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RESEARCH ARTICLE

ASSESSMENT OF CLIMATIC ZONES OF KAZAKHSTAN WITH THE HIGHEST DEMAND FOR ENERGY-EFFICIENT SOLUTIONS

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Abstract. *This study aims to evaluate the influence of sharply continental climatic conditions on heat transfer processes through external wall structures of residential buildings in Kazakhstan, characterized by significant annual temperature amplitudes, a prolonged heating period (up to 210 days), and high values of heating degree-days (HDD). The methodology is based on a comprehensive analysis of regional climatic parameters, including temperature regimes, heating period duration, HDD, humidity, wind characteristics, and solar radiation, combined with the assessment of heat transfer through building envelopes using steady-state heat flux equations, and supplemented by thermographic inspection of a typical multi-storey residential building in Almaty at outdoor temperatures ranging from −11 to −15 °C. The results demonstrate a pronounced spatial differentiation of climatic load: northern, central, and eastern regions are characterized by the highest HDD values and the greatest demand for thermal energy, while southern regions, including Almaty, are also subject to significant heat losses due to temperature fluctuations and the presence of thermal bridges. Thermographic analysis revealed local temperature anomalies of up to 8–12 °C in structural junction areas, indicating reduced thermal resistance. The findings confirm the key role of both climatic factors and structural characteristics of building envelopes in the formation of heat losses and justify the need for developing climate-adaptive energy-efficient solutions.*

Keywords: *climatic zones, wall structures, heat loss, enclosing structures, sustainable construction*

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ҒЫЛЫМИ МАҚАЛА

ЭНЕРГИЯ ҮНЕМДЕУШІ ШЕШІМДЕРГЕ ЕҢ ЖОҒАРЫ СҰРАНЫС БАР ҚАЗАҚСТАННЫҢ КЛИМАТТЫҚ АЙМАҚТАРЫН БАҒАЛАУ

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Аңдатпа. *Бұл зерттеу Қазақстан аумағында тұрғын үйлердің сыртқы қабырға конструкциялары арқылы жылу алмасу процестеріне күрт континенттік климат жағдайларының әсерін бағалауға бағытталған, ол айтарлықтай жылдық температура ауытқуларымен, ұзақ жылыту маусымымен (210 тәулікке дейін) және жылыту градус-күндерінің (HDD) жоғары мәндерімен сипатталады. Әдістеме аймақтық климаттық параметрлерді, соның ішінде температуралық режимдерді, жылыту кезеңінің ұзақтығын, HDD көрсеткішін, ылғалдылықты, жел сипаттамаларын және күн радиациясын кешенді талдауға негізделген, сондай-ақ стационарлық жылу ағыны теңдеулері негізінде қоршау конструкциялары арқылы жылу алмасуды бағалаумен толықтырылған және Алматы қаласындағы типтік көпқабатты тұрғын үйге жүргізілген термографиялық зерттеумен (сыртқы ауа температурасы −11-ден −15 °C-қа дейін) толықтырылған. Нәтижелер климаттық жүктеменің айқын кеңістіктік дифференциациясын көрсетеді: солтүстік, орталық және шығыс өңірлер HDD мәндерінің жоғары болуымен және жылу энергиясына ең үлкен сұраныспен сипатталса, оңтүстік өңірлер, соның ішінде Алматы, температураның ауытқуы мен жылу көпірлерінің болуына байланысты елеулі жылу шығындарына ұшырайды. Термографиялық талдау конструктивтік түйіспелер аймақтарында 8–12 °C дейінгі жергілікті температуралық ауытқуларды анықтап, бұл жылу кедергісінің төмендеуін көрсетеді. Алынған нәтижелер климаттық факторлар мен қоршау конструкцияларының құрылымдық ерекшеліктерінің жылу шығындарының қалыптасуындағы шешуші рөлін растайды және климатқа бейімделген энергия тиімді шешімдерді әзірлеу қажеттілігін негіздейді.*

Түйін сөздер: *климаттық аймақтар, қабырға құрылымдары, жылу жоғалту, қоршаушы құрылымдар, тұрақты құрылыс*

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НАУЧНАЯ СТАТЬЯ

ОЦЕНКА КЛИМАТИЧЕСКИХ ЗОН КАЗАХСТАНА С НАИБОЛЬШЕЙ ПОТРЕБНОСТЬЮ В ЭНЕРГОЭФФЕКТИВНЫХРЕШЕНИЯХ

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Аннотация. *Данное исследование направлено на оценку влияния резко континентальных климатических условий на процессы теплопередачи через наружные стеновые конструкции жилых зданий в Казахстане, характеризующегося значительными годовыми амплитудами температур, длительным отопительным периодом (до 210 суток) и высокими значениями градуса-суток отопления (HDD). Методология основана на комплексном анализе региональных климатических параметров, включая температурные режимы, продолжительность отопительного периода, HDD, влажность, ветровые характеристики и солнечную радиацию, с последующей оценкой теплопередачи через ограждающие конструкции на основе уравнений стационарного теплового потока, а также дополнена термографическим обследованием типового многоэтажного жилого здания в Алматы при наружных температурах от −11 до −15 °C. Результаты демонстрируют выраженную пространственную дифференциацию климатической нагрузки: северные, центральные и восточные регионы характеризуются максимальными значениями HDD и наибольшей потребностью в тепловой энергии, тогда как южные регионы, включая Алматы, также подвержены значительным теплопотерям вследствие температурных колебаний и наличия тепловых мостов. Термографический анализ выявил локальные температурные аномалии до 8–12 °C в зонах конструктивных стыков, что свидетельствует о снижении теплового сопротивления. Полученные результаты подтверждают ключевую роль как климатических факторов, так и конструктивных особенностей ограждающих конструкций в формировании теплопотерь и обосновывают необходимость разработки климатически адаптированных энергоэффективных решений.*

Ключевые слова: *климатические зоны, стеновые конструкции, теплопотери, ограждающие конструкции, устойчивое строительство*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

The authors declare that no generative artificial intelligence technologies or AI-based tools were used in the preparation of this article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу Қазақстан Республикасы Ғылым және жоғары білім министрлігі Ғылым комитетінің №AP25793529 ғылыми жобасы аясында қаржылық қолдауымен орындалды.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Авторлар мақаланы дайындау барысында генеративті жасанды интеллект технологиялары мен жасанды интеллектке негізделген технологияларды пайдаланбағанын мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование выполнено при финансовой поддержке Комитета науки Министерства науки и высшего образования Республики Казахстан в рамках научного проекта №AP25793529.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

Авторы заявляют о том, что при подготовке статьи не использовались технологии генеративного искусственного интеллекта и технологии, основанные на искусственном интеллекте.

1 INTRODUCTION

Kazakhstan is characterized by sharply continental climatic conditions with significant annual temperature fluctuations, low precipitation, and prolonged heating periods, particularly in the northern and central regions. These climatic factors substantially influence the thermal performance of building envelope structures and lead to increased energy consumption for space heating. Under such conditions, heat transfer through external walls becomes one of the key determinants of building energy efficiency.

In the context of global efforts toward sustainable development and reduction of energy consumption in the building sector, the adaptation of architectural and engineering design solutions to regional climatic conditions has become increasingly important. Significant heat losses through building envelope elements, especially external walls, necessitate the implementation of energy-efficient design strategies that account for regional climatic variability and thermal load intensity.

Although previous research has addressed various aspects of building energy efficiency, most studies have focused on individual design solutions, insulation optimization, or modernization measures. Comprehensive assessments linking regional climatic differentiation with heat transfer intensity through external wall structures remain limited, particularly for countries with sharply continental climates such as Kazakhstan. A systematic evaluation of climatic parameters and their influence on thermal performance is required to better understand regional variations in heating demand and envelope efficiency.

This study aims to assess the influence of regional climatic conditions on heat transfer processes in building envelope structures and to identify climatic zones of Kazakhstan with the highest demand for energy-efficient solutions. The research is based on the analysis **(Tao et al., 2021)** of key climatic indicators, including temperature regimes, heating period duration, solar radiation, wind characteristics, and heating degree days. The obtained results contribute to a deeper understanding of the relationship between climatic severity and building thermal performance and provide a scientific basis for improving energy-efficient design approaches for residential buildings operating under sharply continental climate conditions.

Improving the energy efficiency of buildings located in sharply continental climatic conditions represents a significant challenge for sustainable construction. Severe winter temperatures, prolonged heating periods, and the high energy intensity of the existing building stock led to considerable heat losses through building envelopes and require advanced thermal protection strategies.

Recent studies have confirmed the effectiveness of comprehensive approaches to improving building energy performance **(Dyussembekova et al., 2022)** analyzed the energy efficiency of the Kazakh German University building in Almaty using simulation-based methods and demonstrated that modernization of external walls, window systems, and heating equipment can significantly reduce energy consumption. These findings highlight the importance of integrated envelopes and system-level improvements.

In the work of **(Abid Nadeem et al., 2021)** the energy and daylighting performance of various window types was assessed under the climatic conditions of Nur-Sultan. The study confirmed the significant impact of glazing geometry and light transmittance on heat loss and natural lighting levels.

(Tukhtamisheva et al., 2020) explored the technical and economic justification for optimizing insulation thickness in the external walls of residential buildings in the Almaty region. Their findings proposed economically viable insulation parameters based on energy prices, payback periods, and local climatic conditions.

(Kerimray et al., 2016) analyzed energy audit reports of buildings in different regions of Kazakhstan. The study emphasized the need to improve the thermal resistance of wall structures, especially in the northern and central parts of the country and identified the most effective measures for reducing heat loss.

The literature also highlights the importance of alternative heating sources **(Amanzholov et al., 2022)** evaluated the thermal performance of borehole heat exchangers installed in southern Kazakhstan. The results confirm the potential of ground-source heat as a stable and sustainable energy solution for building heating systems.

Despite the growing body of research, few studies offer a comprehensive assessment of Kazakhstan's climatic zones in terms of their specific needs for energy-efficient solutions in building envelope design. The present study seeks to address this gap by combining regional climate data analysis with thermal performance evaluation of wall structures.

2 MATERIALS AND METHODS

The methodological framework of this study is based on a combination of climatic data analysis and thermal performance evaluation of building envelope structures. Climatic indicators for the regions of Kazakhstan were obtained from the Kazhydromet database, national construction standards **(SP RK 2.04-01-2017)**, and international climate datasets. The parameters considered include:

1. Average monthly and annual outdoor air temperatures.
2. Heating degree-days (HDD) and the duration of the heating season.
3. Relative humidity.
4. Wind speed and predominant directions.
5. Solar radiation intensity.

The territory of the Republic of Kazakhstan is characterized by pronounced climatic heterogeneity, which necessitates a differentiated approach to the design of energy-efficient buildings. In this study, five major climatic zones were identified: northern, central, eastern, southern, and western **(Kyritsi et al., 2025).**

Northern Kazakhstan is characterized by a sharply continental climate with long, cold winters and short summers. The average temperature in January is approximately -18 °C, while in July it is about +19 °C. Annual precipitation ranges from 300 to 450 mm.

Central Kazakhstan experiences cold winters and hot summers, with average temperatures of about -15 °C in winter and +25 °C in summer. Annual precipitation varies between 180 and 250 mm.

Eastern Kazakhstan has a continental climate with cold, snowy winters and warm summers (-12 to -15 °C in January and +25 to +30 °C in July). Annual precipitation ranges from 300 to 600 mm.

Southern Kazakhstan is characterized by relatively mild winters (around -5 °C in January) and hot, prolonged summers (up to +30 °C in July), with annual precipitation of 100-200 mm.

Western Kazakhstan exhibits large annual temperature amplitudes (down to -20 °C in winter and up to +40 °C in summer) and relatively low annual precipitation (100-300 mm) **(Climate-Data.org, n.d.)**.

Table 1
Climatic parameters of the regions of Kazakhstan

Region	Average January temperature (°C)	Average July temperature (°C)	Annual temperature amplitude (°C)	Heating period duration (days)	Average annual humidity (%)	Number of sunny days per year	Average wind speed (m/s)
Northern Kazakhstan	-18	+19	37	200-210	70-75	120	3.0-4.0
Central Kazakhstan	-16	+23	39	190-200	65-70	140	3.5-4.5
Eastern Kazakhstan	-14	+25	39	180-190	60-65	160	2.5-3.5
Southern Kazakhstan	-6	+29	35	120-140	55-60	260	2.0-3.0
Western Kazakhstan	-11	+27	38	160-180	50-55	150	4.0-5.0

The main climatic characteristics of the regions of Kazakhstan are summarized in **Table 1.** The data demonstrates significant differences in temperature regimes and heating period duration, which directly affect the thermal performance of building envelope structures.

The data in the figures are averaged across regions and may vary slightly depending on location. Average January and July temperatures are used as winter minimum and summer maximum values, allowing us to estimate the annual temperature range and the climatic load on buildings. For a more objective assessment of the heat load, the heating degree days (HDD) indicator is used

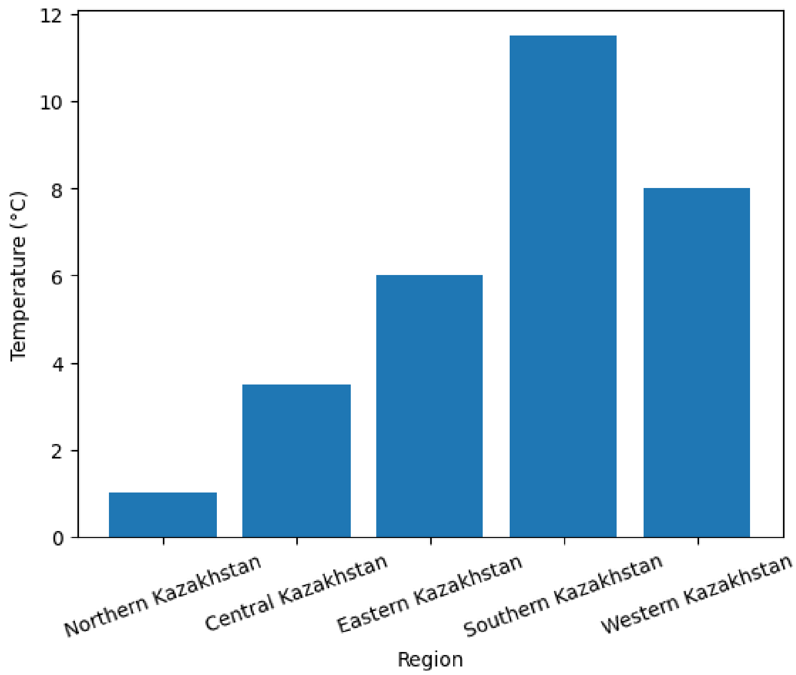

Figure 1 - Average annual temperature by regions of Kazakhstan **(Climate-Data.org, n.d.)**.

The **Figure 1** presents the distribution of average annual air temperature across the regions of Kazakhstan. The lowest values are observed in Northern and Central Kazakhstan, indicating a high climatic load on buildings in these regions. Southern Kazakhstan, including Almaty Region and the city of Almaty, is characterized by warmer climatic conditions and a generally lower demand for heating. However, even in this region, heat losses through building envelope structures remain significant, particularly under conditions of low winter temperatures, daily temperature fluctuations, and the presence of thermal bridges in structural joints. This justifies the necessity of applying energy-efficient solutions and appropriate thermal insulation of external walls for buildings located in Almaty and Almaty Region **(Tukhtamisheva & Adilova, 2025).**

According to the national construction standards of the Republic of Kazakhstan, in particular (**SP RK 2.04-01-2017)**, the territory of Kazakhstan is divided into climatic zones based on winter temperature conditions and other climatic parameters relevant for building design.

The standard distinguishes the following climatic zones:

1. Climatic Zone I - regions with the most severe winter conditions (average January temperature below -20 °C);
2. Climatic Zone II - regions with moderately cold winters (average January temperature between -20 °C and -15 °C);
3. Climatic Zone III - regions with relatively mild winters (average January temperature above -15 °C).

Based on the climatic data analyzed in this study, the regions of Kazakhstan can be conditionally assigned to the climatic zones as follows:

1. Zone I - Northern Kazakhstan;
2. Zone II - Central and Eastern Kazakhstan;

3. Zone III - Southern and Western Kazakhstan.

Such zoning confirms the necessity of a differentiated approach to the design of building envelopes depending on regional climatic conditions. It also indicates that even regions belonging to Climatic Zone III, including Almaty Region and the city of Almaty, require the application of energy-efficient solutions due to temperature fluctuations, heating period duration, and the influence of construction-related factors.

The assessment of climatic load on buildings was based on the analysis of climatic indicators affecting heat transfer through building envelope structures. The main criteria considered in this study were temperature conditions, heating period duration, and the integral indicator of thermal demand expressed by heating degree-days (HDD).

One of the key factors determining the level of heat loss is the temperature gradient, defined as the difference between indoor and outdoor air temperatures. An increase in this difference leads to higher heat losses through external walls and other enclosing structures, thereby increasing the thermal load on buildings **(ISO 52016-1:2017, 2017)**.

A significant influence on total heat losses is exerted by the heating period duration, which is directly related to regional climatic conditions. Under the sharply continental climate of Kazakhstan, this parameter varies from approximately 130 days in southern regions to up to 210 days in northern regions. The regional distribution of heating period duration is presented in **Figure 2.**

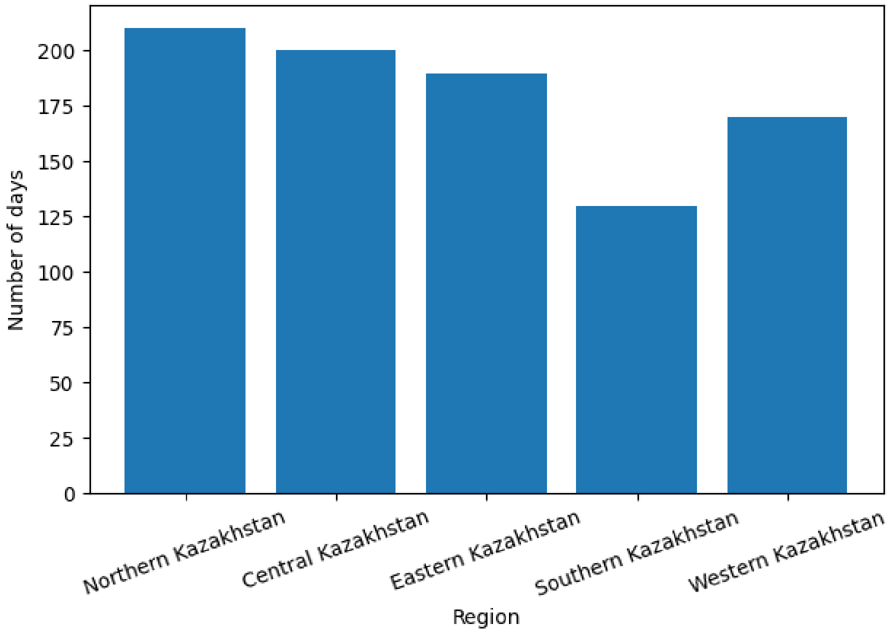

Figure 2 - Heating period duration by regions of Kazakhstan **(Climate-Data.org, n.d.)**.

The longest heating season is observed in Northern Kazakhstan, followed by Central and Eastern Kazakhstan. Southern Kazakhstan has the shortest heating period; however, its duration remains sufficient to justify the application of thermal protection measures in building envelope design.

For a more objective comparative assessment of climatic load, the indicator of heating degree-days (HDD) was used. This indicator reflects the combined influence of temperature conditions and heating period duration and is widely applied in the analysis of building energy performance. The regional distribution of HDD values is shown in **Figure 3.**

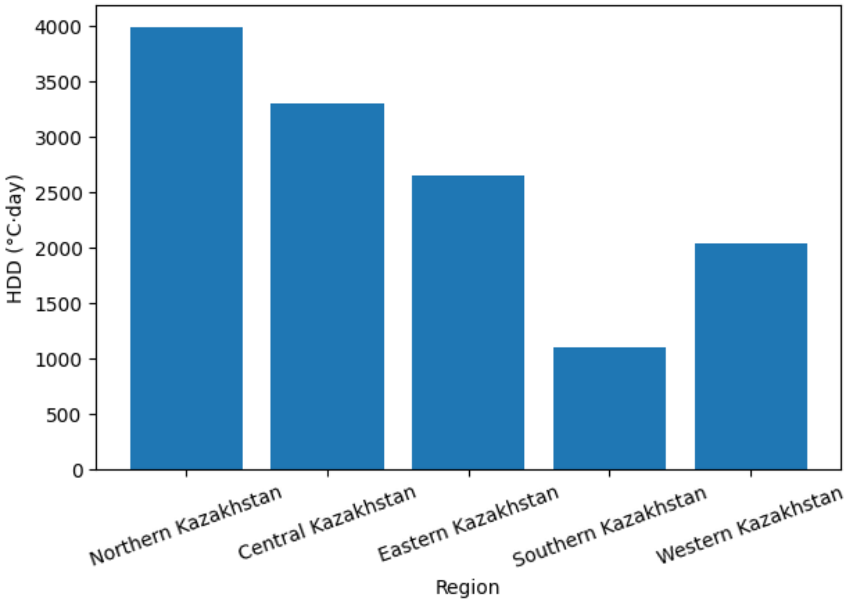

Figure 3 - Heating degree-days (HDD) by regions of Kazakhstan **(Climate-Data.org, n.d.)**.

The highest HDD values are observed in Northern, Central, and Eastern Kazakhstan, indicating the greatest thermal load on building envelope structures in these regions. At the same time, even Southern Kazakhstan demonstrates meaningful HDD values, which confirms the relevance of applying energy-efficient solutions in building envelope design, including for buildings located in Almaty and Almaty Region.

The combined analysis of heating period duration and HDD values provides a comprehensive assessment of climatic load on buildings and forms the methodological basis for the subsequent analysis of heat losses and thermal bridges **(Aloshan et al., 2024).**

The collected climatic data were systematized and processed using standard analytical methods. The values of key indicators (heating period duration and heating degree-days) were grouped by region in order to ensure comparability of the results.

For visual interpretation of regional differences, the processed data were presented in the form of tables and graphical diagrams. Bar charts were used to illustrate the distribution of heating period duration and heating degree-days across the regions of Kazakhstan **(Figures 2-3).** This approach allows clear identification of regional contrasts and supports the comparative analysis of climatic load on buildings.

The use of graphical representation improves the clarity of the results and facilitates the interpretation of climatic impacts on building envelope performance **(Shao et al., 2022).**

The thermal performance of building envelope structures was evaluated using principles of steady-state heat transfer. Heat flux density through external walls was estimated according to the basic heat transfer equation:

$$q = (Ti - To) / R \quad (1)$$

where:

q – heat flux density (W/m²),

Ti – indoor air temperature (°C),

To – outdoor air temperature (°C),

R – total thermal resistance of the wall structure (m²·K/W).

This approach allows evaluation of the relationship between climatic load and heat transfer intensity through building envelope structures. The analysis focuses on the influence of temperature gradients, heating period duration, and heating degree-days on the required thermal resistance of external walls **(Paiho et al., 2015).**

To complement the climatic analysis, a thermographic survey of a multi-storey residential building located in Almaty was conducted. The selected building represents a typical residential structure operating under sharply continental climatic conditions.

Thermal imaging was performed during the heating season under stable meteorological conditions. The outdoor air temperature during the survey ranged from -11 °C to -15 °C, providing sufficient temperature contrast for reliable identification of heat loss zones.

Infrared thermography was used to detect thermal bridges, insulation defects, and areas of increased heat transfer through building envelope structures. Both external façade surfaces and interior wall junctions were examined. Special attention was given to window-to-wall connections, inter-panel joints, façade seams, and corner zones **(Pastori et al., 2021).**

The thermographic images were analyzed by comparing surface temperature distributions across envelope elements. Temperature differences between uniform and anomalous zones were used as indicators of reduced thermal resistance and increased heat loss.

To ensure reliable interpretation of thermographic data, architectural and structural documentation of the investigated residential building was analyzed. The case-study object represents a typical multi-storey residential building located in Almaty and constructed using reinforced concrete panels with internal thermal insulation.

Architectural and structural drawings were examined to determine the configuration of the external wall assembly, insulation thickness, façade detailing, and structural junctions potentially acting as thermal bridges. Attention was paid to wall–floor interfaces, window-to-wall connections, anchoring elements, and insulation continuity **(Zhao et al., 2025).**

The external wall configuration used for thermographic analysis was defined based on the examined documentation. The wall assembly consists of a multilayer system including an internal finishing layer, a reinforced concrete structural panel, an internal thermal insulation layer, and an external protective façade layer. Such configuration is typical for panel residential buildings constructed in the late Soviet and post-Soviet periods.

Special consideration was given to the continuity and positioning of the insulation layer within the wall system, as internal insulation often leads to increased risk of bridging thermals at structural joints. Discontinuities at floor slabs, panel joints, and window openings were identified as critical areas influencing heat transfer performance.

This configuration provided the basis for interpreting thermographic images, allowing correlation between observed surface temperature variations and specific structural elements. As a result, areas of increased heat loss could be linked to construction details and insulation defects, improving the accuracy of energy performance assessment **(Jelle, 2011)**

In addition, environmental conditions during thermographic inspection were carefully controlled to ensure the accuracy of measurements. Thermal imaging was conducted during the heating season under stable weather conditions, with no direct solar radiation, precipitation, or strong wind. The temperature difference between indoor and outdoor air was maintained at no less than 10–15 °C, which is considered sufficient for reliable detection of thermal anomalies in building envelopes. These conditions are particularly relevant for the continental climate of Kazakhstan, where significant seasonal temperature variations enhance the effectiveness of thermographic diagnostics.

The analysis of construction details enabled identification of zones susceptible to increased heat transfer and facilitated comparison between design solutions and thermographic observations. Selected fragments of the window–wall junction detail and the external wall assembly with insulation system used in the analysis are presented in **Figure 4 and 5,** respectively.

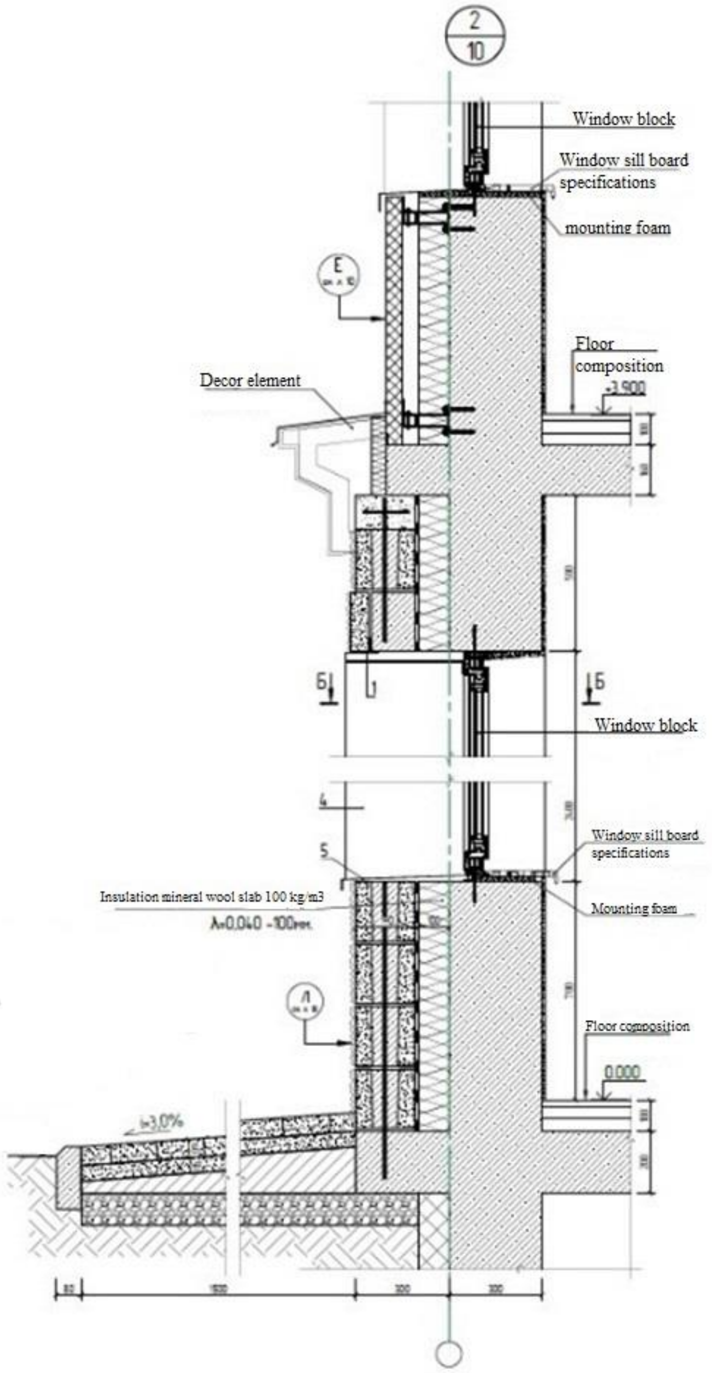

Figure 4 - Vertical section of the window–wall junction showing the interface between the window block and the external wall, including insulation and sealing components (author's materials)

Figure 4 illustrates a vertical section of the window–wall junction, highlighting the interface between the window block and the external wall structure. Attention is given to the arrangement of thermal insulation and sealing components, which play a crucial role in maintaining thermal continuity and preventing air infiltration. The configuration demonstrates how improper installation or discontinuity of insulation at this junction can lead to the formation of thermal bridges and increased heat loss.

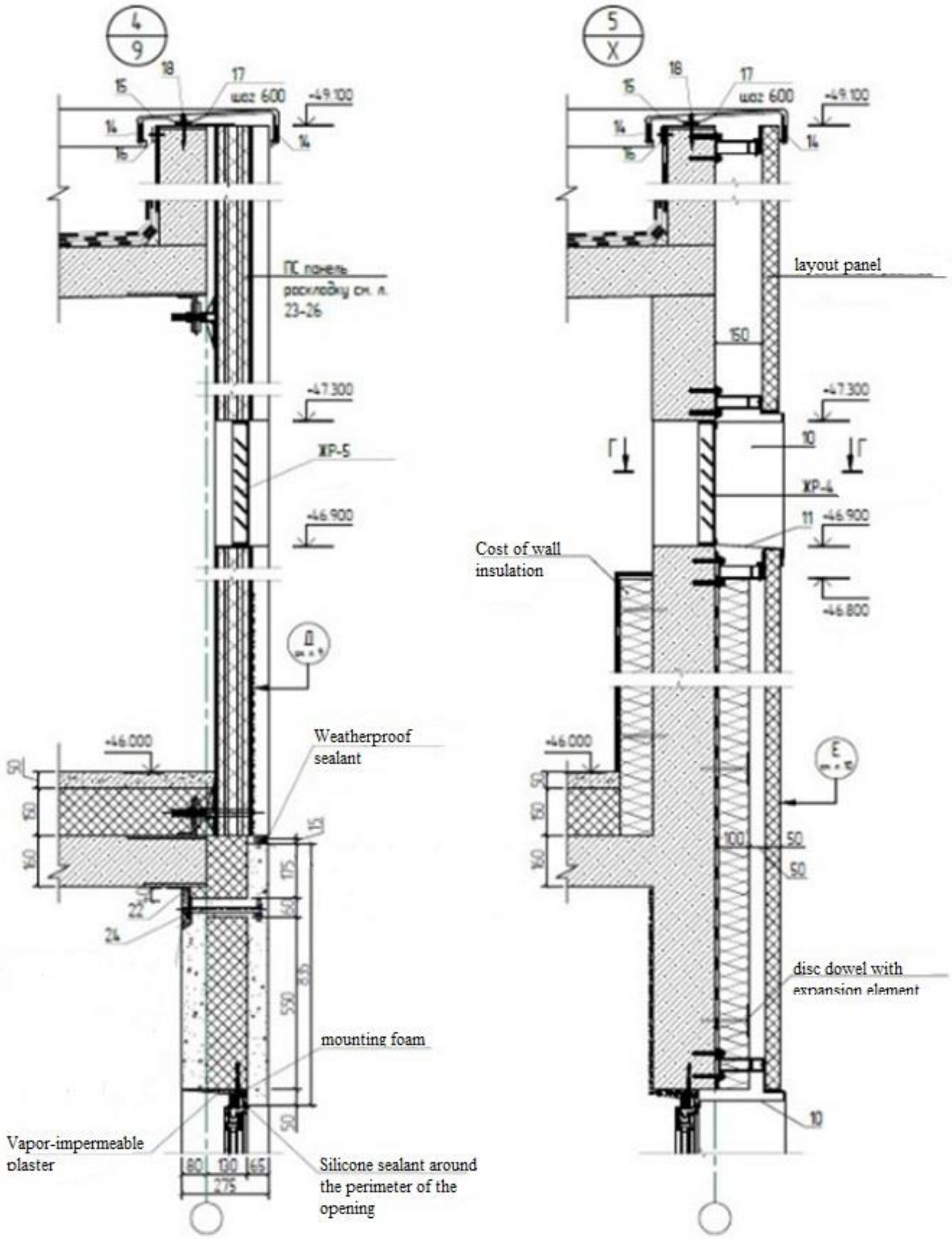

Figure 5 - Vertical section of the external wall assembly with insulation system, indicating structural layers and potential thermal bridge locations (author's materials)

Figure 5 presents a vertical section of the external wall assembly with a thermal insulation system, illustrating the sequence of structural layers, including interior finishing, the load-bearing element, the insulation layer, and the external coating. Attention is given to areas prone to thermal bridging, which may occur at points of structural discontinuity, material inhomogeneity, and junctions between elements. It is shown that insufficient insulation continuity and detailing of construction joints can lead to localized increases in heat transfer and a reduction in the overall energy performance of the building envelope.

3 RESULTS AND DISCUSSION

The analysis of climatic indicators demonstrates significant spatial differences in climatic load across the territory of Kazakhstan. The regional distribution of average annual air temperature (Figure 1) confirms that Northern and Central Kazakhstan are characterized by the lowest temperature values, while Southern Kazakhstan shows the highest temperatures throughout the year. These differences create unequal operating conditions for building envelopes and determine varying levels of heating demand.

The results indicate that the climatic load on buildings increases with decreasing outdoor air temperature and with increasing annual temperature amplitude. Consequently, regions with colder climatic conditions are subject to greater thermal stress on building envelopes and require more stringent thermal protection measures **(Shahrzad & Umberto, 2022).**

Heating period duration is one of the most significant indicators influencing the level of heat loss in buildings. According to **Figure 2**, the heating season reaches up to 210 days in Northern Kazakhstan, while in Central and Eastern Kazakhstan it exceeds 180 days. Southern Kazakhstan exhibits the shortest heating period (approximately 130 days); however, even this value represents more than one-third of the year.

A longer heating period leads to increased cumulative heat loss through external walls and other building envelope components. Therefore, buildings located in northern, central, and eastern regions are exposed to higher annual heat demand and require enhanced thermal insulation and improved envelope performance **(Nizovtsev et al., 2020).**

The indicator of heating degree-days (HDD) provides an integral assessment of climatic severity by combining temperature conditions and heating period duration. The results presented in **Figure 3** demonstrate that the highest HDD values are observed in Northern Kazakhstan, followed by Central and Eastern Kazakhstan. These values indicate the highest level of climatic load and, consequently, the greatest heating energy demand in these regions.

Southern Kazakhstan exhibits lower HDD values; however, the indicator remains sufficiently high to confirm that heat losses through building envelope structures remain relevant even in relatively mild climatic conditions. This is especially important for urban areas such as Almaty and Almaty Region, where real operating conditions of buildings, construction defects, and the presence of thermal bridges can significantly increase actual heat losses.

The results obtained confirm the necessity of a differentiated approach to building design depending on regional climatic conditions. In regions with high climatic load (Northern, Central, and Eastern Kazakhstan), priority measures should include:

- application of high-performance thermal insulation materials.
- minimization of thermal bridges in construction joints.
- optimization of wall-floor and wall-window connections.
- improvement of airtightness and thermal continuity of building envelopes.

For Southern Kazakhstan, including Almaty and Almaty Region, although the overall climatic load is lower, the results demonstrate that the application of energy-efficient solutions remains justified. Moderate winter temperatures, significant daily temperature fluctuations, and construction-related factors contribute to measurable heat losses. Therefore, improving the thermal performance of external walls and reducing thermal bridges are also relevant for buildings located in this region.

The results of the regional climatic analysis provide a scientific justification for further detailed investigation of building envelope performance in Almaty. Despite belonging to a milder climatic zone, the city of Almaty experiences a sufficiently long heating period and non-negligible HDD values, which makes the study of heat losses and thermal bridges in real buildings both relevant and necessary **(Asdrubali et al., 2012).**

Thus, the obtained results form a reliable basis for the subsequent analysis of heat transfer through external wall structures and the evaluation of thermal bridges in selected buildings in Almaty.

Furthermore, the integration of climatic analysis with in-situ thermographic assessment enhances the reliability of conclusions regarding building energy performance. This combined approach allows not only the identification of general regional trends but also the detection of specific construction-related deficiencies affecting heat transfer. As a result, it provides a comprehensive framework for developing climate-responsive and energy-efficient design strategies, ensuring that both regional climatic characteristics and actual building conditions are taken into account in the process of improving the energy performance of residential buildings **(Balaras & Umberto, 2002).**

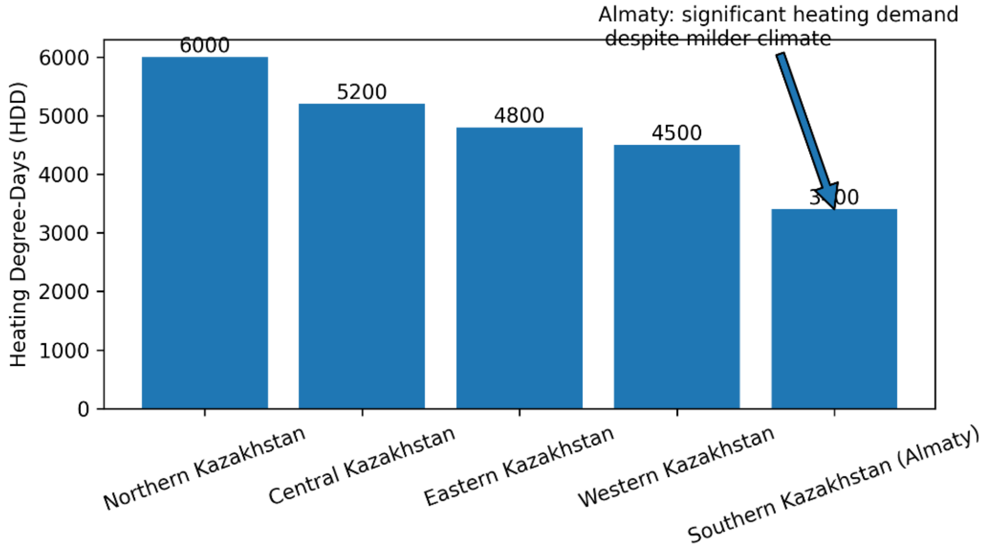

Figure 6 - Comparative heating demand in climatic regions of Kazakhstan expressed in heating degree-days (HDD), highlighting the position of Almaty (author's materials)

Figure 6 presents the regional distribution of heating demand across Kazakhstan expressed in heating degree-days (HDD). The highest values are observed in Northern Kazakhstan, followed by Central, Eastern, and Western regions. Although Almaty belongs to the southern climatic zone, the HDD value remains considerable, confirming that heating demand in the city is still significant compared to other regions of the country.

To validate the climatic analysis and assess actual heat loss distribution, thermographic inspection of a multi-storey residential building located in Almaty was carried out during the heating season.

The survey was conducted at outdoor temperatures ranging from -11 °C to -15 °C, providing sufficient thermal contrast for identifying irregular heat transfer. Both external façade surfaces and interior structural junctions were examined using infrared thermography.

The thermographic images revealed pronounced thermal bridges at window-to-wall junctions, inter-panel seams, façade connections, and balcony slab interfaces. Surface temperature differences between uniform wall areas and anomalous zones reached 8–12 °C, indicating increased heat flux and reduced local thermal resistance **(Ürge-Vorsatz D. et al., 2015).**

These findings confirm that the most significant heat losses are concentrated in localized structural elements rather than uniformly distributed across the building envelope. Window junctions, panel connections, and balcony slab interfaces act as critical points of thermal discontinuity, where insulation is either insufficient or interrupted. The presence of such thermal bridges leads to increased energy demand for heating and reduces overall building energy performance, especially under severe winter conditions typical for Kazakhstan.

Based on the obtained thermographic data, priority measures for improving energy efficiency can be identified. These include enhancement of insulation continuity at structural joints, application of external thermal insulation systems, and modernization of window installation detailing to minimize air leakage and thermal bridging. The integration of thermographic analysis with climatic zoning thus provides a reliable basis for targeted retrofit strategies aimed at reducing heat losses and improving the thermal performance of residential buildings.

Interior thermograms **Figure 7** confirmed temperature reductions in corner zones and wall–ceiling junctions. Surface temperatures in these areas ranged from +10 to +13 °C, compared to +19–

22 °C in central wall sections. Such variations indicate thermal discontinuities and potential condensation risk.

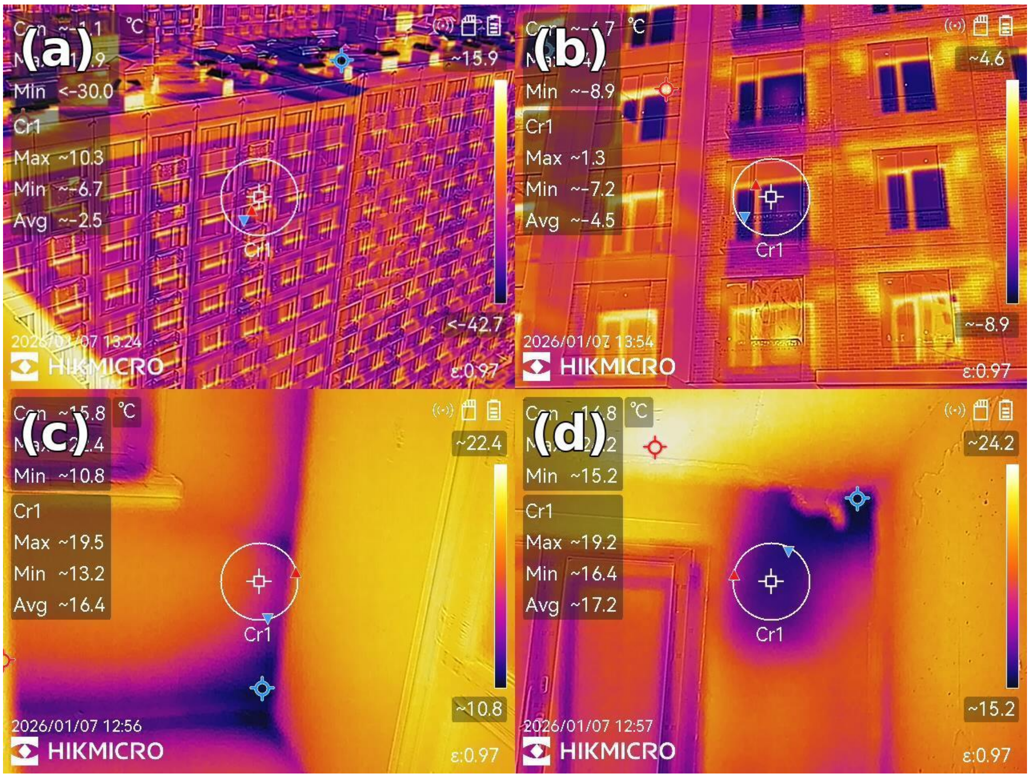

Figure 7 - Thermographic identification of heat-loss zones in a multi-storey residential building in Almaty: (a) external façade view; (b) inter-panel thermal bridge; (c) interior corner anomaly; (d) wall-ceiling junction (author's materials)

The obtained results demonstrate that even in relatively milder climatic conditions of Southern Kazakhstan, actual heat losses may increase significantly due to thermal bridges and construction-related defects. The thermographic assessment confirms the necessity of integrating climatic analysis with in-situ diagnostics for accurate evaluation of building energy performance.

3 CONCLUSIONS

1. Sharply continental climatic conditions of Kazakhstan result in pronounced regional differentiation of thermal loads on residential building envelopes.
2. The highest climatic severity and heating demand are observed in the northern, central, and eastern regions, as confirmed by temperature regimes, heating period duration, and heating degree-days (HDD).
3. Decreasing winter temperatures and extended heating periods significantly increase heat transfer intensity through external wall structures.
4. Substantial spatial variability in HDD values highlights the need for region-specific energy-efficiency strategies.
5. Thermographic assessment of a multi-storey residential building in Almaty revealed that heat losses are driven not only by climatic factors but also by envelope discontinuities.
6. Thermal bridges at inter-panel joints, window–wall interfaces, and wall–ceiling junctions cause measurable temperature drops and increased heat flux, even under relatively mild climatic conditions.
7. Effective improvement of building energy performance requires integration of regional climatic analysis with in-situ thermographic diagnostics.

8. The proposed approach provides a reliable basis for evaluating thermal demand and supports the development of energy-efficient design solutions for residential buildings in sharply continental climates.

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