throughout the course of the year is a crucial consideration.

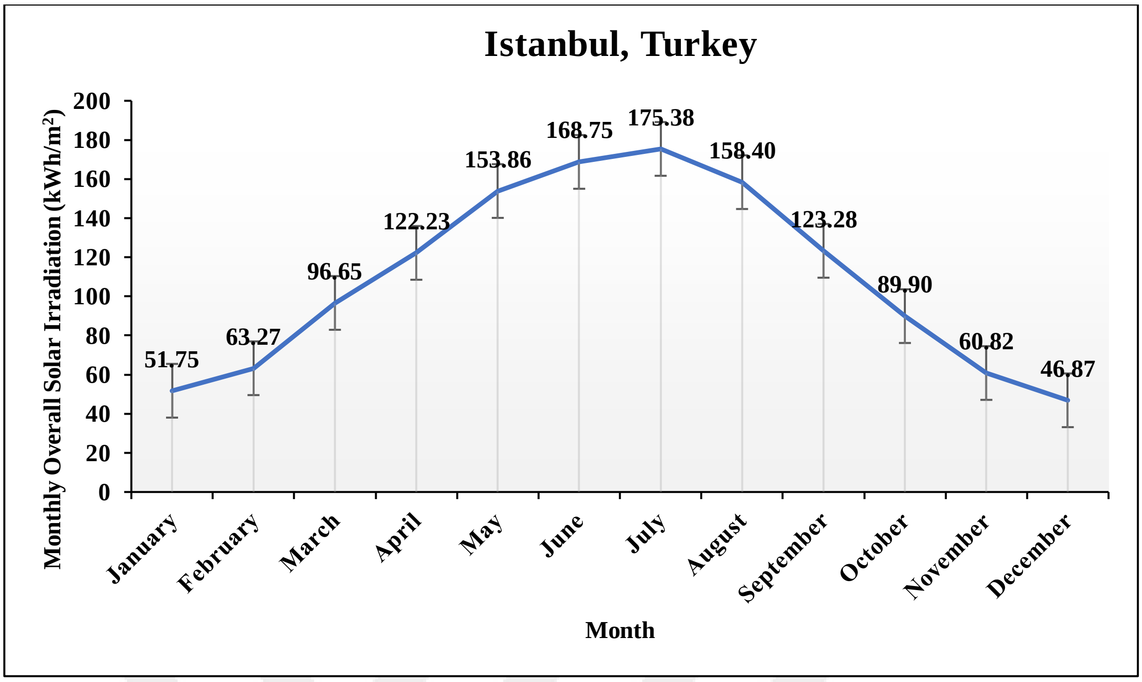

Figure 3.2: Monthly Solar Irradiation Profile of Istanbul, Turkey [80].

The annual profile of Istanbul's maximum and lowest temperatures is shown in Figure 3.3. The two months with the greatest temperatures, around 28°C, are July and August, while the two months with the lowest temperatures, roughly 5.3°C and 6.0°C, are January and February, respectively. These temperature changes have a substantial impact on the building's thermal efficiency and energy use.

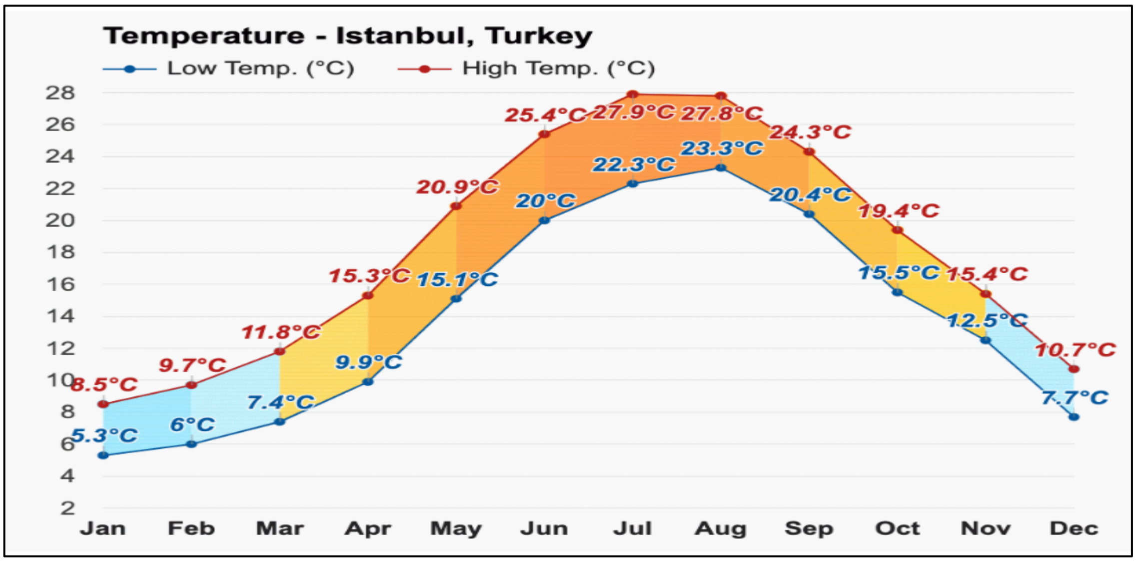

Figure 3.3: The Monthly Profile of Maximum and Minimum Temperature Values in Istanbul, Turkey, Per Annum [81].

The Istanbul yearly relative humidity is described in Figure 3.4. According to the statistics, relative humidity reaches its peak point in February (78%), and its lowest point in June and July (67%). The thermal comfort inside the building and the amount of energy used for heating and cooling are both impacted by the fluctuation in humidity levels throughout the year.

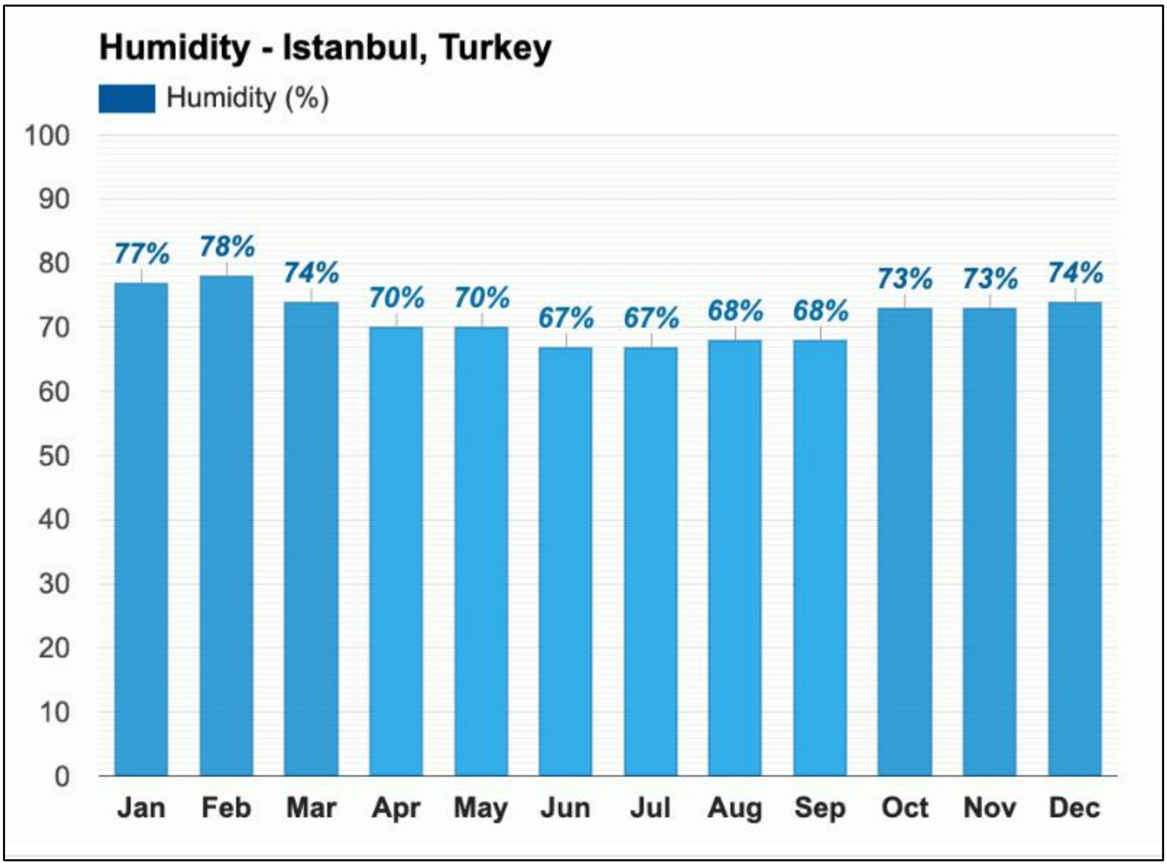

Figure 3.4: The Annual Relative Humidity of Istanbul, Turkey [81].

Together, these numbers offer critical climate information for Istanbul that is necessary for our numerical simulation procedure and the ensuing evaluation of the building's energy efficiency.

A collection of crucial information needed for the numerical simulation software is provided in Table 3.1. Understanding the environmental circumstances around the one-floor flat in Istanbul, Turkey, requires knowledge of this information. The table lists seven essential criteria.

Table 0.1: Some Vital Data Required to Define in the Numerical Simulation Program [81].

No.	Category	Value
1	Longitude	28.9784° E
2	Altitude	41.0082° N
3	Elevation from the Sea	40 m
4	Average Annual Solar Irradiation	1,303 kWh/m^2/annum
5	Average Annual Ambient Temperature	14 °C (57 °F)
6	Mean Maximum Annual Ambient Temperature	33 °C (91 °F)
7	Mean Minimum Annual Ambient Temperature	− 6 °C (21 °F)

Istanbul's longitude and latitude, which are 28.9784° E and 41.0082° N, respectively, define its physical position. It is also stated that the city is 40 meters above sea level. Understanding the city's location on the globe and its relative exposure to sunlight depends heavily on these geographic factors.

The table also includes information on the ambient temperature and sun irradiation. The possibility for using solar energy is indicated by Istanbul's average yearly sun irradiation of 1,303 kWh/m2. The mean ambient temperature for the whole year is 14°C (57°F), with the mean maximum and mean minimum temperatures being 33°C (91°F) and -6°C (21°F), respectively. Understanding the thermal conditions that the building is subjected to throughout the year depends on knowing these temperature figures.

These variables give a thorough overview of Istanbul's geographical and meteorological circumstances, which is essential for the numerical simulation process and the study of the building's energy efficiency that follows.

3.3 SIMULATION SOFTWARE AND ANALYSIS

In this study, we carried out high-performance inspection and mathematical analysis of the thermal performance of the building using two potent simulation software programs, MATLAB and Python.

The MathWorks product MATLAB, a high-level language and interactive environment, was mostly employed for numerical calculation and visualization. We modeled the thermal dynamics of the building, ran simulations of various energy-saving measures, and displayed the findings using MATLAB's powerful toolbox. Making graphical representations of our system and modeling the thermal behavior over time made use of MATLAB's Simulink package.

The high-level, general-purpose programming language Python, on the other hand, is renowned for being straightforward and readable. For numerical calculations, we combined Python with libraries like NumPy and SciPy, as well as Matplotlib for data visualization. Data processing and analysis were also done using the Pandas package.

We were able to build a robust simulation environment by combining MATLAB and Python. We were able to simulate many situations, model intricate thermal dynamics, and conduct a very visual and understandable analysis of the outcomes. To assure the quality and dependability of the simulation results, they were afterwards evaluated and confirmed by knowledgeable mechanical engineers, building experts, and numerical thermal analysis consultants.

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The building's thermal performance was then simulated using a variety of situations using the model. For instance, we may model how the structure would perform on a hot summer day or a chilly winter night or use various energy-saving methods. We were able to anticipate the building's heat transfer coefficient and other important thermal variables, including its internal temperature and energy consumption, thanks to the simulation outputs.

The accuracy of these forecasts was then evaluated by comparing them to real data from the structure. Any differences between the model's predictions and the observed data were utilized to increase the model's precision.

Mechanical engineers, building industry experts, and consultants in numerical thermal analysis also independently confirmed the numerical results and simulation outputs. These professionals examined our technique, examined our calculations, and validated the accuracy of our findings. Their knowledge and unbiased confirmation gave our results even more credibility.

Through the prediction and verification process, we were able to learn a lot about the thermal performance of the building as well as the efficacy of various energy-saving strategies. Additionally, it made sure that our conclusions were solid, trustworthy, and relevant to actual circumstances.

3.4 ENERGY EFFICIENCY TECHNIQUES

The energy efficiency techniques used in the case study:

a. Double Glazing Windows and Thermal Insulation: The walls, floors, and ceilings of the building are thermally insulated, and the windows are double-glazed. The double-glazing windows have two panes of glass with a space between them to lessen heat transmission and preserve the building's interior temperature. Materials like fiberglass and rock wool, which are renowned for their strong thermal resistance capabilities, are used for the thermal insulation in the walls, floors, and ceilings. These components considerably lessen heat gain in the summer and loss of heat in the winter, increasing the building's energy efficiency.
b. Passive Cooling and Heating Methods: The structure makes use of passive heating and cooling techniques, including shaded glass and natural ventilation. Shaded glass lowers solar heat gain, and passive air cooling is made possible by natural ventilation. These techniques assist in lowering the demand for mechanical heating and cooling, conserving energy.
c. Passive Lighting Methods: The structure was created to make the most of natural light while using less artificial lighting. Larger window areas that let more light into the

apartment's interior spaces help to achieve this. The building may drastically lower its energy use for lighting by optimizing the use of natural light.

d. Smart Energy Management Devices: The building is equipped with smart energy management devices, such as programmable sensors for the HVAC (Heating, Ventilation, and Air Conditioning) system. These devices allow for more precise control over the building's heating and cooling, thereby improving energy efficiency.

The combination of various energy-saving methods offers a thorough strategy for enhancing the building's energy performance. They improve the building's comfort and livability in addition to consuming less energy. Through the use of energy-efficient procedures, this strategy illustrates the potential for large energy savings in residential structures.

3.5 SIMULINK DIAGRAM DEVELOPMENT AND ANALYSIS

The creation of the Simulink diagram is essential for outlining the case study's research parameters and data. According to Figure 10, the setup for Simulink in the MATLAB Simulink environment was created to make it easier to analyze all relevant aspects and variables related to the contributions of contemporary energy-saving techniques and methodologies.

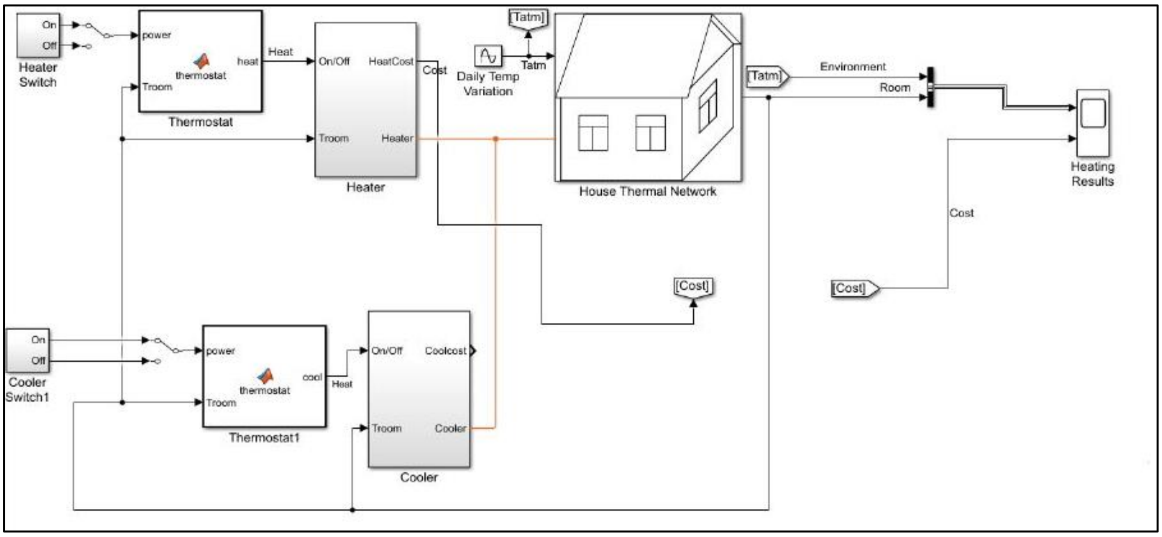

Figure 3.5: The Simulink Diagram of the Case Study Designed in the MATLAB Simulink Environment [82].

The Simulink figure includes a number of elements, such as thermostats, heaters, coolers, cost, and some significant thermal energy information. These parts stand as a crucial element of the building's energy system. The HVAC system, which significantly contributes to the building's energy use, is represented by thermostats, heaters, and coolers. While the thermal energy data offers insights into the building's thermal performance, the cost component indicates the financial element of the building's energy usage.

To get the crucial findings, the Simulink diagram was executed once each parameter had the proper values defined. In order to comprehend how numerous elements impact the building's energy consumption and the efficacy of the energy efficiency strategies, this approach entailed conducting simulations under various situations.

The outcomes of these simulations were then utilized to compare different energy efficiency techniques. Insightful information on the potential for large energy savings in the building through the use of contemporary energy efficiency techniques and methodologies is provided by this study, which is covered in depth in the following sections.

This procedure of creating and analyzing Simulink diagrams is essential to our research technique. It enables us to simulate several scenarios, model the intricate dynamics of the building's energy system, and conduct highly visual and understandable analyses of the outcomes.

3.6 ENERGY-EFFICIENCY THEORY AND MATHEMATICAL FORMULATION

We used a number of mathematical formulae to assess the effectiveness, dependability, and features of the energy efficiency concepts used in the building. We were able to calculate the effects of many variables on the building's energy usage and thermal efficiency thanks to these formulae.

The effectiveness of thermal insulation was one of the primary factors we looked at. This was evaluated by calculating its thermal resistance, represented by the letter "R." There are two formulae that may be used to express thermal resistance. The first formula, as some scholars have suggested,

$$R = \frac{t}{\lambda} \quad (3.1)$$

Where 't' is the thermal insulation thickness and 'λ' denotes the thermal conductivity of the insulation material. The second formula is

$$R = \left\{e^{\left(\frac{T}{t^2}\right)}\right\} \quad (3.2)$$

Where 'T' is the time the heat transfer occurs across the insulation material.

We also analyzed the cooling load for the building. According to a scholar's study, the cooling load, denoted as Q_{Cool}, equals the amount of heat load, Q_{Heat}. Generally, Q_{Cool} or Q_{Heat} can be estimated depending on sensible and latent heat transfer amounts. The typical Q_{Cool}/Q_{Heat} can be expressed

$$Q_{Cool} = Q_{Heat} = Q_{External\ Loads} + Q_{Internal\ Loads}, \quad (3.3)$$

In a more detailed expression, the previous relationship can be described as shown in Equation (4.)

$$\begin{aligned} Q_{Cool} = Q_{Heat} &= [U][A][CLTD] + A_{Unshaded} \times SHGF_{Max} \times SC \times CLF \\ &+ \dot{m}_o \times C_{p,m} \times (T_o - T_i) + \left[\left(N_{People}\right)(\bar{Q}_{Sens})(CLF)\right] + Q_{Light} \\ &+ Q_{Applia(s,l)}, \end{aligned} \quad (3.4)$$

This equation incorporates various factors, including the heat transfer coefficient (U), the surface area of the internal zones requiring cooling/heating (A), the Cooling Load Temperature Difference (CLTD), the area subjected to solar irradiation ($A_{Unshaded}$), the maximum solar heat gain factor ($SHGF_{Max}$), the Shading Coefficient (SC), the cooling load factor (CLF), the infiltration mass flow rate ($\dot{m}_o$), the heat capacity of moist ($C_{p,m}$), the outside temperature (T_o), the inside temperature (T_i), the number of residents (N_{People}), sensible thermal energy per person ($\bar{Q}_{Sens}$), the heat transfer of light fixtures (Q_{Light}), and the thermal energy of appliances ($Q_{Applia(s,l)}$).

These mathematical formulations provide a theoretical framework for understanding and quantifying the building's energy performance. They allow us to model the complex dynamics of the building's energy system, simulate various scenarios, and analyze the results in a highly precise and quantifiable manner.

3.7 CHAPTER SUMMARY

We have described the approach for our study in Chapter 3, including the creation of the Simulink diagram, the use of mathematical formulae and energy-efficiency theories, and the comparison of several energy-efficient techniques. We have also included details on the case study building in Turkey, such as its size, design, population, and location.

For high-performance inspection and mathematical analysis, we have employed the simulation software packages MATLAB and Python. We have been able to anticipate thermal effectiveness qualities and other important thermal factors thanks to these technologies. Mechanical engineers, building industry experts, and consultants in numerical thermal analysis analyzed and confirmed the numerical results and simulation outputs.

Additionally, we covered the case study's energy-saving strategies, which included passive cooling and heating, passive lighting, double glazing windows, thermal insulation, and smart energy management systems. The comparison research revealed considerable gains in a number of measures, including the relative humidity of the building zone, the interior temperature, the cooling and heating loads, and the overall yearly energy cost of cooling and heating.

This methodology offers a thorough strategy for comprehending and enhancing buildings' energy performance. It enables us to simulate many situations, model the intricate dynamics of a building's energy system, and conduct highly visual and understandable analyses of the outcomes. The findings of this study will shed important light on the possibility of substantial energy savings in residential buildings through the use of energy efficiency strategies.

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter's main objective is to present, examine, and interpret the research's findings. This chapter will go in-depth on the specific findings that came from employing our methodology in Chapter 3, concentrating on how different energy-saving methods affected the performance of the case study building.

The variations in the building's relative humidity, interior temperature, cooling loads, heating loads, and the overall yearly energy cost of cooling and heating are all included in the simulation findings that we will give. These findings will be examined in relation to the building's energy efficiency and the efficacy of the adopted energy efficiency measures.

Additionally, this chapter seeks to offer a thorough analysis that links our findings to the body of information already available in the area of building energy efficiency. We will evaluate similarities and differences between our findings and those of earlier research, as well as offer potential reasons for these findings.

The ramifications of our results for theory and practice will next be discussed. Discussing the potential for large energy savings in residential structures via the use of energy efficiency measures and offering helpful advice for building designers, engineers, and decision-makers are included in this.

In summary, the purpose of this chapter is to increase our understanding of energy efficiency in residential structures by presenting our findings and engaging in a meaningful conversation.

4.2 PRESENTATION OF RESULTS

4.2.1 Simulation Work's Comparative Analysis

MATLAB and Python simulation software packages, which were used to direct high-performance inspection and mathematical analysis, were used to obtain the simulation findings. Using these methods, we were able to forecast some of the thermal efficiency characteristics and other important thermal variables of the case study building in Turkey. Mechanical engineers, building industry experts, and consultants in numerical thermal analysis analyzed and confirmed the numerical results and simulation outputs.

The structure chosen for this case study is an example of a typical residential residence, with seven occupants and a total surface area of around 240 m2. Figure 3.1 of Chapter 3 details the building's layout.

In Table 4.1, the results of the critical comparison analysis regarding the inclusion and exclusion of contemporary energy-efficient materials and technologies in the case study are shown. The relative humidity of the building zone, interior temperature, cooling and heating loads, and the total yearly energy cost of cooling and heating are the five important thermal metrics listed in this table. The table shows values before and after using the energy-efficient techniques for each parameter.

Table 0.1: The Critical Comparative Analysis Outcomes Regarding the Inclusion and Exclusion of Modern Energy-Efficient Materials and Technologies in the Case Study.

No.	Thermal Parameter	Energy Efficient Methods Implementation (Value)	
		Before	After
1	Building Zone's Relative Humidity	60.4%	25.1%
2	Internal Temperature	29.8 ºC	21.3 ºC
3	Cooling Loads	216.8 kW	99.5 kW
4	Heating Loads	452.8 kW	112.4 kW
5	Total Annual Energy Cost of Cooling and Heating	103.1 USD	49.7 USD

The results shown in Table 4.1 show that the building zone's relative humidity, internal temperature, cooling loads, heating loads, and overall annual budget of cooling and heating requirements were significantly more significant before using intelligent insulation materials, passive cooling and heating methods, and novel energy-efficiency approaches than they were in the second scenario, where those five variables recorded lower values after the application of these three types of innovative energy-efficiency approaches.

Graphical representations provide additional information and numerical explanations of these advantages. Figure 4.1, for instance, shows the layout of building zone humidity levels before and after using those useful notions.

Figure 10's findings illustrate how the interior humidity of the building changed both before and after new energy-saving devices were implemented. The data shows that the humidity levels have significantly improved after these technologies were put in place.

The facility's interior humidity was 60.4% prior to the implementation of energy-saving measures. This suggests that the humidity level within the structure is rather high, which may cause discomfort or other problems like mold growth or moisture damage.

However, the facility's internal humidity dropped dramatically to 25.1% with the installation of new energy-saving measures. This decrease shows a significant improvement in regulating and maintaining ideal humidity levels inside the structure.

The use of different energy-saving techniques, such as intelligent insulating materials, passive cooling and heating techniques, and other energy-efficient ways, can be credited with the decrease in humidity. These actions help the inner sections of the structure to better control and regulate moisture.

The facility gives its users a more cozy and healthy interior atmosphere by obtaining a lower humidity level of 25.1%. Additionally, it aids in preventing the development of mold and other moisture-related problems, enhancing the building's general quality and durability.

The reduction in humidity is a crucial result for energy efficiency since it means less energy will be needed for cooling and dehumidification procedures. The institution may optimize its energy use and lower associated expenses by controlling humidity levels appropriately.

The large difference in humidity levels before and after implementing new energy-saving technology demonstrates the efficacy and beneficial effects of these measures on establishing a more pleasant and energy-efficient building environment.

The simulation findings showed that implementing novel energy-saving measures had a considerable influence on the building's internal temperature. Figure 11 provides a comparison of the interior temperature of the building before and after the use of various technologies, which demonstrates this point clearly.

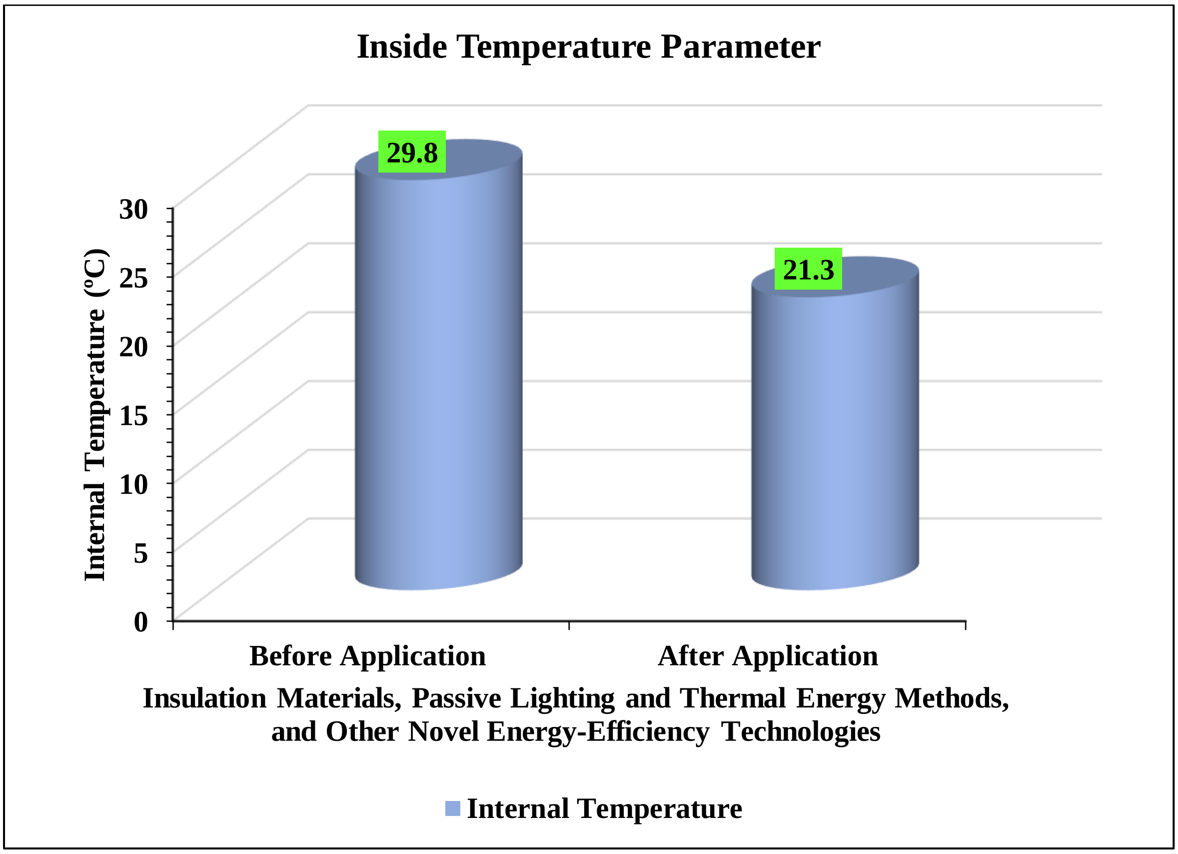

Figure 4.1: Facility's Internal Temperature Before and After Applying New Energy-Saving Technologies.

The building's interior temperature was measured at 29.8°C prior to the use of energy-saving technology. Even while the temperature isn't too high, it can make the building's residents uncomfortable, especially in the summer. High interior temperatures can also increase the need for cooling systems, which can result in more energy being used and more money being spent.

However, a significant drop in interior temperature was seen after the use of energy-saving technology. 21.3°C was the new average temperature, a decline of around 8.5°C. This drop in temperature can greatly increase indoor comfort, creating a more comfortable space for the building's inhabitants.

A lower internal temperature may also lessen the demand for cooling systems, which would result in less energy being used and less money being spent. This illustrates the efficacy of the energy-saving technology used in the building, showing that they are successful in increasing energy efficiency while simultaneously enhancing comfort levels.

4.2.2 Cooling and Heating Energy Results and Their Associated Cost

Our numerical simulations also looked at additional critical factors to further evaluate the usefulness of insulating materials and other critical energy efficiency techniques in enhancing the facility's energy performance, in addition to the findings that have already been mentioned.

Additional data on the facility's comparative study are shown in Figure 4.2, with an emphasis on the total cost, cooling loads, and heating demand before and after the use of innovative energy-saving strategies.

The building's cooling and heating loads were measured at 216.8 kW and 452.8 kW, respectively, prior to the use of these procedures. These high loads show that a large quantity of energy was needed to keep the facility at a suitable temperature. This results in significant energy expenses in addition to excessive energy usage. In actuality, the cost of heating and cooling was estimated to be 103.1 USD per year.

The cooling and heating loads, as well as the overall yearly energy cost, were, however, significantly reduced with the adoption of energy-saving devices. The heating demands declined to 112.4 kW and the cooling loads to 99.5 kW. This shows the success of the energy-saving devices in lowering the building's energy consumption by more than 50% for both metrics.

Additionally, the overall yearly energy expenditure for heating and cooling was decreased by more than 50% to 49.7 USD. These substantial cost savings highlights the financial advantages of using energy-saving systems in buildings.

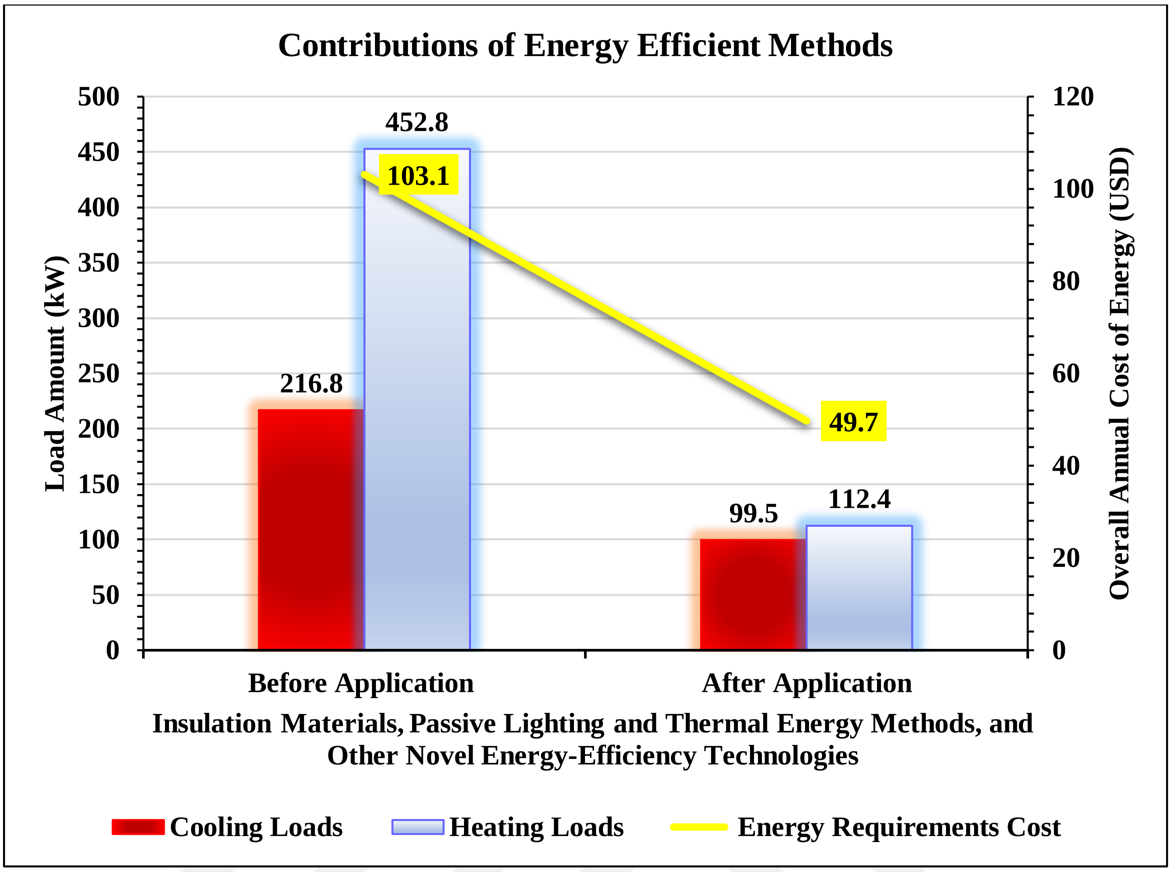

Figure 4.2: Further Comparative Findings on the Use and Nonconsideration of New Energy-Saving Technologies in the Facility Investigated.

These results offer compelling evidence of the significance and usefulness of contemporary energy efficiency concepts and techniques in enhancing economic profitability, yearly cost-effectiveness, and energy feasibility.

Figure 4.3 indicates some simulation findings attained from the Python mathematical simulation processes of the Turkish building.

The first figure shows a comparison between the outside temperature, the pace of cooling, and the rate of heating over time. The outdoor temperature is shown as a red line that changes over time. The cooling rate, represented by the blue line, shows how much cooling power is being consumed at each time step. The heating rate is shown by the magenta line, which displays the amount of heating power being consumed at each time step.

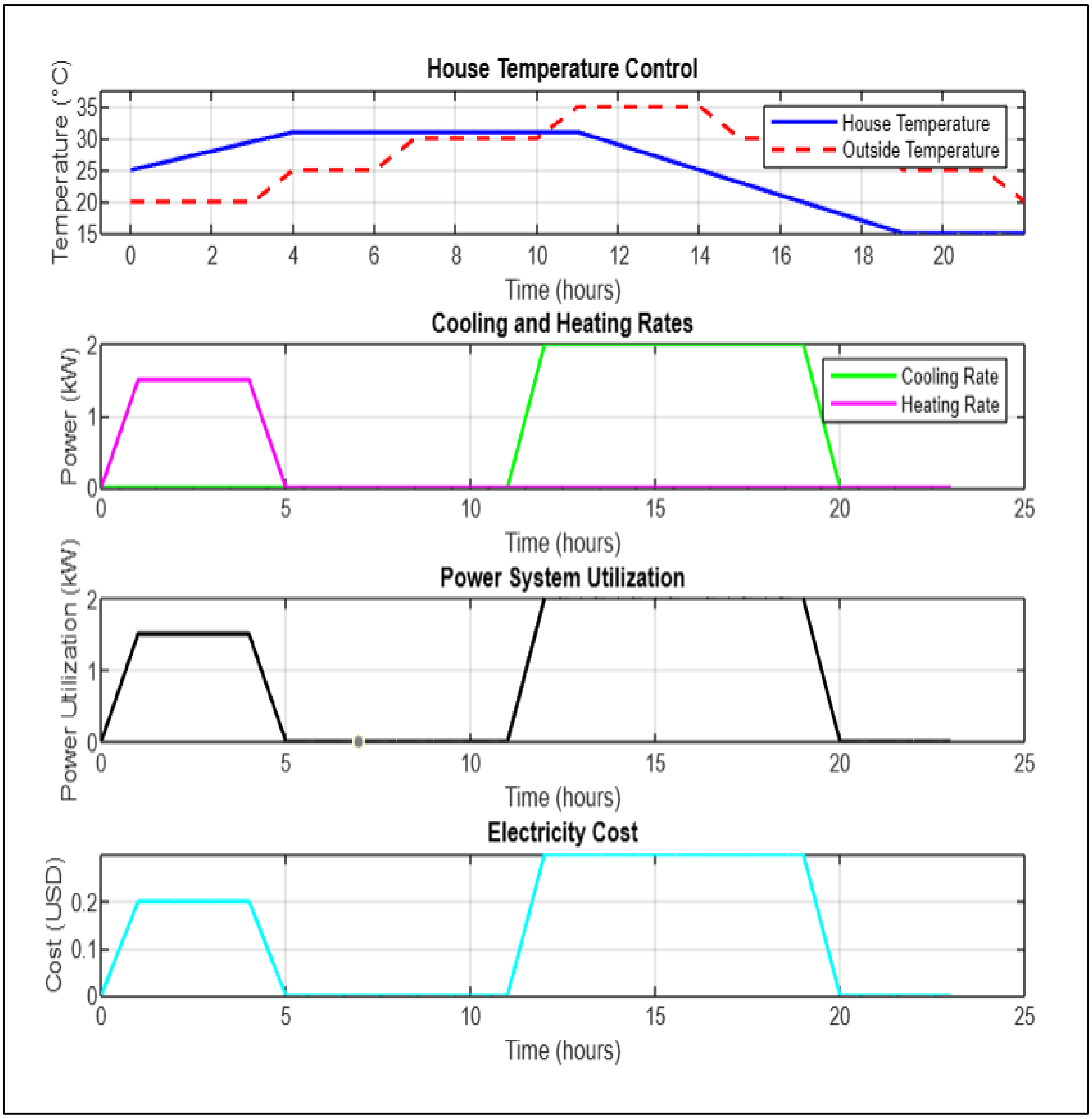

Figure 4.3: Cost, Power Utilization, Power and Temperature Display.

It can be inferred from Figure 4.3 that the difference between the inside and outside temperatures is used to calculate the cooling and heating rates. Cooling is required, and the cooling rate rises when the inside temperature is higher than the outdoor temperature. In contrast, heating is required, and the heating rate rises when the indoor temperature is lower than the outdoor temperature. Additionally, there are times when no heating nor cooling is required, in which case both rates are zero.

The green line in the second illustration shows the evolution of the cost of power. Based on the rates for cooling and heating, this expense is estimated. The cost of power rises with high cooling or heating rates. The cost of power is zero when neither heating nor cooling is required. This graph makes it easy to see how using cooling and heating systems affects the price of power over time.

These numbers offer essential information about the long-term energy use and expense of keeping the residence at a suitable temperature. They emphasize the need of effective cooling and heating systems for lowering energy costs and utilization.

Three energy-efficient techniques were used in the Python simulation, and their effects on the building's performance were examined. These techniques most likely indicate several approaches to enhancing the building's energy effectiveness, such as enhancing insulation, enhancing HVAC systems, or putting in place smart energy management devices.

Total Energy Cost Comparison: Before and after each method's adoption, the total energy cost was compared. This comparison gives a good idea of the financial advantages of each approach. The strategies' ability to increase a building's energy efficiency and lower operating costs would be shown by a substantial drop in general electrical expenses following their installation:

a. Temperature Decrease Comparison: The interior temperature decrease of the building was also compared for each technique. This comparison is essential for determining how well the strategies work to increase thermal comfort in the building. A greater drop in temperature would suggest a more efficient technique, especially for structures in hot areas where cooling accounts for a sizable portion of the building's energy usage.
b. Comparison of the relative humidity change in the building zone: The relative humidity change in the building zone was compared for each technique. This comparison is crucial for determining how the techniques affect the indoor air quality of the structure. High relative humidity can cause problems for the residents, such as the formation of mold. As a result, techniques that successfully lower relative humidity can greatly enhance the building's indoor environmental quality.

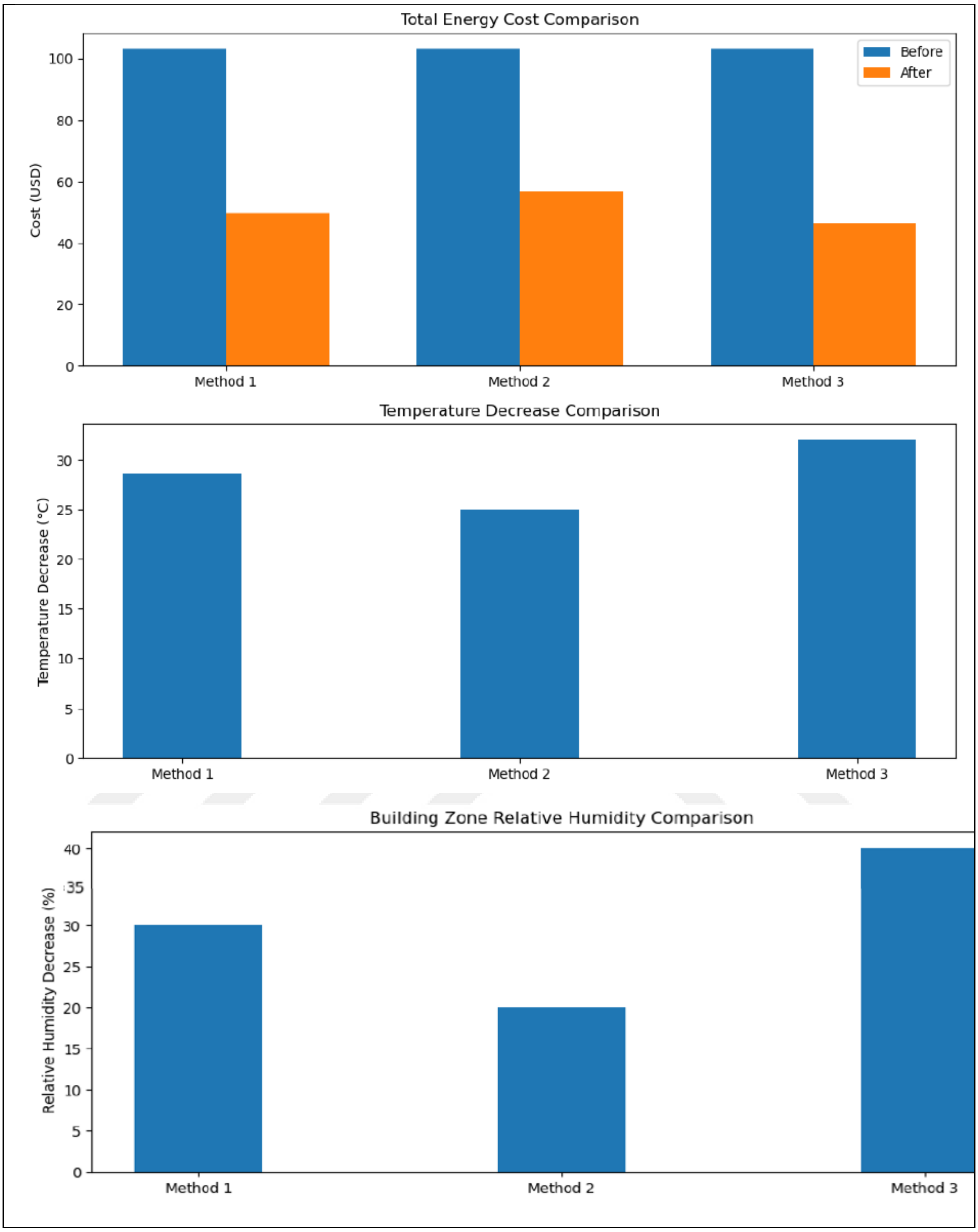

Figure 4.4: Python Results.

These comparisons offer a thorough evaluation of how well the three energy-efficient techniques perform. They help us comprehend how these techniques affect the thermal comfort and indoor air quality of the building in addition to their financial advantages.

4.3 CHAPTER SUMMARY

Our research showed that the building's thermal performance had significantly improved, as evidenced by drops in relative humidity, interior temperature, cooling and heating loads, and the overall yearly energy cost of cooling and heating. These results emphasize the success of the energy-efficient techniques used in the building and highlight their potential to improve residential buildings' energy efficiency and occupant comfort.

Additional insights into our findings were gained through the comparison with prior research. It deepened our understanding of the complex dynamics of energy efficiency in buildings by assisting us in identifying similarities and differences between our findings and those of earlier studies.

We also spoke about the consequences of our results for theory and practice. Our study offers useful advice for building designers, engineers, and legislators while also advancing the theoretical knowledge of energy efficiency in residential structures.

In conclusion, the findings and debates discussed in this chapter offer insightful information on the possibility for substantial energy savings in residential buildings through the use of energy efficiency strategies. These results lay the groundwork for the last chapter, in which we will review our study and talk about its potential directions.

5. CONCLUSIONS AND FUTURE WORK

5.1 INTRODUCTION

This chapter presents, examines, and evaluates the findings of the research. The simulation findings provide a thorough insight into how different energy efficiency methods affected the performance of the case study building.

5.2 CONCLUSIONS

In this study, investigations were led and executed on how different energy-saving strategies affected the thermal performance of a residential structure in Turkey. The research, which was based on extensive simulations and comparative studies, has shown that these strategies have a substantial potential to improve residential buildings' energy efficiency and occupant comfort. The building's thermal performance was significantly enhanced through the use of clever insulating materials, passive cooling and heating techniques, and innovative energy-efficiency strategies. Relative humidity, interior temperature, cooling and heating loads, as well as the total yearly energy cost of cooling and heating, were decreased in the building zone. The study offers useful advice for building designers, engineers, and legislators while also advancing the theoretical knowledge of energy efficiency in residential structures. The knowledge gathered from this research may be used to design and run energy-efficient residential structures, resulting in substantial energy savings and increased occupant comfort.

5.3 FUTURE WORKS

Depending on the research's numerical outcomes obtained in this master's work, it is worth mentioning that there are a number of critical future work suggestions for further investigation, even if this study has yielded insightful information.

First, more investigation may examine the effects of other energy-efficiency measures not addressed in this study. This might involve installing cutting-edge HVAC systems or using renewable energy sources like solar or wind power.

Second, future research may potentially take various building kinds and climates into account. A more thorough understanding of the application and efficacy of energy efficiency strategies in many situations would result from this.

Third, the accuracy of the forecasts may be improved by the creation of more complex simulation models. These models might include more accurate depictions of the structure's physical characteristics and how various building systems interact.

The economic benefits of employing these energy efficiency strategies, including the initial investment costs and payback duration, should potentially be studied in future study. This would offer a more thorough evaluation of the practicality and commercial viability of these strategies.

The influence of energy-saving strategies on residential structures has been better understood thanks to our study, but there is still more to learn about this crucial area.

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