

BUILDING ENERGY PERFORMANCE, OCCUPANT COMFORT AND RETROFIT STRATEGIES UNDER THE CLIMATE CHANGE ADAPTATION PROCESS

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by

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To my dear family ...

ABSTRACT

Increasing energy consumption in our developing and changing world, which has become a critical risk, is among the main reasons for climate change. Buildings are among the high priority sectors in climate change due to their high CO₂ emissions, significant energy consumption and increasing comfort demands of building occupants. Therefore, integrating buildings with climate-resistant strategies and energy-efficient parameters in the adaptation process to climate change is of great importance for sustainable development. The necessity of taking measures to adapt buildings to climate change in the future and the importance of reducing the effects of climate change is obvious. Therefore, a comprehensive and quantitative assessment of how climate change will affect future building energy performance is essential for designing climate-resilient structures and making long-term strategic decisions. It is predicted that this change may affect each region in different ways and degrees. It is therefore critical to evaluate different climatic zones and different emission scenarios.

The thesis aims to investigate how buildings and their energy performance will be affected by climate change in the future. In the reports announced by the IPCC, two different emission scenarios, RCP 4.5 and 8.5, were considered. The housing type, which constitutes a major part of the building stock, has been selected and analyzed comparatively with two different climatic regions, Istanbul, and Izmir. Future climate data of different climatic regions were obtained using the morphing method. Different scenarios have been developed to improve building energy and thermal comfort during the climate adaptation process. In this context, it aims to explore approaches to improve

the climate resilience of residential buildings by using energy efficient integrated building design criteria.

According to the results obtained, it has been proven that climate change affects each region differently. According to the RCP 8.5 scenario, the temperature increased by +4.3 °C in Istanbul and +5 °C in Izmir. Especially in Izmir, overheating has increased during the summer months. Within the scope of improvement strategies, a decrease in overheating rates was observed remarkably. Another critical outcome is that the integration of renewable energy sources into the building is of critical importance in the adaptation process to the climate. In addition, the selection of appropriate insulation thicknesses has resulted in significant energy savings in both climate zones. Although it changes according to emission scenarios compared to the current situation, approximately 65-70% of energy improvement was achieved in Istanbul, while 60-65% of energy savings were achieved in Izmir. On the other hand, in terms of thermal comfort values, significant decreases were calculated in both provinces in the suggested most efficient scenarios. In this direction, the thesis emphasizes the importance of reducing the adverse effects of climate change and aims to increase awareness of the importance of using future climate scenarios in building energy efficiency analysis and design.

Key Words: Climate Change, Building Energy Performance, Building Energy Retrofit, Occupant Comfort

ÖZETÇE

Gelişen ve değişen dünyamızda kritik bir risk haline gelen artan enerji tüketimi, iklim değişikliğinin başlıca nedenleri arasında yer almaktadır. Binalar, yüksek CO2 emisyonları, önemli miktarda enerji tüketimi ve bina sakinlerinin artan konfor talepleri nedeniyle iklim değişikliğinde yüksek öncelikli sektörler arasındadır. Bu nedenle, iklim değişikliğine uyum sürecinde binaların iklime dayanıklı stratejiler ve enerji verimli parametrelerle bütünleştirilmesi sürdürülebilir kalkınma için büyük önem taşımaktadır. Gelecekte binaların iklim değişikliğine uyum sağlayacak önlemlerin alınmasının gerekliliği ve iklim değişikliğinin etkilerinin azaltılmasının önemi açıktır. Bu nedenle, iklim değişikliğinin gelecekteki bina enerji performansını nasıl etkileyeceğine dair kapsamlı ve nicel bir değerlendirme, iklime dayanıklı yapıların tasarlanması ve uzun vadeli stratejik kararlar alınması için gereklidir. Bu değişimin her bölgeyi farklı şekillerde ve derecelerde etkileyebileceği tahmin edilmektedir. Bu nedenle, farklı iklim bölgelerini ve farklı emisyon senaryolarını değerlendirmek kritik öneme sahiptir.

Tez, binaların ve enerji performanslarının gelecekte iklim değişikliğinden nasıl etkileneceğini araştırmayı amaçlamaktadır. IPCC tarafından açıklanan raporlarda, RCP 4.5 ve 8.5 olmak üzere iki farklı emisyon senaryosu dikkate alınmıştır. Yapı stokunun önemli bir bölümünü oluşturan konut tipi seçilmiş ve iki farklı iklim bölgesi olan İstanbul ve İzmir ile karşılaştırmalı olarak incelenmiştir. Farklı iklim bölgelerinin gelecekteki iklim verileri geçiş (morphing) yöntemi kullanılarak elde edilmiştir. İklim uyum sürecinde bina enerjisini ve ısı konforu iyileştirmek için farklı senaryolar geliştirilmiştir. Bu bağlamda, enerji verimli entegre bina tasarım kriterlerini kullanarak konut binalarının iklim direncini iyileştirmeye yönelik yaklaşımları keşfetmeyi amaçlamaktadır.

Elde edilen sonuçlara göre iklim değışikliđinin her bölgeyi farklı şekilde etkilediđi kanıtlanmıřtır. RCP 8.5 senaryosuna göre sıcaklık değeri İstanbul'da +4,3 °C, İzmir'de +5 °C arttı. Özellikle İzmir'de yaz aylarında aşırı ısınma oranı artış gösterdi. İyileřtirme stratejileri kapsamında aşırı ısınma oranlarında dikkat çekici bir düşüş gözlemlendi. Bir diđer kritik sonuç ise yenilenebilir enerji kaynaklarının binaya entegrasyonunun iklime uyum sürecinde kritik öneme sahip olmasıdır. Ayrıca uygun yalıtım kalınlıklarının seçilmesi her iki iklim bölgesinde de önemli ölçüde enerji tasarrufu sağlamıřtır. Mevcut durumda emisyon senaryolarına göre değışmekle birlikte İstanbul'da yaklaşık %65-70 oranında enerji iyileřtirmesi sağlanırken, İzmir'de %60-65 oranında enerji tasarrufu sağlanmıřtır. Buna karşılık, termal konfor değeri açısından, önerilen en verimli senaryolarda her iki ilde de önemli düşüşler hesaplanmıřtır. Bu doğrultuda tez, iklim değışikliđinin olumsuz etkilerini azaltmanın önemine vurgu yapmakta ve bina enerji verimliliđi analiz ve tasarımında geleceđin iklim senaryolarını kullanmanın önemi konusunda farkındalıđı artırmayı amaçlamaktadır.

Anahtar Kelimeler: İklim değışikliđi, Bina Enerji Performansı, Bina Enerji İyileřtirmeleri, Kullanıcı Konforu

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CHAPTER I

INTRODUCTION

“One can see from space how humans have changed the Earth. Nearly all the available land has been cleared of forest and is now used for agriculture or urban development. The polar ice caps are shrinking, and the desert areas are increasing.

At night, the Earth is no longer dark, but large areas are lit up. All of this is evidence that human exploitation of the planet is reaching a critical limit. But human demands and expectations are ever-increasing. We cannot continue to pollute the atmosphere, poison the ocean, and exhaust the land. There isn't any more available.” (Stephen Hawking, Physicist & Author)

In an ever-changing and evolving world, human activities, which are the rapid increase in population, burning of fossil fuels, deforestation, industrial processes, and urbanization cause the rapid depletion of resources and the deterioration of the balance with greenhouse gas accumulations in the atmosphere. Remarkably, after the industrial revolution, with the acceleration of human activities, the atmosphere's composition changed, and greenhouse gas emissions increased severely [1] (Figure 1).

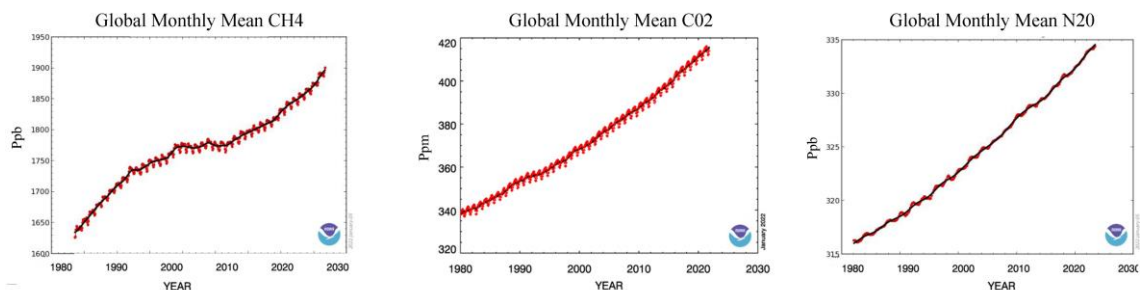


Figure 1 National Oceanic and Atmospheric Administration, Trends in Atmospheric Greenhouse Gases [1]

Due to all these variations, climate change is a proven truth. Since 1970, global surface temperatures have risen faster than 50-year periods in the last 2000-year timeframe, as noted in the most recent Intergovernmental Panel on Climate Change (IPCC) report (Figure 2). These transformations are progressing faster than anticipated, and the consequences of changes in climate are now irreversible [2]. Over the period 1990 to 2100, the average temperature of the Earth's surface is anticipated to rise by 1.4 to 5.8 degrees Celsius [3]. Also, these changes are not limited to the warming of the world. According to the predictions in the report announced by the IPCC, changes in the water cycle, precipitation regime and related droughts and floods, melting of glaciers and sea-level rise, heat waves, forest fires, ocean acidification, and the occurrence of extreme weather events are included. This situation's most critical adverse effects are now being seen and felt more clearly. Climate change is not a concern for the future; it is a severe and pressing issue that must be addressed immediately. However, its effects were often overlooked because they were not fully felt and seemed temporary. To put it another way, climate change has turned into a global problem in every way since its effects are now being felt severely. It has so many influences on human health, ecosystems, creatures, economy, and other areas. Climate models have been developed in which the possible consequences of this change in the near future are estimated under various situations. Unless the necessary precautions are taken, many regions will face much more serious problems regarding climate change in the coming years [2].

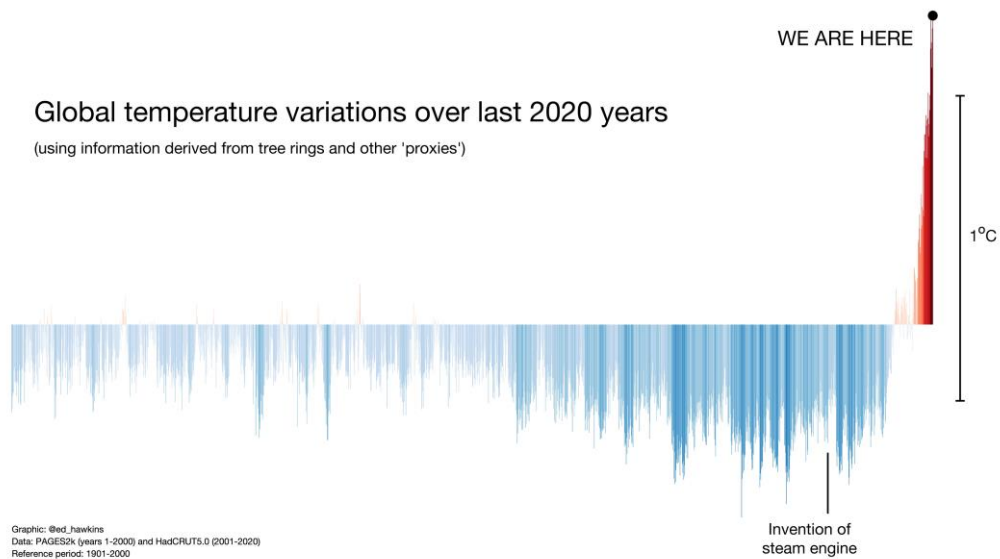


Figure 2 Global Temperature Variations over last 2020 years [2]

In the adaptation process to climate change, when the construction sector is considered, buildings on a small scale and cities in a broader scale have critical importance. Cities, which host more than half of the world's population, are a significant cause of climate change and one of the critical factors in achieving the goal. A large proportion of worldwide energy use occurs in increasingly crowded cities. Approximately 75% of total energy consumption originates from cities. Therefore, considering the causes and effects of climate change, the construction sector is too important to be neglected due to both greenhouse gas emissions and energy consumption [4]. Since 1970, construction industry greenhouse gas (GHG) emissions have more than tripled, reaching 9.18 Gt CO₂eq [5]. Also, according to IEA Report in 2018, the highest percentage of worldwide final energy usage (36%) and energy-related CO₂ emissions (39%) was accounted for by building construction and operations in Figure 3 [6].

Global share of buildings and construction final energy and emissions, 2019

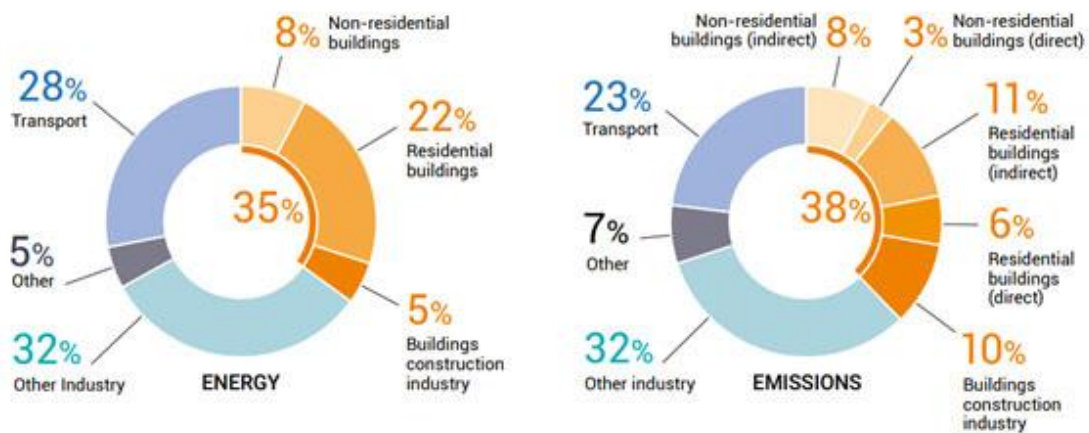


Figure 3 The global percentage of final energy and emissions from buildings and construction [6]

In this context, while buildings cause climate change, they are also subject to the effects of climate change. Buildings are the most sensitive to climate change, according to an UN-Habitat assessment (2009), since all signs of climate change, such as global warming, floods, hurricanes, and other detrimental impacts, have significant ramifications the effective operation of buildings. Also, changing climatic conditions have significant effects on building systems and their performance. In general, the increase in outdoor temperatures causes changes in energy use. The demand for heating will decrease, while the demand for cooling will increase significantly. Observed extreme weather events will affect thermal comfort, and capacity mismatch and inefficiencies caused by overloading HVAC systems of buildings will adversely affect building systems [7]. All these effects will ultimately affect the building occupants. In this direction, the construction sector plays a vital role in reducing the adverse effects of climate change. The lengthy lifespan of structures (50-75 years) corresponds to the period over which the climate is predicted to change significantly [7]. For this reason, it is substantive that the buildings to be built are sensitive to climate and revised according to the climate adaptation process.

1.1 Importance and Purpose of Thesis

Due to significant carbon emissions, buildings are one of the primary contributors to climate change. Building and construction energy demand is continuing to rise, owing to increasing energy availability in emerging nations, increased ownership and usage of energy-consuming gadgets, and significant development in the global building floor area [6]. Parallel to this, Turkey is one of the developing countries and the demand for housing is increasing accordingly. However, critically inadequate are Turkey's policies and actions. The critically inadequate assessment implies that Turkey's policies and actions in 2030 show little to no action and are incompatible with the 1.5°C temperature target set by the Paris Agreement [8]& CCPI (Climate Change Performance Index). Suppose global carbon dioxide emissions continue like this, according to climate models. In that case, each region of Turkey will be affected differently by climate change. However, the overall average temperature will increase by 4.2 C by 2100. In the scenario where the emissions increase, Turkey will warm up to an average of 6.4 C [9].

These evaluations show that climate change significantly and immediately impacts on the built environment, and each region in the world will be affected to varying degrees. Buildings and cities are one of the reasons for this critical process. There are both influencing and affected components. Architects must develop climate-resilient strategies to respond to a changing climate. Especially in Turkey, there is still a knowledge gap about how buildings will be affected by climate change and how to minimize emissions from built environments.

In line with the identified gaps and problems, the thesis is based on the comparison and determination of the methods of obtaining future climate data, the effects of climate change on buildings in Turkey, and the determination of the risks in the built environment. The primary purpose of this thesis is to evaluate the impact of the existing residential

building on different climatic regions of Turkey by using future climate models to develop different scenarios to improve energy demand and thermal comfort. Climate change differs according to each region's climate type and parameters. Therefore, it is necessary to evaluate how the regions will be affected separately and propose solutions. Climate-resistant, energy-efficient, and environmentally friendly measures suitable for the chosen residential building are determined in this context. Weather files are created according to the climate model selected in the context of Izmir and Istanbul which have different climate characteristics. Finally, various measures and combinations are compared, and evaluated, and recommendations are developed. Within the scope of the determined purpose, specific focal points were established in the research:

- Understanding the causes and result of climate change
- Clarify the relationship between climate scenarios and the building sector
- The effects of climate change on the energy performance of buildings,
- Investigation of different climate models used to obtain future climate models,
- Calculating the current energy consumption and comfort level of the existing residential building and comparing the energy consumption and comfort level with the future scenarios obtained,
- Determining different strategies to improve the energy performance of the building in selected cities with different climatic characteristics,
- Developing mitigation strategies and making recommendations for the climate adaptation process of existing residential buildings.

1.2 Scope of the Thesis

The effects of climate change on cities are far-reaching. However, only building-scale mitigation strategies have been developed within the scope of this study. In addition, studies were carried out on the residential building within the scope of the thesis.

Therefore, other building typologies are not within the scope of the study. IPCC's RCP 4.5, and 8.5 scenarios were considered to calculate the current possible risks of climate change on buildings. Other scenarios were excluded from the scope of the study. The buildings' energy performance and thermal comfort were evaluated during the improvement and adaptation process. The study does not include acoustics, visuals, and indoor air quality parameters. Finally, as explained earlier, climate change will affect each region to varying degrees. This study covers the provinces of Istanbul and Izmir.

1.3 Hypothesis

To determine the scope and content of the thesis, main research questions and sub-research questions were developed during this study. The following question is the main question:

- How does climate change affect the energy and thermal performance of buildings and what can be effective mitigation and adaptation strategies?

The sub-research questions are:

- What are the effects of climate change on buildings and cities?
- What strategies are applied to improve buildings' energy performance and thermal comfort conditions during the climate adaptation process?

1.4 Methodology of the Thesis

The research technique has been depicted and explained in this part; however, the details of the methodology used to fulfill the study's objectives are explored and provided in the later chapters. Climate change is affected differently according to each region's climate type, parameters, and characteristics of different climate types. This study is

based on the method of comparing different climate types. According to the Köppen-Geiger classification, the temperate Mediterranean climate Izmir region and the temperate Istanbul province were selected within this framework. Istanbul's summers are hot and humid; winters are cold, rainy, and sometimes snowy. Because of the humidity, the air is warmer than it is hot, it may feel colder than it is cold. The hottest months are July and August. Compared to Istanbul, İzmir has a higher average temperature. The summer season is hot and dry, the winter is warm and rainy. The hottest months are June, July, and August.

For future climate data, emission scenarios published by IPCC are considered. In this context, there are four different emission scenarios, namely RCP 2.6, 4.5, 6.0 and 8.5. The RCP 2.6 scenario is the most optimistic, and emissions are assumed to be reduced. RCP 4.5 and RCP 6.0 scenarios are moderate scenarios. Compared to RCP 4.5 and RCP 6.0, RCP 4.5 is the more optimistic scenario and emissions are lower in this scenario. The more pessimistic scenario is the RCP 8.5 scenario, where emissions are higher compared to this scenario. For building energy simulations, the methods of obtaining future climate data were compared and the most suitable method, the morphing method, was chosen. The future climate set was arranged to be used in building modeling programs. Climatic data in the future of selected provinces were obtained. While obtaining climate data, RCP 4.5 and RCP 8.5 scenarios were selected by considering different emission scenarios. The reason for choosing the RCP 4.5 scenario is how the change will occur and how it will affect buildings if emissions are kept to a certain extent. In the RCP 8.5 scenario, it is a measure of what would happen if no action was taken. Then, the effects of climate change on building performances and built environment were investigated according to different emission scenarios and appropriate mitigation strategies were determined. The current performance of the building was analyzed in separate climatic zones using a simulation-

CHAPTER II

LITERATURE REVIEW

The issue of climate change is a phenomenon that needs to be examined from a very broad perspective. Therefore, this section briefly covers the general concept of climate change to provide basic information to the reader. Explain the possible effects of this process on the built environment. Finally, it provides a comprehensive overview of the studies carried out within the framework of mitigation and adaptation within the scope of the construction sector in the world. This section aims to understand the subject of climate change in its most basic form and determine its relationship with the built environment.

2.1 Climate System & Climate Change

Weather and climate have a significant impact on life on the planet. To comprehend, detect, and anticipate the human impact on climate, one must first comprehend the system that belongs to the Earth's climate, as well as the processes that contribute to climate change [10]. The changeable condition of the surrounding environment defined by temperature, wind, precipitation, clouds, and other meteorological aspects is referred to as "weather." On the other hand, "climate" refers to the mean and average of weather conditions across a certain time period and a certain area in terms of their variability [11]. The climate system on Earth is a complex and interacting system with numerous variables. To make an understanding of this changing process, people need to first comprehend the fundamental ideas of the Earth's climate system as in Figure 5.

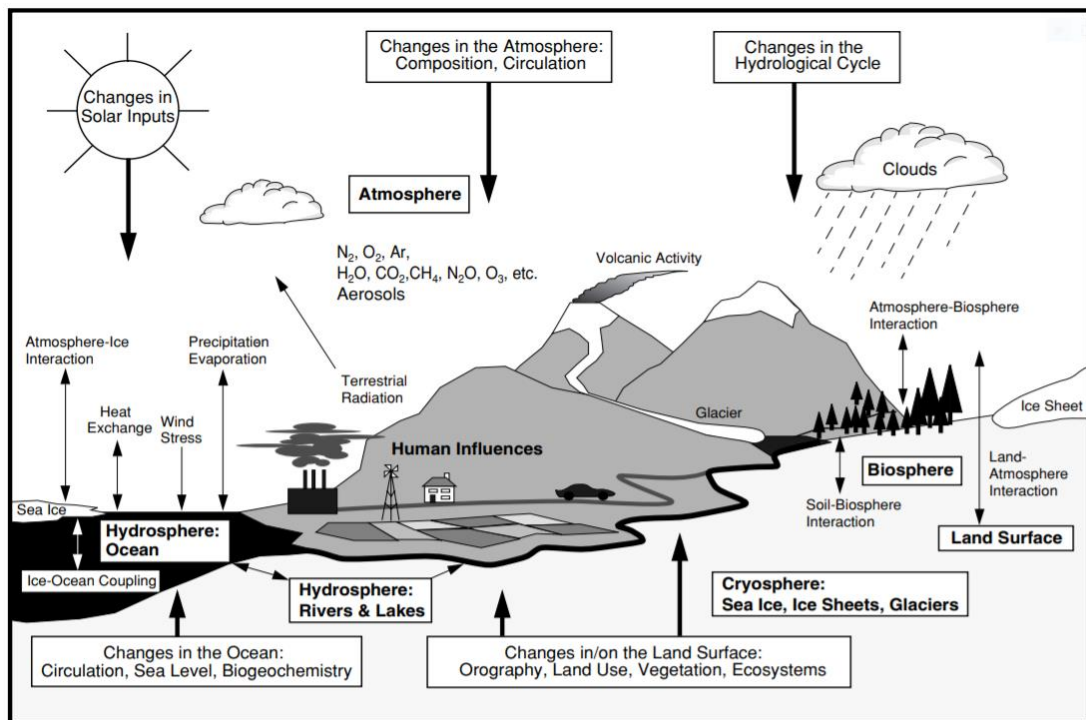


Figure 5 The Global Climate System's Components [10]

The atmosphere, land surface, snow and ice, seas, and other bodies of water, as well as living beings, make up the climate system, which is a complex, interacting system [12]. The hydrosphere is a component that includes ground and surface water. The cryosphere is the area of the Earth's surface where ice sheets, snowfields, etc., have a large overlap with the hydrosphere. The pedosphere is the foundation of both the Earth's soil layer and life on the surface. Rocks and minerals make up the lithosphere, which is the uppermost section of the outer shell and includes critical minerals. And other, the biosphere is the part that includes all living things on earth. The atmosphere, another climate system component has the most unstable and rapidly changing system and contains particles and gases [10]. While the atmosphere allows living things to live with the oxygen it contains, it also fulfills another important function. Greenhouse gases, which are 1% of the gases in the atmosphere, are gas formations that absorb and re-emit infrared radiation in the

atmosphere together with water vapor. Thanks to the gases in their content, it functions as a cover that prevents the rays coming from the sun from getting away from the earth [13]. For living things to survive on the earth, these gases must be in balance. The components of this complex and interconnected system contain natural and anthropogenic influences. The interplay of these components can cause climate fluctuations. Skinner and Muck (2011) argue that, especially since the Industrial Revolution, the atmosphere has become a more vital and important component of the climate system because of gas emissions [12].

2.1.1 Causes & Effects of Climate Change

The IPCC defines the concept of climate change as “climatic changes that occur over time as a result of natural changes or human activities” [14]. In other terms, the UNFCCC, it is expressed as "the change that occurs as a result of natural changes observed in the climate over a long period of time and human activities, directly or indirectly, and disrupts the composition of the global atmosphere" [15].

One of the crucial natural causes can be defined as major natural disasters and the movement of continents. These conditions affect long-term weather events and cause climate change [16]. Another natural reason is solar energy and the global energy balance. Radiation from the Sun is the ultimate source of energy that drives the climate system [17]. It is expected that the short-wave solar energy coming to the earth from the sun and the long-wave radiation emitted back to be balanced. Some gases in the atmosphere, which are permeable to short-wave solar energy but not too long-wave radiation, have the so-called "greenhouse effect". The increase in the number of related gases in the atmosphere triggers global warming, and global warming triggers global climate change [12]. The greenhouse effect is a naturally occurring effect and is necessary for the

continuation of life on earth. However, this harmony must be in a certain balance for living things to survive. One of the main causes of climate change is the deterioration of the radiation balance on earth. According to the IPCC report, the factors causing the highest radiative forcing are CO₂ and other greenhouse gases. Radiative forcing is briefly called the difference between the energy coming into the atmosphere and the energy leaving the atmosphere [14].

In addition to natural causes, anthropogenic causes are also a significant cause of climate change. Anthropogenic (human-based) factors, which are the reason for the increase in CO₂ and other greenhouse gases, have caused the amount of greenhouse gases in the atmosphere to exceed their natural limits, especially after the industrial revolution, as well as the excessive use of fossil fuels. According to the latest IPCC report, the climate crisis is now unquestionably human-induced [2]. Only the difference in variation caused by climate from natural sources and variation from human-based sources were compared in Figure 6.

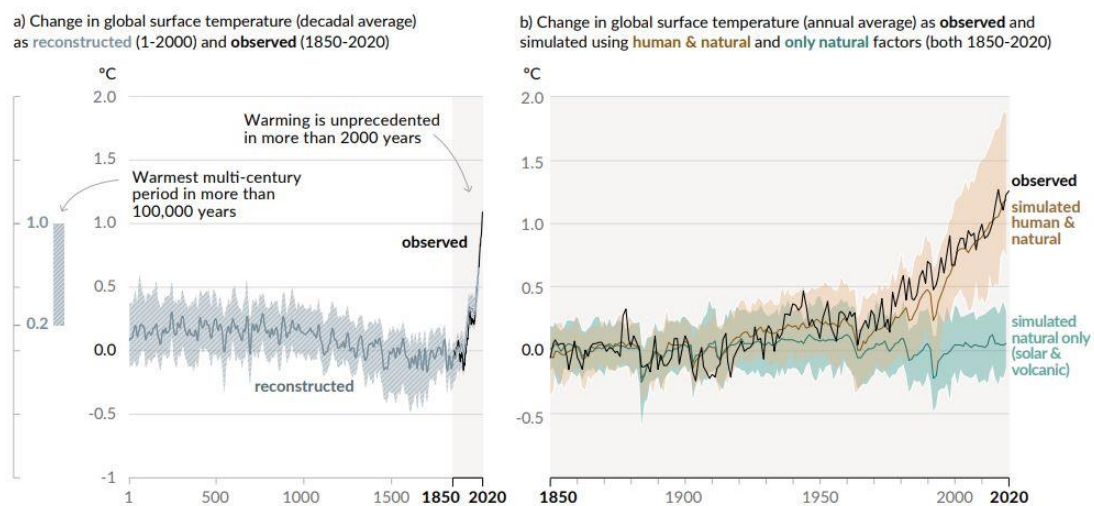


Figure 6 Change in Global Surface [2]

The main reasons for this human-induced increase are fossil fuel uses, deforestation, rapid population growth, industrial and agricultural activities, urbanization, industrialization, energy use, building operations and climate policies. As a result of all these phenomena, changes that have not been seen for thousands of years in the climate system are progressing faster than expected, and every part of the world is adversely affected by this change, albeit at different levels [2]. The last 7 years have gone down in history as the 7 hottest years in human history with a dramatic difference [9] [18]. Snow and ice levels are falling, sea levels are rising, the atmosphere and oceans are warming dramatically, plant and animal species are dramatically disappearing, heatwave, forest fires rates are increasing, and extreme weather conditions such as droughts, floods and hurricanes are occurring. In parallel to this, for instance, 396 temperature records were broken in Australia and Europe in 2019 alone. In the same year, a record was broken with a heatwave measuring 49.9°C in Israel. The lowest amount of Arctic Sea ice ever measured. One region of Iran received 70 percent of its annual precipitation in a single day. Many species perished because of months of forest fires in Australia [19]. All these adverse conditions are some of the striking results of this rapid change and affect all systems in a broad perspective.

2.1.2 Future Climate Scenarios

To be prepared for the consequences of climate change and to minimize its negative effects, it is necessary to predict how the observed changes and trends in the climate will be in the future and to determine the effects of these changes on natural and human systems. The worldwide organization working in this direction is the IPCC organization. This organization was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to evaluate the situation and studies on climate change considering current scientific, technical, and

socioeconomic information. Evaluation Reports compiled by many researchers and scientists on the current and possible future state of the world climate system are shared at regular intervals. Various models and scenarios are presented in these reports. Models, which are mathematical representations of the climate system's components, interactions, and feedbacks, are used to understand observed and past climate and predict future climate. In future climate models, different scenarios are developed, and possible effects are determined. In this context, future atmospheric concentrations of substances that disrupt the earth's radiation balances such as greenhouse gases and aerosols, are estimated with emission scenarios [20]. For projections on a possible future climate change, the IPCC has published the Special Report on Emissions Scenarios (SRES) in its 3rd Assessment Report [10]. The report announced later that the new method, RCP (Representative Concentration Pathways) scenarios, was used instead of SRES. The difference between the two representative methods is that SRES scenarios directly depend on socio-economic parameters. While determining different scenarios, different assumptions are considered for population growth, energy use, economies, technological developments, agriculture, and changes in land use. Until today, 6 assessment reports have been prepared and presented by the organization as shown in Table 1.

Table 1 IPCC Assessment Reports

Scenario Name	Year of Publication	Used IPCC Evaluation Report
SA90	1990	1st and 2nd Assessment Report (FAR, SAR)
IS92a-f	1992	3rd Assessment Report (TAR)
SRES A-B (Special Report on Emissions Scenarios)	2000	3rd and 4th Assessment Report (TAR, AR4)
RCPs (Representative Concentration Pathway)	2007	5th Assessment Report (AR5)
SSPs (Shared Socioeconomic Pathways)	2021	6th Assessment Report (AR6)

It includes new technologies and new approaches in the creation of each climate change scenario. The aim is to evaluate more parameters in a shorter time and simultaneously. In parallel to this, after the AR5 report, General Circulation Models have now turned to RCP scenarios that produce more sensitive results [5]. The concentration scenarios developed with this approach are called RCP. And four RCP types are defined for radiative forcing levels and GHG emissions. On the other hand, RCP and SSP scenarios are created to complement each other. While RCP scenarios provide an analysis of greenhouse gas emissions and the amount of warming that may occur by the end of this century, SSP scenarios determine the stages of whether these reductions in emissions can be achieved as in shown Figure 7.

The RCP 2.6 scenario, with the lowest radiative forcing and greenhouse gas consumption, requires a 70% reduction in GHG emissions and critical changes from the second half of the 21st century. Predicted CO₂ concentration 400 ppm and Total Radiative Force in 2100 (RF) 2.6 Wm⁻² [21] [22] [23].

The RCP 4.5 scenario brings with it the obligation to limit emissions because of the increase in population rates (8.7 billion). According to this scenario, it includes new technologies and systems with lower emissions. By 2035, CO₂ emissions from energy and industrial sources are expected to increase and then decline significantly. Projected CO₂ level 650 ppm and Total Radiative Force 4.5 Wm⁻² [21] [22] [24].

RCP 6.0 is the scenario predicting 9.8 billion population. Under this scenario, GHG emissions will increase until 2060 and then decline drastically. Projected CO₂ 850 ppm and total radiative forcing is 6.0 Wm⁻² [21] [24] [25].

The RCP 8.5 scenario is the scenario with the highest emissions. The estimated population is 12 billion in 2100. This leads to very high energy demands and greenhouse gas emissions if climate policies are ignored. The predicted CO₂ level is 1370 ppm, and

the total radiative forcing is 8.5 Wm^{-2} [21] [22] [26].

SSP-RCP Scenario Pathways						
RCP in the IPCC Sixth 5th Report	2046–2065 Mean (likely range)	2081–2100 Mean (likely range)	SSP in the IPCC Sixth 6th Report	(2041–2060)	(2081–2100)	Very likely range in °C (2081–2100)
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)	SSP1-1.9 (very low GHG emissions)	1.6 °C	1.4 °C	1.0 – 1.8
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)	SSP1-2.6	1.7 °C	1.8 °C	1.3 – 2.4
RCP6	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)	SSP2-4.5	2.0 °C	2.7 °C	2.1 – 3.5
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)	SSP3-7.0	2.1 °C	3.6 °C	2.8 – 4.6
			SSP5-8.5 (very high GHG emissions)	2.4 °C	4.4 °C	3.3 – 5.7

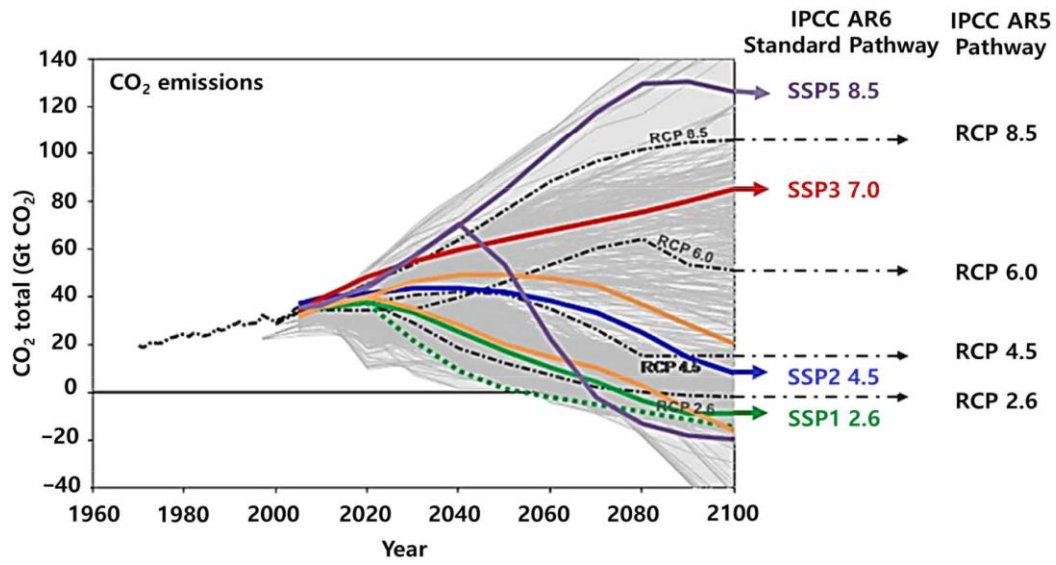


Figure 7 IPCC Scenarios Representation for Climate Change, Adapted from IPCC's Reports [14] [2]

Among the scenarios, even though some mitigation techniques are being implemented worldwide, these are insufficient. Calculations based on predicted climate models are currently in the range of approximately SSP2-4.5 to SSP3-7.0 globally according to the AR6 report and RCP scenarios 4.5 to 8.5 according to the AR5 report. [27] [28]. Accordingly, the temperature is expected to increase by 2.8 to 4.6 °C on average. In the highest emissions scenario, the temperature is expected to rise by more than 5 °C on average by the end of this century if the necessary measures are not taken or are insufficient.

As mentioned earlier, all these changes affect each region to varying degrees. When this situation is evaluated from the perspective of Turkey, it is calculated that the temperatures have increased by 2.3 °C compared to the 1900s. According to the moderate scenario, it is expected to reach 4-5°C and continue to increase by the end of this century as in Figure 8. According to the high emission SSP3-7.0 scenario an increase of 6-7 °C is expected across Turkey [9].

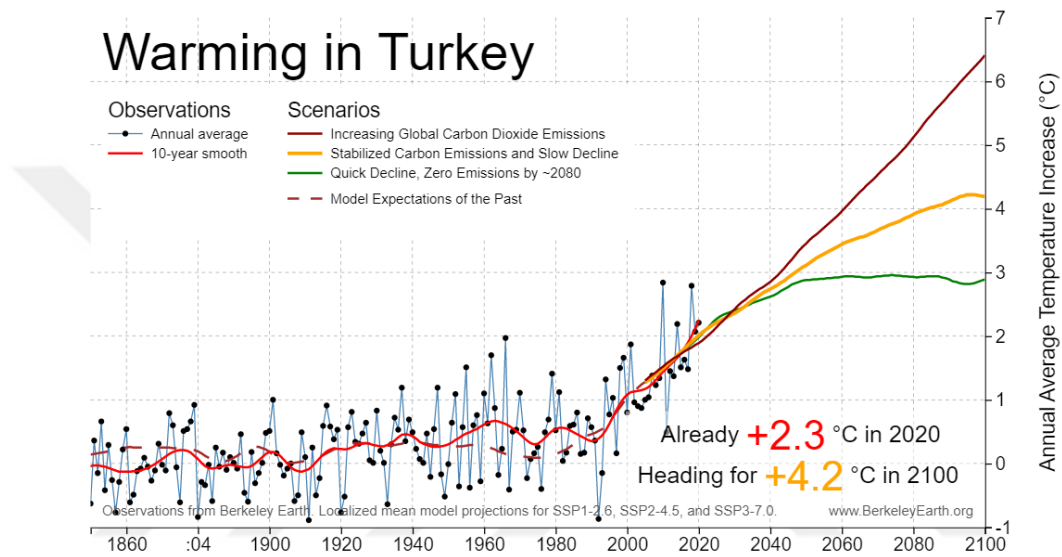


Figure 8 Climate Change Scenarios for Turkey [9]

2.1.3 International and National Strategies for Climate Change

Countries have determined various strategies to reduce the potential negative effects of climate change. In addition to the measures taken throughout the country, universal decisions have been taken and tried to be implemented for climate change, which is a serious global problem. Two agreements that stand out in this direction are the Kyoto Protocol and the Paris Climate Agreement. These agreements aim to strengthen international cooperation against the threat of climate change. However, as a result of the decisions taken, the targets set have not been achieved yet [29]. When evaluated on a large-scale, cities and buildings on a small scale are vulnerable to this process. Therefore,

2.2 The Built Environment and Climate Change Relation

As emphasized earlier, the level of human development, technology, and the climate system have a complex relationship that affects each other. In parallel, the built environment, and man-made structures, which provide an environment for human activities, cause an anthropogenic effect, significantly increasing the risk of climate change. And it will also be the sector that will be significantly affected by this change.

2.2.1 Impacts of Climate Change on the Built Environment

The resulting risks of climate change impacting on the built environment are expected to increase dramatically. Risks related to climate change are accepted as the most common of the problems affecting the social area, natural environment, and human system, with the damages and risks to the built environment [5]. Cities contribute dramatically to climate change, according to the UN-Habitat report. Because cities use 78% of the world's energy and produce more than 60% of greenhouse gas emissions [4]. The greater human use of fossil fuels and the urban population make cities even more vulnerable to climate change. It is estimated that urban land cover will increase dramatically by 1.2 million km² by 2030 and 43 megacities will have populations of more than 10 million [4]. As a result of this, climate change is anticipated to render most cities untenable and uninhabitable [14]. The threats to the built environment are significant, and experts have researched them extensively. These consequences will vary widely depending on the local features, density, and climatic type, as well as the physical aspects of the current environment. Climate change might have both direct and indirect effects on the built environment. While the direct consequences will influence the building's physical texture, the indirect effects will affect the environment's economic, social, and

environmental context, and so will have indirect effects on the built environment [30].

2.2.2 Types of the Risks on Building Sector

On a smaller scale, buildings both contribute to and are affected by climate change. Buildings serve as a link between the outer environment, which is inclined to climate change, and the internal environment, which must be kept within a range that keeps building dwellers safe and comfortable while also is acceptable for any critical processes going place within the structure [7]. Due to their extended service life, buildings' operating period energy consumption often accounts for the majority of total energy consumption. In this context, they are one of the issues that should be considered carefully in the process of adaptation to the climate [31]. They both affect and are critically affected by this change. However, this interaction may vary depending on parameters such as climate type, building materials, and building type.

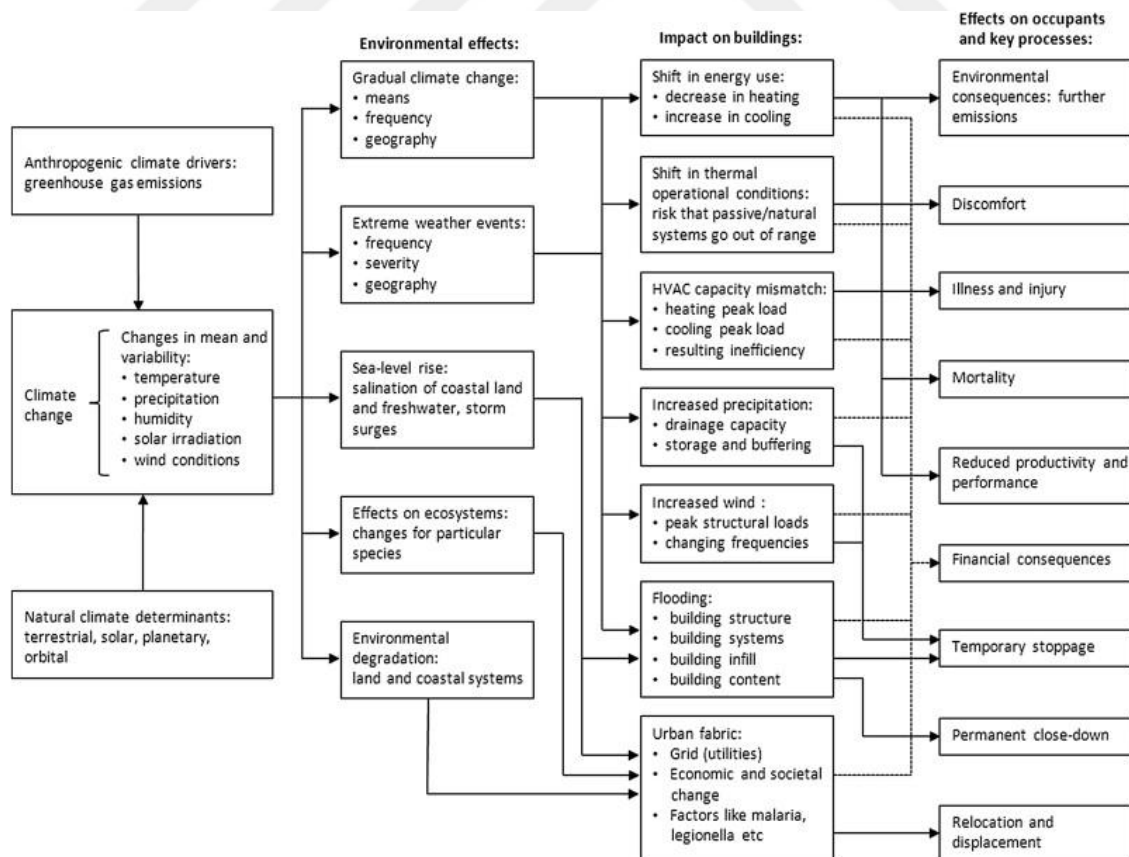


Figure 10 Representation of Climate Change and Building [7]

Climate change has effects on building behavior and performance. Rising temperatures affect the internal temperatures of buildings and thus their thermal performance. As the heating needs of buildings decrease, their cooling needs increase. This situation can cause capacity issues in Heating, Ventilating and Air Conditioning (HVAC) systems. In addition, severe weather events affect the building's exterior surfaces and interior comfort levels. Flooding and sea-level rise can cause damage to buildings and damage to foundations. Both building users and buildings are adversely affected by all these processes [32]. These processes have an interactive and complex relationship with each other (Figure 10).

2.2.2.1 Energy Consumption in Buildings

Increasing population and urbanization in the world dramatically increase energy consumption, especially in developing countries such as Turkey, this rate is high. Turkey has a high rate of urbanization. Of this proportion, total energy uses, including residential, commercial, and public buildings, were responsible for about one-third of the country's total final energy consumption in 2015 [33]. In this context, the rapid increase in the energy demand of the sector, has effectively made Turkey much more energy dependent in recent years. Most of the energy consumed in buildings is utilized to maintain a comfortable interior environment in terms of thermal comfort (heating and cooling) and air quality (ventilation) [6]. However, due to climate change, it will be more difficult to provide this indoor comfort, and this will also affect the energy use in buildings. Temperature variations have an impact on structures both inside and out. Changes in climate, increasing energy use for cooling and heating, and greater fire dangers are all examples of internal risk. Damage to the building's fabric and green spaces around

structures are examples of external consequences. The most visible effect on the energy performance of buildings is that as the temperature rises, the demand for increased cooling will increase [34]. According to the IPCC report on the danger of severe events “it is quite probable that there has been an overall drop in the number of cold days and nights, and an overall rise in the number of warm days and nights [14].” Although it varies according to the climate type and location, heat waves and overheating problems will occur in some regions. The increase in cooling demand will lead to higher energy consumption, if necessary, precautions are not taken. Extreme weather events due to climate change can be deadly, especially for the elderly, due to heat waves [5]. In contrast, there will be a decrease in the need for heating in general. If this situation in energy use is not considered, problems will arise in mechanical systems. According to the latest IPCC report released, summer heat waves can cause power outages and blackouts or even mechanical systems problems due to increased air conditioning demand [2].

Considering the change in Turkey, there is an increase as seen in the warming strip in Figure 11. Although it varies according to the regions, it is thought that there will be a difference of 4 °C in winters and 6 °C in summers in general temperature increases [16]. This situation will be felt more in some cities due to heat waves.

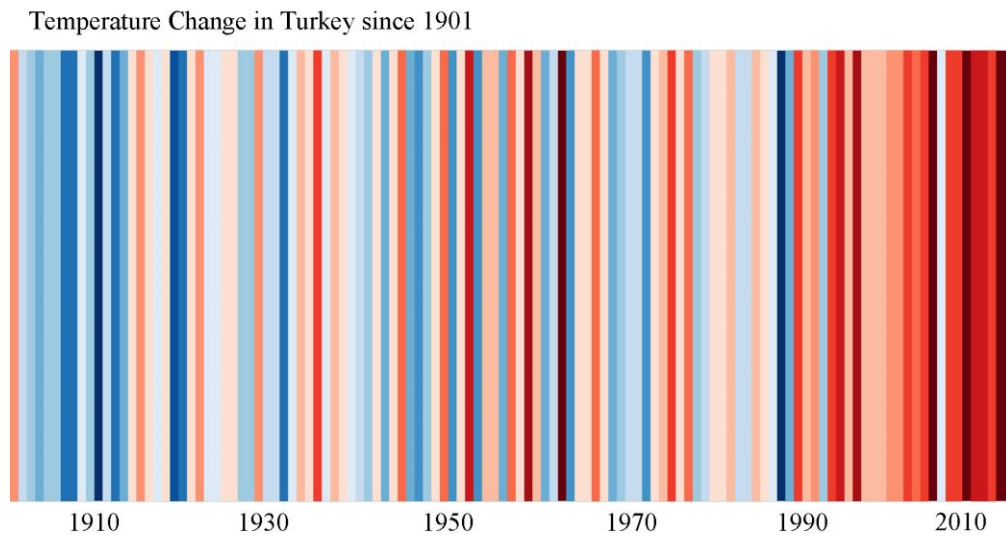


Figure 11 Warm-up strips for Turkey (Obtained via Copernicus & Python)

2.2.2.2 Impact on Energy Efficient Buildings

In today's world, increasing energy consumption has led to new searches and various strategies have been determined to limit energy consumption in buildings. In this direction, the concept of Nearly Zero Energy Building (nZEB) and Zero Energy Building (ZEB) emerged. In the simplest way, according to the Energy Performance of Buildings Directive (EPBD), a nearly zero energy building is defined as a building with high energy performance [35]. A zero-emission building is defined as generates enough renewable energy to meet the building's greenhouse gas emissions on an energy basis throughout the course of its lifetime and does not require external energy [36]. The issue of how buildings that meet these definitions will be affected by the negative effects of climate change has been one of the current research topics. It is clear that these buildings will also be affected by climate change, but the extent of this interaction will be revealed as a result of research. Research is being conducted on whether buildings that currently need little or no energy will still be able to maintain these features in future weather scenarios or how they will be affected.

In a study conducted by Agostino, Parker et al. (2022), 16 cities in Europe with different climatic characteristics were selected. Using the RCP 8.5 scenario for 2060, the energy consumption of a standard nZEB building is compared with the current weather scenarios. According to the results obtained, the temperatures have increased in each city, but the degrees are different. It has also been found that extreme summer temperatures will become much more common. On the other hand, a significant reduction of the cooling load in hot climates has reduced the total air conditioning load of the building. However, in cold climates, there is still a significant energy requirement. Within the scope

of these results, the nZEB building has provided a significant advantage in hot climates, and even in some regions, nZEB designs have turned into Positive Energy Buildings (PEB). Thus, it has been proven that they will produce more energy than they need, thanks to renewable energy sources. The importance of energy-efficient, low-energy systems and efficient lighting related to the overheating problem in the summer months has been emphasized and it has been observed that active systems will be needed for cooling in some regions. Especially in the summer months, it has been obtained that PV panels can produce more energy and about three times more energy than needed initially. Considering the results obtained, it highlights that energy efficiency is an effective protection up to a certain point against climate change, as better insulated and optimized nZEBs are more resistant to extreme temperatures and negative weather events [27].

According to the study carried out by Summa, Tarabelli, Ulpiani, Perna (2020), a building in Rome that complies with Italy's nZEB standards was selected and IPCC's RCP4.5 and RCP8.5 scenarios were considered. According to the results obtained, an increase of 3.4 °C and 3.9 °C was observed in air temperatures. Based on this situation, an increase of 47.8% and 50.3% in terms of cooling loads and a decrease of 129.5% and 185.8% in terms of heating needs are analyzed. Therefore, as the demand for cooling loads will increase, it was determined that in the future, efficiently reducing air conditioning demands by focusing on a durable nZEB design will lead to energy savings. In addition, the increase in solar energy gains in summer did not adversely affect thermal comfort due to solar control elements, while in winter, solar gains decreased energy needs, especially in January, October, November, and December. Based on these results, climate change has affected nZEB buildings in terms of energy and thermal comfort, but this interaction has fewer negative consequences compared to standard buildings [37].

The study carried out by Guarda, Domingos, Jorge, Durante et al. (2020) analyzed the ZEB building in a city located in the south of America. According to the results obtained, it has been revealed that the increased cooling demands due to rising air temperatures do not meet the consumption although the increase in the gain of the PV panels and different systems will be needed. In addition to being short-lived, systems made according to current conditions have revealed the energy production problem encountered in the coming years. The necessity of capacity and efficiency of renewable energy installation is emphasized in future scenarios [38].

In the study carried out by Hernández, Yousif, Gatt, Gómez, et al (2018), research was conducted on the Lucia building, which is one of the buildings with the three highest LEED certifications in the world. It has been proven that in the building located in Valladolid, Spain, the air temperatures will increase due to climate change, and accordingly, the cooling demand will increase significantly, but the space heating will decrease. The absorption cooling systems in the building will operate at maximum capacity to meet the additional 25% increased demand. Therefore, additional chiller systems will be needed, burning more biofuel, and incurring extra costs for maintenance. In addition, the building's excess electricity produced by photovoltaics in the current system will cause it to be completely consumed inside the building due to the increased cooling demand, and even if the difference is small, it will be insufficient in 2080 [39].

The study conducted by Attia, Gobin (2020) analyzes thermal comfort on nZEB buildings operating without active cooling during summer in Belgium. According to the results obtained, overheating hours increased dramatically in 2050 and 2100, emphasizing the thermal comfort discomfort problem. Based on this, the building has proven that natural ventilation will not be sufficient in future scenarios and an extra air conditioning system will be needed for cooling demand [40].

In summary, climate change also has adverse effects on energy-optimized buildings, as evidenced by research studies. However, this rate of impact varies depending on the climate system in which the building is located and the characteristics of the building. In particular, the increase in cooling demands will cause problems in buildings' air conditioning capacities, and even the energy produced in some regions will be insufficient. Extra systems will be needed to provide thermal comfort, which will increase both the cost and the energy consumption of the buildings. Therefore, considering the longevity of buildings, energy-efficient strategies can benefit the building in the long term by considering the adaptation process to the climate.

2.2.2.3 Urban Heat Island (UHI)

The urban population is growing rapidly around the world. The total urban population, which was 746 million in 1950, reached 3.96 billion in 2015. As of 2018, 54% of the world's population lives in cities. According to calculations, the proportion of urban dwellers in the world population is expected to increase to 68% in 2050 [41]. In parallel, a large proportion of the world's total energy use takes place in increasingly crowded cities. Approximately 75% of the total energy consumption in the world originates from cities [4]. However, there is a two-way relationship between climate change and cities. While cities have serious effects on the natural environment and climate change due to their activities, the events expected to occur as a result of climate change threaten the existence of the systems that make up cities [42]. An important dimension of the pressure of climate change on cities is related to the increase in temperatures. It also increases the frequency and severity of heat waves, which occur when the air temperature rises to abnormal levels in certain time periods. The extreme heat and humidity created by the combination of heat waves with the effect of the urban heat island threaten the urban population.

Increased human activity in cities, changes in the physical organization of urban tissue, decrease in vegetal surfaces, and rise in hard surfaces prepare the way for the establishment of undesirable microclimate conditions. Solar radiation is utilized to evaporate water in plants and soil in rural locations, where it is not obstructed. Due to the lack of flora and natural land cover in cities, part of the incoming solar radiation is absorbed by urban geometry features such as high-rise structures, street widths, and other variables, creating delays in its backpropagation [43]. The daytime radiation collected by the city's buildings and asphalt roads is transformed into heat and released back into the environment, raising the city's air temperature. The solar energy that the city's buildings and asphalt roads have collected throughout the day is slowly released into the environment at night. As a result, whereas the atmosphere cools swiftly in rural regions, it cools slowly in cities, resulting in large temperature fluctuations. The difference in night temperature between the region enclosed by buildings in the city center and the open space has been recorded to be up to 4°C. The urban heat island effect is the name given to this phenomenon [44] (Figure 12). According to Oke (1982), this difference can be dramatic up to 10-15°C [45]. It causes a decrease in urban air quality, an increase in energy consumption for building cooling, malfunctions in electricity distribution networks due to the intensive use of air conditioning systems, pollution in the city's upper layer, and changes in wind, precipitation regimes, and humidity depending on the situation.

Extreme heat poses a serious threat to the elderly, and those with cardiovascular disease, diabetes, and other chronic conditions especially the elderly [46]. Effects and frequency of heat waves due to high temperatures. It has increased dramatically since the 2003 heat wave, with high death rates in Western European countries [47]. Record temperature was recorded, with the overall average of July 2021 as the world's hottest

month ever recorded [48]. In addition to all this, an increase in the number of extreme weather events with increasing frequency and magnitude is predicted in the future as a result of climate change [49].

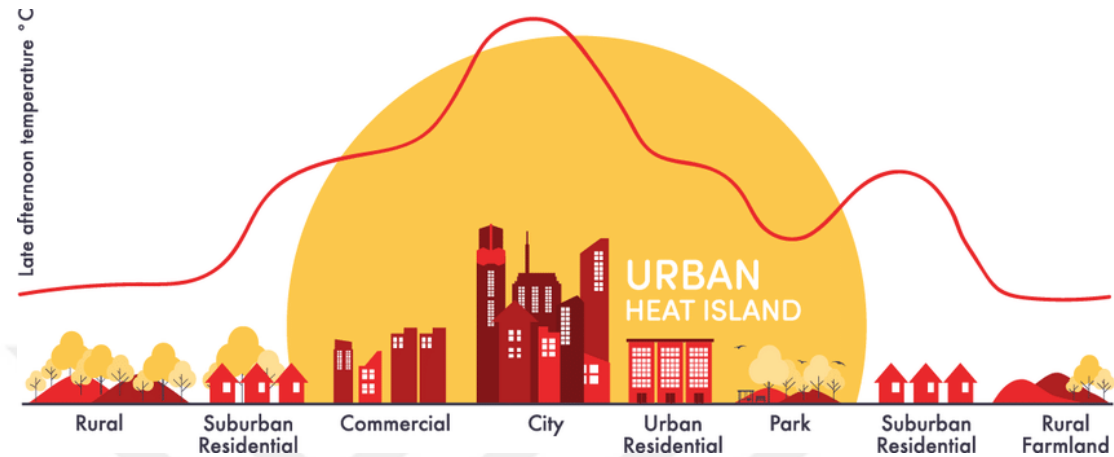


Figure 12 The effects of the Urban Heat Island [149] [150]

Parallel to this, many studies have been conducted to see these effects more frequently. In a study on this subject, it was investigated how the most used urban pavement construction materials affected the tropical climate of Sri Lanka. Materials with three different textures (smooth, rough, and jagged) and colors (black, grey, and red) were compared. It was observed that gray pavers with a smooth texture performed best, reducing the heat island effect by 2.6 °C [50]. The density of urban heat islands varies over time, according to research conducted in Moscow on the subject. The research was confined to the years 1977 through 2020. The consequences of climate change in the Moscow region are readily seen. The UHI effect has been seen to warm urban areas by 23 percent more than rural regions every ten years, whereas rural areas warm by 0.52 °C. [51]. Another investigation on this topic was conducted in Jinan, China. The heat island neighborhood scale was measured using a method based on the Landsat-8 remote sensing

approach. Although the results vary according to the building density, it has been determined that metropolitan areas are warmer than rural areas [52].

All results consider, 30% of the world's population is exposed to air temperatures that threaten human health for at least 20 days a year, and this rate is increasing day by day. If greenhouse gas emission rates continue in this way, this rate is expected to increase to 74% in 2100 with the striking effect of climate change [54]. This situation is an indication that the effects of climate change will lead to more and more severe consequences in cities. Because cities are more open and sensitive to the impacts of climate change as they are centers of population, economic activities, industry, infrastructure, and built environment.

2.2.2.4 HVAC System Design-Challenges

The warmer the weather, the greater the need for air conditioning and cooling systems. Hydrofluorocarbon (HFC) refrigerants are the chemical component of the large CO₂ release [55]. Also, most of the carbon emissions in many countries today come from natural gas and petroleum-based fuels as heating sources. For this reason, air conditioning systems both increase the impact of climate change and are adversely affected by this situation [6]. The demand for heating, ventilation, and air conditioning (HVAC) accounts for approximately 40% of building energy usage [56]. Extreme weather occurrences, and the breakdowns that follow, can put additional strain on energy infrastructure. As a result, it may cause buildings and energy systems to malfunction, putting people's thermal comfort and health at risk [57].

In parallel, overheating days, heat waves and an increase in average temperatures due to climate change, will cause discomfort in terms of heating and cooling systems of buildings, additional costs, and interruptions due to overloading. As the energy consumed

by the cooling processes reaches the maximum, it also causes indirect problems with the emergence of energy shortages [58]. In addition, extreme weather events due to climate change and the potential increase in the frequency, severity and duration of such events can render networks inefficient and cause frequent power outages. This leads to damage and deterioration in air conditioning systems [59].

In buildings designed to use natural ventilation instead of an electric cooling device, ventilation will often be insufficient due to rising temperatures. Accordingly, air conditioning systems will be needed, especially in the summer months [60]. Also, better HVAC systems are now expected to be required to limit the increased humidity and heat gain effects of outdoor air during the summer months resulting from higher outdoor, wet, and dry bulb temperatures [60]. It has been proven that the efficiency of HVAC systems decreases at high Wet Bulb Temperature / Dry Wet Bulb Temperature (WBT/DBT). For this reason, it is expected that the share of HVAC systems in energy consumption will increase significantly in regions where this value increases [61].

It is estimated that the world currently consumes about 1 trillion kilowatt-hours (kWh) of electricity for air conditioning. And it has been concluded that at this rate, the need for cooling will increase tenfold by 2050 [62]. A study observed that people in California would cause high energy demands when cooling their homes. Therefore, researchers proved that more power outages during the summer and early fall months are caused by extreme heat [63]. According to the study conducted in Spain, it was concluded that extreme temperatures correspond to the highest annual energy consumption, which causes serious problems for the stability of electricity distribution systems and air conditioning systems.

As a result, it is clear that climate change has effects on the air conditioning systems of buildings. Due to all these effects and possible negative consequences, many countries aim to integrate renewable energy sources into their building systems during the climate adaptation process [19].

2.2.2.5 Thermal Comfort

Climate change will undoubtedly impact thermal comfort due to increased temperatures and extreme weather events. To make sense of these effects, it is necessary to understand the thermal comfort parameters and comfort models.

Certain comfort requirements, which are indications of a user's happiness with an environment, must be met in terms of health and efficiency in a living space in line with the intended usage [64]. Thermal comfort has a significant impact on productivity and health. It is determined by the thermal balance between heat gains from the body's metabolism and heat losses to the environment [65]. People in urban regions spend most of their time (60-90 %) indoors, therefore most of the unfavorable exposures they are exposed to occur there [66]. Both the mental and physical activities of people are highly affected by thermal situations. According to American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE 55-74 Standard) "Users' state of mind that shows their contentment with the surrounding environment" [67]. In this direction, the parameters that affect thermal comfort can be divided into two categories: personal and environmental conditions. Personal parameters include a person's metabolic activity level and clothing. Environmental parameters include ambient temperature, ambient relative humidity, ambient air velocity, and average radiant temperature [68].

Air Temperature: According to ASHRAE, air temperature is the temperature of the air surrounding residents [67]. Temperature is one of the essential factors in thermal comfort.

It is because the ambient air temperature influences the amount and method of heat loss in the human body [69]. The air temperature is usually referred to as dry-bulb temperature (DBT) since it is measured with a dry-bulb.

Radiant Temperature: Thermal comfort is influenced by the radiant exchanges between the human body and its surroundings. The temperature of the surrounding surfaces affects a person's radiant temperature [70]. The mean radiant temperature (MRT) is measured to evaluate the influence of radiant temperature and radiation is always moving from a hotter to a cooler temperature.

Air Velocity: The velocity of the air affects the heat lost by convection. In parallel, the body is exposed to air and air movement causes moisture to evaporate. This affects thermal discomfort by causing heat loss from the body. In other words, if the air temperature is lower than the skin temperature, convection causes heat loss. Therefore, air velocity significantly affects thermal comfort [70].

Relative Humidity: The rate of evaporation from the skin is affected by the relative humidity of the environment [71]. The humidity ratio in the air when it is saturated at the same temperature and pressure is expressed as a percentage [69].

Clothing& Metabolic Rate: Clothing is the insulation that surrounds the body and forms a thermal barrier between the skin's surface and the surrounding environment. Clo units are used to measure clothing's thermal resistance and $0.155\text{m}^2 \text{ K/w}$ is equal to one clo. Summer clothing has a thermal resistance of roughly 0.5 clo, whereas indoor winter gear has a thermal resistance of 1.0 clo [69]. The total of chemical events that occur within the body to maintain its optimal internal temperature of 36.7°C is referred to as the metabolism. The amount of metabolic energy produced is determined by the individual's degree of activity. The met is the metabolic energy unit [71].

Based on these parameters, two fundamental techniques have been developed in thermal comfort research: the physiological and adaptive models. The physiological model asserts that humans are all alike and that comfort can be described using a physiological approach in all situations. The adaptive model claims that in naturally conditioned environments controlled by the user, the external climate influences the thermal response and hence the comfort zone [71].

The physiological comfort model is based on laboratory studies in which the parameters that can be changed are precisely controlled. Technical standards defining thermal comfort conditions are developed. The aim is to determine the effect of comfort indexes on thermal sensation based on physically variable parameters [72]. The method is based on six different variables: air temperature, radiant temperature, humidity, air velocity, clothing, and metabolic rate. Known as the Fanger method, this method tightly controls these factors in climate rooms and then evaluates how people perceive their comfort index on ASHRAE's seven-point comfort scale, from cold (−3) to hot (+3) and neutral at 0 in Table2. The experiment was based on the actual measured condition and perceived comfort index, Predicted Mean Vote (PMV), and Predicted Percentage Dissatisfied (PPD) [70].

Table 2 Thermal Comfort Scale adapted from ASHRAE and Bedford

Comfort Scale	Ashrae	Comfort Scale	Bedford
+3	Hot	7	Much too Hot
+2	Warm	6	Too Warm
+1	Slightly Warm	5	Comfortably Warm
0	Neutral	4	Comfortable
-1	Slightly Cool	3	Comfortably Cool
-2	Cool	2	Too Cold
-3	Cold	1	Much too Cold

The main theory of "Adaptive Thermal Comfort" considers that humans react in such a way as to achieve their comfort level even in a thermally neutral environment. As a result, there is a distinction between the perceived and intended comfort level; therefore, well-being is related to neutrality, allowing the PMV index to be expressed [76]. In parallel, the thermal neutrality of the human body was investigated by Humphreys and Auliciemes [77]. The result obtained was called the temperature at which the human felt thermally 'neutral', and the results were statistically analyzed with the help of regression analysis in Figure 13. These methods can be calculated but are valid between 18°C (64.4°F) and 28°C (82.4°F) temperatures and are not intended to provide design advice (Figure 13).

$$T_n = 17.6 + 0.314T_m \text{ (} T_n = \text{Neutral temp. } T_m = \text{Mean Outdoor Temp.) As cited as [76]}$$

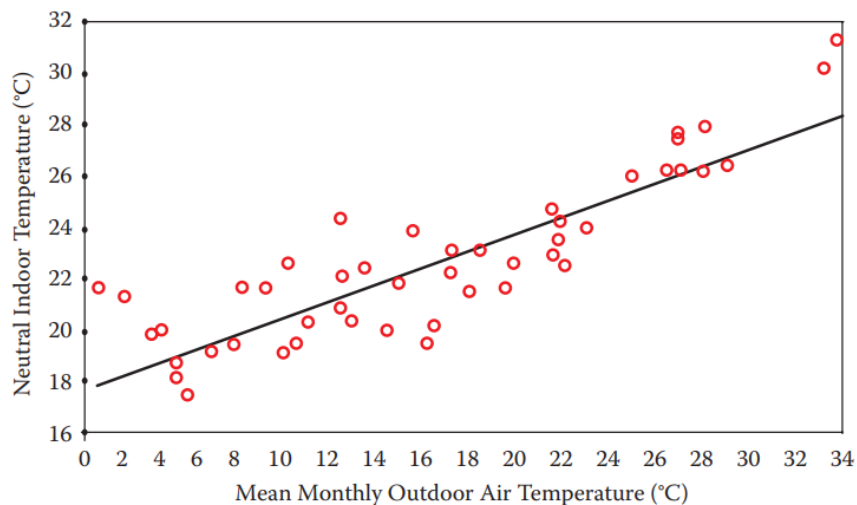


Figure 13 Relationship between outdoor temperature with neutral temperature [71]

Indoor environmental conditions should be designed and controlled in such a way as to ensure the health and comfort of the users in the place [78]. Therefore, different models have been developed to determine the comfort zones that can be used in design

decisions. In this direction, bioclimatic charts facilitate analysis in psychometric charts. Psychometric charts allow the physical properties of air to be expressed in numerical values. Thus, it aims to analyze the environment of a place from the perspective of human comfort with the simultaneous combination of temperature and humidity at any given moment. It enables the development of strategies to improve indoor comfort conditions when the interior of the building is not mechanically conditioned [64].

The bioclimate chart, developed by Olgyays in the 1950s, is considered one of the first attempts at climate-sensitive building design to incorporate the external environment climate into building design [79]. The developed graph aims to calculate human comfort intervals with six different categories average radiant temperature, humidity, ambient temperature, wind speed and solar radiation and evaporative cooling [71]. The Y-axis represents dry bulb temperature while the X-axis represents relative humidity (Figure 14). The area under the comfort zone is the limit where shading is needed. At temperatures exceeding the comfort limit, the wind speed required to restore comfort is shown in relation to humidity. In cases where the ambient conditions are hot and dry, evaporative cooling required for comfort is specified.

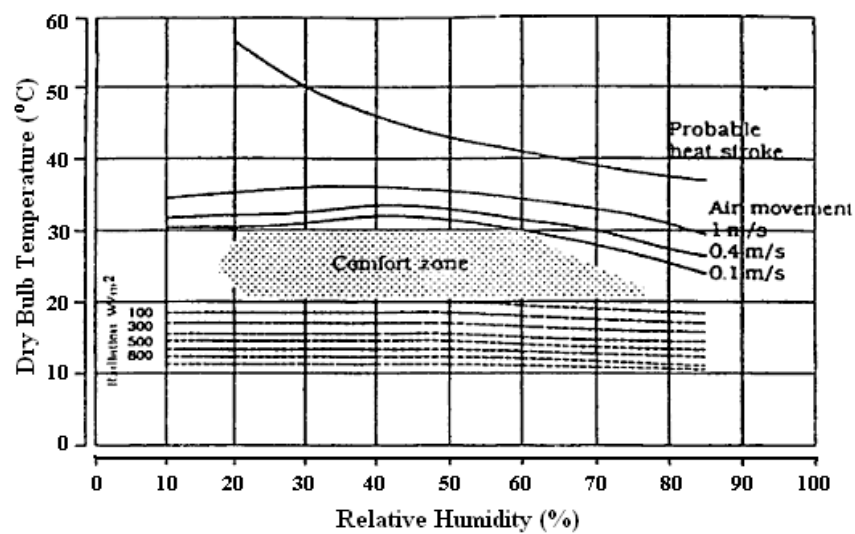


Figure 14 Olgyay's Bioclimatic Chart [152]

Another bioclimatic chart is Givoni's climate chart in Figure 15. It aimed to analyze the interior conditions of the building according to the exterior conditions. He based his findings on the linear relationship between temperature amplitude and vapor pressure of outside air in different places [80]. The appropriate passive strategies are specified according to the climatic conditions prevalent outside the building envelope in his chart, which is based on the relationship between the average monthly vapor pressure and temperature amplitude of the external air. Evaporative cooling, thermal mass, natural ventilation cooling, and passive heating are some of these methods [71].

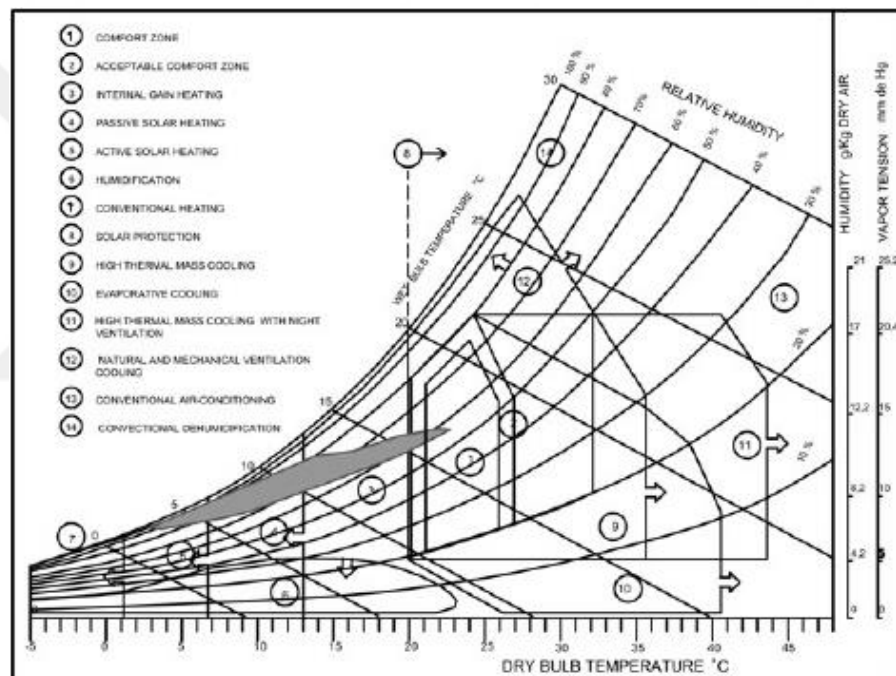


Figure 15 Givoni's Bioclimatic Chart [80]

By using some thermal comfort calculation models described above, the thermal comfort range of people has been tried to be determined. There are many parameters that affect thermal conditions and people's satisfaction levels can vary [77]. However, it is obvious that extreme weather conditions have negative consequences for human health. According to ISO 7730, PMV values are recommended to stay between ± 0.5 values for a

comfortable environment, which means less than 10% of the dissatisfied people in the environment [81]. Also, according to CIBSE, the acceptable summer comfort air temperature is 25 °C and recommended indoor air temperature upper limit of 24 °C for winter [82].

In research on this subject, Silvero et al. (2019) analyzed buildings in Paraguay using statistical and adaptive thermal comfort models. The results obtained proved that the predicted temperature increase significantly increases thermal disturbance rates. These adverse effects can only be reduced with energy renewal strategies [83]. Rodrigues et al. (2020) study on thermal comfort found that under the current climate and the anticipated climate of the A2 scenario in 2050, there is a danger of overheating residential structures in 16 Mediterranean areas [84]. Peacock et al. (2010) in a study on UK buildings, even using the option to open windows in the future, the average interior temperature was above 28 for almost 12% of the year [85]. In the study carried out in four different cities in Turkey, they found that the risks of overheating would arise especially in buildings with only natural ventilation [86].

In summary, thermal comfort is one of the critical issues in the climate change process. As a negative consequence of climate change, overheating, heat waves and heat stresses have dramatic effects on people's thermal comfort. With the increase in humidity and temperatures, the temperatures felt increased and the potential for extremely high temperatures will continue to increase (Figure 16). According to the information obtained from Raymond studies, when the temperature felt reaches 35-37 °C, it is called deadly humid heat and people need air conditioning systems to live. Since the 1990s, northern Pakistan's Indus River Valley and the southern coast of the Persian Gulf have reached these values [87]. However, it has been proven that wet-bulb temperatures in some places can regularly exceed 35°C if the world exceeds the 2°C warming limit set in the Paris

climate agreement [88]. Therefore, thermal comfort is one of the vital issues to be considered in the adaptation process to the climate.

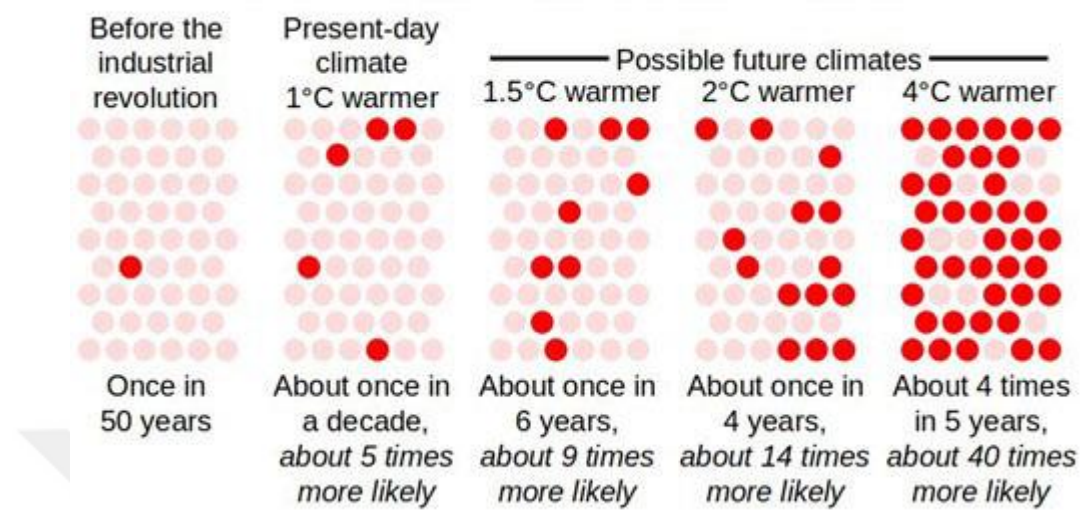


Figure 16 The potential for extremely high temperatures [149][153]

2.2.3 Future Scenarios for Energy Simulations

Climate is one of the most complex systems to simulate due to its many interrelated components and extensive spatial and temporal physical processes, but its effects must be observed before mitigation policies can be implemented in changing climatic conditions. Scenarios derived from these changeable conditions highlight the urgent and crucial need for emission reduction in different sectors. Within these sectors, the building stock is one of the major emitters of greenhouse gases with growing CO₂ emissions. In addition, current research in the literature-based paradigms shifts on the energy performance of buildings [89]. Therefore, building energy simulations (BES) are essential support tools for evaluating and investigating a building's performance against future climate scenarios. BES requires a reliable weather dataset that characterizes the building's exterior boundary conditions across its lifetime. To reflect the average area climatic condition and characterize the dynamic energy behavior of the building, a sample

year of hourly weather data is always necessary. For this reason, to produce this one-year climatic data from historical climate records, many different strategies have been devised [90].

One of the most well-known of these methods is the Typical Meteorological Year (TMY) strategy. It is based on the temporal range of data obtained from weather stations for certain locations in open areas and uses historical records. Based on Finkelstein-Schafer (FS) statistics, this method is a compilation of weather sets selected for a particular location and uses a data source of at least 12 years. With long-term averages, typical representative months are selected based on averages for each of the twelve months of the year, and these are combined in a year called TMY [91]. Furthermore, to make future climate analysis, the future is based on different scenarios and projections of climate models. However, the disadvantages of this method are because the weather stations are in certain places and in certain numbers and make use of historical records. Future weather files will need additional fixes due to factors such as increasing population, urban heat island effects, and extreme weather events [92]. For this reason, different scenarios and projections of climate models are being developed for future climate analysis.

There are climate models developed for scenarios to predict the possible effects of climate change. In the first step, datasets called General Circulation Models or Global Climate Models (GCMs) are used to provide their parameters. GCMs provide 150-600 km² of global scale and spatial resolution climate information. However, to observe the effects of climate change in a building or region at the local level, these models need to be minimized to scale [93]. At this stage, the two approaches developed are dynamic and statistical reduction methods. The dynamic downscaling approach provides higher resolution data but requires both more time and higher computer capacity. In addition,

revisions are required to provide the EPW file needed in simulation programs for building performance. On the other hand, the statistical reduction method, which is another approach, is simpler and requires less time and computer capacity. It provides weather data by establishing a statistical connection with climate variables. It also provides the needed EPW format directly [94]. Both methods are used by researchers, and building scientists, through different programs [95] [96]. The advantages and disadvantages of both methods are still being analyzed but studies show that both methods can be used in building models to investigate the response to climate change [97]. Figure 17 shows the different methods and tools used to reconstruct future weather files from climate projections.

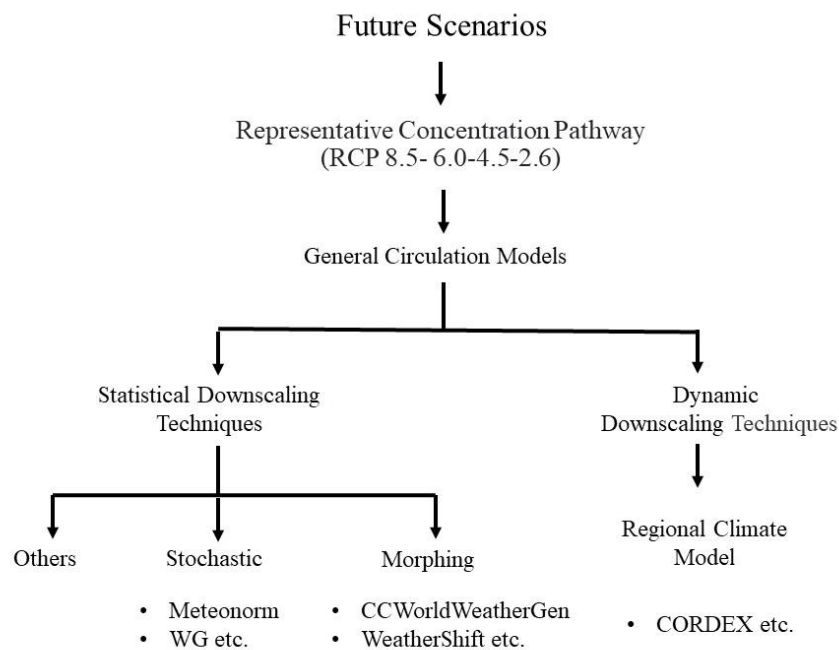


Figure 17 Different Methods and Tools for Future Weather Data

2.3 Climate Change Adaptation and Mitigation Research Using Architectural Solutions

There are two types of approaches in the framework of addressing the identified negative consequences of climate change. These are “mitigation” and “adaptation” strategies. These concepts are handled by the IPCC as follows. Mitigation is defined as limiting greenhouse gases and other adverse conditions, while adaptation is defined as the adaptation of the external environment and people in response to the actual expected climatic effects [5]. While mitigation strategies aim to avoid the devastating effects of climate change in the long term, adaptation measures are designed to offer solutions in the short and medium term. In this direction, mitigation and adaptation strategies are of remarkable importance. In the general perspective, studies are carried out for this purpose universally. However, the characteristics of each region and country are different, and therefore it should be considered that climate change will be affected in different ways depending on social, economic, and geographical factors.

2.3.1 Climate Adaptative Building Design

Buildings are an integral and critical component of a low-carbon and sustainable future. For this reason, the built environment and buildings become an important issue in minimizing the negative effects of climate change. In particular, it is aimed to reduce annual emissions and increases in global temperature to below 2 °C compared to the pre-industrial period [98] [99]. To achieve these goals, the built environment and buildings must be designed or adapted in harmony with their local climate and environment.

Bioclimatic design strategies are based on these goals. It defines an architectural approach based on local architecture, in which climate and environmental conditions are the main drivers in the creation of the interior climate of the building [79]. This approach highlights the interaction of biological, sociological, climatological, and building physics principles through space design to overcome the challenges of climate control along with the importance of local climate [100]. Topographic and local climate data (altitude, topography, radiation, temperature, humidity, wind, etc.,) specific to the place where the building design will be made is the main source of bioclimatic designs. For this reason, the most important design parameters and strategies that affect the formation of indoor thermal comfort and energy savings have been developed considering the climate. In this context, among the critical design parameters, the location, direction, shape of the building, the distance between the buildings and the optical and thermophysical properties of the building envelope can be given as examples.

In the studies conducted on this subject, it has been observed that bioclimatic architectural strategies provide great energy savings, although they vary according to the climate type. For example, in studies conducted in India, it has been observed that wind catchers allow the indoor temperatures to be reduced to approximately 10 °C at temperatures up to 40 °C outdoors [101]. In another study conducted in Greece, the use of rooftop water tanks for passive cooling at night resulted in a reduction of cooling loads by 87% [102]. In studies conducted in China, the use of solar chimney provided internal comfort temperatures and reduced energy consumption [103]. Overall, it is clear that in the current climate, bioclimatic strategies are generating a positive response for energy efficiency. However, studies on future weather scenarios based on climate change have concluded that these strategies may be insufficient [104] [105]. Therefore, it is significant to include complementary strategies alongside bioclimatic strategies for building

resilience and adaptation to the climate.

In this regard, the "European Commission's Roadmap" regarding the building sector has shown that greenhouse gas emissions can be reduced by approximately 90% by 2050 compared to 1990 [106]. One of the most practical and economical ways to achieve this goal has been determined as the implementation of renewable and energy-efficient strategies, reducing the energy demands of buildings. The reorganization of the Buildings Energy Performance Directive (EPBD) is set to meet the climate adaptation targets of buildings [107]. In particular, it aims to remodel all new buildings and nearly zero-energy (nZEB) buildings identified in the EPBD by the end of 2020. According to the European Commission, nearly zero-emission building (nZEB) is defined as a building with high energy performance, with almost zero or very low required energy being met by renewable energy sources produced on-site or nearby as much as possible. On the other hand, a zero-emission building (ZEB) is described as a structure with extremely high energy efficiency that is powered entirely by renewable energy sources and emits no carbon from on-site fossil fuels [108].

The development of these criteria is contentious issue, as they appear to range significantly between nations [109]. Turkey takes measures in this direction in its National Energy Efficiency Action Plan (NEEAP). With energy efficiency studies, it is aimed to reduce Turkey's Energy Intensity (energy consumed per national income) by at least 20% until 2023, compared to 2011 [110]. However, as stated previously, it has been observed that Turkey's climate policy is critically insufficient, and it has been investigated that even some these criteria that can be taken are vulnerable to climate change. Therefore, it is necessary to investigate how each region will be affected by this change and take proper resilient precautions.

2.3.2 Mitigation and Adaptation Strategies for Building

To take the necessary measures in the process of adaptation and mitigation to climate change, using different architectural solutions, future climate scenarios and how energy efficient strategies are applied to buildings are investigated. Various databases were examined to examine the relationships between studies and to conduct more comprehensive research with sub-titles. As a result, databases based on structure and climate change and containing the most research on this subject were determined and statistical relationships between them were investigated.

A data library was created with the studies examined and these data were visualized through the Vosviewer program. When the reviewed studies are visualized statistically, the concepts of building, action policies, energy and risk are the most intense in climate change-based articles (Figure 18). When the centrality and densities of the clusters are examined, building performances, energy consumption, and especially residential buildings show intensity. On the other hand, in the area where the concept of energy is centralized, the concepts of energy efficiency and emissions are concentrated. In the harmony cluster, the concepts of awareness, community, and resilience come to the fore. It is seen that the centrality of strategic planning and social consciousness is high, but the intensity varies. When examined in general, all cluster groups strongly interact with each other. Buildings have a high centrality and density among other groups. Their interactions with energy consumption and risk factors are quite high. Considering all these concepts, it should be developed with a holistic approach for the climate adaptation process to be carried out efficiently. In addition, buildings have critical importance with their high energy consumption in mitigation policies and they are at the main point of these plans.

strategic reinforcement steps such as insulation did not provide the necessary efficiency in this climate. Alternatively, the temperature setpoints have been changed. The results revealed that average decreases of 0.9-8.7% for Quebec City, 1.6-9.1% for Toronto, and 1.4-9.9% for Vancouver could occur. Changing the temperature setpoints both reduces building energy consumption and hourly PMVs are calculated as a suitable reduction in comfort [111]. Different scenarios were created in the research carried out in Poland. According to 2018 TMY data, there is a 0.1% discomfort rate in summer. Based on future climate data and local standards, the building's characteristics were revised as outer wall U value of 0.23, roof 0.18 and glass 0.9. With these values, it was calculated at the rate of 14.6%. Based on passive system standards only, the U-value has been updated to wall U value of 0.15, the roof 0.15, and the glass 0.9. As a result, the thermal comfort discomfort rate decreased to 6% [112].

In the research carried out in Cyprus, the outer wall with a lower U value decreased the heating degree hours (HDH) value by 5–6.8%. Conversely, however, the Cooling Degree Hours (CDH) value has increased. In roof insulation, it has been observed that this ratio significantly reduces HDH value by approximately 4.2-4.8% and CDH value by 65-75%. However, as in the wall scenario, it increased the CDH value. Natural ventilation reduced the CDH rate by 10%, while night ventilation decreased by 46%. Finally, in the study, while passive strategies alone are not sufficient on heating and cooling degree hours, combination solutions may be more effective [113]. In the study carried out in Canberra and Brisbane, analysis was made within the scope of glass and exterior wall insulation parameters. Overheating hours have decreased from approximately 385 hours in the current state to 221 hours in the energy-optimized state. It has been emphasized

that there will be an overheating problem in 2080 and the current HVAC system will be insufficient in the future [114].

In the study carried out in southern Spain, the percentage of comfort hours deteriorated as the outside temperatures increased. It has been observed that the percentage of comfort hours, which is measured as 96-100% in the building analyzed today, will decrease to 17% in 2080. In the improvement scenarios, natural night ventilation and daytime closed blinds gave positive results in terms of thermal comfort in summer, but it was analyzed that in some cases natural ventilation was not sufficient in terms of cooling needs. For this, additional maintenance and renewable integrated systems were applied to the mechanical system. In winter, positive results have been observed if the ventilation is kept to a minimum and the shutters are opened during the daytime in winter [115].

Table 3 Research on Thermal Comfort

Scale	Type	Location	Focus On	Ref.
Building (Classroom)	Statistical (Morphing)	Southern China	Thermal comfort& Daylighting Performance	[116]
Building (Residential)	Statistical CCWorldWeatherGen	A (tropical), B (arid), C (temperate), D (continental), and E (polar)	Thermal comfort	[117]
Building (Residential)	Statistical, CCWorldWeatherGen	Italy, Lecce	Thermal Comfort & Heating and Cooling Energy Demand	[118]
Building (Office)	Statistical, WeatherShift	Canada, Vancouver	Thermal Comfort& Building Retrofit	[119]
Apartment Buildings Blocks	Statistical, Morphing	Sweden	Thermal Comfort& Heating and Cooling Demand	[120]
Building (Residential)	Statistical, Morphing, WeatherShift	Turkey, 4 Different Cities	Thermal Comfort& Heating and Cooling Demand	[121]
Residential Building Block	Dynamical	Taiwan	Thermal Control & Cooling Demand	[122]
Building at urban scale	Statistical (Sequential K-)	Iran, 10 Different Cities	Thermal comfort	[123]
30–40 Story Rental Housing at Building scale	Statistical CCWorldWeatherGen, WeatherShift & Dynamical	China,Hong Kong	Thermal Comfort& Heating and Cooling Demand	[124]
Office Building	Dynamical	Australia	Thermal Comfort& Energy Consumption	[125]
School Building	Statistical, Morphing, Meteonorm	Southampton	Thermal Comfort	[126]

In future climate scenarios, the effects of increasing temperatures on the heating and cooling demand of buildings at varying degrees in different locations and architectural solutions are investigated in Table 4.

In the study conducted in Greece, a building typology of approximately 85% of the building stock was created and evaluated in 13 different climate zones. Especially in the southern part of the country, a critical increase of 248% was expected in cooling demand, while a 50% decrease in heating demand was observed. In this study, three different building typologies were selected, built with traditional, contemporary, and passive house standards. The traditional house model was both the most energy consuming and overheated in summer in 2050, creating thermal discomfort. In the worst-case climate scenario, annual energy use would exceed 120,000–130,000 GWh if only 10% of the building stock were high performing and all new construction after 2020 had nearly zero energy consumption. According to the optimistic climate model scenario, when the building stock is improved to the level of passive buildings and almost zero energy consumption is achieved in all new buildings, the total annual energy demand will be limited to approximately 22,000–25,000 GWh [127].

In a study conducted in Norway, renovations of the building envelope according to the national standards of old houses built before 1955 provided energy savings of 100 kWh/m², and 30 kWh/m² with standard revisions in houses built between 1956-2000. On the other hand, integration with advanced and renewable energy sources resulted in energy savings of up to 84 kWh/m² [128]. Building envelopes were discussed in the study carried out in Taiwan. In the future weather data obtained by the morphing method, annual cooling energy demand in 2020, 2050 and 2080 revealed increases of 31%, 59% and 82%, respectively. Different passive strategies have been integrated into the building,

but none have been able to neutralize increases in cooling energy use. Increasing the insulation layers of the outer walls and decreasing the U values, decreased the cooling energy by 6.0, 6.5 and 6.6 kWh/m², respectively. Likewise, reducing the U value of the roof system provides a reduction of 7.8, 8.8 and 9.6 kWh/m². On the other hand, in the glass system, cooling energy through shading elements helped to reduce it by 65.5%, 37.5% and 27.7% for the 2020s, 2050s and 2080s, respectively. The combination of individual strategies (reducing U-values of exterior walls and roofs, increasing SHGC of glass, and adding shading) was calculated as the most efficient scenario. While the annual consumption was 63.9 kWh/m² at the beginning, it was calculated as 39.4 kWh/m² in 2080 with the combination scenario [129].

Residential buildings in 16 different cities of the Mediterranean region were discussed by Rodrigues and Fernandes. The results proved that at all locations and as the U value increases, the cooling demand will increase significantly at different rates. It has been observed that while the cooling demand reaches an increase of 137% in some regions (Venice), the heating demand can decrease to 63% (Alexandria). However, the increase in the U value is not always directly proportional to the cooling demand, for example, it creates a negative effect in the city of Casablanca. Therefore, suitable U value calculations should be made according to each region. It is concluded that strategies such as the use of shading elements, small windows and the orientation of windows can be effective in minimizing the cooling demand [130].

Retrofit strategies include adding layers of insulation to exterior walls, energy-efficient windows, faucets, and shower heads in a Swedish study. Compared to the existing situation and the optimized situation, the total operation final energy was decreased by 58%, while the primary energy consumption was reduced by 54% [131]. In

the study carried out in Benevento, Italy, weather data from 2015 to 2020 is collected and a climate data file is created, and 2080 forecast weather data is obtained using the morphing method. According to the results, while heating demand decreased by 56%, cooling demand increased by 62%. Only insulating layers could not prevent energy consumption and overheating in scenarios created using glass systems. On the other hand, the cool roof and shading elements reduced the cooling demand by 33% [132].

The research conducted in Al-Ain, United Arab Emirates, examined the potential consequences of climate change on the energy performance of residential buildings. In the scenario where the city under consideration warmed up by 5.9 °C, the cooling requirement increased by 23.5%. In the scenario where the results were the most efficient, good insulation of the building envelope provided a significant reduction in energy consumption by 14.8%, while the revision of the window area and glass systems and the use of shading elements resulted in savings of 8.1-10.9% in energy consumption. As a result, according to the research conducted for this study, thermal insulation, thermal mass, and renovated glazing systems were evaluated as beneficial energy design elements for residential buildings [133].

According to a study conducted in Istanbul, Turkey, the heating energy of the existing residential building was 170.85 kWh/m² in 2020, according to the HadCM3-A2 scenario, and it was calculated as kWh/m² by reducing it in 2080. On the contrary, while the cooling energy was 53.14 kWh/m² in 2020, it reached 106.95 kWh/m² in 2080. In parallel with this, primary energy consumption in 2080 has been calculated as 274.69 kWh/m². As a result of insulating the building envelope in the climate adaptation process, replacing the glazing systems with a better option, and supporting the HVAC systems

with renewable energy sources, primary energy consumption was reduced to 112.46 kWh/m² in 2080, resulting in significant energy savings [134].

Table 4 Research on Heating& Cooling Demand

Scale	Type	Location	Focus On	Ref.
Building Residential	Statistical, Morphing, WeatherShift	Italy, Milan	Heating and Cooling Energy Demand	[135]
Building, Office	Statistical, CCWorldWeatherGen	2 cities, Australia	Heating and Cooling Energy Demand	[136]
Building, Office	Statistical, CCWorldWeatherGen	Italy, Luxembourg, and Palermo	Heating and Cooling Energy Demand	[137]
Building Residential	Statistical, CCWorldWeatherGen	Italy, Lecce	Heating and Cooling Energy Demand& Thermal Comfort	[118]
Building, Residential	Statistical, Meteonorm	United States and 14 Different Climate Type	Heating Demand	[138]
Building, Residential	Statistical, CCWorldWeatherGen , Weather Shift	Italy, Benevento	Heating and Cooling Energy Demand	[139]
Building (Office)	Statistical, WeatherShift	Southeast Asia	Annual Energy Consumption	[140]
Apartment- Hospital- Office-Retail- Warehouse-School- Restaurant	Statistical CCWorldWeatherGen , WeatherShift, Dynamic	Canada,Toronto	Heating and Cooling Energy Demand& Cost	[141]
Building, Office	Statistical, Morphing	15 European Cities	Heating & Cooling Demand	[97]
Office building, Residential Apartment	Statistical, Morphing	Hong Kong	Energy Consumption	[142]

Studies and research show that climate change is a very important problem on a global scale that can dramatically affect every country and region to varying degrees. On

the other hand, adaptation and mitigation efforts are still not at the expected and necessary levels [146] [147]. The world is facing a big and serious problem, but it has the potential for a solution. The energy efficiency potentials, especially in the building sectors, are remarkable and it is clear that significant energy savings can be achieved when adaptation strategies are developed. These potentials vary from region to region depending on social, geographical, economic, and societal parameters [148]. Similarly, the conclusion drawn from the literature review is that to design climate-resistant and adaptable structures, the first step is to analyze how and to what extent each region is affected. Then, limiting energy consumption with energy efficient strategies will help reverse the devastating effects of this problem. Therefore, in the next section, it is aimed to contribute to the adaptation and mitigation process with architectural solutions from the perspective of two different climate types in Turkey based on the literature research.

CHAPTER III

CASE STUDY& METHODOLOGY

Previous chapters have examined the causes and consequences of climate change, its effects on buildings, and mitigation strategies. In this section, methods will be determined based on literature research and will be examined through a case study. In the first step, an existing typical residential building, which constitutes a significant part of the building stock in Turkey, will be selected and modeled. Accordingly, a typical residential structure in Turkey has been selected. The city of Istanbul is taken as a basis to calculate the current energy consumption of the residential building. The province of Izmir was included in the study to compare different climates. The case building will be modeled in the “DesignBuilder” program and then “EnergyPlus” software will be used for analysis. In the second stage, different climate files for both cities will be created using “CCWorldWeatherGen”, using the morphing method, and RCP 4.5 and 8.5 emission scenarios for 2050 and 2080 for both Izmir and Istanbul provinces. Then, improvement strategies will be developed in the climate adaptation process. In the first stage, the heating, cooling, and primary energy consumption of these strategies will be compared with the current situation. Then, the thermal comfort analysis of the efficient scenarios selected in terms of energy consumption and the thermal comfort analysis of the current situation will be made comparatively. The architectural strategies developed in the process of adaptation to climate change will be presented by analyzing comparatively for the two cities. The diagram showing the flow is in Figure 19.

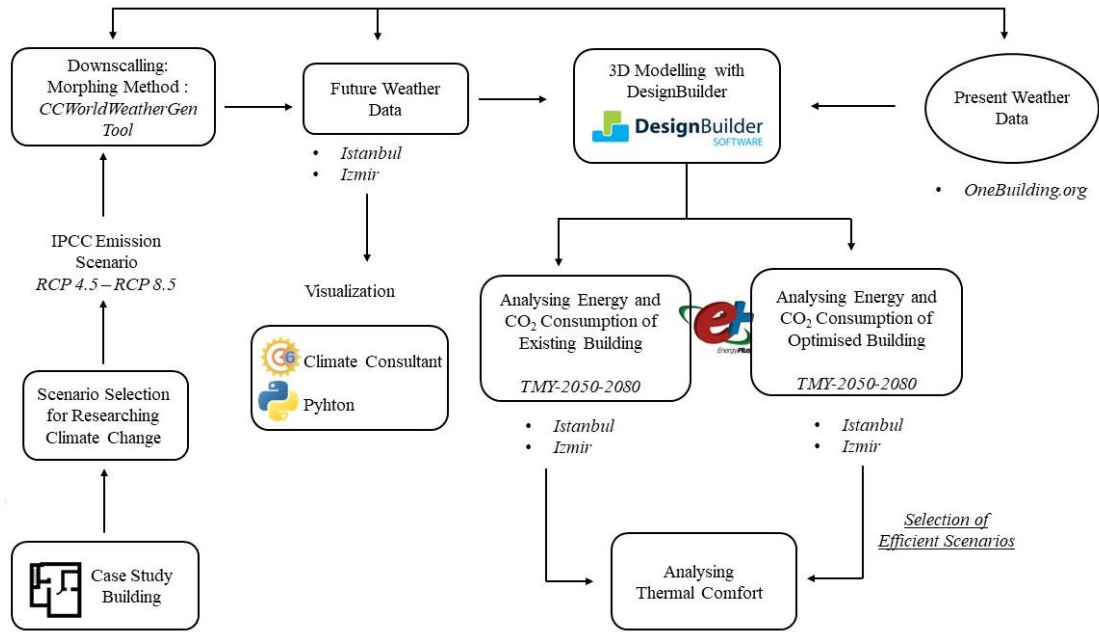


Figure 19 Thesis Methodology Flow Chart

3.1 Building Properties and Modelling

The case study building was chosen as a typical residential building common in Turkey. The building has a total of 10 floors, one of which is a basement, and there are a total of 27 flats, 3 flats on 9 floors excluding the basement. On the basement floor, there are areas such as mechanical rooms, shelters, and warehouses. The building has a total area of 3915.32 m² and each flat has an average of 5-8 rooms. The plans for the building were edited with the Autocad program. Then, transferred to the Designbuilder program for 3D modeling (Figure 20) and EnergyPlus program for performance analysis. To ensure that the simulation results are as accurate as possible, the internal heat gain data, physical properties and materials used are obtained from the information obtained, similar studies and related standards and transferred to the software.

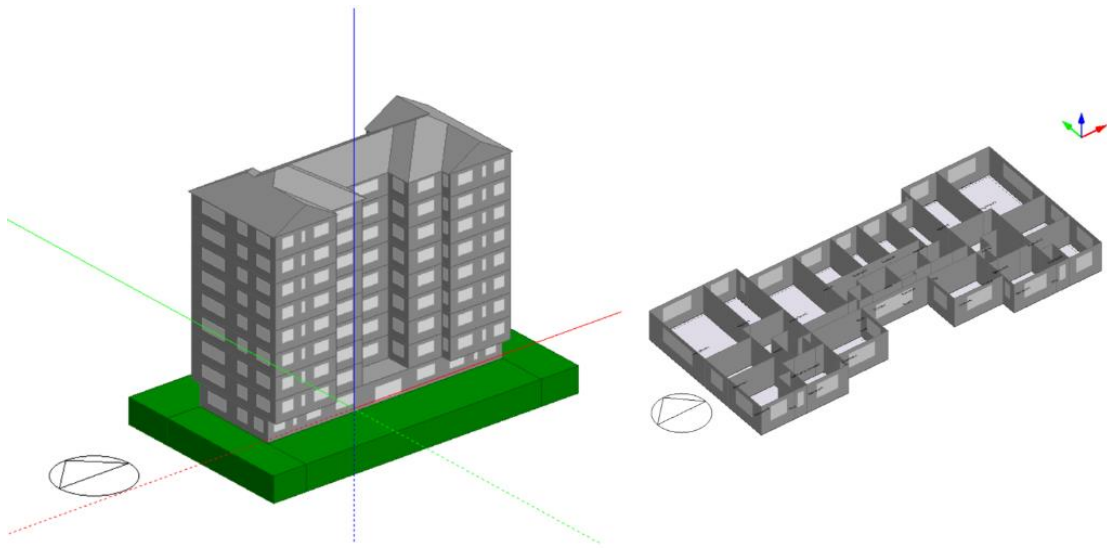


Figure 20 Building 3D Modelling in Design Builder

The materials of the building envelope are modeled by obtaining from architectural plans and sections. The detailed properties of the materials were obtained from the TS 825 standard in Table 5. The properties of the glasses are taken from the standards with common double-glazing properties. The U value is $2.7 \text{ W/m}^2\text{-K}$, the solar heat gain coefficient (SHGC) value is 0.8 (80%), and the visible transmittance (VT) value is 0.75 (75%).

Table 5 Building Material Details

Building Elements	Layers	Thickness [m]	Conductivity [W/m-K]	Specific Heat [J/kg-K]	Density [kg/m3]	U-Value [W/m2-K]
WALL	Plaster (TS 825-4.9)	0.03	0.29	1000	800	1.6
	Concrete (TS 825-5.2.1)	0.25	0.89	1000	1500	
	Plaster (TS 825-4.9)	0.02	0.29	1000	800	
	Brick (TS 825-7.1.3.1)	0.2	0.33	840	600	0.71
	EPDM (TS 825-9.2.3)	0.025	0.30	1000	1200	
	Plaster (TS 825-4.9)	0.03	0.29	1000	800	
	Concrete (TS 825-5.2.1)	0.3	0.89	1000	1500	
	Plaster (TS 825-4.9)	0.03	0.29	1000	800	
	Plaster (TS 825-4.9)	0.03	0.29	1000	800	1.12
	Brick (TS 825-7.1.3.1)	0.15	0.33	840	600	
	Plaster (TS 825-4.9)	0.02	0.29	1000	800	
	Roof Tile (DesignBuilder)	0.01	0.8	880	1890	1.17
	OSB (TS 825-8.2.2.1)	0.03	0.15	1880	650	
	EPDM (TS 825-9.2.3)	0.025	0.30	1000	1200	
	Air Gap	0.025	N. A	N. A	N. A	
ROOF	Concrete (TS 825-5.2.1)	0.15	0.89	1000	1500	1.35
	Plaster (TS 825-4.9)	0.02	0.29	1000	800	
	Plaster (TS 825-4.9)	0.05	0.29	1000	800	
	Concrete (TS 825-5.2.1)	0.15	0.89	1000	1500	
	Screed (TS 825-4.9)	0.05	0.29	1000	800	
	Ceramic Tiles (DesignBuilder)	0.01	0.8	850	1700	1.35

Other parameters that can affect energy consumption and thermal comfort are transferred to the program as follows.

Occupancy: The occupancy rate is defined as the maximum number of people using a space. In the data transferred to the program, although the number of people varies according to the number of rooms in the apartments, the average number of families is defined as 3-5 people [151]. Details of the schedule are given in Table 6

Lighting: The lighting rate is defined as the equipment (watts) that provides the lighting in a place. It is entered in the Designbuilder program in w/h. Information about lighting was obtained from the project drawings. In parallel with the occupancy calendar and considering the appropriate standards, the usage calendars were transferred to the program [151]. Details of the schedule are given in Table 6.

Electrical equipment: Electrical equipment, kitchen equipment and items that consume electricity such as televisions and computers are defined. Usage charts were entered into the program in parallel with the occupancy rates. In this step, suitable standards were considered. In addition, the air conditioners in the hall were operated for an average of 4 hours a day between 1 June and 31 August between 12:00 and 16:00, when the indoor temperatures exceed 24°C [151]. Details of the schedule are given in Table 6.

Natural ventilation: According to ASHRAE Standard 62-1, there is no fixed value for air changes per hour (1/h) (ACH); but in residential buildings; 7-8 for the kitchen, 3-6 for the living room, 2-4 for the bedroom and for the bathroom 6-8 ach [66]. Considering this standard, the minimum and maximum values are defined for the relevant zones according to the size of the rooms and the number of people.

Air infiltration: Air infiltration, the value of which is suggested as 0.4- 0.6 (1/h) air changes per hour, the average value recommended for 6-10 story buildings according to the CIBSE standard [143]. This value was accepted as 0.5 1/h considering the building materials and the construction year.

Table 6 Internal gains of the building

Time (Hours)	Occupancy Rate (%)		Lighting Rate (%)		Equipment Rate (%)	
	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends
00:00-01:00	100	100	15	15	10	10
01:00-02:00	100	100	15	15	10	10
02:00-03:00	100	100	15	15	10	10
03:00-04:00	100	100	15	15	10	10
04:00-05:00	100	100	15	15	10	10
05:00-06:00	100	100	15	15	10	10
06:00-07:00	50	100	10	15	25	10
07:00-08:00	50	100	10	15	25	10
08:00-09:00	25	75	10	10	25	25
09:00-10:00	25	25	10	10	25	25
10:00-11:00	25	25	10	10	40	40
11:00-12:00	25	25	10	10	40	40
12:00-13:00	25	25	10	10	40	40
13:00-14:00	25	25	10	10	40	40
14:00-15:00	25	25	10	10	40	40
15:00-16:00	25	25	10	10	25	25
16:00-17:00	50	25	10	10	25	25
17:00-18:00	50	50	30	30	50	50
18:00-19:00	50	50	50	50	50	50
19:00-20:00	75	50	75	75	75	75
20:00-21:00	75	50	100	100	75	75
21:00-22:00	100	75	100	100	75	75
22:00-23:00	100	100	75	100	50	75
23:00-00:00	100	100	75	100	50	50

The building is heated by radiators connected to the condensing boiler. Considering the construction year of the building and its maintenance, the boiler efficiency was entered into the program as 90%. The boiler operation schedule was created to operate from 1 January to 15 April and 15 September to 31 December. Also,

some apartments have air conditioning in the living rooms for their cooling needs. Hot water is provided by water heaters connected to the boiler for use in kitchens and bathrooms. The water calculation has been calculated assuming that an average family stays at home 320 days a year and a family of four can consume 160 lt/day of hot water per day [144]. Also, it is defined as a heating setpoint of 21°C and a cooling setpoint of 24°C according to literature and standards [144] [145] [151] .

3.2 Generating Future Weather Data for Simulations

Various emission scenarios developed to calculate the extent of the effects of climate change have been developed and these scenarios have been explained in the previous section. General (also known as Global) Circulation Models (GCMs) are used to predict changes in climate and measure the impact of predicted emissions scenarios. Computer-aided models that allow simulating physical processes in the Earth's atmosphere and oceans are called GCM. In short, GCMs calculate climatic conditions with a high degree of spatial resolution. However, this calculation is not suitable for direct use in simulation software. For this reason, the downscaling method is used to convert the data from these models to appropriate temporal and spatial resolution and make them suitable for simulation programs. There are two basic approaches to downscaling, statistical and dynamic. The method to be used in this study is the statistical downscaling method. The reason for this is that this method is suitable for this study, as explained under the heading 2.2.3 *“Future Scenarios for Energy Simulations”*, based on the literature review. It directly provides the appropriate plug-in for the simulation program, is free, does not require regional data as in the dynamic downscaling method and does not require high computer capacity.

In the statistical downscaling method, the morphing method was used through the "CCWorldWeatherGen" tool. This tool provides an Excel file into which climate files can be converted. In the first stage, TMY files of Istanbul and Izmir provinces were obtained with onebuilding.org. Afterward, the climate data of the provinces were created with the Excel program. The created .epw files were converted to .csv extension with "EnergyPlus Weather Converter" and the climate data were analyzed. These files were reviewed in IPCC, Berkeley, and ISIMIP reports and revised in .csv files for different emission scenarios. Then, revised climate data with different emission scenarios were created with the "Elements" program to be used in the simulation. The data visualizations and comparisons of different scenarios were made with the "Python" and "Climate Consultant" programs.

According to the Koppen climate classification, the future climate data of Istanbul, which has a transitional temperate climate between Cfa (mediterranean climate) and Cfb (oceanic climate), were created. The TMY climate file is based on the years 2006-2014. The average temperature between these years was calculated as 14.5 °C. Respectively, the average annual temperature was 16.5 °C in 2050 according to the RCP 4.5 scenario and 17.1 °C according to the RCP 8.5 scenario. In 2080, it was calculated as 16.9 °C

according to the RCP 4.5 scenario and 18.8 °C according to the RCP 8.5 scenario (Figure 21).

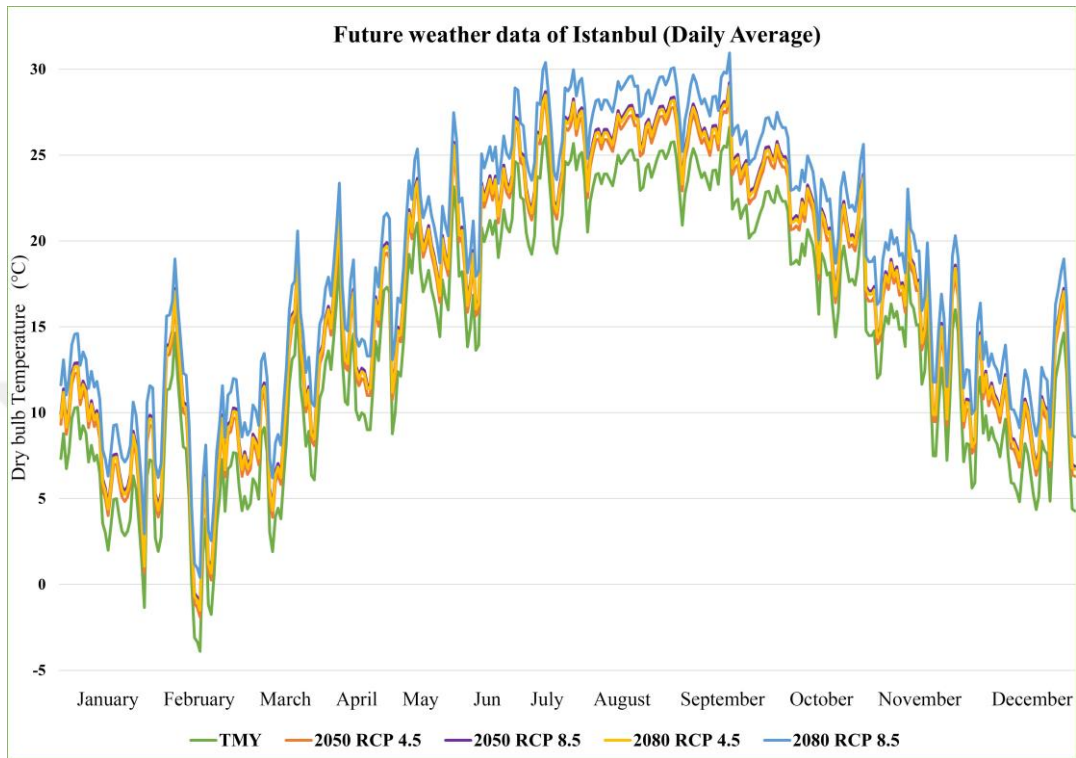


Figure 21 Obtaining Istanbul's future weather data

According to the Koppen climate classification, the future climate data of İzmir, which has a Csa (Warm Mediterranean climate) climate, was created. The TMY climate file is based on the years 2006-2014. The average temperature between these years was calculated as 16.8 °C. Also, the average annual temperature was 18.9 °C in 2050 according to the RCP 4.5 scenario and 19.6 °C according to the RCP 8.5 scenario. In 2080, it was calculated as 19.2 °C according to the RCP 4.5 scenario and 21.8 °C according to the RCP 8.5 scenario (Figure 22).

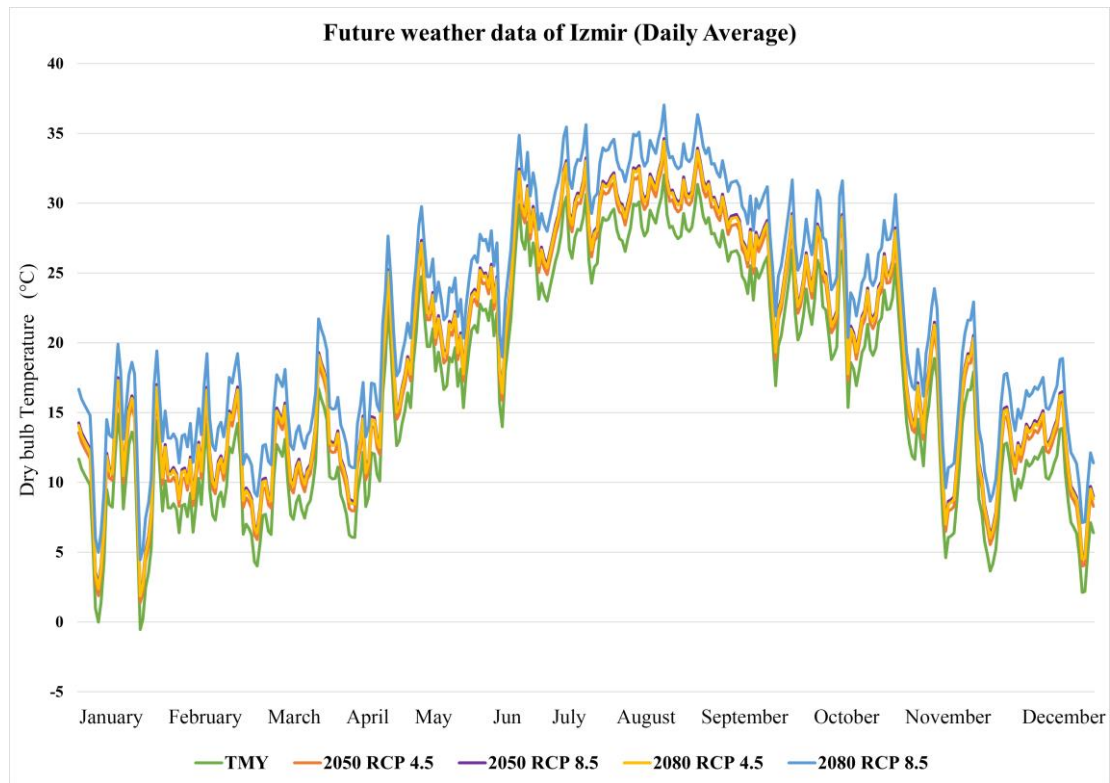


Figure 22 Obtaining Izmir's future weather data

Future climate data files created by the morphing method will be used in building energy performance (BEP) evaluations in the later section.

3.3 Performance Evaluation Approach

Two main approaches were considered to observe the change of climate change according to the obtained future climate files and to analyze the building performance. In the first stage, efficient strategies will be determined by considering energy consumption, and then thermal comfort analyzes will be carried out over efficient scenarios.

3.3.1 Energy Consumption and CO₂ Emission

To perform the performance analysis of the building, future climate data will be compared with different improvement strategies developed. In this direction, primary

energy consumption (PEC), heating and cooling energy demand will be analyzed (1). In addition, a comparison will be made by considering the CO₂ emissions of different scenarios (2).

Conversion factors are used to calculate the primary energy consumption of buildings. These factors are realized by considering the delivered and exported energy quantities. While the conversion factors are 2.36 for electricity in Turkey, this value is 1 for natural gas.

To calculate the primary energy consumption,

$$\text{PEC} = (1 \times \text{End Use Energy Consumption for Natural Gas}) + (2,36 \times \text{End Use Energy Consumption for Electricity}) / \text{Net Conditioned Area} \quad (1)$$

To calculate the CO₂ emissions,

$$\begin{aligned} & \text{Electricity (kWh) Total End Use} \times 0,626 + \\ & \text{Natural Gas (kWh) Total End Use} \times 0,234 / \text{Net Conditioned Area} \end{aligned} \quad (2)$$

3.3.2 Thermal Comfort

To analyze the effects of climate change on thermal comfort, firstly, the change in heating and cooling degree days will be examined. Then, an adaptive thermal comfort model analysis will be made by choosing one of the rooms (bedroom) with only natural ventilation. In addition to natural ventilation, the effect of the change will be observed by using the fanger method in places where there is mechanical cooling (living room).

Depending on the climate, the degree and extent of this change in energy consumption and thermal comfort can only be determined with the help of day-degree calculations. Hot days are considered when calculating the degrees of the cooling day (CDD), and cold days are considered when calculating the degrees of the heating day (HDD). HDD (3) and CDDs (4) represent the energy demand required to heat or cool a given building, to provide thermal comfort. For this reason, before proceeding to the thermal comfort analysis, HDD and CDD days were calculated separately for both cities and the dimensions of the change were analyzed.

To calculate the HDD,

$$\bullet \text{ HDD } (T_h) = \sum_{k=1}^N (T_h - T_o) \quad (3)$$

T_o = Daily Average Outdoor Temperature

T_h = Threshold Temperature for Heating Period (18 °C)

N = Total Number of Days in Heating Period

To calculate the CDD,

$$\bullet \text{ CDD } (T_c) = \sum_{k=1}^M (T_o - T_c) \quad (4)$$

T_o = Daily Average Outdoor Temperature

T_c = Threshold Temperature for Cooling Period (24 °C)

M = Total Number of Days in Cooling Period

HDD is a measure of how much the outside temperature is below a certain equilibrium temperature. Therefore, if the value of any day is less than or equal to zero, that day has the HDD. It helps to analyze the energy consumption required to heat buildings. CDD is a measure of how much the outside temperature is above a certain equilibrium temperature. They are used for the analysis of the energy consumption required to cool buildings.

Considering the monthly heating and cooling degree days for the province of Istanbul in Figure 23, the TMY situation has the highest number of heating days. This rate decreases remarkably when all scenarios are evaluated in 2050 and 2080, respectively. Especially when the TMY and RCP 8.5 scenarios are compared, heating degree days dominate in April in TMY. However, when it comes to 2050 and 2080, this value has decreased regularly, and in the 2080 RCP 8.5 scenario, heating degree days have been replaced by cooling degree days. In other words, cooling will be needed even in April for the RCP 8.5 scenario. Another noteworthy inference is that in the case of TMY, there are heating-degree days in October and no cooling-degree days. However, it shows that by 2050, there will be a need for cooling even in October in all other scenarios except the RCP 4.5 scenario. Especially, when the summer months of June, July, and August are considered, a sharp increase is observed in the days with cooling-degree days. The TMY and RCP 8.5 scenarios show an outstanding increase of 78% when their numbers in these three months just are even evaluated.

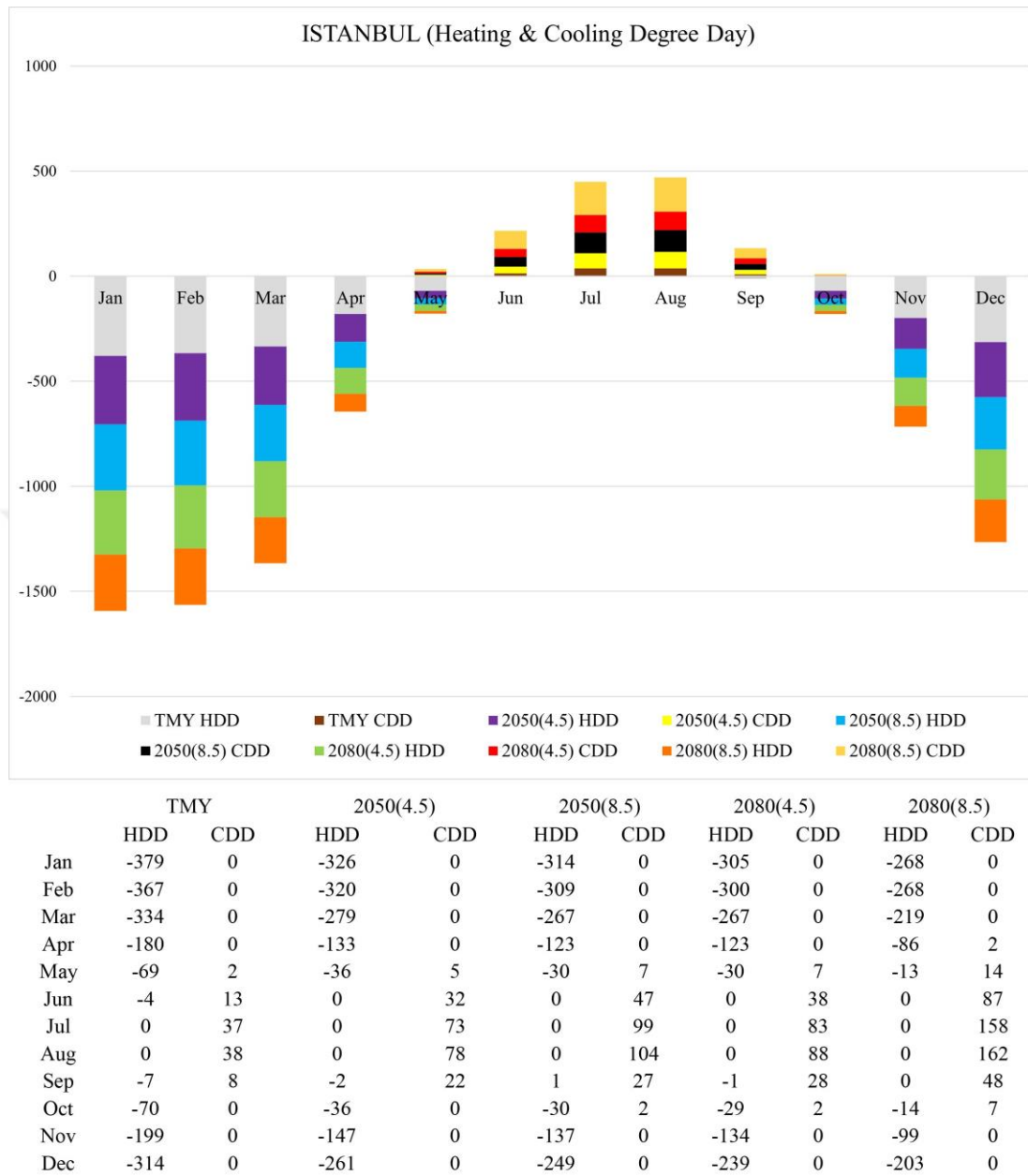


Figure 23 Heating and cooling degree-day calculation for the province of Istanbul

When Izmir and Istanbul are compared, in all scenarios, cooling is needed more in Izmir, while the need for heating is less. When the TMY situation for both provinces are compared, the annual number of cooling degree days is 294% higher in Izmir, and the heating degree day degrees are calculated as 19% higher in Istanbul. Compared to Istanbul, there is a need for cooling even in October in the current situation in Izmir.

Considering the monthly heating and cooling degree days for Izmir in Figure 24, the TMY situation has the highest number of heating days, similar to the situation in Istanbul. When all scenarios are evaluated in 2050 and 2080, respectively, this rate drops significantly. In TMY, the cooling degree days last from May to September. However, in the RCP 8.5 scenario, the need for cooling continues from April to October. This proves that the duration of the months with cooling will increase. When the cooling degree days of TMY and 2050 RCP 4.5 and 8.5 scenarios are calculated, respectively, an increase of 52% was calculated in the RCP 4.5 scenario and a significant increase of 78% in the RCP 8.5 scenario. When TMY is compared with the year 2080, an increase of 81% in RCP 4.5 and a sharp increase of 147% in the scenario of RCP 8.5 stands out. It is calculated that the number of heating degree days will decrease by 28.20% when TMY and 2080 RCP 4.5 are compared, while a 44.02 % decrease is analyzed in the 8.5 scenarios. Accordingly, the cooling requirement is important for the conditioning of buildings in all future scenarios in the province of Izmir. In some months, it will even need cooling instead of heating. In this direction, when the RCP 4.5 and 8.5 scenarios in 2050 and 2080 are compared, it is clearly seen that the 8.5 scenario, where emissions increase, causes temperatures to increase even more. For this reason, 8.5 scenarios are scenarios where CDD values are high and HDD degree days are lower.

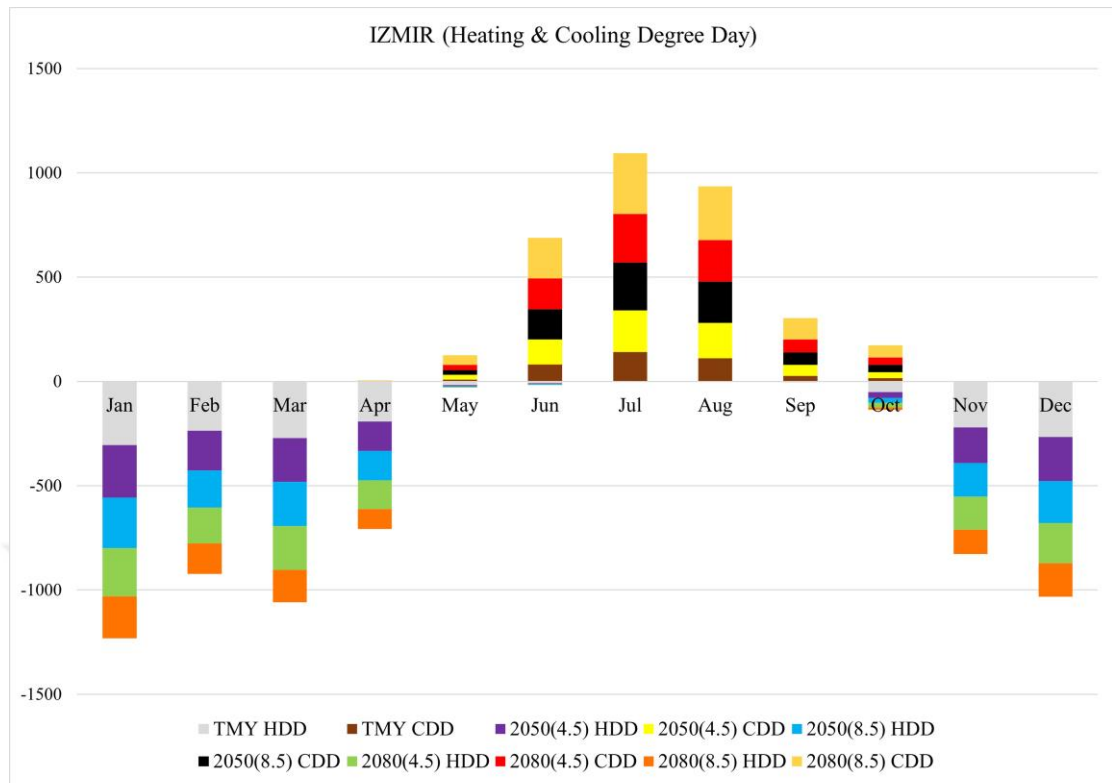


Figure 24 Heating and cooling degree-day calculation for the province of Izmir

The change in the number of heating and cooling degree days will affect the energy and thermal comfort of the buildings. Calculation of variations in thermal comfort in buildings will be calculated diversely in different zones due to different physical properties.

Adaptive comfort model analysis can be applied to user-analyzed and naturally conditioned spaces (bedroom). For this reason, analysis was made in places where natural ventilation is dominant in the building. The heating system is not active during analysis (15 May-15 Oct). The CBE Thermal Comfort Tool was used for this analysis and the analysis will be made according to ASHRAE Standard 55-2020. With the EnergyPlus program, the operative temperature and mean outdoor temperature temperatures of the spaces will be compared and it will be evaluated whether they are in the thermal comfort range according to the ASHRAE standard.

In addition to natural ventilation, the analysis will be carried out according to the fanger method in places where mechanical cooling takes place (living room). The Fanger method calculates two indices, Estimated Average Vote (PMV - Projected Average Vote) and Percentage Dissatisfied (PPD - Expected Percent Satisfied). This analysis will be performed and analyzed with the EnergyPlus software.

3.4 Building Different Retrofit Scenarios

Different retrofit scenarios were created for the energy improvements of the existing building during the climate adaptation process. These scenarios are considered as building envelope, HVAC systems, and renewable energy integration. The TS 825 standard was considered in the scenarios developed in the building envelope.

The recommended U values in the second climatic region where Istanbul is located are respectively; 0.6 for exterior walls, 0.4 for the roof, 0.6 for the floor, and 2.4 for glass. The suggested U values in the first region where İzmir is located are respectively; 0.7 for exterior walls, 0.45 for the roof, 0.7 for the floor, and 2.4 for glass.

The improvement measures are generally as follows,

- Envelope: improvement of glass systems (G), retrofit of opaque components (O)
- HVAC: Strategies to improve the efficiency of HVAC systems (H)
- Renewable Energy: integration of renewable systems (R)

Table 7 Building Opaque Component Retrofit Strategies

Building Envelope Component		Insulation layer		U Value (W/m ² °K)	
		Istanbul	Izmir	Istanbul	Izmir
Base	External Wall	No Insulation		1.6	
	Roof			1.17	
	Floor			1.35	
O1 (insulation level based on TS825)	External Wall	4 cm EPS	3 cm EPS	0.56	0.67
	Roof	6 cm Stone Wool	5 cm Stone Wool	0.42	0.47
	Floor	4 cm XPS	3 cm XPS	0.53	0.62
O2 (insulation level x2 higher than TS825)	External Wall	8 cm EPS	6 cm EPS	0.34	0.42
	Roof	12 cm Stone Wool	10 cm Stone Wool	0.26	0.29
	Floor	8 cm XPS	6 cm XPS	0.33	0.4
O3 (insulation level x3 higher than TS825)	External Wall	12 cm EPS	9 cm EPS	0.24	0.31
	Roof	18 cm Stone Wool	15 cm Stone Wool	0.18	0.21
	Floor	12 cm XPS	9 cm XPS	0.24	0.3

Since the U values suggested in the building envelope retrofit strategies are different, Istanbul and Izmir are considered separately (Table 6). Firstly, an insulation layer was added to the existing structure, and it was brought closer to the TS 825 standard. Then, strategies were developed by increasing the insulation thickness according to the regions at certain rates. While EPS, which has more advantages than XPS, is used on the

external wall, XPS material is preferred on the floor due to its water resistance. The thickness of the existing stone wool insulation on the roof has been increased.

Since according to the TS 825 recommended U values for two cities in glass systems are similar, retrofit strategies were considered together (Table 7).

Table 8 Building Glazing Retrofit Strategies

Building Glazing Component	U Value (W/m ² °K)	SHGC (%)	Tvis (%)
Base	2.7	0.8	0.75
G1 (Double Glass)	1.3	0.55	0.79
G2 (Double Glass)	0.9	0.48	0.69
G3 (Triple Low-E Air Glass)	0.7	0.63	0.39

The HVAC system retrofit strategies of the building are considered together for the provinces of Istanbul and Izmir, and different alternatives in different climates will be analyzed and compared (Table 8).

Table 9 Building HVAC Retrofit Strategies

Building HVAC System	Details
Base	Radiator Heating, Boiler HW, Natural Ventilation+PTAC
H1	Fancoil Unit (4-Pipe), Air Cooled Chiller
H2	Solar-Assisted (PV Panels) Heat Pump Systems for Heating and Cooling
H3	Ground Source Heat Pump+ PV Panels (GSHP)

For other retrofit strategies, the use of solar panels within the scope of renewable systems will be analyzed. In the next step, in addition to single improvement measures, packages will be created by combining different strategies, and it is aimed to create efficient strategies by analyzing improvement scenarios in different climates.

3.5 Combination of Retrofit Scenarios

Retrofit packages were created by combining individual improvement strategies of different components with different possible scenarios. Combination packs in the first step focus on improving the building envelope. In this context, nine packages were created (Table 9).

Table 10 Building Envelope Retrofit Packages

PACKAGE	Opaque Component	Glazing
Base	Base	Base
P1	O1	G1
P2	O1	G2
P3	O1	G3
P4	O2	G1
P5	O2	G2
P6	O2	G3
P7	O3	G1
P8	O3	G2
P9	O3	G3

In the next step, the opaque components of the building envelope will be combined with the best-performing glazing scenarios (PE). These scenarios will then be combined with HVAC retrofit strategies (Table 10). In the last step, the integration of renewable energy sources with the most efficient scenario (R).

Table 6 Efficient Building Envelope and HVAC Combination Packages

Selecting Efficient Building Envelope Packages (P1-P9)		HVAC Scenarios
$P_{(X)}$	$\rightarrow$	$P_{(X)}+HE$
		$P_{(X)}+H1$
		$P_{(X)}+H2$
		$P_{(X)}+H3$
$P_{(Y)}$	$\rightarrow$	$P_{(Y)}+HE$
		$P_{(Y)}+H1$
		$P_{(Y)}+H2$
		$P_{(Y)}+H3$

CHAPTER IV

RESULT & DISCUSSIONS

At this stage, firstly, the current situation of the two cities and climate files and analyzes for the future were made. Then, the strategies described in the previous section will be implemented one by one and analyzed in terms of energy consumption. And then, the best-performing efficient scenarios in terms of consumption will be combined and analyzed. Finally, thermal comfort analyzes will be made by selecting the most efficient scenarios according to the combined energy consumption.

4.1 Existing Energy Consumption and CO₂ Emission of Building

Currently, the energy consumption of the building in the province of Istanbul is shown in Figure 26. Primary energy consumption (PEC) is calculated as 128.32 kWh/m² with the TMY climate file. While 62.17 kWh/m² of this consumption is used for heating energy consumption (HEC), 4.18 kWh/m² is used for cooling energy consumption (CEC). Considering the year 2050, a decrease in HEC and an increase in CEC are observed for the RCP 4.5 scenario. However, this increase is small compared to the RCP 8.5 scenario. This is because the planet has warmed more due to the proportion of emissions released in the RCP 8.5 scenario. The RCP 4.5 scenario is a more optimistic scenario, although the climate has changed, albeit to a lesser extent, due to natural causes. However, a change is not observed as much as in the RCP 8.5 scenario. As a result, less demand for HEC and more demand for CEC in the RCP 8.5 scenario. When the current situation and 2050 scenarios are compared, the HEC in the RCP 4.5 scenario has decreased from 62.17

kWh/m² to 50.01 kWh/m². There is a difference of about 12 kWh/m². In CEC, the consumption which was 4.18 kWh/m² at the beginning has increased to 9.21 kWh/m². This means that the demand for cooling has increased significantly by 125% in a period of 30 years. PEC is 121.33 kWh/m² and 120.14 kWh/m² in RCP 4.5 and 8.5 scenarios, respectively. According to the TMY scenario, the reason for the decrease in PEC is that even though the demand for CEC, the decrease in the HEC is significant, so a decrease in total energy consumption has been observed.

When the PEC of the TMY and 2080 scenarios is compared, RCP 4.5 is calculated as 117.8 kWh/m² and RCP 8.5 is 113.79 kWh/m². In the RCP 8.5 scenario, 30% of the energy consumption is due to CEC. Initially, this rate was as low as 6%, according to TMY climate data. In the RCP 8.5 scenario, a significant decrease in the need for HEC is observed. Comparing the RCP 4.5 scenarios, the difference is quite small, from 50.01 kWh/m² to 46.06 kWh/m². Considering that emissions are low in this scenario, it can be said that the effects of climate change are less felt. However, the situation in RCP 8.5 scenarios is quite different. HEC, which is calculated as 62.17 kWh/m² in the TMY climate file, is calculated as 39.53 kWh/m² by 2080. There was a significant decrease of about 40%. In CEC, a critical increase of approximately 200% was calculated from 4.18 kWh/m² to 12.1 kWh/m². In this direction, the changing climate is clearly visible.

Considering that Turkey is critically inadequate in the adaptation process to the climate, this situation needs to be considered. A decrease is observed in total PEC like 2050. The need for CEC has increased considerably. However, it is assumed that there is only one air conditioner in the living rooms in the existing building. Therefore, it is considered that the cooling energy is insufficient. The next step will be addressed in the thermal comfort analysis. Therefore, more energy consumption is required to provide

thermal comfort, but in this case, it is insufficient. It is thought that the decrease in PEC, is due to both this reason and the decrease in heating consumption.

In the comparison of CO₂ emissions in Figure 25, it is currently calculated as 32.1 kgCO₂ /m² with the TMY climate file. It is observed that this ratio gradually decreases. The reason for this is the decrease in natural gas consumption arising from the need for heating. Even though the cooling demand increased, natural gas consumption decreased rapidly, and it decreased in parallel. Respectively, while the average was approximately 30 kgCO₂ /m² in 2050, it was calculated as approximately 29 kgCO₂ /m² in 2080.

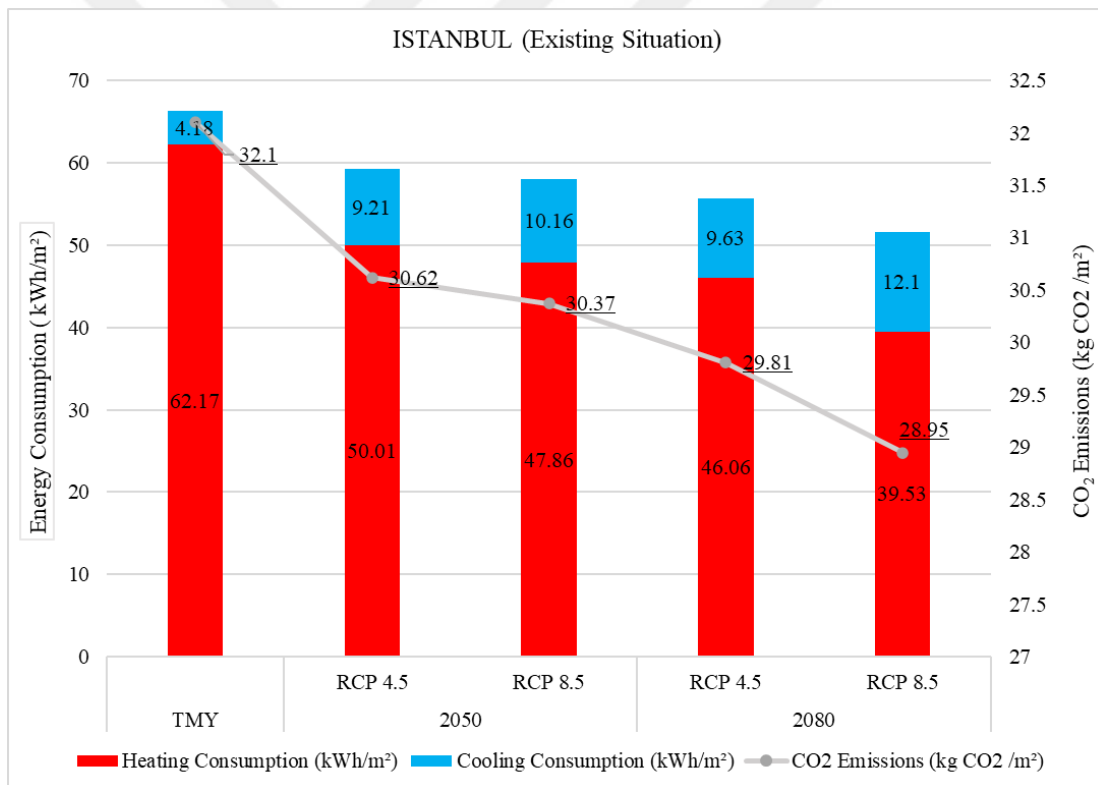


Figure 25 Energy Consumption and CO₂ Emissions of the current building in Istanbul

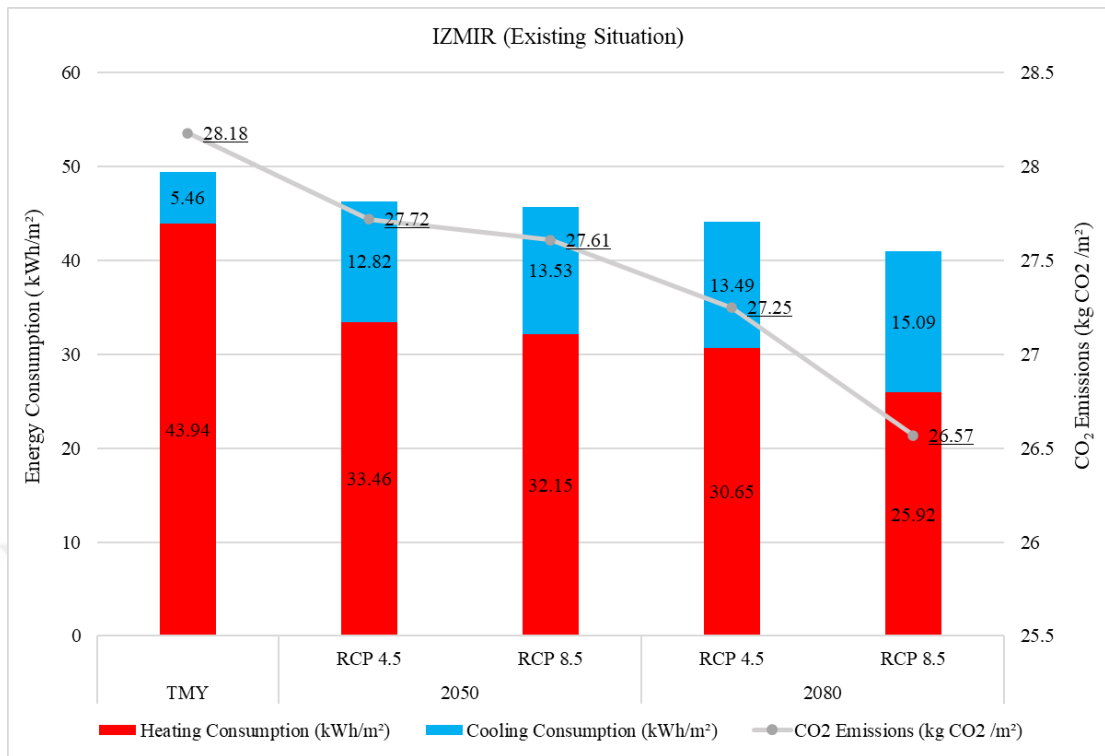


Figure 26 Energy Consumption and CO2 Emissions of the current building in Izmir

Currently, the energy consumption of the building in the province of Izmir is shown in Figure 26. PEC is calculated as 111.4 kWh/m² with TMY climate data. This consumption was used for 43.94 kWh/m² HEC and 5.46 kWh/m² CEC. When the current situation CEC is compared, more cooling and HEC is seen in Izmir than in Istanbul. In 2050, similar to the situation in Istanbul, it is seen that HEC decreases. PEC is calculated as 108.45 kWh/m² in the 2050 RCP 4.5 scenario and 107.87 kWh/m² in the RCP 8.5 scenario. Compared to TMY data, HEC decreases by approximately 23% in the RCP 4.5 scenario, while CEC increases by approximately 140%. Considering the RCP 8.5 scenario, HEC decreases by approximately 25%, while CEC increases by approximately 160%. The difference between the CEC in TMY and 2050 RCP 4.5 is calculated as 7.36 kWh/m². In the same comparison, this value was calculated as 5.03 kWh/m² in Istanbul. This proves that the cooling demand in Izmir is increasing faster than in Istanbul.

In 2080, the increase in CEC is more serious. In the RCP 8.5 scenario, the CEC constitutes 40% of the PEC. In TMY data, this rate has been calculated as approximately 10%. Compared with TMY 2080 RCP 4.5, HEC decreased by 30% while CEC increased sharply by 160%. RCP 8.5 HEC decreased by 40% while CEC remarkably significantly by 200%. Also, in 2080, PEC are observed as 106.33 kWh/m² in RCP 4.5 scenario, and 103.22 kWh/m² in RCP 8.5, respectively. The decrease in PEC is similar to that in Istanbul, which can be said to be insufficient cooling and a sharp decrease in HEC.

In the comparison of CO₂ emissions in, it is currently calculated as 28.18 kgCO₂/m² with the TMY climate file. Respectively, while the average was approximately 27 kgCO₂/m² in 2050, it was calculated as approximately 26 kgCO₂/m² in 2080. The reason for the decrease in emissions is like the reasons explained in Istanbul.

4.2 Existing Thermal Comfort of Building

In the current situation, using the Fanger method, the living room zone, which is heated by radiator heating, cooled by an air conditioner, and has natural ventilation, has been evaluated in Istanbul (Figure 27). In the analysis performed with the TMY climate file, the values in the most felt range are the slightly cool-neutral range, which is calculated as approximately 49% with 4354 hourly values. The lowest comfort level value obtained is the warm-hot range with 0.5%. In other words, with the TMY climate file, the value that felt excessively hot in the living room in the current situation is negligible. When the TMY climate data is evaluated, the most felt comfort range is obtained as a slightly cool-neutral range, and slightly warm-neutral. Considering the 2050 RCP 4.5 scenario, the slightly cool-neutral value range has decreased significantly, while the

slightly warm-warm value range has increased. However, this change is felt more in the RCP 8.5 scenario in 2050.

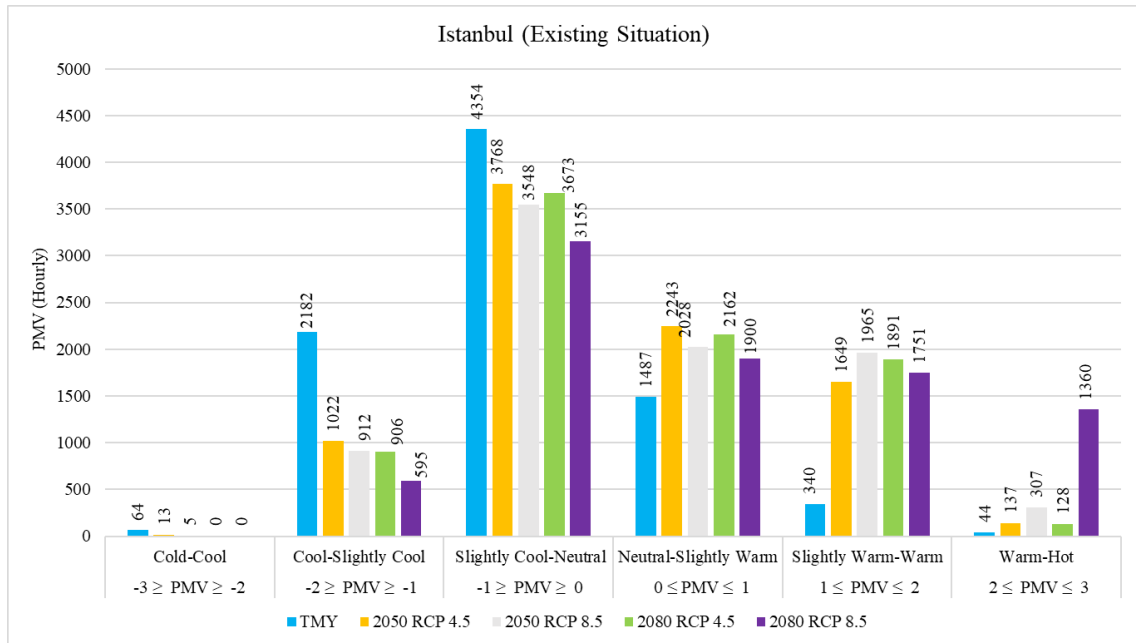


Figure 27 PMV Calculation Result of the existing building in Istanbul

Considering the year 2080, the most important thing is that there is no value in the cold-cool range anymore. Another outstanding parameter is that less warming will occur if emissions are reduced. As evidence for this situation, the slightly warm-warm interval, which was calculated as 1965 per hour in the 2050 RCP 8.5 scenario, decreased by 316 hourlies in the RCP 4.5 scenario in 2080. In other words, even after 30 years, if the emissions decrease, the warming will be less. When the different emissions in 2080 are evaluated, if the necessary precautions are not taken, the rate measured as 128 hourlies in the warm-hot interval in the RCP 4.5 scenario will increase by 10 times and reach 1360 in the 2080 RCP 8.5 scenario. In addition, especially in the RCP 8.5 scenario, the warm-hot interval was calculated as approximately 15.51% with an hourly value of 1360. This

range of values is very critical. In extremely hot environments, various health problems begin to emerge. Although this place is cooled by air conditioning, it still feels extremely hot.

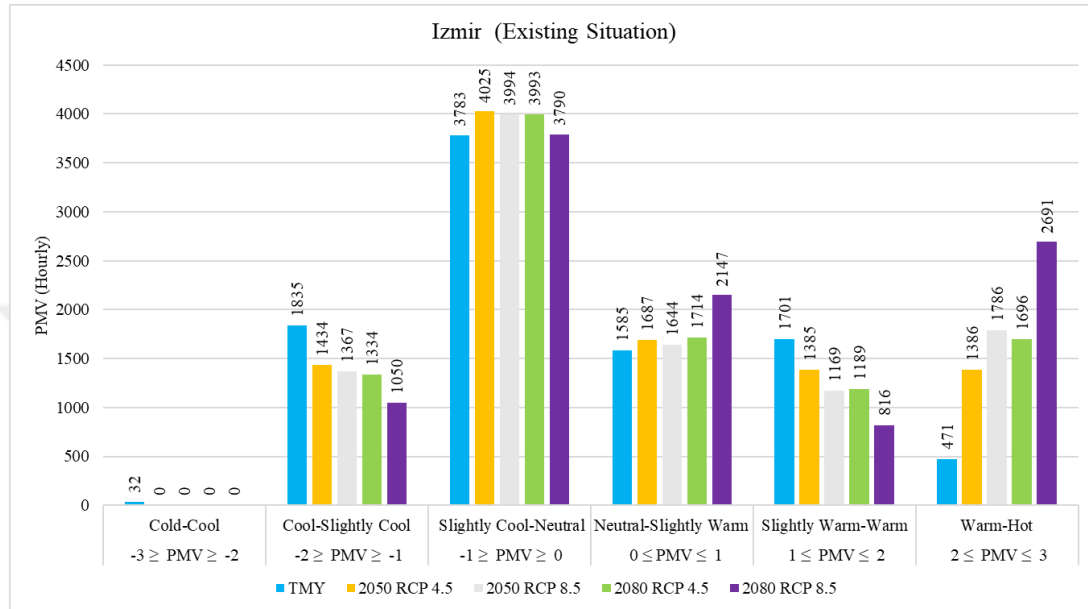


Figure 28 PMV Calculation Result of the existing building in Izmir

The results of the living room were evaluated with a similar method in Izmir, which has a different climate (Figure 28). The results obtained with TMY climate data are higher compared to Istanbul with 427 hourly values in the warm-hot range. According to TMY climate data, the comfort range most intensely felt in Izmir is slightly cool-neutral. In the warm-hot range, TMY climate data and hourly values make up 5.37%. Compared to Istanbul, this value was initially calculated as 0.5%. This proves that in the current situation, the hours that feel warmer in the living room are more common in Izmir than in Istanbul. Considering the data of 2050, it has been observed that some of the values in the cool-slightly cool range have shifted to the slightly cool-neutral range. This decrease is more in the RCP 4.5 scenario. With TMY climate data, 0.5% of hourly values

are in the warm-hot range. When it comes to 2050, this value has gradually increased in the RCP 4.5 scenario and RCP 8.5 scenario. In 2080, when compared to other years, the most remarkable increase is in the warm-hot range in the RCP 8.5 scenario. While the value in this range was initially 471 hours with the TMY climate file, this value increased critically in the RCP 8.5 scenario, reaching 2691 hourlies. Compared to Istanbul, the RCP 8.5 scenario in the warm-hot range was calculated as 1360 hourly and 2691 in Izmir. This sharp difference proves that the warming in Izmir is at a more critical level.

After the situation in the living rooms with air conditioners was evaluated with the Fanger method, the bedrooms were evaluated with a different method. When the heating system is turned off in the bedroom, the space is conditioned only by natural ventilation. In this direction, the adaptive thermal comfort method was applied.

Considering the ASHRAE standard in the values obtained with the TMY (blue) climate data in the province of Istanbul, some of them are outside the 90% limit, while all of them comply with the 80% limit standard (Figure 29). This situation proves that this place remains in comfortable conditions with TMY climate data. By 2050, values that exceed comfort limits have begun to emerge. When the RCP 4.5 scenario (green) is compared with the RCP 8.5 (grey), it is observed that the values exceeding the comfort limits of the RCP 8.5 (red) scenario are more intense. When it comes to 2080, the values at the 80% limit according to the ASHRAE standard, especially in the RCP 8.5 (red) scenario, are at a negligible level. This means that by 2080, natural ventilation will not be sufficient to provide comfortable conditions. The operative temperatures measured in this place have reached critical levels for human health at 34-35 °C.

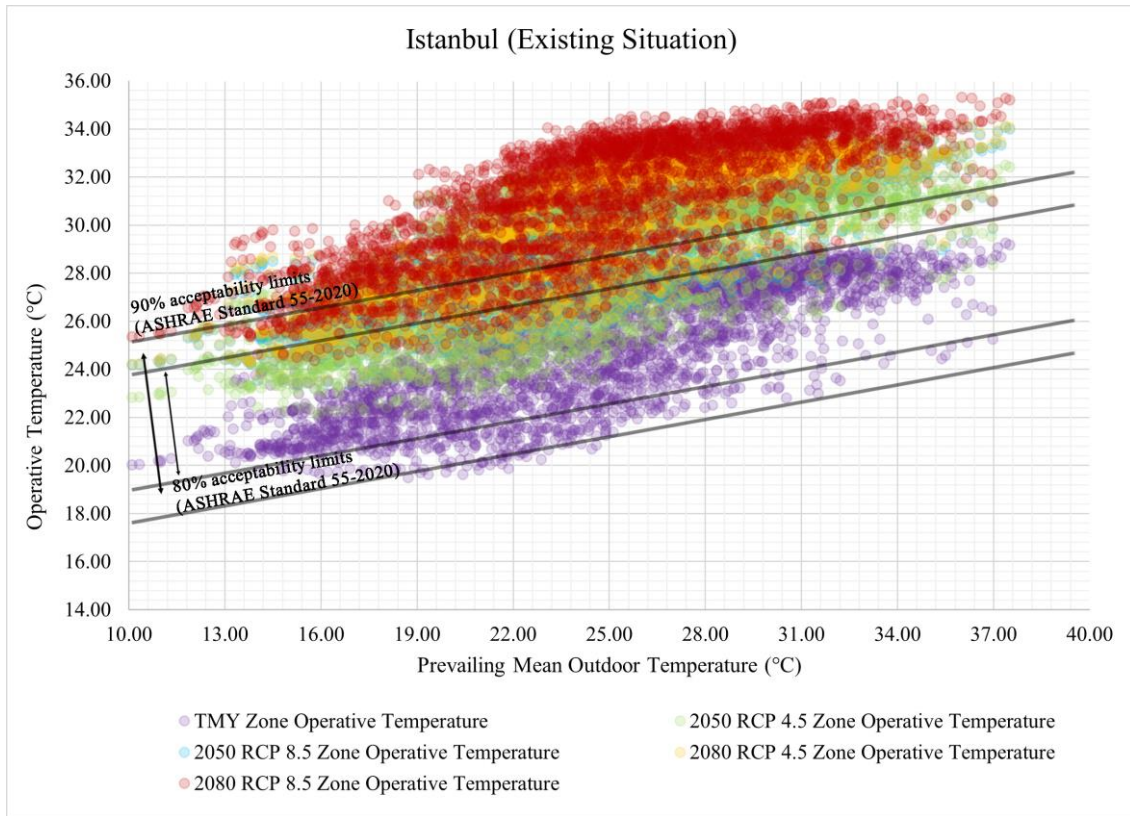


Figure 29 Adaptive Thermal Result of the existing building in Istanbul

When the Izmir TMY (blue) climate data is compared with Istanbul, the values in the ASHRAE 90% limit in Izmir are less dense and it has been observed that the intense values are in the 80% limit range (Figure 30). However, when other scenarios are taken into account, it is seen that comfort measures are largely provided with the TMY climate data. By 2050, a situation similar to that in Istanbul has been observed. Compared to TMY, the ratio of values providing the comfort range decreased significantly, especially RCP 8.5 (grey). When it comes to 2080, ASHRAE has no value at the 90% limit, while a small amount of value at the 80% limit has only been able to provide the comfort condition. Especially in the RCP 8.5 (red) scenario, the operative temperature was calculated as 36-37 °C. It is clear that the observed temperature situation is higher when compared to Istanbul.

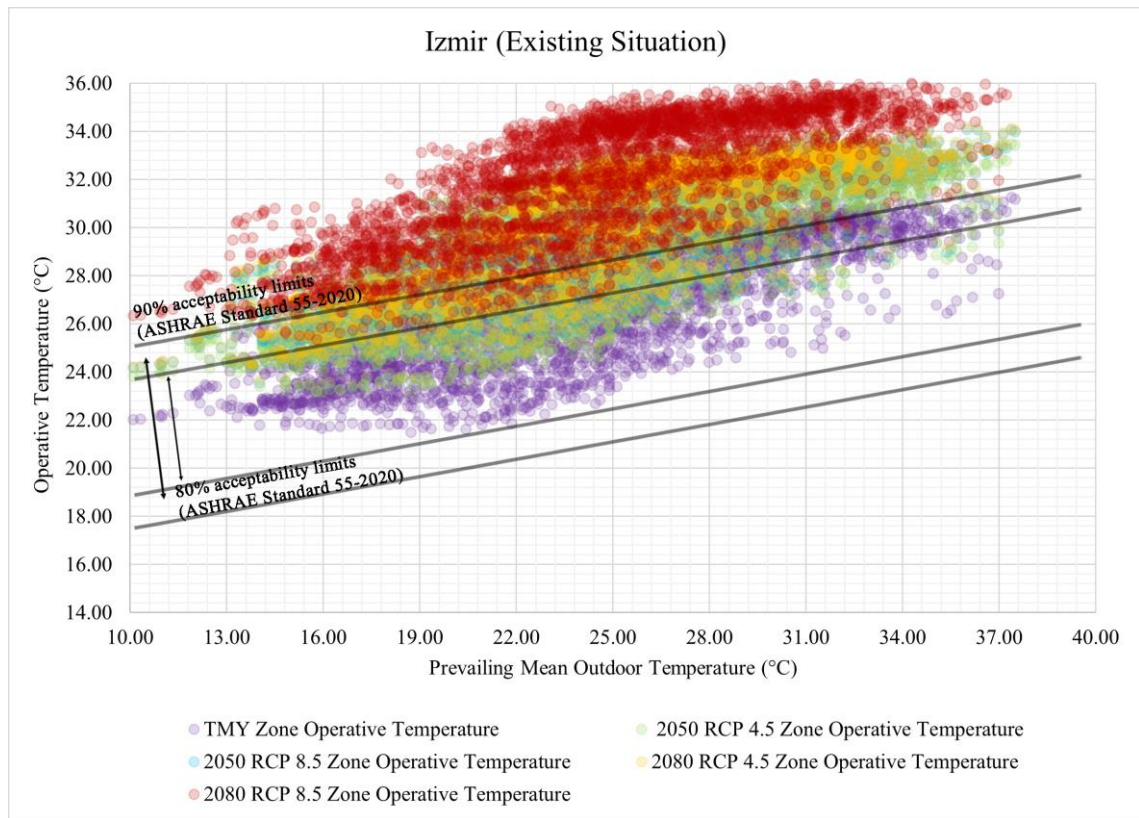


Figure 30 Adaptive Thermal Result of the existing building in Izmir

4.3 Retrofit Strategies Energy Consumption Results

The energy performance and comfort analyze of the existing building, TMY climate file, and future climate files were made in the previous section. This section aims to analyze the individual improvement scenarios described in the previous sections individually by comparing them with the existing situation with the TMY climate file and future climate files.

4.3.1 Opaque Component Retrofit Strategies

In the first step of the improvement scenarios, insulation layers were added to the wall, roof and floor components without insulation layer, taking into account the different climatic conditions of Istanbul and Izmir provinces.

In the current uninsulated condition (Base) in Istanbul, in all scenarios, the increase in temperatures due to climate change from 2050 to 2080 undoubtedly caused a decrease in HEC and an increase in CEC (Figure 31). From TMY to 2050 and 2080, this situation can be seen clearly. However, in the 2080 RCP 4.5 scenario, when compared to the 2050 RCP 8.5, the CEC value is lower even after 30 years. This may be an indication that if emissions are reduced in climate change, the effects of the change will feel less.

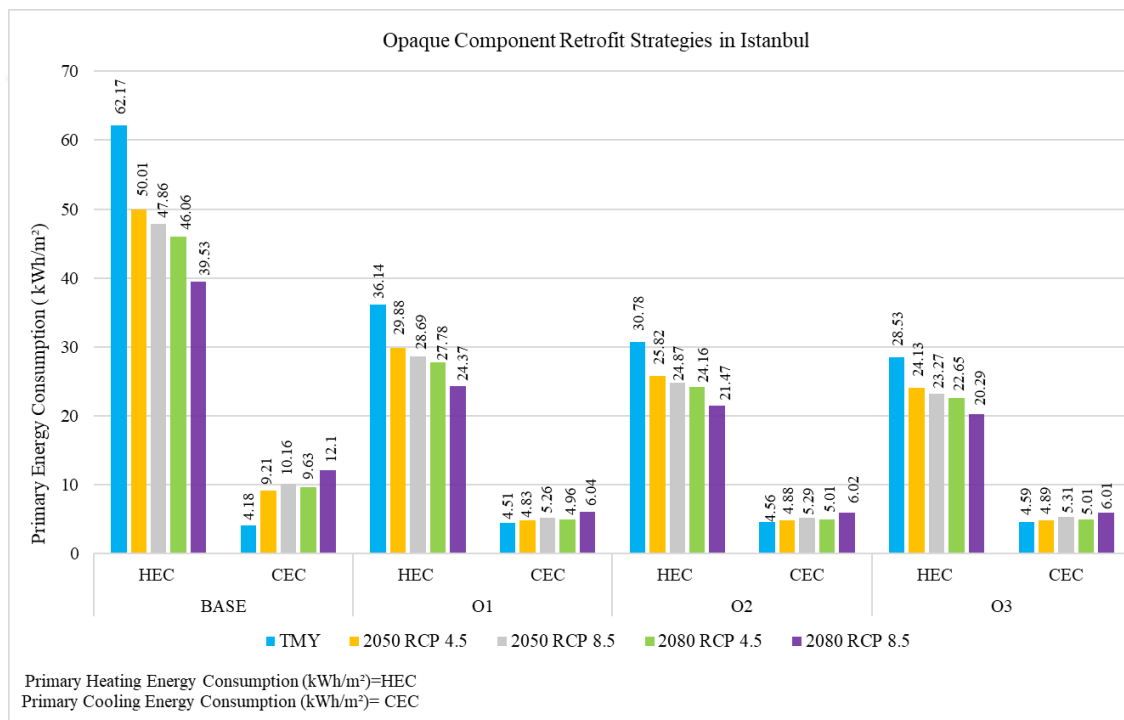


Figure 31 Opaque Component Retrofit Strategies Result for Istanbul

Comparing O1 and Base, it is seen that the HEC is significantly reduced in all scenarios. However, when it comes to CEC, there is not as much difference as in HEC. However, the addition of the insulation layer provided significant energy savings, especially in 2080. Another remarkable change is that while the TMY in Base and the 4.5 scenarios in 2050 increased significantly, O1 did not show the same sharp increase when these two weather scenarios are compared. Instead, a slight increase was calculated from

4.51 kWh/m² to 4.83 kWh/m². The reason for this can be explained as the insulation layer prevents the building from overheating in summer periods, therefore there is less need for cooling consumption.

Compared to Base, O1 has lower PEC values in each climate scenario. In parallel, the building was revised according to the TS 825 standard, resulting in energy savings in PEC, even in RCP 8.5 scenarios with the highest emission values, 19.5% in the TMY data. Respectively, energy savings of 20.14% kWh/m² were achieved in the 8.5 scenarios of 2050 and 18.5% kWh/m² in the 8.5 scenarios of 2080. This proves that initially, the building is permeable, and without an insulating layer, it needs to consume more energy to warm up in winter and cool in summer.

When the O3 scenario was evaluated, the most efficient values in terms of energy performance were obtained according to all emission scenarios compared with other scenarios. When the OE-O3 scenarios are compared, even when compared to the RCP 8.5, which has the highest emission scenario, energy savings of 48% in HEC and 22% in PEC have been achieved. In summary, as the insulation thickness increases, energy consumption savings have been achieved, but the obtained values are not as clear as the difference between the non-insulated (Base) and insulated (O1) scenarios according to TS 825 standards. However, increasing the energy savings of buildings in the climate adaptation process plays a critical role in this process.

When the improvement scenarios are evaluated for the province of Izmir (Figure 32), which has different climatic conditions and recommended insulation thicknesses, it is striking that it has less HEC compared to the province of Istanbul at the beginning. Conversely, CEC is higher in this city.

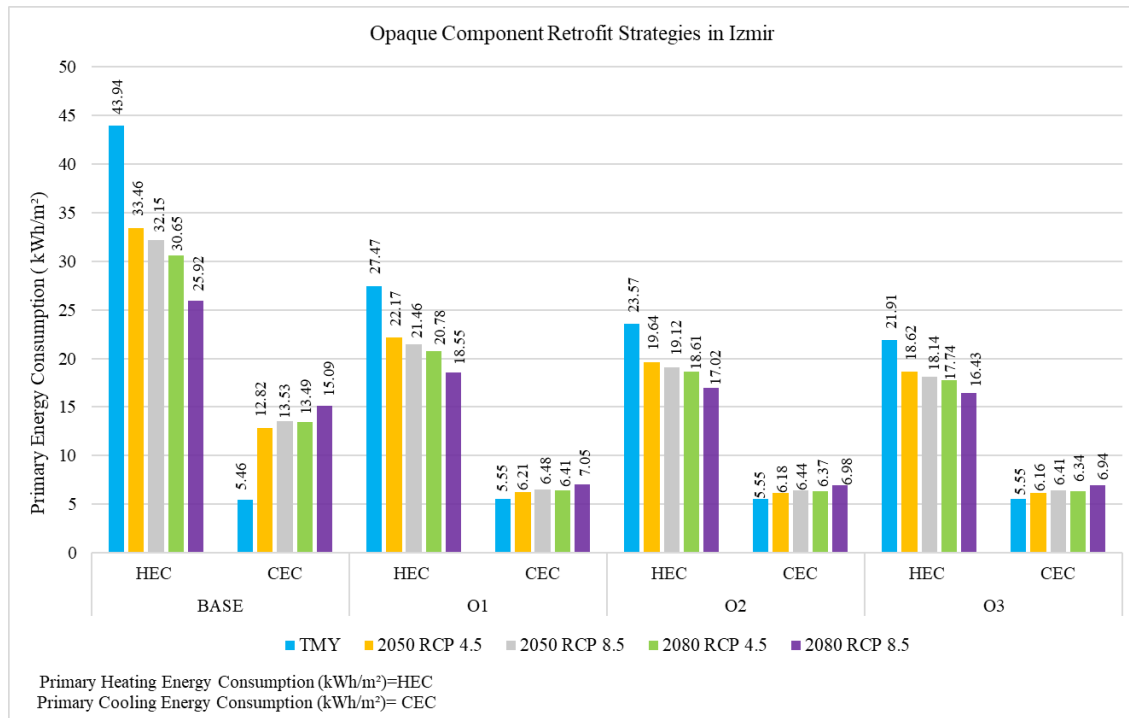


Figure 32 Opaque Component Retrofit Strategies Result for Izmir

When Base is compared with future climate data, a sharp decrease is observed in the RCP 4.5 scenario in 2050. Another sharp drop is RCP 8.5 in 2080. While HEC is 25.92 kWh/m², CEC is calculated as 15.09 kWh/m². This may indicate that almost half of the energy consumed in Izmir in the future will be used for cooling needs. There is an increase in cooling consumption. Especially, the CEC value of the existing building (Base) in all scenarios in and after 2050 has reached more than double the values even though there is only one air conditioner. In other words, due to overheating, the building will need much more CEC in the future.

In the O1 scenario, which is carried out taking into account TS 825 standards, there is no sharp increase in CEC values, especially in 2050 and beyond. This situation exhibited a more balanced consumption compared to the Base scenario. The addition of the insulation layer made the HEC drop even more. When the consumption of Base and O1 scenarios in 2080 is compared, 28% kWh/m² savings in HEC and 53% kWh/m² in CEC have been achieved.

In the O2 scenario, where the insulation is doubled, the remarkable detail is that while the CEC was 5.55 kWh/m² with the TMY climate data in the O1 scenario, the same result was obtained with the O2 TMY climate data. However, by 2050, it has been observed that the CEC value of the O2 scenario outperforms the O1 scenario. Especially in the 2080 RCP 8.5 scenario, the CEC value decreased from 7.05 kWh/m² to 6.98 kWh/m². In other scenarios, small changes were observed, but the values obtained in the O2 scenario are lower than in the O1 scenario. This means that more energy savings are achieved in the O2 scenario.

Considering the O3 scenario, more efficient results were obtained for HEC in all climate scenarios, respectively, compared to other improvement scenarios. Compared to OE, with TMY climate data, a decrease of 51.16% kWh/m² was calculated from the HEC value from 43.94 kWh/m² to 21.91 kWh/m². On the other hand, 5.55 kWh/m² was calculated, similar to CEC O2, with TMY climate data. However, when compared to O2 for 2050 and beyond, the O3 scenario seems to be more efficient. Increasing the insulation thickness provided energy savings, but the difference is not as sharp as between Base - O1. This means that similar to the situation in Istanbul, the difference between non-insulated and insulated scenarios is greater.

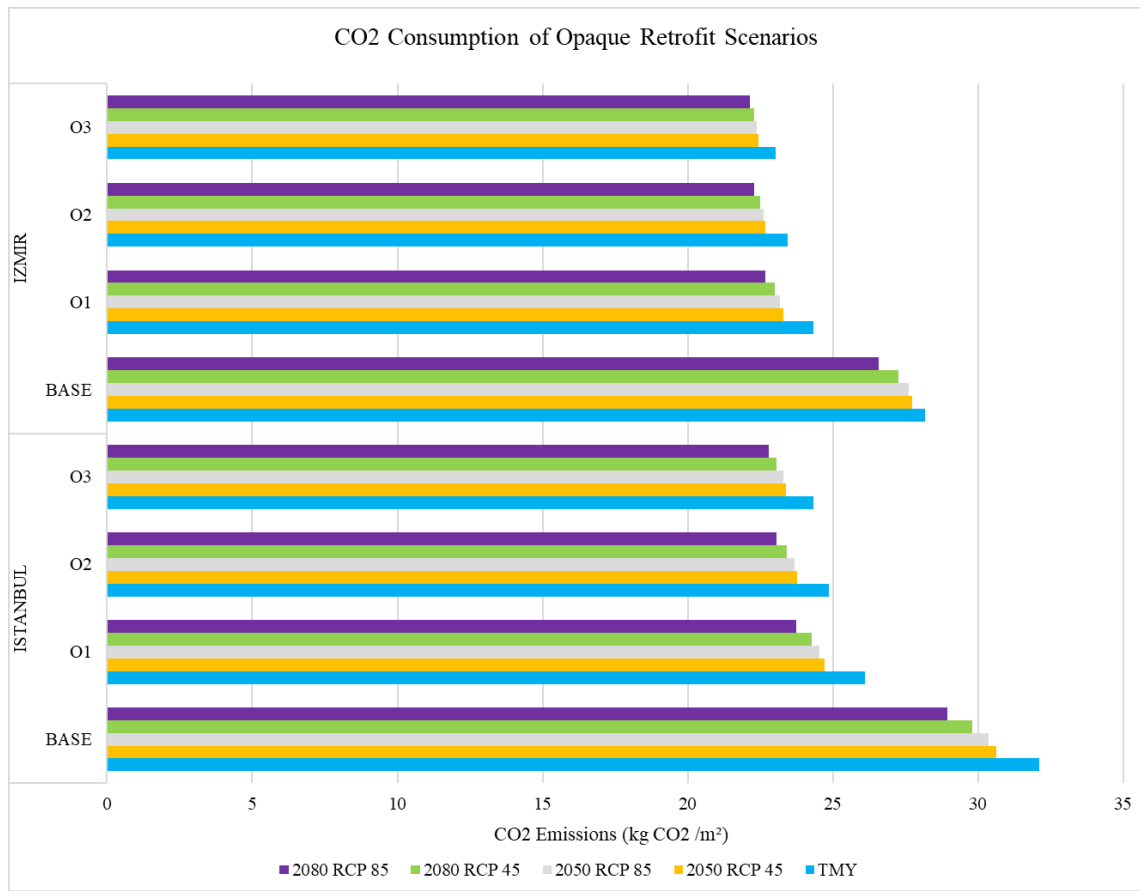


Figure 33 CO₂ Consumption Result of Opaque Retrofit Scenarios

As a result of the opaque retrofitting energy performance analyzes carried out in two different cities, the CO₂ consumption of the improvement packages was compared (Figure 33). In the results obtained, the highest consumption value was obtained with the current situation (Base) of Istanbul and TMY climate data. The reason for this is that the highest amount of natural gas consumption for heating needs was realized in this scenario with 32.1 kgCO₂/m². Similarly, the highest consumption value in the province of Izmir with 28.18 kgCO₂/m² was obtained with the current situation (Base) and TMY climate data. One of the most important factors that increase CO₂ consumption is the gas released by the burning of coal, which is one of the driving forces of climate change. When the other scenarios are examined, it is seen that the CO₂ consumption is gradually decreasing

as the energy consumption decreases. The O3 scenarios have the lowest CO₂ consumption with the lowest PEC values, compared to 22.79 kgCO₂/m² in Istanbul and 22.13 kgCO₂/m² in Izmir. The reason for this is that the need for heating is gradually decreasing. Even if the electricity consumption increases due to the cooling need, it has been observed that the total CO₂ consumption has decreased due to the decrease in the heating need at a more serious rate.

4.3.2 Glazing Component Retrofit Strategies

After the strengthening strategies of the opaque components of the building, the improvement scenarios of the transparent components of the building were analyzed separately in two different cities by simulating four different glazing types determined in the section "*3.4 Building Different Retrofit Scenarios*".

According to the data obtained in the province of Istanbul, ordinary double glazing has the lowest performance values in the current situation (Base) in Figure 34. However, when the other scenarios are examined, it is noteworthy that the CEC values in all scenarios obtained in the analysis of opaque components in the previous section are higher. In other words, retrofitting the transparent components of the building had a greater impact on the building's CEC energy consumption than directly with the opaque component. In addition, the decrease in CEC values, especially in the more optimistic scenario of 2080, RCP 4.5 indicates that the effects of climate change will be less affected if necessary precautions are taken.

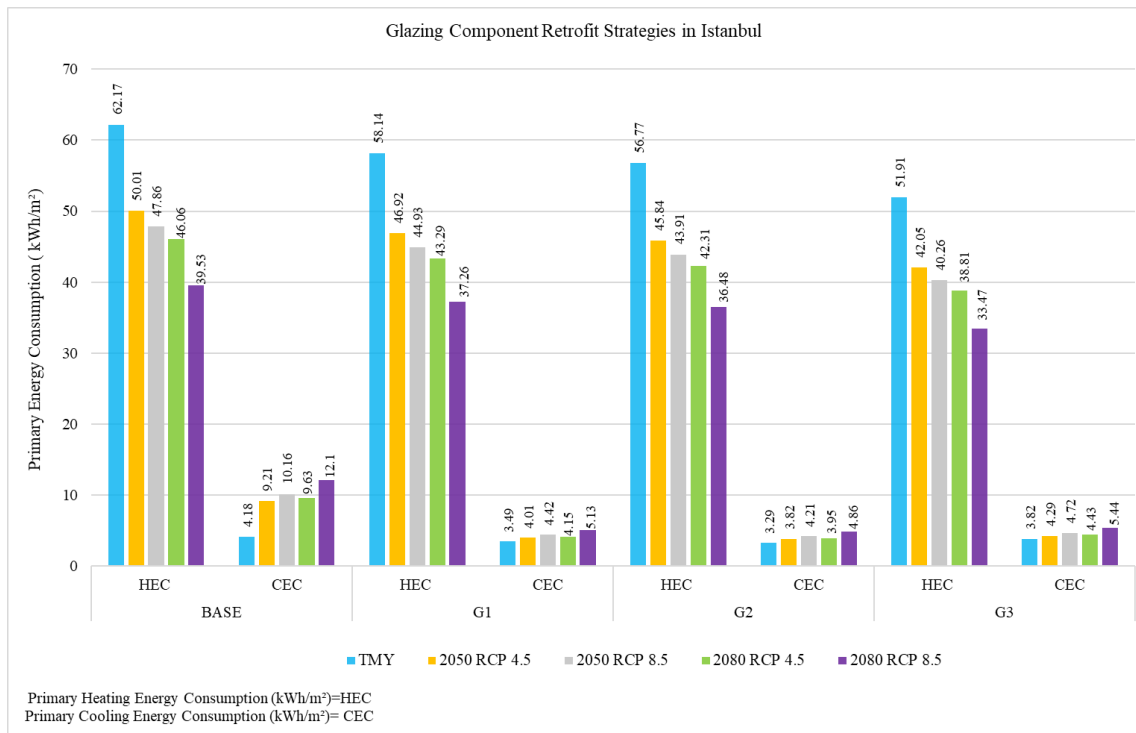


Figure 34 Glazing Component Retrofit Strategies Result for Istanbul

When the Base-G1 scenarios are compared with all climate scenarios, G1 saves energy by showing lower consumption. Considering the G1 and G2 glazing scenarios, both have double glazing. However, G2 has a lower U-value and SHGC ratio. In parallel, when all scenarios are considered, G2 performed better. Both HEC and CEC consumptions are lower than in the G1 scenario. In particular, lower SHGC means better solar control, and a lower U value provided better insulation and played an important role in lowering HEC and CEC values.

The G3 scenario has a triple glass feature. However, although its U value is low, it has a higher SHGC ratio. This has resulted in a decrease in HEC values in winter as it has better insulation properties. However, the CEC values caused more energy consumption in the G3 scenario, which has a high SHGC ratio compared to G2. This is because, with high SHGC, more heat from the sun entered the room. Therefore, as a result

of the increase in air temperatures with climate change, more heat entering the interior has caused the need for more cooling. Therefore, the CEC of the G3 scenario is higher. When G2 and G3 PEC values are compared, G3 less energy consumption was achieved. The reason for this is that although it consumes more energy for cooling, it consumes less energy for heating needs. Therefore, the PEC value was obtained more efficiently than the whole G3 and G2.

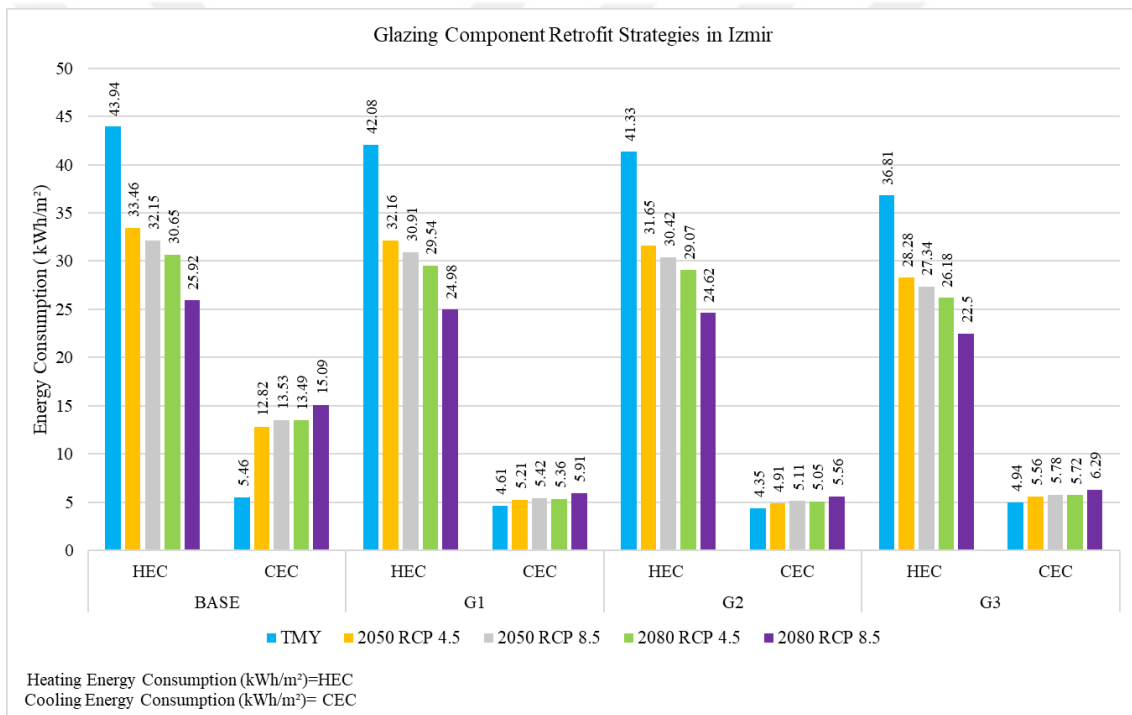


Figure 35 Glazing Component Retrofit Strategies Result for Izmir

When the results obtained for the city of Izmir (Figure 35) are compared with the city of Istanbul, it is clear that the need for heating is less and the need for cooling is more due to the characteristic feature of the climate type. Therefore, in scenarios realized with TMY and future climate data, HEC values are lower and CEC is higher when compared to Istanbul. Base has the worst performance when compared to other scenarios. Base and

G1 have double glazing features. However, when the two are compared, G1 has lower U and SHGC values. Considering the Base-G1 scenarios, both HEC and CEC have been observed to decrease considerably in G1.

Evaluating G2 scenario, both CEC and HEC performed better than G1 and GE scenarios. Also, G3 scenario has triple glass feature. The G3 scenario has a lower U value and a higher SHGC value compared to G2. This resulted in a higher CEC ratio while providing a lower HEC. Considering the hot summer climate of Izmir, more energy will be needed for cooling in summer. However, when the PEC values are compared, the G3 scenario performed better than G2. This is because the HEC rate drops significantly in the G3 scenario. However, with the high SHGC rate of G3, it will cause more heating of the room in Izmir in summer and increase the thermal discomfort. Considering the PEC values, although the G3 poses a disadvantage in terms of CEC, it showed the most efficient performance due to its low HEC values.

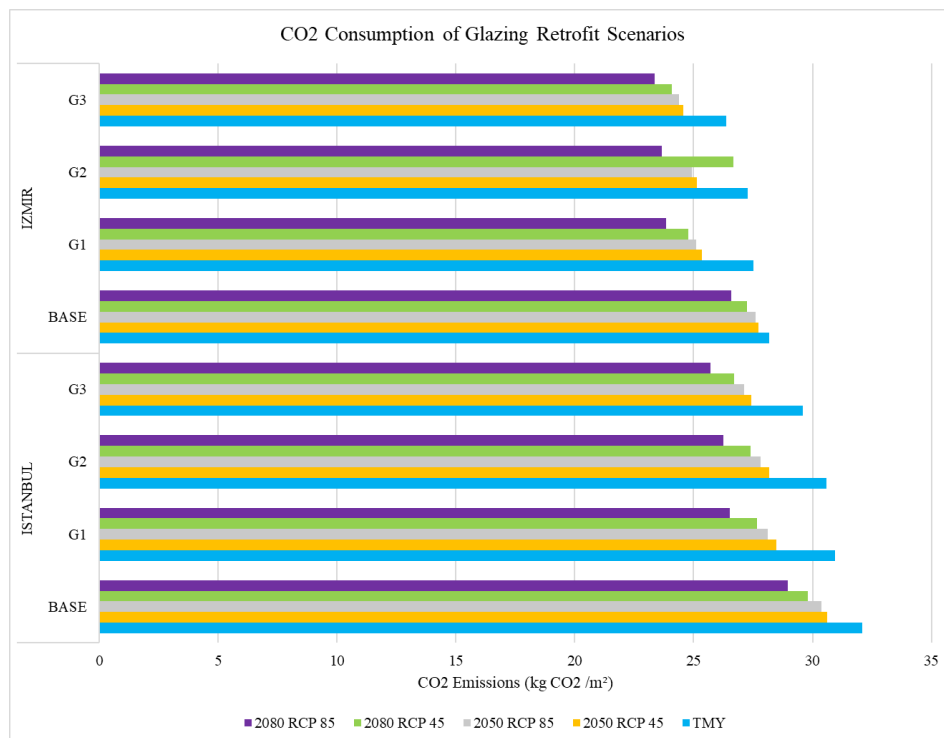


Figure 36 CO₂ Consumption Result of Glazing Retrofit Scenarios

The effect of improvement suggestions in the building's glazing system on CO₂ consumption is as in Figure 36. In the G3 scenario showing the lowest CO₂ consumption, these values were calculated as 29.59 kgCO₂/m² and 25.72 kgCO₂/m², respectively. Similar to Istanbul, the scenario with the highest consumption in Izmir is Base and TMY climate data. In the G3 scenario, which shows the lowest CO₂ consumption, these values were obtained as 26.36 kgCO₂/m² and 23.37 kgCO₂/m². In both cities, the G3 scenarios resulted in lower CO₂ consumption compared to the Base condition.

4.3.3 Building HVAC Retrofit Strategies

After retrofitting strategies for the opaque and transparent components of the building, scenarios for upgrading the HVAC systems were analyzed. The results in Istanbul province are as indicated in Figure 37.

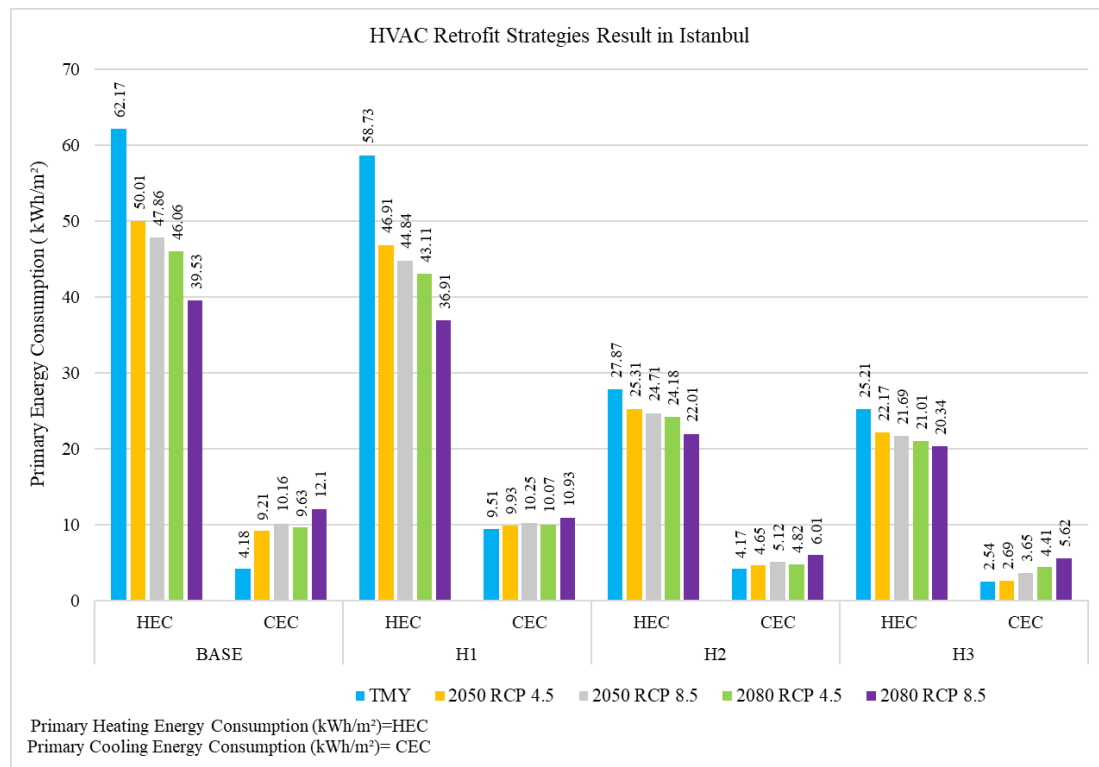


Figure 37 HVAC Retrofit Strategies Result for Istanbul

When Base-H1 (Fancoil) scenario is compared, HEC consumption decreased in each compared scenario, but the difference is more pronounced with TMY climate data. In contrast, CEC showed higher consumption except for the 2080 RCP 8.5 scenario. In parallel, although H1 had lower HEC values in every scenario without exception, PEC was calculated higher than Base in all scenarios, as CEC increased significantly. When the H2 (Solar Assisted System) is compared, it is seen that the entegration of PV panels in the system provides a significant advantage. There is a remarkable decrease in both HEC and CEC values. This situation affects the PEC value, resulting in lower consumption compared to the H1 and H2 scenarios. The H3(GSHP+PV) scenario stands out as the most efficient scenario. This is because it takes advantage of the thermal energy storage properties of the soil for heating. Therefore, less heating requires energy. Also, energy consumption has decreased thanks to the energy produced by the PV panels on the roof. Thus, the H3 scenario performed more efficiently than the other scenarios in every scenario and it has the lowest HEC, CEC, and PEC values among the scenarios.

The results obtained within the scope of HVAC scenarios in the city of Izmir are as in Figure 38. Compared to the province of Istanbul, higher CEC values stand out. Considering other scenarios, the lowest performance scenario is Base. In this scenario, both HEC and CEC values are high. In parallel, PEC values also showed high consumption in all compared scenarios. In the H1 scenario, a decrease in HEC values is noticeable. However, no significant decrease was observed in CEC values. In fact, TMY climate data and 8.5 scenarios showed more consumption. In the H2 scenario, on the other hand, the integration of renewable energy provided an advantage by causing a decrease in energy consumption values.

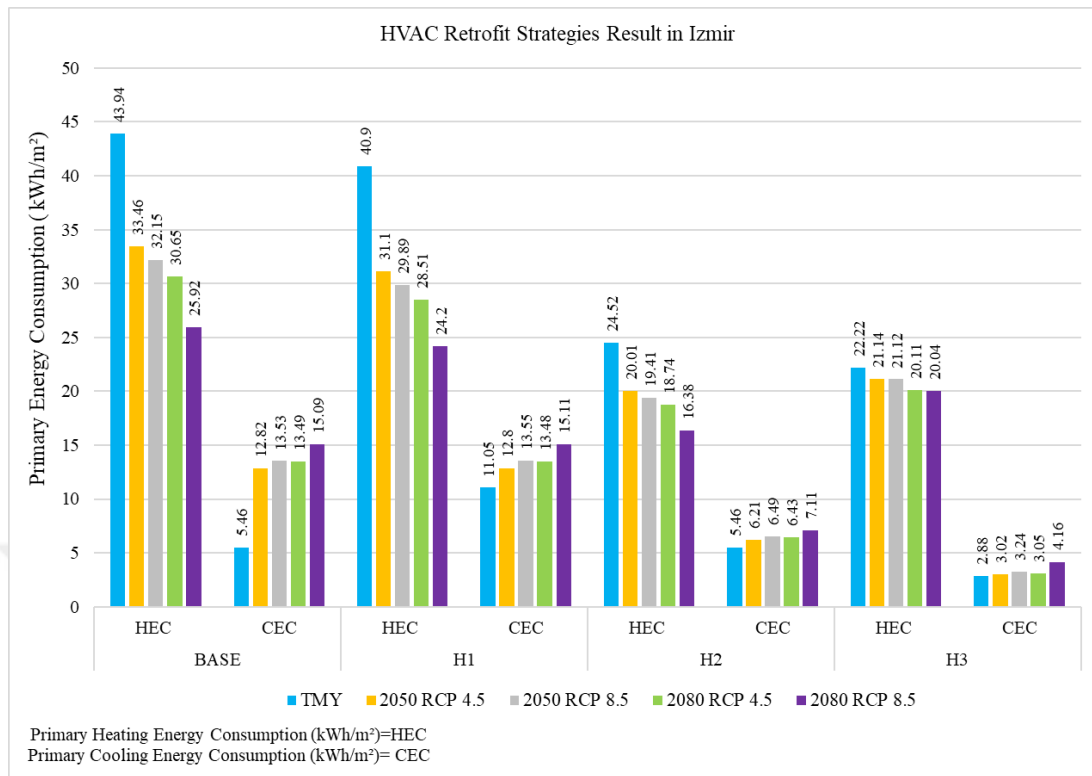


Figure 38 HVAC Retrofit Strategies Result for Izmir

Particularly, a decrease by half in CEC values was calculated. When it comes to the H3 scenario, more HECs were observed than H2 in other scenarios, except for the TMY climate data. However, this difference is small enough to be eliminated. When the CEC values are compared, the H3 scenario is more efficient than H2. When the PEC of H2-H3 scenarios is calculated, H3 stands out as being more efficient with less consumption.

Another notable implication worth noting is the power generation of PV panels. With TMY climate data, 5.878 kWh generation was achieved in Istanbul. This value showed an increasing production with 6.062 kWh in 2050 and 6.268 kWh in 2080. With the climate data of TMY in Izmir, 6.092 kWh, 6.306 kWh in 2050, and 6.472 kWh in 2080 have provided a rise in production. This proves that being able to benefit more from solar energy in the future will provide a critical advantage to the energy performance of

buildings.

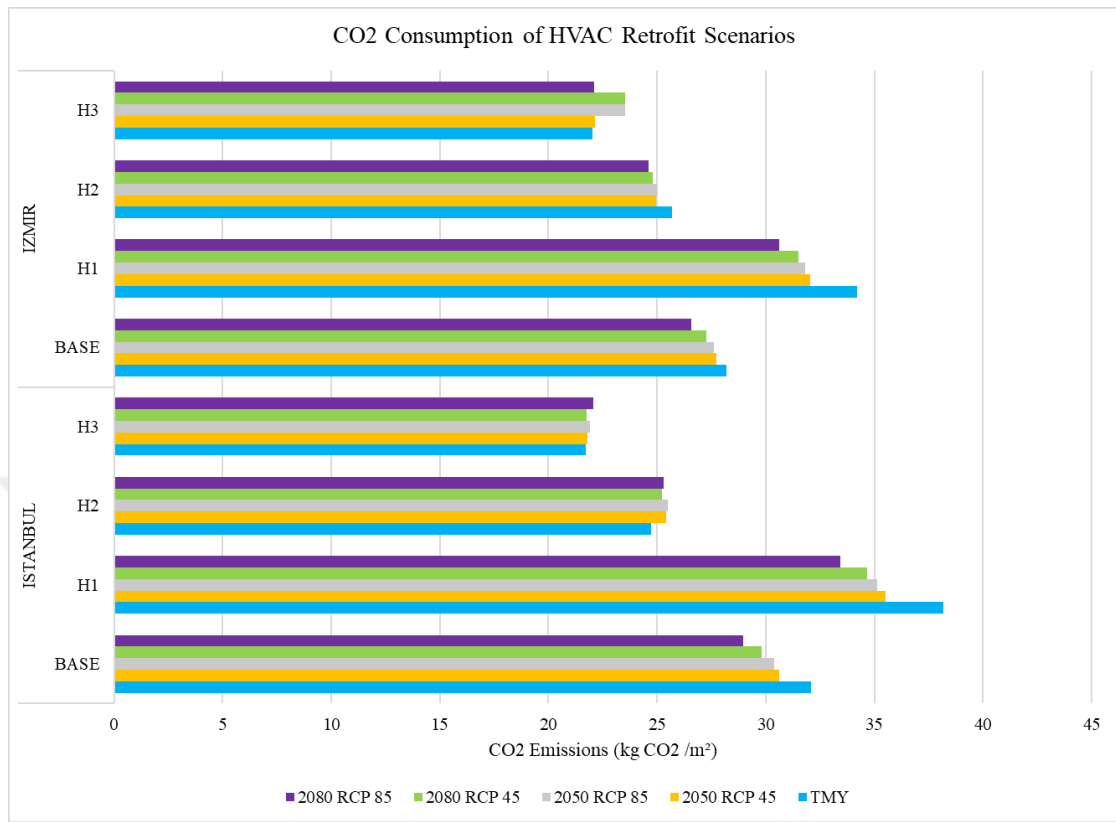


Figure 39 CO₂ Consumption Result of HVAC Retrofit Scenarios

The CO₂ consumption results of the HVAC scenarios for the provinces of Istanbul and Izmir are given in Figure 39. In both cities, the H1 scenario caused more consumption than Base. The most efficient scenarios are the scenarios integrated with renewable energy sources. All scenarios were H3 scenario, showing the least consumption in both cities evaluated.

4.3.4 Building Envelope Package Retrofit Strategies

After the analysis of the individual improvement scenarios, the combination of the retrofit strategies given under the title of "*Combination of Retrofit Scenarios*" and the retrofit packages within the scope of the building envelope were created and the simulation results were analyzed. Then the best-performing building envelope and the

best-performing HVAC scenarios will be integrated. In the last stage, thermal comfort analyzes of the best-performing scenarios will be performed.

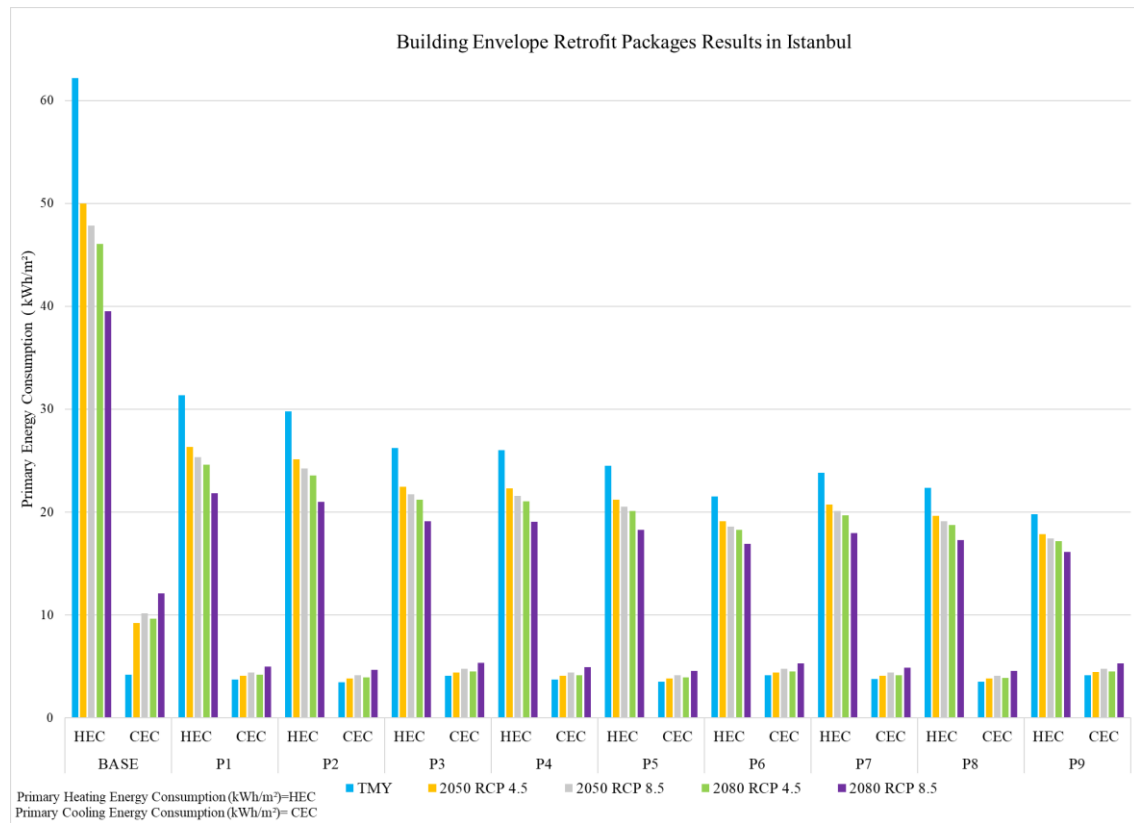


Figure 40 Building Envelope Retrofit Strategies Result for Istanbul

The best efficient performing scenarios for the province of Istanbul in the combination packages of retrofit measures were calculated as P6 and P9 (Figure 40). The glazing (G3) type is common in these two scenarios. Among these glass type scenarios, the U value is the lowest and the SHGC ratio is higher than G1 and G2. The low SHGC ratio created a disadvantage for Istanbul in winter and resulted in higher consumption as seen in HEC values P7 and P8. The difference between P6 and P9 is due to the opaque components. P9 has a lower U-value. Therefore, it performed better in winter, but the

thickness of the insulation in summer caused a slight increase in the CEC value by creating a disadvantage. However, it still has the lowest PEC value. Based on these evaluations in the province of Istanbul, P6 and P9 scenarios were selected as the most efficient scenarios in terms of PEC. In addition, in terms of CO₂ consumption, these P6 and P9 scenarios showed lower consumption than the other scenarios and stood out as the most efficient scenarios.

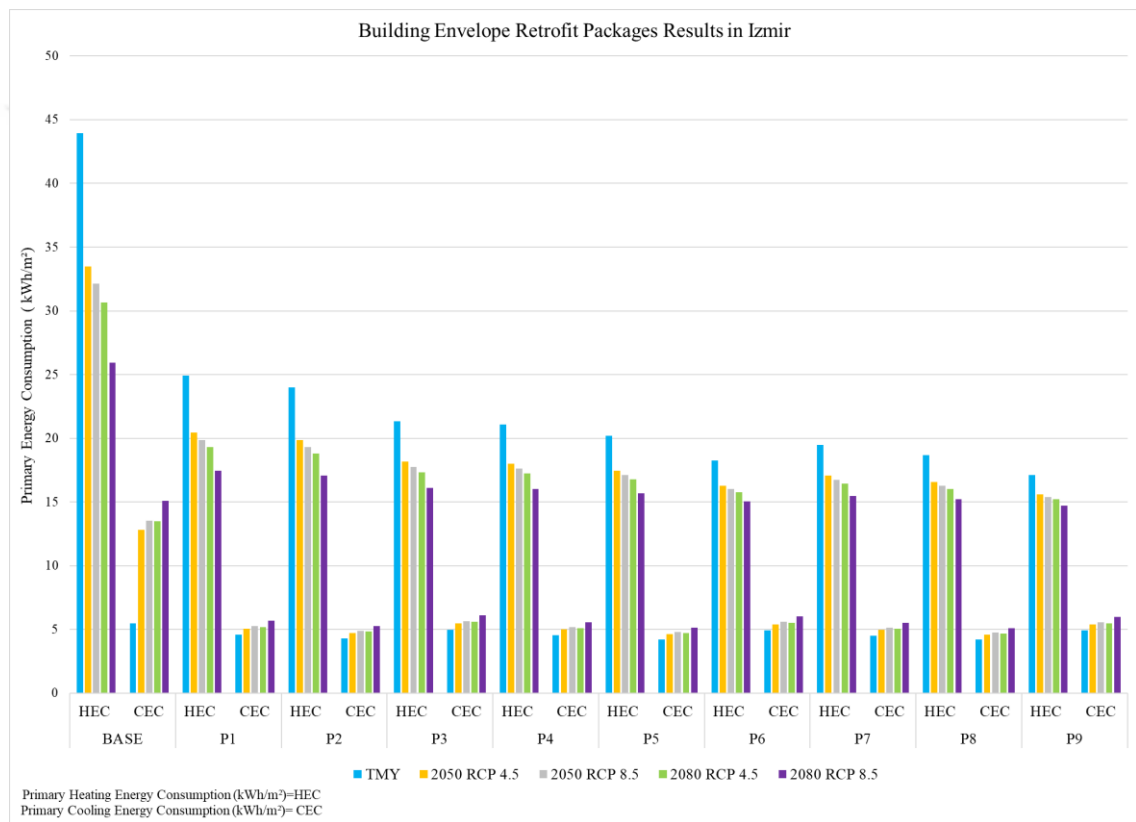


Figure 41 Building Envelope Retrofit Strategies Result for Izmir

After Istanbul, when Izmir province was evaluated, the most efficient scenarios were calculated as P8 and P9 (Figure 41). The opaque components of the building in the P8 and P9 scenarios are common and have the lowest U-value. The low U value provided an advantage for HEC. When the scenarios are examined, it is seen that the P6 scenario has low consumption values, but due to the P6 glass type, it resulted in a high CEC value.

Accordingly, the PEC value of P6 is also higher than that of P8 and P9. P8 has the lowest SHGC rate. Therefore, the CEC exhibited the lowest consumption among the scenarios. Unlike Istanbul, the low SHGC has given Izmir an advantage. This is because high SHGC resulted in a higher CEC rate in Izmir, especially in summer, as the heat gain from the sun increased. Considering these evaluations, the most efficient scenarios in terms of PEC and CO₂ consumption were determined as P8 and P9 in Izmir.

After these evaluations, the building envelope scenarios P6 and P9 scenarios which show the most efficient performance for the province of Istanbul will be combined with the HVAC scenarios. For the province of İzmir, the P8 and P9 scenarios, which show the most effective performance, will be combined with the HVAC scenarios. Thus, among the scenarios, the scenarios with the most efficient performance will be selected in both cities separately and thermal comfort analyzes will be carried out in the next stage.

4.3.5 Combined Efficient Building Retrofit Packages

The results of the combinations of the most efficient building envelopes with HVAC systems for the province of Istanbul are given in Figure 42. In the results obtained, high consumption in the current (Base) state drew attention. It is clearly at its most inefficient in all climate scenarios. On the other hand, the H1 system for P6 caused an increase in consumption compared to other systems. The scenarios that give the most efficient results are those that are integrated with the renewable system. For P6, the scenario with the lowest consumption stood out as H3. Especially when it is assumed that the cooling consumption will increase in 2080, the PV-integrated GSHP has caused this value to decrease significantly.

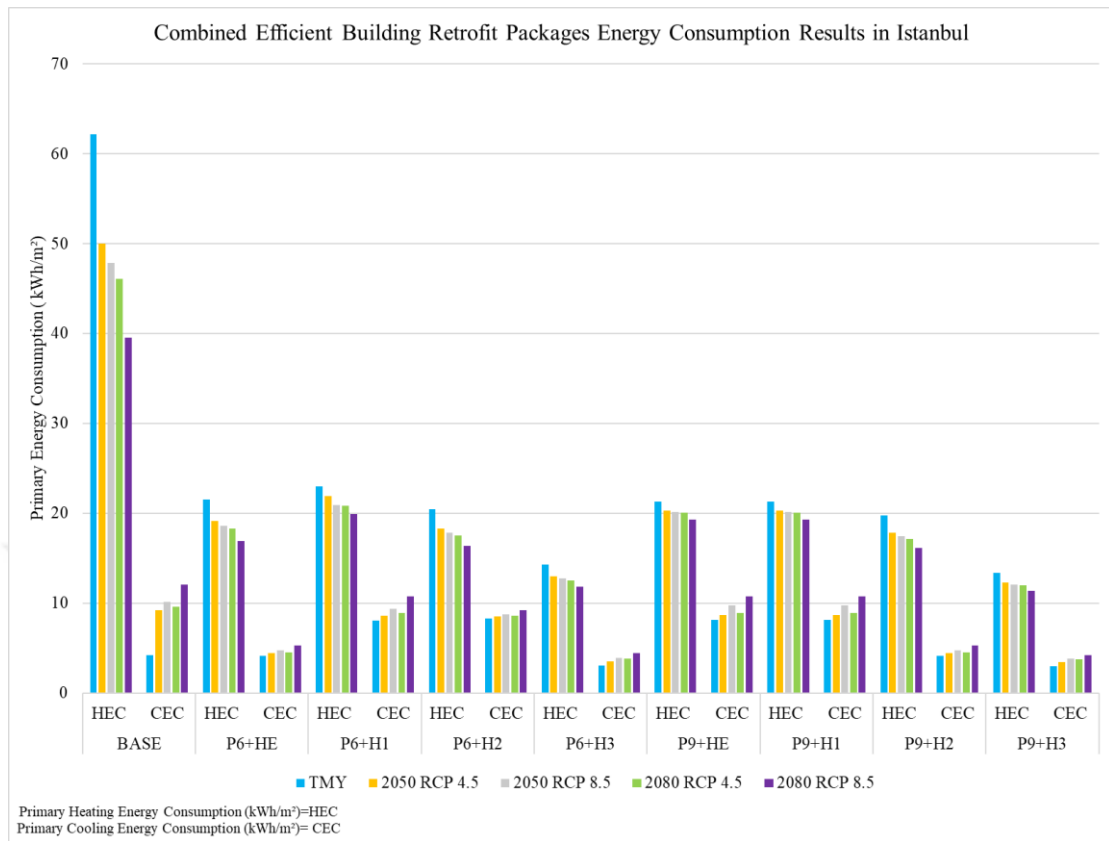


Figure 42 Combined Efficient Building Retrofit Strategies Result for Istanbul

On the other hand, it performed better than other systems by providing advantages in heating consumption. In the P9 scenario, the H1 system is not as inefficient as in P6. However, it still resulted in high consumption. Especially, the H2 system has a lower CEC value than the P9. However, the lowest consumption was observed in H3. When the P6+H3 and P9+H3 scenarios, which provide the most efficient consumption, are compared, P9+H3 has a slightly lower PEC value and therefore, stands out as the more efficient scenario. Similarly, it has the lowest consumption in terms of CO₂.

In brief in Istanbul, when Base and most efficient performed (P9+H3) scenarios are compared with TMY climate data, HEC is 77.7 %, and CEC is a 28.22% decrease significantly. Also, in the 2050 RCP 4.5 scenario showed HEC 75.24%, CEC 62.86%,

and 2080 RCP 4.5 climate data HEC 74.05% and CEC 61.37 % less consumption. In addition, it has been proven that in the 2050 RCP 8.5 climate scenario, HEC 74.73%, CEC 62.10%, in the 2080 RCP 8.5 scenario HEC 71.23%, CEC 64.87% energy saving.

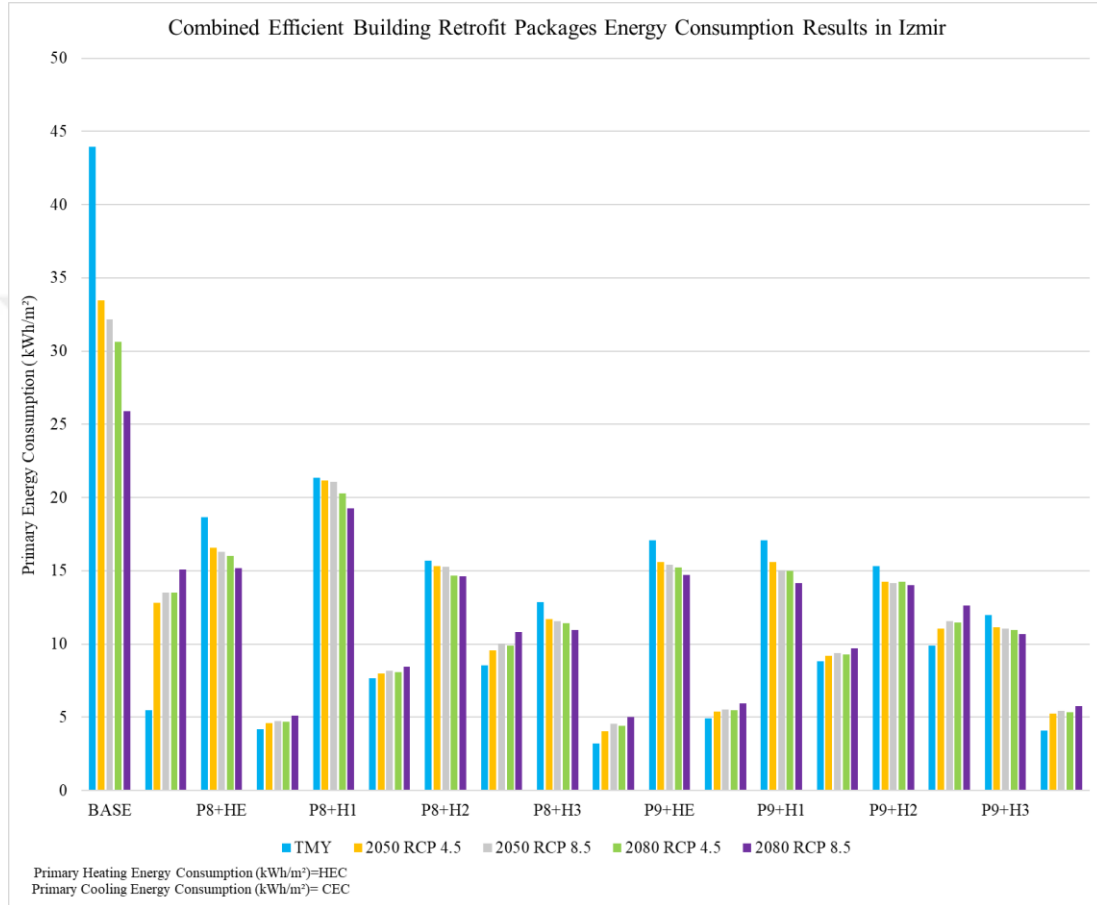


Figure 43 Combined Efficient Building Retrofit Strategies Result for Izmir

On the other hand, the results of the combination of the most efficient building envelope and HVAC systems for the province of Izmir are given in Figure 43. The current situation (Base) climate scenarios and high consumption are remarkable in this province. With the improvement of the building envelope, consumption has decreased significantly. However, unlike Istanbul, the efficiency of solar energy recovery systems is more obvious, the solar gain is higher in Izmir than in Istanbul. These scenarios performed

better. On the other hand, similar to Istanbul province, the P8+H1 (Fancoil) scenario resulted in higher consumption among the improvement strategies scenarios. Another remarkable situation in the results obtained is between P9+H3 and P8+H3. These two scenarios exhibited low consumption. However, considering the HEC values, P9 showed more efficient performance, and considering the CEC values, P8 showed more efficient performance. This difference is caused by the SHGC property of the glass. However, in terms of PEC values, P9+H3 emerged as the most efficient scenario with the lowest consumption. Similarly, CO₂ consumption has the lowest value.

Shortly in Izmir, when Base and most efficient performed (P9+H3) scenarios are compared with TMY climate data, HEC is 74.41 %, and CEC is a 18.31% decrease significantly. Also, in the 2050 RCP 4.5 scenario showed HEC 66.6%, CEC 58.3%, and 2080 RCP 4.5 climate data HEC 66.6 % and CEC 61.5 % less consumption. In addition, it has been proven that in the 2050 RCP 8.5 climate scenario, HEC 65.62%, CEC 61.53%, in the 2080 RCP 8.5 scenario HEC 60%, CEC 66.6% energy saving.

When the CO₂ consumption of the energy efficient combined scenarios is compared, the P6+H3 and P9+H3 scenarios for Istanbul showed lower CO₂ emissions than the base condition. However, the most efficient scenario stands out as P9+H3. Similarly, a decrease was observed in Izmir compared to the base situation. The lowest scenario was calculated as P8+H3 (Figure 44).

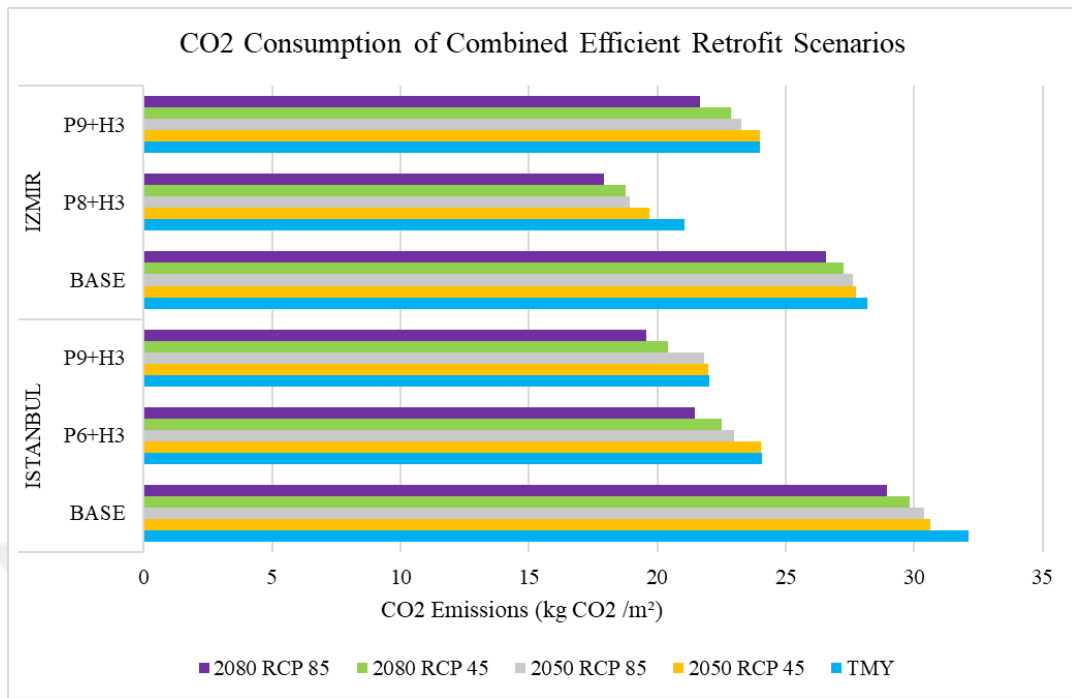


Figure 44 CO₂ Consumption Result of Combined Efficient Retrofit Scenarios

After this stage, thermal comfort analyzes of the best-performing scenarios in terms of energy consumption will be performed in both cities.

4.4 Most Efficient Retrofit Strategies Thermal Comfort Results

The thermal comfort analysis with Fanger method in the living room zone results of the scenarios with the most efficient energy performance in Istanbul are given in Figure 45. Considering the most critical 2050 and 2080 RCP 8.5 scenarios, the warm-hot range in the Base situation is quite high. However, in the P6+H3 scenario, a significant decrease was observed with the RCP 8.5 climate data. In P9+H3, this rate is at the lowest level compared to the other two scenarios. In other words, even in the most pessimistic scenario, the warm-hot period in the P9+H3 scenario is quite low. Building users feel most in the neutral-slightly-warm range in the RCP 8.5 scenario. When P6+H3 and

P9+H3 are evaluated, the most critical evaluation is that proper insulation thickness has a very significant part in thermal comfort in the climate adaptation process. As a result, the P9+H3 scenario is considered more advantageous in terms of thermal comfort between the two scenarios.

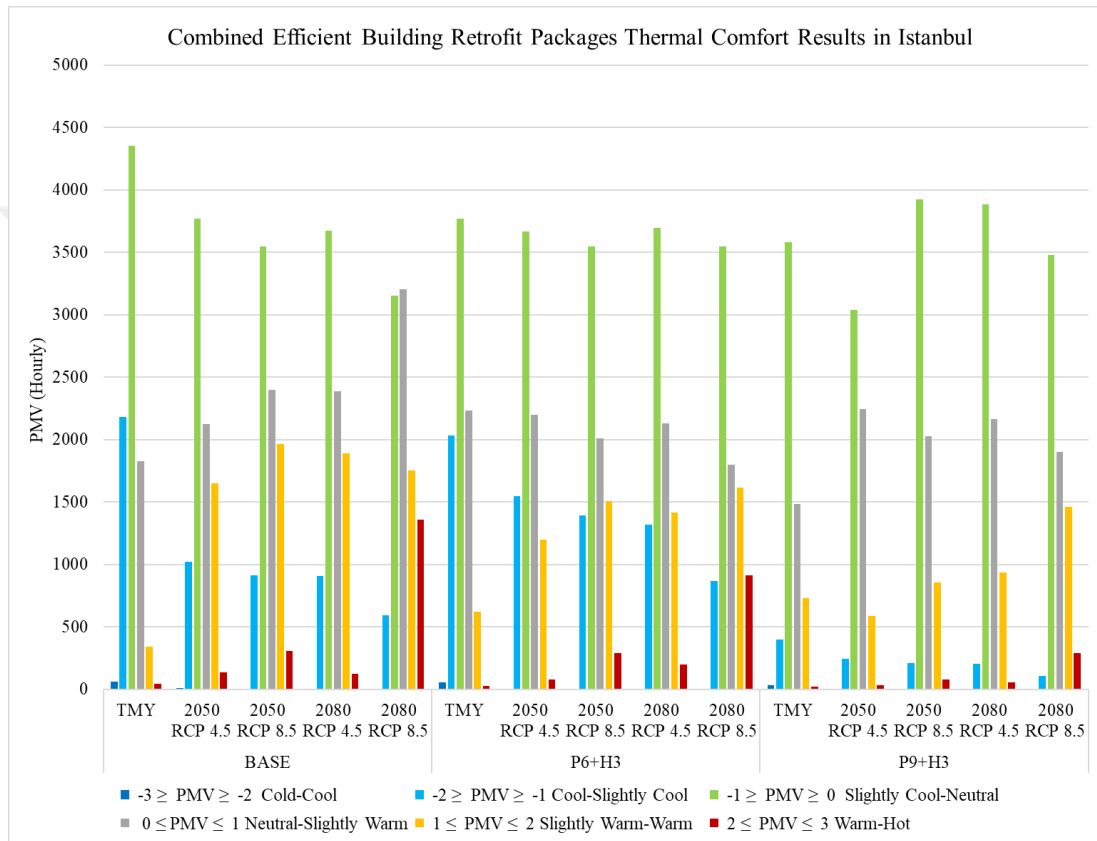


Figure 45 Combined Efficient Retrofit Strategies Thermal Comfort Result for Istanbul

The findings of the thermal comfort study using the Fanger method in the living room zone for the scenarios in Izmir with the best energy performance are shown in Figure 46. When Istanbul and Izmir are compared, the warm-hot range is higher in Izmir in all scenarios. Especially in the Base case, even with the TMY climate file, the value ratio in the warm-hot range is quite high, which has increased even more in 2050 and

2080. Namely, the Base in the uninsulated situation is vulnerable to temperature increase.

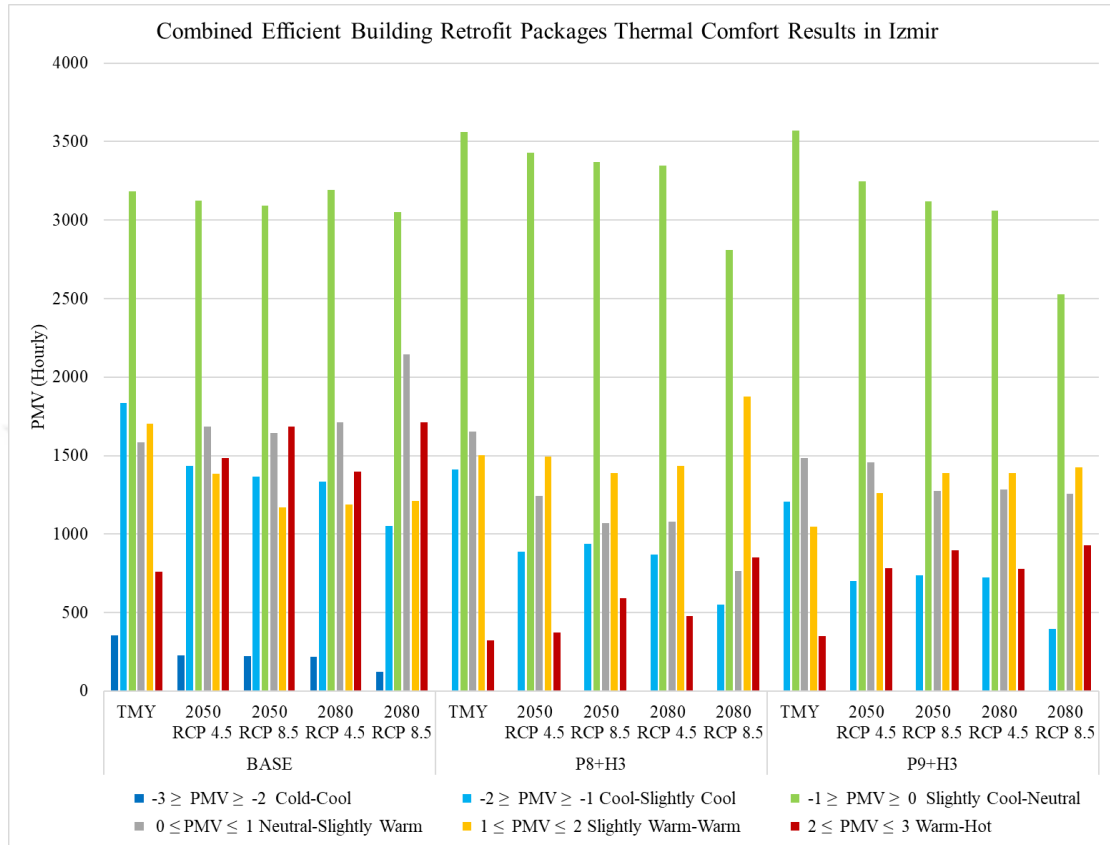


Figure 46 Combined Efficient Retrofit Strategies Thermal Comfort Result for Izmir

However, when the scenarios in which improvement strategies are applied are evaluated, the values in the warm-hot range have decreased. Especially in RCP 8.5 scenarios, P8+H3 performed better than P9+H3. However, according to Istanbul, the values in this range are still high. This situation proves that more interventions strategies can be needed in Izmir province. On the one hand, it is clearly seen that glass systems are an important part of the climate adaptation process in scenarios P9 and P8. The rate of SHGC in P8 is lower than in P9. For this reason, the low SHGC in the climate adaptation process provided an advantage in Izmir as it reduced the heat gained from the Sun.

After evaluating the situation in the conditioned living rooms with the Fanger method, only natural ventilation was provided in the bedroom so that the bedrooms could be compared with the initial Base situation. In this direction, the adaptive thermal comfort method was applied.

The analysis results in the base condition in Istanbul are presented under the heading *4.2 Existing Thermal Comfort of Building*. The most obvious result is observed in the RCP 8.5 scenario when compared with the base case of energy-efficient combination packages. It has been analyzed that the operative temperature values in the base case are as high as 34-35 °C. However, in the analysis of the P6+H3 scenario, it is observed that this value has partially decreased and observed by 31-32 °C (Figure 47). Compared to the base case, it is analyzed that most of the hours that meet the ASHRAE 80% limit belong to the TMY and 2050 RCP 4.5 scenarios.

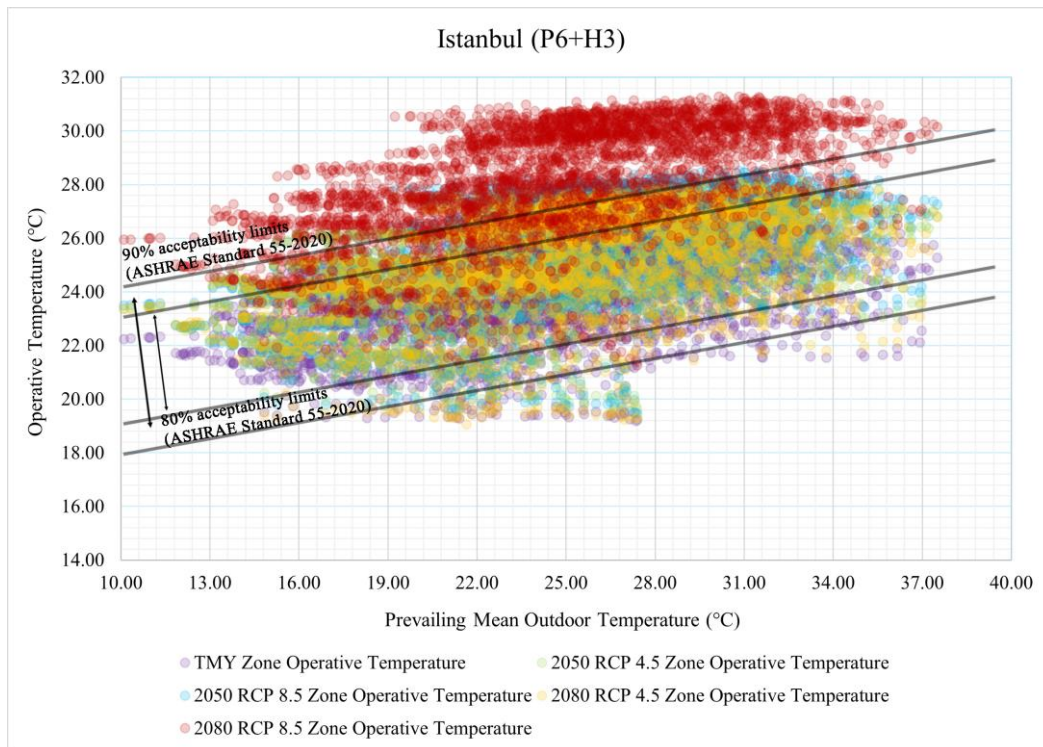


Figure 47 In Istanbul Retrofit Strategies Thermal Comfort Result for P6+H3

However, it is observed that some of the hours in the 2050 RCP 8.5 and 2080 RCP 4.5 scenarios are included in this range in the P6+H3 scenario.

In the P9+H3 scenario, the operative temperature value is seen as 30-31 °C in the 2080 RCP 8.5 scenario. It is seen that this scenario is closer to the comfort range in 2080 and provides more advantages compared to the base and P6+H3 scenarios (Figure 48).

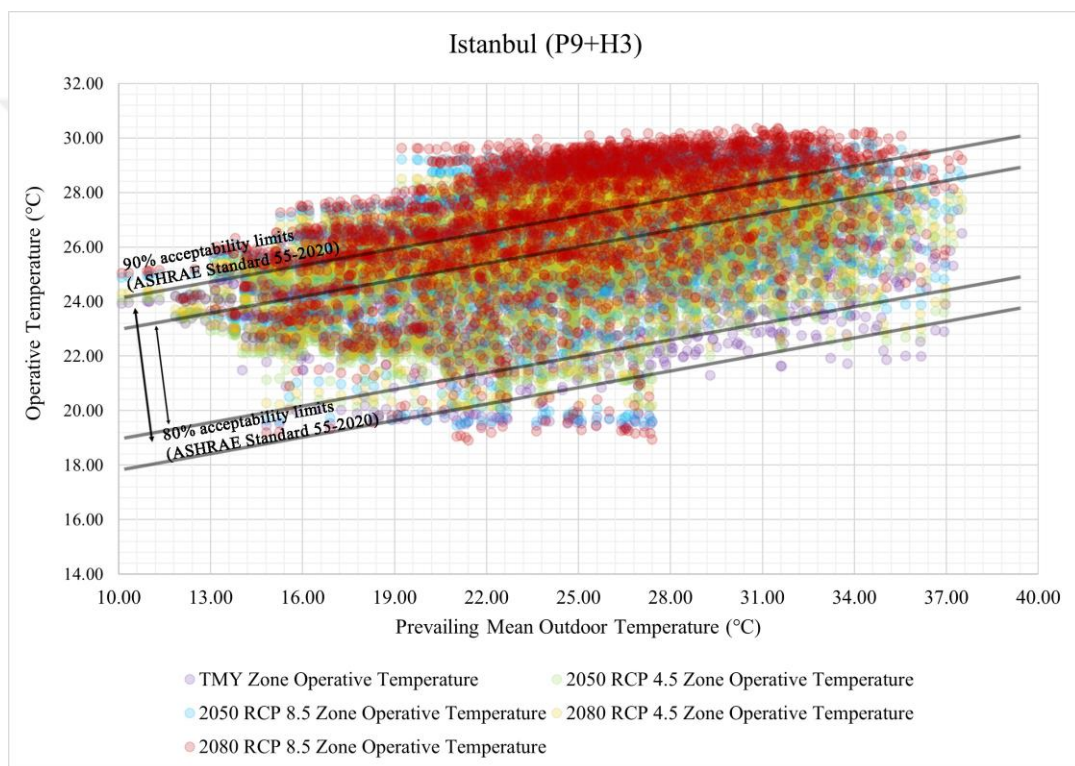


Figure 48 In Istanbul Retrofit Strategies Thermal Comfort Result for P9+H3

The analysis results in the base situation in Izmir are presented under the heading *4.2 Existing Thermal Comfort of Building*. Compared to the province of Istanbul, it has been analyzed that there are fewer hours in the ASHRAE acceptable limit range. However, it is the base case TMY that contains the most hours in an acceptable limit. When the Izmir scenarios are analyzed, it is noteworthy that there are more hours between the TMY climate data and the ASHRAE acceptable limit range in P8+H3. On the other

hand, the operative temperature values, which increased up to 36°C-37 °C in the base case in 2080, were analyzed as 34°C-35 °C in the P8+H3 scenario (Figure 49).

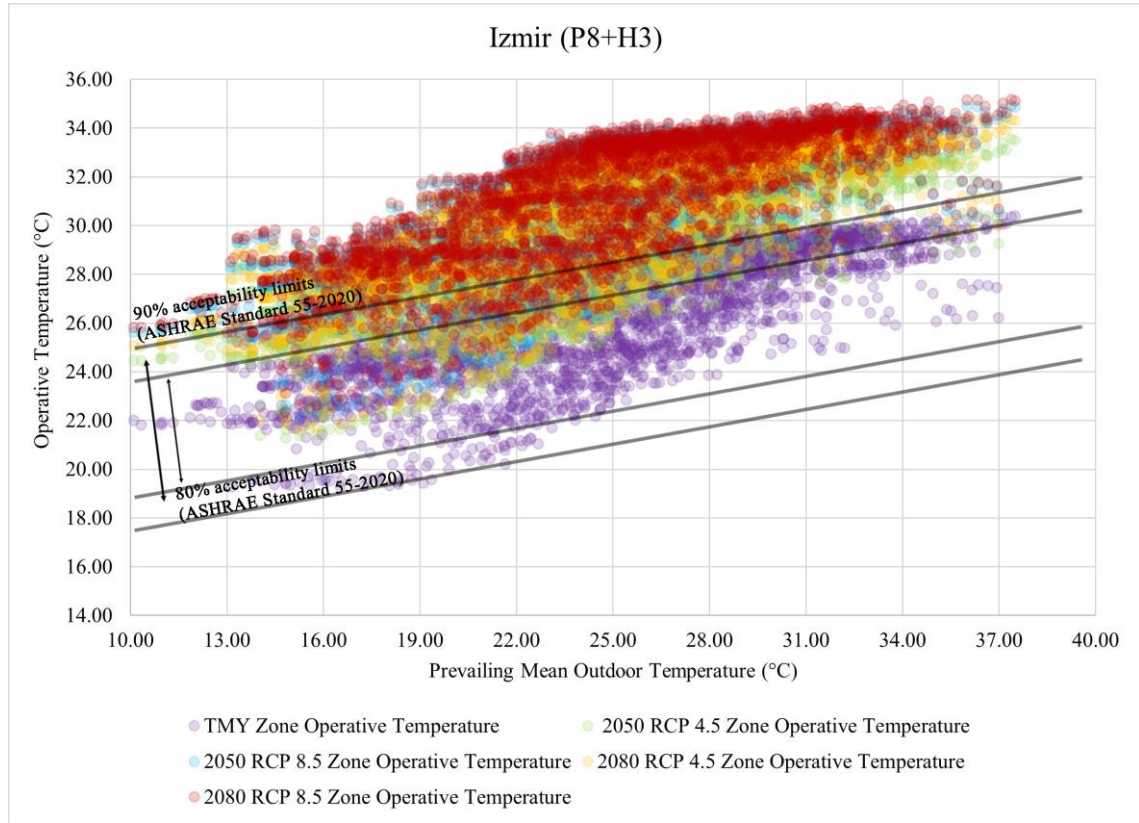


Figure 49 In Izmir Retrofit Strategies Thermal Comfort Result for (P8+H3)

Comparing the Base–P9+H3 scenarios, there are more hours in the ASHRAE acceptable limit range than in the base case, similar to the P8+H3 scenario. However, the P9+H3 scenario was analyzed as 35°C-36 °C with 2080 RCP 8.5 climate data. Therefore, the P8+H3 scenario provides more advantages than the P9+H3 scenario (Figure 50).

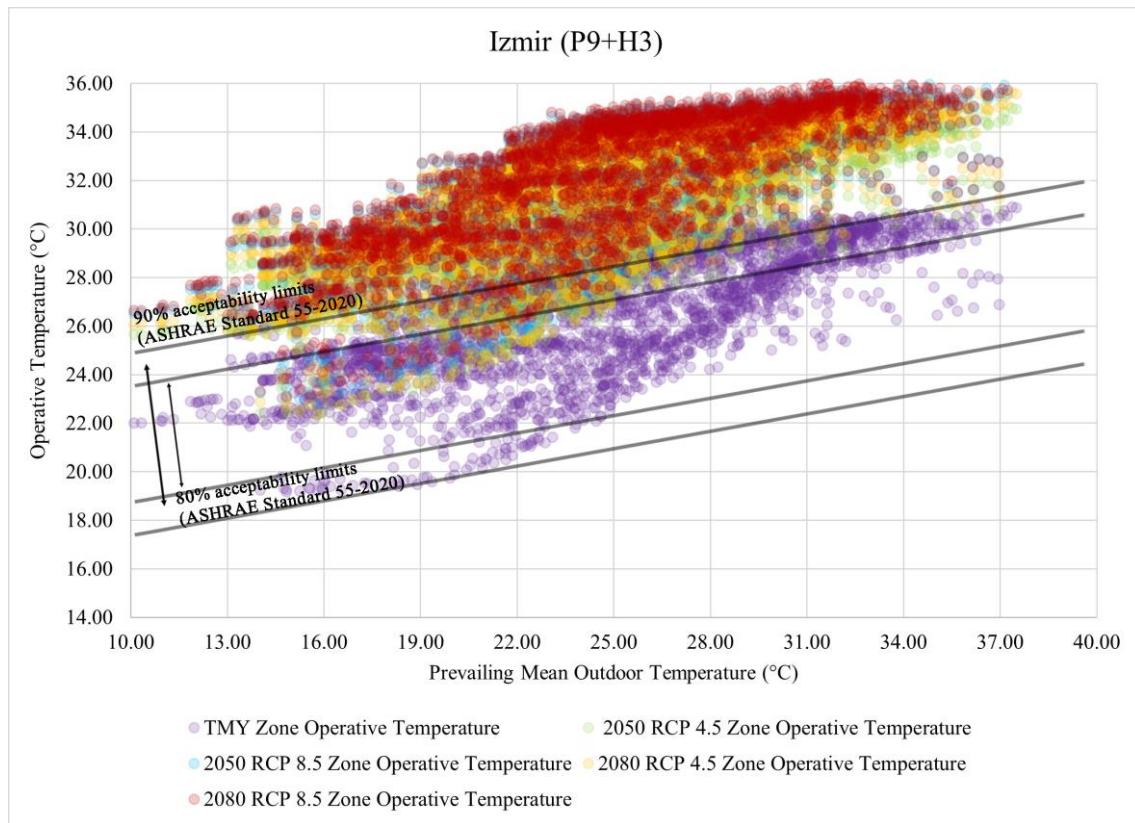


Figure 50 In Izmir Retrofit Strategies Thermal Comfort Result for P9+H3

Climate change is one of the most critical global problems that puts human life at risk in terms of its dimensions and long-term consequences. Since climate change is not experienced at the same rate in every region, it has different effects in different climate types and regions. The results obtained within the scope of improvement strategies provided quite an advantage compared to the current situation in both provinces. However, due to the different climate types that both cities have, the results have been affected in different ways and degrees. Based on this, shortened comparisons of the results obtained from the study are presented in Table 12.

Table 12 Result Comparison in Two Cities

		Istanbul	Izmir
Temperature Rise (°C)	2050 RCP 4.5	2	2,1
	2050 RCP 8.5	2,6	2,8
	2080 RCP 4.5	2,4	2,5
	2080 RCP 8.5	4,3	5
		2080 RCP 8.5 no needs for heating in September	2080 RCP 8.5 no heating needed from April to November
		2080 RCP 8.5 needs cooling in October	2080 RCP 8.5 even in April need cooling
HDD and CDD		The TMY and RCP 8.5 scenarios increase of 78% in Jun-Aug	The TMY and RCP 8.5 scenarios increase of 112% in Jun-Aug
		When the TMY situation compared, HDD are calculated as 19% higher in Istanbul.	When the TMY situation compared, the CDD are 294% higher in Izmir.
Opaque Component		As the insulation thickness increases, energy consumption savings achieved, but the obtained values are not as clear as the difference between the non-insulated current and insulated scenarios according to TS 825 standards.	As the insulation thickness increases, energy consumption savings achieved, but the obtained values are not as clear as the difference between the non-insulated current and insulated scenarios according to TS 825 standards. But after a certain point it increases the cooling load, which is critical in this climate.
Glazing Component		SHGC and U value played an important role in reducing energy consumption.	SHGC and U value played an important role in reducing energy consumption. But SHGC played as critical a role.
HVAC		Ground-source systems provide an more advantage, but solar-assisted systems are not as much as Izmir.	Solar powered systems provided more advantages
Energy Consumption		% 65-70 energy saving compared the current situation	% 60-65 energy saving compared the current situation
Thermal Comfort		Warm-hot interval decreased by nearly 60% with PMV in living room in current situation. Naturally ventilated bedroom, the highest temperature felt dropped by 3-4°C.	Warm-hot interval decreased by nearly 40% with PMV in living room in current situation. Naturally ventilated bedroom, the highest temperature felt dropped by 2-3°C.

CHAPTER V

CONCLUSION

"To the days when we realize that we cannot fight against nature..."

Climate change, together with human impact, is a fact that can no longer be denied. Therefore, it is necessary to accept this reality and take action to reduce its effects. This thesis research aims to investigate the effects of climate change on the energy and thermal comfort of buildings and to minimize these negative effects. According to the results obtained from future climate data, climate change will undoubtedly cause an increase in temperatures, but this increase will be different in each region. According to the results obtained from HDD and CDD calculations in Izmir, cooling will be needed in Izmir and Istanbul even in April in 2080. On the contrary, in 2050 in Izmir and 2080 in Istanbul, the need for heating will disappear in October and November.

According to the results obtained from the simulation results, uninsulated building envelopes are the most vulnerable to climate change. While it causes high energy consumption, it has a high thermal comfort discomfort rate. In addition, buildings without proper insulation need more heating in the winter and more cooling in the summer due to permeability. Therefore, optimum insulation thickness is critical in terms of energy saving and thermal comfort.

Moreover, glazing systems have a significant role in the climate adaptation process. Especially according to the TS 825 standard, the glass U value recommended for Istanbul and Izmir is the same. However, the remarkable point is that in addition to the U value, the SHGC ratio is another critical point to be considered in climate change. Contrary to Istanbul, in Izmir, which has a warm Mediterranean climate, the same U value and high SHGC ratio have resulted in high cooling needs as it increases heat gain from the sun in summer months. Considering that temperatures will increase due to climate change, SHGC will be even more critical. The thesis research has revealed that even glazing systems and building envelope improvements provide significant advantages in climate change.

Furthermore, changes in heating and cooling loads as temperatures rise will affect buildings' HVAC systems. Unless fossil-based systems are supported by renewable energy sources, they are disadvantageous in climate change due to high CO₂ emissions. Particularly in HVAC types where renewable systems are integrated, remarkable energy and emission savings have been achieved with the increase in solar gain. Although it changes according to emission scenarios compared to the current situation, approximately 65-70% energy improvement was achieved in Istanbul, while 60-65% energy savings were achieved in Izmir. On the other hand, in terms of thermal comfort values, significant decreases were calculated in both provinces in the suggested most efficient scenarios. Also, since the need for cooling will increase remarkably in regions with warm Mediterranean climate, HVAC systems must be selected by taking these increases into account.

Different building envelope and HVAC scenarios were evaluated with different climate types and different future emission scenarios, supporting that climate change has a profound impact on energy consumption and comfort levels. Appropriate examination of both energy consumption and comfort parameters is necessary when deciding on the best possible combination to achieve higher energy efficiency.

As a result of the study, it is seen that the CO₂ results decrease year by year, which is related to the decrease in the need for heating energy. However, the evaluation is only within the scope of the building, so it cannot be said that CO₂ consumption will decrease over the years on average. In addition, this situation is closely related to the function of the building. The research covers the residential building and both climates are not cooling-dominated climates. However, when the base situation is compared with the most efficient scenario, it is observed that CO₂ consumption drops significantly. Therefore, buildings are in a remarkable position to keep emissions at a certain level.

There are some limitations to this thesis. Basically, this thesis focused on building scale and developed strategies to improve building scale performance. However, regional measures that can be taken in climate change are also important in the process of adaptation to the climate. Accordingly, urban design strategies and their effects on the performance of buildings can be explored in future studies.

Also, in this research, the proposed framework focuses on building energy consumption and thermal comfort. In future studies, in addition to these, multiple optimization methods such as cost, and life cycle analysis can be used. Thus, more effective, and economical strategies can be created.

One of the challenges is the transfer of future weather data to building energy simulations. There are very few free tools that directly provide the appropriate plug-in for

the simulation program. Therefore, different tools could not be tried to obtain future weather data. In future studies, different scenarios can be determined by comparing future weather data obtained from different tools.

In this study, it is discussed how climate change will affect the energy and thermal comfort of buildings. Adaptation and mitigation studies are required in order to feel the effects of this change less and to limit its negative effects. The study emphasizes that the negative effects of climate change can be reduced by evaluating different climate and emission scenarios with different building design scenarios. It aims to draw attention to adaptation mitigation studies for climate change.

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VITA

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