# OPTIMIZATION OF COOLING ENERGY CONSUMPTION AND THERMAL COMFORT IN EXISTING RESIDENTIAL BUILDINGS AGAINST CLIMATE CHANGE: A CASE STUDY IN MEDITERRANEAN CLIMATE

**A Thesis Submitted to**
**the Graduate School of**
**İzmir Institute of Technology**
**in Partial Fulfillment of the Requirements for the Degree of**

**MASTER OF SCIENCE**

**in Architecture**

**by**
**Sedef UÇARYILMAZ**

**December 2023**
**İZMİR**

We approve the thesis of **Sedef UÇARYILMAZ**

**Examining Committee Members:**

**Assos. Prof. Dr. Zeynep DURMUŞ ARSAN**
Department of Architecture, İzmir Institute of Technology

**Prof. Dr. Gülden GÖKÇEN AKKURT**
Department of Energy Systems Engineering, İzmir Institute of Technology

**Prof. Dr. Türkan GÖKSAL ÖZBALTA**
Department of Civil Engineering, Ege University

**11 December 2023**

**Assos. Prof. Dr. Zeynep DURMUŞ ARSAN**
Supervisor, Department of
Architecture
Izmir Institute of Technology

**Prof. Dr. Koray KORKMAZ**
Head of the Department of
Architecture

**Prof. Dr. MEHTAP AENES**
Dean of the Graduate School
of Engineering and Sciences

# ACKNOWLEDGMENTS

The successful completion of this thesis would have been unattainable without the invaluable counsel of my advisor, assistance from my friends, and unwavering support from my family.

I express my gratitude to my advisor, Associate Professor Dr. Zeynep Durmuş Arsan, for her unwavering support, guidance, counsel, encouragement, patience, assistance, and expertise.

I would like to thank IYTE Scientific Research Projects (BAP): This research is funded by IZTECH Coordinatorship of Scientific Research Projects with the number of 2022IYTE-1-0008 in 2022. I would like to thank the IZTECH Coordinatorship of Researches for proving funding to purchase a IoT device. I also would like to express my gratitude to the Building Physics Laboratory of Faculty of Architecture for providing student license of DesignBuilder software and measurement equipment.

I would like to thank my father Turgut Yerlikaya and mother Nazlı Yerlikaya, my brother Arda Yerlikaya, my sister Deniz Yerlikaya for their unending support, motivation and patience. I am extremely fortunate to have such a family.

I would want to express my profound gratitude to Aybüke Taşer, Ece Özyılmaz, and Doğa Çakmak for their invaluable emotional support.

Lastly, I want to express my gratitude to my beloved husband, Kaan Uçaryılmaz, who was consistently there for me and provided unwavering support during this process. I am also grateful to our 8-month-old son, Aras, who is still inside me, for being patient and not causing any trouble for his mother. Thank you for becoming a part of my nuclear family.

# ABSTRACT


OPTIMIZATION OF COOLING ENERGY CONSUMPTION AND THERMAL COMFORT IN EXISTING RESIDENTIAL BUILDINGS AGAINST CLIMATE CHANGE: A CASE STUDY IN MEDITERRANEAN CLIMATE

The built environment is at risk of facing significant impacts due to climate change and extreme weather occurrences. An adverse consequence of climate change on the construction industry is the degradation of thermal comfort within buildings, leading to increased energy usage for air conditioning. Because existing residential buildings are unprepared for the future climate. The Mediterranean climate is one of the climate classes that will be mostly affected by the global climate, especially in terms of temperature increases. Yet, to access sensitive and accurate climatic data and find the best retrofit scenarios is problematic. Two IoT devices were used in this study to overcome this problem. This study aims to observe and minimize the energy consumption and thermal heat comfort of the flat on the ground floor of a 3-story residential building located in Aydın province, which has a Mediterranean climate, against climatic conditions. In the study, climate predictions for 2049-2050 and 2079-2080 were also made, and it was investigated whether the currently optimized building would remain optimized in future climate conditions. According to the results, while the cooling energy consumption of the currently optimized building decreased by 43% compared to the base case, it decreased by 25% according to the 2049-2050 climate predictions and by 8% according to the 2079-2080 climate predictions. There was no visible change in discomfort hours. In the separate optimization results for the 2049-2050 and 2079-2080 periods of the building, which could not remain optimized according to future climate conditions, a 30% and 21% decrease in cooling energy consumption was observed, respectively, compared to the base case. There was no visible change for discomfort hours. According to this study, it was concluded that the building should be re-optimized in future climate scenarios.

# ÖZET

## MEVCUT KONUT YAPILARINDA İKLİM DEĞİŞİKLİĞİNE KARŞI SOĞUTMA ENERJİSİ TÜKETİMİ VE ISIL KONFORUN OPTİMİZASYONU: AKDENİZ İKLİMİNDE BİR ALAN ÇALIŞMASI

İklim değişikliği ve aşırı hava olayları, yapılı çevrede ciddi sonuçlar doğuracak potansiyel sorunlar olarak görülmektedir. İklim değişikliğinin yapı sektörü üzerindeki olumsuz etkilerinden biri binalardaki ısıl konforun bozulması ve iklimlendirme için daha fazla enerji tüketilmesidir. Çünkü mevcut konut binaları geleceğin iklimine hazırlıksızdır. Akdeniz iklimi küresel iklimden özellikle sıcaklık artışlarından en çok etkilenecek iklim sınıflarından biridir. Ancak hassas ve doğru iklim verilerine ulaşmak ve en iyi güçlendirme senaryolarını bulmak sorunludur. Bu sorunun üstesinden gelmek için bu çalışmada iki IoT cihazı kullanıldı. Bu çalışmanın amacı Akdeniz iklimi'ne sahip Aydın ili'nde bulunan 3 katlı bir konut binasının zemin katındaki dairenin iklim koşullarına karşı enerji tüketimini ve termal ısı konforunu gözlemlemek ve minimize etmek için optimizasyon çalışması yapılmasıdır. Çalışmada aynı zamanda 2049-2050 ile 2079-2080 iklim tahminleri yapılmış olup, mevcut durumda optimize edilmiş binanın gelecek iklim koşullarında da optimize kalıp kalmayacağı araştırılmıştır. Sonuçlara göre mevcut durumda optimize edilmiş binanın soğutma enerji tüketimi mevcut konuta göre 43% azalırken, 2049-2050 iklim tahminlerine göre 25%, 2079-2080 iklim tahminlerine göre ise 8% azalmıştır. Rahatsızlık saatlerinde gözle görülür bir değişim olmamıştır. Gelecek iklim koşullarına göre optimize kalamayan binanın 2049-2050 ve 2079-2080 dönemleri için ayrı ayrı yapılan optimizasyon sonuçlarında mevcut durumdaki konuta göre soğutma enerji tüketiminde sırasıyla 30% ve 21% azalma gözlemlenmiştir. Rahatsızlık saatleri için gözle görülür bir değişiklik olmamıştır. Bu çalışmaya göre binanın gelecek iklim senaryolarında tekrar optimize edilmesi sonucuna ulaşılmıştır.

# TABLE OF CONTENTS

# LIST OF FIGURES

**Figure** **Page**

# LIST OF TABLES

**Table** **Page**

# CHAPTER 1

# INTRODUCTION

## 1.1. Problem Statement

Climate change and extreme weather events are seen as potential problems that will seriously affect the built environment. These can be seen from the two reports published by the General Directorate of Meteorology (GDM) and the International Energy Agency (IEA). According to the GDM's Türkiye 2022 Climate Assessment Report (2023), the average temperature of Türkiye in 2022 was recorded as 14.5°C. Further, the IEA's 2021- Türkiye Climate Resilience Policy Indicator Report (2021) showed that the annual average temperatures in Türkiye have been increasing since 1994 (except for 1997 and 2011). The increases in temperature in the last 20 years exceed 0.0665°C annually, significantly above the world average of 0.0313°C. With these increases in temperature in Turkiye, especially in the Mediterranean Basin, climate change brings with it the risk of overheating in residences. It can be noted that the Mediterranean region is warming 20% faster than the rest of the world, and with the current policies, temperatures are expected to increase by 2.2 °C by 2040 (MedECC, 2020).

One of the negative effects of climate change and the overheating factor occurring in residences in the construction sector is the deterioration of thermal comfort in buildings and more energy consumption for air conditioning (Yang et al., 2021Residences account for almost 35% of worldwide energy consumption and 38% of greenhouse gas emissions, as stated in the United Nations Environment Programme's 2020 Emissions Gap Report (UNEP, 2020). Additionally, according to Tedaş 2022 Turkey Electricity Distribution Sector Report; for 2020, while residences have a 27.8% share in net electricity consumption in the world, residences rank third with a 21.5% share in the distribution of net electricity consumption by sectors in Türkiye (TEDAŞ, 2022). According to 2020 data, residences rank first among sectors with a 32.3% share in natural gas consumption (EPDK, 2021). According to the greenhouse gas inventory results, the energy sector ranks first in Türkiye with a share of 87.4% in total $CO_2$

emissions in 2019, 34.6% of which comes from electricity and heat production (TUIK, 2021). Looking at the current situation in Türkiye, it can be seen that the country has become dependent on foreign sources as the energy they produce cannot meet the energy consumed and energy consumption thus creating a significant burden on the economy (Yalçın and Doğan, 2023). Türkiye 's reliance on foreign sources for its energy supply grown steadily over the years. In 1990, it was at 52%, but by 2000, it had risen to 67%. In 2010, the dependency reached 70%, and by 2015, it had further increased to 76%. In 2020, five years later, the percentage reduced to 70%, primarily due to the rise in solar, wind, and geothermal energy sources (TEG, 2022). Despite the decline, this rate is still very high. Thus, it is of great importance to limit consumption in sectors that use non-renewable energy resources as soon as possible.

Housing is one of the main building types responsible for energy consumption and greenhouse gas emissions. Existing buildings should be prepared for future climate scenarios with structural strengthening or energy-efficient renovation. For this reason, working with sensitive climate data and achieving the most accurate results are among the important topics of discussion today.

In Türkiye, studies on energy saving and $CO_2$ emission reduction in residences came into force in 2007, when the Energy Efficiency Law was published in the Official Gazette No. 26510 dated 2/5/2007. The Energy Performance Regulation in Buildings (BEP) came into force one year after with the Official Gazette No. 27075 publication dated 05/12/2008. The preparation of the regulation was based on the European Union's "Energy Performance of Buildings Directive" No. 2002/91/EC (Energy Performance in Buildings Directive, 2008). In addition, energy identity certificates of buildings have started to be issued with the Bep-Buy program, which evaluates the energy performance of buildings (Aydın and Saylam, 2017). The inputs in this program have been determined with a focus on heating, according to the calculations and U values in the TS 825 (Thermal Insulation Rules in Buildings) standards regarding the limitation of energy demand for heating purposes in new buildings. However, it does not include any measures regarding the energy demand of buildings for cooling purposes.

In Türkiye, the BEP-BUY energy certification program is utilized to enhance the energy efficiency of buildings. This program establishes minimum U values for various components of the building envelope, or sets a certain norm for energy consumption in both new and existing structures. Nevertheless, the current research are inadequate in assessing the impacts of contemporary climate change and devising strategies for constructing energy-efficient structures. According to the data obtained from the General Directorate of Meteorology, when the HDD (Heating Degree Days) and CDD (Cooling Degree Days) values of Aydın Province are examined, it is seen that the difference between the two values has decreased since 2007. The closest results were seen in 2021. According to these results, HDD is 941 and CDD is 823. This shows that cooling loads have become as important as heating loads in this region. (Figure 1.1).

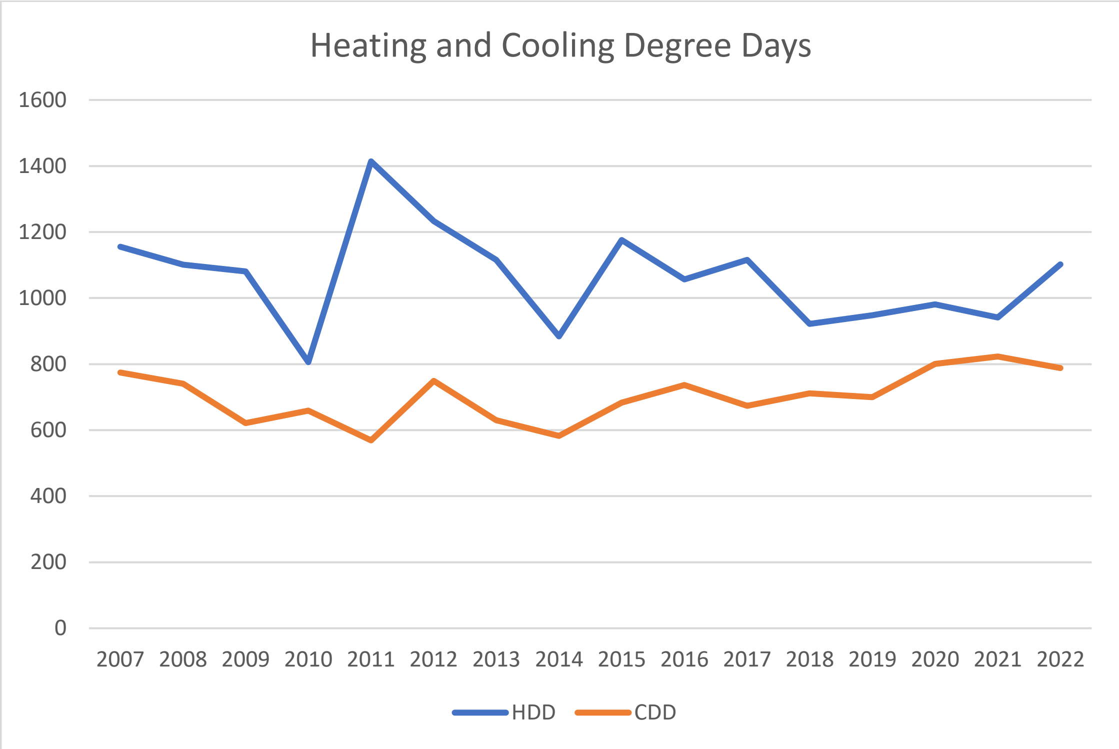



Figure 1.1. Heating and Cooling Degree Days Chart between 2007-2022 in Aydın

This study focuses on the main problem or issue that existing residential buildings are unprepared for future extreme climatic conditions (e.g. increase in air temperatures, thermal discomfort, and energy need, etc.). A comprehensive planning study is required to reduce the effects of climate change and adapt housing to changing conditions. If the effects of climate change can be minimized, the adaptation effort will be less, too. Therefore, energy-efficient renovation strategies for climate-compatible buildings need to be urgently developed and implemented (Gething and Puckett, 2019).

## 1.2. Research Aim and Scope

Currently, houses lack the necessary preparations to adapt to the shifting climate conditions caused by rising temperatures. Hence, it is crucial to assess the energy efficiency of buildings in their present condition and enhance cooling energy usage and thermal comfort conditions. Specifically, it should be assessed whether the enhancements are congruent with forthcoming climate conditions.

The selected residence is located in an area that accounts for 28.1% of the dwelling stock built in 2011-2021 and after in Türkiye (Figure 1.2). In addition, considering that the whole life cycle of a building is 50 years, it is intented to emphasize the importance of preparing the residences for new climatic conditions as much as possible within the framework of this cycle. It was also examined whether the regulations on energy performance of buildings in Türkiye provide sufficient precautions.

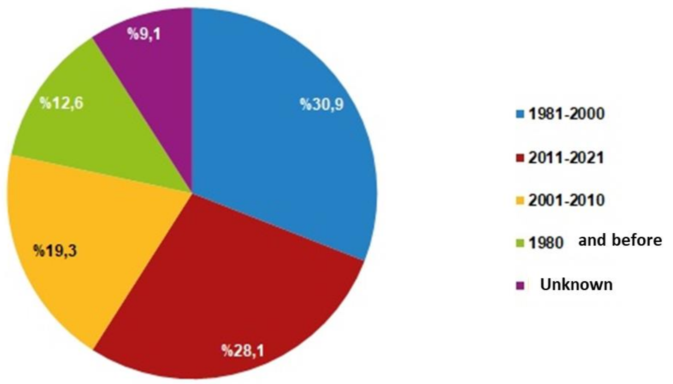



Figure 1.2. Proportion of house by construction year of the residential building (Source: TUIK, 2021)

Hypothetically entering microclimate data into simulation programs reduces the sensitivity and reliability of the studies about climate change and energy performance calculations. However, depending on the condition and environmental data of the house, microclimatic factors directly affect energy use and indoor thermal comfort in buildings. Therefore, the selected house was monitored with IoT-based sensitive data loggers for 11 months, a smulation model was prepared, and the calibration of model was achieved between this data and program data.

Answers to the following questions were sought for the study:

- Is the energy performance of the existing building sufficient to cover the effects of overheating specifically?

- In today's climatic conditions, what are the best retrofit scenarios to improve thermal comfort, and reduce the cooling energy consumption in the existing building?

- Are the improvements also effective in 2050 and 2080 climate change scenarios? What are the best improvement scenarios and outcomes in these conditions? (Will a particular design that is energy-optimized under current climatic conditions will remain energy-optimized in the future?)

The objective of this study is to assess the energy efficiency of residential buildings in their present condition, compare the existing situation with the projected climate conditions of 2050 and 2080, and conduct multi-purpose optimization to enhance thermal comfort and decrease cooling energy usage. The goal of optimization is to determine the most effective refurbishment scenarios that minimize cooling energy usage while enhancing thermal comfort. The study selected a 3-storey flat constructed in 2013 in the Nazilli district of Aydın province, Turkey. This region has a Mediterranean environment, which tends to warm up more quickly than other climates. One major factor contributing to the preference for this apartment complex is its adherence to consistent external construction standards. The majority of dwellings in Nazilli consist of 3+1 units. The heating system is powered by natural gas, while the cooling system is provided by air conditioning. Furthermore, given the significance of the user profile in determining energy use in a household, the study specifically chose an apartment with a high user density.

## 1.3. Limitations and Assumptions

In the thesis, some limitations and assumptions were encountered during the recording of indoor and outdoor climate data and the calibration of the simulation program.

1. In total, air temperature and humidity data could be recorded over approximately 11 months, from 01.08.2022 at 01:00 to 29.07.2023 at 15:00. The reason why the measurements could not be completed within a year is that the users in the house examined for the research changed the internet on July 29, 2023. Therefore, the

information flow on the gateway with IoT-based devices was interrupted and the data received from the cloud on the Internet was terminated.

2. Additionally, there is the data loss due to the internet connection problem between 29.05.2023 at 09:00 and 1.06.2023 at 00:00.

3. The process of calibrating the simulation model with the real data monitored was prolonged. Since the house had an active user profile, a detailed data entered to the model need more time. Besides, it was difficult to upload sensitive data correctly and control the process. However, looking at the totality of the project, working with this sensitive data allowed the researchers to get more accurate results.

4. The limitations arising from the dynamic building simulation software DesignBuilder are important for two reasons. First of all, since it does not contain all types of building components in Türkiye, the materials included in the TS825 standards used by the Bep-buy program were specially created when modeling the building, wall components such as pumice, insulated plaster, and windows, except for the door. The lamp values entered for electricity consumption are taken as averages since there are 3 types of lighting (LED, spot, bulb) in the rooms.

## 1.4. Structure of the Study

The thesis consists of five main chapters.

In the first chapter, the problem of the thesis is explained, and its purpose and research questions are stated. The limitations encountered during the thesis process and the assumptions that these limitations were transferred to the thesis are explained. Finally, the main parts of the thesis are explained.

In the second chapter, the effects of changing climate and overheating , which are the main subjects of the thesis, on the world and the Mediterranean climate are explained. Consequently, researchers are employing dynamic building modeling software to assess the influence of climate change on the energy efficiency of buildings and the effects of different retrofit scenarios.

The third chapter provides a comprehensive account of the chosen flat and the research methods employed in the thesis. It provides detailed information regarding the features and structural elements of the chosen building, as well as numerous schedules related to occupancy, HVAC systems, lighting, and other electrical devices.

Methodology, process characteristics, inputs (such as building envelope information), and the process of collecting microclimate data were the primary areas of attention in the study. Additionally, the simulation tool used, the creation process of simulation model, and the calibration methodology are explained. In the last section, the optimization method used for the best retrofit scenarios is mentioned.In the fourth Chapter, the results of microclimate evaluation, model calibration, simulations, simulation and optimization results, and a discussion of the results are presented.

In the last chapter, the 5th chapter, the overall results of the thesis are interpreted.

# CHAPTER 2

# LITERATURE REVIEW

This section highlights the impacts of climate change on the global scale and specifically focuses on the alterations brought about by rising temperatures in the Mediterranean region. An investigation has been conducted on the impact of this alteration on individuals and structures, particularly in the Mediterranean climate. Research on climate forecast scenarios (2050 in the medium term, 2080 in the long term) was examined. Lastly, this study encompasses optimization research on the impact and enhancement of overheating on the energy efficiency and thermal comfort of buildings.

## 2.1. Climate Change

Climate change is a significant and influential problem in the 21st Century, and there is a substantial amount of research that supports its causes and potential outcomes. The prevailing scientific agreement asserts that the primary driver of global climate change is predominantly the result of escalated emissions of greenhouse gases stemming from human activities. (Dino and Akgül, 2019)

The main cause of climate change is the disruption of the radiation balance on Earth. (Can, 2019). Natural greenhouse gases in the atmosphere ensure that the climate is balanced and that suitable living conditions are created for our world. However, gases such as carbon dioxide ($CO_2$), methane (CH4), nitrogen oxide (N2O), some synthetic chemicals, and aerosols have begun to accumulate uncontrollably in the atmosphere. This situation causes the short-wave solar energy to enter the earth and atmospheric system and the long-wave solar energy reflected from the earth to be retained in the atmosphere. Therefore, it causes warming to increase. The increase in this temperature also called the greenhouse effect, causes the climate and weather conditions to change and, accordingly, the conditions required for the environment in which living creatures on earth can live (Karamızrak, 2018).

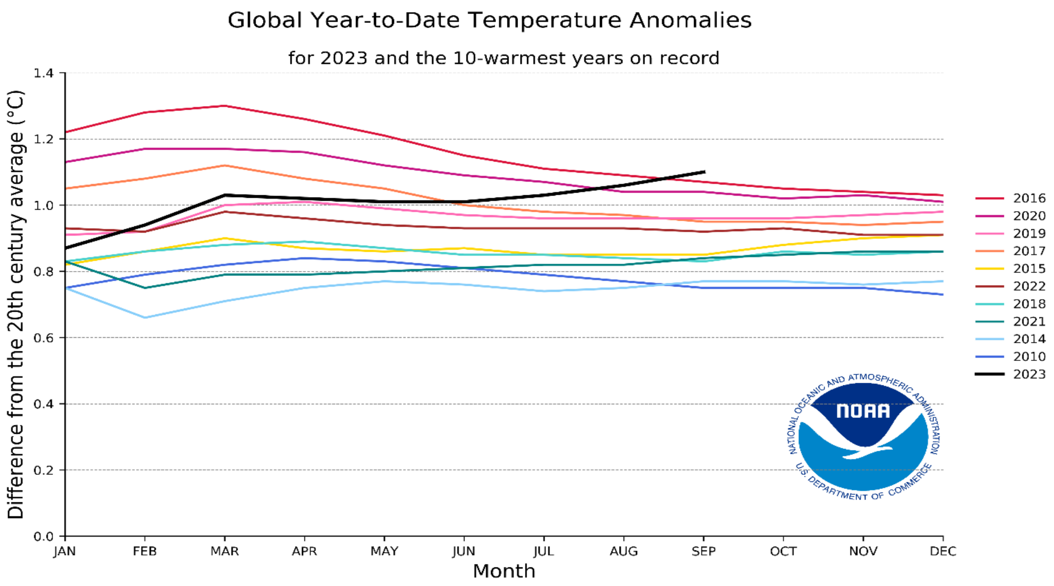



Figure 2.1. Global Year-to-Date Temperature Anomalies (Source: NOAA, 2023)

A comparison of the average temperature of the last 10 years is shown graphically in Figure 2.1. The January-September global surface temperature was 1.10°C (1.98°F), above the 1901-2000 average of 14.1°C (57.5°F), the warmest on the 174-year record. (NOAA National Centers for Environmental Information, 2023). According to climate forecast models, it is estimated that the winter season will be 1 to 3 weeks shorter and the summer season will be 1 to 3 weeks longer by 2050 (Roaf, Crichton and Nicol 2009). This transformation will lead to a change in the growing season of plants and will cause plants sensitive to extreme temperatures to become vulnerable. Global warming will cause the expansion of both desert and tropical regions in terms of land area due to prolonged higher temperature levels (IPCC 2018). According to IPCC reports, the surface temperature increase may range from 1.1 to 6.4 in 2100 (Alcamo et al. 2007).

In addition to increasing temperatures, climate change has caused increasingly irreversible losses and significant damage to terrestrial, freshwater, coastal, and open ocean ecosystems. Geographical shifts and biological adaptations to alterations in seasonal patterns are inadequate for dealing with climate change. Human-induced climate change is also responsible for the impacts of gradual processes on ecosystems, such as ocean acidification, sea level rise, and reduced precipitation. Climate change has exacerbated desertification and land degradation, particularly in low-lying coastal areas, river deltas, arid regions, and frozen regions (IPCC, 2023).

Climate change is expected to lead to changes in meteorological conditions that will affect current building performance, operation, and human behavior, including changes in air infiltration rates, air conditioning operation, and window opening patterns (Ilacqua et al. 2015). Because people spend their time mostly indoors during the day. Therefore, providing comfortable conditions in the artificial environment of space designs is of great importance in terms of user satisfaction, human health and comfort, and the quality of the space. Factors such as planning, temperature, air quality, and light level of the artificial environment have positive and negative effects on human health and comfort levels (Özkaya, 2023).

### 2.1.1. Mediterranean Climate Change and Overheating

The Mediterranean Basin has been affected by recent climate change at rates exceeding global averages, especially the air and sea have experienced faster warming in every season. Mediterranean countries are especially susceptible to changes in climate and environmental circumstances due to their strong dependence on economic activity and supporting infrastructure such as cities, ports, and farmland in low-lying river deltas. Several Mediterranean countries, particularly those in the southern and eastern regions, face significant economic strain and have limited financial resources available for adaption measures. The convergence of these elements contributes to the Mediterranean Basin being a focal point of climate change. While there are several locations worldwide that will experience the impacts of climate change presently and in the near future, this particular place is among the most vulnerable (Soed, 2020).

The Mediterranean region has experienced more significant changes in many factors related to climate than the global average. The present global mean surface temperature is around 1.1°C above pre-industrial levels, with a probable range of ±0.10°C. However, the Mediterranean region is nearing a temperature of 1.54°C (Figure 2.2), Cramer et al. 2018). In 2014, $CO_2$ emissions from Mediterranean countries contributed to almost 5% (1,954 Mt) of the total global yearly emissions (World Bank, 2019a).

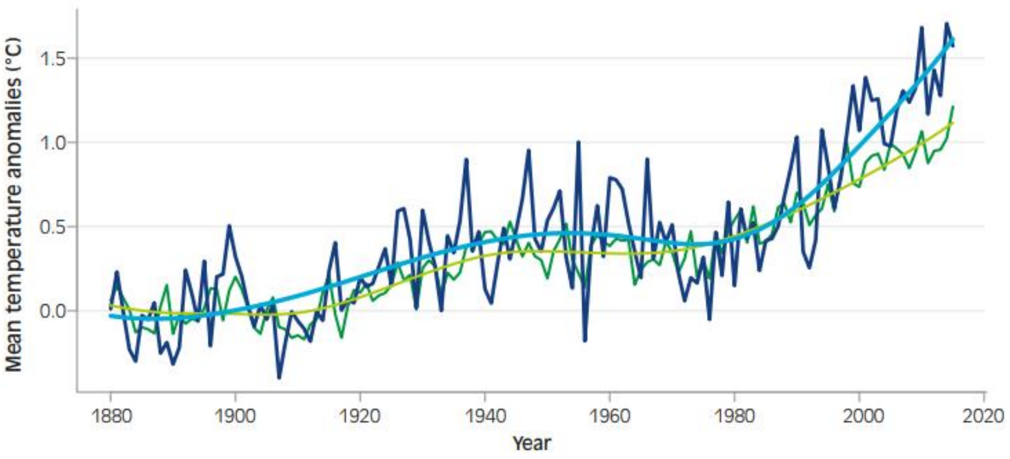



Figure 2.2. Historic warming of the atmosphere, globally and in the Mediterranean Basin (Source: Data from Berkeley Earth cited in Cramer et al. 2018)

Based on the First Mediterranean Assessment Report (2020) by the Mediterranean Climate and Environmental Change Experts Network (MedECC), the Mediterranean Basin has experienced significant impacts from climate change, particularly in relation to rainfall patterns and the hydrological cycle. For a particularly high greenhouse gas concentration scenario, temperatures are projected to increase by an additional 3.8°C to 6.5°C by 2100. Additionally, despite regional differences, precipitation will likely decrease by 10% to 30% in some regions, causing current water shortages and desertification. It is pointed out that increasing temperatures, especially in the summer months, will cause overheating problems and the use of air conditioning, and, accordingly, electricity consumption will increase to balance internal comfort conditions (MedECC, 2020).

## 2.2. Building Energy Performance

Buildings contribute to a minimum of 30% of global energy consumption, and their energy usage has been on the rise in recent times. Given the anticipated future climate circumstances, it is likely that this demand would further escalate. The yearly growth rate of building energy consumption is projected to be 1.5% from 2012 to 2040 (Cao, Dai, and Liu 2016).

### 2.2.1. Building Energy Simulation

Many academics utilize dynamic simulation tools to construct sustainable high-performance new structures or to generate retrofit concepts for existing buildings (Rafaat, 2019). These research contribute to the advancement of simulation-based computerized analysis tools by focusing on enhancing the design and performance aspects of buildings. Consequently, there has been significant progress in modeling development during the past two decades in the field of dynamic building simulation tools ( Ahn et al., 2013 ).

In the literature, some studies have examined building energy performance changing according to future climate scenarios using dynamic simulation tools and developed various renovation/improvement suggestions. In recent studies, it is seen that the use of 'optimization' methods has increased (Ervural et al., 2016). Much of the scientific literature on building energy optimization focuses on combining an optimization tool with building energy simulation software to optimize building energy efficiency.

EnergyPlus, DesignBuilder, IESVe, and TRNSYS are the most often utilized software for simulating building energy. There are multiple simulation programs available for a thorough analysis of entire buildings, as well as specific simulation tools for lighting, ventilation, HVAC components and systems, and other areas of building energy management. However, in studies in the literature based on energy optimization and prediction in buildings, most of the prediction models have been evaluated using a single data set or several data sets. This may cause incorrect generalization of the models created to estimate energy consumption and comfort conditions (Pham et al., 2020).

### 2.2.2. Effects of Climate Change (overheating ) on Building Performance and Energy Consume

Climate change is a major determinant of building energy performance. Because indoor comfort, energy usage, carbon emissions, and building maintenance costs may vary based on the local climate (Nematchoua et. al., 2023). Given the extended lifespan of buildings and the anticipated effects of climate change scenarios in the 21st century, it is crucial to do further study in order to comprehend the energy consequences of existing design choices (Wilde and Coley, 2012). Because most buildings are designed to last more than 50 years, they will be exposed to a warmer climate under changing climate conditions. Contemporary studies on the influence of climate change on the future functioning of buildings suggest that there will be a fundamental change in the energy efficiency of buildings. In climate-related energy consumption forecast studies, while there will be a significant increase in the cooling energy of buildings, a moderate decrease in heating energy use is predicted (Shen, 2017). In order to obtain meaningful outcomes, it is crucial to perform energy simulations of buildings for the purpose of design, optimization, and decision-making. Moreover, it is crucial to conduct these simulations utilizing forthcoming meteorological data, considering the impact of climate change on the energy efficiency of buildings and the level of thermal comfort they provide (Dias et. al., 2020).

The magnitude of the effects of climate change differs depending on the scenarios, case studies, and regions. Hence, given the potential health hazards faced by building inhabitants due to fluctuating climate conditions, it is crucial to proactively equip buildings at a regional level to anticipate various scenarios and mitigate issues like excessive heat and electrical failures (Tootkaboni et. al, 2021). Therefore, studies using local climate data are important.

There are also predictions for building energy consumption in future climate conditions although there are various studies in the literature on building energy performance and thermal comfort under today's conditions. Da Guarda et al. conducted an analysis on the susceptibility of a zero-energy building (ZEB) to the effects of climate change during the time periods of 2020 (2011 - 2040), 2050 (2041 - 2070), and 2080 (2071 - 2100). The findings indicated that as cooling energy consumption increases, there would be a corresponding rise in energy usage of 14.1% in the 2020s, 26.3% in the 2050s, and up to 40.2% in the 2080s.

In their study, Soutullo et al. (2020) specifically investigated the effects of climate change over the past ten years on two specific buildings in Madrid. They found that the yearly heating requirements decreased by approximately 22% while the cooling requirements increased by the same percentage (Soutullo et. al., 2020). Dino and Akgül (2019) evaluated the impact of climate change on residential reference buildings in various cities in Türkiye. Research was conducted on 768 scenarios for four cities (Izmir, Istanbul, Ankara, Erzurum) representing different climatic conditions in

Türkiye. For cities, it is predicted that in 2060, the average annual temperature will increase by 3.0–3.5 °C, while the ambient temperature will increase by 1.8–3.2 °C. It is anticipated that the fluctuating environment will lead to a decrease in the overall energy needs of buildings that do not have air conditioning, ranging from 21% to 49%. The anticipated rise in the cooling demand of air-conditioned buildings is predicted to be variable in magnitude. The computed findings emphasize the crucial significance of natural ventilation and the utilization of higher cooling set points in diminishing cooling energy consumption.

Currently, writers are focusing on optimizing the assessment of various passive retrofit solutions that enhance thermal comfort in the context of climate change, particularly for future research purposes. According to the research, night ventilation, window shading systems, and the use of reflective coatings for the building envelope are regarded to be highly successful methods for the CSA climate zone (Soutullo et. al, 2020 ). However, reinforcement measures based on these parameter results need to be evaluated for 2050 and 2080 climate projections.

There is no consensus in the literature on the impact of insulation on climate change among the parameters chosen to reduce cooling energy. Most studies show that better-insulated buildings, especially when combined with efficient glazing, will have a positive impact mainly on reducing heating energy consumption. Still, studies analyzing the impact on cooling demand are scarce (Andrić et al., 2019).

Rodrigues and Fernandes (2020) investigated the effects of overheating with building geometries and random heat transmittance values (U) in 16 different locations in the Mediterranean region. The simulations created were compared in terms of climate data for today and 2050. The average dry bulb temperature difference between the reference value and the 2050 projection varies between 1.8 °C and 2.9 °C in all locations. The research findings indicate that buildings with effective insulation are unlikely to experience excessive heat in the future. The desired U-values of upcoming construction materials are comparable to or lower than existing levels. Furthermore, it has been noted that in the majority of instances, the reduction in heating energy offsets the rise in cooling energy.

Muhammad et al. (2022) conducted an optimization study to improve energy performance in their research on a residential building in the Kuwait region, which has a hot and dry climate. The study showed that the most effective parameters on energy consumption and carbon emissions were building insulation, with a contribution of 33%

and 26%, respectively, while the cooling set point was effective with a contribution of 31% during uncomfortable hours. As a result of the optimization, the improvements made in energy performance reduced disturbance hours, energy consumption values, and carbon emissions by 62.8%, 39.3%, and 40.5%, respectively.

Ascione et. al. (2017), carried out an optimization study to find the best strategies that provide optimum energy consumption and the most affordable cost for a typical residential building in Naples, which has a Mediterranean climate. The resulting solution includes the use of thermal insulation, plastering, and radiation properties of the exterior walls and roof, double-glazed, air-filled low-e window systems (Uw = 1.69 W/m 2 K), as well as the use of existing energy systems with condensing boilers and efficient air cooling, recommends changing it to electric cooling.

De Masi et. al. (2021), examined the energy performance of a selected residential building in a climate dominated by cooling, with the current situation, 2050 and 2080 climate scenarios. As a result of the study, they concluded that traditional parameters such as selected low-emission windows, cool roofs, insulation, and shading elements are not sufficient against the expected climate change. It has been observed that the most effective parameters in the current scenario are the insulation of the opaque coating, the installation of selected windows and external shades, as well as the cold paint applied to the roof. As a result of the applications, it was observed that the reduction in cooling energy varied between 44% and 55%, while the reduction in heating energy varied between 19% and 23%.

Fabrizio Ascione (2017) did a literature analysis to examine energy-saving techniques and factors for buildings in order to comprehend the impacts of climate change and reduce cooling energy consumption. In these studies, it was seen that the most effective passive strategies to reduce the coolingenergy consumption are the use of cold colors on the facade, thermal mass, sun curtains, and natural ventilation. Moreover, although cooling demand is predicted to grow continuously, envelope optimization is suggested to be one of the most effective adaptation measures against future climate change variability, regardless of the climate type (Shen et. al. 2020).

Li et al. (2023), in their study on residential buildings in Huangshan, China, examined the change in the building envelope in the current situation and the 2050 climate scenario to optimize building design by considering climate change. As a result, according to 2020, 2020-2050, and 2050 meteorological data, roof heating permeability was determined as 0.38, 0.26, and 0.19, respectively. Specifically, according to the dynamic meteorological data of 2020, 2020-2050, and 2050, the optimum ground floor brick thickness was determined as 0.28 m, 0.32 m, and 0.4 m.

The majority of researched optimization studies have focused on building energy optimization with constant building load parameters (e.g. building internal loads, infiltration, etc.) under current climate conditions (Nyguen et al 2014). However, studies investigating the design of energy-optimized buildings in future climates are fewer than those examining designs optimized in current climates. In short, there are very few studies to evaluate the energy consumption of using a current climate-optimized building in a future climate. (Bamdad et al. 2021)

Andreu et. al. (2018), conducted an optimization study on heating and cooling energy consumption and improvement due to climate change in a house with a Mediterranean climate. While the parameters determined during optimization such as infiltration, insulation thickness, glass and frame type, window area, and heat recovery control reduce heating energy as much as possible; parameters such as shading devices, natural cross ventilation, and control of extra mechanical ventilation were effective in reducing cooling energy consumption. When all measures are implemented, at least 80% of total energy savings were achieved in the 2050 climate scenario, and at least 65% of total energy savings were achieved in the 2100 climate scenario. Window shades, increased thermal insulation, and reduction in leakage have been shown to have a greater impact in terms of global energy demand.

Bamdad et. al. (2021) sought an answer to the question of whether a design that is energy-optimized under current climate conditions will remain energy-optimized in the future. For the study, one office building in two cities in Australia, Canberra and Brisbane, was examined. Insulation thickness (0-15 cm), window type (clear, reflective, Low-E, tinted), and overhang dept (0-1.5m) were selected as parameters in optimization. As a result of the study, a 60% reduction in heating load is observed, while a 19.6% increase in cooling load is expected. It has been shown that under current climate conditions, the optimized building could deliver energy savings of up to 28% and 24% in the future (i.e. 2080 projected climate scenario) for the cities of Canberra and Brisbane respectively. This means that the energy-optimized design under current climate conditions will remain (almost) optimized in the future for both cities.

One significant consequence of climate change on cooling energy is the projected rise in temperatures, which is expected to lead to a corresponding increase in the need for air conditioning. Consequently, there will be a surge in power usage.

Santamouris et.al. (2015), pointed out that a 1 °C increase in urban temperature can cause an increase in electricity demand in the range of 0.45% - 4.5%. Figueiredo et. get. (2020) examined the future (2050) housing stock increase in Portugal and the changes in electricity consumption and cooling and heating energies. The study found a possible rise of 5% to 60% in the total electricity usage in the sector. In addition, there is an anticipated 33% drop in space heating, while there is a potential 20-fold improvement in space cooling. Zhang et. al (2022), in a study conducted in China, found that an extra day when the average temperature exceeds 32°C, it has been observed that a day in the range of 10°C–16°C leads to an 8.9% increase in annual electricity consumption. In a study conducted in Malaysia, it was observed that the probability of turning on the air conditioner in residences was highest at an indoor temperature of 32°C, and the probability of turning it off was highest at 26°C (Aqilah et. al 2021).

In the literature review, 20 studies were examined to evaluate the future energy needs of buildings, and dynamic simulation techniques were used in 17 of them. 6 study, the optimization method was used to improve energy consumption under current conditions. Additionally, 6 studies used the CCWorldWeatherGen calculation tool for climate scenarios. Only two studies have sought to answer the question of whether the existing optimized building remains optimized in the 2050 and 2080 climate scenarios. While calculating the heating and cooling enegy consumption of 14 studies, 4 studies focused only on the cooling effect.

The literature review emphasizes the growing interest in studying the impact of climate change on the energy efficiency of buildings. Nevertheless, research mostly concentrates on scrutinizing the energy efficiency of the structure in situations where its existing configuration is taken into account. This subject necessitates additional research owing to the multitude of uncertainties linked to the input meteorological files, climate model outputs, and IPCC emissions scenarios. Given the significance of intervening in preexisting structures to accomplish societal objectives over a moderate to extended duration, there is a scarcity of research examining the notion of resilience for buildings undergoing energy retrofit (De Masi et al. (2021).

Table 2.1. Key attributes of the studies discovered through a systematic literature review

| Publication Date | Authors | Type | Country | Climate | Building Type | CCWorldWeatherGen | Future Climate Forecasts | Method | Parameters | Energy Consumption | Optimization |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | Modeste Kameni Nematchoua, Mahsan Sadeghi, Sigrid Reiter, Shady Attia, | Paper | Australia, Tunisia, USA, Libya..Russia, Kazakhstan, Finland | Desert climate and coldest region | residence, school, hospital, hotel | × | 2050-2100 | Design Builder, energy plus | Photovoltaic panels wind energy, natural ventilation | Heating, cooling, Annual | × |
| 2021 | Mamak P.Tootkaboni *ORCID,Ilaria Ballarini ORCID,Michele Zinzi ORCID andVincenzo Corrado | Paper | Italy | Hot-summer Mediterranean climate | residential buildings | ✓ | 2050 | Time Series, energy plus | Shape factor,window-to-wall,envelope components, | Heating, cooling, thermal comfort | × |
| 2019 | Ipek Gürsel Dino, Cagla Meral Akgül, | Paper | Türkiye | Mediterranean | residential buildings | × | 2060 | Energy plus, | Building orientation angle (Ɵ) | heating, cooling, thermal comfort | × |
| 2021 | Debaditya Chakraborty , Arafat Alam , Saptarshi Chaudhuri , Hakan Başağaoğlu , Tulio Sulbaran , Sandeep Langar | Paper | ABD | Hot–humid, mixed–humid climate | residential buildings | × | 2020 between 2100 | Energy plus, Al, calibration, coloration | Wwr, cooling type, number of floors, floor height | heating, cooling | × |
| 2020 | David Bienvenido-Huertas , Daniel Sanchez-García , Carlos Rubio-Bellido , | Paper | Spain | Mediterranean | residential buildings | ✓ | 2050 and 2080 | design builder and | Wall insulation | heating, cooling, annual | × |
| 2021 | Rosa Francesca De Masi , , Antonio Gigante , Silvia Ruggiero , Giuseppe Peter Vanoli | Paper | Italy | Mediterranean (Csa) | residential buildings | ✓ | 2050 and 2080 | statistical analysis, energy plus, sensor | Cool roof, external shadings, window type, insulation | heating, cooling | × |
| 2020 | Eugenio Rodrigues, Marco S. Fernandes | Paper | Mediterranean | Mediterranean | residential buildings | ✓ | 2050 | statistical analysis, energy plus | Wall insulation, wall type | heating, cooling | ✓ |
| 2020 | Raquel Figueiredo, Pedro Nunes, Marta J. N. Oliveira Panão, Miguel C. Brito, | Paper | Portuguese | Mediterranean | residential building | × | 2060 | Monte Carlo-based approach | Wall U value, thermal bridges, opaque envelope area, Ceiling-to-floor height | heating, cooling | × |
| 2020 | Soutullo, S.; Giancola, E.**;** Jiménez, M.J.; Ferrer, J.A.; Sánchez, M.N. | Paper | Madrid, Italy | Mediterranean (Csa) | residential building | × | 2050 | TRNSYS dynamic simulation program, MATLAB, statistical analysis, | Night-time ventilation, window mobile shading devices, evaporative systems, reflective coatings | Heating, cooling, thermal comfort | × |
| 2017 | Fabrizio Ascione | Paper | × | × | residential building | × | 2050 and 2080 | Literature review | Sun shades, cool colors, thermal mass, natural ventilation | Cooling | × |

Table 2.1. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2021 | Mamak P. Tootkaboni, Ilaria Ballarini, Vincenzo Corrado | Paper | Italy | hot-humid (Cfa) | " | × | 2040 and 2100 | Energy Plus | Wall-roof u value, window type | heating, cooling | × |
| 2020 | Heba Elsharkawy, Sahar Zahiri | Paper | Londra | A temperate oceanic climate (Cfb) | residential building | × | 2030, 2050, and 2080 | The survey, design builder, sensors | Wall U value, user occupancy | Heating, cooling, thermal comfort | ✓ |
| 2022 | Seyed mohammad Ebrahimi Saryazdi , Alireza Etemad , Ali Shafaat , Ammar M. Bahman | Paper | Kuveyt | hot and dry, (BWh) | residential building | × | × | ANN, optimization, Energy Plus | Wall insulation, cooling set point | Annual, thermal comfort | ✓ |
| 2021 | Naja Aqilah , Sheikh Ahmad Zaki , Aya Hagishima , Hom Bahadur Rijal , Fitri Yakub | Paper | Malaysia | Hot, humid tropical climate ( Af ) | residential building | × | × | Statistical Package for Social Sciences (SPSS) Statistics Version 25, SURVEY, DATA MEASUREMENT | total electricity consumption, air conditioner electricity consumption, and indoor temperature | thermal comfort, cooling | × |
| 2017 | Fabrizio Ascione, Nicola Bianco, Rosa Francesca De Masi, Gerardo Maria Mauro, Giuseppe Peter Vanoli | Paper | Napoli,Italy | Mediterrian (Csa) | residential building | × | 2050 | Energy Plus and Matlab, optimization | wall-roof thermal insulation, external plaster radiation properties, window type, HVAC | Annual, Heating, cooling | ✓ |
| 2018 | Víctor Pérez-Andreu , Carolina Aparicio-Fernández , Ana Martínez-Ibernón , José-Luis Vivancos | Paper | Spain(Csa) | Mediterrian | residential building | × | 2050-2100 | TRNSYS simulation program, YSA | Wall insulation, window type, shading elements, mechanical ventilation Wall insulation, window type, shading elements, mechanical ventilation | Annual, Heating, cooling | ✓ |
| 2021 | Rajat Gupta, Alastair Howard, Mike Davies, Anna Mavrogianni, Ioanna Tsoulou, Nishesh Jain, Eleni Oikonomou, Paul Wilkinson | Paper | Londra | A temperate oceanic climate (Cfb) | older care home | × | 2080 | Design Builder, sensors, | Night ventilation, external shading, wall type | Thermal Comfort, cooling | × |
| 2021 | Keivan Bamdad , Michael E. Cholette , Sara Omrani , John Bell | Paper | Australia | Cfa, Cfb | office | ✓ | 2080 | Energy Plus | izolasyon ,pencere tipi, overhang dept | cooling, annual | ✓ |

Table 2.1. (cont.)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | Zhixing Li, Yafei Zhao, Huijuan Xia, Shujing Xie | Paper | China | Humid continental climate (Dfb) | residential building | × | 2050 | Rhino and Grasshopper, BIM, Energy Plus | Wall-roof İnsulation, wall type, window type | heating, cooling | ✓ |
| 2023 | Elçin Özkaya | Thesis | Ankara, Türkiye | Hot humid continental climate (Dsb) | university | ✓ | 2050 and 2080 | Energy Plus | Shading elements, Wwr, window type, night ventilation | × | × |

## 2.3. The Things of the Internet (IOT)

The case building selected in Aydin is equipped with one indoor (living room) IoT device equipped with a PIR motion sensor to measure temperature, humidity, and user occupancy, and one outdoor IoT device to measure humidity and temperature. First, smart sensors are combined with a physical device (computer, phone, etc.) to collect real-time status, operating conditions, or location-related data. These environmental data (indoor air temperature, humidity ) and occupancy rate are set to be sent by IoT devices every 15 minutes and connected via the internet with a gateway device. Efficient data collection has been achieved by the utilization of Long Range Wide-area Networks (LoRaWAN), which are low-power wide area network (LPWAN) technologies. By discussing the interconnection of sensor devices for utilization in the Internet of Things (IoT) (Santa et. al., 2020). Wide-range large area networks (LoRaWANs) connect mobile, secure, bi-directional battery-powered devices. The LoRaWAN specification defines three device types: Class A, Class B, and Class C. All LoRaWAN devices are Class A implemented, and Class A devices support bidirectional communication between a device and a gateway. Uplink messages (from device to server) can be sent at any time. Lorawan network architecture consists of four parts: end device node, gateway, network server, and application, as shown in Figure 2.3 (Lora-alliance, 2015). The Lorawan device that will be used for this study is the Lorawan device type A/C class (configurable) Elsys's ers eye device.

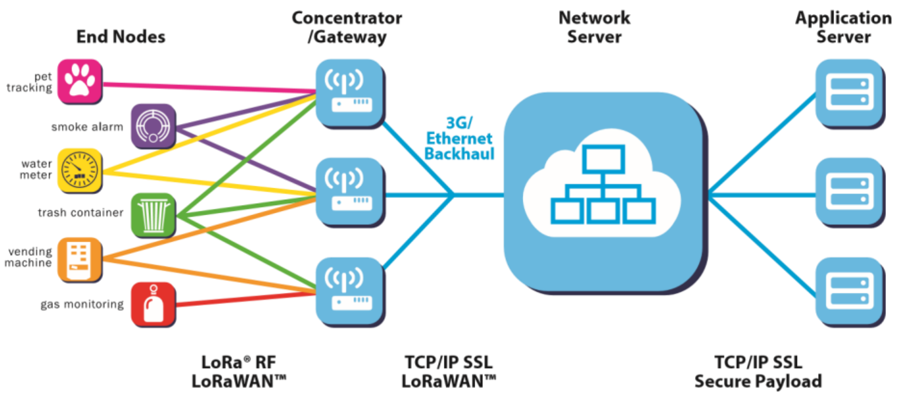



Figure 2.3. Lorawan network Architecture (Source: Lora-alliance, 2015)

All sensor settings are configured wirelessly via an NFC (Near Field Communication) enabled smartphone/tablet app or via the network server and connection data to the sensor. After the device is installed, a cloud computing network will be used to ensure that the data flow is not interrupted, and real-time monitoring and access to the data are provided. For this purpose, a Lorawan-supported Things network account has been opened. Things Network is a protocol and infrastructure that provides connectivity from LoRa gateways to cloud applications. All IoT devices were registered to this application and later integrated from the (webhook) tab. When ThingSpeak integration with Things Network was established, the collected sensor data was automatically transmitted to ThingSpeak™.

The most important reasons for choosing Thingspeak as the IoT platform in this study are; being able to instantly retrieve data from devices from the cloud environment via the internet, regardless of time and place. Furthermore, it is feasible to generate immediate visual representations of real-time data without the need for coding using Matlab. The method suggested by this study is to transfer data in an integrated manner in the shortest way and to minimize data loss. The connection diagram of the IoT data flow is presented in Figure 2.4.

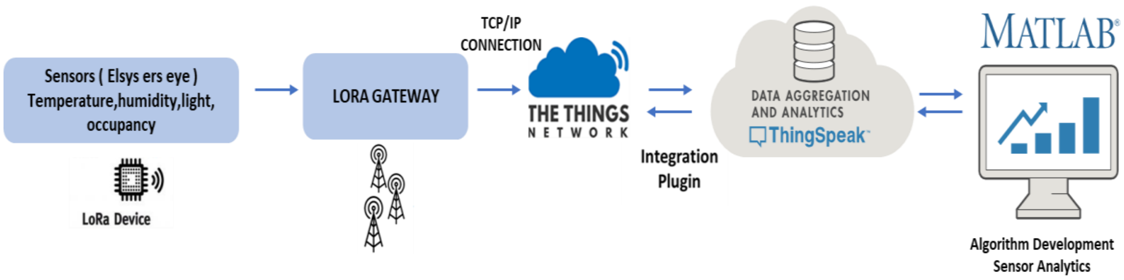



Figure 2.4. IoT devices data flow diagram

# CHAPTER 3

# METHODOLOGY

In this section, firstly, the method of the thesis is explained. Accordingly, first the material materials of the selected building were collected and entered into the dynamic simulation model. During this process, environmental (temperature, humidity) data of the building were monitored for 11 months. These data were also transferred to the dynamic simulation program. Afterwards, 2049-2050 and 2079-2080 climate predictions of these climatic data were created and analyzed. Finally, the optimization process was carried out by determining certain parameters.

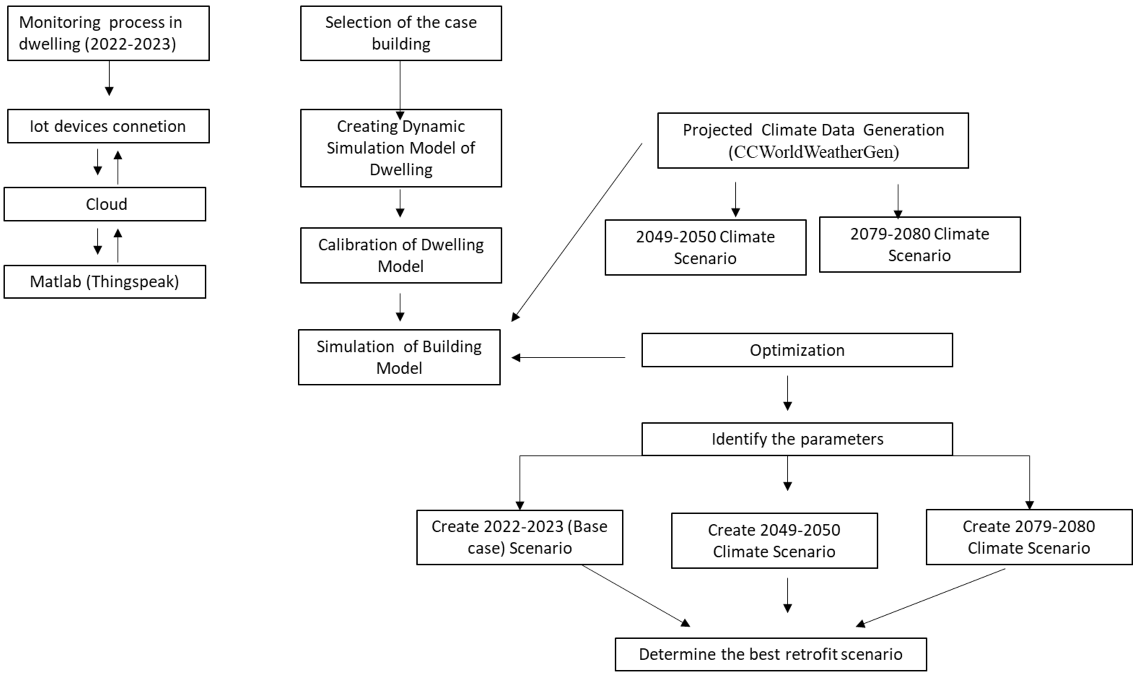
## 3.1. Study Design

First of all, the sensitivity to the climate and the energy performance of a house selected in the Nazilli district of Aydın, where the Mediterranean climate is observed, are examined. For this, it is first monitored with data logger devices. Then, instant data is recorded in the cloud environment with IoT devices and visualization and analysis studies are carried out thanks to the IoT platform. In addition, temperature threshold values are determined for situations that fall below or exceed a certain temperature, and alarms are generated. Differences between data from data loggers and IoT devices were observed and analyzed in detail with this difference. Then, a dynamic simulation model of the house was created and calibrated with the environmental data obtained. Afterwards, the calibrated model was used to investigate cooling energy consumption and disturbance hours. The bian performance of this model was analyzed for 2049-2050 and 2079-2080 climate forecasts. As a result, the optimization process was carried out by determining the design variables for 3 different climate scenarios. According to the results of the study, optimization studies were carried out and optimum scenarios were selected. These scenarios are compared with current situation and future climate scenarios.

The thesis technique comprises a series of sequential studies (Figure 3.1). The studies establish the foundation for the subsequent phase to commence. Some research seek to validate their findings by comparing them with one another.

## 3.2. Case Building

Table 3.1. Methodology flowchart




The selected flat is the first floor of a 3-storey residential building in Nazilli, Aydın. Its coordinates are 37.54 N and 28.18 S. It is 74 m above sea level. The construction year of the building is 2010. In the selected building, the ground floor and the first floor have the same plans and systems (3+1), differ in terms of user profile and number, and the last floor is a duplex. The building (Fig.3.2. (b)) has a separate layout and has a garden on all four sides. In addition, there are balconies on each side of the apartment. While the gross area of the flat is 179 m², its net area is 116 m².


(a) (b)

Figure 3.1. (a) Location of the building on the site view and (b) Plan of the residence

An essential aspect of studies that aim to determine thermal comfort as an objective is the evaluation of the microclimatic features and climatic classification of a location, typically using the Köppen-Geiger classification (Nikolopoulou and Steemers, 2003). The geographical location of Türkiye exhibits a diverse range of climatic elements that predominantly impact the estimation of thermal comfort. Aydın falls inside the mild temperate zone (Csa) according to Köppen's climatic classification (Çetinkaya, Aydın, and Öztürk 2017). The Aegean coastal region, including Aydın, experiences a dry-hot Mediterranean climate. Fig. 3.3 displays the Köppen climatic classification for the region where Aydın is situated.

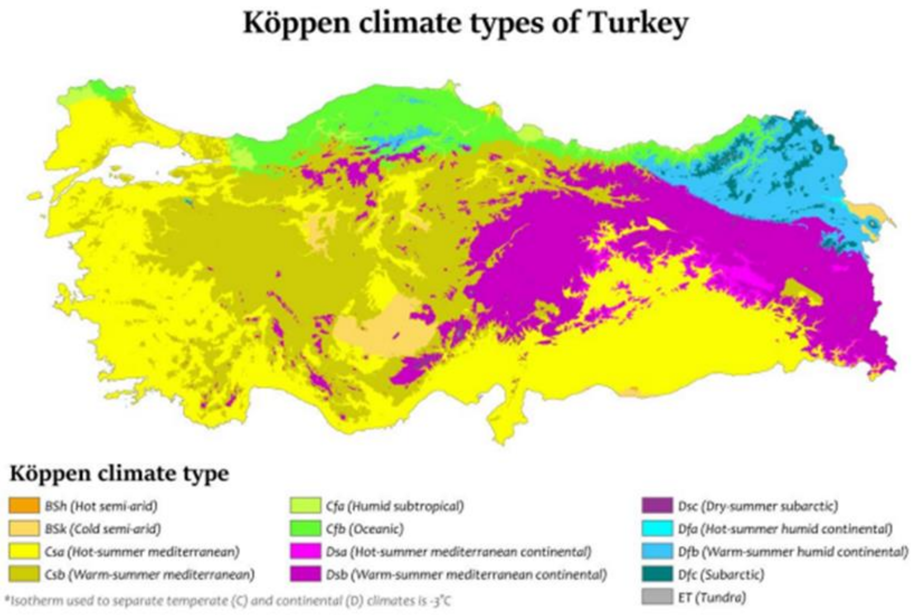



Figure 3.2. World map of Köppen-Geiger Climate Classification
(Source: Rubel and Kottek 2010)

Based on data from the General Directorate of Meteorology (MGM), Aydın experiences an average annual temperature of approximately 17.7◦C. Monthly average temperatures range from 8.1◦C in January to 28.2◦C in July. The values of 42.6 ◦C for May and 39.6 ◦C for October, measured in 2020, are above the seasonal normals and are extremely high values. In addition, August 2021, when the highest temperature was seen at 45.1 ◦C to date, is also a new record. This is an indication that the climate is starting to change.

Aydın, which has a mild climate in winter, monthly precipitation changes between 5.8 mm (in August) and 126.2 mm (in December). The region receives the highest precipitation during the winter months. In Aydın, the wind has a speed of 10.8 km/h, while a maximum of it is recorded as 77 km/h on the 27th of July, 1975. The prevailing wind direction of Aydın is East, secondary prevailing wind direction is west-northwest due to seasonal changes.

### 3.3. Experimental Setting

Within the scope of the study, two IoT devices made measurements between 01.09.2022 and 29.07.2023. To transfer the data received from this device to the internet, the gateway device was installed in the unused master bathroom. The locations of these devices in the house are shown in Figure 3.4.

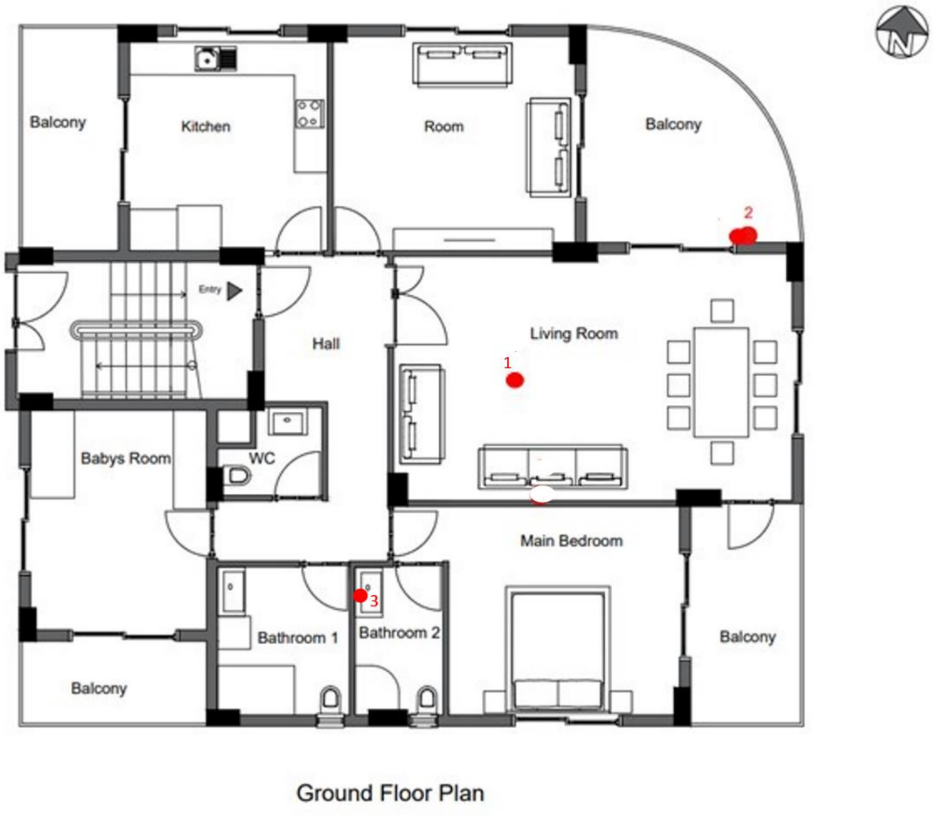



Figure 3.3. The location of the measuring devices on the house plan
(1,3: indoor, 2: outdoor)

The device, which was installed outdoors, was placed at a height of 1.80 m from the ground. The device installed in the interior (living room) is mounted on the ceiling to detect user occupancy. Refer to Figure 3.5. (a) for visual representation. The device utilized in this study measures indoor temperature and occupancy, while also capturing humidity data. However, it is important to note that indoor humidity is not considered as one of the characteristics in this particular research. The reason for this is that we can only get the data of four parameters for free on the Thingspeak platform. Therefore, interior room humidity data is not included among the four parameters. The IoT device, which measures the outside temperature and humidity, is mounted on the balcony at a height of 1.8 m from the floor (Figure 3.5. (b)). In addition, the sensor (gateway) that will connect the data in these IoT devices with the cloud environment is mounted in the parent bathroom as storage. The biggest reason for choosing this room is that it is an area that the child cannot reach.


(a) (b)

Figure 3.4. (a) View from the residential hall: IoT device (1) used to measure indoor temperature and occupancy rate (b) View from the balcony: Iot device (2) to monitor outdoor temperature and relative humidity

Within the scope of the study, the EM300-TH-868 M Milesight brand IoT device purchased from England via cargo was installed on the exterior (northeast balcony) of the house on 14.08.2022 (Fig 3.4. (b)). The ERS2 Eye brand IoT device purchased from Switzerland by cargo was also mounted on the ceiling of the hall on 01.09.2022 to measure the interior temperature and occupancy rate (Fig. 3.4.(b)). Internal temperature, user occupancy rate, external temperature, and humidity parameters were measured between 01.09.2022 and 29.07.2023 from both devices. The device that measures indoor temperature and occupancy also measures humidity, but indoor humidity is not included in the parameters in this study. The reason for this is that we can only get the data of four parameters for free on the Thingspeak platform. Therefore, interior room humidity data is not included among the four parameters.

The internal and external range and accuracy ranges of the IoT devices used for the study are shown in Table 3.1. The temperature range for the Ers-eye device used for indoor use is between 0 °C and +50 °C. The margin of error in this range is 0.2 °C. It is seen that this value varies between -30 °C and +70 °C for the IoT device called EM300-TH-868 MMilesight, which measures outdoor data. The margin of error in this range is +0.3 °C. For Rh sensitivity, the sensitivity value ranges from 0% to 100% ±3% from 10% RH to 90% RH, (±5%) from under 10% RH and above 90% RH.

Table 3.2. Features of indoor-outdoor IoT devices
(Source: Elys.se datasheet,2019, EM300-THDatasheet )

| **Sensor** | | | |
|---|---|---|---|
| ERS2 Eye | Temperature | 0°C to 50 °C | ±0.2 °C from 0° to 50°C |
| ERS2 Eye | Humidity | 5% to 95% RH | ± 2% RH from 10 to 85% RH |
| ERS2 Eye | Occupancy | Up to 5 meters | |
| EM300-TH-868 MMilesight | Temperature | -30°C to + 70°C | (±0.3°C) from 0°C to + 70°C (±0.6°C.) from -30°C to 0°C |
| EM300-TH-868 MMilesight | Humidity | 0% to 100% RH | (±3%) from 10% RH to 90% RH, (±5%) from under 10% RH and above 90% RH |

The measurement data of IoT devices were obtained from Thingspeak, an IoT platform, through the Internet. The Thingspeak platform is a cloud-based service that enables the collecting, display, and analysis of real-time data streams in the field of Internet of Things (IoT) analytics. One can transmit data from various devices to ThingSpeak, generate real-time visual representations of the data, and issue notifications. Furthermore, with the Matlab program connection, all the received data may be evaluated using Matlab. The data gathered in Thingspeak within the cloud environment were transmitted to Matlab, where hourly averages were computed. Subsequently, visualizations and analyses were conducted within the Excel platform.

## 3.4. Simulation Models

The study employed the Design Builder simulation program to analyze the energy performance and thermal comfort of buildings. The DesignBuilder simulation program (DB) is a sophisticated modeling tool that utilizes the EnergyPlus (E+) calculation method and features a user-friendly interface. This software is utilized by architects and engineers to analyze the energy usage in buildings. The architectural design of the house, including the floor plans, cross-sections, and visual aspects, were obtained from the project's architect using the Autocad software. Subsequently, the floor plans underwent a process of simplification and were transformed into the dxf format before being transmitted to the Design-Builder program. A model was created based on floor plans by dxf files, the living room, kitchen, baby room, bedroom, parent's bathroom, main bathroom, hall, and toilet areas were modeled. Once all openings have been modeled, the creation of the modeling process is complete. The modeling part was finalized after all openings (doors and windows) were modeled (Figure 3.6).

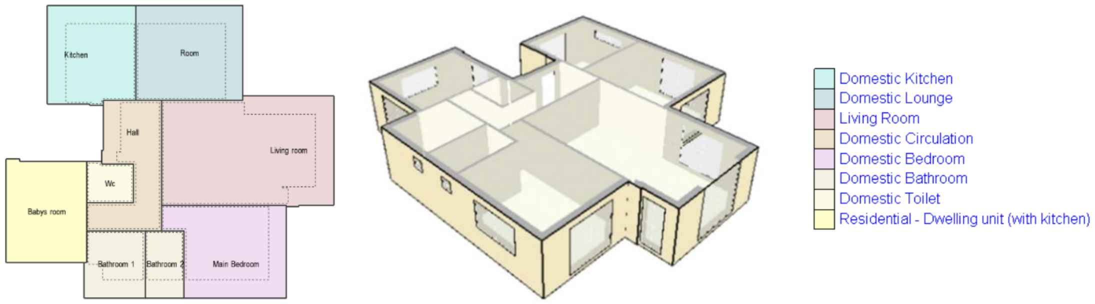



Figure 3.5. Simulation Model

Residential building material information was obtained from the contractor and project architect. HVAC information, and heating and cooling system information were also obtained by the building's contractor. The number and location of air conditioners in the building were learned by the tenants living in the house. Again, HVAC set points were obtained from temperature data provided during the year. After entering this information, the buildings surrounding the building, grass areas, etc. were modeled (Figure 3.7).

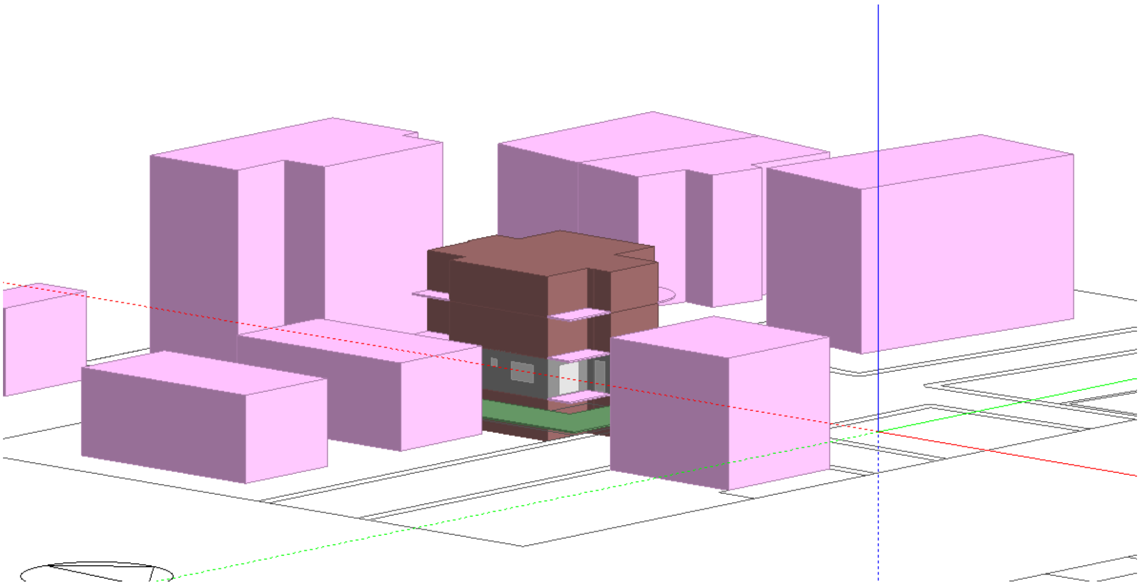


Figure 3.6. Exterior View of Simulation Model

### 3.4.1. Structural Components

Tables 3.2, 3.3, 3.4, 3.5, and 3.6 contain the material details and U values of the structural components of the selected residential building. Layer thicknesses were decided based on the drawings in the AutoCAD files and the information received from the mechanical engineer. These components are created from materials found in DesignBuilder's material library. The thermally insulated plaster detail only on the exterior wall was defined in DesignBuilder by taking the features in the Bep-Tr program and creating new material. U value, density, conductivity, and specific heat information of the building components in the tables were created by DesignBuilder according to the layer of the components.

#### 3.4.1.1. Walls

The chosen house has an outside wall thickness of 24 cm. Table 3.2 displays the conductivity (W/m-K), specific heat (J/kg-K), density (Kg/m3), thickness (m), and total U-value of the layers in the outer wall.

Table 3.3. Information on external wall materials (Source: DesignBuilder, 2023)

| COMPONENT | MATERIAL LAYER | CONDUCTIVITY (W/m-K) | SPESIFIC HEAT (J/kg-K) | DENSITY (Kg/m3) | THICKNESS (M) | U - VALUE (W/m².K) |
|---|---|---|---|---|---|---|
| External Wall | Plaster with insulation | 0.1 | 840 | 324 | 0.03 | 0.664 |
| | BIMS | 0.19 | 1000 | 715 | 0.19 | |
| | Cement/Plaster | 0.72 | 840 | 1860 | 0.02 | |
| | Gypsum Plasterboard | 0.25 | 1000 | 900 | 0.002 | |

The internal wall thickness of the selected house was determined as 9 cm. Layer information and the total u-value of the wall are shown in Table 3.3.

Table 3.4. Information on internal wall materials (Source: DesignBuilder, 2023)

| COMPONENT | MATERIAL LAYER | CONDUCTIVITY (W/m-K) | SPESIFIC HEAT (J/kg-K) | DENSITY (Kg/m3) | THICKNESS (M) | U - VALUE (W/m².K) |
|---|---|---|---|---|---|---|
| Internal Wall | Gypsum Plaster | 0.51 | 960 | 1120 | 0.01 | 2.115 |
| | Cement/Plaster | 0.72 | 840 | 1760 | 0.02 | |
| | Brick | 0.72 | 840 | 1920 | 0.85 | |
| | Cement/Plaster | 0.72 | 840 | 1760 | 0.02 | |
| | Gypsum Plaster | 0.51 | 960 | 1120 | 0.01 | |

#### 3.4.1.2. Floors

Ground floor layers and their detailed information and U-value are shown in Table 3.4. Since it is a mezzanine floor, the floor and roof have the same layers. These layers consist of hollow block flooring, screed, foam polyurethane, and ceramic coating. The biggest reason why floors are ceramic is that heat conduction is better in houses with underfloor heating and HVAC systems.

Table 3.5. Information on internal floor materials (Source: DesignBuilder, 2023)

| COMPONENT | MATERIAL LAYER | CONDUCTIVITY (W/m-K) | SPESIFIC HEAT (J/kg-K) | DENSITY (Kg/m3) | THICKNESS (M) | U - VALUE (W/m².K) |
|---|---|---|---|---|---|---|
| Internal Floor | Gypsum Plasterboard | 0.25 | 1000 | 900 | 0.002 | 0.652 |
| | Cement/Plaster | 0.72 | 840 | 1760 | 0.02 | |
| | Concrete | 1.9 | 840 | 2300 | 0.3 | |
| | Foam-Polyurethane | 0.028 | 1470 | 30 | 0.03 | |
| | Floor /Roof screed | 0.41 | 840 | 1200 | 0.02 | |
| | Ceramic | 1.4 | 840 | 2500 | 0.015 | |

### 3.4.1.3. Windows and Doors

The home contains a total of 12 windows. Table 3.5 displays that the glazing type for all the windows in the building is 4mm double clear, with a U-Value of 2.56 (W/m²-K). Within the residence, there exists a solitary external entrance constructed from steel. The internal doors are constructed from wood. Table 3.6 provides the specifications. Furthermore, the base example has a window-to-wall ratio of 43%.

Table 3.6. Information on glazing type (Source: DesignBuilder, 2023)

| | Options | Total Solar Transmissions | Light Transmissions | U - VALUE (W/m².K) |
|---|---|---|---|---|
| **Glazing Type** | 4 mm double glass | 0.743 | 0.801 | 2.56 |

Table 3.7. Information on door type (Source: DesignBuilder, 2023)

| | Options | CONDUCTIVITY (W/m-K) | SPESIFIC HEAT (J/kg-K) | DENSITY (Kg/m3) | U - VALUE (W/m².K) |
|---|---|---|---|---|---|
| **Interior Door** | Wooden Door | 0.19 | 2390 | 700 | 2.823 |
| **Exterior Door** | Steel Door | 50 | 450 | 7800 | 3.124 |

## 3.4.2. Schedules

DesignBuilder software requires program data as input to ensure the most accurate calibration between the existing building and its simulation. The data include user occupancy rate, heating, cooling, ventilation details, lighting, and equipment consumption. The schedules for the model developed in the thesis were generated by taking into account the devices and user data associated with the household.

### 3.4.2.1. Occupancy Schedule

The user occupancy schedule of the house was created especially by taking into account the information received from the IoT device regarding occupancy. In addition, tenants were interviewed and information was obtained about their work schedules, departure and entry times, and the people who were in the house during this period. Generally, three people live in the house: a man, a woman, and a child. However, when men and women go to work, the grandmother comes home and stays with the child. Sometimes he even stays at home in the evenings. All other information regarding rooms and usage times shown in the Table 3.7. and 3.8..

Table 3.8. User occupancy rate information for kitchen and living room (Source: DesignBuilder, 2023)

| OCCUPANCY | | Living room | | Kitchen | |
|---|---|---|---|---|---|
| | MALE | 2 | | - | |
| | FEMALE | 2 | | 2 | |
| | TOTAL # | 4 | | 2 | |
| | AREA (M2) | 31.44 | | 13.83 | |
| | DENSITY (PEOPLE/M2)[1] | 0.127 | | 0.144 | |
| | PERIOD: DAY (ALL WEEK WEEKDAYS / WEEKENDS) | WEEKDAY | WEEKEND | WEEKDAY | WEEKEND |
| | PERIOD: HOURS (ALL DAY / 23:00-08:00 / 08:00-18:00 / 18:00-23:00 | Until: 08:00, 0,<br>Until: 17:00, 1,<br>Until: 19:00, 0,<br>Until: 24:00, 1, | Until: 08:00, 0,<br>Until: 17:00, 1,<br>Until: 19:00, 0,<br>Until: 24:00, 1, | Until: 07:00, 0<br>Until: 08:00, 1<br>Until: 17:00, 0<br>Until: 19:00, 1<br>Until: 22:00, 0.2<br>Until: 24:00, 0 | Until: 07:00, 0,<br>Until: 08:00, 1<br>Until: 17:00, 0,<br>Until: 19:00, 1,<br>Until: 22:00, 0.2,<br>Until: 24:00, 0, |

Table 3.9. User occupancy rate information for the main bedroom, baby room, ands room (Source: DesignBuilder, 2023)

| OCCUPANCY | Main Bedroom | | Babys room | | Room | |
|---|---|---|---|---|---|---|
| | 1 | | 1 | | 2 | |
| | 1 | | 0 | | 2 | |
| | 2 | | 1 | | 4 | |
| | 16.37 | | 12.99 | | 16.58 | |
| | 0.122 | | 0.076 | | 0.24 | |
| | WEEKDAY | WEEKEND | WEEKDAY | WEEKEND | WEEKDAY | WEEKEND |
| | Until: 07:00, 1<br>Until: 23:00, 0<br>Until: 24:00, 1 | Until: 09:00, 1<br>Until: 23:00, 0<br>Until: 24:00, 1 | Until: 08:00, 1<br>Until: 22:00, 0<br>Until: 24:00, 1 | Until: 08:00, 1<br>Until: 22:00, 0<br>Until: 24:00, 1 | Until: 08:00, 0<br>Until: 17:00, 0<br>Until: 19:00, 1<br>Until: 24:00, 0 | Until: 08:00, 0<br>Until: 17:00, 0<br>Until: 19:00, 1<br>Until: 24:00, 0 |

### 3.4.2.2. Heating, Cooling, and Ventilation Schedule

The air conditioning system is utilized for the purpose of cooling. The underfloor heating system is employed to warm the house. The house is equipped with air conditioning units in two separate locations. The rooms in question are the master bedroom and living room. While natural gas is utilized for heating purposes, electrical energy is employed for the purpose of cooling. The Table 3.9 displays the set points for heating and cooling. This HVAC information has been processed into the Design Builder system. Natural ventilation was applied in the first 2 weeks of October. The main reason for this is the moderate air flow and its contribution to the accuracy of the calibration process.

Table 3.10. HVAC values for simulation model (Source: DesignBuilder, 2023)

| | Simulation Model |
|---|---|
| **Heating** | 26.5 °C |
| **Heating Setback** | 25 °C |
| **Cooling** | 27.5 °C |
| **Cooling Setback** | 29.5 °C |

### 3.4.2.3. Equipment Schedules and Lighting

In this project, the electrical equipment used in the house was ignored because its accuracy would be low. Only the lighting devices and their intensity in the rooms are defined in the program.

## 3.5. Calibration

Evaluation of the calibration is necessary to understand the accuracy of the relationship between the actual conditions and the simulation model (Taşer et al.,2022). According to the ASHRAE Guideline 14-2002 procedure (ASHRAE, 2002), two types of error ratios are calculated s (3.2) and ±30% for CV(RMSE)s (3.1). In this study, the data's temperature values and simulated environmental conditions monitored for eleven months (between September and August (2022-2023)) were calibrated.

CV-RMSE (%) = (100/Tma)*[1/N*(S (Ts-Tm) 2)] 1/20 (3.1)

MBE (%) = (100/Tma)*[S (Ts-Tm)] /N (3.2)

Where: N: is the number of observations.

TMA: average measured temperatures for N observations.

Ts: simulated hourly temperatures.

Tm: measured hourly temperatures.

For the calibration of the existing building with the simulation, the hourly temperature averages of the IoT device installed in the hall and the hourly indoor temperature averages of the hall as a result of the simulation were taken into account.

## 3.6. Future Climate Scenarios

The CCWorldWeatherGen computation software was utilized to generate meteorological data for two specific time periods, namely the medium-term (2050) and long-term (2080), in order to forecast the energy efficiency of buildings in the chosen residential area under the influence of climate change. CCWorldWeatherGen is an Excel-based program created by the Sustainable Energy Research Group at the University of Southampton. (Jentsch et. al.,2013)

Dynamic building performance systems utilize diverse climatic data formats that are derived from location-specific meteorological data, compiled based on the average of specified years. Every software often generates its own format. The EPW extension for the DesignBuilder application, which serves as the interface for Energy Plus, was generated by computing the average of local climatic data. The weather data for the modeling program is generated by incorporating the measured weather data from the specific location into Aydin's existing hourly climate data in IWEC format. This information was additionally utilized to generate climate projections for the years 2050 and 2080.

## 3.7. Optimization in Simulation Model

Multi-objective optimization refers to the automated execution of several simulations, guided by an optimizer that systematically selects parameters to match design criteria. This procedure iteratively tests new generations of parameters until the optimal result is achieved. Optimization is a common technique today used to search for design options that best meet performance targets, especially in energy performance improvement scenarios. This technique analyzes how differences in building configuration change building performance by making optimal use of design curves. In multi-objective optimization, where two separate objective functions are determined, as was done in this study, the concept of optimality, where there are conflicting constraints between the objectives, is different. DesignBuilder employs a Genetic Algorithm (GA), also known as an Evolutionary Algorithm (EA), which is based on the NSGA2 approach, sometimes referred to as NSGA-II (Deb et al., 2002). This method is commonly employed as a "rapid and exclusive multi-objective" approach, offering a favorable balance between a highly convergent and a well-distributed collection of solutions. NSGA2 employs the non-dominated sorting technique, which has been demonstrated to be highly efficient in prioritizing competing objectives. An inadequacy of the original NSGA2 algorithm is the lack of an efficient mechanism for handling constraints. This is known as the Pareto optimum. Pareto optimum is shown with a red dot in the optimization analysis tables.

The Design Builder optimization tool allows for the testing of over 120 distinct design variables, such as glass type and quantity, thermal mass, HVAC, natural ventilation, lighting system type, and associated control settings. Additionally, it offers the capability to choose a maximum of 2 design objectives, various restrictions, and up to 10 design variables from a diverse set of Key Performance Indicators (KPIs) and variable kinds. There are two objective functions in this study. These are the minimization of cooling energy and discomfort hours. Meanwhile, since the heating energy should not be ignored, it is stated in the restrictions section that the current heating energy should not be exceeded. Additionally, five variables were selected as design parameters. These are glazing type (176 pieces), insulation thickness (between 1 cm and 8 cm), local shading type (south and east facade between 0 m, 0.5 m, 1 m, 1.5 m, and 2 m), window-to-wall ratio (between 20% and 80%) and window blind type. It is determined as (27 options). EPS (Expanded Polystyrene Standard) was used as the insulation material and 9 options were entered by increasing the thickness by 1 cm. Double and triple were used as window types and U values varied between 0.78 $W/m^2.K$ and 3.159 $W/m^2.K$. In optimization, the maximum generation was selected as 100 and the initial population size was selected as 20. As a result, approximately 2000 optimization results were obtained.

# CHAPTER 4

# RESULTS AND DISCUSSION

In this section, 11 months of climate data and the results of 2049-2050 and 2079-2080 climate predictions are analyzed. Calibration results were analyzed as a result of dynamic simulation. The energy consumption and discomfort hours of the base case and the improvements made as a result of optimization and their percentages were compared. In this way, it has been discussed whether the optimized building remains optimized in future climate scenarios.

## 4.1. Iot Devices’s Measurement Results

Two IoT devices (Fig 4.1, no 2-outside, Fig 4.1, no 1-inside) devices started to collect data at 15-minute intervals on 1st September 2022. The data in this period were analyzed as hourly averages in quarterly periods. Data (indoor temperature, indoor user occupancy rate, outdoor temperature, and outdoor humidity) measurements were made between September 1, 2022, and August 1, 2023.

Autumn 2022 measurements:

When the outside temperature measurements of September, October, and November (2022) were examined, the hottest day was observed on September 4, 2022, at 16:00 and the temperature was 33.2°C. On November 16, 2022, at 08:00, the temperature reached its lowest point, measuring 7.9°C, as depicted in Figure 4.1. The temperature delta between the peak hour and the lowest hour is 25.3 °C.

Based on the recorded internal temperature measurements, the highest temperature occurred on September 2, 2022, at 11:00, with a value of 30.07°C. The coldest day was measured on September 15, 2022, at 07:00, and the temperature value was 19.2°C. The temperature difference between the hottest hour and the coldest hour is 10.87°C as shown in Figure 4.1.

The mean ambient temperature in September is 25.36°C, in October it is 20.62°C, and in November it is 15.73°C. The mean internal temperature in September is 27.66 °C, in October it is 25.12 °C, and in November it is 26 °C.

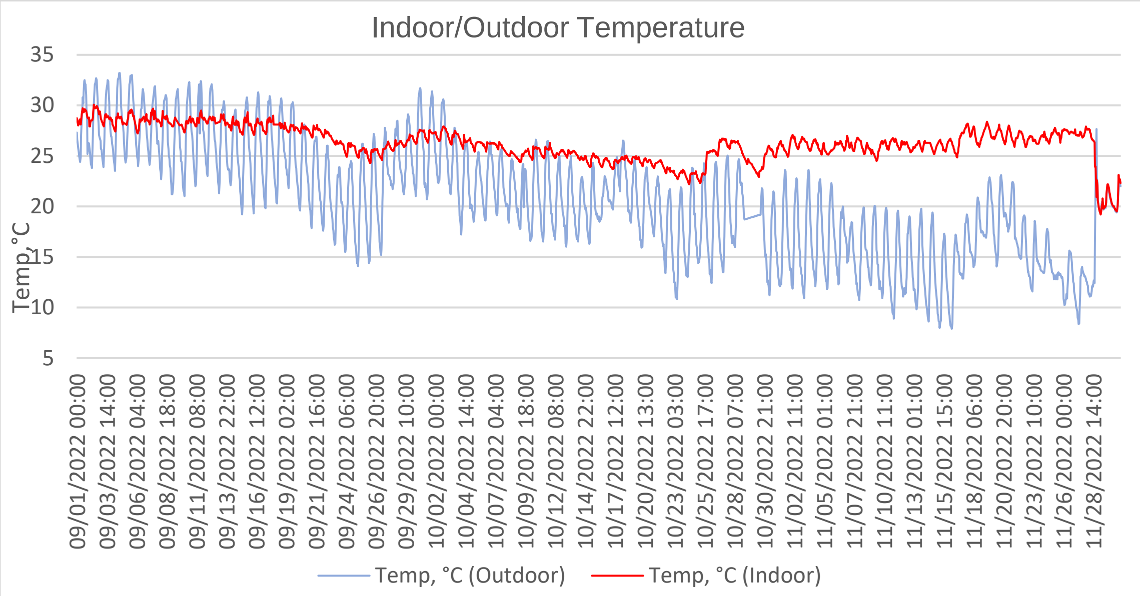



Figure 4.1. Indoor (no: 1) and outdoor (no:2) temperature measurements for September, October, and November (2022)

When the outdoor humidity values of September, October, and November (2023) were compared, the highest humidity value was measured at 95% on September 9, 2022, at 15:00. The lowest external humidity value was measured as 19% on September 23, 2022, at 15.00 as show in Figure 4.2. While the average external humidity in September is 45.60%, the average external humidity in October is 47.50%, and the average external humidity value in November is 58.84%.

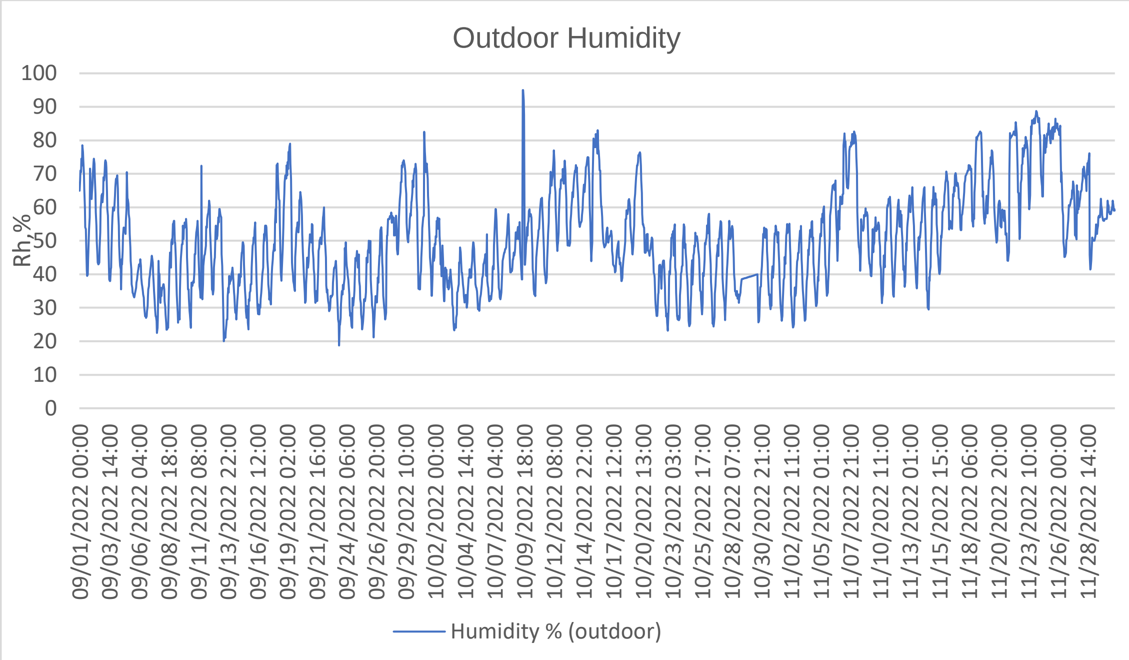



Figure 4.2. Outdoor (no: 2) humidity measurements for September, October, and November (2022)

When the room occupancy rate data for September, October, and November (2022) are analyzed, it is observed that there is no movement between midnight and 07:00 in the morning, as in August. Apart from this, the activity of the motion sensor is observed between 00:00 am and 07:00 am sometimes during the week (Fig. 4.3). In addition, the weekend occupancy rate varies according to the week. This varies depending on whether the user is at home or not.

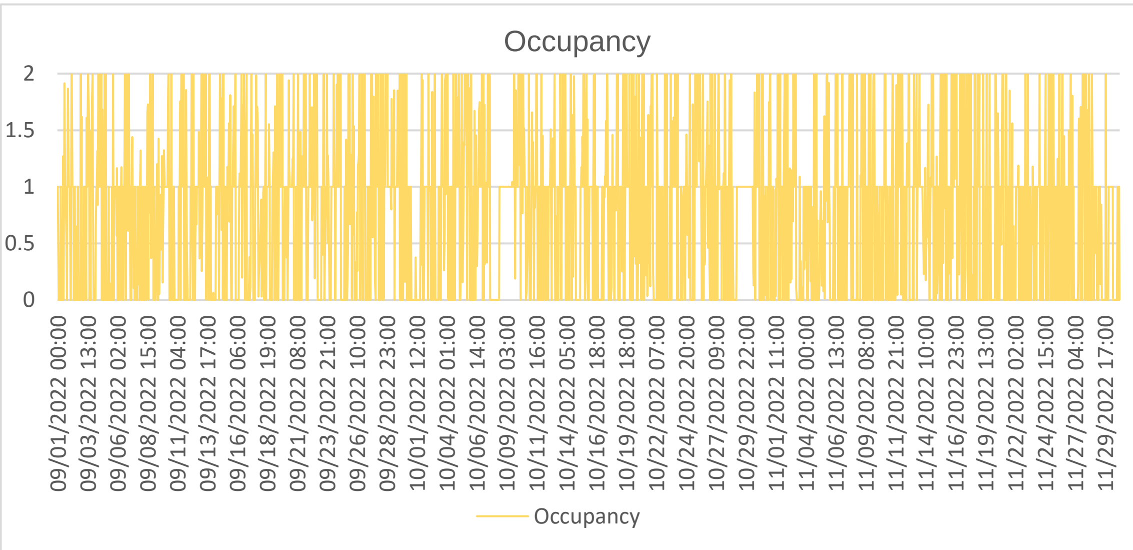



Figure 4.3. User occupancy values in the living room for September, October, and November (2022)

Winter months (2022-2023) measurements:

When the outside temperature measurements of December, January, and February (2022-2023) are examined, the hottest day was observed on 1 December 2022 at 00:00 and the temperature was 21.6°C. The lowest recorded temperature occurs on December 19, 2022, at 22:00, with a temperature reading of 1.13°C. The temperature delta between the peak hour and the lowest hour is 20.47 °C, as depicted in Figure 4.4.

Considering the internal temperature measurements, Figure 4.4 shows that the hottest day is December 2, 2022, at noon, while the temperature value is 28.54°C. The coldest day was measured on December 1, 2022, at noon, and the temperature value was 19.7°C. The temperature difference between the hottest hour and the coldest hour is 8.84°C.

While the average outdoor temperature in December is 12.68°C, the average outdoor temperature in January is 11.07°C, and the average outdoor temperature in February is 9.72°C. While the average internal temperature in December is 26.10 °C, the average internal temperature in January is 26.36 °C, and the average internal temperature in February is 26.76 °C.

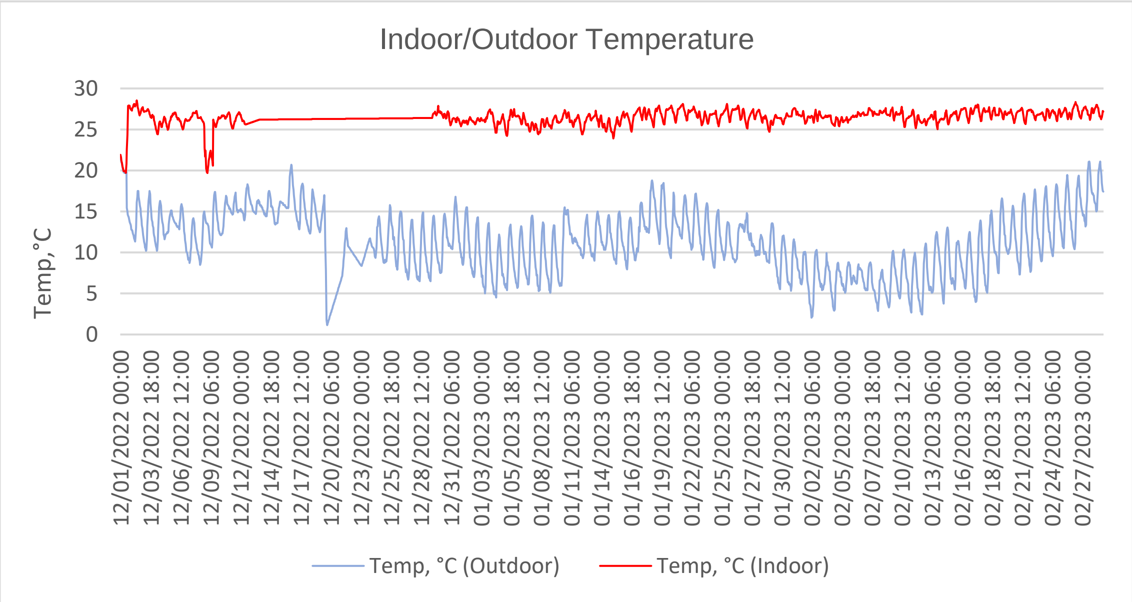



Figure 4.4. Indoor (no: 1) and outdoor (no:2) temperature measurements for December, January, and February (2022-2023)

When the outdoor humidity values of December, January, and February (2022-2023) are compared, the highest humidity value was measured at 89% on 13 December

2022 at 21:00. The lowest outdoor humidity value was measured as 2% on 19 December 2022, at 22:00 (Figure 4.5). While the average external humidity in December is 70.50%, the average external humidity in January is 69%, and the average internal humidity in February is 53.67%.

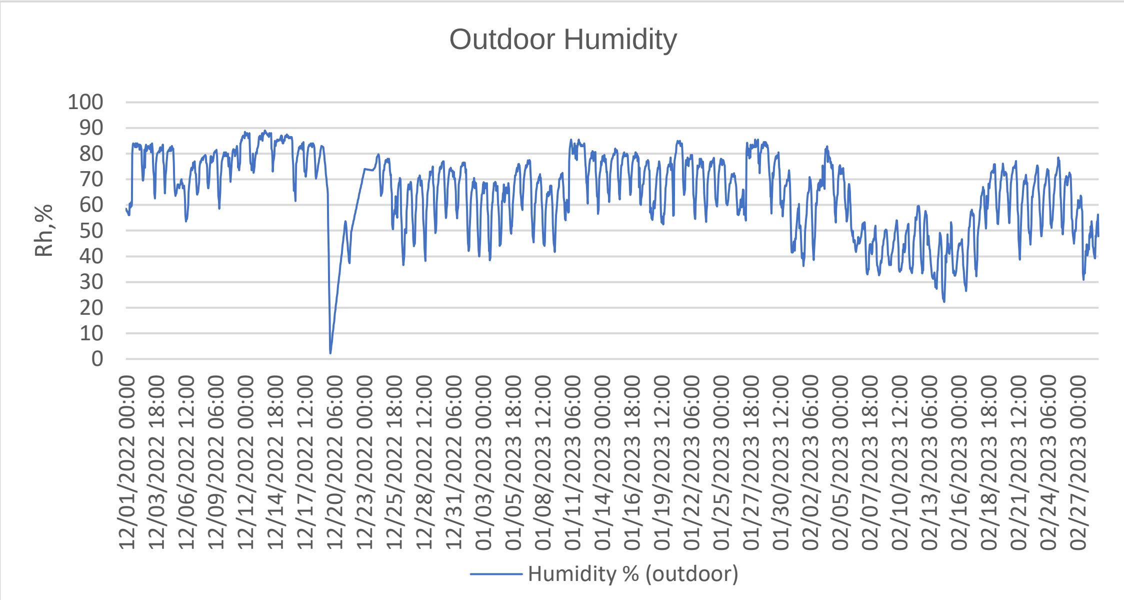


Figure 4.5. Outdoor (no: 2) humidity measurements for December, January and February (2022-2023)

When the user occupancy rate data for December, January, and February (2022-2023) are examined in Figure 4.6., it is observed that there is no movement between midnight and 07:00 in the morning, as in August. The reason for this is that the grandmother, who stays at home during the week, sleeps in the living room at night. In addition, the weekend occupancy rate varies according to the weekdays. This varies depending on whether the user is at home or not. In addition, during the period from December 15, 2022, 22:00 to December 29, 2022, 15:00, the motion sensor data connection was disconnected, and it was constantly stuck in the 1 code, that is, the user on the move. Data from this period will not be taken into account.

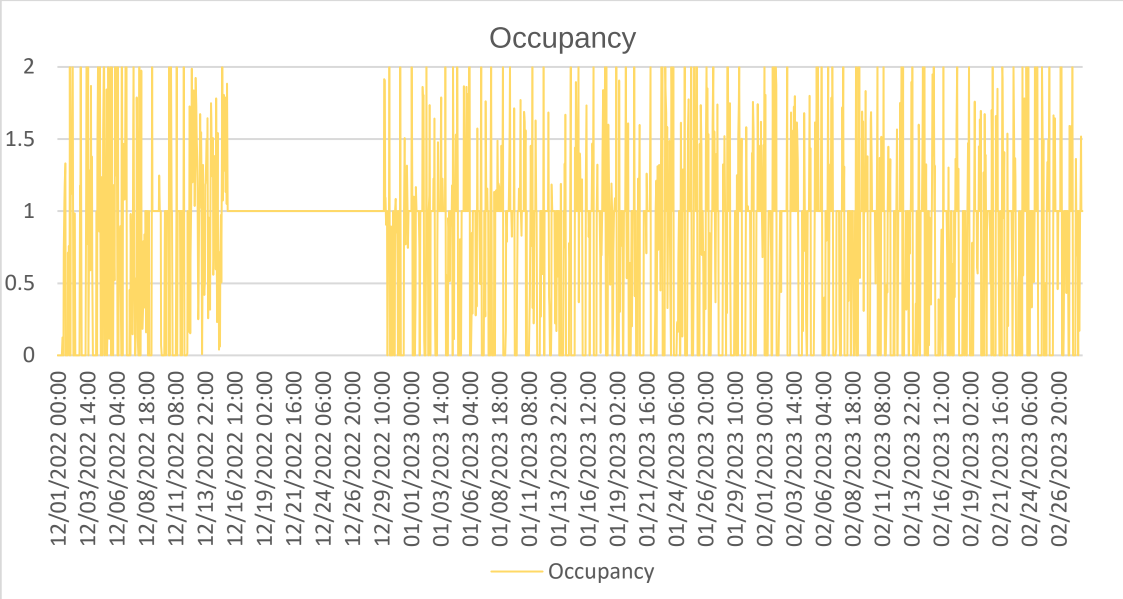



Figure 4.6. User occupancy values in the living room for December, January, and February (2022-2023)

Spring months (2023) measurements:

When the outside temperature measurements of March, April, and May (2023) are examined in Figure 4.7., the hottest day was observed on May 16, 2023, at 16:00 and the temperature was 31.87°C. The coldest day is March 30, 2023, at 08:00, while the temperature value is 4.77°C. The temperature difference between the hottest hour and the coldest hour is 27.1°C.

Considering the internal temperature measurements of March, April, and May (2023), the hottest day is May 2, 2023, at 11:00, while the temperature value shows 29.2°C. The coldest day was measured on May 14, 2023, at 07:00, and the temperature value is 24.1°C. The temperature difference between the hottest hour and the coldest hour is 5.1°C as shown in Figure 4.7.

The mean ambient temperature in March is 14.74°C, in April it is 16.71°C, and in May it is 21.39°C. The mean internal temperature in March is 26.83 °C, in April it is 26.56 °C, and in May it is 26.60 °C.

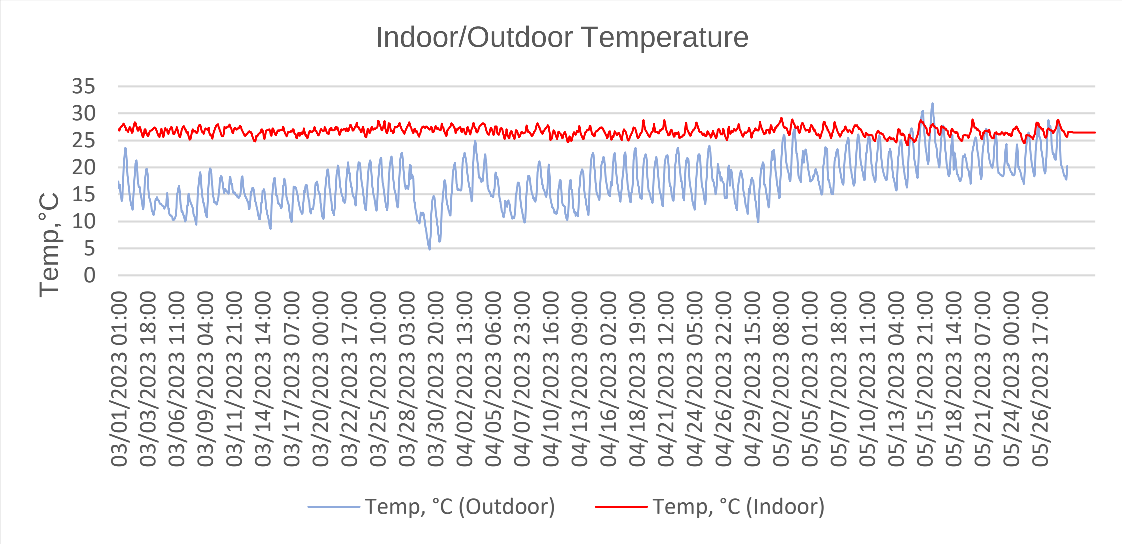



Figure 4.7. Indoor (no: 1) and outdoor (no:2) temperature measurements for March, April, and May (2023)

When the outdoor humidity values of March, April, and May (2023) are compared, the highest humidity value was measured at 92.6% on April 30, 2023, at 20:00. The lowest external humidity value was measured as 20.7% on May 2, 2023, at 15.00 as shown in Figure 4.8. While the average external humidity in March is 61.97%, the average external humidity in April is 60.27%, and the average external humidity value in May is 60.77%.

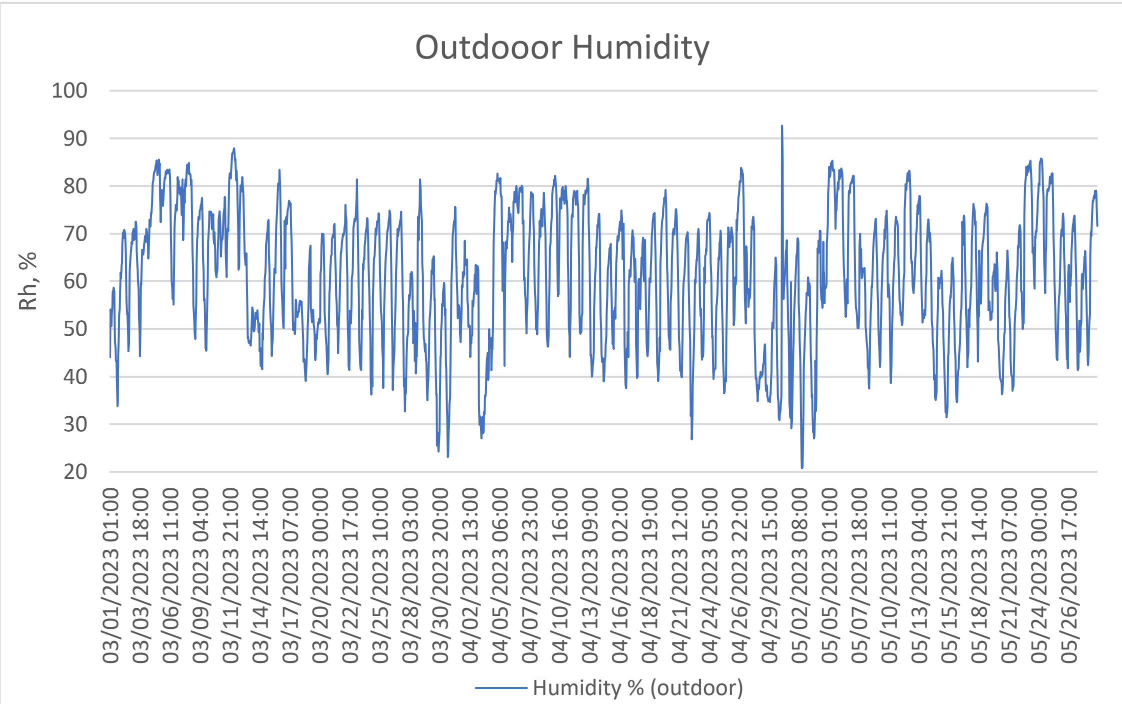



Figure 4.8. Outdoor (no: 2) humidity measurements for March, April, and May (2023)

When the room occupancy rate data for March, April, and May (2023) are examined, it is observed that there is no movement between midnight and 07:00 in the morning as shown in Figure 4.9.

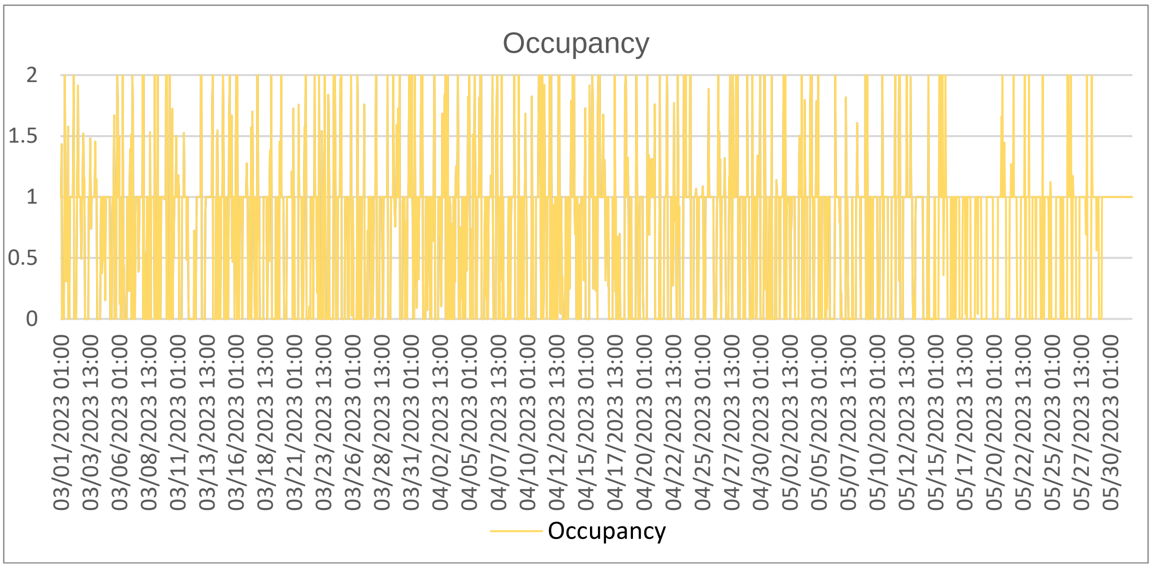


Figure 4.9. User occupancy values in the living room for March, April, and May (2023)

Summer months (2023) measurements:

When the outside temperature measurements of June and July (2023) are examined, the hottest day was observed on 23rd July 2023 at 18:00 and the temperature was 39.45°C. The coldest day is June 3, 2023, at 06:00, while the temperature value is 19.54°C. The temperature difference between the hottest hour and the coldest hour is 19.91 °C as shown in Figure 4.10.

Considering the internal temperature measurements, Figure 4.10. shows that the hottest day is July 24, 2023, at 11:00, while the temperature value is 32°C. The coldest day was measured on June 2, 2023, at 07:00, and the temperature value was 25.5°C. The temperature difference between the hottest hour and the coldest hour is 6.5°C.

The average outdoor temperature in July is 31.72°C, while the average outdoor temperature in June is 26.31°C. While the average internal temperature in June is 28.05 °C, the average internal temperature in July is 29.86 °C.

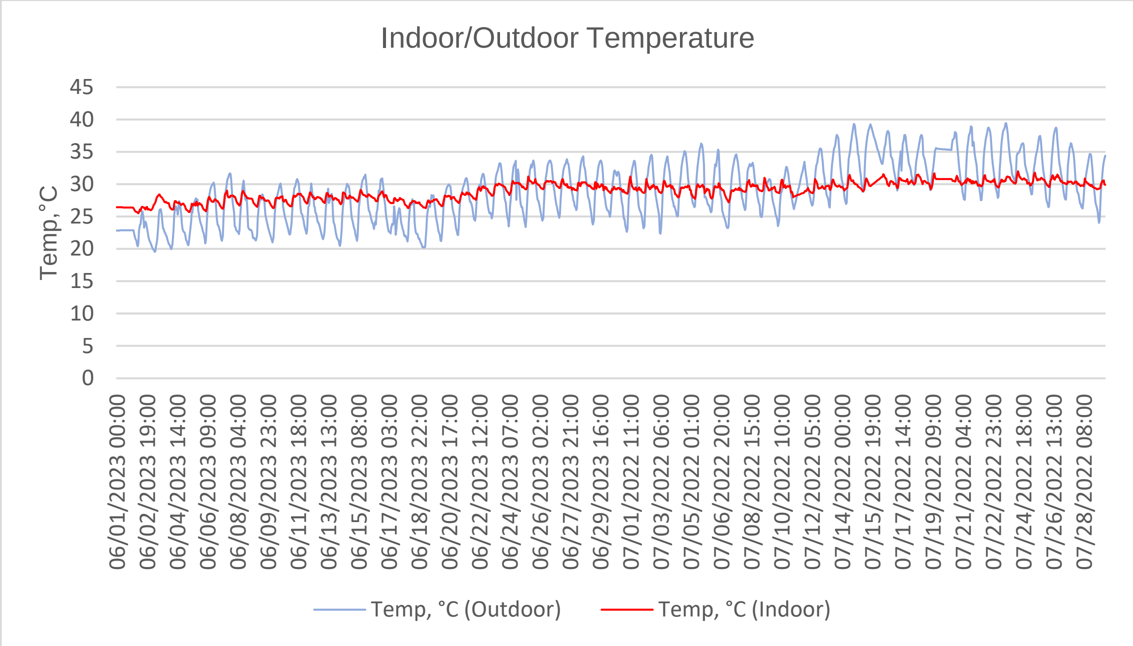



Figure 4.10. Indoor (no: 1) and outdoor (no:2) temperature measurements for June and July (2023)

The highest humidity value was measured at 91% on 3 July 2023 at 05:00, when the outdoor humidity values of June and July (2023) are compared. The lowest outdoor humidity value was measured as 15% on 25 July 2023, at 16:00 (Figure 4.11). While the average external humidity in June is 55.37%, the average external humidity in July is 36.67%.

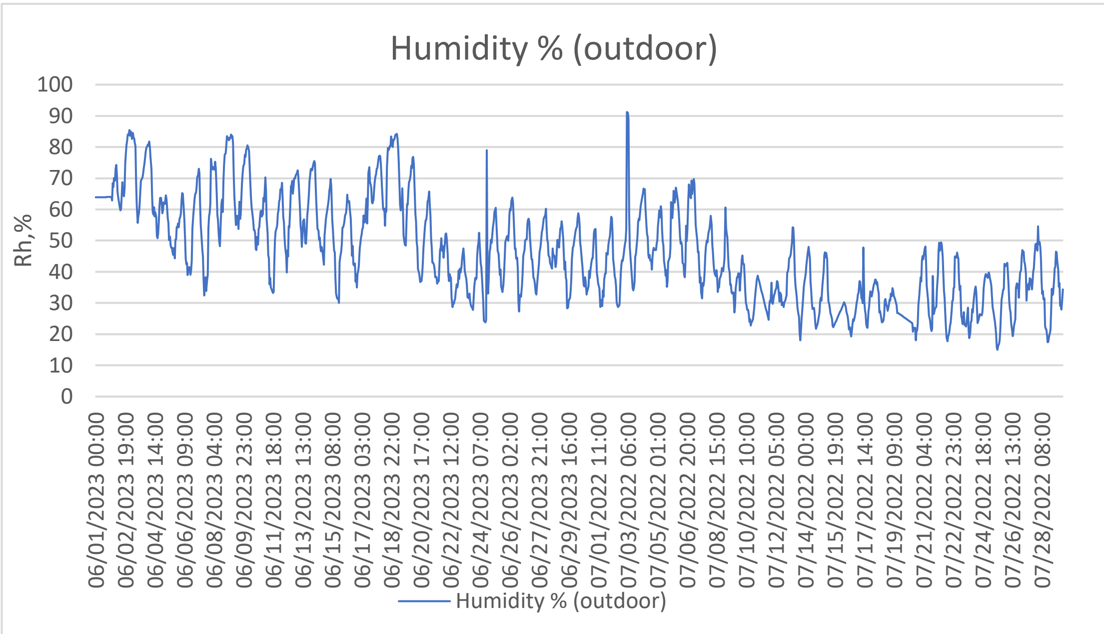



Figure 4.11. Indoor (no: 1) and outdoor (no:2) temperature measurements for June and July (2023)

When the user occupancy rate data for June and July (2023) are examined in Figure 4.6., it is observed that there is no movement between midnight and 07:00 in the morning, as in the other months. Also, When user occupancy rate is examined, it is seen that the rate of time when the room is empty is 36.5%, while the rate of movement and occupancy is 63.5% in total in these months.

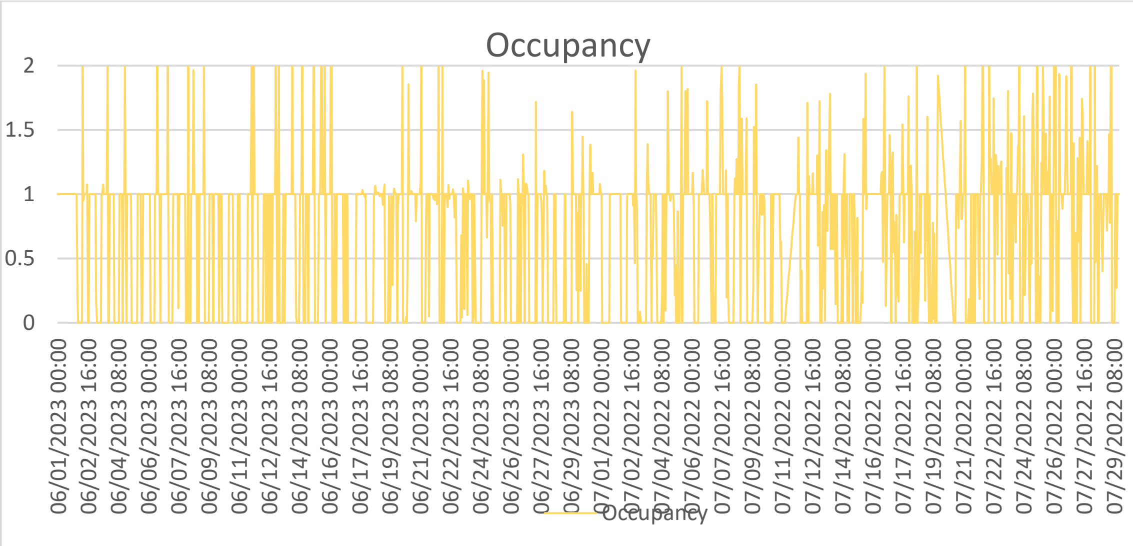



Figure 4.12. User occupancy values in the living room for June and July (2023)

## 4.2. Calibration Results

The BES model of the chosen residential structure was adjusted based on the error determination algorithms outlined in ASHRAE Guideline 14, specifically using RMSE and MBE. The root mean square error (RMSE) for the year is 4.52%, while the mean bias error (MBE) for the year is 1.13%. Consequently, based on the findings, the yearly calibration simulation outcomes fall within the boundaries specified in ASHRAE Guide 14. Upon monthly analysis, it is observed that the Root Mean Square Error (RMSE) and Mean Bias Error (MBE) findings for all months remain below the specified limits set by the ASHRAE Guideline 14. November has the largest Root Mean Square Error (RMSE) at 7.83%, while February has the lowest at 2.26%. October has the greatest MBE at 3.74%, while September has the lowest at -0.6%. Generally, the winter season exhibits less variation compared to the summer season. This disparity could also be attributed to the HVAC systems employed throughout these two seasons. Table 4.1 displays the calibration results.

Table 4.1. RMSE and MBE results for simulation

| | RMSE % | MBE% |
|---|---|---|
| September | 4.34 | -0.6 |
| October | 6.45 | 3.74 |
| November | 7.83 | 3.35 |
| December | 5.47 | 2.04 |
| January | 3.08 | 0.71 |
| February | 2.26 | -0.63 |
| March | 3.98 | 1.78 |
| April | 3.74 | 2.23 |
| May | 4.734 | 3.11 |
| June | 4.83 | -1.99 |
| July | 3.02 | -1.22 |
| Annual | 4.52 | 1.13 |

## 4.3. Climate Scenario Assessments for 2022_2023, 2049-2050, 2079-2080

Climate conditions of the current building (2022-2023), and future climate predictions were made within the scope of the thesis. Accordingly, graphs of temperature, humidity, global horizontal radiation, wind direction, wind speed, and total sky cover for 2049-2050 and 2079-2080 were created and compared.

Temperature values of 3 climate weather files were compared and graphed in Figure. 4.13. When the current (2022-2023) temperature data is examined, the lowest temperature was measured in December at 1 °C. In addition, the highest temperature is July, which is 39°C. When considering the average temperatures on a monthly basis, February had the lowest average temperature at 10 °C, while July had the highest average temperature at 32 °C. Upon analyzing the climate data from 2049-2050, it is evident that January had the lowest temperature, measuring at 1 °C, but July had the highest temperature, reaching a scorching 44 °C. However, the second highest month was September, with a record temperature of 39°C. When average temperature values are examined, the highest month was July with 35 °C, while the month with the lowest average was January with 10 °C. For the 2079-2080 period, when the effects of climate change were seen to be higher, the month with the lowest temperature was January with 1°C, while the month with the highest temperature was July with 47°C. In average temperatures, the highest value is July with 38 °C, while the lowest value is January with 11 °C.

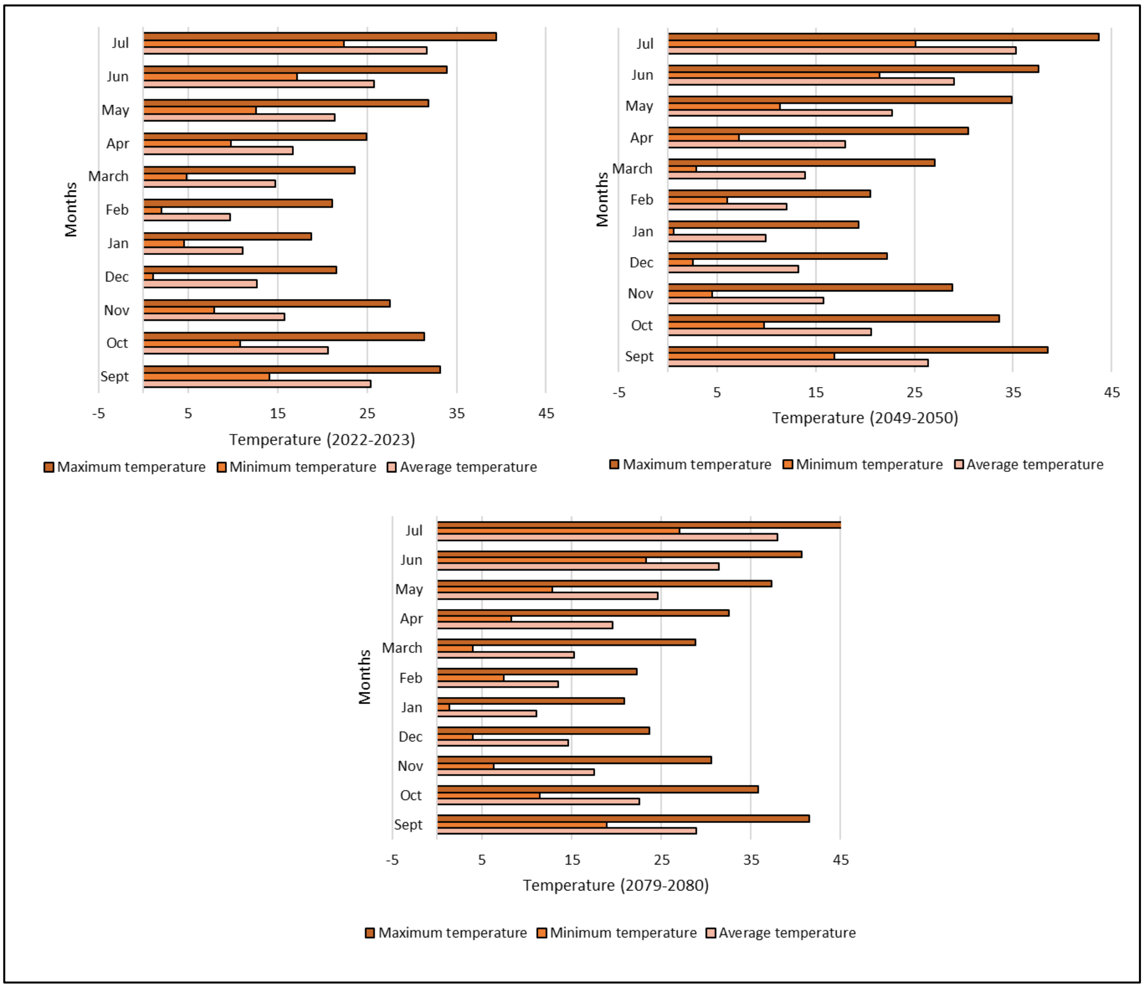



Figure 4.13. Minimum, maximum and average temperature comparisons for 2022-2023, 2049-2050, 2079-2080

Rh values of the 2022-2023, 2049-2050, 2079-2080 climate periods were examined and graphed Figure 4.14. Rh values of the 2022-2023, 2049-2050, and 2079-2080 climate periods were examined and graphed. According to the results, according to the current (2022-2023) climate data, the month with the lowest rh value was

December with 2%, and the highest value was October with 95%. July had the lowest average humidity, reaching a minimum of 37%. In terms of average humidity, December recorded the highest level at 71%. Based on climatic projections for the years 2049-2050, February had the lowest relative humidity (rh) value of 1%, while October had the highest value of 99%. July had the lowest average humidity, which was recorded at 41%. November saw the highest average humidity, reaching 72%. Regarding climatic predictions for the period of 2079-2080, February had the lowest relative humidity (RH) value at 1%, while November and December had the greatest levels at 98%. July had the lowest average humidity, which was recorded at 37%. November saw the highest average humidity, reaching 71%.

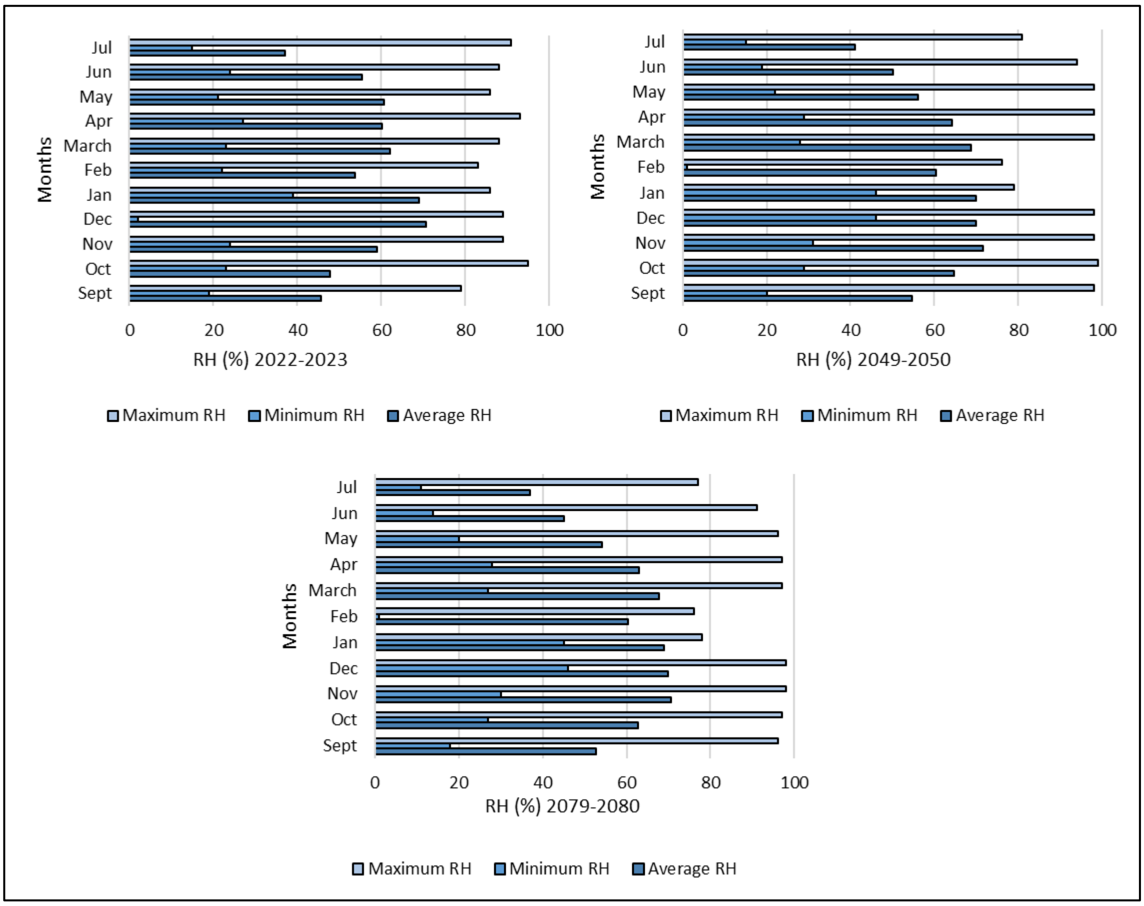



Figure 4.14. Minimum, maximum and average humidity comparisons for 2022-2023, 2049-2050, 2079-2080

The lowest average Global Horizontal Radiation values for 2022-2023, 2049-2050 and 2079-2080 climate data are the same for all three months, December, while the values are 90, 90, 89 respectively in Figure 4.15**.** The months with the maximum

Global Horizontal Radiation values for 2022-2023, 2049-2050 and 2079-2080 climate data are June, May and July, respectively, and the values are 1018, 1052 and 1086.

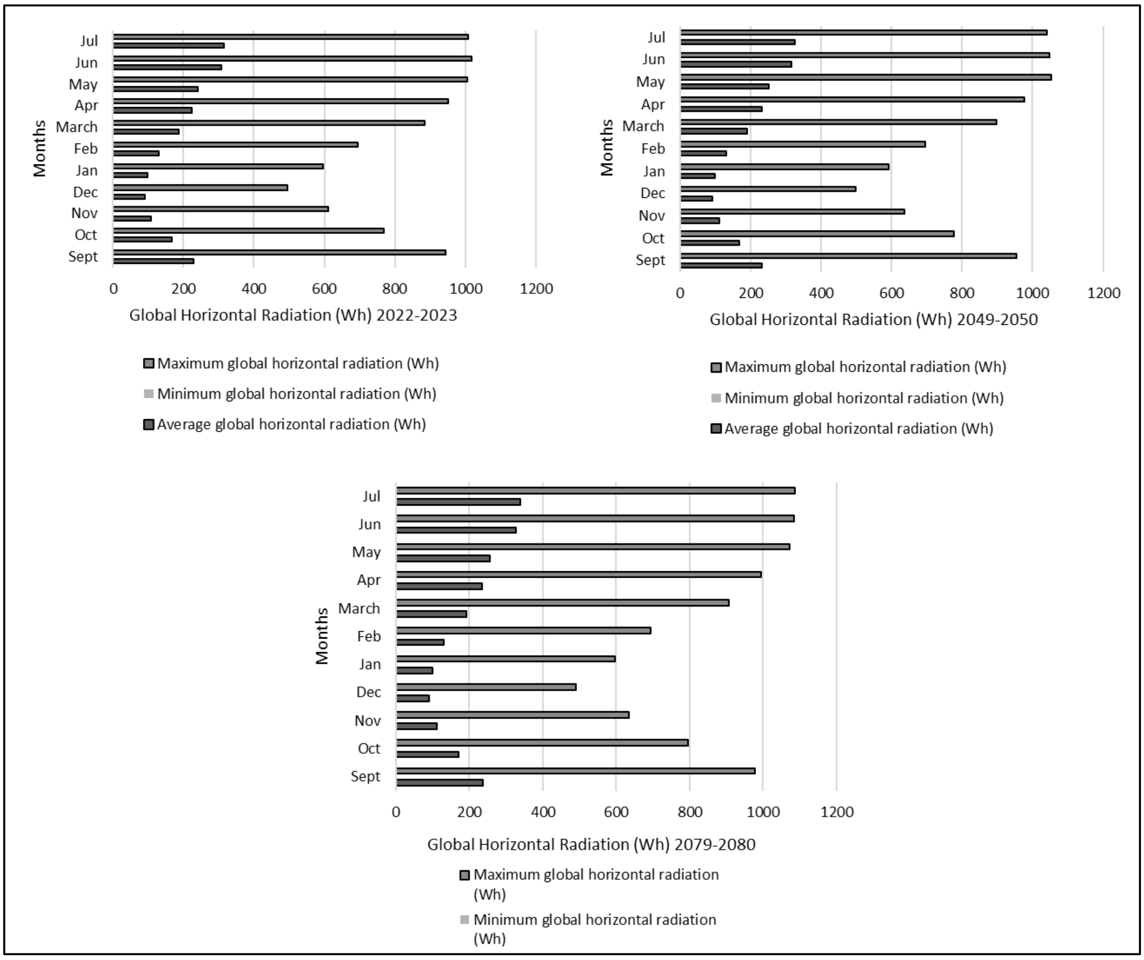



Figure 4.15. Minimum, maximum and average global horizontal radiation (Wh) comparisons for 2022-2023, 2049-2050, 2079-2080

According to the climate data of the current situation (2022-2023), the month with the highest wind speed is July with 23 m/s. According to the climate forecasts for 2049-2050 and 2079-2080, the highest wind speed was seen in July and this value was 24 m/s as shown in Figure 4.16. Again, when the average wind speed values of the 3 climate periods were examined, it was observed that the highest month was July and the average wind speed in the other months varied between 4 m/s and 7 m/s.

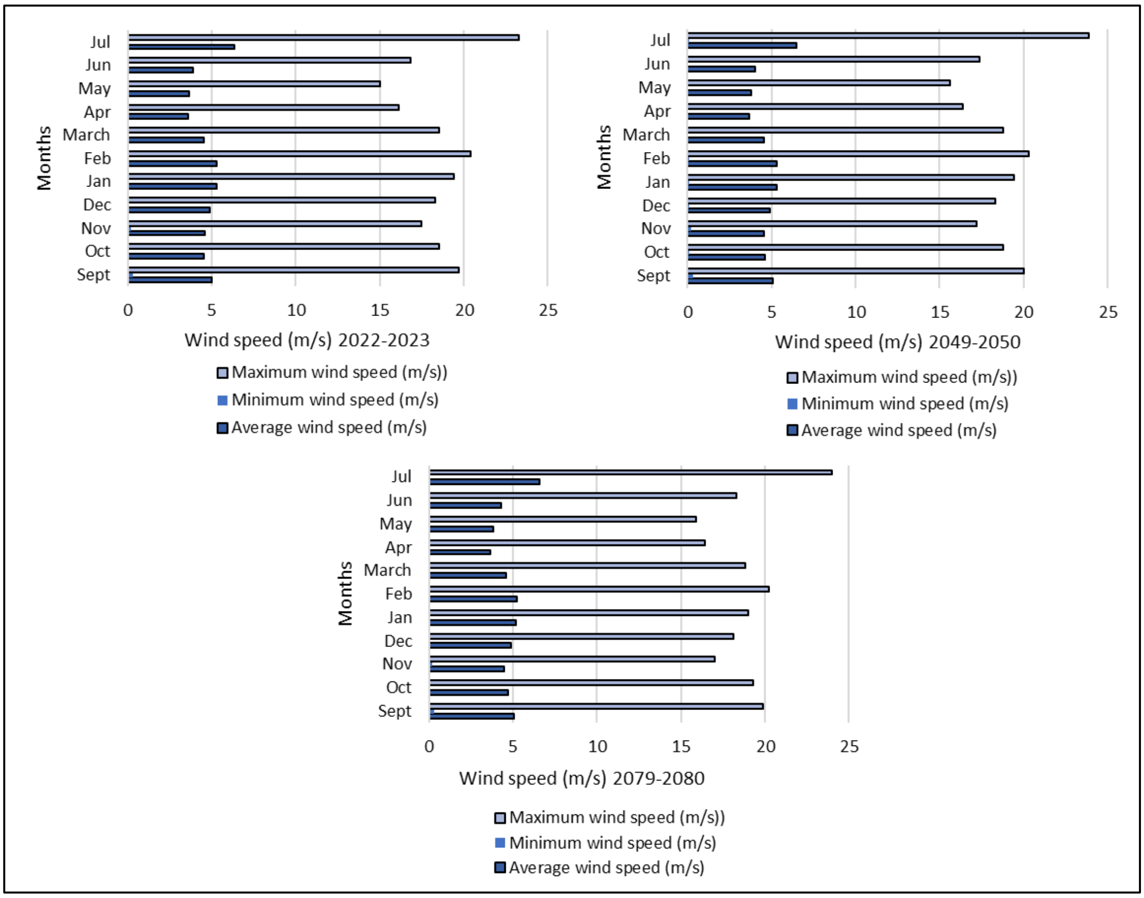



Figure 4.16. Minimum, maximum and average wind speed (m/s) comparisons for 2022-2023, 2049-2050, 2079-2080

## 4.4. Heating, Cooling Energy Consumption and Discomfort Hours Results for Base Case Dwelling

Table 4.2 displays the energy usage for cooling and heating as well as the number of discomfort hours in the base case scenario. Based on the data on energy consumption and thermal comfort, the heating energy consumption amounted to 2471.306 kWh, while the cooling energy consumption was recorded at 1711.624 kWh. Also, The amount of cooling energy per square meter was 31.6 kWh. As a result of the analysis, discomfort hours were found to be 2936.138 hours. 33% of the year is discomfort. Additionally, 11-month discomfort hours are graphed and shown in Figure 4.17. As a result, the month with the highest number of discomfort hours was December with 271 hours, while the month with the lowest was October with 175 hours. However, the season with the highest discomfort hours is winter.

Table 4.2. Heating and cooling energy consumption and discomfort hours for 2022-2023

| Year | Heating Energy Consumption (kWh) | Cooling Energy Consumption (kWh) | Discomfort Hours |
|---|---|---|---|
| 2022-2023 | 2471.306 | 1711.624 | 2936.138 |

The Discomfort hours data is determined by assessing if the humidity ratio and the operative temperature fall within the specified range outlined in ASHRAE Standard 55-2004. For these results, the operative temperature is calculated as the average of the air temperature and the mean radiant temperature. The 0.5 Clo level is utilized throughout summer, whereas the 1.0 Clo level is employed during winter. Occasionally, you may encounter a significant amount of discomfort hours in a certain area, despite the ambient temperature in that location falling within the usual range. There are several possible explanations for this.

- Operative temperatures may vary significantly in spaces with a high amount of glass during the summer or spaces with inadequate insulation during the winter.

The humidity levels are within the acceptable range, however it is possible to see excessive or insufficient humidity due to inadequate ventilation.

It is important to acknowledge that in extremely dry weather conditions, the recommended minimum temperature for comfortable winter apparel is 21.7°C / 71°F. This temperature may be lower than certain heating temperature settings.

In the summer, when the air is highly humid, temperatures exceeding 26.8°C / 80.2°F are deemed excessively hot when wearing summer clothing.

The study attributes the prolonged periods of discomfort to the elevated HVAC set points, which are contingent upon user preferences, during both winter and summer months.

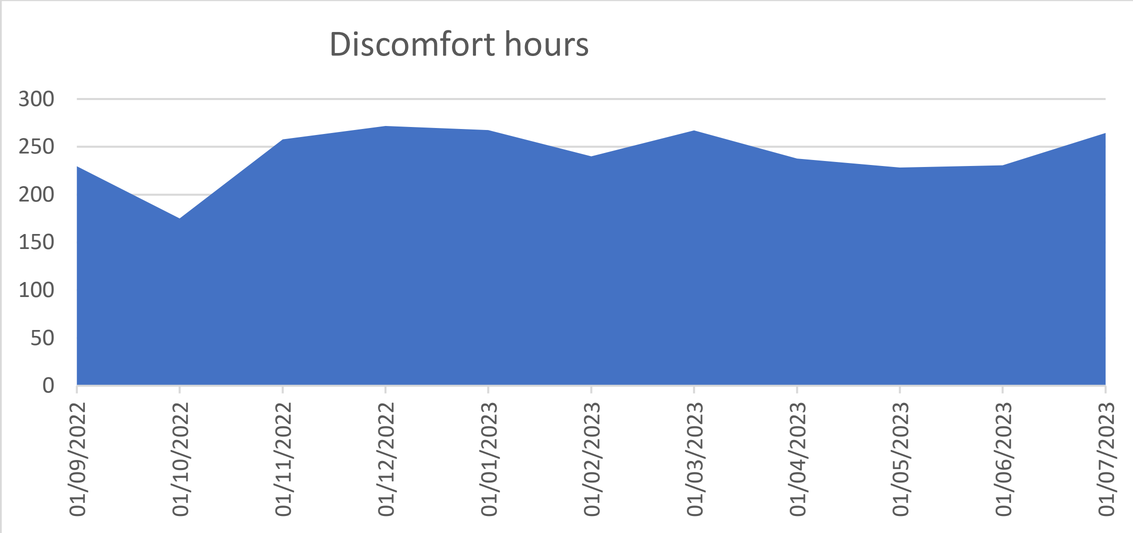



Figure 4.17. Monthly discomfort hours values for 2022-2023

### 4.4.1 Heating, Cooling Energy Consumption and Discomfort Hours Results for 2049-2050 and 2079-2080

Climate predictions for the base case for 2049-2050 and 2079-2080 were made, and heating and cooling energy consumption and discomfort hours in these periods were analyzed. Analysis results are shown in Table 4.3. As a result of the analysis, heating energy for the 2049-2050 climate period is 2294.787 kWh, while cooling energy is 2143.375 kWh. The amount of cooling energy per square meter was 39.7 kWh. It is seen that while the heating energy decreases by 7% compared to the base case, the cooling energy increases by 25%. Discomfort hours are 2974.676 hours. For the 2079-2080 climate period, heating energy is 1695.773 kWh while cooling energy is 1695.773 kWh. It is seen that while the heating energy decreases by 31% compared to the base case, the cooling energy increases by 55%. Discomfort hours are 3006.492 hours.

Table 4.3. Heating and cooling energy consumption and discomfort hours for 2049-2050 and 2079-2080

| Year | Heating (kWh) | Cooling (kWh) | Discomfort Hours |
|---|---|---|---|
| 2049-2050 | 2294.787 | 2143.375 | 2974.676 |
| 2079-2080 | 1695.773 | 2650.569 | 3006.492 |

## 4.5. Heating, Cooling Energy Consumption and Discomfort Hours Results of Optimization Option

Building enhancement analyses were conducted based on the findings from the Base Case, as well as the climate periods of 2049-2050 and 2079-2080. Additionally, optimization investigations were performed in three distinct scenarios. The aim of this optimization study is to identify the most suitable materials for minimizing cooling energy consumption and reducing discomfort hours by modifying certain structural components. Hence, assessments were conducted to determine if the already optimized structure remains optimal under the climate scenarios projected for 2049-2050 and 2079-2080.

### 4.5.1. Optimization Results for Base Case

In this scenario, an optimization study was carried out to minimize the cooling energy and discomfort hours of the existing building under the current climate conditions. While doing this, a value of 2500 kWh was entered as a restriction value to ensure that the extra heating energy was not more than the value in today's conditions. The result of the study is shown in Figure 4.18. The values shown with a red dot are the optimal optimization result, while the values shown with a yellow dot are the results where the heating exceeds 2500.

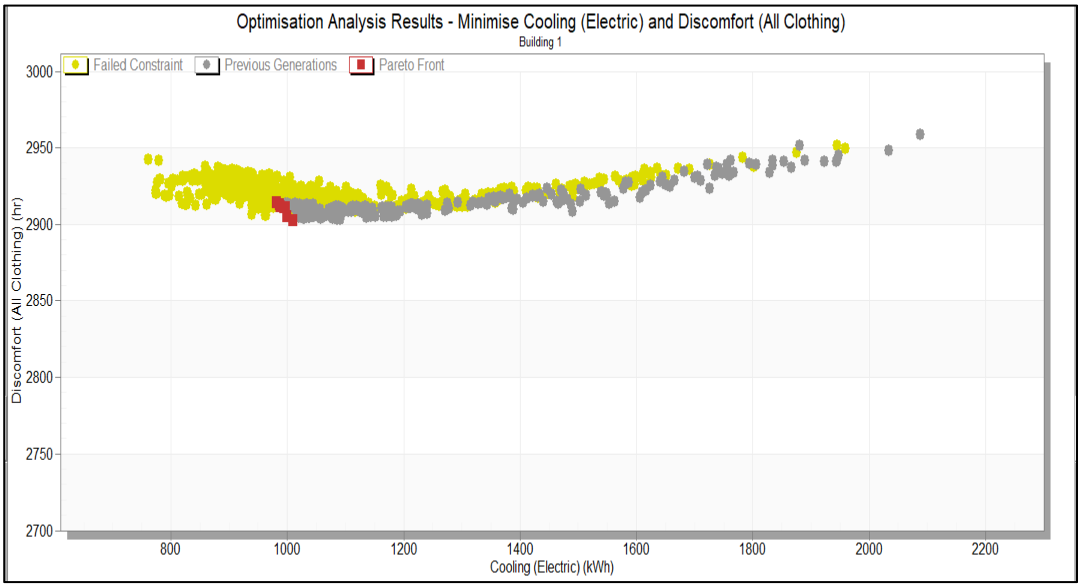



Figure 4.18. Optimization results of 2022-2023

As a result of the optimization, 7 optimal design scenarios are given as a result in Table 4.4. When cooling energy consumption and discomfort hours were compared, it was observed that discomfort did not change much. Therefore, the results are ranked from best to worst, with cooling energy consumption first. Accordingly, the S1 scenario, colored gray in Table 4.4., gave the best results in cooling energy consumption. The parameter values that give this result are Trp LoE Film (44) Bronze 6mm/13mm was chosen as the glazing type, local sheathing type was 1.5 m, insulation thickness was 6 cm, window to wall ratio was 72%, and window blind type was determined as microlouvre. As a result of this scenario, heating and cooling energy consumption values and discomfort hours are shown in Table 4.5. While the heating energy consumption value of the best scenario is 2498.50 kWh, the cooling energy consumption value is 981.01 kWh. The amount of cooling energy per square meter was 15.32 kWh.

A comparison of heating and cooling energy consumption and discomfort hours of 7 optimal scenarios is presented in Figure 4.19. When the results are evaluated, it is seen that there is no visible change in the discomfort hours. Since the heating energy consumption values were entered as a restriction in the first place, they are below 2500 kWh, as seen in the graph. Cooling energy consumption values increase from S1 scenario to S7, with a minimum of 981 and a maximum of 1009.

Table 4.4. Optimal design variables of optimization for Base Case (2022-2023)

| Optimaziton Scenarios | | 2022-2023_Optimization | | | | |
|---|---|---|---|---|---|---|
| | | **Variable** | | | | |
| | | **Glazing type** | **Local shading type** | **Insulation (m)** | **WWR (%)** | **Window blind type** |
| | S1 | Trp LoE Film (44) Bronze 6mm/13mm Air | 1.5m Overhang | 0.06 | 72 | MicroLouvre |
| | S2 | Trp LoE Film (44) Bronze 6mm/13mm Air | 1.0m Overhang | 0.06 | 74 | <None> |
| | S3 | Trp LoE Film (44) Bronze 6mm/13mm Air | 0.5m Overhang | 0.05 | 60 | M. reflectance - medium transmittance sh. |
| | S4 | Trp LoE Film (55) Bronze 6mm/13mm Air | 0.5m Overhang | 0.08 | 44 | High reflectance - low transmittance shade |
| | S5 | Trp LoE Film (44) Bronze 6mm/13mm Air | 0.5m Overhang | 0.07 | 74 | <None> |
| | S6 | Trp LoE Film (44) Bronze 6mm/13mm Air | No shading | 0.07 | 72 | High reflectance - low transmittance shade |
| | S7 | Trp LoE Film (44) Bronze 6mm/13mm Air | No shading | 0.01 | 40 | Blind with high reflectivity slats |

Table 4.5. Optimal designs of scenarios for energy consumption and discomfort hours

| | **Cooling Energy Consumption (kWh)** | **Discomfort hours** | **Heating Energy Consumption (kWh)** |
|---|---|---|---|
| S1 | 981.013683 | 2914.106933 | 2498.502792 |
| S2 | 986.704475 | 2913.04853 | 2475.231263 |
| S3 | 988.101231 | 2911.611438 | 2467.943123 |
| S4 | 994.500701 | 2911.253053 | 2473.808337 |
| S5 | 997.145251 | 2910.714461 | 2430.323013 |
| S6 | 999.292738 | 2904.978781 | 2457.657616 |
| S7 | 1009.597492 | 2902.763496 | 2392.767062 |

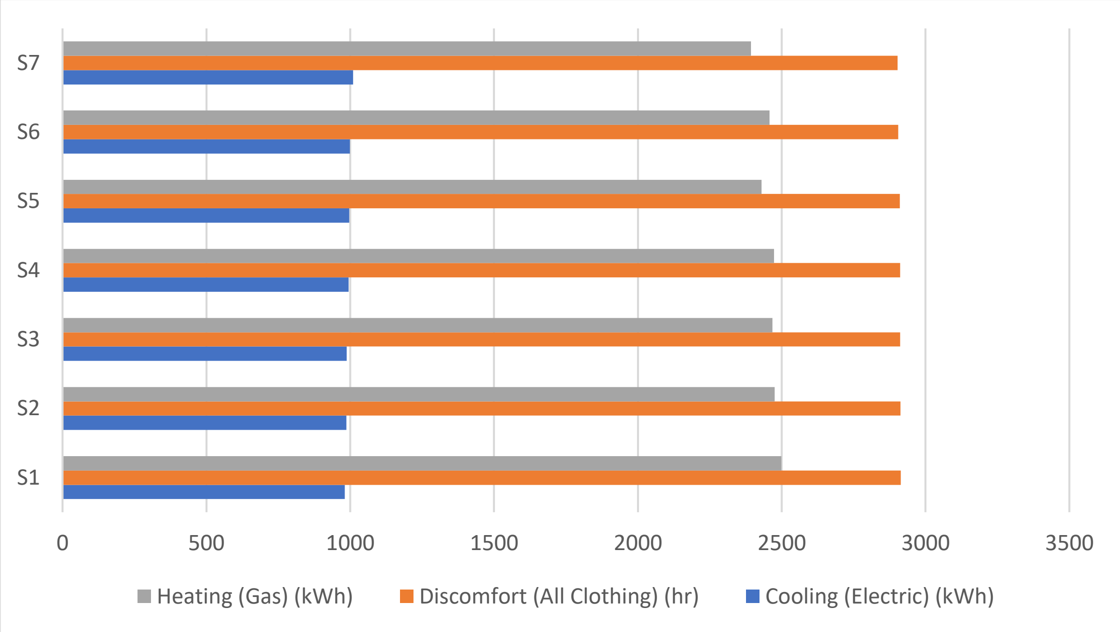



Figure 4.19. Comparison of the best optimization scenarios for 2022-2023

Discomfort hours were found to be 2914.10 hours. Discomfort hours values by month are graphed in Figure 4.20. While the maximum discomfort hours were 271 hours in December, the minimum was 148 hours in October. Additionally, 33% of the year is discomfort. Winter is characterized by the highest levels of discomfort hours.

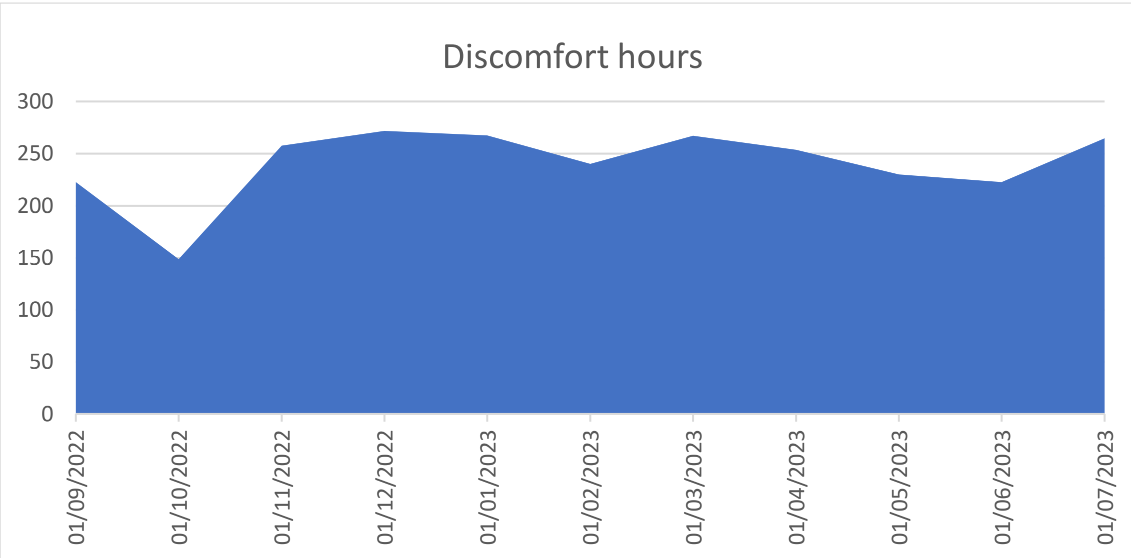



Figure 4.20. Monthly discomfort hours values for 2022-2023 S1

### 4.5.2. Optimization results for 2049-2050

In this scenario, an optimization study was carried out to minimize the discomfort hours with the best cooling energy consumption of the existing building in the 2049-2050 climate scenario and is shown in the graphic in Figure 4.21. The values shown with a red dot are the optimal optimization result, while the values shown with a yellow dot are the results where the heating exceeds 2500.

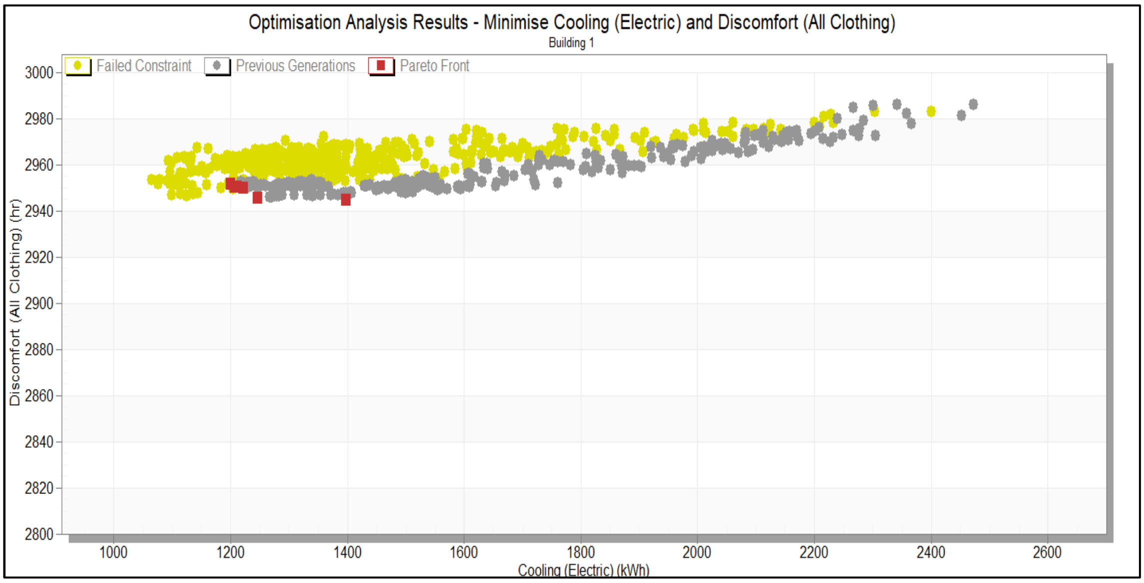



Figure 4.21. Optimization results of 2049-2050

The parameters of the 6 optimal optimization results are listed from best scenario to worst. In the scenarios, glass types vary between triple and double, and thermal insulation thickness varies between 3 cm and 8 cm. The window-to-wall ratio varies between 20% and 80%, and the local shading type varies between 0.5 m and 1.5 m. Finally, the window blind type varies between high reflectance - low transmittance shade and blind with high reflectivity slats.

The optimal situation in S1 is shown by the characteristics highlighted in gray in Table 4.6. The glazing type is Trp LoE Film (33) Bronze. The air gap measures 6mm/13mm, the distance of the shading from the source is 1 m, and the thickness of the insulation is 3 cm. Furthermore, the window-to-wall ratio stands at 74%, and the window blind type is classified as a shade with high reflection and low transmittance.

Table 4.6. Optimal design variables of optimization scenarios for 2049-2050 climate forecast

| | | 2050_Optimization | | | | |
|---|---|---|---|---|---|---|
| | | Variable | | | | |
| | | Glazing type | Local shading type | Insulation (m) | WWR (%) | Window blind type |
| Optimaziton Scenarios | S1 | Trp LoE Film (33) Bronze 6mm/13mm Air | 1.0m Overhang | 0.03 | 74 | High reflectance - low transmittance shade |
| | S2 | Trp LoE Film (33) Bronze 6mm/13mm Air | 1.5m Overhang | 0.08 | 20 | Blind with high reflectivity slats |
| | S3 | Trp LoE Film (33) Bronze 6mm/13mm Air | 0.5m Overhang | 0.03 | 80 | High reflectance - low transmittance shade |
| | S4 | Trp LoE Film (33) Bronze 6mm/13mm Air | 0.5m Overhang | 0.05 | 30 | Blind with high reflectivity slats |
| | S5 | Trp LoE Film (55) Bronze 6mm/13mm Air | 1.0m Overhang | 0.06 | 54 | High reflectance - low transmittance shade |
| | S6 | Dbl LoE Spec Sel Tint 6mm/13mm Arg | No shading | <None> | 80 | High reflectance - low transmittance shade |

The ranking of heating and cooling energy consumption and discomfort hours of the 6 optimal scenarios is presented in Table 4.7. When the results are evaluated, it is seen that there is no visible change in disturbance hours, as seen in the 2049-2050 climate predictions. Since the heating energy consumption values were entered as a restriction in the first place, they are below 2500 kWh as seen in the graph. Therefore, cooling energy consumption values will be taken into account at the end of the study. Cooling energy consumption values increase from S1 scenario to S6 scenario, with a minimum of 1199 kWh and a maximum of 1397.80 kWh. In S1 scenario, which is the best optimization result, cooling energy consumption is 1199.70 kWh while heating energy consumption is 2478.64 kWh. The amount of cooling energy per square meter was 22.20 kWh. Discomfort hours are given as 2951 hours.

Table 4.7. Optimal designs of scenarios for energy consumption and discomfort hours for 2049-2050 climate scenario

| | Cooling Energy Consumption (kWh) | Discomfort hours | Heating Energy Consumption (kWh) |
|---|---|---|---|
| S1 | 1199.694446 | 2951.360156 | 2478.640222 |
| S2 | 1207.221017 | 2950.24033 | 2443.558984 |
| S3 | 1210.645631 | 2950.008345 | 2438.568522 |
| S4 | 1221.154672 | 2949.946921 | 2379.22624 |
| S5 | 1289.537407 | 2951.183501 | 2344.118228 |
| S6 | 1397.809924 | 2944.673182 | 2076.024517 |

The best scenarios of the optimization to minimize cooling energy consumption and discomfort hours are shown in Figure 4.22. from S1 to S6. Accordingly, it is observed that the discomfort hours do not change noticeably. It is seen that the cooling enegy consumption increase from S1 to S6.

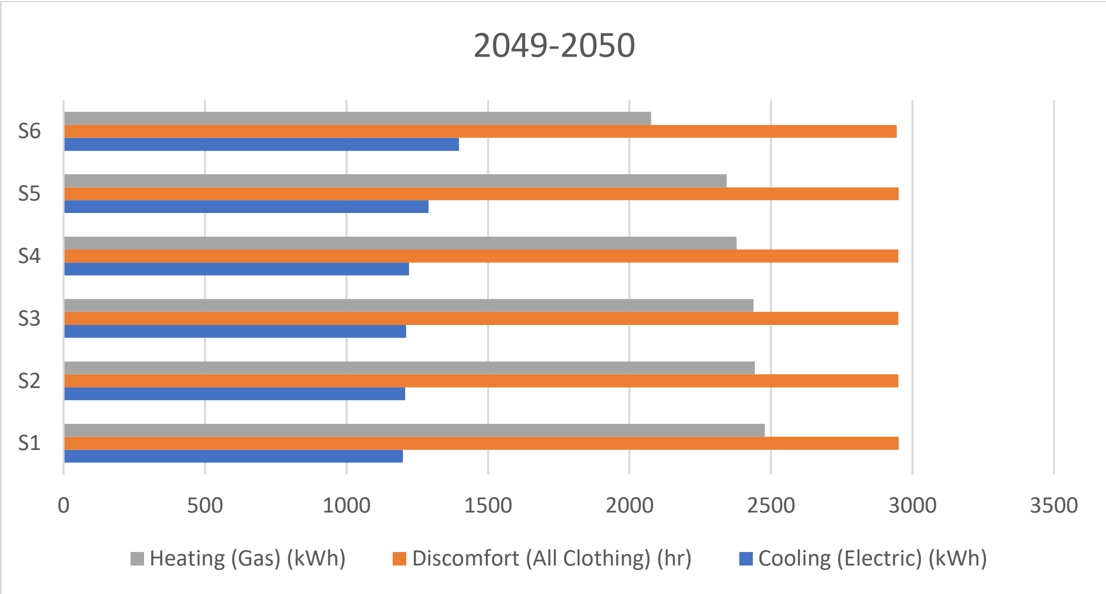



Figure 4.22. Comparison of the best optimization scenarios for 2049-2050

According to 2049-2050 climate forecasts, the best optimization scenario (S1) discomfort hours were analyzed for an 11-month period, shown in Figure 4.23. Accordingly, among the months, the month with the maximum discomfort hours was December with 271 hours, while the month with the minimum disturbance hours was October with 194 hours. Additionally, discomfort occurs 33% of the year. The season of winter is distinguished by its most extreme discomfort hours.

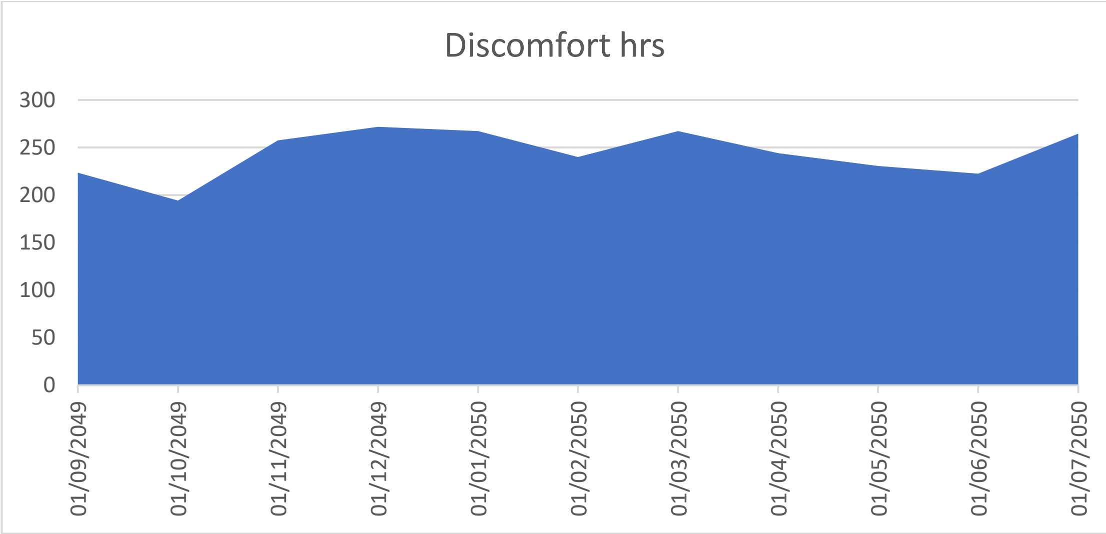



Figure 4.23. Monthly discomfort hours values for 2049-2050 S1

### 4.5.3. Optimization results for 2079-2080

In this scenario, an optimization study has been carried out to minimize the disturbance hours with the best cooling energy consumption of the existing building in the 2079-2080 climate scenario, which is the latest climate forecast, and is shown in the graph in Figure 4.24. As in other climate scenarios, the values shown with a red dot are; The optimum optimization result, and the values shown with a yellow dot are the results where the heating exceeds 2500. Therefore, red external dots were ignored.

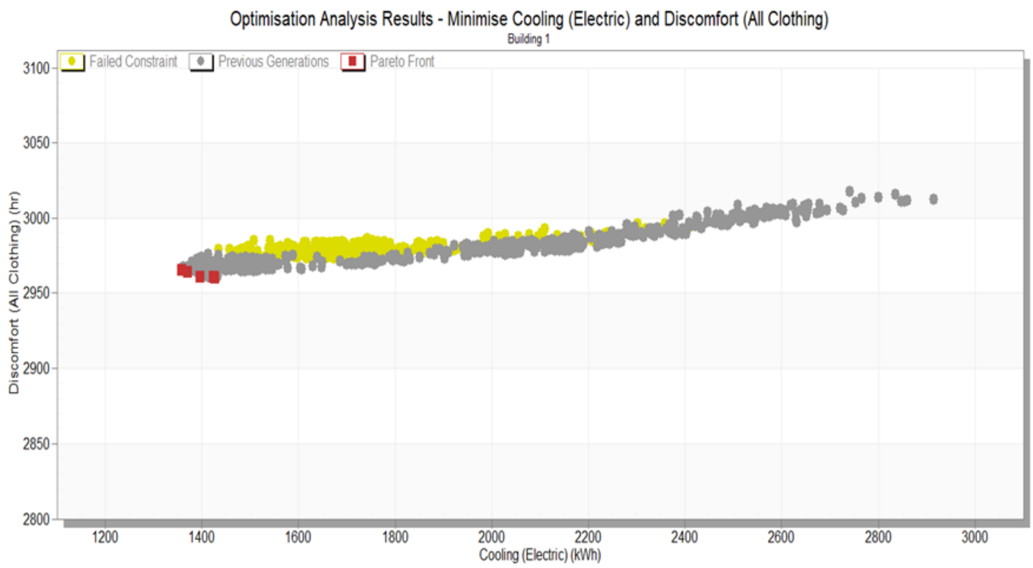



Figure 4.24. Optimization results of 2079-2080

All glass types are triple in the scenarios, and thermal insulation thicknesses vary between 1 cm and 8 cm. The window-to-wall ratio varies between 40% and 74%, and the local shading type varies between 0 m and 1.5 m. Finally, window blinds consist of microlouvre, M. reflectance - medium transmittance shade, high reflectance - low transmittance shade, and blind with high reflectivity slats options. In S1, which is the best optimal design scenario, the parameters are as follows: Trp LoE Film (44) Bronze 6mm/13mm Air is used for glass type, local shading type is 1.5 m overhang, insulation is 6 cm, window to wall ratio is 70%, window blind type is microlouvre. has been selected. Scenario S1, which gives the best optimization result, is colored gray in Table 4.8.

Table 4.8. Optimal design variables of optimization scenarios for 2079-2080 climate forecast

| | | **2079-2080_Optimization** | | | | |
|---|---|---|---|---|---|---|
| | | **Variable** | | | | |
| | | **Glazing type** | **Local shading type** | **Insulation (m)** | **WWR (%)** | **Window blind type** |
| **Optimaziton Scenarios** | S1 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | 2.0m Overhang | 0.07 | 54 | High reflectance - low transmittance shade |
| | S2 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | No shading | 0.05 | 48 | Drapes - open weave light |
| | S3 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | No shading | 0.05 | 72 | Low reflectance - high transmittance shade |
| | S4 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | No shading | 0.06 | 68 | High reflectance - low transmittance shade |
| | S5 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | 0.5m Overhang | 0.07 | 66 | High reflectance - low transmittance shade |
| | S6 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | No shading | 0.03 | 42 | Mid-pane blind with medium reflectivity slats |
| | S7 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | 1.5m Overhang | none | 26 | High reflectance - low transmittance shade |

The heating and cooling energy consumption and discomfort hours results of the 7 optimal scenarios are presented in Table 4.9. When the results were evaluated, there was no visible decrease in discomfort hours as seen in the 2079-2080 climate predictions. As a result of the restriction, heating energy consumption values are below 2500 kWh, as seen in the graph. Cooling energy consumption between the scenarios is minimum 1358 kWh and maximum 1426.32 kWh. In scenario S1, which is the best optimization result, cooling energy consumption is 1358 kWh and heating energy consumption is 2066 kWh. The amount of cooling energy per square meter was 25.14 kWh. Disturbance hours are given as 2965 hours.

Table 4.9. Optimal designs of scenarios for energy consumption and discomfort hours for 2079-2080 climate scenario

| | **Cooling Energy Consumption (kWh)** | **Discomfort hours** | **Heating Energy Consumption (kWh)** |
|---|---|---|---|
| S1 | 1358.041434 | 2965.239396 | 2066.679696 |
| S2 | 1424.783844 | 2960.565673 | 1933.789493 |
| S3 | 1424.575243 | 2960.706793 | 1928.765484 |
| S4 | 1397.024838 | 2960.712377 | 1973.3967 |
| S5 | 1370.360174 | 2964.31653 | 2008.414212 |
| S6 | 1426.322721 | 2960.001191 | 1939.965338 |
| S7 | 1358.752973 | 2965.098276 | 2055.454612 |

7 best optimization scenarios, listed from S1 to S7, are graphed in Figure 4.25. Accordingly, it was observed that none of the discomfort hours exceeded 3000 hours. It was also observed that heating energy consumption decreased below 2000 kWh in scenarios S2, S3, S4 and S6. The reason for this is that the heating energy in the 2079-2080 climate scenario is already less than the current situation.

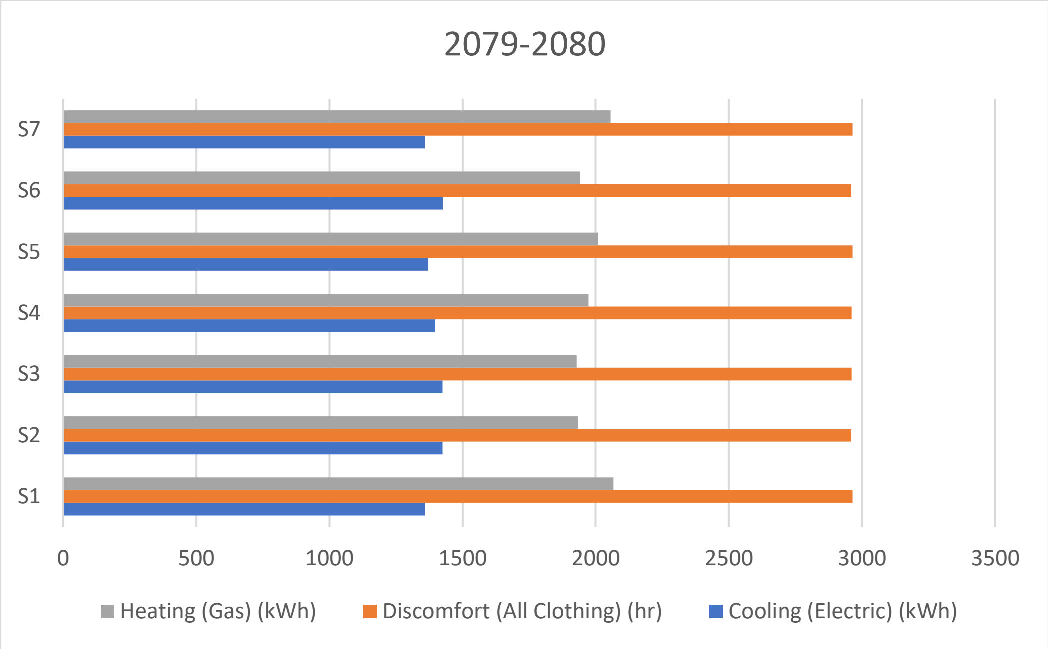



Figure 4.25. Comparison of the best optimization scenarios for 2079-2080

According to 2079-2080 climate forecasts, the best optimization scenario (S1) discomfort hours were analyzed for 11 months, shown in Figure 4.26. Accordingly, among the months, the month with the maximum discomfort hours was December with 271 hours, while the month with the minimum disturbance hours was October with 211 hours. Furthermore, there is a 34% occurrence of discomfort throughout the year. Winter is characterized by its most severe discomfort hours.

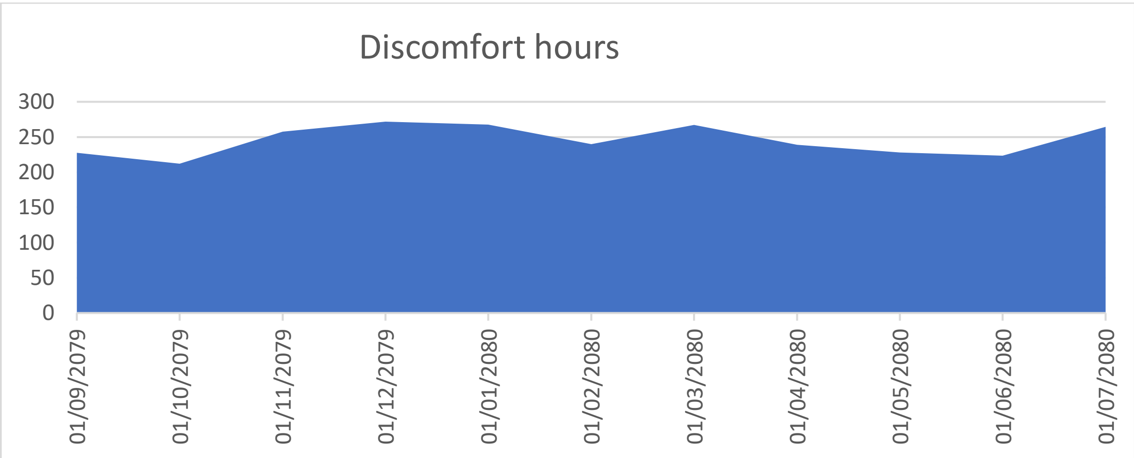



Figure 4.26. Monthly discomfort hours values for 2079-2080 S1

### 4.5.4. Discomfort Hours and Cooling Energy Comparisons of the Best Optimization Scenarios for the Years 2020-2023, 2049-2050 and 2079-2080

In Table 4.10, the characteristics of the base case and the best optimization scenario variables in all climate scenarios are listed. When the best scenarios as a result of optimization are evaluated, it is seen that different parameters are created for each climate prediction.

Table 4.10. Base case design variables and optimal design variables of best scenario for 2022-2023, 2049-2050, 2079-2080 climate forecast

| **Best Optimaziton Scenarios** | **Desing Variables** | | | | |
|---|---|---|---|---|---|
| | **Glazing type** | **Local shading type** | **Insulation** | **WWR** | **Window blind type** |
| Base Case | 4 mm double glass | - | - | 43 | - |
| 2022-2023 S1 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | 2.0m Overhang | 0.07 | 54 | High reflectance - low transmittance shade |
| 2049-2050 S1 | Trp LoE Film (33) Bronze 6mm/13mm Air | 1.0m Overhang | 0.03 | 74 | High reflectance - low transmittance shade |
| 2079-2080 S1 | Trp LoE Film (44) Bronze 6mm/13mm Air | 1.5m Overhang | 0.06 | 72 | MicroLouvre |

It is analyzed whether the building optimized for 2022-2023, that is, for the current climate, remained optimized in the 2049-2050 and 2079-2080 climate scenarios. According to these results, cooling energy and discomfort hours are shown in Table 4.11. According to the analysis results, the currently optimized building could not remain optimized in the climate predictions and the cooling energy gradually increased.

Table 4.11. Base case cooling energy consumption and discomfort hours and 2022-2023 optimized building's scenario for energy consumption and discomfort hours for the climate forecast 2049-2050, 2079-2080

| Year | Cooling Energy Consumption | Discomfort Hours |
|---|---|---|
| Base case | 1711.624 | 2936.138 |
| 2022-2023 S1 | 981.013683 | 2914.106933 |
| (2049-2050) 2022-2023 S1 | 1284.091 | 2936.138 |
| (2079-2080) 2022-2023 S1 | 1574.055 | 2971.487 |

The cooling energy consumption and discomfort hours of the base case and the cooling energy consumption and discomfort hours of the optimized existing building in the 2049-2050 and 2079-2080 climate scenarios are shown in Figure 4.27. Accordingly, it was observed that there was not much change in the discomfort hours. Still, there were noticeable increases in cooling energy consumption.

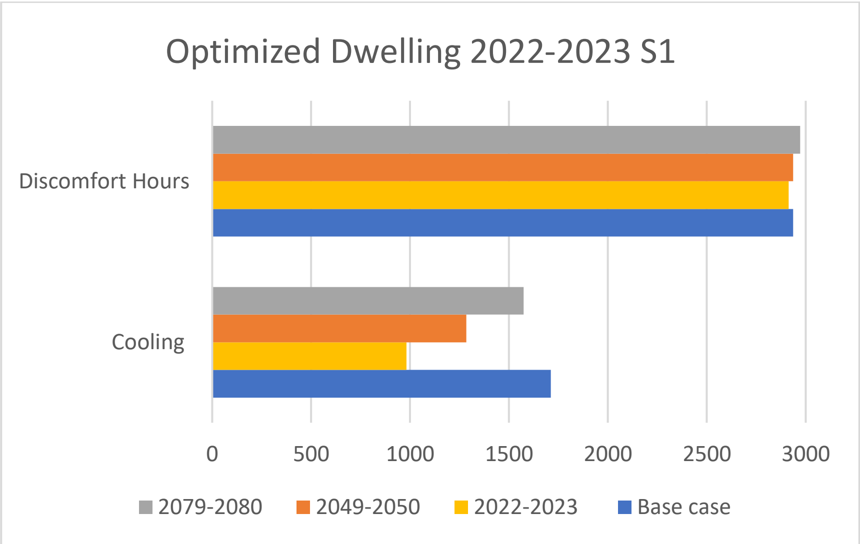



Figure 4.27. Comparison cooling energy consumption and discomfort hours for the base case, optimized base case, optimized base case in 2049-2050 climate and optimized base case in 2079-2080 climate

In order to account for potential changes in future climate circumstances, a distinct optimization study was conducted for the 2049-2050 and 2079-2080 climate scenarios, as the existing optimal building may not remain optimized under these conditions. The optimal optimization scenario for each climate condition has been identified, and the cooling energy consumption and discomfort hours associated with these scenarios are presented in Table 4.12. The 2079-2080 S1 scenario has the largest cooling energy consumption, amounting to 1358 kWh, whilst the 2022-2023 S1 scenario demonstrates the lowest cooling energy consumption, totaling 981 kWh. When assessing these values, it is imperative to take into account the fluctuating climate conditions and adjust the cooling energies accordingly.

Table 4.12. Base case cooling energy consumption and discomfort hours and cooling energy consumption and discomfort hours of the best optimization scenario (S1) of each climate forecast

| **Year** | **Cooling Energy Consumption** | **Discomfort Hours** |
|---|---|---|
| Base case | 1711.624 | 2936.138 |
| 2022-2023/ S1 | 981.013683 | 2914.106933 |
| 2049-2050 /S1 | 1199.694446 | 2951.360156 |
| 2079-2080 /S1 | 1358.041434 | 2965.239396 |

Figure 4.28 compares the cooling energy consumption and discomfort hours of the base case and the three most optimal scenarios for the time periods 2023-2023, 2049-2050, and 2079-2080. The scenario with the fewest hours of discomfort is 2022-2023 S1, with a total of 2914 hours. The 2022-2023 S1 scenario had the lowest cooling energy consumption, while the 2079-2080 S1 scenario had the highest cooling energy consumption.

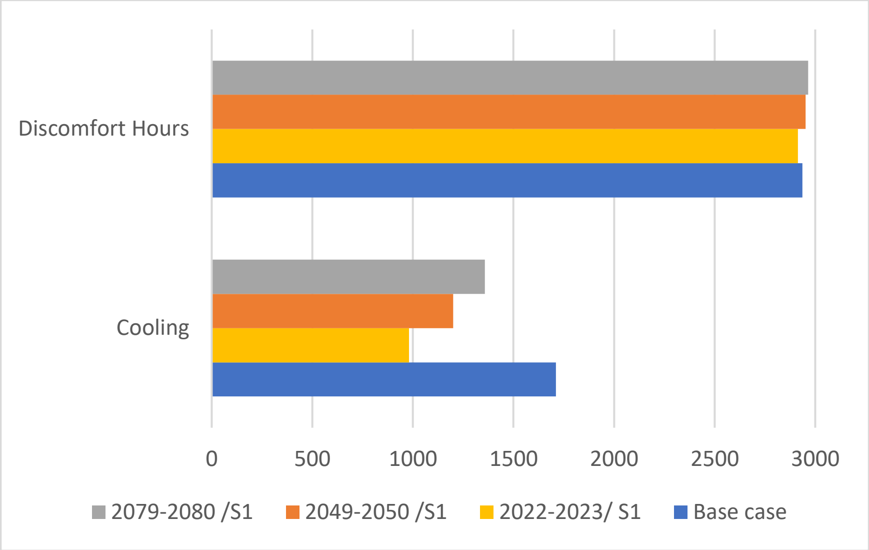



Figure 4.28. Comparison 2022-2023 optimized scenario 1, 2049-2050 optimized Scenario 1, and 2079-2080 optimized scenario 1 in terms of cooling energy and discomfort hours

Comparing monthly discomfort hours to the base case, the optimal optimization scenario for 2022-2023 shows that December remains the same, but there is a 15% decrease in these hours for October. It is shown in Figure 4.29. This value increased by 10% for the 2049-2050 climate period and 21% for the 2079-2080 climate period. The reason for this increase is changing climatic conditions.

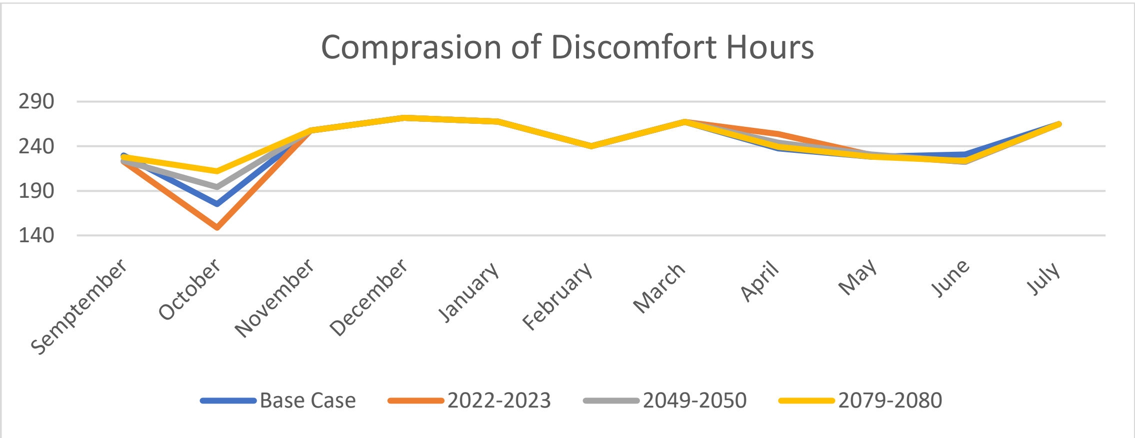



Figure 4.29. Comparison of Discomfort hours with the base case and the best optimization scenario in the 2022-2023, 2049-2050 and 2079-2080 climate scenario

# CHAPTER 5

# CONCLUSION

Within the framework of this thesis study, ways to transform existing buildings by adapting them to future conditions were investigated, and it was aimed to transfer existing buildings to the future. For this purpose, optimization studies have been carried out and suggestions have been made on adapting and harmonizing today's existing structures in their transfer to the future. As a result of the study, two situations were compared. The first is whether the currently optimized structure will remain optimized in future climate conditions. Furthermore, taking into account the weather patterns of 2049-2050 and 2079-2080, a distinct optimization analysis was conducted for each scenario, identifying the parameter choices that yielded the most favorable outcomes. As a result of the study, two studies are compared.

Firstly, the cooling energy change and the discomfort hour change in the current (2022-20223) house in the future climate conditions (2049-2050, 2079-2080) were observed. The change percentages are shown in Table 5.1. Accordingly, cooling energy consumption increased by 25% and 55% for the periods 2049-2050 and 2079-2080, respectively.

Table 5.1. Change in cooling energy consumption and discomfort hour rates according to base case's 2049-2050 and 2079-2080 climate forecasts

| **Year** | **Cooling Energy Consumption** | **Discomfort Hours** |
|---|---|---|
| 2049-2050 | 25% | 1% |
| 2079-2080 | 55% | 2% |

Secondly, the existing housing was optimized through the parameters shown in Table 5.2. In this optimized house, climate forecasts for 2049-2050 and 2079-2080 were uploaded to the system, and cooling energy change and discomfort hours change were observed according to the base case. The results are shown in Table 5.3. According to the results, a 43% decrease in cooling energy consumption was observed in the current climate conditions of the optimized building, while a 0.7% decrease in discomfort hours was observed. Under the 2049-50 and 2079-2080 climate scenarios, the cooling energy consumption of the optimized building decreased by 25% and 8%, respectively, compared to the base case. Discomfort hours remained the same for 2049-2050, and a 1% increase was observed for the climatic conditions of 2079-2080. As cooling energy consumption increases in future climate conditions, it has been observed that it is not optimized compared to the initial conditions of the building.

Table 5.2. Design variables for best optimization Scenarios

| **Best Optimaziton Scenarios** | **Desing Variables** | | | | |
|---|---|---|---|---|---|
| | **Glazing type** | **Local shading type** | **Insulation (m)** | **WWR (%)** | **Window blind type** |
| 2022-2023 S1 | Dbl LoE Elec Abs Colored 6mm/13mm Arg | 2.0m Overhang | 0.07 | 54 | High reflectance - low transmittance shade |
| 2049-2050 S1 | Trp LoE Film (33) Bronze 6mm/13mm Air | 1.0m Overhang | 0.03 | 74 | High reflectance - low transmittance shade |
| 2079-2080 S1 | Trp LoE Film (44) Bronze 6mm/13mm Air | 1.5m Overhang | 0.06 | 72 | MicroLouvre |

Table 5.3. Change in cooling energy consumption and discomfort rate of the currently optimized building in the 2049-2050 and 2079-2080 climate scenarios

| **Year** | **Cooling Energy Consumption** | **Discomfort Hours** |
|---|---|---|
| 2022-2023 S1 | -43% | -0.70% |
| (2049-2050) 2022-2023 S1 | -25% | 0 |
| (2079-2080 ) 2022-2023 S1 | -8% | 1% |

Finally, a separate optimization study was carried out for each climate scenario and the results are presented in Table 5.4. Accordingly, while the cooling energy consumption of the optimized building in the current situation decreases by 43% compared to the base case, this value is 30% for the 2049-2050 climate forecast and 21% for 2079-2080. There is no visible change in discomfort hours.

Considering that the cooling energy consumption of the base case increases by 25% to 55% for the 2049-2050 and 2079-2080 climate scenarios, these results evaluated according to the base case as a result of the optimization are quite successful.

Table 5.4. Comparison between base case and best scenarios' optimization in all climate scenarios in terms of energy consumption and discomfort hours

| Year | Cooling Energy Consumption | Discomfort Hours |
|---|---|---|
| 2022-2023/ S1 | -43% | 0.70% |
| 2049-2050 /S1 | -30% | 0.50% |
| 2079-2080 /S1 | -21% | 1% |

## 5.1. Future Studies

In the light of the results obtained, the following studies will be carried out:

- Expanding the range of actions targeted at decreasing cooling energy usage will result in more precise and comprehensive outcomes. Proposals for alterations to the building's exterior will offer a fresh outlook on the necessary renovations, allowing for the evaluation of their advantageous or disadvantageous impacts.
- Sensitivity analysis can be performed in DesignBuilder Software. Sensitivity analysis shows how input parameter uncertainties affect important building parameters such as cooling energy consumption or discomfort hours. Accordingly, it determines their weight in optimization. Sensitivity analysis should be used before optimization analysis to arrive at the most effective parameters.

- IoT devices can be used more extensively in future studies. Thus, real-time optimization can be made while evaluating values such as instantaneous temperature and humidity. In this way, it is faster to understand and evaluate the effects of climate change.
- Additionally, thanks to IoT-based devices, two-way communication can be established and control mechanisms can be created in buildings. Heat, humidity, and energy alarm systems can be created. Digital twins of buildings can be created. In this way, energy leaks in the building can be intervened immediately.
- This study can be an example for municipalities in terms of regional energy improvement studies. Considering that the same wall types are determined for each region and climate conditions are ignored, regional improvement strategies can be determined for future conditions.
- Conducting a cost analysis of the parameters in the chosen optimal scenarios and selecting the most suitable one in this regard offers greater assurance in terms of the practicality and feasibility of the study.

# REFERENCES

Ahn, Ki-Uhn, Young-Jin Kim, Deuk-Woo Kim, Sung-Hwan Yoon, and Cheol-Soo Park. 2013. “Difficulties and Issues in Simulation of a High-Rise Office Building.” *Building Simulation Conference Proceedings*, August. https://doi.org/10.26868/25222708.2013.1082.

Alcomo, Joseph, Jose M. Moreno, Bela Novaky, Marco Bindi, Roman Corobov, Robert Devoy, Christos Giannakopoulos, Eric Martin, Phil Graham, Jorgen E. Olesen, and Anatoly Shvidenko. 2007. “Europe.” In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Seppo Kellomäki, 541-80. Cambridge: Cambridge University Press.

Andrić, Ivan, Віктор Кочкодан, and Sami G. Al-Ghamdi. 2019. “A Review of Climate Change Implications for Built Environment: Impacts, Mitigation Measures and Associated Challenges in Developed and Developing Countries.” *Journal of Cleaner Production* 211 (February): 83–102. https://doi.org/10.1016/j.jclepro.2018.11.128.

Aqilah, Naja, Sheikh Ahmad Zaki, Aya Hagishima, Hom Bahadur Rijal, and Fitri Yakub. 2021. “Analysis on Electricity Use and Indoor Thermal Environment for Typical Air-Conditioning Residential Buildings in Malaysia.” *Urban Climate* 37 (May): 100830. https://doi.org/10.1016/j.uclim.2021.100830.

Ascione, Fabrizio, Nicola Bianco, Rosa Francesca De Masi, Gerardo Maria Mauro, and Giuseppe Peter Vanoli. 2017. “Resilience of Robust Cost-Optimal Energy Retrofit of Buildings to Global Warming: A Multi-Stage, Multi-Objective Approach.” *Energy and Buildings* 153 (October): 150–67. https://doi.org/10.1016/j.enbuild.2017.08.004.

ASHRAE. 2002. “ASHRAE Guideline 14: *Measurement of Energy and Demand Savings.*” ASHRAE Standards Committee.

Attia, Shady, Mohamed Hamdy, William O’Brien, and Salvatore Carlucci. 2013. “Assessing Gaps and Needs for Integrating Building Performance Optimization Tools in Net Zero Energy Buildings Design.” *Energy and Buildings* 60 (May): 110–24. https://doi.org/10.1016/j.enbuild.2013.01.016.

Aydin, Özlem, and Deniz Saylam Canım. 2017. “Binalarda Enerji Performansı Hesaplama Yöntemi (BEP-TR1)’in Kullanılabilirliğinin ve EKB Uygulamasının

Değerlendirilmesi.” *Kocaeli Üniversitesi Mimarlık Ve Yaşam Dergisi*, December. https://doi.org/10.26835/my.334594.

Bamdad, Keivan, Michael E. Cholette, Sara Omrani, and John Bell. 2021. “Future Energy-Optimised Buildings — Addressing the Impact of Climate Change on Buildings.” *Energy and Buildings* 231 (January): 110610. https://doi.org/10.1016/j.enbuild.2020.110610.

Binalarda Enerji Performansı Yönetmeliği [Energy Performance Regulation in Buildings]. 2008. T.C. Resmi Gazete [T.R. Official Gazzette]. 27075.

Calvin, Katherine, Dipak Dasgupta, Gerhard Krinner, Aditi Mukherji, Peter Thorne, Christopher H. Trisos, José Romero, et al. 2023. “IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (Eds.)]. IPCC, Geneva, Switzerland.”: 35-115. https://doi.org/10.59327/ipcc/ar6-9789291691647.

Canan, Can. 2019. “*Küresel İklim Değişikliği Ve Uluslararası Çabalar*.” MSc. Thesis, Süleyman Demirel University.

Cao, Xiaodong, Xilei Dai, and Junjie Liu. 2016. “Building Energy-Consumption Status Worldwide and the State-of-the-Art Technologies for Zero-Energy Buildings during the Past Decade.” *Energy and Buildings* 128 (September): 198–213. https://doi.org/10.1016/j.enbuild.2016.06.089.

Çetinkaya, Gülden, Selman Aydın, Muhammed Zeynel Öztürk. 2017. "Climate Types of Turkey According to Köppen-Geiger Climate Classification." *Journal of Geography* 35(1): 17.

Crämer, Wolfgang, Joël Guiot, and Katarzyna Marini. 2021. “Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future.” *HAL (Le Centre Pour La Communication Scientifique Directe)*, January. https://doi.org/10.5281/zenodo.4768833.

Crämer, Wolfgang, Joël Guiot, Katarzyna Marini, Brian Azzopardi, Mario V. Balzan, Sémia Cherif, Enrique Doblas-Miranda, et al. 2020. “MEDECC 2020 Summary for Policymakers.” In *HAL (Le Centre Pour La Communication Scientifique Directe)*. https://doi.org/10.5281/zenodo.5513887.

Crämer, Wolfgang, Jöel Guiot, Marianela Fader, Joaquim Garrabou, Jean-Pierre Gattuso, Ana Iglesias, Manfred A. Lange, et al. 2018. “Climate Change and

Interconnected Risks to Sustainable Development in the Mediterranean." *Nature Climate Change* 8 (11): 972–80. https://doi.org/10.1038/s41558-018-0299-2.

De Masi, Rosa Francesca, Antonio Gigante, Silvia Ruggiero, and Giuseppe Peter Vanoli. 2021. "Impact of Weather Data and Climate Change Projections in the Refurbishment Design of Residential Buildings in Cooling Dominated Climate." *Applied Energy* 303 (December): 117584. https://doi.org/10.1016/j.apenergy.2021.117584.

De Wilde, Pieter, and David Coley. 2012. "The Implications of a Changing Climate for Buildings." *Building and Environment* 55 (September): 1–7. https://doi.org/10.1016/j.buildenv.2012.03.014.

Deb, Kalyanmoy, Samir Agrawal, Amrit Pratap, and T. Meyarivan. 2000. "A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-Objective Optimization: NSGA-II." In *Lecture Notes in Computer Science*, 849–58. https://doi.org/10.1007/3-540-45356-3_83.

DesignBuilder. 2022. Retrieved from: https://designbuilder.co.uk (Accessed August 1, 2022)

Dias, João Bravo, Guilherme Carrilho Da Graça, and Pedro M. M. Soares. 2020. "Comparison of Methodologies for Generation of Future Weather Data for Building Thermal Energy Simulation." *Energy and Buildings* 206 (January): 109556. https://doi.org/10.1016/j.enbuild.2019.109556.

Dino, İpek Gürsel, and Çağla Meral Akgül. 2019. "Impact of Climate Change on the Existing Residential Building Stock in Turkey: An Analysis on Energy Use, Greenhouse Gas Emissions and Occupant Comfort." *Renewable Energy* 141 (October): 828–46. https://doi.org/10.1016/j.renene.2019.03.150.

Elsys. Documents.Retrieved from: https://www.elsys.se/en/documents-firmware/ (Accessed May 1, 2022)

Enerji Verimliliği Kanunu [Energy Efficiency Law]. 2007. T.C. Resmî Gazete [T.R. Official Gazette], 26510, (Accessed May 2, 2022)

Ervural, Beyzanur Çayır, Bilal Ervural, and Ramazan Evren. 2016. "Enerjide Optimizasyon Uygulamaları: Bir Literatür Araştırması." *Ege Academic Review* 16 (OZEL). https://doi.org/10.21121/eab.2016ozel24419.

Figueiredo, Raquel, Pedro Nunes, Marta J.N. Oliveira Panão, and M.C. Brito. 2020. "Country Residential Building Stock Electricity Demand in Future Climate –

Portuguese Case Study.” *Energy and Buildings* 209 (February): 109694. https://doi.org/10.1016/j.enbuild.2019.109694.

Gething, Bill, and Katie Puckett. 2019. *Design for Climate Change.* 1st ed. RIBA Publishing, p. 196. ISBN 9780429347641. https://doi.org/10.4324/9780429347641.

IPCC. 2018. “2018 1,5°C'lik İklim Değişikliği Küresel Isınma Hükümetlerarası Paneli: Politika Yapıcılar için Özet [2018 Intergovernmental Panel on Global Warming of 1.5°C Climate Change: Summary for Policy Makers.].” Switzerland. Retrieved from: www.ipcc.ch. (Accessed August 10, 2022)

Jentsch, Mark F., P.A.B. James, Leonidas Bourikas, and A.S. Bahaj. 2013. “Transforming Existing Weather Data for Worldwide Locations to Enable Energy and Building Performance Simulation under Future Climates.” *Renewable Energy* 55 (July): 514–24. https://doi.org/10.1016/j.renene.2012.12.049.

Karamızrak, P.T., 2018. “Kentlerin Küresel İklim Değişikliğine Uyum Politika ve Eylem Stratejlerinin İncelenmesi ‘Londra Örneği’.” MSc. Thesis. Yıldız Technical University, İstanbul.

Köppen. 2021. “World Maps of Köppen-Geiger Climate Classification.” Retrieved from: http://koeppen-geiger.vu-wien.ac.at/. (Accessed April 22, 2022).

Lora-alliance. 2015. “A Technical Overview of Lora and Lorawan.” Retrieved from: https://lora-alliance.org/about-lorawan/ (Accessed October 25, 2022).

Met Office HadCM3. “Met Office Climate Prediction Model.” Retrieved from: https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/climate-models/hadcm3 (Accessed June 1, 2022).

Milesight. Retrieved from: https://www.milesight.com/iot/product/lorawan-sensor/em300-th (Accessed November 3, 2022)

Nematchoua, Modeste Kameni, Mahsan Sadeghi, Sigrid Reiter, and Shady Attia. 2023. “Roadmap to Reduce the Direct Effects of Climate Change on Building Performance; A Case Study Applied to the Top 8 Deserts and Top 8 Coldest Regions in the World.” *Next Sustainability* 1 (March): 100007. https://doi.org/10.1016/j.nxsust.2023.100007.

Nguyen, Anh Tuan, Sigrid Reiter, and Philippe Rigo. 2014. “A Review on Simulation-Based Optimization Methods Applied to Building Performance Analysis.”

*Applied Energy* 113 (January): 1043–58. https://doi.org/10.1016/j.apenergy.2013.08.061.

Nikolopoulou, Marialena, and Koen Steemers. 2003. “Thermal Comfort and Psychological Adaptation as a Guide for Designing Urban Spaces.” *Energy and Buildings* 35 (1): 95–101. https://doi.org/10.1016/s0378-7788(02)00084-1.

NOAA National Centers for Environmental Information. 2023. “Monthly Global Climate Report for September 2023.” Retrieved from: https://www.ncei.noaa.gov/access/monitoring/monthlyreport/global/202309/supplemental/page-1. (Accessed November 8, 2023).

Özkaya, Elçin. 2023. “*Mevcut Binaların Dönüştürülmesinde İklim Değişikliğine Karşı Uyumlandırma Çalışmalari Üzerine Bir Araştırma*.” MSc Thesis, Çankaya University.

Pham, Anh-Duc, Ngoc-Tri Ngo, Thi Thu Ha Truong, Nhat-To Huynh, and Ngoc-Son Truong. 2020. “Predicting Energy Consumption in Multiple Buildings Using Machine Learning for Improving Energy Efficiency and Sustainability.” *Journal of Cleaner Production* 260 (July): 121082. https://doi.org/10.1016/j.jclepro.2020.121082.

Roaf, Susan, David Crichton, and Fergus Nicol. 2009. *Adapting Buildings and Cities for Climate Change: A 21st Century Survival Guide*. Routledge.

Rubel, Franz, and M. Kottek. 2010. “Observed and Projected Climate Shifts 1901-2100 Depicted by World Maps of the Köppen-Geiger Climate Classification.” *Meteorologische Zeitschrift* 19 (2): 135–41. https://doi.org/10.1127/0941-2948/2010/0430.

Santa, José, Luis Bernal-Escobedo, and Ramón Sánchez-Iborra. 2020. “On-Board Unit to Connect Personal Mobility Vehicles to the IoT.” *Procedia Computer Science* 175 (January): 173–80. https://doi.org/10.1016/j.procs.2020.07.027.

Santamouris, M., Constantinos Cartalis, Afroditi Synnefa, and Δ. Κολοκότσα. 2015. “On the Impact of Urban Heat Island and Global Warming on the Power Demand and Electricity Consumption of Buildings—A Review.” *Energy and Buildings* 98 (July): 119–24. https://doi.org/10.1016/j.enbuild.2014.09.052.

Saryazdi, Seyed Mohammad Ebrahimi, Alireza Etemad, Ali Shafaat, and Ammar M. Bahman. 2022. “Data-Driven Performance Analysis of a Residential Building Applying Artificial Neural Network (ANN) and Multi-Objective Genetic

Algorithm (GA).” *Building and Environment* 225 (November): 109633. https://doi.org/10.1016/j.buildenv.2022.109633.

Shen, Jingchun, Benedetta Copertaro, Lorenzo Sangelantoni, Xingxing Zhang, Hua Suo, and Xinxin Guan. 2020. “An Early-Stage Analysis of Climate-Adaptive Designs for Multi-Family Buildings under Future Climate Scenario: Case Studies in Rome, Italy and Stockholm, Sweden.” *Journal of Building and Engineering* 27 (January): 100972. https://doi.org/10.1016/j.jobe.2019.100972.

Shen, Pengyuan. 2017. “Impacts of Climate Change on U.S. Building Energy Use by Using Downscaled Hourly Future Weather Data.” *Energy and Buildings* 134 (January): 61–70. https://doi.org/10.1016/j.enbuild.2016.09.028.

Soutullo, Silvia, Emanuela Giancola, M.J. Jiménez, José Antonio Ferrer, and M.N. Sánchez. 2020. “How Climate Trends Impact on the Thermal Performance of a Typical Residential Building in Madrid.” *Energies* 13 (1): 237. https://doi.org/10.3390/en13010237.

T.C. Enerji Piyasasi Düzenleme Kurumu [T.R. Energy Market Regulatory Authority] (EPDK). 2022. “Doğal Gaz Piyasası 2021 Yılı Sektör Raporu. [Natural Gas Market 2021 Sector Report.]” Strateji Geliştirme Dairesi Başkanlığı [Strategy Development Department]. Ankara.

Taşer, Aybüke. 2023. “*Multi-objective Evolutionary Optimization of Photovoltaic Glass for Thermal, Daylight, and Energy Consideration*.” MSc. Thesis, İzmir Institute of Technology.

TMMOB. 2022. “Türkiye’nin Enerji Görünümü [Turkey's Energy Outlook.].” pp. 12, ISBN: 978-605-01-1531-4, Ankara.

Tootkaboni, Mamak P., Ilaria Ballarini, Michele Zinzi, and Vincenzo Corrado. 2021. “A Comparative Analysis of Different Future Weather Data for Building Energy Performance Simulation.” *Climate* 9 (2): 37. https://doi.org/10.3390/cli9020037.

Turkish Statistical Institute (TUIK). 2021. “Survey on Building and Dwelling Characteristics 2021.”

“Türkiye Climate Resilience Policy Indicator – Analysis - IEA.” n.d. IEA. Retrieved from: https://www.iea.org/articles/turkey-climate-resilience-policy-indicator. (Accessed May 4, 2023)

Türkiye Elektrik Dağitim A.Ş. Genel Müdürlüğü (TEDAŞ) [Türkiye Electricity Distribution Inc. General Directorate ]. 2023. “2022 Yılı Türkiye Elektrik

Dağıtımı Sektör Raporu [2022 Türkiye Electricity Distribution Sector Report.].” Strateji Geliştirme Dairesi Başkanlığı [Department of Strategy Development.].

United Nations Environment Programme. 2020. “Emissions Gap Report 2020.” Nairobi.

United Nations Environment Programme/Mediterranean Action Plan and Plan Bleu. 2020. “State of the Environment and Development in the Mediterranean.” Nairobi.

WHO. 2019. “Draft WHO Global Strategy on Health, Environment and Climate Change: The Transformation Needed to Improve Lives and Well-Being Sustainably Through Healthy Environments.” A72/15.

Yalçın, Arman Zafer, and Metin Dogan. 2023. “The Problem of External Dependence in Energy: An Empirical Analysis for Turkey.” *Yönetim Ve Ekonomi* 30 (2): 203–23. https://doi.org/10.18657/yonveek.1206158.

Yang, Yanjiang, Kavan Javanroodi, and Vahid M. Nik. 2021. “Climate Change and Energy Performance of European Residential Building Stocks – A Comprehensive Impact Assessment Using Climate Big Data from the Coordinated Regional Climate Downscaling Experiment.” *Applied Energy* 298 (September): 117246. https://doi.org/10.1016/j.apenergy.2021.117246.

Zhang, Shaohui, Qinxin Guo, Russell Smyth, and Yao Yao. 2022. “Extreme Temperatures and Residential Electricity Consumption: Evidence from Chinese Households.” *Energy Economics* 107 (March): 105890. https://doi.org/10.1016/j.eneco.2022.105890.