EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2026, 27(9), 379–390
https://doi.org/10.12912/27197050/226607
ISSN 2719–7050, License CC-BY 4.0

Received: 2026.06.30
Accepted: 2026.08.03
Published: 2026.08.15

Bioclimatic architectural design for climate resilience in Kazakhstan

Talgatbek Khasenovich Aliev[1], Bekmurat Zhumashevich Yespenbetov[2*], Bekbolat Nurdanbek[3], Sholpan Tuleshevna Abdykarimova[2]

[1] Department of Design and Engineering Graphics, Eurasian National University named after L.N.Gumilyov, Kazakhstan
[2] Department of Architecture and Design, Faculty of Land Management, Architecture and Design, Kazakh Agrotechnical Research University named after S.Seifullin, Kazakhstan
[3] Department of Design and Art, International University Astana, Kazakhstan
* Corresponding author's e-mail: espenbetov55@mail.ru

ABSTRACT

This study examines the role of bioclimatic architectural design as a key instrument for enhancing climate resilience and energy efficiency in the Republic of Kazakhstan, a country characterized by a continental, cold semi-arid climate and increasing exposure to climate-related risks. The research emphasizes the importance of integrating local climatic conditions, vernacular architectural principles, and passive design strategies into contemporary building practices. A qualitative-descriptive methodology was applied, combining climatic data analysis, policy review, and psychrometric assessment based on ASHRAE Standard 55 to identify adaptive and passive strategies for achieving indoor thermal comfort. The findings indicate that the application of bioclimatic design solutions – such as optimized building orientation, thermal mass utilization, natural ventilation, vegetation integration, and passive solar heating – can reduce building energy consumption by approximately 30–35% and improve thermal regulation by 20–40%. The integration of renewable energy technologies, including solar panels and small-scale wind systems, has the potential to reduce the carbon footprint of buildings by up to 25%. The study also highlights the critical role of urban green infrastructure in mitigating the urban heat island effect and enhancing microclimatic conditions, particularly during periods of extreme heat and drought. In addition to architectural considerations, the research situates bioclimatic design within Kazakhstan's broader climate policy framework, including national adaptation strategies and long-term carbon neutrality goals. The results demonstrate that bioclimatic architecture can contribute simultaneously to climate change mitigation and adaptation by reducing energy demand, enhancing resilience to extreme weather events, and supporting sustainable urban development. The study concludes that incorporating bioclimatic principles into national building regulations and climate adaptation plans represents a cost-effective and scalable pathway for strengthening climate resilience in Kazakhstan and other regions with similar climatic conditions.

Keywords: bioclimatic architecture, climate change, sustainability, passive systems, renewable energy sources

INTRODUCTION

The global population is steadily increasing, generating diverse demands that have significantly transformed land use patterns in residential areas. While certain changes – when implemented through strategic planning – have contributed positively to community development, others have had detrimental effects on the environment and, consequently, on human well-being. Poorly managed land use transitions, such as converting forested areas into rangelands, damming rivers, draining downstream lakes, or transforming fertile agricultural land into urban zones, illustrate these negative impacts. Such practices can increase the frequency and severity of local and regional natural disasters, including floods, desertification, dust storms, elevated aerosol concentrations, and global warming. (Widera, 2021).

Climate change is one of the most critical global challenges of the twenty-first century, with profound implications for resource management, architecture, urban planning, and human health. Extreme weather events – ranging from heat waves and droughts to floods and storms – are becoming increasingly frequent and intense, necessitating a dual approach that integrates both adaptation and mitigation strategies. Adaptation involves modifying systems and structures to withstand climate-related stresses, while mitigation focuses on reducing greenhouse gas (GHG) emissions through renewable energy deployment, improved energy efficiency, and sustainable transportation.

Recent studies underscore the importance of integrated approaches to climate policy and planning. For instance, in their decomposition analysis of CO_2 emissions in Greece, Tsepi et al. (2024) emphasize the pivotal roles of energy structure and technological innovation in emission reduction strategies. Similarly, Martín-Ortega et al. (2024) highlight the importance of transparency and monitoring through the MITICA integrated GHG mitigation framework, which could serve as a model for enhancing climate policy accountability in countries such as Kazakhstan. Nydrioti et al. (2024) provide practical guidance on managing urban water resources in diverse climatic contexts – a topic particularly relevant to Kazakhstan's semi-arid regions. Taken together, these studies underscore the value of integrating modeling approaches, empirical evidence, and systemic planning to develop effective climate solutions.

For people around the world, energy is a fundamental part of daily life, with one of the primary drivers of consumption being the need to maintain comfort in homes and communities. Residential energy use is strongly influenced by both local and regional climates, which are, in turn, shaped by geographic complexity. For instance, communities located near glacial mountains, arid deserts, or large bodies of water exhibit markedly different patterns of energy use. Consequently, land use changes and urbanization can significantly affect both energy demand and quality of life in such areas (Vakharia and Joshi, 2024).

The primary objective of this project is to investigate the impact of forest cover on urban climate patterns and, consequently, on building energy requirements. Following the ASHRAE Standard 55 guidelines, the thermal comfort approach is applied by incorporating climatic conditions into a psychrometric chart. This method identifies both active and passive strategies for achieving indoor thermal comfort and offers a practical framework for assessing the environmental effects of the presence or absence of forest vegetation. The findings of this study are evaluated against ASHRAE Standard 55 and its adaptive comfort model.

Recent research suggests that bioclimatic design principles – while traditionally focused on passive strategies and environmental harmony – should be embedded within broader climate mitigation frameworks. Martín-Ortega et al. (2024) demonstrate how transparent governance structures can facilitate the implementation of GHG mitigation measures, whereas Tsepi et al. (2024) show that achieving emission reductions requires both technological innovation and systemic energy planning. Nydrioti et al. (2024) highlight the role of climate-resilient infrastructure in strengthening local capacities to cope with climate uncertainty, particularly in water-stressed, semi-arid regions. Integrating these interdisciplinary perspectives into bioclimatic design ensures that architecture actively contributes to national climate objectives rather than merely responding to them.

Urban green spaces – particularly marginal urban forests – offer numerous social, economic, and ecological benefits. These include strengthening social cohesion, fostering environments conducive to children's development, supporting mental health, and enhancing overall living standards and community resilience. In addition to increasing cities' capacity to adapt to climate change and associated risks such as flooding, green infrastructure can substantially reduce energy consumption for heating and cooling. Vegetation helps lower ambient temperatures through evapotranspiration, with unshaded surfaces often being 11–25 °C hotter than shaded areas (Ozarisoy and Altan, 2021). When evapotranspiration and shading are combined, peak summer temperatures can be reduced by 1–5 °C.

Among the most effective mitigation strategies is the strategic planting of trees and vegetation around buildings and in public spaces such as parking lots and streets. Urban forests and green areas are key to reducing the urban heat island effect. However, challenges arise during prolonged dry periods, when many plants, including lawns, dry out and their cooling capacity through evapotranspiration declines. This issue is further exacerbated by climate change, which is expected to bring more consecutive dry days and extended heatwaves during the summer months (Ozarisoy and Altan, 2021).

By adapting bioclimatic architecture principles to Kazakhstan's unique climatic and socioeconomic conditions, this study provides novel insights. Its distinctive contribution lies in the methodological integration of contemporary climate-adaptive strategies – grounded in macroeconomic modeling – with elements of traditional vernacular design. Unlike previous research, which has predominantly focused on tropical or temperate regions, this study examines cold desert steppe environments, a context largely absent from the existing bioclimatic literature. Moreover, the findings have potential applicability beyond Kazakhstan, particularly in other countries with continental climates and comparable urbanization challenges, providing a replicable foundation for integrating climate policy, green infrastructure, and passive systems into architectural practice. The COVID-19 pandemic has also had a significant influence on global perspectives regarding climate vulnerability and the resilience of the built environment. During the temporary slowdown in human activity caused by quarantine measures, measurable environmental improvements – such as reductions in carbon emissions and air pollution – were recorded. Progiou et al. (2022) demonstrated the direct influence of human behavior on urban air quality by documenting decreased pollutant concentrations in Athens under COVID-19 restrictions. These findings underscore the importance of resilient urban planning and low-emission building practices.

Moreover, the pandemic prompted a reevaluation of energy use and environmental impact in academic and professional sectors. Papadogiannaki et al. (2023) showed that the carbon footprint of research projects was significantly reduced due to remote operations, raising questions about long-term architectural planning in a post-pandemic world. This context highlights the growing importance of passive, decentralized, and resilient bioclimatic designs that can maintain comfort and sustainability even under crisis conditions.

Despite growing interest in climate-adaptive architecture, there remains a lack of research focused on bioclimatic design strategies tailored to continental, semi-arid regions such as Kazakhstan. Much of the existing literature centers on tropical or temperate zones, with limited applicability to the Central Asian context. Furthermore, current studies rarely integrate climate policy, macroeconomic modelling, and architectural practice into a unified framework.

This study addresses this gap by analyzing Kazakhstan's climatic, institutional, and energy contexts to propose design principles that are both environmentally responsive and economically grounded. The novelty lies in the application of a systemic, region-specific bioclimatic approach that incorporates vernacular architecture, policy analysis, and macroeconomic modelling to enhance climate resilience at the building and national levels.

METHODS

This study employs a qualitative-descriptive and analytical research design, combining literature review, climatic data analysis, and policy review to assess the applicability of bioclimatic architectural principles in the context of Kazakhstan's climate resilience strategy.

The primary sources include:

- Meteorological data from Kazhydromet and regional weather stations (for temperature, humidity, solar radiation, wind patterns);
- Official policy documents from Kazakhstan's Ministry of Ecology, Geology and Natural Resources, and Ministry of National Economy;
- Academic sources including peer-reviewed articles on bioclimatic design, climate adaptation, and energy policy.
- Analytical techniques include the following elements:
- The ASHRAE Standard 55 and its adaptive comfort model were used to evaluate thermal comfort zones. Climatic data were plotted on psychrometric charts to identify suitable passive strategies such as natural ventilation, thermal mass use, and solar orientation.
- Climate adaptation frameworks were compared against international benchmarks to assess institutional readiness and integration of bioclimatic principles.
- Based on the data analysis, regionally appropriate passive design recommendations were formulated. Emphasis was placed on vernacular adaptation, energy conservation potential, and integration into Kazakhstan's National Adaptation Plan.

Research design

The study followed a approach:
1. Assessment of Kazakhstan's climatic risks and architectural vulnerability;
2. Identification and analysis of passive design strategies through climate-adaptive methods;

Bioclimatic architecture

Bioclimatic design prioritizes energy efficiency and indoor comfort by employing passive techniques that minimize energy consumption while enhancing interaction with the natural environment. It emphasizes adaptation to local climate conditions, reducing reliance on active energy systems. Prominent proponents of this approach include Olgyay, Szokolay, Kristinsson, and Yeang.

Bioclimatic architecture is a design method that aligns buildings with the needs of their occupants while optimizing energy use according to regional climatic conditions. It ensures that the building's form is appropriate for its function and environmental context. This approach incorporates several passive strategies –such as building orientation, spatial organization, façade design, the use of vegetation, natural ventilation, and thermal mass – to reduce energy consumption and enhance indoor comfort without the need for mechanical systems. Modern bioclimatic design often begins either with climate analysis or by drawing on traditional architectural solutions adapted to local conditions.

With roots in prehistoric human settlements, bioclimatic design is considered the oldest architectural approach. Although interest in climate-responsive architecture has fluctuated throughout history, numerous examples of vernacular architecture reflect the longstanding significance of climate-conscious building practices (Barea, 2022). Traditional architecture has evolved to suit specific climatic conditions, and modern bioclimatic buildings should draw upon these vernacular precedents. Design solutions should be evaluated using scientific and engineering methodologies to ensure their effectiveness and relevance.

The first step in developing modern climate-responsive buildings is to identify suitable examples of vernacular architecture for inspiration. The next step involves extracting and conceptualizing the bioclimatic principles embedded in these structures into distinct passive solar architecture (PSA) strategies. However, this approach assumes a relatively stable climate and may be inadequate for addressing dynamic, human-induced climate change. Given the accelerating pace of global warming, the symptomatic application of bioclimatic design principles must be critically reassessed.

An analytical bioclimatic design method begins with climate analysis, followed by identifying opportunities and constraints for adaptation. It includes evaluating the bioclimatic potential to determine comfort periods and suitable design strategies. While this method offers a systematic framework, its assumption of climatic constancy limits its applicability in the face of ongoing environmental transformations (Chondrogianni, and Stephanedes, 2024).

Framework of climate-resilient in Kazakhstan

A revised Nationally Determined Contribution (NDC), which emphasizes adaptation in critical sectors such as agriculture, water, and forestry, along with the adoption of a new Environmental Code providing a legal foundation for adaptation planning, are key elements of Kazakhstan's climate resilience framework. This framework aims to integrate adaptation measures into existing institutional structures and steer the national economy towards a climate-resilient development pathway through macroeconomic modelling. The overarching objective is to achieve carbon neutrality by 2060, as outlined in the country's Low Emissions Development Strategy (LEDS).

Kazakhstan's climate-resilient framework

Law and policy consist of:
- A revised NDC that incorporates adaptation commitments across multiple priority areas.
- The updated Environmental Code, enabling structured adaptation planning.
- The National Carbon Neutrality Strategy, outlining pathways to achieve net-zero emissions by 2060.

Sectoral priorities includes:
- Agriculture: Implementation of climate-smart practices and adoption of drought-resistant crop varieties.
- Water Management: Modernized irrigation systems and improved efficiency in water use.

- Forestry: Sustainable forest management and reforestation programs.
- Disaster Risk Management: Preparedness strategies and early warning systems.

Implementation and Monitoring

- Mainstreaming climate change considerations into national planning at all administrative levels.
- Establishing a climate reporting system to track progress and assess policy effectiveness.
- Strengthening cooperation with international organizations, such as the United Nations Development Programme, to support adaptation efforts.
- Integrating climate-resilient development into economic planning to ensure alignment with long-term growth objectives (Poulsen, 2020).

The Ministry of Ecology, Geology and Natural Resources (MEGNR) was established by the Government of Kazakhstan in 2019 to consolidate state functions related to waste management, geological exploration, environmental protection, natural resource management, and mineral resource replacement (Republic of Kazakhstan, 2019). Within MEGNR, the Department of Climate Policy and Green Technologies is responsible for the development and implementation of national climate change policies, including adaptation-related activities, and oversees Kazakhstan's participation in the United Nations Framework Convention on Climate Change (UNFCCC).

The country's hydrometeorological service, Kazhydromet, serves as the primary provider of climate data. It uses global climate model outputs to produce long-term climate projections, which are incorporated into reports submitted to the UNFCCC. However, it remains unclear which Kazakh institution is officially responsible for conducting systematic climate risk and vulnerability assessments.

Kazakhstan has adopted several long-term strategic documents that aim to guide the country's sustainable development and environmental protection efforts. These include the Low-Emission Development Strategy (LEDS), the Concept for Transition to a Green Economy, Strategy Kazakhstan 2050, and the updated Environmental Code. While both the LEDS and the Green Economy Concept acknowledge climate change as a critical threat, only the updated Environmental Code and the revised LEDS recommend specific actions for reducing climate risks.

RESULTS AND DISCUSSION

A catalogue of challenges across multiple sectors

In recent years, Kazakhstan has faced a series of emergencies directly linked to climate change. Official data indicate that in 2022–2023, forest fires in the Kostanay and Abay regions destroyed more than 100,000 hectares of forest. In 2023, a severe shortage of transboundary water resources for agricultural needs prompted the declaration of a state of emergency in southern Kazakhstan. In 2024, devastating floods – affecting almost all regions except the south – caused damage estimated at over 300 billion tenge.

Kazakhstan's climate challenges span multiple sectors and require a comprehensive, coordinated response. Food security is under serious threat from heat waves, droughts, and shifting precipitation patterns, all of which have a profound impact on agriculture. Climatic conditions largely determine both the productivity and resilience of the agricultural sector. Given the country's already stressed water resources, sustainable water management – particularly through modernized irrigation systems and strengthened regional cooperation on shared water resources – must be prioritized.

Forests are becoming increasingly vulnerable to fires and extreme weather events, making strengthened forest management critical for preserving biodiversity and reducing carbon emissions. Furthermore, with climate-related disasters such as floods and droughts occurring more frequently, Kazakhstan's sustainable development depends on improving early warning systems, enhancing disaster preparedness, and implementing comprehensive risk reduction strategies (Großmann et al., 2023).

National adaptation plans – a key role in countering climate change

According to 2024 emergency data, three key factors will help Kazakhstan navigate these challenges: cooperation with civil society and local authorities, coordinated action at all levels of government, and a clear understanding of national needs. In line with its commitments under the Paris Agreement, Kazakhstan included climate change adaptation measures in its 2023 Nationally Determined Contributions (NDCs). These measures focus on four priority sectors: water resources, agriculture, forestry, and civil protection/ disaster risk reduction.

Advancing adaptation projects will require the integration of digital technologies to improve early warning systems, monitor environmental changes, and support data-driven decision-making. The next step is the development of a National Adaptation Plan (NAP), which will define strategies and actions to address climate change impacts in the identified sectors, clearly delineate institutional roles and responsibilities at all levels of government, and ensure effective coordination between national and local institutions (Webber, 2017).

Building strong partnerships, mobilizing funding, engaging the private sector

The success of the NAP depends on effective collaboration among all stakeholders. Civil society organizations will play a critical role in advancing grassroots initiatives and ensuring transparency. International partners – such as the Green Climate Fund (GCF) and other multilateral organizations – will provide the technical expertise and financial resources necessary for implementation. National institutions will coordinate priorities and maintain communication with key stakeholders throughout the adaptation process.

Given the scale of the challenge, public funding alone will be insufficient to meet Kazakhstan's adaptation needs. Private sector engagement is essential for mobilizing additional resources and fostering innovation. Further priorities include expanding access to national and international financing mechanisms – such as the Global Environment Facility and the GCF – strengthening partnerships with regional and global financial institutions, and establishing dedicated financial channels to support investment in climate-resilient projects.

The Government of Kazakhstan actively promotes collaborative and efficient water management, particularly in light of escalating climate risks. A recent example is the Water Partnership Initiative, launched by the Ministry of Water Resources and Irrigation in cooperation with the United Nations Development Programme (UNDP). This initiative establishes a framework for donor engagement and fosters cooperation between the public and private sectors. Its overarching goal is to enhance climate resilience and promote sustainable water management through regional collaboration and institutional capacity-building (Sabirova, 2022)[13].

Flooding in Kazakhstan can also result from dam failures caused by high water levels and poor structural conditions. Notable examples include the Kyzyl-Agash dam failure in 2010, the Jumabek dam failure in 2011, and the Kokpekty dam failure in 2014. Due to the large number of transboundary rivers, dam failures in neighboring countries can also have significant impacts on Kazakhstan; the 2020 Sardoba dam collapse in Uzbekistan is one such case.

In 2015, the number of hydrometeorological emergencies – such as floods, mudslides, and heavy precipitation – was approximately double the long-term average. Around 22% of moraine lake outbursts and 75% of extreme rainfall events frequently trigger mudflows. In Almaty, the most recent mudflow occurred in 2015; in 2019, the city was spared damage thanks to the protective capacity of its dam.

Kazakhstan is also vulnerable to other climate change-related extreme weather events (EWEs), including heat waves, storms, and droughts. As shown in Table 1, storms, blizzards, and heavy rain were the most frequent EWEs between 1990 and 2015. Between 1967 and 2015, most EWEs occurred in the southern, southeastern, and northern regions of the country (Figure 1). Lowland rivers in western, northern, and central Kazakhstan, along with the mountainous areas of the south and southeast, experienced more frequent flooding than the more drought-prone western and southern regions.

Mudflows threaten approximately 13% of Kazakhstan's territory, particularly in the southeast, where Almaty is located and more than 26% of the national population resides. Over the past 150 years, nearly 800 mudflows have been recorded (Akhanova, 2020). In the regional abbreviations used, WK refers to West Kazakhstan, NK to North Kazakhstan, SK to South Kazakhstan, and EK to East Kazakhstan

Integration of renewable energy sources in reduction for energy consumption of buildings

Integrating renewable energy sources – such as solar, wind, and geothermal – into buildings can significantly reduce energy consumption by generating electricity and heat directly on-site.

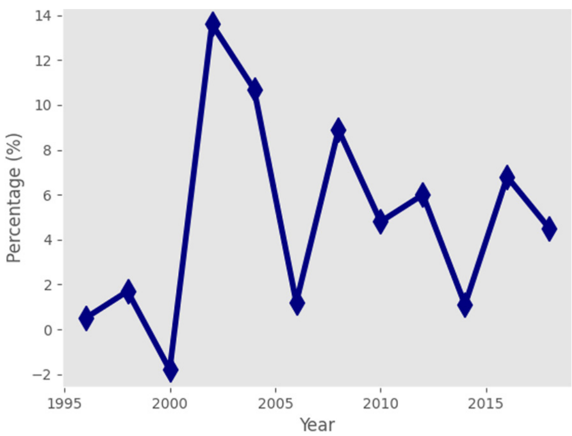

Figure 1. Real GDP growth rate (% p.a.) 1996–2019

This approach decreases reliance on traditional fossil fuel-based power grids, supporting more sustainable and environmentally responsible building operations. Practical methods include installing rooftop solar panels, deploying small-scale wind turbines, and implementing geothermal heat pumps. These systems can be further optimized by designing buildings to maximize the utilization of renewable energy sources and by applying energy-efficient construction methods.

Renewable energy in buildings: Key aspects of energy conservation

Major sources of renewable energy

The main renewable energy sources used in buildings are solar, wind, and geothermal energy. Solar energy is the most widely adopted option in the building sector. Photovoltaic (PV) panels convert solar radiation into electricity, whereas solar thermal collectors use solar energy to produce hot water and support space heating. Wind turbines can also generate electricity for buildings, although their efficiency depends largely on the availability of sufficiently high and consistent wind speeds. Geothermal systems use the relatively stable temperature below the ground surface to provide energy-efficient heating and cooling through heat pumps.

Table 1. Average annual number of EWEs in Kazakhstan

EWE	Number of EWEs	
	1990–2002	2003–2015
Heavy rain	20.1	49.3
Strong blizzard	42.4	23.5
Heavy snow	9.1	24.9
Strong wind	38	45.8
Hail	2.5	3.2
Strong dust storm	2.7	0.8
Strong fog	18.6	6.8

Benefits of renewable energy integration

Integrating renewable energy systems into buildings provides economic, environmental, and energy-security benefits. On-site electricity generation reduces reliance on the power grid and can lower overall energy costs. Replacing fossil-fuel-based energy with renewable sources also reduces greenhouse gas emissions and the environmental impact of buildings. Furthermore, locally generated renewable energy improves energy security by decreasing vulnerability to energy price fluctuations and potential supply disruptions.

Renewable energy integration strategies

Renewable energy technologies can be integrated into buildings through several complementary strategies. Appropriate building orientation and architectural design can maximize solar gain, support passive heating, and improve natural lighting. Building-integrated photovoltaic (BIPV) systems can be incorporated into roofs, façades, and other components of the building envelope, thereby serving both functional and aesthetic purposes. Smart-grid integration enables more efficient monitoring and management of energy generation and consumption. In addition, battery storage systems can store surplus renewable energy and supply it during periods of peak demand or insufficient energy generation.

The Republic of Kazakhstan has begun its transition from fossil fuels to low-carbon energy sources. Coal remains the dominant energy resource, accounting for 64.7% of total electricity generation and 74.0% of thermal power output in 2019. The government is actively working to diversify the national energy mix. According to the National Green Growth Plan, by 2030 the mix is projected to include 10.0% hydroelectricity, 8.0% nuclear power, 21.0% natural gas, 49.0% coal, and a substantial share of renewables. However, projections for 2028 suggest that coal will still generate approximately 64.9% of total electricity and 74.0% of thermal energy, indicating a slower decline than initially targeted.

By 2050, the government aims for non-thermal sources to supply at least half of Kazakhstan's energy needs. This strategy includes launching a national nuclear energy development program and significantly expanding non-hydro renewable energy capacity. While investor skepticism regarding the business environment may hinder progress, Kazakhstan continues to seek foreign investment to attract the capital and expertise necessary to meet these goals. According to Kazakhstan's First President, Nursultan Nazarbayev, the country targets a 50% renewable share in its energy mix by 2050, with interim goals of 3% by 2020 and 10% by 2030.

Expanding wind, solar, and biomass power generation could significantly increase the share of renewables in Kazakhstan's energy mix, improving both geographic distribution and meteorological suitability. According to a study by *Samruk-Energy*, five renewable energy projects were introduced to Kazakhstan's coal and electricity markets for the first time in January 2019:

- A 1.3 MW biogas plant operated by the Kurma agrofirm in the Karaganda region.
- Two wind farms (Kerbulak-1 and Kerbulak-2) with capacities of 4.5 MW each in the Almaty region.
- The Wind Energy Technologies wind farm with a capacity of 52.8 MW in the Mangistau region.
- The Gulshat solar power plant, operated by KPM Delta, with a capacity of 40 MW in the Karaganda region (Faragalla, 2022).

In January 2019, Kazakhstan's power plants generated 9,944.4 million kWh of electricity. Compared to January 2018, electricity production in the Turkestan region rose by more than 20%, while output in the Almaty, Zhambyl, Kostanay, and Pavlodar regions fell by over 5%.

To accelerate RES deployment, the Government of Kazakhstan collaborates with several financial institutions, most notably the European Bank for Reconstruction and Development (EBRD). The Eurasian Development Bank (EDB) has committed over USD 600 million to the renewable energy sector. Under the *National Green Energy Development Plan*, 30% of household energy consumption should come from renewable sources by 2030, rising to 50% by 2050. Solar, wind, biomass, and geothermal energy are expected to account for approximately 80% of this total. In February 2014, the government announced its goal of achieving 1,040 MW of installed renewable capacity by 2020. While thermal power will likely remain the dominant source of electricity in the near term, the government's commitment to renewables ensures they will continue to play a growing, albeit modest, role in the national energy mix (Cantatore, 2021).

Hydro power

To accelerate the deployment of renewable energy sources (RES), the Government of Kazakhstan has partnered with several financial institutions, most notably the European Bank for Reconstruction and Development (EBRD). The Eurasian Development Bank (EDB) has pledged more than USD 600 million to support Kazakhstan's renewable energy sector. According to the National Green Energy Development Plan, renewable sources are projected to supply 30% of household energy by 2030 and 50% by 2050, with solar, wind, biomass, and geothermal energy together accounting for approximately 80% of this total. In February 2014, the government announced its target of installing 1,040 MW of renewable energy capacity by 2020. Although thermal power is expected to remain the dominant source of electricity generation in the foreseeable future, the government's commitment to renewables ensures that they will play an increasingly important, albeit relatively modest, role in the national energy mix.

WIND POWER

Several regions of Kazakhstan possess favorable wind conditions for the installation of wind turbines, as confirmed by specialized studies conducted within the framework of a joint project between the United Nations Development Programme (UNDP) and the Ministry of Energy and Mineral Resources of the Republic of Kazakhstan. Based on meteorological data, the Atlas of Winds of Kazakhstan was developed, providing a detailed map of wind speed distribution across the country.

With UNDP support, the Ministry of Energy and Mineral Resources prepared a National Wind Energy Development Plan through 2015, with projected targets extending to 2030. The plan envisaged the construction of wind farms with a total capacity of 250–300 MW by 2015 and 2.000 MW by 2030. These facilities were expected to generate up to 1 billion kWh of electricity annually by 2015 and up to 5 billion kWh annually by 2030.

Kazakhstan's wind energy potential is considerable. In certain locations, average wind speeds at a height of 15 meters range from 27 to 36 m/s, while at least eleven sites have average speeds of 8–10 m/s – indicative of strong suitability for power generation. The highest wind resources are concentrated in the Dzungarian Gate, where annual wind energy potential reaches approximately 17,000 kWh/m². Other promising locations include Kordai (Zhambyl Region), Fort-Shevchenko (Caspian Sea coast), and Erementau (Akmola Region).

Solar power

Kazakhstan has the potential to produce an estimated 2.5 billion kWh of solar energy annually, equivalent to approximately 10 km² of solar cells operating at an overall efficiency of 16%. Modern photovoltaic panels typically achieve efficiencies of 15–25%. Around two-thirds of the country's territory is suitable for large-scale solar energy deployment. In the southern regions, annual solar radiation amounts to 2.800–3.000 hours, corresponding to 1.280–1.870 kWh/m² per year.

Certain areas – particularly South Kazakhstan, Kyzylorda, and the Aral regions – are especially favorable for solar power generation in June, when daily solar energy on a horizontal surface ranges from 6.4 to 7.5 kWh/m². In line with the Republic of Kazakhstan's Strategic Development Plan and its "green economy" transition concept, approximately 28 solar power plants were planned to be operational by the end of 2020.

Biomass

Over ten million hectares, or 4% of Kazakhstan's entire land area, are covered by forests, with 4700 thousand hectares of that area being saxaul. In 1990, the nation's annual logging volume was approximately 3 million m3. Almost 1.3 million m^3 or 1 million tonnes of wood waste are produced by logging and woodworking businesses, in addition to wood used for firewood. As a result, the potential energy from wood waste exceeds 200 thousand tonnes. It's also critical to remember that using biological fuel has its limitations. The processing of agricultural waste can yield up to 44 million mega calories of thermal energy and 35 billion kWh of electricity every year (Tsepi, 2024).

Renewable energy resources of Kazakhstan

Kazakhstan is working to reduce the greenhouse effect, having first ratified Kyoto Protocol and then Paris Agreement. This is particularly true now that Astana, country's capital, is holding EXPO 2017 „Future Energy." Numerous new initiatives focused on using green energy and reducing amount of energy generated from fossil fuels have been created in preparation for this event. Kazakhstan has a lot of potential for producing renewable energy.

Kazakhstan has enormous potential for renewable energy because of its vast territory. The majority of renewable energy sources – wind, sun, hydro, biomass – may be accessible. Regretfully, none of these sources have been extensively developed up to this point. In Kazakhstan, hydropower facilities are the only ones that generate enough energy. In 2012, that accounted for around 12% of total energy generated. Use of renewable energy resources is shown in Table 2.

In 2030, district heat consumption is reduced by 38% more in fuel-switching + EE scenario due to energy efficiency measures than in fuel-switching scenario, indicating a decrease in supply-side emissions. The fuel-switching scenario is projected to use 135 502 TJ of district heating in 2030, whereas fuel-switching + EE scenario is projected to use 83 679 TJ. Large plants with capacity greater than 100 gigacalories per hour (Gcal/h), primarily cogeneration units and HOBs, currently provide the majority of district heating (74%). All HOBs in Kazakhstan utilise coal, while a few in western and southern cities use gas (UNDP, 2007). Accordingly, coal accounted for 65% of district heating in 2014, with natural gas accounting for 32% and oil for 3% (Kerimray, Kolyagin, and Suleimenov, 2018). Regretfully, there are no more recent data on heat generation by fuel. Furthermore, future investigations must investigate scenarios for supply-side emissions reductions, as supply side of power and heat generation is outside purview of this study. Under the BaU and fuel-switching scenarios, electricity consumption increases by 21%, from 2 451 TJ in 2017 to 2 977 TJ in 2030. However, it drops to 2 224 TJ with energy efficiency measures in fuel-switching + EE scenario, a 10% decrease from 2017. In fuel-switching + EE + heat pumps scenario, the usage of heat pumps raises electricity consumption to 12 841 TJ in 2030, which is five times the current level. This suggests that power plants will need to

Table 2. Renewable energy potential and use in Kazakhstan

Capacity	Energy resources					
	Hydro power plants		Solar	Wind	Bioenergy	Geothermal
	Large HPP	Small HPP				
Technical Potential for installation	105 billion kWh	65 billion kWh	3.9–5.4 billion kWh	1820 billion kWh	3.5 billion kWh	0.02 billion kWh free flow
Available in operation	8.5 billion kWh	0.54 billion kWh	0.3 billion kWh	0.3 billion kWh	3 million kWh	Heating of houses

generate more electricity. According to the 2013 Decree of President of Republic of Kazakhstan, pollution from coal-fired power plants in Kazakhstan is significantly worse than that from those in Europe, with PM levels being 900% higher, NOx levels being 20% higher, and SOx levels being 150% higher. However, the installation of emissions control systems could make coal burning at power plants more efficient as well as less emissions-intensive. Furthermore, increasing amount of electricity generated from renewable sources would assist fulfil future demand without adding to emissions or pollution (Martín-Ortega, 2024).

State support for the renewable energy generation

Gaining independence, Kazakhstan has taken a highly active role in establishing a sustainable environment. The nation is a party to the UNFCCC, or United Nations Framework Convention on Climate Change. Kazakhstan has committed to reducing greenhouse gas emissions by signing Paris Agreement on Climate Change and ratifying Kyoto Protocol to UNFCCC in 2009. One of the most effective ways to lessen the negative environmental effects of energy sector operations is to develop renewable energy sources. The Program for Accelerated Industrial and Innovative Development includes all of the efforts involved in developing renewable energy sources. The right laws were created to encourage the use of renewable energy sources. One of the top priorities for creating sectors of economy of future was development of renewable energy. Law of RK on Support to usage of Renewable Energy Sources, which was adopted in 2009 and revised in 2013, governs the usage of RES. This Law of RK on encourage to Use of RES lays out the fundamentals of governmental regulation of RES use and offers financial instruments to encourage the development of RES.

According to Article 9 of the Law on Support to Use of RES, the regional power grid businesses are in charge of connecting RES capacity to grids and buying all electricity produced by RES by their local generating companies. These RES generation businesses are also not required to pay for power transmission services. Incentives for these generating firms are also provided by the government, such as feed-in tariffs and the ability to link new facilities to the current electricity networks. 31 RES projects totalling 1040 MW in capacity must be completed between 2013 and 2020, according to the Government of Kazakhstan Regulation on Planning of Renewable Energy Development in Kazakhstan. These projects include 13 wind power plants with a capacity of 793 MW, 14 hydro power plans with a capacity of 170 MW, four solar power plants with a capacity of 77 MW. As part of its overall transition to a green economy, Kazakh government hopes that by 2030, 10% of domestic electricity output will come from renewable sources, and by 2050, 50%. In order to make renewable energy generation more appealing, government has promised to buy all of the energy produced by RES using higher pricing with yearly revisions.

CONCLUSIONS

This study underscores the role of bioclimatic architectural design as a strategic response to the climate challenges facing Kazakhstan. By integrating climate analysis, vernacular architectural elements, and passive design strategies, it proposes a context-specific framework aimed at improving the energy efficiency, resilience, and thermal comfort of buildings in cold semi-arid conditions.

A key contribution of the research is its demonstration of how bioclimatic principles can serve both climate change mitigation – by reducing energy consumption and associated emissions – and climate adaptation, by enhancing resilience to heat waves, droughts, and other climate-related hazards. The methodological integration of psychrometric analysis with the broader policy context offers a richer understanding of how building design can align with national climate objectives.

The findings provide practical guidance for architects, urban planners, and policymakers, suggesting that climate-smart design principles should be incorporated into Kazakhstan's building codes and national adaptation plans. Moreover, the proposed strategies are applicable to other countries with comparable climatic and urban conditions, particularly in Central Asia, Eastern Europe, and other arid continental regions.

While the study lays a solid conceptual foundation, further empirical research is necessary to evaluate the real-world performance of bioclimatic buildings in Kazakhstan. Future investigations should prioritize post-occupancy evaluations, cost–benefit analyses, and digital simulation modeling to validate and refine the proposed approaches.

Overall, this research contributes to the academic discourse on sustainable architecture while bridging theory and practice, offering actionable solutions to advance climate-resilient development.

REFERENCES

1. Akhanova, G., Nadeem, A., Kim, J. R., Azhar, S. (2020). A multi-criteria decision-making framework for building sustainability assessment in Kazakhstan. *Sustainable Cities and Society, 52*, 101842. https://doi.org/10.1016/j.scs.2019.101842
2. Barea, G., Mercado, M. V., Filippin, C., Monteoliva, J. M., Villalba, A. (2022*).* New paradigms in bioclimatic design toward climatic change in arid environments. *Energy and Buildings, 266*, 112100. https://doi.org/10.1016/j.enbuild.2022.112100
3. Cantatore, E., Fatiguso, F. (2021). An energy-resilient retrofit methodology to climate change for historic districts: Application in the Mediterranean area. *Sustainability, 13*(3), 1422. https://doi.org/10.3390/su13031422
4. Chondrogianni, D. V., Stephanedes, Y. J. (2024). Assessment of the Bioclimatic Index for resilient urban spaces in Mediterranean cities. *Environment and Planning B: Urban Analytics and City Science, 51*(1), 234–258. https://doi.org/10.1177/23998083231175894
5. Faragalla, A. M., Asadi, S. (2022). Biomimetic design for adaptive building façades: A paradigm shift towards environmentally conscious architecture. *Energies, 15*(15), 5390. https://doi.org/10.3390/en15155390
6. Großmann, A., Flaute, M., Lutz, C., Hohmann, F., Banning, M. (2023). Modeling climate resilient economic development. In *Climate Change Strategies: Handling the Challenges of Adapting to a Changing Climate* (pp. 57–75). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-28728-2_4
7. Košir, M. (2026). Climate Change and Its Implications for Bioclimatic Design. In *Climate Adaptability of Buildings: Bioclimatic Design in the Light of Climate Change* (pp. 257–326). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-032-11798-4_6
8. Martín-Ortega, J. L., et al. (2024). Enhancing transparency of climate efforts: MITICA's integrated approach to greenhouse gas mitigation. *Sustainability, 16*(10), 4219. https://doi.org/10.3390/su16104219
9. Nydrioti, I., et al. (2024). Effective management of urban water resources under various climate scenarios in semiarid Mediterranean areas. *Scientific Reports, 14*(1), 28666. https://doi.org/10.1038/s41598-024-79938-3
10. Ozarisoy, B., Altan, H. (2021). Systematic literature review of bioclimatic design elements: Theories, methodologies and cases in the South-eastern Mediterranean climate. *Energy and Buildings, 250*, 111281. https://doi.org/10.1016/j.enbuild.2021.111281
11. Papadogiannaki, G., et al. (2023). Evaluating the impact of COVID-19 on the carbon footprint of two research projects: A comparative analysis. *Atmosphere, 14*(9), 1365. https://doi.org/10.3390/atmos14091365
12. Poulsen, M., Lauring, M., Brunsgaard, C. (2020). A review of climate change adaptive measures in architecture within temperate climate zones. *Journal of Green Building, 15*(2), 113–130. https://doi.org/10.3993/1943-4618.15.2.113
13. Progiou, A., et al. (2022). Impact of COVID-19 pandemic on air pollution: The case of Athens, Greece. *Environmental Engineering and Management Journal, 21*(5), 879–889. https://doi.org/10.30638/eemj.2022.080
14. Raihan, A., Tuspekova, A. (2022). Role of economic growth, renewable energy, and technological innovation to achieve environmental sustainability in Kazakhstan. *Current Research in Environmental Sustainability, 4*, 100165. https://doi.org/10.1016/j.crsust.2022.100165
15. Roshan, G. R., Farrokhzad, M., Orosa, J. A. (2019). A climate-architecture modeling to explore the effect of land use change scenario on building bioclimatic design pattern in order to provide human thermal comfort. *Journal of Environmental Health Science and Engineering, 17*, 1131–1151. https://doi.org/10.1007/s40201-019-00427-1

16. Sabirova, Z. (2022). The effectiveness of climate financing intermediaries: Comparative study of Kazakhstan and Ukraine. *Journal of Global Social Sciences, 3*(11), 33–56.
17. Soltangazinov, A., Smagulova, Z., Amirova, M., Kashuk, L., Karimbergenova, M., Kadyrova, A., Zhaltyrova, O. (2020). Energy efficiency as a factor of sustainable development in Kazakhstan. *International Journal of Energy Economics and Policy, 10*(1), 325–330. https://doi.org/doi:10.32479/ijeep.8618
18. Taing. K, (2024). *Architectural design process for a bioclimatic building: Study of methods and design strategies for building comfort in the tropical climate*. Doctoral thesis. University of Liege and Institute of Technology of Cambodia.
19. Tsepi, E., et al. (2024). Decomposition analysis of CO_2 emissions in Greece from 1996 to 2020. *Strategic Planning for Energy & the Environment, 43*(3). https://doi.org/10.13052/spee1048-5236.4332
20. Umana, A. U., Garba, B. M. P., Ologun, A., Olu, J. S., Umar, M. O. (2024). Architectural design for climate resilience: Adapting buildings to Nigeria's diverse climatic zones. *World Journal of Advanced Research and Reviews, 23*(3), 397–408.
21. Vakharia, M. N., Joshi, M. (2024). Climate-responsive wada architecture: a bioclimatic design for climate change resilience. *Journal of Asian Architecture and Building Engineering*, 1–14. https://doi.org/10.1080/13467581.2024.2396609
22. Webber, C. (2017). Moving towards sustainable energy in a resource-rich country: Setting the context for Kazakhstan. In *Sustainable Energy in Kazakhstan* (pp. 34–62). Routledge.
23. Widera, B. (2021). Comparative analysis of user comfort and thermal performance of six types of vernacular dwellings as the first step towards climate resilient, sustainable and bioclimatic architecture in western sub-Saharan Africa. *Renewable and Sustainable Energy Reviews, 140*, 110736. https://doi.org/10.1016/j.rser.2021.110736
24. Yussupov, A. N., Yussupova, A. A. (2022). Ecological houses of Southern Kazakhstan using renewable energy sources. *Smart and Sustainable Built Environment, 11*(3), 593–607. https://doi.org/10.1108/SASBE-06-2020-0088