



Investigation of the Relationship Between Building Functions and Energy Performance Using BIM/BES Methods Across Different Climate Types

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ABSTRACT

Many design parameters influence the energy demand of buildings. While research on building energy performance typically emphasizes physical design parameters and the technical characteristics of buildings, the behavior, actions, duration, and intensity of use by occupants are also critical factors impacting energy performance. Buildings should be constructed with functions aligned to the intended actions within spaces, ensuring user needs are considered during the design process. In this study, the variation in building energy performance was analyzed based on 9 different building functions and 3 climate types. Building energy models were developed using the BIM-BES methodology, and energy simulations were conducted using DesignBuilder software. The simulation results were analyzed through graphs, and energy performance characteristics were compared. Regression analyses were performed in Excel to explore the linear relationship between energy performance and occupant-related parameters, while correlation matrices were prepared and analyzed in Python. The findings revealed energy differences exceeding 80% due to variations in climate parameters and building functions. These results highlight the importance of context-specific design and demonstrate, through numerical data, the necessity of user-centered approaches to improve building energy performance.

Farklı İklim Tiplerinde BIM/BES Yöntemleri Kullanılarak Bina İşlevleri ve Enerji Performansı Arasındaki İlişkinin İncelenmesi

MAKALE BİLGİSİ

Anahtar Kelimeler:

Bina Bilgi Modellemesi (BIM), Bina Enerji Modellemesi (BEM), Bina Enerji Simülasyonu (BES), Bina İşlevleri, Kullanıcı Davranışı, Bina Enerji Performansı

ÖZET

Binaların enerji talebi üzerinde birçok tasarım parametresi etkili olmaktadır. Bina enerji performansı üzerine yapılan araştırmalar genellikle binaların fiziksel tasarım parametreleri ve teknik özelliklerine odaklanırken, kullanıcıların davranışları, faaliyetleri, kullanım süreleri ve yoğunlukları da enerji performansını etkileyen kritik faktörlerdir ve genellikle arka planda kalmaktadır. Binalar, mekan içinde gerçekleştirilecek faaliyetlere uygun işlevlerle tasarlanmalı ve kullanıcı ihtiyaçları tasarım sürecinde göz önünde bulundurulmalıdır. Bu çalışmada, bina enerji performansındaki değişimler, 9 farklı bina işlevi ve 3 farklı iklim türüne göre analiz edilmiştir. BIM-BES yöntemi kullanılarak bina enerji modelleri oluşturulmuş ve DesignBuilder yazılımı ile enerji simülasyonları gerçekleştirilmiştir. Simülasyon sonuçları grafikler aracılığıyla analiz edilmiş ve enerji performansı özellikleri karşılaştırılmıştır. Enerji performansı ile kullanıcıya bağlı parametreler arasındaki doğrusal ilişkiyi incelemek için Excel'de regresyon analizleri yapılmış, ardından Python'da hazırlanan korelasyon matrisleri ile sonuçlar değerlendirilmiştir. Bulgular, iklim parametreleri ve bina işlevlerindeki farklılıklardan kaynaklanan enerji farklılıklarının %80'i aşabileceğini göstermiştir. Bu sonuçlar, yerel bağlama uygun tasarımın önemini vurgulamakta ve bina enerji performansını iyileştirmek için kullanıcı odaklı yaklaşımların gerekliliğini sayısal verilerle ortaya koymaktadır.

INTRODUCTION

Energy consumption in buildings has become a crucial issue in recent years. According to the International Energy Agency (IEA), the building sector accounts for one-third of global energy consumption (IEA, 2021). Similarly, the World Green Building Council reports that buildings contribute to 39% of global energy-related carbon emissions, with 28% resulting from heating, cooling, and power usage (W.G.B.C., 2022). As part of the global climate agenda, researchers are increasingly focusing on strategies to reduce building energy consumption (Guizar Dena et al., 2024). While studies on building energy performance typically assess physical design parameters, aspects such as functional characteristics, user density, and occupant needs remain underexplored. Given the significant energy demand of the building sector, improving energy efficiency is essential for reducing greenhouse gas emissions and mitigating climate change. The IEA further underscores that leveraging real building energy data provides the most accurate means of assessing and minimizing carbon emissions (IEA, 2021; Wang et al., 2023). Energy studies are also a significant part of architectural science, which focuses on space design and production. Spaces are shaped according to the activities they accommodate, and their design approach is influenced by multiple factors, including the building's function in relation to space production, user types and needs, and aesthetic considerations (Özgen, 2020). Hasol (2008) defines space as an environment that separates individuals from their surroundings to a certain extent while allowing them to carry out their intended activities. At this stage, designers must ensure that the proposed functions align with user needs, offer tangible solutions to design challenges, and breathe life into both design and materials without disregarding usability. In this context, an essential aspect of the design process is understanding how users interact with and benefit from the built environment (Özgen, 2020; Yoshino et al., 2017). Beyond spatial and functional aspects, ensuring a building's energy efficiency and sustainability is crucial. Research identifies six primary factors influencing energy consumption in buildings: climate, building services and energy systems, building envelope, occupant activities and behaviour, building operation and maintenance, and indoor environmental quality (IEA EBC Annex, 2017). Among these, user-related factors can be as influential, if not more so, than a building's physical characteristics (Hong et al., 2017; Hong et al., 2016; Yan et al., 2015). The impact of occupant behaviour is evident in the significant variations in energy consumption among similar buildings. However, distinguishing between building-related and user-related energy use remains a challenge. A comprehensive comparative analysis of energy consumption across these six factors can provide valuable insights into energy-saving opportunities (Yoshino et al., 2017). Occupants play a critical role in energy consumption (IEA EBC Annex, 2017). Their presence contributes to internal heat gains, while their interactions with HVAC systems, lighting, and equipment significantly influence overall energy use (Webber, 2001; Yan et al., 2015; Heyderian et al., 2020; Chong et al., 2021). Due to the unpredictable nature of user behaviour, assumptions about occupant interactions with building systems often lead to significant uncertainty in energy forecasting (Brom et al., 2018). This unpredictability complicates energy consumption forecasting in buildings, potentially leading to over- or underconsumption scenarios (Wang et al., 2023). Several studies highlight the extent of user behaviour's impact on actual energy consumption. Loga et al. (2015)

observed that measured energy consumption was consistently lower than calculated performance values. Similarly, Majcen (2016) found that user behaviour accounted for 9.1% of variations in energy use, while Cozza et al. (2020) and Guerra-Santin & Itard (2010) emphasized that occupant behaviour is one of the most significant determinants of residential energy demand.

Energy demand plays a crucial role in the design of buildings with various functional spaces tailored to user requirements. Ensuring high energy performance during the design phase is essential, particularly in relation to building functions. This study aims to examine how energy requirements vary in buildings with identical design parameters but different functional characteristics across diverse climate zones. A key aspect of this analysis is the integration of BIM-BEM-BES, which facilitates energy expenditure simulations to support energy efficiency improvements in the design process. Building Information Modeling (BIM) represents all aspects of traditional 2D drawings (plans, sections, and elevations) in a 3D environment, enabling advanced data modeling, visualization, virtual construction environments, construction management, and project coordination (Hijazi et al., 2015). Additionally, BIM fosters interdisciplinary collaboration among various stakeholders, including architects, interior designers, engineers, construction service providers, planners, investors, government agencies, and consultants (Khodeir, 2017; Al Sehrawy, 2021; Alsharif, 2019). Its extensive application in enhancing energy efficiency has been widely recognized (Liu et al., 2023). Recent advancements in building energy efficiency have introduced new opportunities for integrating BIM with Building Energy Modeling (BEM) to optimize energy consumption. BEM/BES methods function as computational analysis tools that operate synergistically with BIM systems. In this context, BEM/BES input-output processes involve datasets and parameters essential for conducting energy simulations and analyses. Key input parameters include building geometry, HVAC systems, materials, weather data, and occupancy schedules, all of which play a critical role in ensuring accurate energy assessments and predictions (Alhammad et al., 2024). These elements are fundamental to generating precise energy simulations in BEM/BES systems, which subsequently translate into BEM formats for further analysis in BES tools. BES tools assess building performance based on various metrics, such as daylight utilization, natural ventilation, and annual energy consumption. Output parameters encompass energy usage, carbon emissions, resource management, thermal performance, solar performance, heating and cooling loads, daylighting evaluations, life cycle cost analysis, lighting design, water use, ventilation, airflow analysis, and alternative design scenario comparisons (Reeves, 2015; Alhammad et al., 2024). The BES process primarily evaluates the baseline energy performance through data visualized in graphs or spreadsheets. Furthermore, it facilitates the exploration of environmentally sustainable improvements aimed at reducing CO₂ emissions and energy consumption (Alaa et al., 2024; Gigliarelli, 2021; Ulu, 2017). Additionally, BES supports the development and evaluation of retrofit strategies, integrating them into simulation scenarios to identify the most suitable design alternatives. This approach enables accurate energy estimations for both the base case model and alternative design cases, contributing to the selection of energy-efficient solutions (Tomrukcu and Ashrafian, 2022; Şahin et al., 2016).

In this study, a square-shaped building prototype was used as a reference model to systematically analyse the impact of different indoor functions and climate zones on energy consumption. The building was modelled using Building Information Modelling (BIM), and Building Energy Models (BEMs) were created to facilitate Building Energy Simulations (BES). The simulations were conducted by altering the functional use of the space and testing it across three different climate zones in Türkiye. The selected cities represent distinct climate types, allowing for a comprehensive analysis of energy performance variations. Nine different building functions were considered in this study: residential buildings, educational buildings, hospitals, offices, industrial buildings, terminals, hotels, museums, and restaurants. The DesignBuilder software was used to simulate the energy performance of these buildings, incorporating climate-specific characteristics and functional differences. The data derived from these simulations were systematically analysed using tables and graphs to compare energy consumption patterns. The results revealed significant variations in the energy demands of buildings with different functions, highlighting the strong influence of building use on energy performance. To examine the relationship between building function and energy demand in greater detail, regression analysis was conducted using Excel, while correlation analysis was performed in Python. Linear regression analysis was used to develop predictive models by estimating the dependent variable based on independent variables that can be more easily or previously measured (Alper, 2010). Simple regression analysis was applied to evaluate the linear relationship between a single response variable and a single explanatory variable (Arı and Önder, 2021; Okur, 2009; Weisberg, 2005). Therefore, this method was employed in the study to identify linear relationships. Additionally, correlation analysis was conducted to detect nonlinear and complex relationships that could not be captured through linear regression. These findings align with previous studies emphasizing the impact of functional use on energy performance. However, unlike previous studies, this research uniquely examines nine different building functions in relation to both climate conditions and energy performance within a comprehensive framework. This integrated approach provides a broader perspective on how functional and climatic variations influence energy consumption, offering new insights into sustainable building design and energy efficiency strategies. By incorporating both climate-based and function-based analyses, this study provides a comprehensive framework for optimizing energy efficiency in building design. The insights gained from this research offer valuable contributions for architects, engineers, and policymakers, fostering the development of sustainable building practices.

In the following sections of this study, a literature review is presented to highlight how this research differs from previous studies. A flowchart illustrating the study methodology is also included. Subsequently, the characteristics of climate zones and reference buildings are explained, followed by the presentation of research results. Finally, the study concludes with a discussion on the findings, their implications, and potential directions for future research. This structured approach ensures a clear understanding of the study's contributions and its broader significance.

METHODOLOGY

Importance and General Structure of the Study

The need for shelter is one of the most fundamental human requirements, leading to the emergence of various spatial forms over time. As human needs have evolved, the demand for spaces beyond mere shelter has increased, making it essential for architectural design to address functionality as a key factor. The design of a space is not only about its physical form but also about creating an environment that enables dynamic experiences shaped by user interaction. This perspective introduces a new dimension to architecture, where spatial functionality plays a crucial role in defining the nature of built environments (Sözen & Tanyeli, 2018). Özkan (2017) defines space as an environment arranged for human movement and behaviour. Similarly, Lefebvre (1995) emphasizes that space is not merely a scientific object detached from ideology and politics, nor is it a passive setting for social relations and actions. Instead, space is a socially produced phenomenon, shaped by interactions and environmental conditions. This perspective highlights the importance of evaluating architectural design through both functional and contextual factors. However, in Türkiye, building design processes often disregard these contextual and functional variations and rely heavily on standardized prototype designs.

Many buildings in Türkiye are constructed based on standardized prototype designs, commonly referred to as "type projects." Despite the fact that building functions determine spatial requirements, these projects are implemented in different cities without considering regional variations. For instance, the Public Housing Administration applies standardized residential projects, while the Ministry of National Education uses uniform designs for educational buildings across different locations (Figure 1a, b, c, d, e, f). This widespread use of type projects contradicts the principle of site-specific architecture, which argues that buildings should be designed according to the climatic characteristics and environmental conditions of their location.

The figures above show examples of public housing and educational buildings constructed in different cities. Although the climate type is completely different, similar building typologies have been applied. Similar applications are also seen in building types with other functions. Each climate type has different environmental data and buildings specific to that climate type should be built. Likewise, each function has different user needs. Buildings with identical forms and material properties are often assigned different functions, even though each function has its own unique spatial requirements. The specific spatial and environmental needs dictated by building functions should not be overlooked. Lefebvre (1995) and Özkan (2017) stress that space is shaped by user interactions and must be adapted to contextual needs. Therefore, disregarding functional and contextual factors in building design leads to a typified approach that fails to address both user needs and local environmental conditions. A design approach that considers both function and contextual awareness is essential to ensuring that buildings align with their intended purpose and their environmental setting. Rather than relying on a uniform type-project system, it is necessary to adopt a more adaptable and functionally responsive architectural strategy.



Figure 1. Example of (a) public housing in the city of Van, which has a cold climate type, (b) public housing in Mersin, a city with a hot humid climate type, (c) public housing in Rize, a city with a four-season rainy climate type, (d) educational building in the city of Adana, where the hot humid climate type is observed, (e) educational building in Sivas, a city with a cold continental climate type, (f) educational building in the city of Istanbul ([Url-1,2,3,4,5,6](#)).

This shows the importance of functional features in building design. Due to environmental and economic concerns, energy performance of buildings is among the priority areas all over the world. In Türkiye, the TSE 825 Regulation on Thermal Insulation Rules in Buildings, which requires energy efficient designs to reduce energy consumption and carbon emissions of buildings, came into force in 2008 and was revised and finalized in 2013 (TSE 825 2013). In addition, the Energy Performance of Buildings Directive and the Energy Efficiency Law were taken into consideration and the Building Energy Performance Regulation (BEP) was prepared and entered into force on 5 December 2009. In the "Architectural Project Design and Architectural Practices in terms of Building Energy Performance" section of the Energy Performance Regulation in Buildings, it is stated that the heating / cooling / ventilation / lighting requirements should be kept at the lowest possible level by considering the zoning, island and parcel information

during the design process of the buildings (Uşma 2021). Therefore, it is an important requirement to design buildings in accordance with the climatic characteristics of each city. While designing buildings, analyzing and evaluating user needs well and making designs accordingly are important factors affecting the energy performance of buildings. While evaluating building energy performances, single building function is generally taken into consideration and there are few studies on how different functions affect energy performance. Within the scope of the study, it is aimed to make analyses by considering 9 different functions. These are residences, educational buildings, hospitals, offices, industrial buildings, passenger terminals, hotels, cultural buildings (museums/libraries/galleries) and restaurants. Many studies have been carried out on the energy performance of building types with these building functions. Examples of recent studies are given in the table below (Table 1)

Table 1. Examples of recent studies on the investigated building functions.

Building Type	Reference	Summary of References
Residential buildings	<i>Kim et al. (2022), Alwetaishi (2022), Seo et al. (2022), Deng et al. (2023), Gupta et al. (2023), Cichowicz & Jerominko (2023), Wang et al. (2023), O'Hegarty et al. (2024), Kirme & Kapse (2024).</i>	The common focus of these studies is the assessment, improvement, and prediction of energy performance in residential buildings. The research covers topics such as building design parameters, the impact of climate change, energy certification, the effect of insulation on energy efficiency, and energy consumption prediction models. Additionally, some studies analyse the gap between designed energy performance and actual energy consumption, aiming to identify performance discrepancies. From a methodological perspective, some studies focus on specific regions (e.g., South Korea, India, Poland, China), while others conduct broad methodological comparisons. Data-driven models are used in certain studies to predict energy consumption with minimal input data, whereas others rely on real building data for performance analysis. Additionally, some research models the impact of climate change on residential energy consumption, providing insights into future energy demands. Studies examining the impact of insulation quality on building energy performance offer valuable practical insights that can guide energy efficiency policies and building management strategies.
Education building	<i>Shukri et al. 2022, Dyussebekova et al.2022, Islam et. al. 2022, Vaisi et al.2023, Cao et al. 2023, Ibrahim et. al. 2023, Jaouaf et. al. 2024, Vestfal et. al. 2024, de la Hoz-Torres et. al. 2024.</i>	The common focus of sources related to educational buildings is improving the energy performance of buildings and developing sustainable solutions. Many studies analyse the energy consumption of educational buildings and propose different strategies to enhance efficiency. In this context, topics such as passive design approaches, building energy modelling methods, HVAC systems, and energy consumption prediction models are addressed. Additionally, some studies examine the impact of energy efficiency on student performance. Regarding differences among sources, some studies focus on university buildings, while others investigate the energy performance of schools at different educational levels, such as primary or secondary schools. Furthermore, while some studies conduct energy benchmarking for specific geographic regions, others provide broader systematic reviews. Research on building renovation strategies, as well as studies on zero-energy or smart educational buildings, also offer diverse perspectives.
Hospitals	<i>Dimoudi et. al. 2022, Serghides et. al. 2022, Uddin et. al. 2022, Silva et al. 2023, As and Bilir 2023, Del Regno et. al. 2023, Patil & Kini 2024, Ekhaese et. al. 2024.</i>	The common focus of these sources is exploring different strategies to enhance energy efficiency in hospital buildings. While most studies investigate ways to achieve zero-energy hospitals, some analyse technical solutions such as building envelope improvements, HVAC systems, and energy audits to reduce energy consumption. Additionally, sustainability, smart building systems, and bioclimatic design are common themes among these studies. Regarding differences, some studies focus on specific geographic regions (e.g., the Mediterranean, Southern Balkans, or Nigeria), while others provide broader analyses using general modelling and simulation methods. Furthermore, some research emphasizes renovation strategies, whereas others focus on new hospital building designs or comparisons of different HVAC systems.
Offices/workshop businesses	<i>Lim et. al. 2022, Krarti 2022, Han et. al. 2022 Tamer et al. 2023, Vandembogaerde et. al. 2023, Nkini et. al. 2023, Liu et. al. 2024, Fernandes et. al. 2024, Ke and White 2024</i>	The common focus of these sources is to present different approaches to improving the energy performance of office buildings. The studies cover topics such as heating and cooling energy consumption, smart window controls, building automation systems, the use of phase change materials (PCM), insulation thickness, and building envelope optimization. Additionally, some research examines the relationship between energy consumption in office buildings and climate change, as well as analysing the economic impacts of energy performance. Regarding differences, some studies focus on specific regions (e.g., China, Tanzania, Portugal, and the UK), while others provide more general methodologies. In addition to studies evaluating indoor temperature regulations and energy-saving technologies, there are also investigations into the impact of energy performance on rental values. This diversity highlights the need to consider both technical and economic aspects when improving energy efficiency in office buildings.

General industrial/ special industrial	<i>Patterson et al. 2022, Verstina et al. 2022, Seyis 2022, Zhou & Wang 2023, Özer Yaman et al. 2023, Banti & Krawczyk 2024, Sukarti et al. 2024, Banti 2024, Yaman 2025.</i>	The common focus of these sources is the assessment and optimization of different methods to enhance the energy efficiency of industrial buildings. The studies address topics such as energy assessment processes, energy efficiency measurement methods, comparisons between BIM-based LEED and traditional buildings, multi-criteria evaluation of heating systems, and deep learning-based energy monitoring. Additionally, some studies examine the relationship between energy consumption and thermal comfort in industrial buildings, while others propose methods for optimizing energy performance through energy simulations. Regarding differences, some research focuses on specific regions or building types, whereas others aim to develop general energy efficiency methodologies. In addition to studies analysing energy consumption behaviours in buildings, there are also investigations into how innovative technologies, such as artificial intelligence and deep learning, can be utilized in energy performance analysis. Lastly, review studies focusing on retrofit solutions and multidisciplinary research trends aimed at improving the energy efficiency of existing industrial buildings hold a significant place in the literature.
Passenger Terminals	<i>Yildiz et al. 2022, Gu et al. 2022a, Gu et al. 2022b, Lin et al. 2023, Ereser and Beyhan 2023, Han et al. 2023, Ma et al. 2024, Hu et al. 2024, Xu 2024.</i>	The common focus of these sources is the assessment and optimization of different methods to enhance the energy efficiency of industrial buildings. The studies address topics such as energy assessment processes, energy efficiency measurement methods, comparisons between BIM-based LEED and traditional buildings, multi-criteria evaluation of heating systems, and deep learning-based energy monitoring. Additionally, some studies examine the relationship between energy consumption and thermal comfort in industrial buildings, while others propose methods for optimizing energy performance through energy simulations. Regarding differences, some research focuses on specific regions or building types, whereas others aim to develop general energy efficiency methodologies. In addition to studies analysing energy consumption behaviours in buildings, there are also investigations into how innovative technologies, such as artificial intelligence and deep learning, can be utilized in energy performance analysis. Lastly, review studies focusing on retrofit solutions and multidisciplinary research trends aimed at improving the energy efficiency of existing industrial buildings hold a significant place in the literature.
Hotels	<i>Palani & Karatas 2022, Borowski 2022, Bangwal et al. 2022, Pang et al. 2023, Alhuwayyi et al. 2023, Permana et al. 2023, Tachir et al. 2024, Tong et al. 2024, Zhang et al. 2024.</i>	The common focus of these sources is presenting different approaches to enhancing the energy efficiency of hotel buildings. The studies cover various topics, including holistic approaches to optimizing guests' energy consumption behaviour, the effectiveness of passive shading and insulation systems, and machine learning-based energy prediction models for high-rise hotels. Additionally, the impact of COVID-19 on hotel design and energy consumption, the thermal energy performance of hotels complying with nZEB requirements, and energy-efficient atrium designs are also addressed. Differences among the studies arise from the climate regions, building types, and methodologies they explore. For example, some research investigates the thermal performance of wall systems in hotels located in hot-summer and cold-winter climates, while others conduct multi-criteria analyses for energy consumption and efficiency in hospitality facilities. Moreover, specific topics such as the energy-efficient renovation of historic buildings and the energy consumption patterns of boutique hotels also contribute to the literature.
Libraries/museums/galleries	<i>Bakry et al. 2022, Prizeman et al. 2022, Tan and Dang 2022, Choi et al. 2023, Dabanlis et al. 2023, Sholanke et al. 2023, Vaz et al. 2024, Piras and Muzi 2024, Bekar et al. 2024</i>	The common focus of these sources is exploring different approaches to enhancing energy efficiency in cultural buildings such as museums and libraries. The studies focus on topics such as energy-saving potential in museum spaces, energy efficiency management in historic buildings, and the optimization of lighting quality and energy consumption. Additionally, aspects like daylight utilization, the relationship between indoor air quality and energy consumption, and the integration of BIM/BES for book preservation and energy management are also discussed. Differences among the sources arise from their focus on specific building types and methodologies. For example, some studies evaluate lighting strategies in museums and art galleries, while others examine BIM-based solutions for sustainability in university libraries. Furthermore, certain research focuses on specific geographic locations (e.g., Mardin Sabancı City Museum, Maputo Natural History Museum), whereas others assess the sustainability of historic buildings within a broader energy efficiency framework.
Restaurants/cafes/drinking establishments/hot food takeaways	<i>Uddin et al. 2022, Gunasegaran et al. 2022, ElSharkawy & Ibrahim 2022, Choi et al. 2023, Erdemci and Doğh 2023, Gunasegaran et al. 2023, Saiful et al. 2024, Btsu et al. 2024</i>	The common focus of these sources is examining various strategies to enhance the energy efficiency of restaurant buildings. The studies emphasize the importance of energy management strategies in building design by analysing the energy consumption of restaurants. Additionally, topics such as solar energy integration, passive design solutions, and air quality issues caused by exhaust systems are also addressed. Some studies investigate the impact of using recycled materials in restaurants on energy and acoustic performance, while others evaluate the energy efficiency of converting historic buildings into cafes and restaurants. Differences among the sources stem from their focus on specific regions and methodologies. For example, some studies analyse the energy consumption of the restaurant sector in particular countries (e.g., Malaysia, South Korea, Nigeria), while others explore energy management and sustainability approaches applicable on a global scale. Furthermore, some research examines the relationship between energy consumption and social life, while others analyse how restaurants can remain operational during energy crises.

Many studies on this topic have been conducted to date, and research in this field is ongoing. However, existing studies examining the relationship between building functional characteristics and energy demand are often limited to one or a few building functions. Unlike previous research, this study comprehensively analysis the impact of nine different building functions on energy performance across three distinct climate zones in Turkey: Ankara (continental climate), İzmir

(Mediterranean climate), and Erzurum (cold climate). Despite the significance of climate-responsive building design, studies covering multiple functions and diverse climatic conditions in Turkey remain scarce. By addressing this gap, this research aims to provide a broader understanding of how building functionality influences energy consumption across different climatic contexts. The general framework of the study is illustrated in the diagram below (Figure 2)

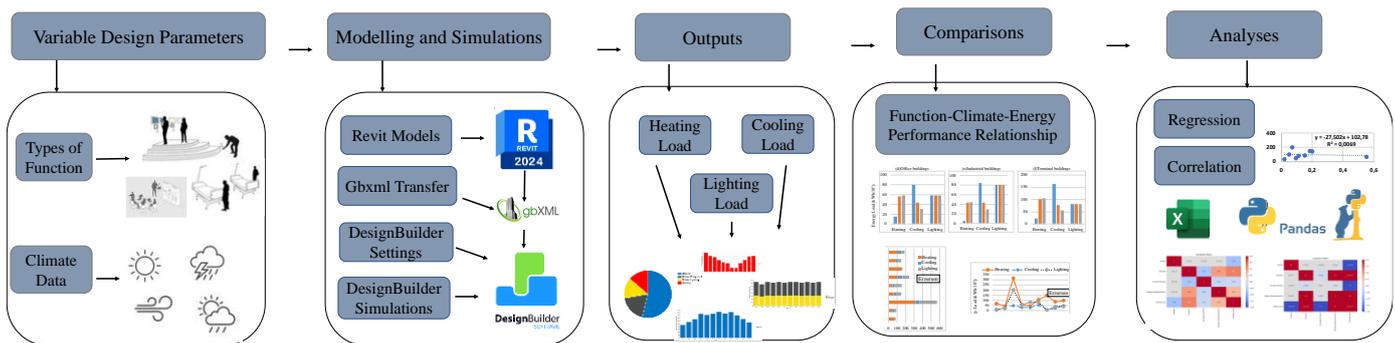


Figure 2. Schematic representation of the general structure of the study

In the first stage of the study, variable design parameters were determined. In the second stage of the study, building models were created in Revit program with BIM (Building Information Modelling) method. Then, building energy simulations (BES) were carried out by transferring to the Design Builder program and a data set consisting of heating, cooling and lighting loads was created. The results obtained were compared with the help of graphs. As a result of the comparisons, linear regression in excel and correlation matrix in python were created in order to establish the relationships of the parameters that are thought to be related and evaluations were made by establishing the relationships of input and output parameters.

Climatic Characteristics of the Research Area

The energy performance of each building is directly affected by the climatic data of the region where it is located. In this study, research has been carried out in Türkiye, which is surrounded by seas on three sides and located at the intersection of Europe and Asia continents. Due to being surrounded by seas and having various landforms, different climate types are observed in Türkiye. Within the scope of the study, three cities with different climatic characteristics in Türkiye were included in the study (Figure 3).

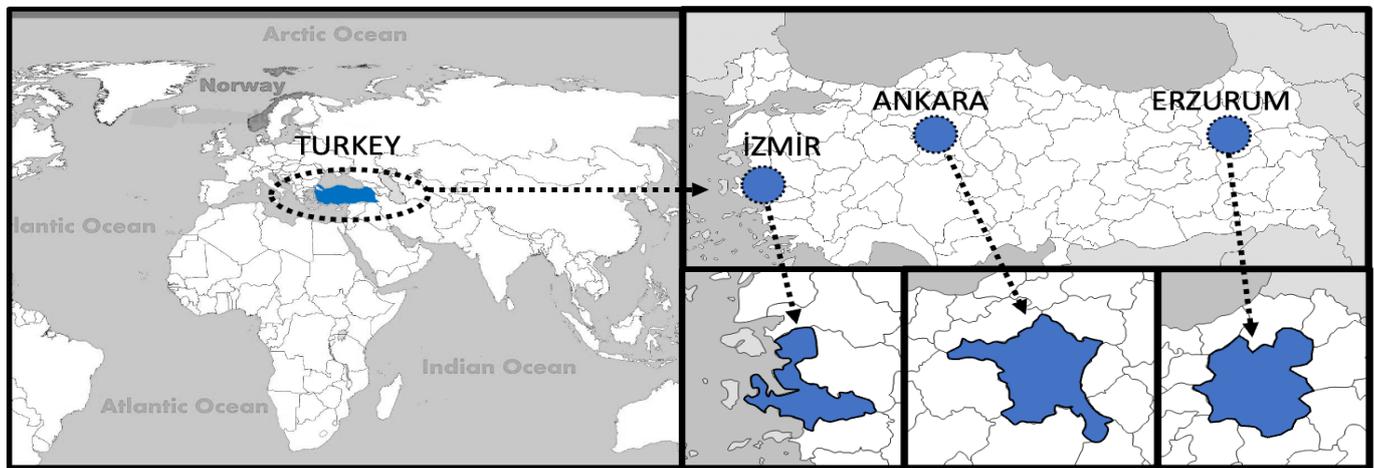


Figure 3. Map representation of the study area

Izmir in the west of Türkiye with a humid climate, Erzurum in the east of Türkiye with a cold climate and Ankara in the central regions of Türkiye with a continental climate were

included in the study. The climate class of these three cities according to different climate classifications is given in the table below (Table 2).

Table 2. Climate classification of Izmir, Ankara and Erzurum cities according to different climate classifications

Climate classification	Izmir	Ankara	Erzurum
TSE 825 (2013)	1. Region	3. Region	5. Region
Trewartha Climate Classification	Cool winters/ Hot summers	Cold winters/ Hot summers	Cold winters / Warm summers

Within the scope of the research, İzmir is located in the 1st climate zone, Ankara is located in the 3rd climate zone and Erzurum is located in the 5th climate zone in the classification of cities according to degree days and regions in TSE 825 (TSE 825, 2013). According to the Trewartha Climate Classification (according to the universal

temperature scale); İzmir has cool winters and hot summers, Ankara has cold winters and hot summers, Erzurum has cold winters and warm summers (T.C. MGM, 2023). The climate data of these three selected cities are given in the table below (Table 3)

Table 3. Climate data of İzmir, Ankara and Erzurum cities (T.C. MGM, 2024).

Climate data	Drought coefficient (Aydeniz Climate Classification)	Precipitation efficiency index (Erinch Climate Classification)	Drought index De (Martonne Climate Classification)	Trewartha Climate Classification (According to the universal temperature scale)	
				January average temperature (°C)	July average temperature (°C)
İzmir	0.92	30.60	13.80	-0.1	27.8
Ankara	1.14	29.19	10.77	-8.6	23.1
Erzurum	0.72	34.06	14.69	-9.5	19.4

As can be seen from the data in the table, there are large differences between the climate data in the selected cities. While there is a difference of approximately 9.5 °C in winter temperature averages between the coldest and the hottest city, there is a difference of approximately 8.5 °C between summer temperature averages. The main criterion for city selection was to identify cities that could represent different climate zones in Türkiye. In this context, Izmir, Ankara, and Erzurum were chosen as they represent the three most distinct climate regions in the country. The selected cities exhibit significant temperature differences, covering a wide temperature range necessary for the study. Instead of expanding the study scope by selecting cities from every region, the aim was to choose cities that best reflect Türkiye's climatic diversity. Izmir has a mild and humid climate, Ankara exhibits the typical characteristics of a continental climate, while Erzurum is

located in a cold climate zone. This selection allows for the evaluation and optimization of building energy performance by considering different heating and cooling loads. In the study, the climate data file of these cities was obtained as a file with 'epw' extension and used in the simulations made in the DesignBuilder program.

Reference Building Features

The study was carried out on a reference building. Within the scope of the study, a square-shaped building model with dimensions of 22m × 22m and a height of 6m was created. The model was simplified while preserving only the essential elements. The fixed parameters of the building and the thermo-physical properties of the building components, defined as a prototype for all building functions, are presented in the table below (Table 4)

Table 4. Values of fixed parameters of the reference building

External Wall U Value (W/m ² K)	0.735	Window U (W/m ² K)	3.159
Ground floor U Value (W/m ² K)	0.848	Flat roof U Value (W/m ² K)	0.979
Winter clothing (clo)	1.00	Summer clothing (clo)	0.5
Heating set back (°C)	12.0	Cooling set back (°C)	28.0
Metabolic Factor (Men=1.00, Women=0.85, Children= 0.75)	1.00	Window/Wall Ratio	%30

The values given in the table above are the same for all building functions. Spaces gain meaning with the actions to be performed in them. Different spaces are required for various activities performed in daily life. Within the scope of this study, the impact of functional changes in the reference building is examined. In this context, nine different building functions have been defined, and relevant activities have been identified for each function. To determine how the building is used at different time intervals, activity data related to the functions performed in the spaces need to be entered into the program. Activity data include the actions taking place within a given space. For example, in an office space, activities such as working while seated and walking are included.

To accurately incorporate these activities into the calculations, usage schedules are utilized. Schedules are time charts that define the usage patterns of each building function throughout the year and are pre-defined in the DesignBuilder software. These schedules vary based on the daily, monthly, and annual usage intensity of spaces. Within the program, schedules can be individually assigned to each space function, either manually created or selected from pre-configured templates available in the program's library. These pre-configured templates are based on data obtained from the United Kingdom (UK) NCM (National Calculation Method) dataset, ASHRAE 90.1 and 62.1 library templates (DB Software, 2025). The abbreviations for the building functions considered in this study, along with their usage schedules and metabolic activity types, are presented in Table 5.

Table 5. Abbreviations and usage information of building types defined according to their functions

<i>Key</i>	<i>Building type</i>	<i>Template/ Schedule</i>	<i>Metabolic Activity</i>
<i>BF-1</i>	Residential buildings	Bed living/Kitchen Occ	Standing/Walking
<i>BF-2</i>	Education building	Teaching areas/ Edu. Classroom occupied	Standing/Walking
<i>BF-3</i>	Hospitals/care homes	24 hrs. Consulting/ treatmentRM Occ	Standing/Walking
<i>BF-4</i>	Offices/workshop businesses	Generic Office Area/ Open off Occ	Light office work/Standing/Walking
<i>BF-5</i>	General industrial/ special industrial	Industrial process area Occ.	Light manual work
<i>BF-6</i>	Passenger Terminals	Terminal Waiting Rooms Occ	Standing/Walking
<i>BF-7</i>	Hotels	Hotel Ensuite bedroom Occ.	Bedroom
<i>BF-8</i>	Libraries/museums/galleries	Display and Public areas/ Lib/Mus Gall-Circulation Pub Occ	Lighter manual work
<i>BF-9</i>	Restaurants/ cafes/ drinking establishments/ hot food takeaways	Rest pub Eating/Drinking Occ	Eating/drinking

The schedules used to define the activities performed in each building function considered in this study are standard time schedules available in the DesignBuilder software and widely used. These schedules define the occupancy durations for specific building functions, determine the periods in which spaces are actively used, and establish the energy consumption dynamics. Occupied density refers to the number of people present in a specific space during defined time periods and varies depending on the building function and occupied density values are derived based on schedules. The occupied density values used in this study are based on data from predefined templates available in the DesignBuilder software, specifically from the United Kingdom (UK) NCM (National Calculation Method) dataset, ASHRAE 90.1, and ASHRAE 62.1 library templates (DB Software, 2025). This database provides

standardized input values based on recognized norms and regulations for energy simulations. These values help establish consistency in energy modelling by defining the typical number of occupants per unit floor area for different building types. Heating and cooling requirements also vary depending on user density and activities performed in the spaces. For example, to ensure indoor thermal comfort, the temperature level for an activity performed while sitting should be higher than for a space where physical work is conducted.

In this context, the indoor occupancy density, heating and cooling requirements, and target illumination levels for the nine different building functions defined in this study vary accordingly. The values of these parameters for each building function are presented in Table 6.

Table 6. Values of changing parameters of the reference building

<i>Variable parameters</i>	<i>BF-1</i>	<i>BF-2</i>	<i>BF-3</i>	<i>BF-4</i>	<i>BF-5</i>	<i>BF-6</i>	<i>BF-7</i>	<i>BF-8</i>	<i>BF-9</i>
<i>Occupied Density</i>	<i>0,0188</i>	<i>0,5523</i>	<i>0,070</i>	<i>0,1110</i>	<i>0,050</i>	<i>0,1846</i>	<i>0,0944</i>	<i>0,1497</i>	<i>0,200</i>
<i>Heating (°C)</i>	<i>21</i>	<i>18</i>	<i>23</i>	<i>22</i>	<i>18</i>	<i>20</i>	<i>21</i>	<i>20</i>	<i>23</i>
<i>Cooling (°C)</i>	<i>25</i>	<i>23</i>	<i>25</i>	<i>24</i>	<i>25</i>	<i>23</i>	<i>25</i>	<i>24</i>	<i>25</i>
<i>Target illuminance (lux)</i>	<i>100</i>	<i>280</i>	<i>500</i>	<i>400</i>	<i>300</i>	<i>200</i>	<i>100</i>	<i>200</i>	<i>150</i>

Climate data files with 'epw' extension were obtained from the internet address 'climate.onebuilding.org', which is a weather data provider for the three cities determined in the simulations for the climate characteristics

investigated. These data were added and used in the hourly weather data section for climate data in the simulation program.

BIM/BEM/BES Method

This study utilizes BIM/BEM/BES integration to analyze building geometry based on different functional characteristics and climate zones. BIM is a technology capable of efficiently storing building data at any scale and complexity, allowing information to be shared and stored without loss through an open format known as IFC (Industry Foundation Classes) (Choi & Lee, 2023). The integration of BIM and BEM has become a fundamental component in the transformation of architectural and construction practices, improving the accuracy of energy efficiency evaluations and enhancing cost estimation precision (Alhammad, 2024).

Therefore, for this study, the building geometry described in Section 2.2 was modeled using Autodesk

Revit, a BIM software. Building models can be created in Revit and converted into analytical models (Özlem & Eşrefiyan, 2022). To ensure interoperability between BIM and energy simulation platforms, the Green Building extensible Markup Language (gbXML) schema was developed as a data exchange solution. gbXML is specifically designed to facilitate data transfer from BIM to BEM, containing both geometric and semantic information compatible with simulation engines (Yang et al., 2022; Guizar Dena et al., 2024). The gbXML file, including all data forms, can be imported, and the BIM model can be converted into BEM (Alaa et al., 2024; Ayman et al., 2018). Thus, the building model created in Revit was converted into the gbXML format and, as shown in Figure 4, was transferred to the DesignBuilder software as a gbXML file.

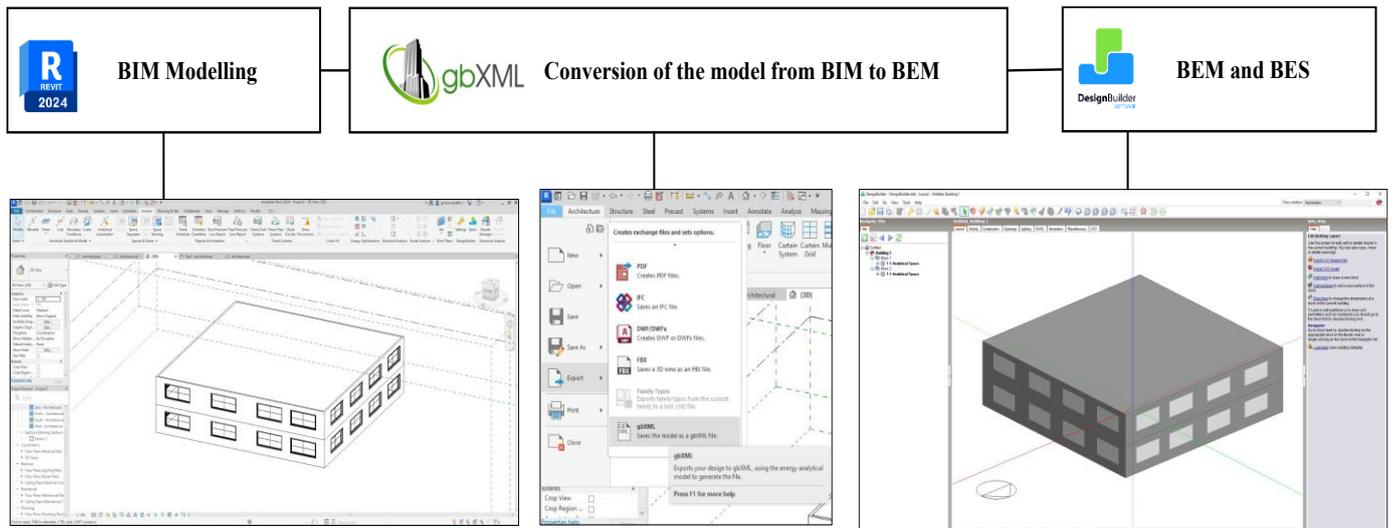


Figure 4. Diagrammatic representation of the transfer of the building example created in the Revit interface to the Design Builder program

The building model was transferred to the DesignBuilder software in gbXML format, which is suitable for BEM generation, and its volumetric accuracy was verified. In this software, the fixed building parameters provided in Table 4 were defined for the building geometry. Then, for each building geometry separately, the values related to building functions given in Table 6 were integrated into the BEM model, and building energy simulations (BES) were conducted individually for each building function and climate zone. A total of 27 simulations were performed, and data related to heating, cooling, and lighting loads were obtained. These data were used for comparisons and statistical analyses. Additionally, during the statistical analyses, extra simulations were conducted to measure the effects of certain parameters, allowing for a more detailed examination of their impacts.

RESULTS and DISCUSSION

In this section, the data obtained from the simulation results in cities with different climatic characteristics for the specified building functions are compared and presented and the results are evaluated. Firstly, the heating, cooling and lighting loads obtained as a result of the analyses performed in each climate type of the building functions such as housing, educational buildings, hospitals,

offices, industrial buildings, terminal buildings, hotels, museums, restaurants are compared. In the second stage, heating, cooling and lighting load comparisons were made with building functions. In the third stage of the study, climate characteristics, function and total energy load comparisons are included. Following these comparisons, linear regression and correlation analyses were performed to investigate the effect of changing parameters. The data obtained as a result of these analyses were evaluated.

Energy Performance of Buildings and Climate Relationship

Climate types have significant effects on building energy performance. In cold climates, spaces need to be heated to provide thermal comfort conditions and energy is needed for this. In hot climates, energy is spent for cooling the spaces. In Türkiye, many building types are implemented as type projects. In other words, the same project is applied in different cities. In this study, simulations of buildings with the functions determined for cities with different climatic characteristics were carried out. First of all, the hourly weather site analyses simulated in the DesignBuilder program for the determined cities are given. Hourly weather site analyses for Izmir, Ankara, Erzurum cities are shown in figure 5, figure 6 and figure 7.

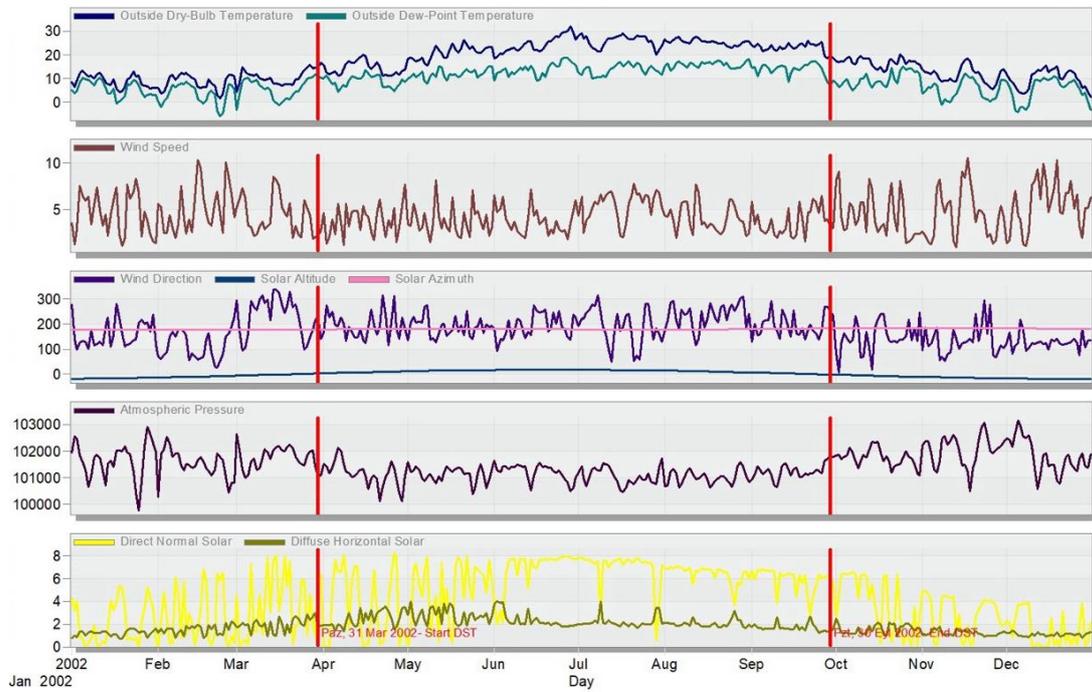


Figure 5. Izmir city hourly weather analysis (1 January-31 December Daily)

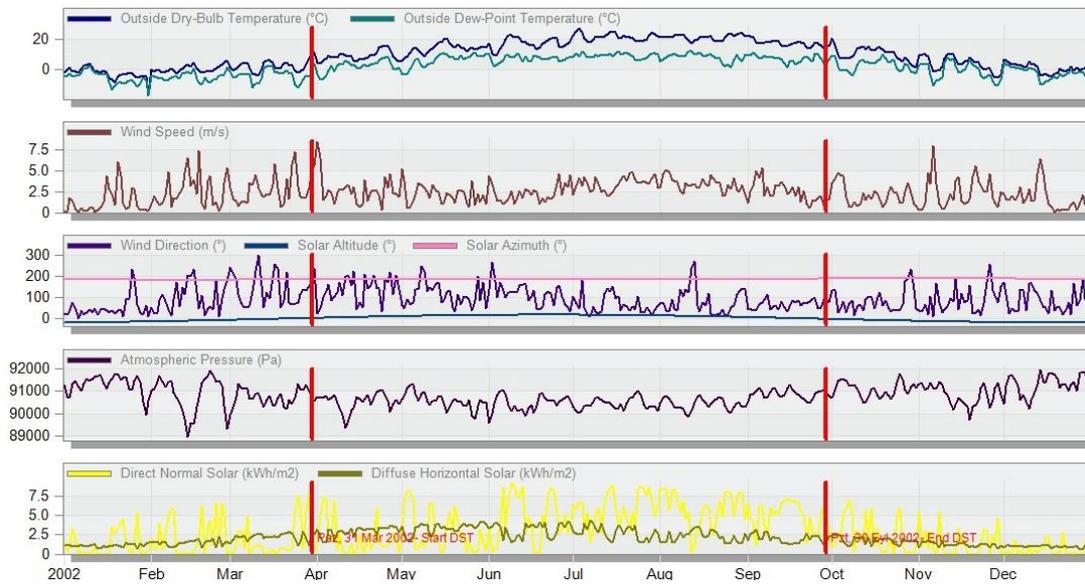


Figure 6. Ankara city hourly weather analysis (1 January-31 December Daily)

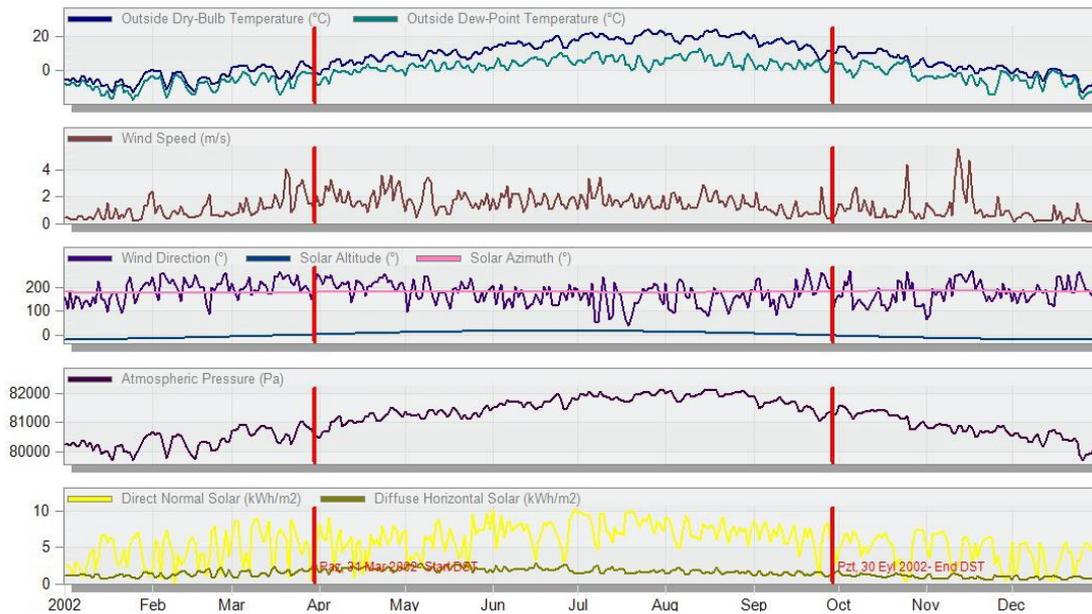


Figure 7. Erzurum city hourly weather analysis (1 January-31 December Daily)

The simulation results show the average temperature values for the cities of Izmir, Ankara, and Erzurum. These values are consistent with the data from the General Directorate of Meteorology (MGM 2025). Significant differences in climate data are observed among these three cities. Using these climatic data, energy simulations were conducted for each city

and each designated building function, and comparisons were made. The graphs comparing the heating, cooling, and lighting loads of residential buildings, educational buildings, and hospitals with the same function in Izmir, Ankara, and Erzurum are provided in Figure 8 a, b, c below.

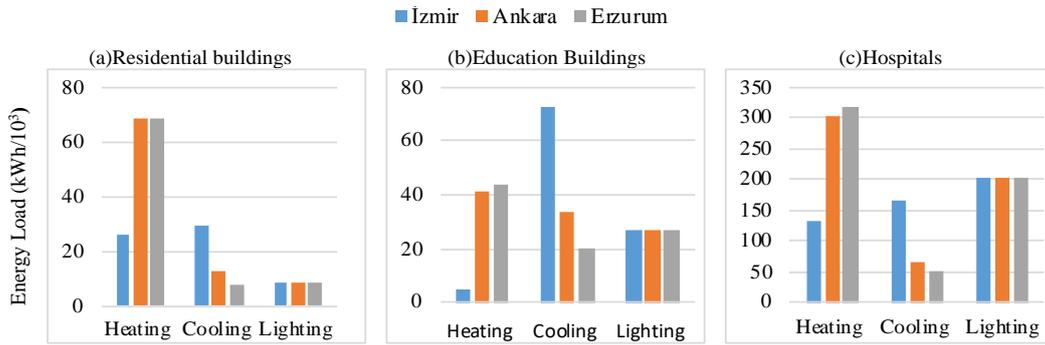


Figure 8. Comparison graphs of heating, cooling and lighting loads of (a)residential, (b)educational and (c)hospitals according to different climate zones

According to the data given in the graph, the heating energy requirement for dwellings is highest in Erzurum and lowest in İzmir. İzmir uses 63% less heating energy than Erzurum. Erzurum and Ankara use heating energy close to each other. In terms of cooling energy requirement, the highest load is observed in İzmir while the lowest load is observed in Erzurum. Erzurum uses 74% less cooling energy than İzmir. Ankara, on the other hand, has a higher cooling energy requirement than Erzurum. Similarly, the heating energy requirement for educational buildings is highest in Erzurum and lowest in İzmir. İzmir uses 89% less heating energy than Erzurum. Erzurum and Ankara use heating energy close to each other. In terms of cooling energy requirement, the highest load is observed in İzmir while the lowest load is observed in Erzurum. Erzurum uses 72% less cooling energy than İzmir. Ankara,

on the other hand, has a higher cooling energy requirement than Erzurum. Hospitals are similar to other building types. In this type of building, the heating energy requirement is highest in Erzurum and lowest in İzmir. İzmir uses 58% less heating energy than Erzurum. Erzurum and Ankara use heating energy close to each other. In terms of cooling energy requirement, the highest load is observed in İzmir while the lowest load is observed in Erzurum. Erzurum uses 70% less cooling energy than İzmir. Ankara, on the other hand, has a higher cooling energy requirement than Erzurum. The graphs of the comparison of the heating, cooling and lighting loads of the same function buildings for offices, industrial buildings and terminals for the cities of Izmir, Ankara and Erzurum are given below (Figure 9 a, b, c).

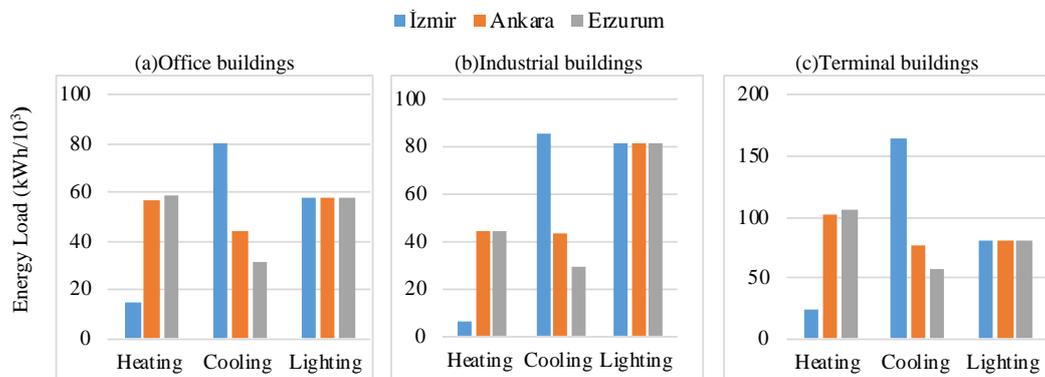


Figure 9. Comparison graphs of heating, cooling and lighting loads of (a) office (b) industrial buildings (c) passenger terminals according to different climate zones

According to the data given in the graph, the heating energy requirement for offices is highest in Erzurum and lowest in İzmir. İzmir uses 74% less heating energy than Erzurum. Erzurum and Ankara use heating energy close to each other. In terms of cooling energy requirement, the highest load is observed in İzmir while the lowest load is observed in Erzurum. Erzurum uses 61% less cooling energy than İzmir. Ankara, on the other hand, has a higher cooling energy requirement than Erzurum. Again, heating and cooling loads for industrial buildings in Ankara are very close to each other and have almost equal values. Similarly, the heating energy requirement for industrial buildings is highest in Erzurum and lowest in İzmir. İzmir

uses 86% less heating energy than Erzurum. Erzurum and Ankara use heating energy close to each other. In terms of cooling energy requirement, the highest load is observed in İzmir while the lowest load is observed in Erzurum. Erzurum uses 65% less cooling energy than İzmir. Ankara has a higher cooling energy need than Erzurum and a lower cooling energy need than Izmir. In Ankara, the difference between heating energy and cooling energy requirement is very small and almost equal. Terminal buildings are similar to other building types. In this building type, the heating energy requirement is highest in Erzurum and lowest in İzmir. İzmir uses 78% less heating energy than Erzurum. In terms of cooling energy

requirement, the highest load is seen in İzmir, while the lowest load is seen in Erzurum. Erzurum uses 66% less cooling energy than İzmir. Ankara, on the other hand, has a higher cooling energy requirement than Erzurum. The

graphs of the comparisons of the heating, cooling and lighting loads of the same function buildings for hotel, museum and restaurant buildings for İzmir, Ankara and Erzurum cities are given below (Figure 10 a, b, c).

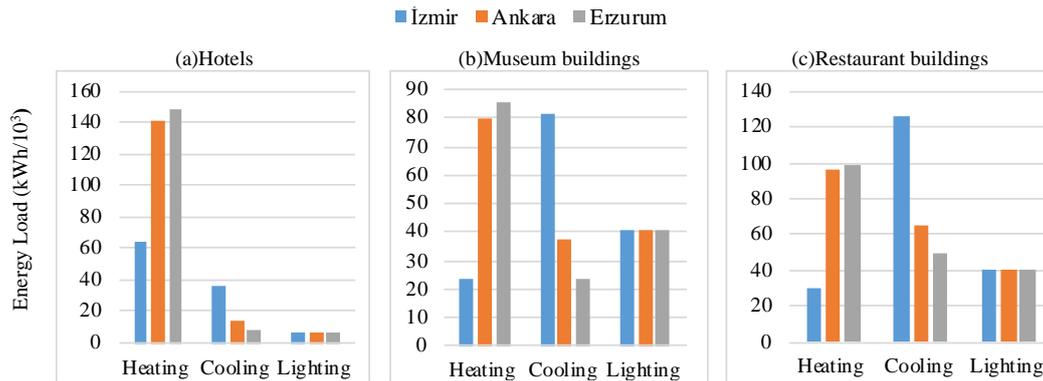


Figure 10. Comparison graphs of heating, cooling and lighting loads of (a) Hotel, (b) Museum and (c) Restaurant buildings according to different climate zones

According to the data given in the graph, the heating energy requirement for hotels is the highest in Erzurum and the lowest in İzmir. İzmir uses 57% less heating energy than Erzurum. Erzurum and Ankara use heating energy close to each other. In terms of cooling energy requirement, the highest load is observed in İzmir while the lowest load is observed in Erzurum. Erzurum uses 78% less cooling energy than İzmir. Ankara, on the other hand, has a higher cooling energy requirement than Erzurum. Similarly, the heating energy requirement for museums is highest in Erzurum and lowest in İzmir. İzmir uses 73% less heating energy than Erzurum. In terms of cooling energy requirement, the highest load is seen in İzmir, while the lowest load is seen in Erzurum. Erzurum uses 71% less cooling energy than İzmir. Ankara has a higher cooling energy requirement than Erzurum and a lower cooling energy requirement than İzmir. Restaurants are similar to other building types. In this building type, the heating energy requirement is highest in Erzurum and lowest in İzmir. İzmir uses 69% less heating energy than Erzurum. In terms of cooling energy requirement, the highest load is seen in İzmir, while the lowest load is seen in Erzurum. Erzurum uses 61% less cooling energy than İzmir. Ankara, on the other hand, has a higher cooling energy requirement than Erzurum.

In the study, an exceptional situation was observed in İzmir, where the heating load for hotels was higher than the cooling load. This is due to the inclusion of hotel bedrooms in the calculations during the simulation. Since hotel bedrooms constitute the largest enclosed spaces within hotels, these areas were considered in the energy analysis.

Additionally, an examination of usage patterns shows that these spaces are predominantly used at night. As night-time temperatures are lower, the cooling energy demand in hotel bedrooms decreases, leading to a higher heating load compared to the cooling load in the calculations.

The similarity of lighting needs across different cities was determined through simulation results. The main reason for this is that Ankara, Erzurum, and İzmir are located at approximately the same latitude. This results in these cities having similar day lengths and thus benefiting from daylight for the same duration. Therefore, there is no significant difference in lighting requirements on a city basis. However, lighting needs vary depending on building functions. Structures such as hotels, museums, and restaurants have different operating hours and, consequently, different lighting requirements. This creates variations in overall lighting demands.

Building Function- Heating/Cooling/Lighting Load Relationship

Buildings have different functions according to the actions performed in them. In this part of the study, the relationship between heating, cooling and lighting loads for residences (BF-1), educational buildings (BF-2), hospitals (BF-3), offices (BF-4), industrial buildings (BF-5), terminals (BF-6), hotels (BF-7), museums (BF-8), restaurants (BF-9) are evaluated with the data obtained as a result of simulations. In this context, the relationship between building functions and heating energy requirement is compared in the graph below (Figure 11).

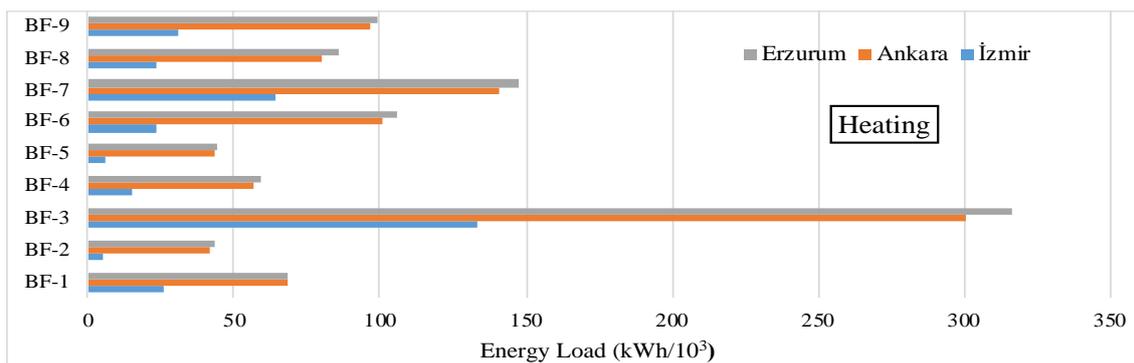


Figure 11. Comparison of heating load and building function relationship according to different climate zones

As seen in the graph and as mentioned in the previous section, Erzurum is the city with the highest heating load in all building functions and İzmir is the city with the lowest heating load. The highest heating load is observed in hospitals and the lowest heating load is observed in education buildings. While educational buildings consume 96% less heating energy than hospitals in İzmir, they consume 86% less heating energy in Ankara and Erzurum. This situation can be said to be due to the fact that educational buildings are not used on holidays and at certain times of the day. It is seen that industrial buildings have values close to the heating load of educational buildings and

have less energy load than other building types. This situation can be explained by the fact that the temperatures felt at physiologically lower ambient temperatures are higher in physiologically working conditions. Hospitals are followed by hotels, restaurants and museums in terms of high heating load. This situation can be explained by the low level of physical activity and high heat demand in the spaces. Another important parameter to be investigated in spaces is the cooling load. In the graph below, the relationship between building functions and heating energy demand is compared (Figure 12).

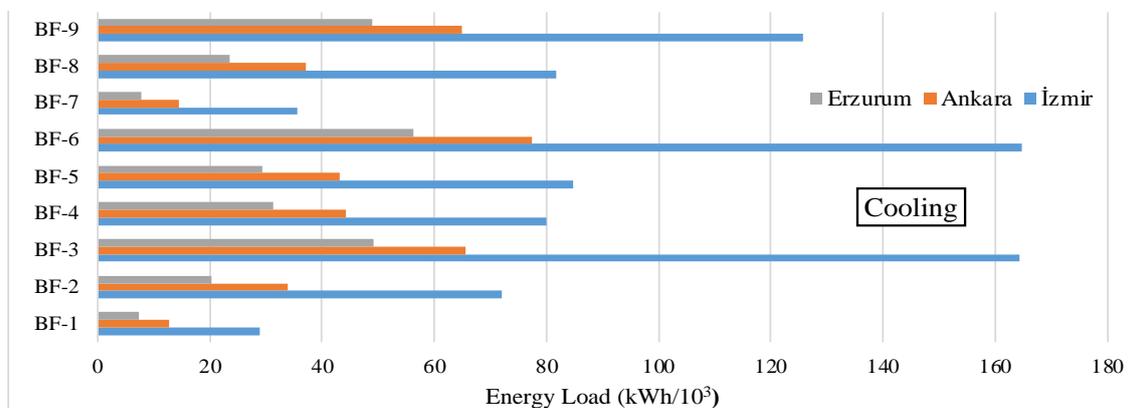


Figure 12. Comparison of cooling load and building function relationship according to different climate zones

Cooling load is highest in terminal buildings in all cities. This is followed by hospitals and restaurants. The buildings with the lowest cooling load are residential buildings, followed by hotels and educational buildings. Residential buildings use 82% less cooling energy than terminal buildings in İzmir. In Ankara, dwellings use 84% less cooling energy than terminal buildings. Again, in Erzurum, the cooling load uses 87% less cooling energy than terminal buildings. As mentioned before, İzmir has

the highest cooling load and Erzurum has the lowest cooling load. The energy load difference between Ankara and Erzurum increases in cooling load. The lighting energy requirement of the spaces also changes according to the functions performed in the spaces. Another parameter investigated in this context is the lighting load. In the graph below, the relationship between building functions and lighting energy requirement is compared (Figure 13).

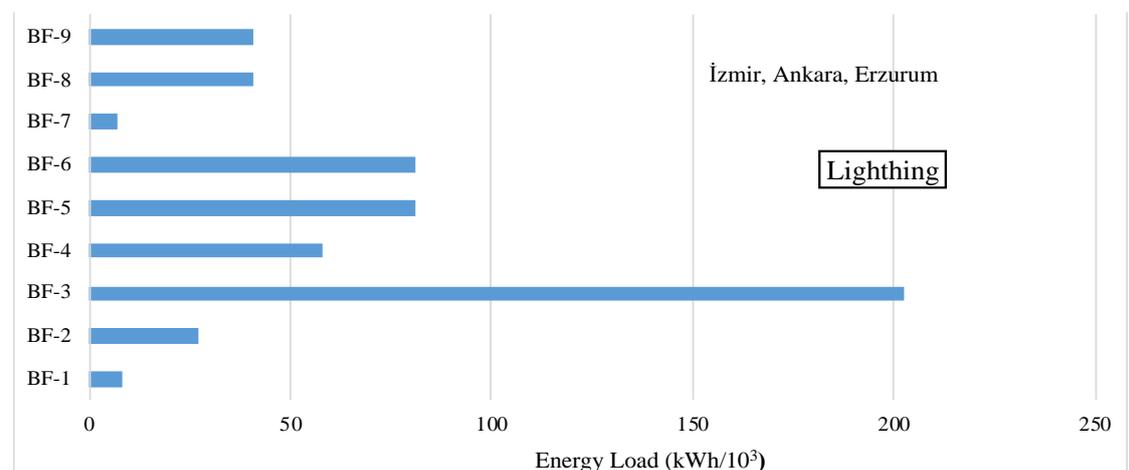


Figure 13. Comparison of lighting load and building function relationship according to different climate zones

The lighting energy load distribution for İzmir, Ankara, and Erzurum is shown in the figure. Since these cities are located at approximately the same latitude, they have similar day lengths, resulting in comparable daylight utilization durations. Consequently, variations in lighting energy loads primarily stem from differences in building functions rather than geographical location. While the lighting load of buildings does not significantly vary between cities, it is directly influenced by their functions.

requirement is seen in hotels. Hotels have 96% less cooling load than hospitals. Residential and educational buildings are also the buildings with low lighting energy demand.

Climate Characteristics- Space Function-Energy Performance Relationship

Again, as in heating loads, hospitals are the type of building with the highest lighting energy requirement. This is followed by terminals and industrial buildings. The lowest lighting energy

In this section, the heating, cooling and lighting loads according to climate characteristics are compared with the help of linear graphs and total load comparisons are given. Firstly, comparisons for İzmir are given in Figure 14.

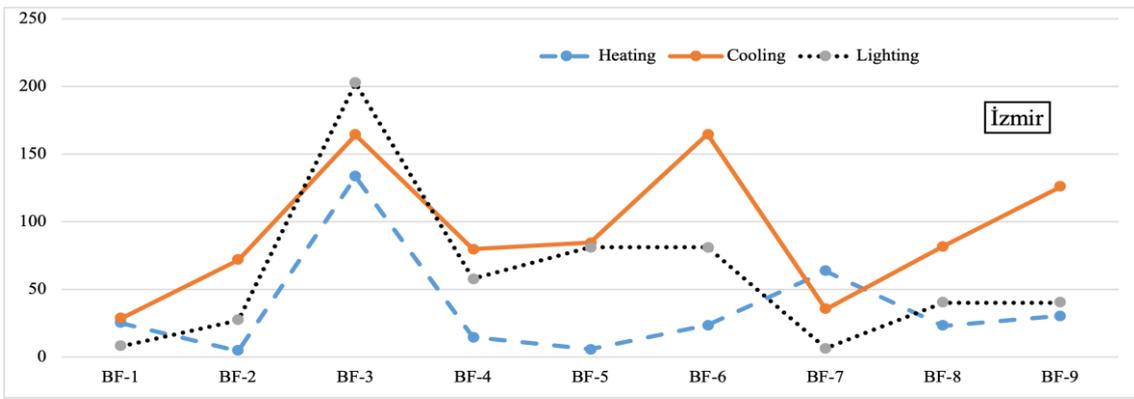


Figure 14. Comparison of energy load and building function relationship for Izmir

In Izmir, total load is mostly observed in hospital buildings. This is followed by terminals and restaurants. The lowest load is observed in dwellings. This is followed by education

buildings and hotels. In terms of total load, residential buildings have 87% less energy load values than hospitals in Izmir. Comparisons for Ankara are given in Figure 15.

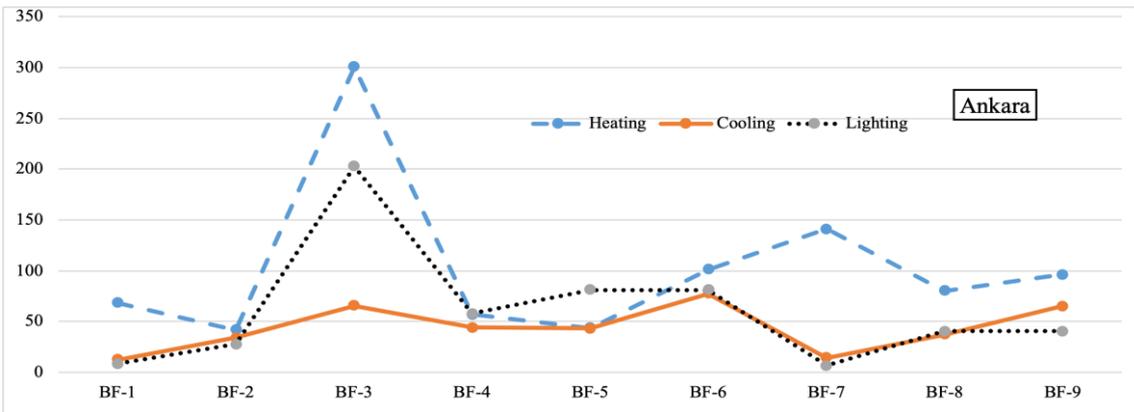


Figure 15. Comparison of energy load and building function relationship for Ankara

In the city of Ankara, the highest total load is observed in hospital buildings. This is followed by terminals and restaurants. The lowest load is observed in residential buildings. This is followed by education buildings and

hotels. In terms of total load in Ankara, residential buildings have 84% less energy load values than hospitals. Comparisons for Erzurum are given in Figure 16.

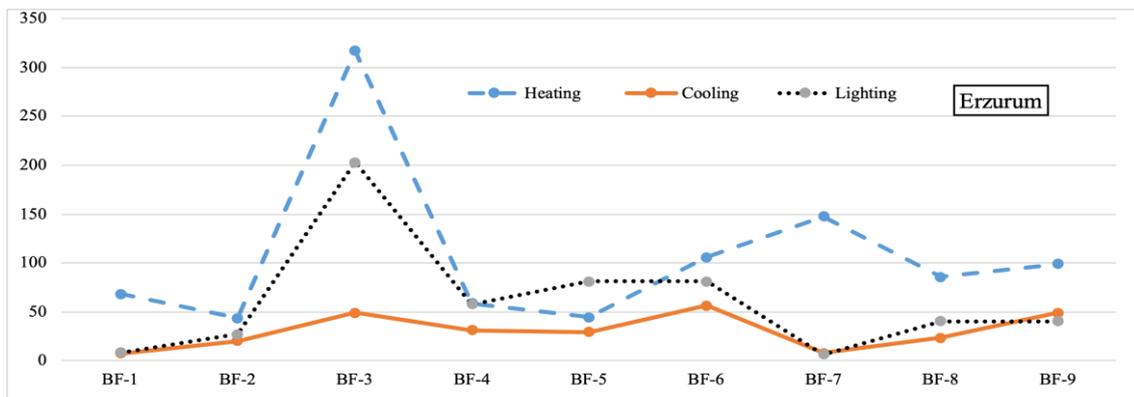


Figure 16. Comparison of energy load and building function relationship for Erzurum

In Erzurum, the highest total load is observed in hospital buildings. This is followed by terminals and restaurants. The lowest load is observed in residential buildings. This is followed by education buildings and hotels. In terms of total load, residential buildings have 85% less energy load values than hospitals in Erzurum.

Statistical analysis of the results

As a result of the comparisons made, it was determined that there are large differences between the energy needs of the buildings although their physical characteristics are the same.

Statistical analysis methods were tried to investigate the relationship between these differences and input and output parameters. Firstly, it was checked whether the obtained values have a linear relationship. For this, simple linear regression analysis was performed. It is an important fact that climate has a great impact on building energy performance. As a result of the comparisons made in this study, significant differences have emerged according to the climate zone.

The purpose of this analysis is to examine the impact of climatic conditions on the energy loads of buildings. In this context, it has been evaluated whether there is a relationship between outdoor weather conditions and energy loads in

different cities, as well as the degree of this relationship. For this purpose, based on the Travartha climate classification provided in Table 3 (according to the universal temperature scale), the relationship between the average outdoor air temperatures in January and July and the heating and cooling loads of buildings in İzmir, Ankara, and Erzurum was analyzed. According to this classification data, the average

temperature in January is -0.1°C and in July is 27.8°C in İzmir. In Ankara, the average temperature is -8.6°C in January and 23.1°C in July, whereas in Erzurum, it is -9.5°C in January and 19.4°C in July. The relationship between January temperature values and heating energy is shown in Figure 17 a, while the relationship between July temperature values and cooling load is presented in Figure 17 b.

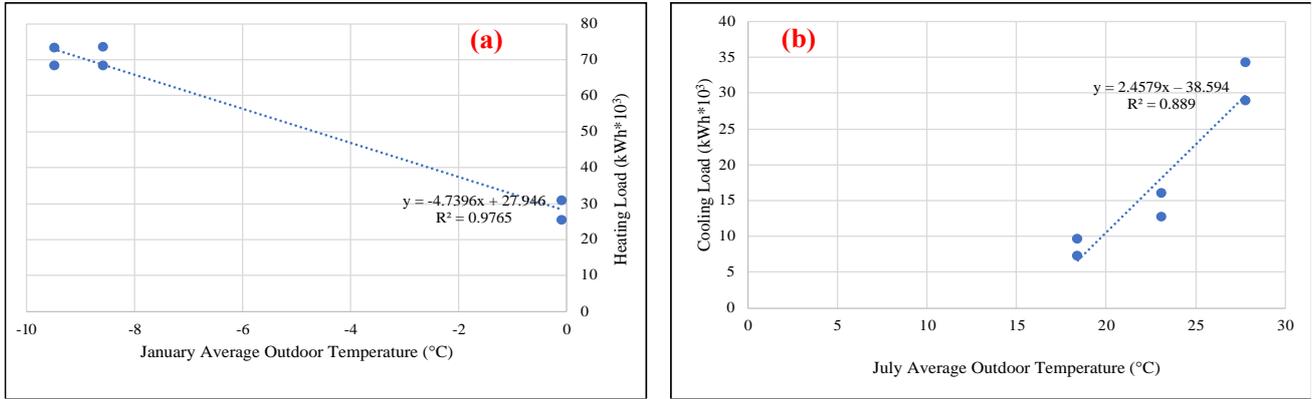


Figure 17. (a) January and heating energy demand relationship, (b) July and cooling energy demand relationship

As can be seen from the graphs comparing the heating energy demand of buildings with seasonal temperature averages, there is a linear relationship between outdoor temperature averages and heating and cooling loads. As the average temperature increases, the heating load decreases and the cooling load decreases. In this case, the relationship between the two variables is statistically significant, it can be said that there is a linear relationship between the two variables. The suitability indicator of the simple linear regression model is expressed as R^2 and the closer the R^2 value is to 1, the better the model is (Kılınc 2013, Alpar 2010, Dawson and Trapp 2001). The R^2 value of the regression value of the relationship between the average temperature in July and the cooling load is 0.889, and the R^2 value between the average temperature in January and the heating load is 0.9765. These values show that the relationship is very strong. Looking at the direction of the curve, as the average temperature increases, the heating load

decreases (inverse proportion) and the cooling load increases (direct proportion). Apart from this, it has been revealed in the graphs in the previous sections that there are large differences between the heating cooling lighting loads when all the physical parameters of the building are constant.

In order to examine this situation, the relationship between the changing parameters of the reference building given in Table 6 was investigated. For this, new simulations were performed by changing one parameter and keeping the others constant. From the comparison of the simulation results, it is concluded that the lighting load has a relationship with the Target illuminance (lux) variable and the scatter plot of these two variables is given below (Figure 18). The aim of this analysis is to understand the relationship between indoor target illuminance levels and lighting load.

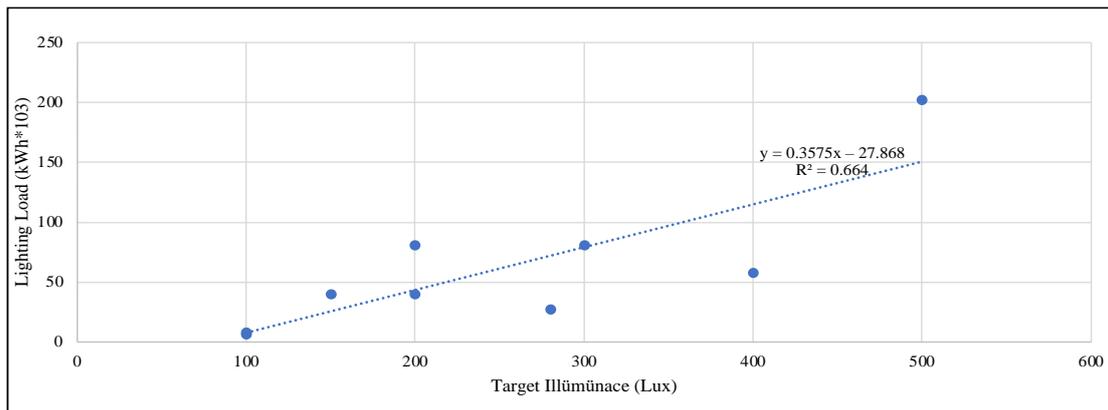


Figure 18. Relationship graph between Target Illuminance and lighting load

According to the relationship graph between target illumination and lighting load, R^2 value is 0.664. With this value, it can be concluded that there is a relationship between them, but it is not a very strong relationship. According to the results in this graph, there is a relationship between the target illuminance level (lux) and lighting load under fixed parameters. However, this relationship is not very strong. In determining the lighting load, not only this parameter but also other parameters are influential. The necessity of conducting

additional analyses arises to better understand and resolve these relationships.

In order to investigate the effect of occupied density variable on heating and cooling load, indoor heating and cooling temperatures were assumed constant as 22°C and 24°C respectively and new simulations were performed. The scatter plot created with the data obtained as a result of this simulation is given below (Figure 19 a, b).

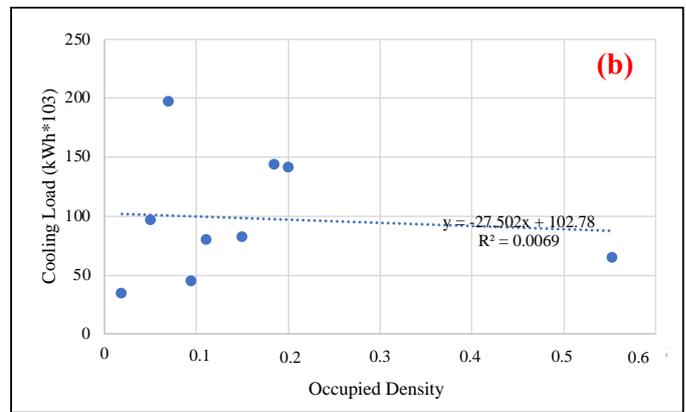
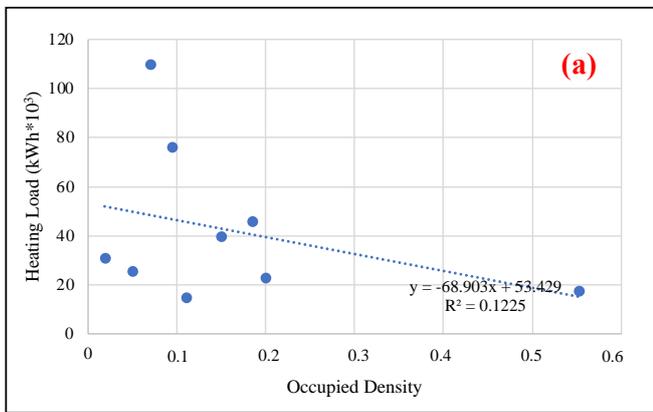


Figure 19. (a) Occupied density and heating load relationship, (b) occupied density and cooling load relationship

According to the relationship graph between occupied density and heating load, R^2 value is 0,12. This means that the relationship is very weak. According to the relationship graph between occupied density and cooling load, R^2 value is 0,0069, which shows that the relationship between these two variables is very weak as regression analysis. In order

to evaluate the effect of indoor heating and cooling values on the heating and cooling load, occupied density values were kept constant as 0.1 and indoor heating and cooling values were changed according to the determined function values and new simulations were taken and compared. The scatter plot of this comparison is given in Figure 20.

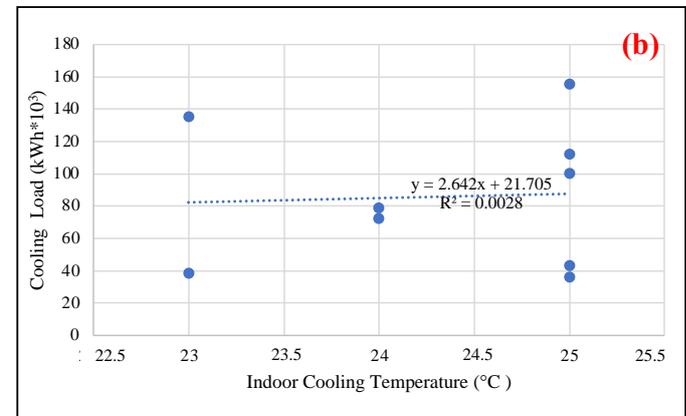
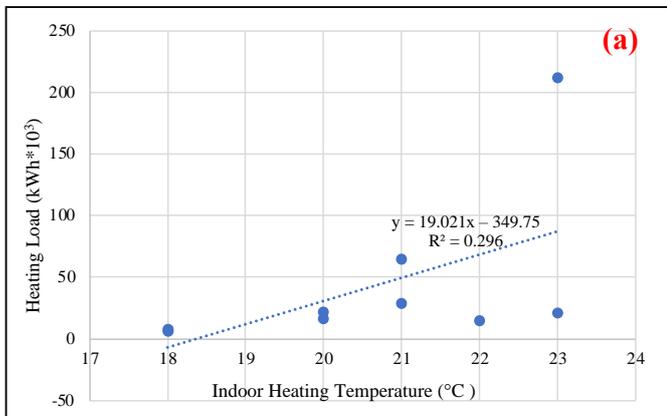


Figure 20. (a) indoor heating temperature and heating load relationship, (b) indoor cooling temperature and cooling load relationship

According to the relationship graph between indoor heating temperature and heating load, R^2 value is 0,29. It shows that the relationship is weak. In the relationship graph between indoor cooling temperature and cooling load, R^2 value is 0.0028. This value shows that there is no relationship. The necessity of conducting additional analyses arises to better understand and resolve these relationships.

The statistical significance of the regression model alone does not explain the cause-and-effect relationship (Kilinc 2013, Alpar 2010, Dawson and Trapp 2001). Apart from these parameters, there are activity characteristics, i.e., the duration of use of the spaces. It varies according to each venue. In order to investigate the effect of this parameter, correlation matrices were created and evaluated. Correlation analysis is a statistical technique used to determine whether a relationship exists between two variables and to assess the strength of that relationship. A correlation heatmap is a visual representation that illustrates the correlation between multiple variables in the form of a color-coded matrix. This tool employs a color scheme to indicate how strongly different variables are related. In a correlation heatmap, rows and columns represent the variables, and each cell reflects the correlation between a pair of variables. The color intensity of a cell signifies the strength and direction of the correlation, with darker shades

indicating stronger relationships (Turan, 2023). The correlation matrix offers insights into the strength and direction of the linear relationship between specified variables. Correlation values range from -1 to +1, where -1 represents a perfect negative correlation (i.e., an increase in one variable corresponds to a decrease in the other), +1 denotes a perfect positive correlation (i.e., both variables increase together), and 0 indicates no correlation between the variables (Çetin, 2024). As the correlation coefficient moves closer to zero, the strength of the relationship diminishes, whereas values closer to one indicate a stronger relationship (Öztuna et al., 2008). The strength of these relationships can generally be categorized as follows:

- 0,00-0,19 No relationship or negligibly low relationship
- 0.20-0.39 Weak relationship
- 0,40-0,69 Moderate relationship
- 0.70-0.89 Strong relationship
- 0,90-1,00 Very strong relationship (Choi et al. 2010, Sheskin 2011, Aslan et al. 2019).

A correlation matrix showing the relationship between climate, schedule, occupied density, target illuminance and lighting load parameters and climate, building type, occupied density, target illuminance and lighting load parameters was created (Figure 21 a, b, c).

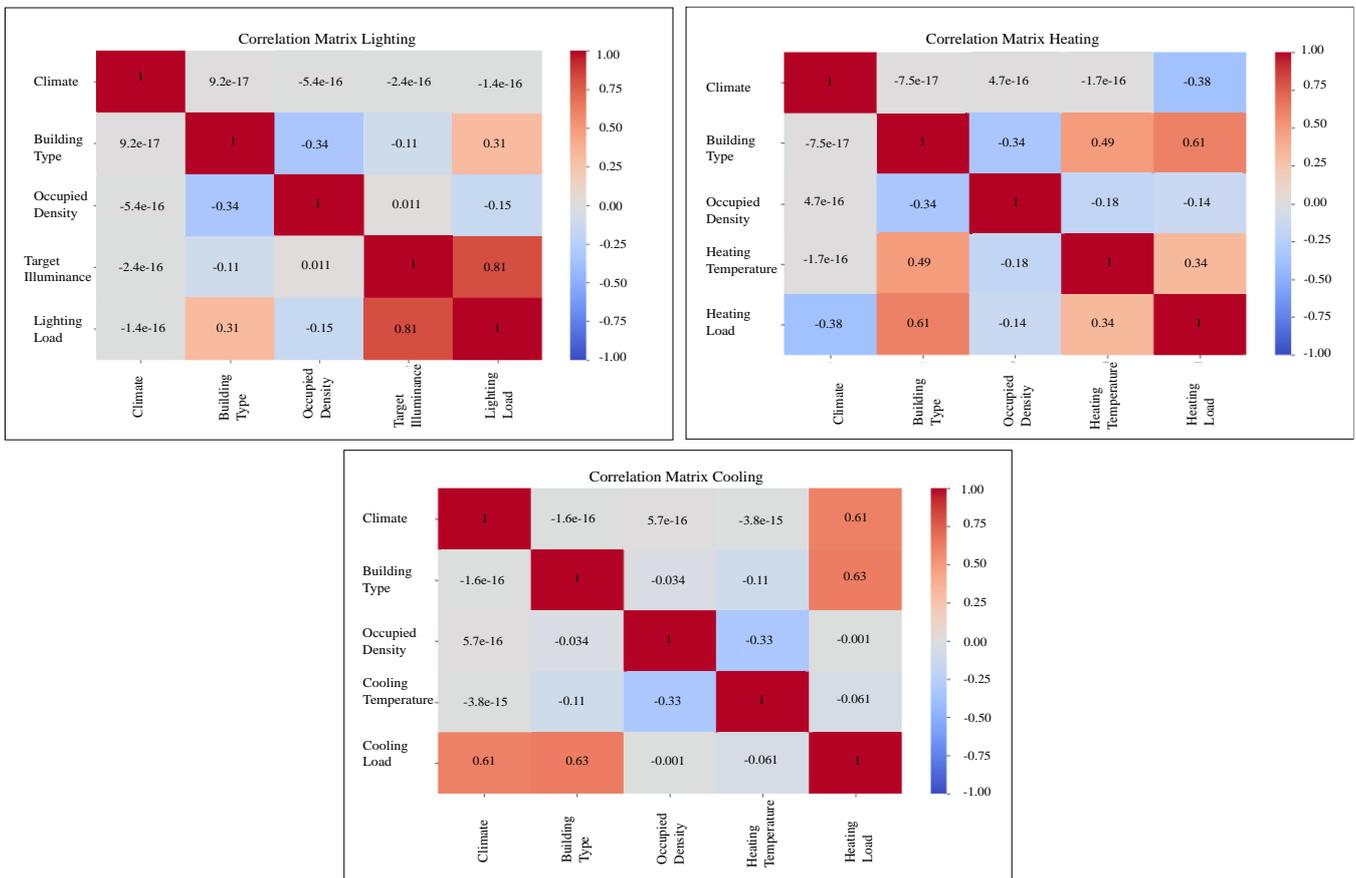


Figure 21. (a) correlation matrix of lighting load and related parameters, (b) correlation matrix of heating load and related parameters, (c) correlation matrix of cooling load and related parameters.

According to the data in the correlation matrix given in figure 21a, the relationship between lighting load and climate seems to be negligible. There is a low positive correlation between lighting load and building type, a weak negative correlation with occupied density and a strong positive correlation between lighting load and target illuminance. With the strong relationship between the lighting load of the buildings and the target illuminance value, it is concluded that while one increases, the other increases. According to the correlation matrix data given in figure 21b, it is seen that there is a positive moderate relationship between heating load and building type. The relationship level with other parameters is weak. Again in Figure 21c, the matrix of the relationship between the cooling load and the changing parameters is given. There is a moderate relationship between cooling load and climate and building type. It seems to be weakly related with other parameters.

CONCLUSIONS AND RECOMMENDATIONS

In this study, the energy performance of buildings according to 9 different building function characteristics in three different climate zones was investigated. The energy differences between the heating-cooling loads of the buildings in climate zones are approximately 50-85%. While all physical design parameters are constant, it is determined that there are large differences between the heating loads according to the functions of the buildings. According to the building functions, 85-95% of the heating load differences between the building functions, the highest heating load is seen in hospitals, while the lowest heating load is seen in residences. This situation can be explained by the low level of physical activity in hospitals and the high heat demand in the spaces. Cooling loads also vary according to the functions of

the buildings. While the highest cooling load requirement is seen in terminals, the lowest cooling load is needed in residences. Houses have approximately 82-87% less cooling load than terminal buildings. Again, there are great differences in the lighting load according to the building function characteristics. The building function with the highest lighting load is hospitals. The lowest lighting load is observed in hotels. Hotels have 96% less lighting load than hospitals. In terms of total energy load, it is seen the highest in hospitals and the lowest in residences in all climate zones. All climate types have an average 85% difference in total energy loads. These are the general findings of the study. According to the statistical researches, while all physical parameters of the buildings are constant, the relationship between the changing parameters and building energy performance has been investigated and it is revealed that there are strong relationships between the climate factor and building energy performance, followed by schedule, occupied density and indoor temperature. The general conclusions and recommendations to be emphasised as a result of this research are given below.

- The heating and cooling load of spaces for all functions is directly related to the climate. It is an important requirement to make site-specific design decisions. It is clear that by developing design strategies by taking into account the physical environmental characteristics of the regions where the buildings are designed, savings of 50% and more can be achieved in the heating and cooling loads of the buildings.
- Functional characteristics of buildings affect the energy performance of buildings by 80% or more. This situation reveals that the function parameter of buildings is a very important parameter in terms of building energy

performance and design strategies should be developed according to the functional characteristics of buildings.

- The main reasons for the increase in energy demand are the user density, duration of use, and the general functional characteristics of buildings, particularly in spaces such as hospitals. Considering user density, duration of use, and the functions performed within the spaces is a critical factor in evaluating the energy performance of buildings.
- This situation, which is not taken into consideration during the design phase, will provide significant improvements in building energy performance by seeking solutions with smart meter systems. Future studies will focus on studies that will improve the energy needs of buildings according to their functional characteristics.
- In this study, BIM and BEM based software are used and the importance of BIM is emphasised. Such studies are frequently carried out in the literature and daily applications. These studies mostly investigate the physical parameters of buildings. However, this study is important in terms of emphasising the importance of parameters such as user density and behaviour.
- Active use hours, arrival and departure times, intensity of use should be investigated in depth. Studies are being carried out for this. By increasing these studies, usage schedules can be created and developed. The relationship between this and energy performance can be investigated.
- In addition to the space utilisation schedules, the demographic-socio-cultural structures of the user profiles and the characteristics of the actions performed should also be investigated in detail. Studies investigating the relationship between these structures and energy needs can be expanded. These recommendations extend to wider research communities and other research areas based on large-scale data.

In conclusion, understanding the role of occupant behavior in building energy performance is essential and warrants further investigation in future studies. The results of this research are anticipated to significantly influence the future of building energy assessments and open new avenues for further exploration in this area.

Data Availability Statement

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

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