ICONARP
International Journal of Architecture and Planning
Received: 12.01.2026 Accepted: 16.06.2026
Volume 14, Issue 1/ Published: 30.06.2026
Research Article *DOI: 10.15320/ICONARP.2026.356 E- ISSN:2147-9380*

Assessing Local Climate Impact on Energy and Emission Performance in Türkiye's Standardized Post-Disaster Housing

Bahar Başarır *
Gonca Özer Yaman **
Ebru Doğan Koç ***
Gürkan Kavuran ****
Beyzanur İnce *****
Gökçe Dağteke ******

Abstract

Designing energy-efficient buildings for reconstruction in disaster areas is essential for mitigating environmental challenges and supporting sustainable recovery. However, in Türkiye, standardized mass housing is often implemented following disasters for rapid reconstruction, frequently overlooking local climatic conditions. The Housing Development Administration of Türkiye (TOKİ) has initiated standardized mass housing projects across 11 provinces in the disaster area of the 2023 Türkiye-Kahramanmaraş earthquake. This study conducts a comparative analysis of heating and cooling energy consumption and CO_2 emissions for a reference TOKİ housing using DesignBuilder simulations across the 11 impacted provinces, to show the environmental impact of standardized material selection. The evaluated archetype features a rectangular geometry with a symmetrical floor plan, comprising 20 dwelling units and a fixed façade configuration governed by orientation. The façade consists of reinforced concrete shear walls, vertically perforated brick walls, and PVC-framed double-glazed windows. The analysis utilized the updated climate zoning of the Turkish Standard for Thermal Insulation in Buildings (TS 825), which recently expanded from four to six climate zones. Findings indicate significant variations: intra-zone annual heating and cooling energy consumption differed by up to 184.85% and 52.84%, respectively. CO_2 emissions showed relatively limited differences, with a maximum of 12.35% intra-zone. These findings show that energy consumption varies significantly both between and within climate zones, highlighting the limitations of relying solely on generalized climate zone data for building design and material selection. Moreover, an evaluation of the latest TS 825 revision shows that the updated classification does not yield consistent heating and cooling energy outcomes for certain provinces. The study concludes that province-specific climatic data should be integrated into post-disaster housing design, particularly during material selection, to improve energy efficiency, reduce emissions, and support sustainable recovery.

Keywords: *Climate-based design, CO_2 emissions, Energy efficiency, Standardized housing, TOKİ.*

*Department of Architecture, Faculty of Architecture, Mimar Sinan Fine Arts University, İstanbul, Türkiye. (*Corresponding author*)
E-mail: bahar.basarir@msgsu.edu.tr

**Department of Architecture, Faculty of Engineering and Architecture, Bingöl University, Bingöl, Türkiye.
E-mail: gozer@bingol.edu.tr

***Department of Interior Architecture, Faculty of Art, Design and Architecture, Malatya Turgut Özal University, Malatya, Türkiye.
E-mail: ebru.dogan@ozal.edu.tr

****Department of Electrical and Electronics Engineering, Faculty of Engineering and Natural Sciences, Malatya Turgut Özal University, Malatya, Türkiye.
E-mail: gurkan.kavuran@ozal.edu.tr

***** Institute of Graduate Studies, Department of Architecture, Mimar Sinan Fine Arts University, İstanbul, Türkiye.
E-mail: 20233101015@ogr.msgsu.edu.tr

****** Department of Architecture, Faculty of Architecture, Fırat University, Elazığ, Türkiye.
E-mail: gdagteke@firat.edu.tr

To cite this article: Başarır, B., Özer Yaman, G., Doğan Koç, E., Kavuran, G., İnce, B. & Dağteke, G. (2026). Assessing Local Climate Impact on Energy and Emission Performance in Türkiye's Standardized Post-Disaster Housing. *ICONARP International Journal of Architecture and Planning,* 14 (1), 131-162. DOI: 10.15320/ICONARP.2026.356

INTRODUCTION

The earthquakes centered in Kahramanmaraş on February 6 of 2023, affected 11 provinces, including Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Kahramanmaraş, Malatya, Hatay, Kilis, Osmaniye, and Şanlıurfa, resulting in one of the most devastating disasters in the history of Türkiye. As a result of the disaster, 20.662 buildings collapsed, and 105.794 buildings were severely damaged (Turkish Ministry of Environment, Urbanization, and Climate Change, [MoEUCC], 2023). That means at least 12.73% of the building stock in this region will be reconstructed. The severe level of destruction caused by the earthquake has led to a prolonged and costly reconstruction process. In particular, urgent housing construction was required to immediately resolve the housing problems in the disaster area.

The strategic planning of this large-scale transformation and new construction in the disaster area is of great importance for the preservation of resources and the achievement of environmental sustainability. It is well established that the construction industry's negative environmental impacts stem largely from high levels of energy and natural resource consumption (Najjar et al., 2019). Approximately 40% of global energy consumption originates from buildings (Sun et al.,2018; Javid et al., 2019; Ebrahimi-Moghadam et al., 2020). Housings are responsible for more than 65% of the total primary energy supply consumption of buildings (Harkouss et al., 2018). Designing new housing in the disaster area with consideration not only for structural integrity but also for environmental factors holds crucial potential for optimizing energy consumption, which is one of the critical challenges of our era.

The Housing Development Administration of Türkiye (TOKİ), a leading institution in post-disaster housing production (Begen, 2020), continues to play a significant role in the reconstruction process following the 2023 Kahramanmaraş earthquake, as it has in past events. However, TOKİ implements mass housing projects going into uniformity in terms of the spatial organizations and material selections across different climate zones, thereby disregarding the necessity for climate-based design (Çiçek, 2019). Whereas climate is the primary environmental parameter that determines a building's energy consumption (Özüer, 2012).

Numerous studies have assessed how standardized TOKİ mass housing projects affect the buildings' energy performance in various climate zones. Table 1 provides a summary of the scope of the 13 studies that were identified in the literature between 2010 and 2026. According to Table 1, the variation in annual cooling and heating energy consumption of typical housing projects in provinces representing different climate zones of Türkiye is largely analyzed; this is followed by lighting energy consumption and CO_2 emissions assessments. Notably, climate zones are typically represented by data from a single province, and provinces within the same climate zone are expected to exhibit similar performance. Meanwhile, according to climate classification

DOI: 10.15320/ICONARP.2026.356

systems from the Turkish Ministry of Environment, Urbanization, and Climate Change General Directorate of Meteorology (MoEUCC, 2025), it has been determined that the climate zones of provinces can vary depending on the classification system. For example, while Adana province is classified as semi-humid under the Aydeniz and Erinc classifications, it is categorized between semi-arid and humid in the DeMartonne classification and is identified as having a very hot climate based on the Turkish Standard for Thermal Insulation in Building (TS 825). This variation is due to differences in parameters such as precipitation, temperature, and evaporation used in different climate classification systems (MoEUCC, 2024).

Table 1. Analysis of studies published between 2010 and 2026 evaluating the effects of implementing standardized TOKİ mass housing projects across different climate zones on building energy performance.

Reference	TOKİ Project Type	Evaluated City / Climate Zone	Compared Data	Simulation Tool
Tuna et al., 2010	Sample project	Ankara and Antalya. According to TS 825, representing two distinct climate zones	Heating, cooling, lighting, and other energy consumption	Energy-10
Ünsal, 2012	Type C housing project	İzmir, Ankara, Erzurum, İstanbul and Diyarbakır. According to TS 825, representing four distinct climate zones	Heating and cooling energy	DB
Bektaş, 2013	Tarımköy housing project	Balıkesir, Mersin, Muğla, and Bolu, representing four distinct wind zones	Heating, cooling, lighting and total energy	DB
Mangan and Oral, 2013	A housing project completed in Istanbul, 2008	İstanbul, Antalya, and Erzurum. According to TS 825, representing three distinct climate zones	Heating and cooling energy, CO_2 emissions	DB and PV*SOL Expert
Sümen-gen and Yener, 2015	Sample project	İstanbul (41°N 28°E), Kayseri (38°N 35°E), and Antalya (36°N 30°E), representing three distinct climate zones	Lighting energy	-
Çetintaş and Yılmaz, 2019	Type C housing project	İstanbul (temperate-humid), İzmir (hot-humid), and Erzurum (cold), representing three distinct climate zones	Heating, cooling, lighting and domestic hot water energy	DB
Çiçek, 2019	Type C housing project	Ankara, İzmir, Erzurum, İstanbul and Gaziantep. According to TS 825, representing four distinct climate zones	Heating and cooling energy	DB
Taştemir, 2020	Type Y housing project	Ankara, Erzurum, İzmir and Antalya, İstanbul and Diyarbakır. According to TS 825, representing four distinct climate zones	Heating and cooling energy	DB

Table 1 (continued). Analysis of studies published between 2010 and 2026 evaluating the effects of implementing standardized TOKİ mass housing projects across different climate zones on building energy performance.

Reference	TOKİ Project Type	Evaluated City / Climate Zone	Compared Data	Simulation Tool
Haydar-aslan, 2021	Type A, B, C, D, K, R and Y housing projects	Representing two provinces from each of Antalya, Ardahan, Bayburt, Bilecik, Çanakkale, Gaziantep, İzmir, Isparta, Kırıkkale, Kütahya, Malatya, Sivas, Şanlıurfa, and Trabzon. Selected based on the highest and lowest average annual outdoor temperatures in Türkiye's seven geographical regions.	Heating, cooling, and lighting energy, and CO_2 emissions	DB
Arslan et al., 2014	Reference 2+1 TOKİ housing project	Gaziantep (hot-dry), Karaman (temperate-dry), Van (cold), Mersin (hot-humid), and Balıkesir (temperate-humid), representing five distinct climate zones in Türkiye	The effect of natural ventilation and wind on heating and cooling energy loads	Solidworks Flow Simulation
Cengiz et al., 2024	Sample project	Istanbul (temperate-humid) and Diyarbakır (hot-dry)	Cooling energy and cost	DB
Aşıkoğlu Metehan et al., 2025	Typical TOKİ building	Istanbul, Ankara, Antalya, Hakkari, and Erzurum. According to TS 825, representing five distinct climate zones in Türkiye	Heating and cooling energy consumption	TRNSYS
Kavuran et al., 2026	Reference TOKİ housing project	Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Kahramanmaraş, Malatya, Hatay, Kilis, Osmaniye, and Şanlıurfa. According to TS 825, representing three distinct climate zones in Türkiye	Electricity performance, energy-related decision framework	DB / AI-supported decision framework
DB: DesignBuilder; TRNSYS: Transient System Simulation Tool				

In TS 825, which is frequently used as a reference for the climate classification of provinces, Türkiye was divided into four degree-day (climate) zones based on heating energy demand in the initial 1998 report (Turkish Standards Institute [TSE], 1998). In the 1999 revision, while the climate zone categories remained the same, the climate zones of Şırnak, Düzce, and Bartın provinces were changed. Additionally, with this revision, adjustments were made for the first time to include certain districts in climate zones different from those of their respective provinces, based on microclimatic conditions (TSE, 1998; TSE, 2008). Most recently, in October 2024, the standard was revised to incorporate both heating and cooling energy demands into design calculations, and the number of climate zones increased from four to six degree-day

DOI: 10.15320/ICONARP.2026.356

(climate) zones (TSE, 2024). This revision resulted in significant changes in the climate zone classifications of many provinces (Table 2).

Table 2. Changes in the climate zones of Turkish provinces in the context of TS 825 revisions (adapted from TSE, 1998; TSE, 2008; TSE, 2024).

Provinces	**1999 and 2008 Climate Zones**	**2024 Climate Zones**
Adana, Antalya, İçel (Mersin)	1st Degree-Day Zone (Hot-Humid Climate Zone)	1st Degree-Day Zone (Very Hot Climate Zone)
Aydın, Hatay, İzmir, Osmaniye	1st Degree-Day Zone (Hot-Humid Climate Zone)	2nd Degree-Day Zone (Hot Climate Zone)
Adıyaman, Batman, Denizli, Gaziantep, Kahramanmaraş, Kilis, Manisa, Mardin, Siirt, Şanlıurfa	2nd Degree-Day Zone (Temperate Climate Zone)	2nd Degree-Day Zone (Hot Climate Zone)
Adapazarı (Sakarya), Balıkesir, Bursa, Çanakkale, Giresun, İstanbul, Kocaeli, Muğla, Ordu, Rize, Samsun, Sinop, Tekirdağ, Trabzon, Yalova, Zonguldak	2nd Degree-Day Zone (Temperate Climate Zone)	3rd Degree-Day Zone (Temperate Climate Zone)
Amasya, Diyarbakır, Edirne	2nd Degree-Day Zone (Temperate Climate Zone)	4th Degree-Day Zone (Cold Climate Zone)
Afyon, Aksaray, Ankara, Artvin, Bilecik, Bingöl, Bolu, Burdur, Çankırı, Çorum, Düzce, Elazığ, Eskişehir, Iğdır, Isparta, Karabük, Karaman, Kırıkkale, Kırklareli, Kırşehir, Konya, Kütahya, Malatya, Nevşehir, Niğde, Tokat, Tunceli, Uşak	3rd Degree-Day Zone (Cold-Dry Climate Zone)	4th Degree-Day Zone (Cold Climate Zone)
Erzincan, Kayseri	4th Degree-Day Zone (Very Cold-Continental Climate Zone)	4th Degree-Day Zone (Cold Climate Zone)
Bayburt, Bitlis, Gümüşhane, Hakkâri, Kastamonu, Muş, Sivas, Van, Yozgat	4th Degree-Day Zone (Very Cold-Continental Climate Zone)	5th Degree-Day Zone (Very Cold Climate Zone)
Ağrı, Ardahan, Erzurum, Kars	4th Degree-Day Zone (Very Cold-Continental Climate Zone)	6th Degree-Day Zone (Extremely Cold Climate Zone)

Climate is established to be the primary environmental parameter determining a building's energy consumption. However, as explained above, since provinces are located in different climate zones within different climate classifications, and due to the changes in the climate zones of provinces over the years, as in TS 825, the approach of designing buildings solely within the context of their climate zones, without considering the microclimate characteristics of the provinces, is also open to debate. As far as the conducted review is concerned, no study has been found in the literature that comparatively analyzes the variations in the energy performance of standardized housing projects across provinces located within the same climate zones. Whereas, identifying the potential energy performance differences of standardized housing projects among provinces within the same climate zone and different climate zones would greatly contribute to understanding the impact of microclimatic variations on building energy performance.

In the context of the problems outlined above, this study aims to conduct a comparative analysis of how the energy consumption and environmental impact performance of a standardized TOKİ housing project planned for construction in 11 provinces affected by the 2023 earthquake centered in Kahramanmaraş, differ among provinces located within the same and different climate zones according to the TS 825 classification. Since TS 825 classifies climate zones according to heating and cooling energy, heating and cooling energy consumption was used to determine the energy performance, and CO_2 emission data was used to determine the environmental impact. These data were obtained on a provincial basis, both annually and monthly, through the modeling and simulation of the standardized housing project using the DesignBuilder software. CO_2 emissions, heating and cooling energy consumption values were examined separately on a monthly and annual basis, and the difference between the province with the lowest values and the other provinces was calculated as a percentage, so that the range in which the data varied between provinces located in the same and different climate zones was analyzed.

The characteristics of the selected reference housing project, the climatic data of the provinces, and the methods used for modeling and simulating the project are presented in Section 2; the analysis of the province's annual and monthly heating and cooling energy consumption as well as CO_2 emission data based on climate zones is provided in Section 3; the comparative analysis of the data in the context of climate zones is discussed in Section 4. The findings indicate that both macroclimatic and microclimatic differences among provinces play a decisive role in energy consumption and CO_2 emissions. Accordingly, it has been demonstrated that adapting housing projects to the local climatic conditions of provinces, and even districts, is crucial for both energy efficiency and environmental sustainability.

MATERIAL AND METHOD

This section details the methodological framework used to analyze the study's reference project. First, the structural and spatial characteristics of the reference TOKİ housing project are defined. Next, the climatic profiles of the 11 provinces affected by the 2023 Kahramanmaraş earthquakes are categorized according to TS 825:2024 standard. Finally, the digital modeling and simulation process is explained, outlining the parameters used to generate the energy and environmental dataset.

Reference TOKİ Housing Project

Due to being one of the first settlements built in the disaster area following the 2023 Kahramanmaraş earthquake, and its project was made available by TOKİ, the mass housing settlement constructed in the Yeşilyurt district of Malatya province was analyzed within the scope of this study (Fig. 1). The settlement utilizes two block types, Type-1 and Type-2 (Fig. 2). Each block type was evaluated individually with respect

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to its structural and material characteristics, spatial organization, spatial dimensions, number of units, and orientation factors. The settlement was established on sloped terrain, and both block types were designed with a basement and four stories above the ground floor. There are 4 flats per floor in both block types. Type-1 was selected as the reference because its rectangular form makes its energy performance more sensitive to orientation. According to information obtained from TOKİ officials, since this block type will continue to be implemented in all earthquake-affected cities, the reference project represents the housing typology commonly constructed in the disaster area.

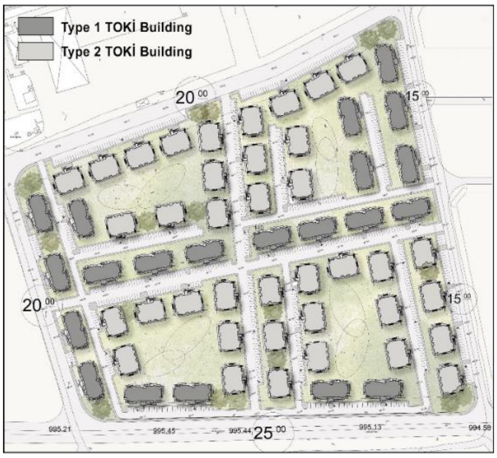

Figure 1. Malatya, Yeşilyurt mass housing settlement constructed by TOKİ (Adapted from the drawings provided by TOKİ).

Figure 2. (a) Block Type -1 and (b) Block Type -2 ground floor plans (Adapted from the drawings provided by TOKİ).

The reference block measures 35.10 m in width and 17.80 m in length. Each floor contains four symmetrically arranged apartments, totaling 20 apartments in a single block. The apartments with a net usable area of 105.16 m^2 consist of three bedrooms, a living room, a kitchen, and wet areas. The block was designed and constructed using the tunnel formwork construction system. According to this construction technique, the façade wall structure consists of two different types: vertically perforated brick walls and reinforced concrete shear walls (Fig. 3). Local stone cladding was used on the ground floor, and acrylic-based exterior paint was used on the upper floors as finishing of the façade walls. Windows feature PVC frames and 4+16+4 mm double glazing with heat-control coating on the first glass.

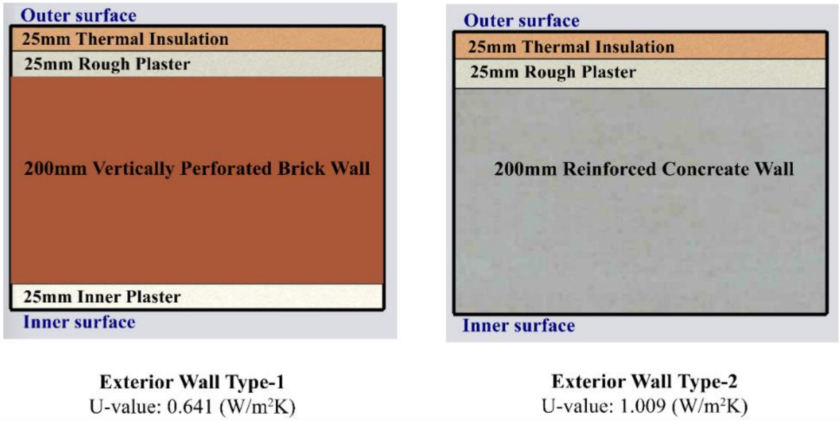

Figure 3. Reference building's façade wall types, their layers, and U-values.

Window-to-wall ratio (WWR) is the variable with the most significant impact on energy consumption (Elgohary et al., 2023). It is also the most important passive façade design parameter affecting both total energy consumption and daylight levels (Abdou et al., 2022). In this context, the WWR values have a critical importance in terms of building energy performance. For the reference block, WWR values were calculated as 29.1247% on the front (entrance), 25.9949% on the rear, and 11.1483% on the side façades.

The building typology and envelope details used in this study were derived from the construction documents of the TOKİ mass housing settlement constructed in the Yeşilyurt district of Malatya province, which were accessible within the scope of the research. This project was used as a representative reference scenario for the comparative simulations conducted across 11 provinces. However, this does not imply that identical construction details are applied in all TOKİ projects or in all provinces. TOKİ implementations may vary depending on local climatic conditions, material availability, construction practices, and project-specific design decisions.

The building envelope properties were defined based on the architectural and technical drawings obtained from TOKİ, including section details, material layers, material types, thicknesses, and material item numbers specified in the tender documents. During the DesignBuilder modelling process, the closest corresponding materials available in the software's material library were selected to represent these components as realistically as possible. Therefore, the calculated U-values and envelope characteristics reflect the accessible construction documents' details rather than idealized or optimized standard solutions.

In this study, the same reference building geometry, envelope configuration, and system assumptions were kept constant across all provinces to isolate the effect of climatic variability on heating and cooling energy consumption and CO_2 emissions. Therefore, the model should be interpreted as a standardized analytical reference scenario, while possible differences between project documents and actual on-site construction practices should be acknowledged as a limitation of the study.

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Climatic Characteristics of the Provinces

Since the reference TOKİ housing project examined in this study is going to be implemented in all provinces affected by the 2023 Kahramanmaraş-centered earthquake, the climatic characteristics of the relevant 11 provinces were examined. The relevant provinces span three of Turkey's six climate zones as defined by TS 825:2024 (Fig. 4). Some districts of these provinces may exhibit different climatic characteristics from the province's primary climate zone (Fig. 4). However, within the scope of this study, the provinces were evaluated based on their primary climate zone, and variations at the district level were disregarded.

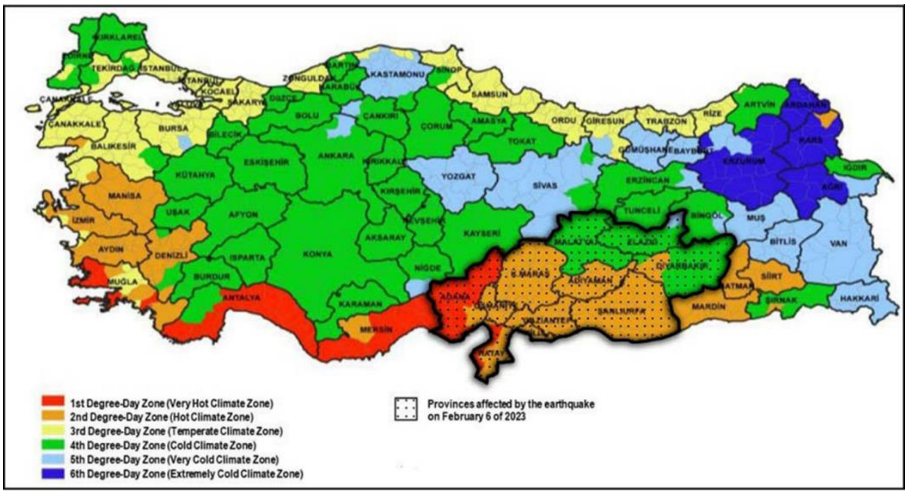

Figure 4. Location of the provinces affected by the 2023 Kahramanmaraş earthquake is shown at TS 825:2024 climate zones map of Türkiye (adapted from İZODER, 2025).

In the energy simulations, the climatic data of the provinces in the EnergyPlus Weather (EPW) format were utilized. The dataset includes monthly values of the following meteorological parameters for each province: outdoor dry-bulb air temperature (°C), outdoor dew-point temperature (°C), wind speed (m/s), wind direction (°), solar altitude angle (°), solar azimuth angle (°), atmospheric pressure (Pa), direct normal irradiance (kWh/m^2), and diffuse horizontal irradiance (kWh/m^2) (Climate One Building, 2025). Since these values vary from one province to another, it is expected that the energy performance of the reference project will likewise differ across provinces.

Modelling and Simulation Methodology

This study utilized DesignBuilder v7.3.1.003 for dynamic building energy simulations to analyze the impact of diverse climatic conditions on the energy performance of reference housing project. Built on the EnergyPlus simulation engine, this software is preferred for obtaining reliable and detailed building energy simulation data. Its simulation results show only minor differences from the actual values when evaluated by considering the building envelope properties and air conditioning system parameters of the comparative model (Liu et al., 2023). Furthermore, the software is validated by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

Building Energy Simulation Test as a highly accurate diagnostic tool (Mousav, et al., 2023). Unlike other software, DesignBuilder enables a holistic assessment of multiple parameters, allowing energy-focused decisions to be integrated directly into the design process (Crawley et al., 2008).

In the DesignBuilder software, the modeling and simulation process was conducted in several stages. First, a mass model was developed by importing 2D AutoCAD drawings, including basement, ground, typical floor, and roof plans, to serve as the architectural basis. The exterior and interior walls were drawn, window and door openings were created, and the floor model was divided into zones. In the modeling process, slabs are automatically defined when the mass is created by following the exterior wall lines. Floor openings for zones such as ventilation shafts, service ducts, and stairwells were created and incorporated into the model. Fig. 5 illustrates the mass model of a typical floor.

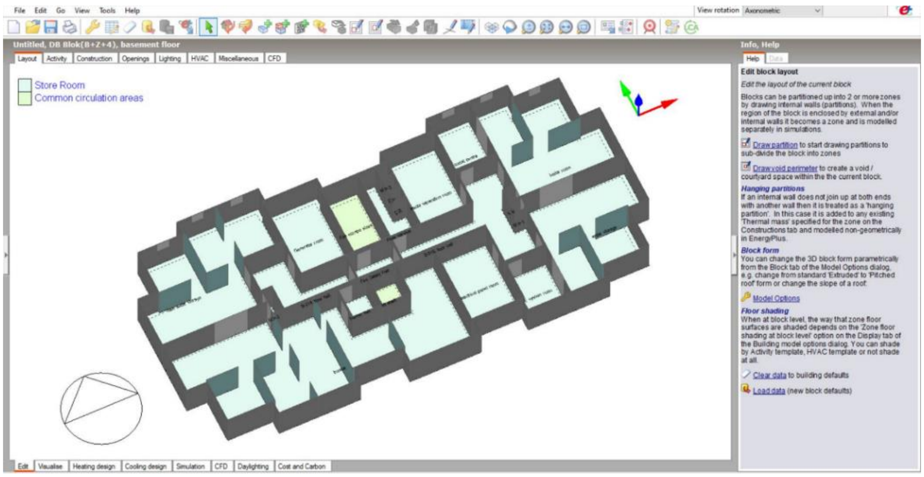

Figure 5. Typical floor mass model of the reference housing project created in DesignBuilder.

The second stage involved defining zone activity types to specify space functions. Activity definitions specify the occupancy rates of the zones and the parameters regarding the days and hours of their use. Accordingly, the activity information for each space within the building's individual units (such as living room, kitchen, bedroom, and bathroom) was defined separately by selecting the appropriate template under the 'Residential Spaces' section available in the software.

Another crucial stage is defining the layers and their materials for all wall, floor, roof, door, and window elements. For this purpose, the relevant building element for which the material is to be defined was selected; the material types, layers, thicknesses, and U-values of each element were entered into the software. The energy model, developed by creating the mass model and defining the materials and activities, is given in Fig. 6.

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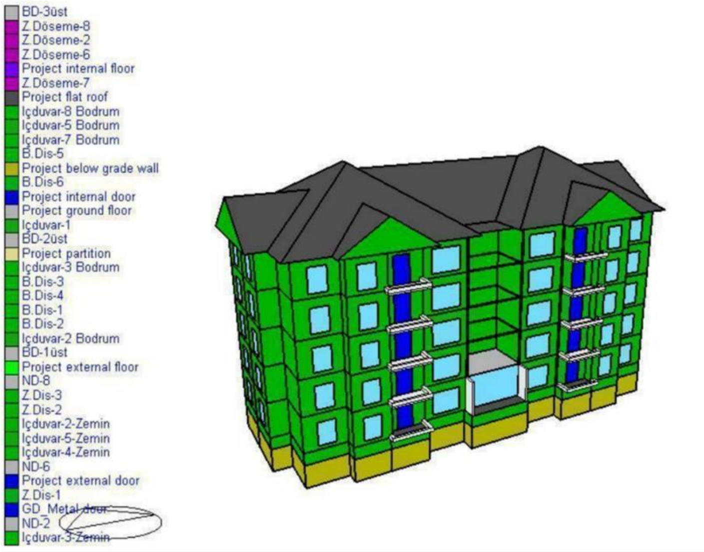

Figure 6. The building energy model obtained by the modelling and simulation process.

The HVAC system used in this study was considered as a standardized system definition to enable a comparable analysis of building energy performance. In this context, the "four-pipe fan coil system supported by an air-cooled chiller" template available in DesignBuilder was used in the model. This system was selected to allow heating and cooling loads to be analysed in a balanced and controllable manner. Although it is known that centralized cooling systems are not commonly used in TOKİ housing, the system was adopted as a fixed reference HVAC assumption to compare the energy performance of the building envelope across different climatic regions. Therefore, this HVAC-related assumption should be regarded as a modelling convention introduced to ensure comparability of the analysis results. Accordingly, the results should be interpreted as relative performance comparisons rather than absolute energy consumption values.

In the simulation model, indoor conditions were defined based on the reference values of the EnergyPlus (EP) calculator. Accordingly, the indoor and outdoor reference temperatures for heat transfer calculations were accepted as 21 °C and −18 °C, respectively. In terms of thermal comfort and system control, heating and cooling set points are defined according to specific temperature values. For the heating system, the indoor set temperature is defined as 21 °C, and 12 °C (setback temperature) during nighttime or off-peak hours. For the cooling system, the indoor set temperature is defined as 25 °C, and 28 °C when not in use. These set points were determined to represent residential use scenarios and were kept constant across all simulations to enable comparable and controlled analysis of building energy performance.

Finally, province-specific climatic data were integrated into the software. Since DesignBuilder operates using the EnergyPlus simulation engine, the climatic data must be in EnergyPlus Weather (EPW) format. The accuracy of building energy simulations is directly dependent on the extent to which the climatic data used in the model reflects actual environmental conditions. In this study, Typical Meteorological Year

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(TMY) weather files in EPW format were used to represent the climatic conditions of the selected provinces. TMY datasets are standard climate files derived from multi-year observations and statistically represent long-term climatic behaviour; therefore, they are widely used in building energy simulations. These data enable simulations to be conducted by considering outdoor climatic conditions throughout the year. TMY weather files in EPW format contain numerous meteorological parameters, including hourly outdoor air temperature, relative humidity, solar radiation, wind speed and direction, and barometric pressure.

Although DesignBuilder includes a built-in climatic data library for various cities around the world, the climatic data for the provinces examined in this study were not available in the software's existing database. Therefore, the meteorological data used in this study were obtained from the Climate One Building (2025) repository, which provides EPW files for building energy simulations. In this context, for each of the 11 earthquake-affected provinces, EPW files were downloaded from the Climate One Building (2025) database and manually imported into DesignBuilder.

Using the model prepared with the method described above, energy simulations were conducted for each province based on their respective climatic data. Since the reference TOKİ project was built in 2023, the energy simulations were set to run from January 1 to December 31 of this year. As a result of these simulations, monthly heating and cooling energy consumption as well as CO_2 emission data were obtained for each province. This approach allowed the effects of local climatic conditions on building energy performance to be comparatively evaluated.

As actual energy consumption data for the examined post-disaster housing units were not available at the time of the study, a measurement- or monitoring-based calibration process could not be conducted. Some of the newly constructed housing units in the earthquake-affected provinces had only recently been occupied, while many others were still under construction or in the planning stage. Therefore, the reliability of the simulation model was addressed through simulation-based comparisons and consistency checks, as commonly applied in building energy performance studies when monitored data are unavailable. In this context, the same reference building geometry, envelope configuration, HVAC assumptions, operational schedules, and indoor temperature setpoints were kept constant across all provinces, allowing the effects of climatic variation to be isolated and compared systematically.

FINDINGS

This section presents the monthly and annual data of heating and cooling energy consumption and CO_2 emission, generated by simulating the reference TOKİ housing project across 11 earthquake-affected provinces, and their analyses according to each province's specific climate zone.

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Heating Energy Consumption

The monthly and annual heating energy consumption (kWh/gas) data of the reference TOKİ housing project for the 11 provinces are given in Table 3. The monthly consumption data is visualized as a graph in Fig. 7 to allow faster and more straightforward identification of consumption tendencies and outliers.

Table 3. Heating energy consumption (kWh/gas) by month for 11 earthquake-affected provinces.

City	January	February	March	April	May	June	July	August	September	October	November	December	Total
Adana	10279,3	8090,04	6986,9	4029,81	38,07	3,76	0	0	16,16	148,98	4766,3	13843,42	48202,67
Osmaniye	17369,2	10391,6	5787	1219,64	111,92	14,21	0,95	0	4,92	108,46	1820,84	11155,17	47983,96
Hatay	14859,6	9742,12	3418,8	653,33	73,24	0,16	0	0	6,5	108,77	1957,7	9849,67	40669,85
Kilis	19226,3	10382,1	5865,9	1152,09	151,18	3,08	0	0,03	13,95	74,71	3594,32	11715,57	52179,23
Gaziantep	27996,5	25223,2	18713	5880,99	370,14	42,62	1,91	0	50,86	2772,7	16104,51	18693,53	115849,8
Kahramanmaraş	24755,7	17011,5	11103	2889,59	325,8	36,69	8,63	0,4	28,39	215	7930,82	17996,02	82301,7
Şanlıurfa	18868,4	14439	6292,6	914,36	131,13	0,11	0	0	1,56	91,78	36,53	12175,97	52951,42
Adıyaman	23892,3	17090,1	9197,6	2246,45	346,37	13,06	0,01	0,49	22,39	234,14	6926,86	17451,96	77421,78
Malatya	29266,2	20427	13048	3798,44	472,6	70,46	36,87	7,83	80,95	2294,6	9279,14	20371,95	99154,09
Diyarbakır	25916,2	18438,4	11515	2856,75	338,95	24,14	0	0,05	31,75	447,35	8938,82	22152,63	90659,64
Elazığ	30591,5	23062,6	15017	6243,55	634,8	76,12	8,3	4,18	111,84	955,77	12776,93	26239,83	115722,2

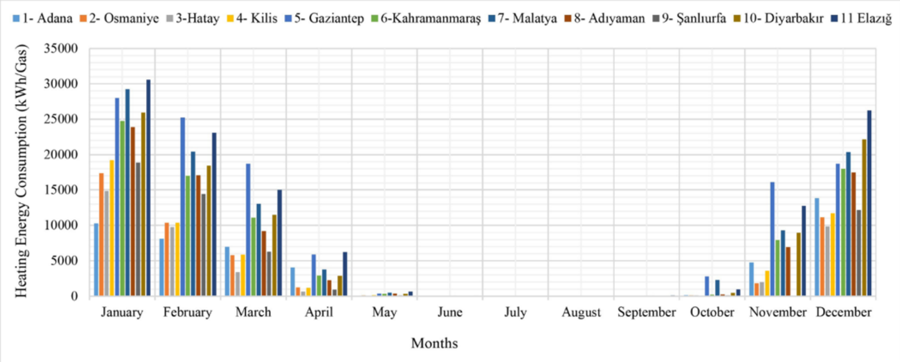

Figure 7. Heating energy consumption graph by month and 11 provinces.

On a monthly basis, the highest heating energy consumption was observed in January. In January, the highest consumption was recorded in Elazığ (4th climate zone), while the lowest consumption was observed in Adana (1st climate zone). The consumption difference between these two provinces is 197,60%. Gaziantep, Malatya, and Diyarbakır, where consumption also exceeded 25.000 kWh/gas in January, became the provinces that consumed the most heating energy after Elazığ. Supporting these high consumption values, Elazığ, Malatya, and Diyarbakır are located in the cold, 4th climate zone, and the consumption difference within this climate zone was limited to 18,4%. However, it is noteworthy that Gaziantep, located in the 2nd climate zone, consumes heating energy at a similar level to the provinces located in the cold climate zone. In January, the difference in heating energy consumption between the highest and lowest consuming provinces in the 2nd climate zone, Gaziantep and Osmaniye, reached 61,18%.

In February, the highest heating energy consumption was recorded in Gaziantep (2nd climate zone), while the lowest consumption was observed in Adana (1st climate zone), representing a 211,78% difference. The highest and lowest consumption in March, with a difference of 447.36%, were recorded in Gaziantep and Hatay, which are both in the 2nd climate zone. As of April, a significant decrease in energy consumption was observed across all provinces. The highest heating energy consumption for the month was observed in Elazığ (4th climate zone), while the lowest consumption was recorded in Hatay (2nd climate zone).

During June, July, and August, heating energy consumption across all provinces remained below 80 kWh/gas, and even dropped to zero in some provinces, representing the lowest values of the year. Therefore, the values for these months are represented in the graphs as being close to zero. In September, heating energy consumption also remained relatively low, staying below 100 kWh/gas in all provinces except Elazığ (4th climate zone). By October, heating energy consumption began to rise again, exceeding 2.000 kWh/gas in Gaziantep (2nd climate zone) and Malatya (4th climate zone). The highest and lowest heating energy consumption of this month were observed in provinces in the 2nd climate zone: Gaziantep at 2.772,70 kWh/gas and Kilis at 74,71 kWh/gas. In

DOI: 10.15320/ICONARP.2026.356

November, the highest and lowest heating energy consumption of the month were recorded in the 2nd climate zone respectively as 16.104,51 kWh/gas in Gaziantep and 36,53 kWh/gas in Şanlıurfa. In December, a significant increase in consumption values was detected across all provinces. The highest consumption was recorded in Elazığ (4th climate zone), while the lowest consumption was observed in Hatay (2nd climate zone), with a difference of 166,40%.

The annual heating energy data of the provinces were also analyzed and visualized as presented in Fig. 8 and Table 4. In Fig. 8, the climatic zones of the provinces were indicated by color codes, and provinces were presented in ascending order based on their annual heating energy consumption. The provinces were classified according to the climate zones specified in TS 825:2024, and the heating energy consumption differences among the provinces were expressed as percentages based on the province with the lowest consumption, in Table 4.

Figure 8. Annual heating energy consumption ranking of the 11 provinces

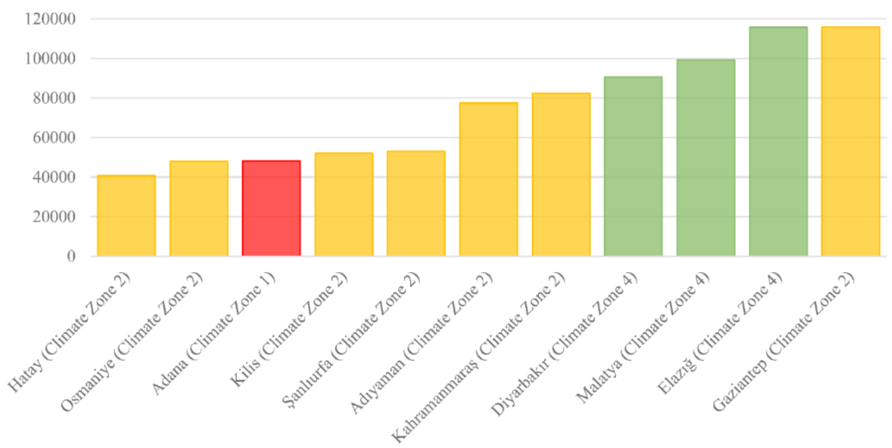

Table 4. Annual heating energy consumption comparison of the 11 provinces with percentage values.

TSE 825 Climate Zones	**Percentage Values of Heating Energy Consumption Differences of Provinces (Low → High)**	**Percentage Values of Heating Energy Consumption Differences of Provinces Within The Same Climate Zone (Low → High)**
1.Climate Zone (Very Hot)	Adana (18,5%)	Adana (N/A)
2.Climate Zone (Hot)	Hatay (base-point) → Osmaniye (17,98%) → Kilis (28,29%) → Şanlıurfa (30,19%) →Adıyaman (90,36%) → Kahramanmaraş (102,36%) → Gaziantep (184,85%)	Hatay (base-point) → Osmaniye (17,98%) → Kilis (28,29%) → Şanlıurfa (30,19%) →Adıyaman (90,36%) → Kahramanmaraş (102,36%) → Gaziantep (184,85%)
4.Climate Zone (Cold)	Diyarbakır (122,91%) →Malatya (143,80%) → Elazığ (184,74%)	Diyarbakır (base-point) → Malatya (9,37%) → Elazığ (27,64%)
Note: N/A (non-applicable)		

According to simulation data, the lowest annual consumption was observed in Hatay, which is in the 2nd climate zone. Hatay is followed by Osmaniye (2nd climate zone), and Adana (1st climate zone), with respectively 17,98% and 18,5% more consumption. The highest annual heating energy consumption values were observed in Gaziantep, followed by Elazığ and Malatya. It is noteworthy that Gaziantep, located in the 2nd climate zone with hot climate conditions, requires 0.11% and 16.84% more heating energy than Elazığ and Malatya, both located in the 4th climate zone with cold climate characteristics.

Significant differences were also identified when comparing the annual heating energy consumption of provinces within the same climatic zone (Table 4). Considering the 2nd climate zone (hot climate), there was a difference of 184.85% between the highest and lowest annual heating energy consuming provinces, Gaziantep and Hatay. In Kahramanmaraş, which is also in the same climate zone, consumption was predicted to be 102,36% higher than Hatay and 28,98% lower than Gaziantep. Comparing the provinces located in the 4th climate zone, Elazığ is expected to consume 16.71% more heating energy than Malatya and 27.64% more than Diyarbakır. Based on these data, it can be clearly stated that provinces within the same climatic zone do not exhibit similar heating energy consumption performance.

Cooling Energy Consumption

The monthly and annual cooling energy consumption (kWh/electricity) data for the reference TOKİ housing in the 11 provinces are presented in Table 5. To facilitate the identification of consumption trends and outliers, monthly consumption data are visualized in Figure 9.

Table 5. Cooling energy consumption (kWh/electricity) values by month for 11 earthquake-affected provinces.

City	January	February	March	April	May	June	July	August	September	October	November	December	Total
Adana	1109,03	1125,58	771,71	891,5	5914,9	10821	16894	21946,1	10554,9	4090,7	1325,29	847,07	76291,8
Osmaniye	1235,68	1151,54	1388,7	1546	3068	7559,2	13968	17290,5	11614,48	5269,1	2152,96	1319,54	67563,7
Hatay	1277,04	1309,64	1430,8	1553	3249,1	9335,5	15846	17189,7	13540,3	6019	1986,77	1246,52	73983,3
Kilis	983,23	1163,26	1233	1516	2524,5	7626,7	12779	13473	10106,0	5611,9	1883,33	1301,14	60201,1

DOI: 10.15320/ICONARP.2026.356

Table 5 (continued). Cooling energy consumption (kWh/electricity) values by month for 11 earthquake-affected provinces.

City	January	February	March	April	May	June	July	August	Septembe	October	Novembe	Decembe	Total
Gaziantep	596,62	306,71	375,04	750,8	1133,8	6290,4	11263	16197,9	8241,85	1945,5	864,04	952,1	48917,76
Kahramanmaraş	1104,77	1120,78	1184	1320	1391,5	6744	12544	13340,4	8623,03	4268,4	1486,8	1090,84	54218,52
Şanlıurfa	1183,22	1285,11	1520,1	1763	2944,1	10905	16373	16398	12510,86	6607,9	1946,63	1329,83	74766,75
Adıyaman	1029,37	1069,65	1332,8	1386	1526,2	8488,5	14755	15117,8	10421,28	5074,7	1506,9	1116,25	62824,45
Malatya	1330,75	1171,63	1577,7	1272	1215,1	5510,9	8951,7	9105,91	5927,6	2305	1480,05	1172,27	41020,6
Diyarba	1063,14	1081,58	1225,5	1325	2256	8736,6	14168	14767,2	8760,89	3640,1	1395,57	1088,67	59508,2
Elazığ	917,37	1070,49	1291,3	1036	1000,2	4754,5	9782,6	11572,9	6209,8	3398,2	1390,58	988,58	43412,5

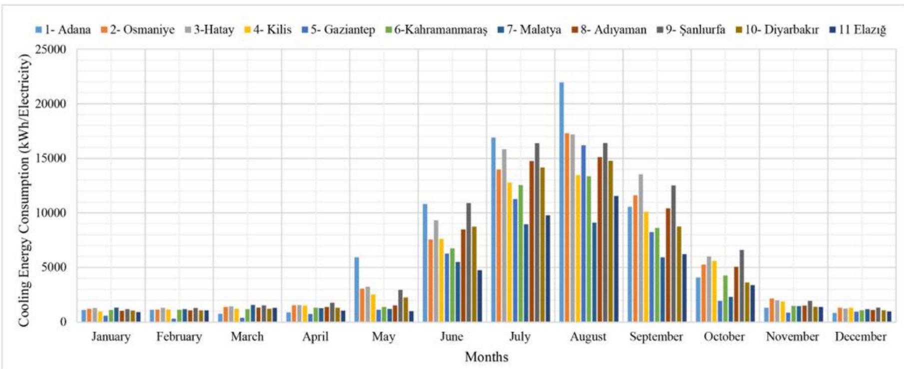

Figure 9. Cooling energy consumption graph by month and 11 provinces.

On a monthly basis, the lowest cooling energy consumption was observed in December, January, February, March, and April. In December, the highest cooling energy consumption was recorded in Şanlıurfa, (2nd climate zone), while the lowest consumption was observed in Adana (1st climate zone), with a difference of 56,99%. In January, the highest cooling energy consumption was recorded in Malatya (4th climate zone), while the lowest consumption was observed in Gaziantep (2nd climate zone), with a difference of 123,05%. In February, the highest and lowest cooling energy consumption, differing by 327%, were recorded in Hatay and Gaziantep, both located in the 2nd climate zone. In March, the highest cooling energy consumption was recorded in Malatya (4th climate zone), while the lowest consumption was observed in Gaziantep (2nd climate zone), with a difference of 320,68%. In April, the highest and lowest cooling energy consumption, differing by 134,82%, were recorded in Şanlıurfa and Gaziantep, both located in the 2nd climate zone. As of May, the lowest cooling energy consumption exceeded 1.000 kWh/electricity in Elazığ (4th climate zone), and the highest cooling energy consumption was recorded in Adana (1st climate zone) with 5.914,9 kWh/electricity. The consumption difference reached 491,37%.

Starting in June, a considerable, gradual increase in cooling energy consumption began across all provinces and continued through July and August. In June, the highest cooling energy consumption was recorded in Şanlıurfa (2nd climate zone), while the lowest consumption was observed in Elazığ (4th climate zone), with a difference of 129,36%. In July, the highest cooling energy consumption was recorded in Adana (1st climate zone), while the lowest consumption was observed in Malatya (4th climate zone), with a difference of 88,72%.

The highest cooling energy consumption of the year was observed in August. That month, the highest consumption was recorded in Adana (1st climate zone), while the lowest consumption was observed in Malatya (4th climate zone). The consumption difference between these provinces is 141,01%. In August, consumption in Osmaniye, Hatay, Gaziantep, Şanlıurfa, and Adıyaman also exceeded 15.000 kWh/electricity, making them the provinces with the highest cooling energy use after Adana. The fact that each of these provinces is in the 2nd climate zone, while Adana is in the 1st climate zone, supports this observation.

A gradual decrease in cooling energy consumption was again observed across all provinces in September, October, and November. In September, the highest cooling energy consumption was recorded in Hatay (2nd climate zone), while the lowest consumption was observed in Malatya (4th climate zone), with a difference of 128,43%. In October, the highest and lowest cooling energy consumption, differing by 239,65%, were projected in Şanlıurfa and Gaziantep, both located in the 2nd climate zone. In November, the highest and lowest cooling energy consumption, differing by 149,17%, were determined in Osmaniye and Gaziantep, both located in the 2nd climate zone.

The annual cooling energy data of the provinces were also analyzed and visualized as presented in Fig. 10 and Table 6. In Fig. 10, the climatic zones of the provinces were indicated by color codes, and provinces were presented in ascending order based on their annual cooling energy consumption. In Table 6, the provinces were classified according to the

DOI: 10.15320/ICONARP.2026.356

climatic zones specified in TS 825:2024, and the cooling energy consumption differences among the provinces were expressed as percentages based on the province with the lowest consumption.

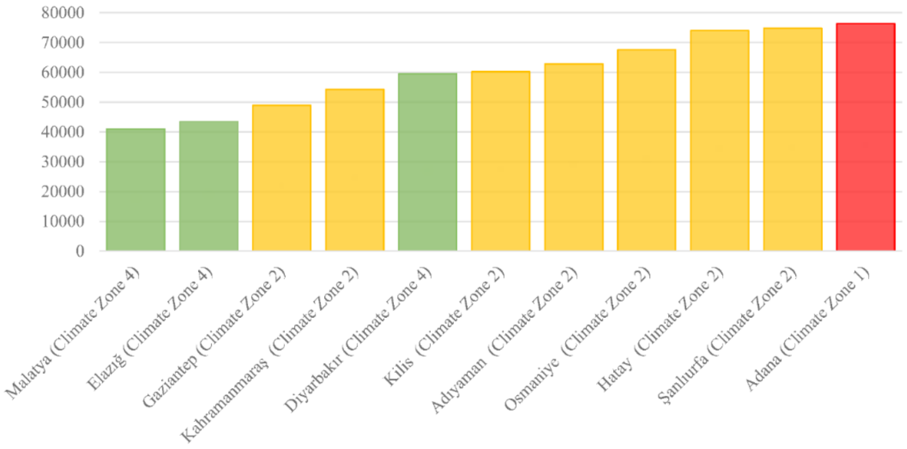

Figure 10. Annual cooling energy consumption ranking of the 11 provinces.

Table 6. Annual cooling energy consumption comparison of the 11 provinces with percentage values.

TSE 825 Climate Zones	**Percentage Values of Cooling Energy Consumption Differences of Provinces (Low → High)**	**Percentage Values of Cooling Energy Consumption Differences of Provinces within the Same Climate Zone (Low → High)**
1.Climate Zone (Very Hot)	Adana (85,98%)	Adana (N/A)
2. Climate Zone (Hot)	Gaziantep (19,25%) → Kahramanmaraş (32,17%) → Kilis (46,76%) → Adıyaman (53,15%) → Osmaniye (64,71%) → Hatay (80,36%) → Şanlıurfa (82,27%)	Gaziantep (base-point) → Kahramanmaraş (10,84%) → Kilis (23,07%) → Adıyaman (28,43%) → Osmaniye (38,12%) → Hatay (51,24%) → Şanlıurfa (52,84%)
4. Climate Zone (Cold)	Malatya (base-point) → Elazığ (5,83%) → Diyarbakır (45,07%)	Malatya (base-point) → Elazığ (5,83%) → Diyarbakır (45,07%)
Note: N/A (non- applicable)		

According to the simulation data, the lowest annual consumption was recorded in Malatya, located in the 4th climate zone. Malatya is followed by Elazığ and Gaziantep, located in the 4th and 2nd climate zones, with 5,83% and 19,25% higher consumption, respectively. Remarkably, Diyarbakır located in the 4th climate zone, has higher cooling energy consumption than Gaziantep and Kahramanmaraş, located in the 2nd climate zone. It is observed that Diyarbakır exhibits 45,07% and 37,08% higher cooling energy consumption compared to Malatya and Elazığ, located in the same 4th climate zone, and 21,65% and 9,76% higher consumption compared to Gaziantep and Kahramanmaraş, located in the 2nd climate zone.

In terms of annual cooling energy consumption, Adana recorded the highest value, which is consistent with its classification in the 1st Climate Zone (very hot). Following Adana, the highest consumption was recorded in Şanlıurfa and Hatay, both located in the 2nd climate zone. Cooling energy demand among these three provinces is relatively uniform, with Adana requiring 2.04% more energy than Şanlıurfa and 3.12% more than Hatay. In contrast, an 85.98% difference was observed between Adana, the highest consumer, and Malatya, the lowest.

Significant differences were also identified when comparing provinces within the same climate zones (Table 6). Considering the 2nd climate zone, there is a 52,84% difference in annual cooling energy consumption between the province with the highest consumption, Şanlıurfa, and the lowest, Gaziantep. Considering the 4th climate zone, there is a 45,07% difference between the highest consumer, Diyarbakır, and the lowest, Malatya. The analysis demonstrates that provinces within the same climate zone can exhibit notable differences in cooling energy demand; while these variations are smaller than those observed for heating energy, they remain statistically significant.

CO_2 Emission Performance

Designbuilder calculates CO_2 emission values based on the energy demands of heating, cooling, lighting, and ventilation systems, user-sourced equipment and device energy consumption, the energy required for domestic hot water production, and the energy demands of auxiliary mechanical systems such as fans and pumps. The CO_2 emission data obtained from the simulations are presented in Table 7 by showing both monthly and annual total emissions for each province. To facilitate a more immediate identification of monthly emission patterns and outliers, these data are also visualized graphically in Figure 11.

Table 7. CO2 emission (kg) values by month for 11 earthquake-affected provinces.

City	January	February	March	April	May	June	July	August	September	October	November	December	Total
Adana	5683,93	4967,92	4798,43	4219,3	6473,96	9313,79	13167,65	16183,96	9331,11	5576,52	4646,05	6252,83	90615.45
Osmaniye	7097,58	5422,34	4924,14	4028,15	4676,62	7280,28	11335,26	13292,73	9930,8	6286,45	4599,94	6031,05	84905.34
Hatay	6648,67	5393,15	4503,49	3924,59	4780,81	8355,53	12471,64	13230,28	11096,7	6740,24	4522,78	5739,11	87407.01
Kilis	7291,54	5425,28	4843,69	4004,76	4363,87	7324,28	10618,74	10985,15	9021	6488,14	4768,62	6123,6	81258.67

DOI: 10.15320/ICONARP.2026.356

Table 7 (continued). CO2 emission (kg) values by month for 11 earthquake-affected provinces.

City	January	February	March	April	May	June	July	August	September	October	November	December	Total
Gaziantep	8701,66	7709,36	6747,47	4488,99	3626,8	6577,1	9757,74	12714,83	7954,57	4768,15	6491,81	7213,85	86752.33
Kahramanmaraş	8395,21	6635,49	5797,56	4212,92	3705,04	6792,81	10476,83	10901,83	8125,82	5700,26	5343,44	7176,6	83263.81
Şanlıurfa	7343,05	6258,62	5099,41	4137,93	4618,25	9314,75	12801,84	12737,28	10481,5	7095,06	4817,87	6226,26	90931.86
Adıyaman	8196,79	6628,52	5530,03	4142,31	3758,68	7850,75	11819,45	11954,84	9193,55	6189,5	5165,97	7089,18	87519.57
Malatya	9374,08	7305,59	6374,64	4366,58	3591,82	6019,19	8271,96	8312,34	6507,21	4899,96	5590,36	7669,29	78283.02
Diyarbakır	8597,18	6889,02	5892,76	4211,99	4207,03	7970,64	11434,8	11755,36	8195,31	5364,89	5476,42	7955,76	87951.16
Elazığ	9374,68	7740,27	6584,83	4702,91	3538,32	5564,1	8773,39	9815,29	6663,09	5309,83	6194,85	8662,68	82924.24

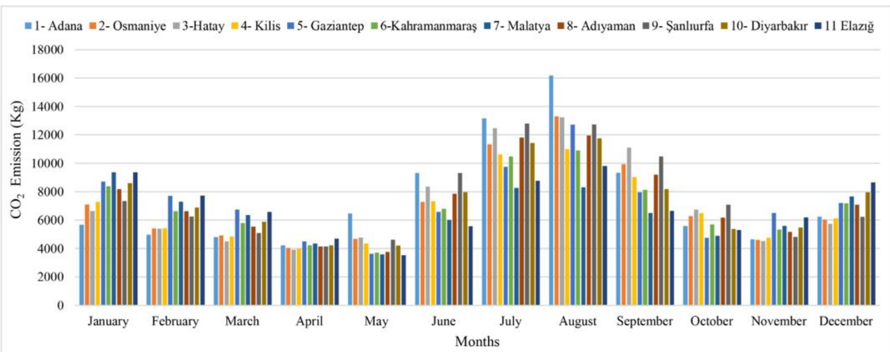

Figure 11. CO2 emission graph by month and 11 provinces.

Analysis of the monthly total CO_2 emissions of the 11 provinces reveals a gradual increase across all provinces during the summer months, rising from 82.363 kg in June to 120.929 kg in July and reaching 131.884 kg in

August, the highest emission level of the year. In June, the highest emissions were recorded in Şanlıurfa (2nd climate zone), while the lowest occured in Elazığ (4th climate zone), representing a difference of 67,41%. In July, Adana (1st climate zone) yielded the highest emissions and Malatya (4th climate zone) the lowest, with a 59.18% variance.

The peak monthly CO_2 emission for a single province was recorded in August within Adana (1st climate zone). In contrast, the lowest emission during the same month was observed in Malatya (4th climate zone). The 94,7% difference in CO_2 emissions between these two provinces is remarkable.

By September, the total CO_2 emissions across all provinces decreased to 96.501 kg, beginning a gradual decline that continued until November. In September, the highest CO_2 emission was recorded in Hatay (2nd climate zone), and the lowest was observed in Malatya (4th climate zone), with a difference of 70,53%. In October, the highest and lowest CO_2 emissions were recorded in Şanlıurfa and Gaziantep, respectively, both located in the 2nd climate zone, with a 48,80% difference. Similarly, in November, Gaziantep and Hatay (both in 2nd Climate Zone) recorded the highest and lowest values, with a 43,54% variance.

In December, the total CO_2 emissions trended upward again due to increased heating energy consumption. Total emissions, which stood at 76.140 kg in December, rose to 86.704 kg in January before dropping to 70.375 kg in February. Throughout the winter months (December–February), the highest emissions were consistently recorded in Elazığ (4th Climate Zone). The variance between these extremes ranged from 50.94% to 64.93%. In March, Gaziantep and Hatay (both in 2nd Climate Zone) again showed the greatest disparity at 49,83%.

The lowest total CO_2 emission was observed in April (46.440,4 kg), marking the transitional spring period when demand for both heating and cooling is minimized. During this month, Elazığ (4th climate Zone) and Hatay (2nd climate Zone) showed the highest and lowest emissions, respectively, with a narrow difference of only 19.83%. Notably, the single lowest monthly emission for any province was recorded in May in Elazığ (4th climate zone). In this province, moderate climatic conditions minimize mechanical system requirements. Conversely, the highest emissions in May occurred in Adana (1st climate Zone), driven by peak cooling energy consumption, resulting in a 82,97% gap between the two provinces.

Annual CO_2 emission data are visualized as shown in Fig. 12 and analyzed in Table 8. Figure 12 presents the 11 provinces in ascending order of annual emissions, using color codes to denote climate zones. In Table 8, the provinces were classified according to TS825:2024 climate zones, and the differences in CO_2 emissions among the provinces were expressed as percentages relative to the province with the lowest emissions.

DOI: 10.15320/ICONARP.2026.356

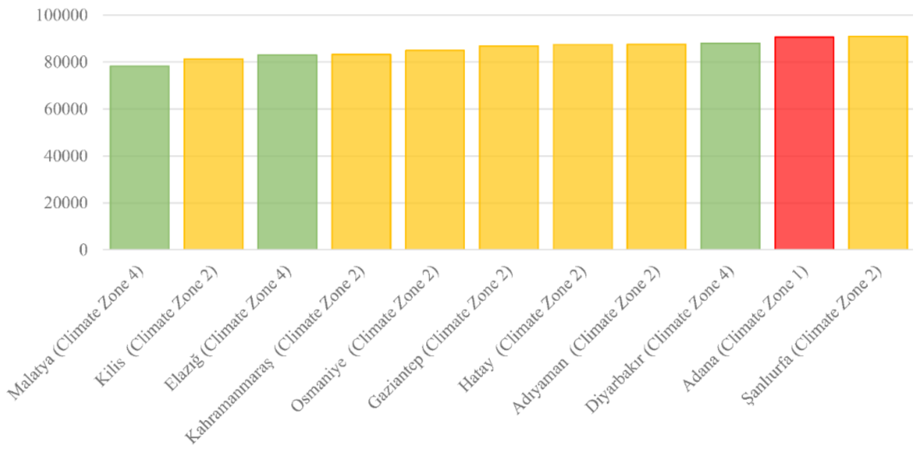

Figure 12. Annual CO2 emission ranking of the 11 provinces.

Table 8. Annual CO2 emission comparison of the 11 provinces with percentage values.

TSE825 Climate Zones	Percentage Values of CO_2 Emission Differences of Provinces (Low → High)	Percentage Values of CO_2 Emission Differences of Provinces within the Same Climate Zone (Low → High)
1.Climate Zone (Very Hot)	Adana (15,75%)	Adana (N/A)
2.Climate Zone (Hot)	Kilis (3,80%) → Kahramanmaraş (6,36%) → Osmaniye (8,46%) → Gaziantep (10,82%) → Hatay (11,66%) → Adıyaman (11,80%) → Şanlıurfa (16,16%)	Kilis (base-point) → Kahramanmaraş (2,47%) → Osmaniye (4,49%) → Gaziantep (6,76%) → Hatay (7,57%) → Adıyaman (7,70%) → Şanlıurfa (11,90%)
4.Climate Zone (Cold)	Malatya (base-point) → Elazığ (5,93%) → Diyarbakır (12,35%)	Malatya (base-point) → Elazığ (5,93%) → Diyarbakır (12,35%)
Note: N/A (non- applicable)		

According to the simulations, the lowest annual CO_2 emission was recorded in Malatya (4th climate zone), which also recorded the lowest annual cooling energy consumption. The highest annual CO_2 emissions were recorded in Şanlıurfa (2nd climate zone) and Adana (1st climate zone), respectively. A negligible difference of 0,35% exists between the emission values of these two provinces. The difference between the provinces with the highest and lowest annual CO_2 emissions remained at 16,16%. Within the 2nd climate zone, the lowest CO_2 emissions were recorded in Kilis and the highest in Şanlıurfa, with a difference of 11.90%. Among the provinces located in the 4th climate zone, the lowest CO_2 emissions were recorded in Malatya and the highest in Diyarbakır, with a 12.35% disparity. The analysis demonstrates that while variations in annual CO_2 emissions are relatively limited, provinces within the same climate zone can still exhibit slight differences.

DISCUSSION

The monthly heating energy consumption data revealed that the projected results for the provinces did not fully align with the conditions within their respective climate zones. Monthly consumption expectations indicate that the lowest consumption should occur in Adana, which is located in the 1st degree-day zone characterized by very hot climatic conditions. However, the lowest values were recorded in Adana only in January, February, May, July, and August. Meanwhile, the highest heating energy consumption is expected to be recorded in Elazığ, Malatya, or Diyarbakır, the provinces located in the 4th degree-day zone, which is characterized by cold climatic conditions. Accordingly, the highest monthly heating energy consumption was recorded in Elazığ during January, April, May, June, September, and December, while in July and August, it was measured in Malatya. However, Gaziantep, located in the 2nd degree-day zone with hot climatic characteristics, unexpectedly required more heating energy than all other provinces during February, March, October, and November, when colder weather typically prevailed. It is also remarkable that in March, October, and November, both the highest and lowest consumption occurred in provinces within the 2nd degree-day zone (hot climate) with substantial differences, clearly demonstrating the significant variability in heating energy consumption that can exist among provinces within the same climate zone.

When evaluating annual data in terms of heating energy consumption, it was also observed that the provinces did not reflect the projected outcomes within the context of their climate zones. While the lowest annual consumption was expected in Adana, located in the 1st climate zone with very hot climatic characteristics, it actually occurred in Hatay, located in the 2nd (hot) climate zone. Although the highest annual consumption was expected in one of the provinces located in the 4th climate zone with cold climatic characteristics, it was actually observed in Gaziantep, located in the 2nd (hot) climate zone. The fact that the highest and lowest annual heating energy consumption occurred in provinces within the 2nd climate zone, with a very significant difference of 184,85% provides a clear indication of how much heating energy consumption can vary among provinces within the same climate zone.

It is also important to note that Hatay and Osmaniye, two provinces with the lowest annual heating energy consumption, were classified within the 1st climate zone with very hot climatic characteristics, along with Adana, prior to the October 2024 revision of TS 825. In terms of heating energy consumption, it can be stated that the previous climate classification provided more consistent results for these provinces. One of the other climate zone changes introduced by the 2024 revision of TS 825 was the reclassification of Diyarbakır from the 2nd climate zone, characterized by temperate climate conditions, to the 4th climate zone, characterized by cold climate conditions. Similarly, Elazığ and Malatya were reclassified from the 3rd climate zone, characterized by cold-dry climate conditions, to the 4th climate zone, characterized by cold climate conditions. Diyarbakır, Malatya, and Elazığ exhibited performance consistent with their newly assigned climate zones. However, this irregularity in Gaziantep, the province that consumes the most heating energy despite

DOI: 10.15320/ICONARP.2026.356

having the characteristics of a hot climate zone, could not be explained by the TS 825 revision, as it was classified in the 2nd climate zone in both.

When monthly data were evaluated in terms of cooling energy consumption, it was determined that the provinces partially showed the predicted consumption trend in the context of climate zones. The lowest cooling energy consumption is expected to be recorded in Elazığ, Malatya, or Diyarbakır, all of which are located in the 4th climate zone with cold climate characteristics. Accordingly, the lowest cooling energy consumption occurred in Elazığ during May and June; in Malatya during July, August, and September. Although in small amounts, cooling energy consumption was also recorded during the shoulder and winter months. This low level of cooling energy consumption observed during the cool or cold months results from the combined effect of internal and external heat gains. In particular, high solar gains and constant internal loads, including lighting, occupants, and equipment, may cause indoor temperatures to exceed the comfort range during certain hours of the day. In January, February, March, April, October, and November, the lowest cooling energy consumption was recorded in Gaziantep, located in the 2nd degree-day zone with hot climatic characteristics; and in December, it was observed in Adana, located in the 1st climate zone with very hot climatic characteristics.

In terms of the highest monthly cooling energy consumption, it is expected to occur in Adana, located in the 1st climate zone, characterized by very hot climatic conditions. This expectation was met only in May, July, and August, when consumption generally increased. In April, June, October, and December, the highest cooling energy consumption was recorded in Şanlıurfa, located in the 2nd climate zone with hot climatic characteristics; in January and March, it was observed in Malatya, located in the 4th climate zone characterized by cold climatic conditions. The highest cooling energy consumption was recorded in Osmaniye in November and in Hatay in February and September. The climate zones of these two provinces have changed from the 1st climate zone, which shows hot-humid climate characteristics, to the 2nd climate zone with the 2024 revision of TS 825. In this context, it can be understood that both cities behave similarly to the characteristics of a very hot climate zone. Another noteworthy finding is that in February, April, October, and November, both the highest and lowest consumptions occurred in provinces located within the 2nd climate zone, with substantial differences between them.

When evaluating annual data in terms of cooling energy consumption, it was observed that the provinces largely reflected the projected outcomes within the context of climate zones. The highest annual consumption was recorded in Adana, located in the 1st degree-day zone with very hot climatic characteristics, while the lowest annual consumption was observed in Malatya, located in the 4th degree-day zone with cold climatic characteristics, showing a significant difference of 85,98%. The only anomaly observed is that Diyarbakır, located in the 4th

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climate zone with cold climatic characteristics, consumed more cooling energy than Gaziantep and Kahramanmaraş, which are located in the 2nd climate zone with hot climatic characteristics. It should also be noted that prior to the 2024 revision of TS 825, Diyarbakır was located in the 2nd climate zone with hot climatic characteristics. When heating and cooling energy consumption are evaluated together, it is observed that Diyarbakır's performance was closer to the provinces in the 2nd climate zone. In terms of annual cooling energy consumption, a maximum difference of 52.84% was detected among the provinces located in the 2nd climate zone, and a maximum difference of 45.07% was found among the provinces located in the 4th climate zone. Although this difference is not as remarkable as the heating energy consumption, it represents a significant value worth noting.

The energy consumption of heating and cooling systems constitutes a significant component of total carbon emissions. Heating energy is supplied through fossil fuels such as natural gas, coal, and fuel oil, or by electricity. Cooling systems generally operate by electricity. The combustion of fossil fuels directly releases large amounts of CO_2, whereas electricity consumption causes indirect CO_2 emissions depending on the source of electricity generation. In this regard, the magnitude of emissions is directly related to the share of fossil fuels in electricity generation supplied to the grid.

Analysis of monthly CO_2 emission values showed a seasonal cycle, increasing in summer and winter, and decreasing in autumn and spring. The main peak was in August when cooling energy consumption was at its highest, and the other peak was in January when heating energy consumption was at its highest. The highest heating energy consumption in January was recorded at 30.591,5 kWh/gas, while the highest cooling energy consumption in August was 21.946,1 kWh/electricity. Even the heating energy consumption was 39,39% higher than the cooling energy consumption; the CO_2 emission was 72,63% higher in August than in January. This indicates that the electricity consumption for cooling has a greater impact on CO_2 emissions than gas consumption for heating. In August, September, and October, the provinces with the highest and lowest CO_2 emissions were the same with the highest and lowest cooling energy consumption. In December, January, and March, the provinces with the highest and lowest CO_2 emissions were the same with the highest and lowest heating energy consumption. In March, October, and November, the highest and lowest CO_2 emissions were recorded in the provinces located in the 2nd climate zone, with a difference between 49,83-43,54%. In conclusion, the monthly simulations revealed that CO_2 emissions vary widely between and within climate zones seasonally. However, annual CO_2 emission values demonstrated a different pattern. The difference between the highest and lowest annual CO_2 emissions in provinces located in different climate zones was limited to 16.16%. The difference between the lowest and highest CO_2 emissions remained at 11,90% among the provinces in the 2nd climate zone and at 12,35%

DOI: 10.15320/ICONARP.2026.356

among the provinces in the 4th climate zone. Considering the significant differences in annual heating and cooling energy consumption among the provinces, it could be stated that the variation in annual CO_2 emissions was relatively limited.

CONCLUSION

The 2023 Kahramanmaraş-centered earthquakes in Türkiye necessitated expedited reconstruction efforts, primarily within the housing sector. Constructing new buildings based on energy efficiency principles in these disaster-affected areas offers a critical opportunity to mitigate contemporary energy and environmental challenges. As the lead institution in post-disaster housing, TOKİ plays a pivotal role in this process; however, its reliance on standardized mass housing projects frequently overlooks site-specific environmental data and energy-efficient design strategies.

While existing literature examines the energy consumption of TOKİ's standardized housing using various reference provinces, there is a notable absence of comparative studies investigating the influence of microclimatic conditions on energy performance among provinces within the same climatic zone. Furthermore, the October 2024 revision of TS 825, which increased the number of climate zones from four to six and integrated both heating and cooling requirements, significantly reclassified most provinces. This regulatory shift raises critical questions regarding whether design adjustments based solely on assigned climate zones are sufficient for optimizing energy performance, or to what extent a given province's microclimatic data influences overall building performance.

To address this knowledge gap, this study conducted a comparative analysis to determine how the heating and cooling energy consumption, as well as CO_2 emissions, of a standardized TOKİ project varied across 11 provinces situated within three climate zones under the revised TS 825 classification. A constructed TOKİ block from the Yeşilyurt district of Malatya was selected as the reference building, characterized by a rectangular shape, a symmetrical floor plan, a fixed façade orientation, defined window-to-wall ratios, and a representative building envelope system consisting of reinforced concrete shear walls, vertically perforated brick walls, and PVC-framed double-glazed windows. It was modeled in detail using DesignBuilder to obtain monthly and annual data. The findings revealed substantial performance disparities: annual heating energy consumption varied by up to 184.85% within the same climate zone. For cooling energy, differences reached 85.98% across zones and 52.84% within the same zone. In contrast, annual CO_2 emissions showed less volatility, with a maximum variance of 16.16% across different zones and 12.35% within the same zone.

This research was conducted within the framework of a hypothetical model developed based on typical details belonging to a specific project group to comparatively reveal the effect of different climatic conditions on building energy performance. In this context, rather than serving as an exact representation of real-world applications, the study aims to provide an analytical approach and prediction by isolating and evaluating the effects of design parameters. This approach may not fully reflect the design and construction variations that may arise in actual applications, depending on local conditions. Therefore, the findings should be interpreted within the scope of a specific reference design scenario.

A primary limitation of this study is the absence of field-based energy consumption data for the examined post-disaster housing units. Since many of these housing projects are newly occupied, under construction, or still in the planning stage, actual operational data could not be collected during the study period. Consequently, the simulation model could not be calibrated or validated using measured energy consumption data. Therefore, the results should be interpreted as comparative simulation-based performance assessments rather than direct representations of actual operational energy use. Once field-based monitoring data become available, the model should be recalibrated, and the simulation results should be reassessed to improve the accuracy and robustness of the findings.

Overall, these results confirm that implementing standardized projects in different climate zones leads to significant discrepancies in energy consumption. Crucially, this study demonstrates that even within the same climate zone, microclimatic variations exert a profound influence on heating and cooling demands. Furthermore, it was observed that the revised TS 825 classification does not consistently predict energy outcomes for certain provinces, such as Gaziantep.

While rapid solutions are essential in post-disaster construction, these findings reveal that standardized designs, developed without consideration of local climate conditions, present significant disadvantages regarding energy efficiency and environmental impact. Integrating microclimatic data into the design process is vital for optimizing energy consumption, resource management, and economic efficiency. Most significantly, the findings suggest that tailoring the thermal and physical properties of façade materials is a highly effective strategy for enhancing building performance. Therefore, the development of computational models that analyze site-specific environmental datasets to generate optimized façade configurations is essential to mitigate the environmental footprint of rapid reconstruction while ensuring climate-responsive outcomes.

FUNDING

This work was supported by The Scientific and Technological Research Council of Türkiye (TÜBİTAK) 1001 Project [123M838].

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Resume

Bahar Başarır, PhD, is an architect, researcher, and Assistant Professor at the Department of Architecture, Mimar Sinan Fine Arts University. She specializes in construction technology, with a core focus on advanced façade design and retrofit. Her expertise lies at the intersection of sustainable façade technologies, architectural detailing, constructability, and industrialization.

Gonca Özer Yaman is an academic and researcher at the Department of Architecture, Bingöl University. Her research focuses on building energy performance, sustainable architecture, thermal comfort, passive design strategies, and building energy simulation. She has published research on building energy performance, climate-responsive design, and sustainable building design.

Ebru Doğan Koç, Assoc. Prof. Dr., is an architect, researcher, and lecturer. Her research focuses on building and construction technologies in architecture. Her expertise encompasses sustainable building technologies and design, along with conservation in buildings, environments and settlements.

Gürkan Kavuran, PhD is an Associate Professor of Electrical and Electronics Engineering, researcher, and project coordinator. His work focuses on artificial intelligence, robotics, control systems, signal processing, and embedded technologies. His expertise lies at the intersection of intelligent systems, automation, data-driven modeling, and real-world engineering applications.

Beyzanur İnce, Ph.D. candidate, is an architect and researcher. She focuses on construction technologies, sustainable design strategies, and circularity in the built environment. Her doctoral dissertation develops a life cycle assessment framework for building products incorporating end-of-life scenarios to support product selection decisions in architectural practice.

Gökçe Dağteke is an architect, researcher, and research assistant. She received her master's degree from Fırat University and is currently pursuing her Ph.D. at Gebze Technical University. Her research focuses on the building and construction technologies in architecture, information and communication technologies in architecture, Building Information Modeling (BIM), and architectural education.

DOI: 10.15320/ICONARP.2026.356