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Assessing the Architectural Design and Implementation Potential of Local Residential Buildings with Net Zero Energy Approach: Cold Climate Region

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Abstract

With the COVID-19 pandemic, residences have taken on a multifaceted function, encompassing activities such as working, producing, and pursuing personal development, in addition to their sheltering function, leading to much longer periods spent indoors. This situation has also caused an increase in the amount of energy needed to maintain the continuity of residential life. This increasing energy consumption creates harmful effects on the environment. Due to the ecosystem starting to suffer damage, and this damage posing a threat to human life, environment-related studies have accelerated worldwide. In this context, the "Energy Performance of Buildings Directive" (EPBD) was enacted in European Union in 2002, and revised directive (EPBD-Recast) in 2010, to assess and certify the energy performance of buildings and thereby increase energy efficiency. The concepts of "nearly zero-energy building" and "net zero-energy building" were introduced within the scope of the revised directive. In this context, the aim of this study is investigating the conditions and methods of using NZEB (Net Zero Energy Building) solutions, developed by considering the parameters affecting energy performance of residences and design variables, in housing production of Turkey for cold climate region, towards solving these problems and developing an optimum housing design approach towards NZEB. Sivas province, located in cold climate region, was chosen as study area. Within the scope of study, design decision steps including passive design criteria, passive systems, active systems, and energy production systems specific to cold climate region were created. A prototype residential building design was made according to design decision steps within the developed guide. The energy efficiency improvement study of obtained housing design was carried out and simulated through the DesignBuilder program, and energy consumption-production analysis results were evaluated. The study demonstrates the potential of residential buildings to reach the NZEB standard, specifically in cold climate regions.

1. INTRODUCTION

The development of industry and technology, rapid population growth, and rising living standards have caused an increase in the need for energy. This situation leads to increased use of fossil energy resources and, consequently, energy and environmental problems such as global warming, depletion of fossil resources, increased air pollution, and destruction of the natural environment. Therefore, in the ongoing struggle for the sustainability of life, approaches focused on increasing energy efficiency in built environments come to the forefront. On one hand, strategies are developed to reduce energy needs through energy conservation-based design and construction principles. On the other hand, increasing the share of clean and harmless energy through ongoing research and applications aimed at obtaining the still-needed energy from renewable sources represents a global problem that has occupied countries worldwide for a long time. International meetings are held, laws and regulations are prepared, and binding protocols are signed to achieve global collaborative action in the field of energy efficiency. Within the scope of these problems, energy efficiency studies in buildings have also accelerated.

Buildings, which encompass a significant portion of the built environment, are responsible for a large part of fossil fuel-based energy consumption. When looking at areas of energy use worldwide, it is observed

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that 36% is consumed in buildings, holding the largest share along with other sectors such as industry and transportation. In Europe, this rate is around 40% [1]. According to the Turkey National Energy Report prepared by the Ministry of Energy and Natural Resources, 40.1% of the energy produced in 2020 in Turkey was used in buildings, accounting for the largest share [2]. In this context, the "Energy Performance of Buildings Directive" (EPBD) dated 2002 was published in the European Union (EU) to assess and certify the energy performance of buildings and increase energy efficiency [4]. As part of process harmonization with EU laws, it became mandatory in Turkey in 2008 with "Regulation on Energy Performance in Buildings" to issue energy identity certificates to all buildings using the BEP-TR calculation method [5]. During this process in Turkey, within the framework of new directive (EPBD-Recast), which entered into force in 2010 with the revision of EPBD in EU countries, the concepts of "cost-optimal energy efficiency," "nearly zero-energy building," and "net zero-energy building" were introduced [6]. The revised directive states that cost-optimal energy efficiency calculations in buildings should be made using national methods developed in accordance with framework method found in regulation published by the European Commission in 2012. However, it is stated that since it is not possible to make separate calculations for each building due to the large number of existing buildings, the calculations should be made over reference buildings that can represent existing and new buildings.

According to Turkish Statistical Institute (TUIK) data cited in 2018 National Energy Efficiency Action Plan 2017-2023, there were 9.1 million buildings in Turkey in 2017, approximately 87% of which were residential [7].

In the literature review conducted on doctoral theses related to net-zero energy buildings, it was found that most of the studies were conducted after 2010. In the doctoral thesis prepared by Kapsalaki, M. [36], the author analyzed two sample building groups, a detached house and a high-rise building, for three climate regions by defining fourteen different design variables and determining the impact hierarchies of NZEB solutions through the methodology developed. In the doctoral thesis by Pittakaras, P. [37], the author selected the island of Cyprus as the study area and conducted analyses on different building types, ultimately proposing an NZEB design guide for hot climates. In Turkey, the doctoral thesis by Ganiç Sağlam, N. [38] focused on the potential of nearly zero-energy buildings with optimal cost for hot-humid, temperate-humid, and cold climate regions, using a reference building representing multi-story apartment buildings in Turkey. In the doctoral thesis by Yıldız Ö.F. [39], the author aimed to achieve NZEB standards for the Erzurum Airport Terminal Building in a cold climate region using specific methods. In the doctoral thesis by Diker, B. [40], the author defined 41 scenarios and conducted simulations on an existing residential building in Turkey to achieve NZEB standards.

In this context, this study aims to investigate the applicability conditions and methods of Net Zero Energy Building (NZEB) solutions, considering the parameters and design variables affecting the energy performance of residences in Turkey's cold climate zones, and to create a design guide to inform designers on the most appropriate residential design approach towards the NZEB target.

2. THEORETICAL FRAMEWORK

Within the scope of the study, a systematic literature review was conducted, focusing on reducing energy loads (energy conservation) during the operational phase of buildings, which account for a significant portion of energy consumption, and obtaining energy production from renewable/independent energy sources (energy generation) within the scope of net-zero energy buildings. Firstly, within the scope of energy conservation, the physical environmental conditions of the design area, which are the most important determinants of energy needs in buildings, were taken into consideration and the design decision issues and the usage decisions of passive systems were examined, then the usage decisions of active systems and the usage of energy production systems were investigated.

2.1. Passive Design Decisions

The physical environmental conditions of design location are among the most critical determinants of a building's energy needs, and decisions made from the initial stages of design process regarding building's location, orientation, form, relationship with neighboring buildings/inter-building distances, building envelope design, spatial organization, and vegetation, as well as the developed solution strategies, are directly related to the building's energy requirements.

By considering the topography in relation to characteristics of climate zone, it is possible to establish the most appropriate relationship between buildings and the sun and wind. In the cold climate zone discussed in this article, the cold season, during which the heating load increases, is long. Therefore, protecting buildings from the cooling effect of the wind is a primary design approach. The most suitable location for construction is on the lower parts of south and southeast-facing slopes near the wind-protected valley floor, with a maximum slope of 22°. However, achieving this may not be feasible in existing urban areas. A controlled relationship with the sun should be established. Building orientation is also a crucial decision step in the building's relationship with the sun and wind. The optimal solar orientation for a cold climate zone is for the building's wide surface to be positioned 22° southeast from south. The best orientation ranges are between 20° southwest and 45° southeast, while acceptable ranges are between 31° southwest and 86° southeast, with the building's alignment preferably chosen along the east-west axis. Protection against north winds should be provided on the building envelope between northeast and northwest [9,10].

Another prominent parameter in the building's relationship with the sun and wind is the distance between buildings within the built environment. The potential for buildings to obstruct sunlight or create wind shadows on each other are important considerations in design decisions. Figure 1 provides the recommended inter-building distance limits and placement suggestions for cold climate zones.

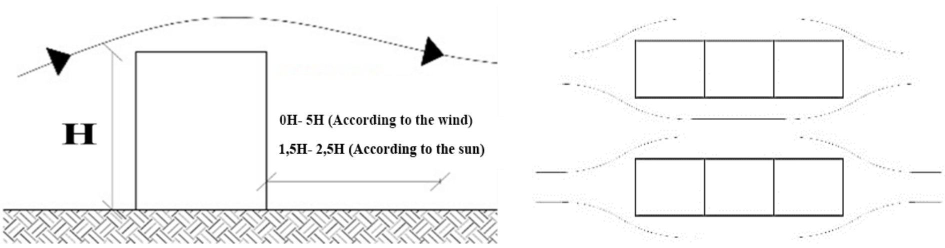


Figure 1. *Inter-Building Distances and Placement Suggestions for Cold Climate Zones, Considering Wind and Solar Conditions [12]*

The building form influences heat loss and gain depending on its geometric shape, volume-to-surface area ratio, and the arrangement of volumes [3]. Therefore, in cold climate zones with high heating loads, compact building forms, such as terraced houses or adjacent configurations, are effective for heat conservation, aiming to minimize the surface area of building envelope exposed to climatic conditions. The optimum ratio for the building form should be 1:1.1, and the maximum ratio should be 1:1.3 [9,10].
The building envelope, acting as a filter between fluctuating external climatic conditions and stable internal comfort conditions, plays the most crucial role in heat loss and gain. In this context, design decisions regarding opaque and transparent surfaces of facades, which constitute the largest surface area, and roof components are most important. For cold climates where heating loads are paramount, Table 1 presents optimal time lag durations, orientations, and color selections for opaque components, and recommended glass and frame types for transparent components.

Table 1. *Optimum time lag duration, orientation, and color selection for opaque components, and recommended frame and glass types for transparent components in cold climates [3,14]*

Opaque			Transparent	
Material Selection	Time Delay Duration and Direction	Color	Frame	Glazing
High thermal mass	On the west facade, 6 hours	Medium colors on sun-exposed surfaces, dark colors on non-sun-exposed surfaces	PVC, wood, or fiberglass	Double or triple glazing. For double glazing; selective transmission on the outer pane, clear glass on the inner pane, or clear glass on the outer pane and low-e glass on the inner pane. For triple glazing; selective transmission on the outer pane and two layers of low-e glass on the inner panes. The layers are filled with argon gas.

Roofs, depending on their form (sloped or flat) and the location of insulation (warm or cold roof), can facilitate heating and cooling or serve as a buffer zone. In this context, sloped roofs are suitable for cold climates due to their climatic properties. Considering insulation placement, warm roofs are appropriate [10].

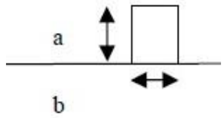
Thermal insulation in buildings aims to minimize heat transfer between external environment and interior, ensuring thermal comfort [32]. This is typically achieved using fibrous (rock wool, glass wool) and foam (XPS, EPS) materials to impede heat transfer through walls, floors, and roof elements. Therefore, in cold climates with high heating loads, high-performance materials with superior insulation values should be used in roofs, floors, and exterior walls to enhance building envelope's thermal resistance. Thermal insulation not only protects building elements from weather due to temperature fluctuations but also significantly improves heat conservation by reducing heat loss. In this context, insulation applications are generally much thicker in Passivhaus, and net-zero energy buildings compared to traditional buildings. According to Passivhaus standards, the thickness of insulation varies depending on the type of material, climate conditions, and the building's design, but it generally ranges from 20 to 40 cm [41]. In net-zero energy buildings, like in Passivhaus standards, the thickness varies according to design, climate, and material factors, typically ranging from 20 to 30 cm. In cold climate regions, the insulation thickness can reach up to 40 cm [42].

Sealing refers to the capacity of the building envelope to prevent the leakage of air, water, and vapor. A building envelope with high airtightness plays a critical role in energy efficiency. Sealing is particularly effective in reducing heating and cooling costs. To prevent heat loss, the building envelope must be properly sealed. If there are air leaks in the building envelope, cold air from the outside can enter, while warm air from the inside may escape. This leads to increased energy consumption by the heating system and, consequently, higher energy costs. Additionally, it causes ventilation and air conditioning systems to operate more frequently.

Thermal bridges are areas in the building envelope where heat transfer occurs more rapidly, significantly impacting energy efficiency. In these areas, heat loss increases, leading to higher energy consumption by heating and cooling systems. Furthermore, thermal bridges can create temperature differences in indoor spaces, resulting in comfort issues. The moisture that accumulates in these areas can lead to the formation of mold and fungi, deterioration of structural materials, and long-term building damage. Moisture buildup can also cause wear on walls and floors, shortening the lifespan of the structure. Ineffective management of thermal bridges leads to both energy loss and issues with indoor comfort and the integrity of the building.

The climatic conditions of the building's location, its function, and user needs and requirements are fundamental factors in spatial organization. To minimize the impact of climatic conditions, spaces with similar heating requirements should be zoned and interconnected, positioned on appropriate facades, and their form factor (depth/width ratio) determined based on regional climate data. Thus, in residential buildings designed for cold climates, living spaces (with high heating needs) and buffer spaces (bathrooms, toilets, storage, etc.) should be juxtaposed horizontally and stacked vertically for optimal heat conservation. Positioning living spaces on the south facade and buffer spaces on the north facade or in the direction of prevailing winds offers the most energy-efficient solution. Optimal space dimensions for cold climates are provided in Table 2 [3].

Table 2. *Optimum space dimensions for cold climates [3]*

Spatial Depth	Formal Expression
Optimal depth, similar width and length, spatial depth (a) > facade length (b)	

The choice of vegetation is also an important parameter in ensuring the energy efficiency of buildings and in benefiting from or protecting from wind and sunlight. In cold climates, vegetation type and placement should maximize solar heat gain during the coldest periods, provide shelter from prevailing winds, and contribute to heat conservation within the building. Deciduous, low-branched trees are preferred on the east, west, and south facades to provide shade and prevent overheating during the hottest periods. Evergreen, low-branched trees on the north facade and direction of prevailing winds offer protection from cold winds during winter, while during the coldest periods they shield the building from wind and maximize solar gain.

2.2. Passive Systems

Passive systems provide thermal comfort without using additional mechanical equipment or consuming extra energy [18]. These systems collect, store, and distribute the necessary heat within the building during the coldest periods using building components or additional systems integrated into them. During the hottest periods, they cool spaces through natural ventilation, radiation, and evaporation to maintain indoor climatic comfort. Passive heating and cooling systems are categorized as direct and indirect. This article focuses specifically on cold climates, and since cooling loads are generally tolerable in these regions, cooling systems are not addressed.

Direct heating systems are categorized into two types: south-facing windows and skylights. In cold climates, windows must be insulated, and their dimensions optimized to balance energy gain and loss effectively. Skylights are unsuitable for cold climates due to high heat loss and low heat gain.

Indirect heating systems operate on the principle of collecting solar radiation on a surface with thermal storage properties, such as water or a wall, or within a buffer zone, before transferring the collected heat to interior space.

Among indirect heating systems, solar walls, Trombe walls, and water walls share similar operating principles. A solar wall comprises a metal surface directly exposed to sunlight and a high thermal capacity wall situated behind it. The stored thermal energy is transferred to the interior space through convection and radiation after a certain time delay. This system is particularly suitable for cold climates with significant diurnal temperature variations [35]. A Trombe wall system incorporates a south-facing glass surface with a high thermal capacity wall placed behind it, and vents positioned on the wall transfer the stored heat energy to the interior. This system can provide both immediate and delayed heat transfer to the interior. Trombe walls operate with lower efficiency in cold climates compared to other climate zones. In a water wall system, containers filled with water or other liquids, instead of an opaque wall, are used as thermal mass, providing continuous and immediate heat transfer to the interior. Due to the risk of liquids freezing in the coldest periods, their use is not recommended in cold climates.

Sunrooms, which utilize glass on the facade and roof to collect solar radiation, aim to enhance the building's heat collection capacity. Sunrooms can be used as living spaces and function as buffer zones, mitigating heat loss due to wind effects and convection. With proper orientation, insulated glazing, and movable insulation, sunrooms become suitable for cold climates.

Roof ponds are heating systems based on radiation. They employ water or water-filled plastic bags as thermal mass. These systems necessitate foldable, movable insulation systems to prevent heat loss. Due to the risk of water freezing during the coldest periods, their use is not recommended in cold climates [3].
Thermosyphon systems utilize a heat-collecting surface separate from the building to gather solar radiation, store it within a thermal mass, and then transfer it to the interior space through convection. This system operates based on convection driven by temperature differences within the environment. It is suitable for cold climates. In the coldest periods, the air passage ducts connecting the collector surface and storage area must be open during the day for airflow and closed at night for heat retention.

Double-skin systems consist of two transparent layers separated by a specific distance. The air cavity between these layers acts as a buffer zone, reducing heat loss [31]. In cold climates, during the coldest periods, closing off the cavity between the two layers to outside air allows the system to function as a thermal insulation element based on the greenhouse effect, reducing the building's heating load. Movable insulation elements are necessary within the glazing to prevent heat loss during nighttime hours.

2.3. Active Systems

Active systems encompass a range of technologies that incorporate fans or other mechanical equipment to enhance user comfort and energy efficiency. Active systems offer high performance with minimal energy consumption to maintain comfortable indoor conditions.

Solar collectors convert solar energy into thermal energy, which can then be used for space heating and domestic hot water production by transferring it to space with the aid of storage and distribution systems [24]. A major challenge with this system is the risk of freezing in cold climates during the coldest periods. This issue is addressed with insulated collectors, pipes, and storage units [25].

Heat pump systems, utilizing electricity for heat transfer, can be sourced from air, water, or ground. These systems aim to harness heat from these sources, capitalizing on their existing thermal levels. In cold climates, air-source heat pumps operate at lower efficiencies compared to other climate zones due to the significant temperature fluctuations between day and night, and summer and winter. Water-source heat pumps offer higher efficiency in cold climates because the temperature of groundwater and surface water, used as a source, fluctuates far less than air temperature throughout the year. However, building locations often lack proximity to suitable water sources. Subterranean temperatures remain relatively constant year-round. Therefore, in cold climates, ground-source heat pumps can leverage this stable ground temperature to provide highly efficient heating.

Condensing boilers aim for efficient energy use by employing condensation technology. This technique condenses water vapor within the exhaust gas and transfers it to the heating water. This process allows the system to achieve high heat gains with low energy consumption, operating with high efficiency in cold climates.

HVAC systems are designed to provide all or some of a building's heating, cooling, and ventilation needs in an energy-efficient manner. These systems ensure desired indoor comfort conditions with minimal energy consumption, offering high efficiency in cold climates [33].

2.4. Energy Production Systems

Photovoltaic (PV) systems operate on the principle of directly converting sunlight into electricity. These systems aim to generate clean electricity from the sun without harming the environment or human health. PV systems consume no resources, producing electricity virtually free of charge after the initial investment and minimal maintenance costs. System efficiency, however, is dependent on weather conditions. The annual daylight hours and sunshine duration at the PV panel installation location determine the system's overall efficiency. Due to generally sufficient annual daylight and sunshine duration across Turkey, PV systems operate efficiently.

Wind turbines are systems that convert kinetic energy of wind first into mechanical energy and then into electrical energy. The energy obtained is transferred to the generator in the body and stored via batteries or delivered directly to the receivers. Like PV systems, wind turbines consume no resources, producing electricity virtually free of charge after the initial investment and minimal maintenance costs. Medium and small-scale wind turbines are suitable for buildings. These turbines can be placed in a suitable location in the garden or installed on rooftops [26]. Because wind speed, the resource for wind turbines, lacks a consistent standard, system efficiency varies.

Cogeneration and trigeneration systems exhibit higher efficiencies compared to single-purpose production systems because they extract more usable energy from the same fuel source. In addition to their efficiency, they also utilize exhaust gases, thus reducing CO2 emissions [34]. These systems operate with high efficiency in cold climates.

3. MATERIALS AND METHOD

This study, aimed at demonstrating applicability of net-zero energy-focused design approaches specifically for cold climates in buildings, which hold the largest share in globally prioritized goal of energy efficiency, has developed guidelines for architectural design processes. The decision-making steps towards achieving net-zero energy in architectural design are examined in four phases: passive design, utilization of passive systems, utilization of active systems, and utilization of energy production systems. In this context, existing theoretical and practical knowledge obtained through a systematic and extensive literature review has been classified, focusing on decision-making stages and their adaptation to design processes (Figure 2).

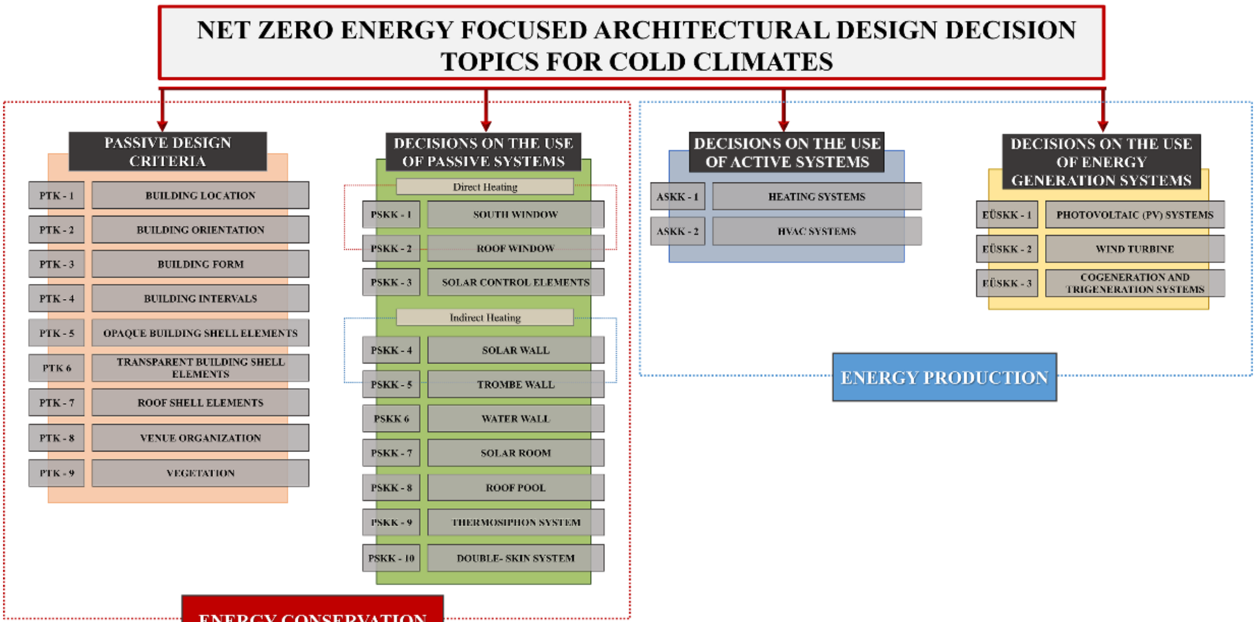


Figure 2. *Flowchart of net-zero energy-focused architectural design decision topics for cold climates*

In net-zero energy-focused architectural design processes, it is an accepted reality that design decisions regarding energy conservation and energy production enable the achievement of the expected performance with the design's inherent capabilities. Based on this fact, the developed design guide is addressed in two parts. Within the scope of performance expectations, which should be focused on energy conservation, it has been determined that passive design decision topics are closely related to building's location on the design site, orientation, form, distance from neighboring buildings, properties of opaque and transparent building elements in building envelopes, roof type and properties, spatial organization, and surrounding vegetation. Considering the climatic elements of the cold climate zone and relationship between the existing built environment and natural environment, the data contextualizing design were determined, and its suitability for the climate zone, along with its advantages and disadvantages regarding its purpose and application potential, were revealed (Figure 3). The suitability status is given with a confirmation code in the red circle on the far right of the figure. The status indicated by an exclamation mark in a yellow circle shows that the decision made will operate with low efficiency and that the expected efficiency can be increased with additional measures, while the question mark in the green circle indicates that even if it is among the energy-efficient design strategies, it will not be efficient for the cold climate zone.

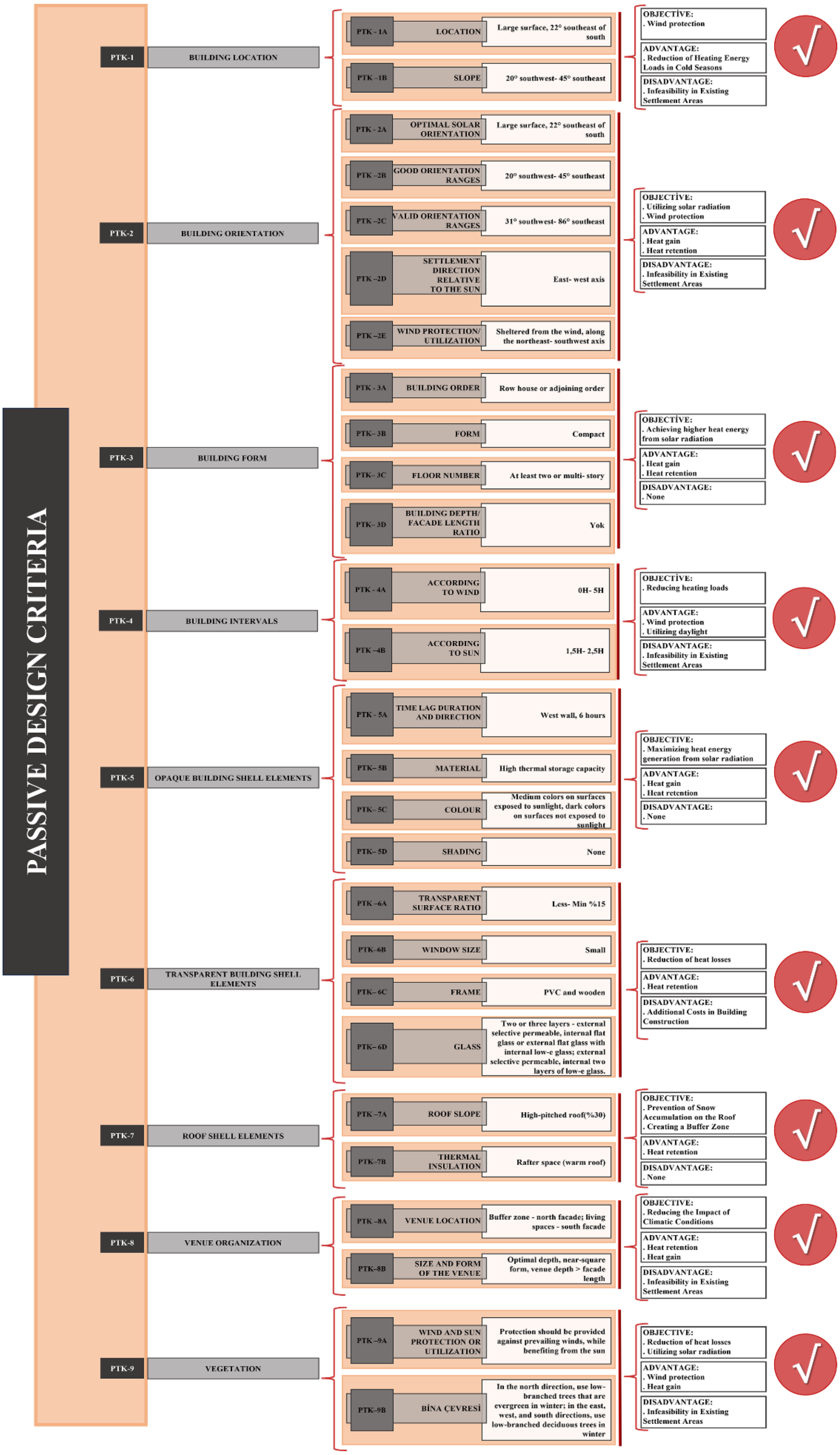


Figure 3. *Net-zero energy-focused passive design decisions for the cold climate zone*

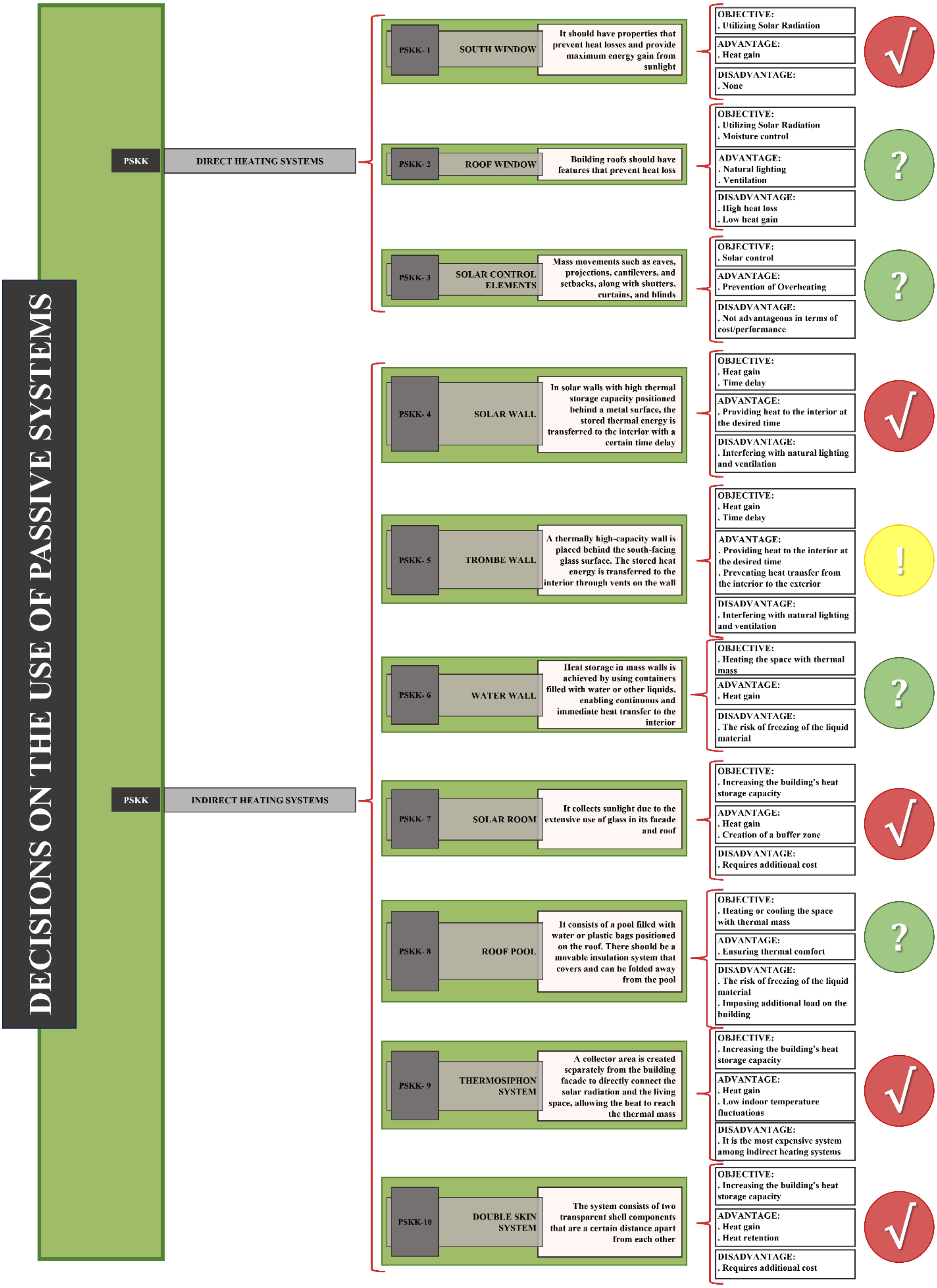


Figure 4. *Net-zero energy-focused passive systems usage decisions for the cold climate zone*

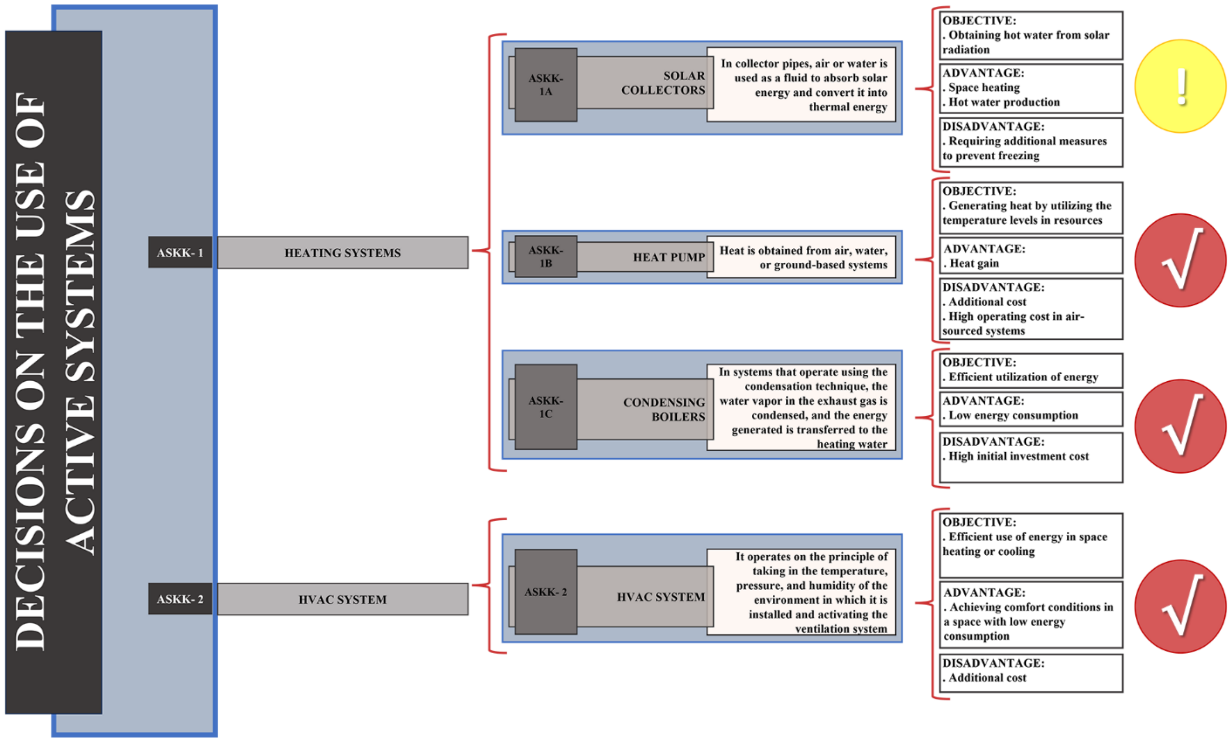


Figure 5. *Net-zero energy-focused active systems usage decisions for the cold climate zone*

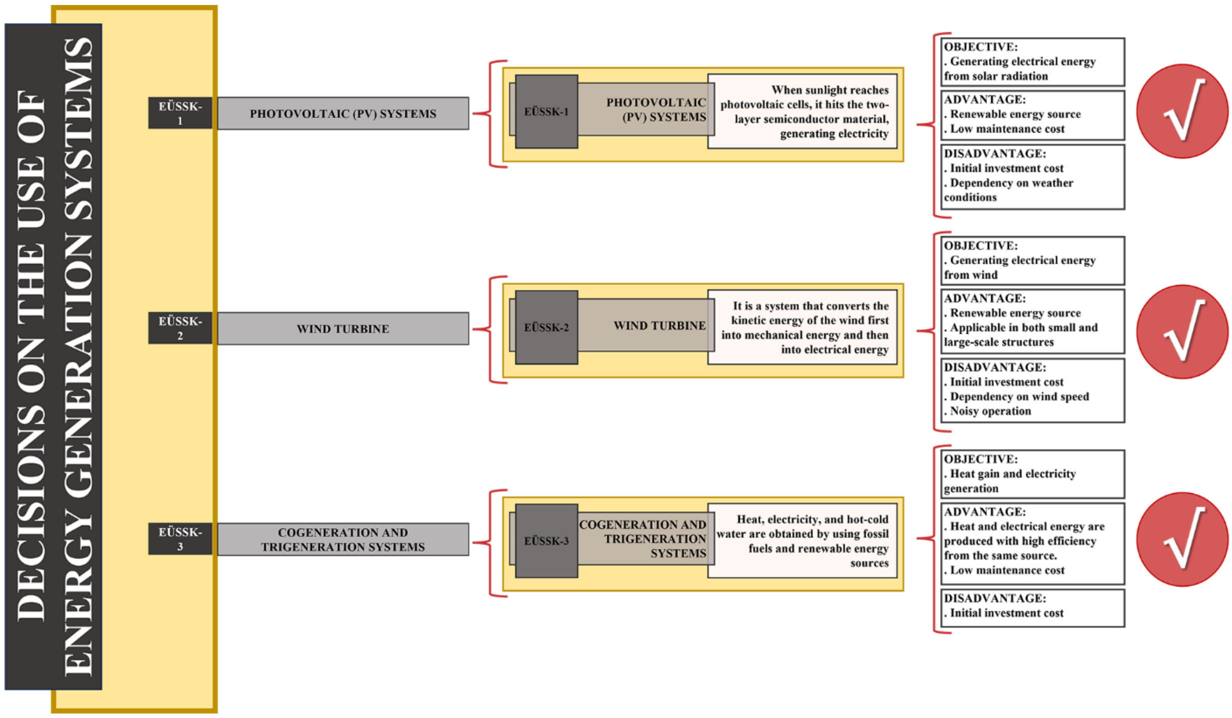


Figure 6. *Net-zero energy-focused energy generation systems usage decisions for the cold climate zone*

4. COLD CLIMATE ZONE ANALYSIS STUDY: SIVAS PROVINCE

The majority of Sivas province's land is in upper Kızılırmak section of Central Anatolia, while other parts are in the Black Sea and Eastern Anatolia regions, between 35° 50' and 38° 14' east longitudes and 38° 32' and 40° 16' north latitudes. With an area of 28,488 km², Sivas is second largest province in Turkey in terms of land area. Sivas is in a cold climate zone. Summers are hot and dry, winters are cold and snowy, and frost events are also observed. Climatic data for Sivas province are provided in Table 3.

Table 3. *Climate data for Sivas province between 193- 2023 [27]*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average temp.(°C)	-3,4	-2,1	2,7	9,0	13,5	17,0	20,0	20,2	16,2	11,0	4,8	-0,6	9,0
Ave. max. temp.(°C)	0,9	2,6	8,1	15,3	20,1	24,1	27,8	28,6	24,7	18,6	10,9	3,7	15,4
Ave. Min. Temp.(°C)	-7,3	-6,2	-2,1	3,1	6,9	9,6	11,7	11,8	8,1	4,2	-0,2	-4,3	2,9
Average sunlight duration(h)	2,6	3,6	4,8	6,3	8,1	10,5	11,9	11,4	9,4	6,5	4,2	2,5	6,8
Average number of rainy days	12,9	12,1	13,3	13,3	13,9	8,7	2,4	2,0	4,2	7,7	9,3	12,2	112,2
Total monthly rainfall amount (mm)	43,0	39,1	46,1	56,3	60,3	35,2	9,3	6,7	17,8	33,0	40,2	44,1	431,1
Highest temp.(°C)	18,6	18,1	25,2	29,0	33,5	35,5	40,0	39,9	37,0	30,5	24,0	19,4	40,0
Lowest temp.(°C)	-31,2	-34,4	-27,6	-11,0	-5,5	-0,6	3,0	3,2	-3,8	-9,0	-24,4	-30,2	-34,4

Table 4. *Average daylight hours (hours) for Sivas province between 1963-2023 [28]*

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9,7	10,7	12,0	13,3	14,4	14,9	14,7	13,7	12,4	11,1	10,0	9,4

In cold climate zones, heating loads account for the largest share of energy consumption. Due to the widespread use of fossil-based fuels for heating in Turkey, it was deemed appropriate to conduct the study specifically for the cold climate zone. Considering the climate data of Sivas province (Table 5), it was chosen as the study area because it reflects the characteristics of the cold climate zone. Looking at the annual sunshine and daylight hours of Sivas province, it is seen that there is sufficient potential for solar electricity generation.

4.1. Design Decisions

Within the scope of the study, the following design decisions were made for the designed building based on the passive design decisions given in Figure 3. The design decision step to which the decisions are related is given in parentheses.

- The building is located on a sloping terrain (PTK-1).
- The wide facade of the building is defined on the east-west axis (PTK-2D).
- The building is oriented towards the south (PTK-2A).
- The building is designed in an adjacent order and compact form (PTK-3A-3B).
- Due to the fact that 4-story zoning is mostly given to building blocks defined as adjacent order in the Sivas implementation zoning plan, the building was designed as B+G+3F according to the road elevation taken as the reference point; basement floor with building entrance, parking garage, and technical volumes; other floors with 2 apartments, each consisting of 3 rooms and 1 living room, for a total of 8 apartments (PTK-3C).
- The gross area of the ground and typical floor apartments in the building is 151.20m2, and the net area is 135.90m2. The floor area is 345 m2, and the total construction area is 1725 m2. The apartment square meters were determined by referencing standard 3+1 residences in Sivas province.
- In the building envelope, materials with low thermal conductivity coefficients were selected. The

thermal conductivity values for the layers are given in Table 5 (PTK- 5B).

- For the building envelope, a near-black anthracite color was chosen (PTK- 5C).
- The ratio of transparent surfaces in the building envelope was kept low, PVC was preferred for the frames, and triple-glazed windows with argon-filled cavities were selected (PTK- 6).
- A 30% sloped awning roof was constructed on the south side of the building's roof. Monocrystalline PV panels were mounted on the awning roof, covering 85.80% of the 14.60 x 24.20 m roof area (PTK- 7).
- In the spatial organization, living spaces such as the living room, kitchen, and sitting room are located on the south facade, while the bedrooms are positioned on the north facade. Balconies were designed on both facades. A 1.10 m high railing wall was defined on the balconies, and triple-glazed folding glass with argon-filled cavities was applied to the surface between the railing and the beam. In this way, it was aimed to create a sunroom on the south facade and a buffer zone on the north facade with the balconies (PTK- 8A).
- The spatial depths were kept minimal and dimensioned in square or near-square rectangular forms (PTK- 8B).

Table 5. *Materials used in the building envelope and U values*

Building Envelope Element	Layers	U-Value (W/M2-K)
Exterior Wall	Paint + gypsum plaster + cement plaster + 19 cm brick wall + 30 cm rock wool insulation + cement plaster + thin plaster + paint	0.141
Adjacent Wall	Paint + gypsum plaster + cement plaster + 9 cm brick wall + 15 cm rock wool insulation + 9 cm brick wall + cement plaster + thin plaster + paint	0.256
Partition Walls	Paint + gypsum plaster + cement plaster + 9 cm brick wall + cement plaster + thin plaster + paint	1.681
Ground Floor	50 cm reinforced concrete foundation + 16 cm XPS insulation + 7 cm screed + wood flooring	0.18
Intermediate Floor	15 cm reinforced concrete slab + 5 cm XPS insulation + 7 cm screed + wood flooring	0.499
Roof Floor	15 cm reinforced concrete slab + 5 cm felt + 24 cm rock wool insulation + roofing	0.157
Glazing Type	Low-e triple glazing with argon gas filling (3+13+3+13+3)	0.78

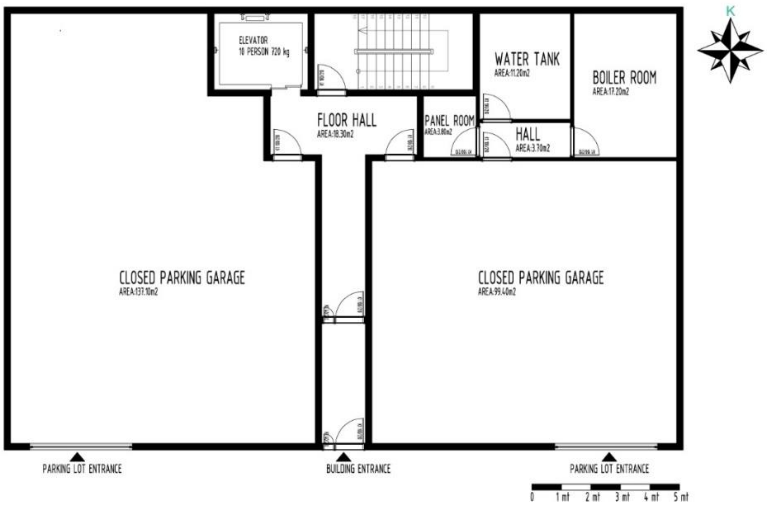


Figure 7. *Basement Floor Plan*

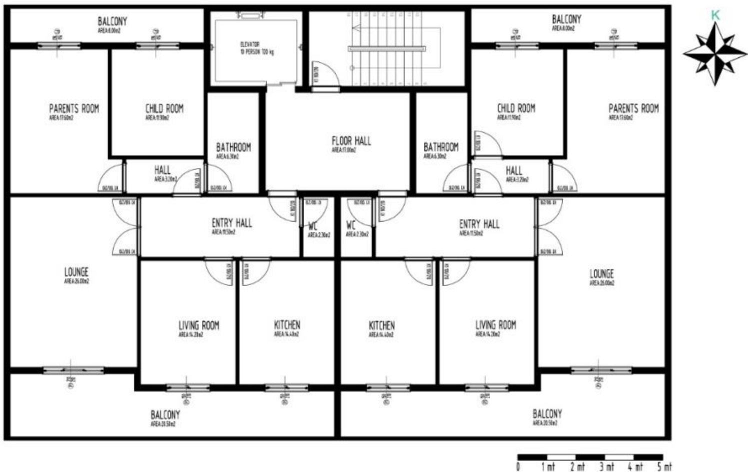


Figure 8. *Ground and Upper Floor Plan*

3.2. Simulation Study

In the study where Sivas province was selected as the cold climate zone, the energy simulation was conducted using the EnergyPlus 9.4 based DesignBuilder v7.0.2 program. The TMYx 2009- 2023 package was used for climate data. The year 2023 was preferred for the simulation as the year 2024 has not yet been completed.

In the designed residential building, which was planned to compare energy-efficient improvements within the scope of the study, parameters such as building orientation, layout, number of floors, spatial organization, and room dimensions were kept constant. The building envelope was defined using the thermal transmittance (U-values) specified in TS 825 as a variable. According to TS 825, the values used are 0.38 for walls, 0.23 for roofs, 0.38 for floors and 1.8 for windows. Additionally, no active or energy generation systems were defined. Subsequently, two separate simulation studies were conducted: first, incorporating the envelope improvements specified in Table 5, and then integrating active and energy generation systems. The results obtained are presented in the tables below.

Table 6. *Annual Total Energy Consumption Data for the Building (According to TS 825)*

	Total energy (kWh)	Energy per total building area (kWh/m2)
Total site energy	96240,02	109,80
Net site energy	96240,02	109,80
Total source energy	294755,28	322,32
Net source energy	294755,28	322,32

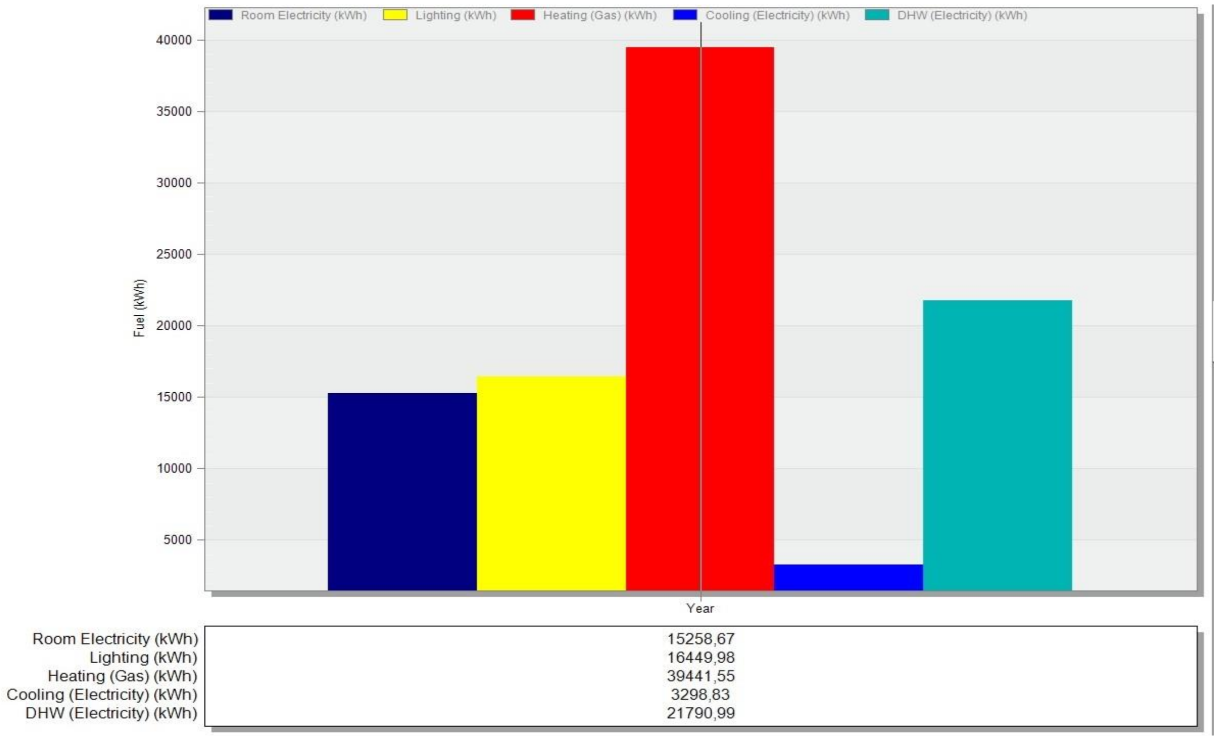


Figure 9. *Annual Total Energy Consumption and Production Distribution Data for the Building (According to TS 825)*

Table 7. *Annual total energy consumption data of the improved structure for NZEB*

	Total energy (kWh)	Energy per total building area (kWh/m2)
Total site energy	86889,21	99,12
Net site energy	-357,22	-0,408
Total source energy	267756,92	305,46
Net source energy	13072,41	14,91

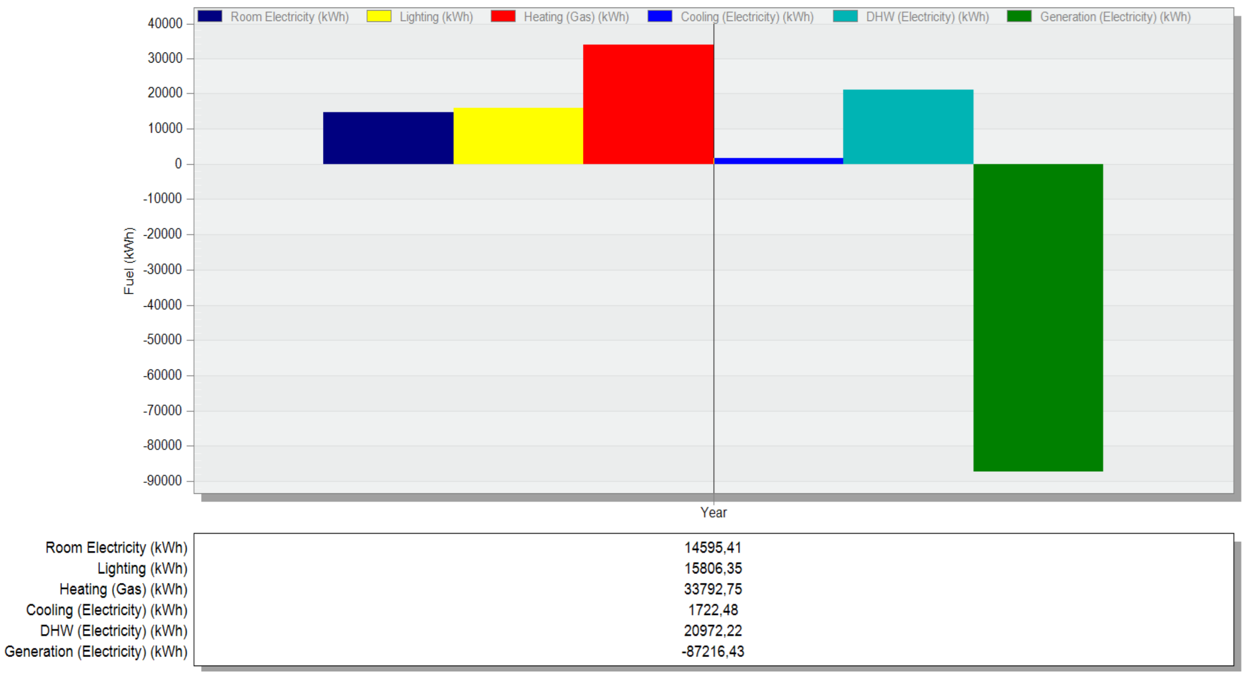


Figure 10. *Annual Total Energy Consumption and Production Distribution Data of the Improved Structure for NZEB*

Table 8. *Monthly Total Energy Consumption and Production Distribution Data of the Improved Structure for NZEB*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Room electricity (kWh)	1240,78	1118,87	1226,51	1219,17	1226,51	1190,63	1255,05	1226,51	1204,90	1240,78	1190,63	1255,05
Lighting (kWh)	1342,94	1212,22	1337,02	1307,27	1337,02	1295,42	1348,87	1337,02	1301,34	1342,94	1295,42	1348,87
Heating (gas) (kWh)	8487,12	7358,30	5130,05	2208,57	755,39	59,99	0,00	0,00	0,00	300,74	3233,66	6258,92
Cooling (electricity) (kWh)	0,00	0,00	0,00	0,02	12,45	94,80	448,63	704,06	386,47	76,04	0,00	0,00
DHW (electricity) (kWh)	1782,67	1607,85	1764,79	1748,24	1764,79	1712,47	1800,56	1764,79	1730,36	1782,67	1712,47	1800,56
Generation (electricity) (kWh)	-4194,25	-5153,67	-7419,55	-8104,46	-9137,27	-9774,80	-10204,61	-9989,61	-8143,79	-6380,22	-4681,34	-4032,87

Table 9. *Summary Table of the Simulation Results for the improved structure for NZEB*

Parameters	Simulation Results
Annual Total Energy Consumption	86889,21 kWh
Electricity Consumption per Total Area	99,12 kWh/m2
Annual Total Heating Load	33792,75 kWh
Annual Total Cooling Load	1722,48 kWh
Ratio of Heating Load to Total Energy Consumption	%38,89
Ratio of Cooling Load to Total Energy Consumption	%1,98
Highest Monthly Heating Load	8487,12 kWh (January)
Highest Monthly Cooling Load	704,06 kWh (August)
Annual Total Energy Production	87216,43 kWh
Annual Total Energy Demand	-357,22 kWh
Energy Demand per Total Area	-0.408 kWh

4. CONCLUSION

Energy consumption, which has accelerated since the Industrial Revolution, has reached considerably high levels. Numerous studies are being conducted at national and international levels on buildings, which account for a significant amount of energy consumption. Following the publication of EPBD-Recast in 2010, studies are ongoing in Turkey, as other countries, to calculate cost-optimal energy efficiency and near-zero energy levels in buildings by establishing national methodologies in accordance with EU framework. In this context, efforts such as enacting regulations and participating in international agreements and protocols are being carried out. However, achieve this goal, Turkey still needs long-term research and evaluations by experts, like the ongoing research in EU countries. In studies to be conducted at national level in parallel with the EPBD-Recast, human, geographical, and climatic data should be considered separately, considering the country's specific conditions, before reaching a conclusion.

Reducing energy dependence, combating global climate change, and preserving the natural environment make it crucial to decrease energy demand through efficient use and to meet this demand from renewable energy sources. According to the statistical data published by TURKSTAT, approximately 87% of the buildings in Turkey are residential, with the majority being multi-family apartment buildings. Therefore, energy efficiency studies conducted in residential buildings are expected to provide faster solutions to Turkey's energy problems. For this reason, this study aimed to enable multi-family residential buildings to reach net-zero energy building standards.

In this context, in the article study prepared after the introduction section, in the second section; passive design criteria, definitions of passive, active and energy production systems and working principles are explained and by creating a design guide that specifies the usage status, usage method, advantages and disadvantages of these criteria and systems specific to the cold climate region, it is aimed to guide designers in net zero energy building design. In the third section, Sivas province located in the cold climate region is accepted as the study area and based on the tables created in the second section, an apartment type residential building is designed and two separate scenarios are defined and energy simulation analyzed are made in the DesignBuilder program. In the first scenario, some variables related to the design are kept constant and the building shell design is made in accordance with the heat transmission coefficients given for the cold climate region in TS 825. Active and energy production systems are not used in this scenario. In the second scenario, an energy efficient improved building shell is defined for the designed residential building and also the accessibility of the building to the NZEB standard is investigated by integrating active and energy production systems.

As a result of the simulation, the annual energy consumption of the structure defined according to TS 825 was 109.80 kWh/m2 per m2, and 96240.02 kWh in total. The annual energy consumption of the structure designed to meet the NZEB standard was 99.12 kWh/m2 per m2, and 86889.21 kWh in total. In this context, the contribution of the improvements made to the energy efficiency of the building was 9350.81 kWh per year. When these values are examined, it is seen that the building envelopes provide 9.71% energy saving to the total energy load of the building. This required energy is met by photovoltaic panels placed on the building's roof, measuring 14.60 x 24.20 m and covering 85.80% of the roof area. The PV panels produce a total of 87216,43 kWh of electricity annually, meeting the entire annual energy demand of the designed residential building and enabling it to achieve the NZEB standard.

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