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RESEARCH ARTICLE

MICROCLIMATIC DIFFERENTIATION OF LOW-RISE HOUSING IN SOUTH-EASTERN KAZAKHSTAN

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Abstract. *Bioclimatic design of low-rise housing in South-Eastern Kazakhstan is constrained by sharply continental climate conditions, pronounced seasonal temperature contrasts, complex terrain, and uneven urban aeration. Conventional design approaches based on averaged regional climate data fail to reflect local variations in temperature, wind, solar exposure, and humidity caused by urban morphology, relief, and landscaping. The aim of the study is to develop a differentiated architectural and planning model for low-rise housing based on microclimatic conditions. The methodology combines comparative-typological analysis, bioclimatic assessment, and graphic-analytical interpretation using case studies of Almaty, Konaev, and Taldykorgan. The comparative analytical component includes the assessment of three representative residential districts formed in the Soviet and post-Soviet periods using measurable spatial and environmental indicators, including development density, building spacing, orientation, degree of enclosure, and basic ventilation characteristics. The qualitative assessment covers spatial configuration, insolation conditions, wind regime and aeration, integration of green elements, thermal adaptation, and energy performance. The results show that urban territories are microclimatically heterogeneous and consist of distinct zones with different combinations of climatic and morphological parameters, affecting ventilation conditions, solar access, and thermal comfort. Five site types were identified: wind-exposed, moderately protected, stagnant-air, green/recreational, and terrain-influenced zones, each requiring specific architectural responses. The identified relationships between spatial configuration and microclimatic performance provide a basis for translating environmental conditions into design parameters. The study proposes a differentiated model of architectural and planning solutions based on microclimatic zoning, enabling context-sensitive design, improving environmental performance, and supporting the development of climate-responsive low-rise housing in Kazakhstan.*

Keywords: *bioclimatic architecture, low-rise housing, microclimatic zoning, urban morphology, design differentiation, South-Eastern Kazakhstan.*

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ОҢТҮСТІК-ШЫҒЫС ҚАЗАҚСТАНДАҒЫ ТӨМЕН ҚАБАТТЫ ТҰРҒЫН ҮЙЛЕРДІҢ МИКРОКЛИМАТТЫҚ ДИФФЕРЕНЦИАЦИЯСЫ

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Аңдатпа. *Оңтүстік-Шығыс Қазақстандағы төмен қабатты тұрғын үйді биоклиматтық жобалау күрт континенттік климат, маусымдық температуралық айырмашылықтардың айқын болуы, күрделі жер бедері және қалалық ортаның біркелкі емес аэрациясымен сипатталады. Орташа аймақтық климаттық көрсеткіштерге негізделген дәстүрлі тәсілдер құрылыс морфологиясы, рельеф және көгалдандыру әсерінен қалыптасатын температура, жел, күн сәулесінің түсуі және ылғалдылықтың жергілікті айырмашылықтарын ескермейді. Зерттеудің мақсаты - микроклиматтық жағдайларды ескере отырып, төмен қабатты тұрғын үйдің сараланған сәулеттік-жоспарлау моделін әзірлеу. Әдістеме салыстырмалы-типологиялық талдауды, биоклиматтық бағалауды және Алматы, Қонаев және Талдықорған қалалары мысалында графикалық-аналитикалық интерпретацияны қамтиды. Салыстырмалы-аналитикалық бөлім кеңестік және посткеңестік кезеңдерде қалыптасқан үш репрезентативті тұрғын ауданды кеңістіктік және орта көрсеткіштері арқылы бағалауды қамтиды, оның ішінде құрылыс тығыздығы, ғимараттар арасындағы қашықтық, бағдарлану, кеңістіктің тұйықталу дәрежесі және желдету сипаттамалары қарастырылған. Қосымша түрде микроклимат қалыптасуына әсер ететін кеңістіктік құрылым параметрлері есепке алынды. Сапалық бағалау кеңістіктік конфигурацияны, инсоляция жағдайларын, жел режимі мен аэрацияны, жасыл элементтердің интеграциясын, жылулық бейімделуді және энергия тиімділігін қамтиды. Нәтижелер қалалық аумақтардың микроклиматтық тұрғыдан әркелкі екенін және желдету жағдайларына, күн сәулесінің түсуіне және жылулық жайлылыққа әсер ететін климаттық және морфологиялық параметрлердің әртүрлі үйлесімдері бар аймақтарға бөлінетінін көрсетті. Бес учаске түрі анықталды: желге ашық, орташа қорғалған, ауа тұрып қалатын, жасыл және рекреациялық, сондай-ақ рельефке тәуелді аймақтар, олардың әрқайсысына сәйкес сәулеттік шешімдер қажет. Кеңістіктік ұйымдасу мен микроклиматтық сипаттамалар арасындағы анықталған байланыстар орта жағдайларын нақты жобалау параметрлеріне айналдыруға мүмкіндік береді. Зерттеу нәтижесінде микроклиматтық аймақтандыруға негізделген сараланған сәулеттік-жоспарлау моделі ұсынылды, ол контекстке бейімделген жобалауды қамтамасыз етеді және тұрғын ортаның экологиялық тиімділігін арттырады.*

Түйін сөздер: *биоклиматтық сәулет, төмен қабатты тұрғын үй, микроклиматтық аймақтандыру, қалалық морфология, жобалауды саралау, Оңтүстік-Шығыс Қазақстан.*

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МИКРОКЛИМАТИЧЕСКАЯ ДИФФЕРЕНЦИАЦИЯ МАЛОЭТАЖНОГО ЖИЛИЩА В ЮГО-ВОСТОЧНОМ КАЗАХСТАНЕ

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Аннотация. *Биоклиматическое проектирование малоэтажного жилья в Юго - Восточном Казахстане осложняется резко континентальным климатом, выраженными сезонными температурными контрастами, сложным рельефом и неравномерной аэрацией городской среды. Традиционные подходы, основанные на усреднённых региональных климатических данных, не отражают локальные вариации температурного режима, ветра, инсоляции и влажности, обусловленные морфологией застройки, рельефом и озеленением. Цель исследования - разработка дифференцированной архитектурно - планировочной модели малоэтажного жилья на основе микроклиматических условий. Методология включает сравнительно-типологический анализ, биоклиматическую оценку и графоаналитическую интерпретацию на примере городов Алматы, Конаев и Талдыкорган. Сравнительно - аналитическая часть включает оценку трёх репрезентативных жилых районов советского и постсоветского периодов с использованием измеряемых пространственных и средовых показателей, включая плотность застройки, расстояния между зданиями, ориентацию, степень замкнутости и характеристики вентиляции. Дополнительно учитывались параметры пространственной структуры, влияющие на формирование микроклимата застройки. Качественная оценка охватывает пространственную конфигурацию, условия инсоляции, ветровой режим и аэрацию, интеграцию зелёных элементов, тепловую адаптацию и энергоэффективность. Результаты показывают, что городские территории характеризуются микроклиматической неоднородностью и включают зоны с различными сочетаниями климатических и морфологических параметров, влияющих на условия вентиляции, инсоляцию и тепловой комфорт. Выделено пять типов участков: ветрооткрытые, умеренно защищённые, застойные, озеленённые и рекреационные, а также рельефно - обусловленные зоны, для которых требуются различные архитектурные решения. Выявленные взаимосвязи между пространственной организацией и микроклиматическими характеристиками позволяют переводить средовые условия в конкретные проектные параметры. Предложена дифференцированная модель архитектурно-планировочных решений на основе микроклиматического зонирования, обеспечивающая контекстно - ориентированное проектирование и повышение экологической эффективности малоэтажного жилья.*

Ключевые слова: *биоклиматическая архитектура, малоэтажное жильё, микроклиматическое зонирование, городская морфология, дифференциация проектирования, Юго-Восточный Казахстан.*

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1 INTRODUCTION

The transition toward environmentally responsive housing has become a strategic architectural task under conditions of climate change, rising energy costs, and increasing pressure on urban infrastructure. In South-Eastern Kazakhstan, this task is especially acute because residential design must respond simultaneously to strong seasonal temperature contrasts, pronounced solar exposure, varied relief, and local differences in wind and aeration regimes. Under such conditions, low-rise housing is significant not only as a building type, but also as a potentially adaptive urban model capable of combining residential comfort, environmental quality, and reduced operational energy demand.

In Kazakhstan, the relevance of climate-responsive housing is reinforced by both international and national agendas for sustainable development and energy efficiency. At the same time, domestic architectural research has increasingly addressed the transformation of residential architecture, ecological parameters of the housing environment, and the influence of urban morphology on environmental quality [5; 7; 13]. These studies confirm the growing attention to residential quality in Kazakhstan, but they also show that design practice still often relies on enlarged territorial regulation, whereas the actual urban environment is microclimatically heterogeneous.

This contradiction is particularly important for South-Eastern Kazakhstan, where the same urban territory may include foothill areas, open wind-exposed plots, stagnant-air zones, green recreational sectors, and terrain-influenced sites. As a result, average climatic parameters do not adequately reflect the real environmental conditions within which low-rise housing is formed and operated. This creates a need for a more differentiated design approach that considers local microclimatic conditions, urban-planning structure, and spatial characteristics of the residential environment.

The purpose of the article is to identify the architectural and planning principles of low-rise urban housing in South-Eastern Kazakhstan and to substantiate a differentiated bioclimatic design model for Almaty, Konaev, and Taldykorgan. The article focuses on the relationship among urban microclimate, spatial and volumetric organization, site typology, and climate-sensitive architectural response in low-rise housing.

The scientific novelty of the study lies in the development of an integrated approach to low-rise housing design based on microclimatic differentiation at the urban scale. Unlike existing studies in Kazakhstan, which primarily address either building-level bioclimatic performance or general urban morphology, the present research establishes a direct link between microclimatic heterogeneity, site classification, and architectural-planning solutions.

For the first time in the context of South-Eastern Kazakhstan, the study proposes a systematized classification of low-rise residential environments based on microclimatic conditions and translates this classification into a set of differentiated design strategies. The novelty also consists in combining comparative-typological analysis, bioclimatic assessment, and graphic-analytical interpretation within a unified methodological framework applicable to urban residential design.

The contemporary discussion of climate-responsive housing is shifting from generic energy-efficiency rhetoric toward territorially specific models that connect landscape, climate, and architectural form. In the context of recent architectural research in Kazakhstan, this line is developed through studies of architecture in extreme climatic conditions and regional design, where adaptation is treated not as a decorative motif but as a planning and environmental strategy [1; 8; 9]. This shift moves the discussion away from formal stylistic interpretation toward the relationship between environmental constraints and architectural decision-making. This perspective is consistent with foundational studies in urban climatology and climate-sensitive design, which emphasize the role of spatial structure, urban morphology, and environmental parameters in shaping microclimatic conditions [16-19].

This direction is reinforced by recent research on building bioclimatic microclimate, which demonstrates that envelope configuration, solar exposure, ventilation, and the interaction between form and local environmental conditions should be assessed as an integrated system rather than as isolated parameters [12]. Similarly, broader housing-performance studies show that energy efficiency depends on the integration of passive design, envelope-related decisions, and site-sensitive planning,

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rather than on isolated technical measures alone [2]. However, these studies are primarily focused on building performance and do not sufficiently address the differentiated urban placement of low-rise housing under varying microclimatic conditions.

A second group of studies is directly relevant to the evolution of housing architecture and residential complexes in Kazakhstan. Historical and contemporary transformations of residential buildings in Astana show that housing form is shaped by socio-economic change, typological restructuring, and new demands for comfort, safety, and accessibility [13-14]. Parallel studies of social housing and indoor environmental quality indicate that affordability alone is insufficient without adequate microclimatic performance and spatial quality [11; 15]. This argument is consistent with research treating indoor air quality and ventilation in residential buildings as integral sustainability factors rather than secondary technical issues [4]. This aligns with research emphasizing the role of urban ventilation strategies and airflow management in high-density residential environments, where spatial configuration directly affects air movement and environmental quality [20]. Yet these works concentrate mainly on housing quality and residential evolution and do not develop an operational model that links climatic heterogeneity to differentiated low-rise design decisions.

A third group of studies addresses the urban and environmental scale. Research on Almaty's public realm and urban morphology shows that spatial structure, density, interfaces, and environmental fragmentation strongly influence the everyday quality of urban life [6-7]. Related work on the socio-ecological microclimate of residential environments emphasizes the role of greening, environmental quality, and regional factors in shaping residential complexes [5]. At the theoretical level, this perspective intersects with studies exploring the convergence of organic architecture and city planning and arguing for stronger ecological continuity across building and urban scales [10]. These contributions are highly relevant, but they remain analytically fragmented: some focus on regional identity, others on housing typology, others on urban morphology, and others on socio-ecological performance.

The main research gap, therefore, lies in the absence of an integrated model that directly links microclimatic differentiation, site classification, and architectural-planning decisions for low-rise housing in South-Eastern Kazakhstan. The present study addresses this gap by combining typological analysis, bioclimatic assessment, urban microclimatic interpretation, and architectural synthesis in order to formulate a differentiated model of low-rise housing design adapted to local environmental conditions.

2 MATERIALS AND METHODS

The empirical basis of the study includes three cities in South-Eastern Kazakhstan: Almaty, Konaev, and Taldykorgan, selected to represent different combinations of natural-climatic conditions, urban morphology, and stages of low-rise residential development. The methodological framework is based on a four-stage research design combining comparative-typological analysis, bioclimatic assessment, graphic-analytical interpretation, and architectural synthesis.

Within each city, one representative low-rise residential district was selected (total n = 3 districts). The selection was guided by a set of criteria, including the presence of low-rise housing (up to three storeys), the period of formation (Soviet or post-Soviet development), distinct urban morphology in terms of block structure, density, and layout type, the availability of an open spatial structure enabling microclimatic interpretation, and representativeness for typical residential development patterns of each city.

The selected districts include a low-rise residential area located in the foothill zone of Almaty, a low-rise development area in Konaev characterized by open wind exposure, and a low-rise residential district in Taldykorgan with a mixed morphological structure. Within each district, between 10 and 15 residential units or building groups were analyzed, resulting in a total sample of approximately 35-40 observational units.

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The methodological framework consists of four sequential stages. The first stage involves comparative-typological analysis, which identifies the main types of low-rise housing, including detached houses, duplexes, townhouses, clubhouses, and low-rise apartment buildings, with consideration of spatial organization, functional zoning, and their relationship to the urban context. The second stage focuses on bioclimatic assessment, evaluating environmental factors influencing residential performance, including temperature regime, solar radiation (insolation), wind conditions and prevailing directions, aeration potential, terrain characteristics, landscaping and vegetation, and development morphology.

The third stage consists of graphic-analytical interpretation, which examines spatial structure and environmental interactions through parameters such as development density, building placement and orientation, courtyard configuration, the presence of ventilation corridors, and the degree of enclosure or openness of the urban fabric. The fourth stage involves architectural synthesis, in which the results are systematized into a differentiated model and a classification of site types with corresponding design responses.

The comparative analytical component of the study is based on the assessment of selected residential districts using measurable urban and architectural indicators. These indicators include development density (built-up area ratio), building height expressed as the number of storeys, distances between buildings, orientation of buildings relative to cardinal directions, insolation conditions categorized as sufficient, limited, or insufficient, the degree of enclosure of courtyard spaces (open, semi-enclosed, or enclosed), the presence of green elements (low, moderate, or high), and ventilation conditions (favorable, moderate, or weak).

The data collected were systematized in a comparative analytical matrix and used to identify recurring spatial and environmental patterns across the three case studies. The resulting classification is summarized in Table 2. The qualitative analysis complements the comparative analytical component and focuses on the architectural and environmental performance of low-rise housing, including spatial-volumetric characteristics, functional zoning, integration of natural elements, thermal adaptation strategies, energy-efficiency related design features, and the interaction between buildings and microclimatic conditions. The qualitative assessment is structured as a system of interrelated indicators (Figure 1), forming the analytical basis for subsequent interpretation.

The integration of measurable spatial indicators and qualitative assessment enabled the identification of stable relationships between urban morphology and microclimatic performance. Based on this synthesis, five microclimatic site types were defined, including wind-exposed zones, moderately protected zones, stagnant-air zones, green and recreational zones, and terrain-influenced zones. These categories were validated through cross-case comparison of the three cities and used as the basis for developing differentiated architectural and planning solutions.

The reliability of the analysis was ensured by a consistent set of spatial and environmental indicators applied across all case studies. The comparison of districts was conducted using identical evaluation criteria, which allowed the identification of recurring patterns independent of local morphological variations. Cross-case validation was performed by correlating observed spatial configurations with corresponding microclimatic conditions in each city.

The limitations of the methodological approach are related to the use of analytical and comparative methods without detailed instrumental measurements or numerical simulation. However, the selected framework provides a sufficient level of generalization for identifying stable relationships between urban morphology and microclimatic performance. The proposed approach can be further developed through the integration of BIM and CFD based modeling for quantitative validation of the identified design patterns.

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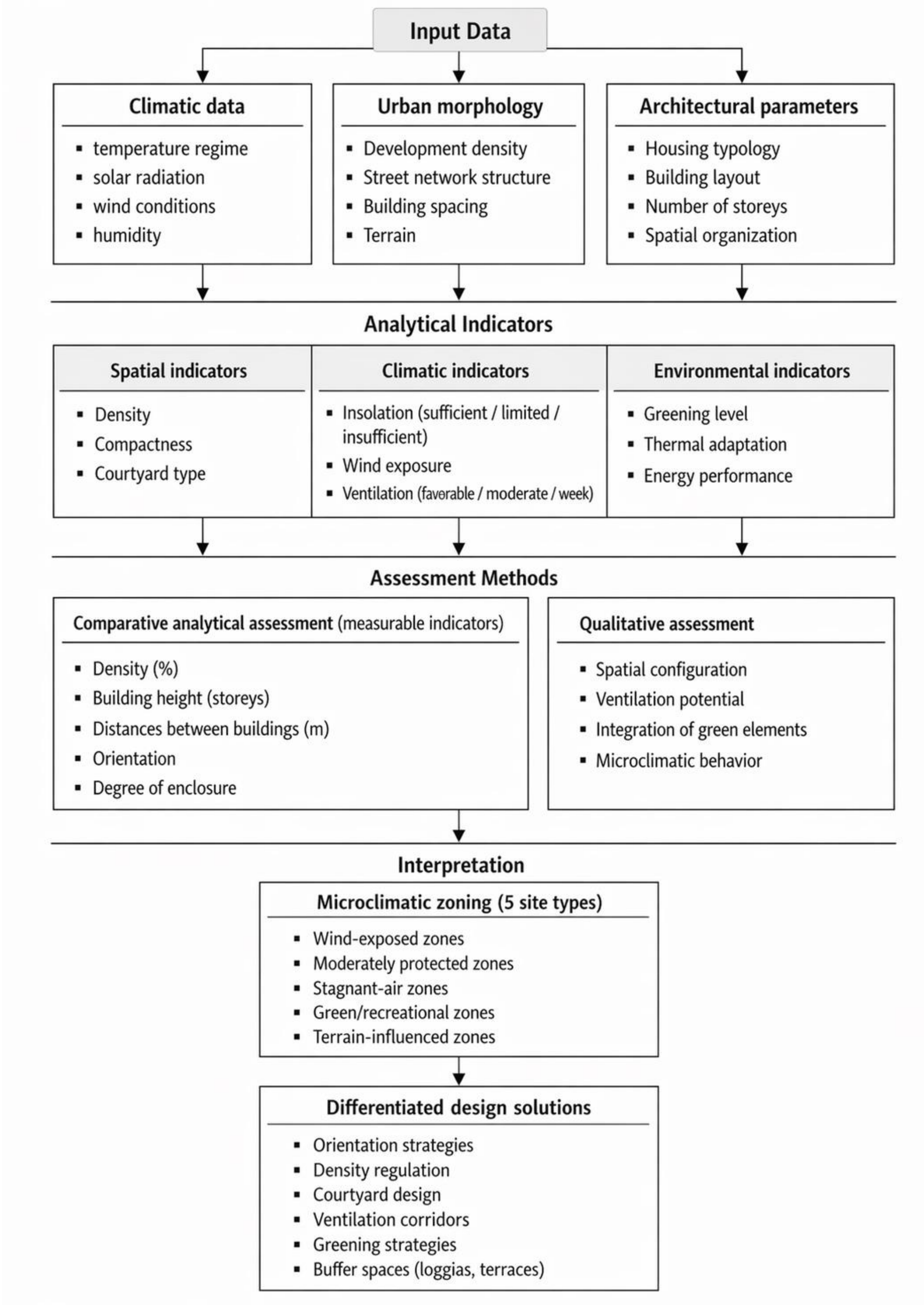

Figure 1 - Analytical framework integrating input data, analytical indicators, and quantitative and qualitative methods for microclimatic zoning and differentiated design of low-rise housing [Authors' material]

Overall, the methodology is comparative, typological, and graphic-analytical. It is aimed at

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identifying the relationship between environmental conditions and architectural solutions and at developing a context-sensitive model for low-rise housing in South-Eastern Kazakhstan.

3 RESULTS AND DISCUSSION

The analysis shows that the environmental performance of low-rise housing in South-Eastern Kazakhstan depends on the combined interaction of natural-climatic, urban-planning, and architectural-planning factors rather than on any single parameter. The comparative analysis of the selected districts in Almaty, Konaev, and Taldykorgan confirms that low-rise housing should be considered as a differentiated architectural system, whose spatial organization and environmental effectiveness depend on local microclimatic conditions, development morphology, terrain, and the degree of environmental exposure or protection.

Accordingly, the principal result of the study is the identification of microclimatic heterogeneity as the key basis for differentiated low-rise housing design. The analytical framework presented in Figure 1 integrates climatic, urban, and architectural parameters and demonstrates how these variables are translated into a system of qualitative and quantitative indicators, forming the basis for subsequent interpretation and design decision-making.

The analysis also shows that the regional typology of low-rise housing including detached houses, duplexes, townhouses, clubhouses, and low-rise apartment buildings does not determine environmental performance by itself. The same typological unit may function differently depending on its orientation, spatial configuration, density, and relationship to airflow and solar exposure. Therefore, generalized design approaches based on average climatic parameters are insufficient and require refinement through site-specific microclimatic assessment.

At the same time, the comparative analysis of the examined districts revealed a number of recurring deficiencies associated with the insufficient consideration of bioclimatic factors in architectural-planning decisions. Across the analyzed cases, these deficiencies include limited adaptation of building layouts to prevailing wind and solar conditions, insufficient use of buffer spaces, weak integration of greenery, and inadequate response to terrain and site exposure. In morphologically dense or poorly ventilated areas, these features are associated with reduced aeration potential and less favorable courtyard microclimate, particularly under summer conditions. In Almaty, these effects appear more pronounced due to basin-like topography and restricted air circulation, which intensify local environmental discomfort.

Thus, the findings of the present study are consistent with previous research demonstrating that residential environmental quality depends on the combined influence of urban morphology, ventilation conditions, landscaping, and envelope-related design decisions [2; 4; 5; 7; 12] . Accordingly, the main contribution of the study lies not in asserting universal technical deficiencies, but in identifying stable relationships between local microclimatic conditions and the need for differentiated architectural and planning solutions.

The analysis shows that low-rise urban housing in South-Eastern Kazakhstan represents a typological field rather than a fixed architectural form. The identified types: detached houses, duplexes, townhouses, clubhouses, and low-rise apartment buildings, are distributed unevenly across the three cities and reflect different stages of residential development and varying levels of environmental adaptation.

As shown in Table 1, key planning parameters of low-rise development, such as building height, density, orientation, and distances between buildings, are directly related to microclimatic performance. These parameters influence solar access, ventilation potential, shading conditions, and the formation of courtyard microclimate. Table 1 summarizes key planning parameters identified through comparative analysis of the selected case studies and interpreted in relation to commonly applied regulatory provisions in Kazakhstan.

The comparative analysis of the selected districts made it possible to identify a set of recurring spatial parameters that systematically influence microclimatic performance. These parameters are not

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isolated characteristics but function as interdependent variables shaping ventilation conditions, solar access, and thermal behavior at the scale of residential environments. Development density, building spacing, orientation, and the configuration of courtyard spaces were found to play a decisive role in the formation of local microclimatic conditions.

At the same time, the analysis indicates that these parameters cannot be interpreted independently of their regulatory and planning context. Their values and spatial configurations are partially constrained by commonly applied planning provisions, while their environmental performance depends on the specific combination and spatial arrangement within each district. This necessitates a structured interpretation of planning parameters not only as formal indicators but also as variables directly related to environmental performance.

Table 1 - Planning parameters of low-rise development and their bioclimatic relevance [Authors' material]

Parameter	Typical planning provision	Bioclimatic significance
Building height	Up to 3 storeys (low-rise category)	Reduces wind load and enhances connection with the surrounding environment
Development density	Low to medium	Ensures adequate solar access, ventilation, and reduced overheating effects
Insolation	Compliance with solar access standards	Forms a comfortable microclimate and reduces energy consumption
Building orientation	Consideration of cardinal directions and prevailing wind patterns	Optimizes natural lighting and natural ventilation
Distances between buildings	Regulated sanitary and insolation spacing	Prevents excessive shading and improves site aeration
Greening/landscaping	Mandatory landscaping of courtyards and surrounding areas	Reduces overheating, improves microclimate, and enhances environmental quality
Courtyard spaces	Formation of semi-enclosed and safe courtyards	Creates buffer zones and a comfortable social environment
Parking and transport	Placement of vehicles outside courtyard areas	Reduces noise and pollution and improves environmental quality
Materials and facades	Application of energy-efficient and environmentally friendly solutions	Increases thermal performance and overall building sustainability

Across the examined cases, more effective solutions are associated with compact and spatially coherent layouts, rational orientation relative to cardinal directions, and clear functional zoning. L-shaped and semi-enclosed configurations more often form protected courtyard environments, while perimeter arrangements provide more stable insolation conditions and increased spatial definition. Buffer elements such as loggias, terraces, verandas, galleries, and vestibules act as transitional zones between exterior and interior environments and contribute to environmental regulation at the building scale.

As illustrated in Figure 2, spatial-volumetric characteristics, including building form, articulation of facades, shading elements, and transitional spaces, define the architectural structure of low-rise housing and its spatial organization. These findings are consistent with studies emphasizing the role of passive design strategies and envelope-related solutions in improving environmental performance [12].

These relationships indicate that spatial-volumetric solutions in low-rise housing operate as a direct interface between planning parameters and environmental performance. Variations in building form, degree of enclosure, and articulation of volumes influence airflow patterns, solar exposure, and the formation of microclimatic conditions within residential spaces. As a result, architectural form should be understood not only as a compositional element but also as a functional component of environmental regulation. In particular, the configuration of built volumes determines the distribution of shaded and ventilated zones, directly affecting thermal comfort and air movement at the courtyard and street levels.

In this context, the effectiveness of design solutions depends on the coordinated interaction between building configuration, open space structure, and transitional elements. The integration of

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shading devices, semi-open spaces, and articulated facades contributes to the moderation of climatic impacts and enhances adaptability to local environmental conditions. This relationship between spatial structure and climatic response forms the basis for the interpretation of spatial-volumetric characteristics presented in Figure 2. Thus, the identified design principles can be interpreted as operational strategies linking spatial organization with microclimatic performance in low-rise residential environments.

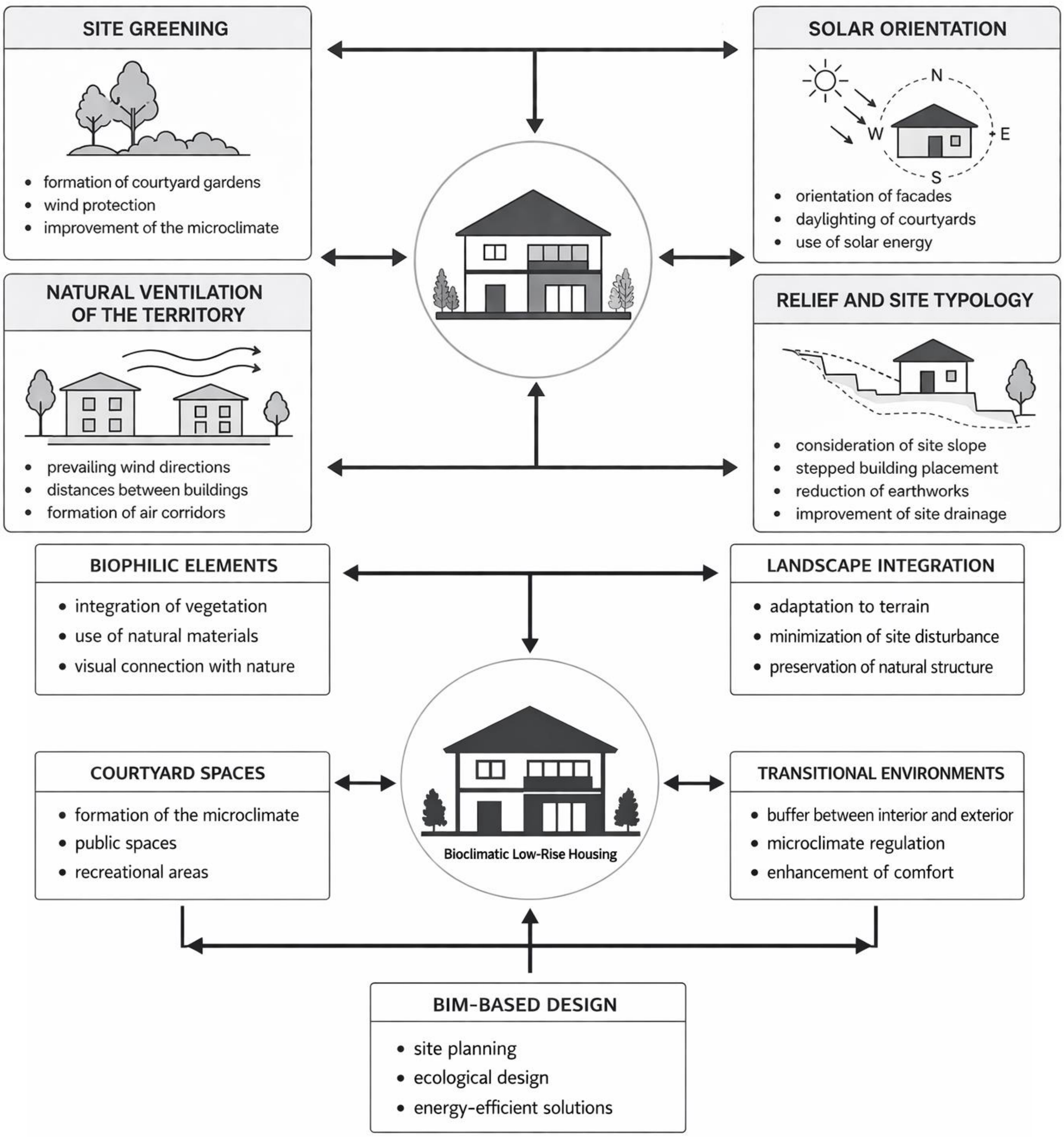

Figure 2 - Spatial-volumetric configurations of low-rise housing and their architectural characteristics [Authors' material]

The analysis shows that spatial-volumetric configurations act as a key mechanism through which architectural form translates planning parameters into environmental performance. Variations

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in building arrangement, enclosure, and facade articulation influence the distribution of solar exposure, the formation of shaded areas, and the continuity of airflow within residential spaces. As a result, the same planning parameters may lead to different microclimatic outcomes depending on their spatial implementation.

At the same time, the effectiveness of these configurations depends on the integration of architectural elements that regulate environmental interaction at the building scale. The presence of transitional spaces, shading devices, and articulated volumes enhances the adaptability of housing to local climatic conditions by moderating thermal loads and supporting natural ventilation. These relationships between spatial form and environmental response are illustrated in Figure 3, where spatial-volumetric solutions are associated with climatic effects such as solar control, thermal moderation, and protection from wind exposure.

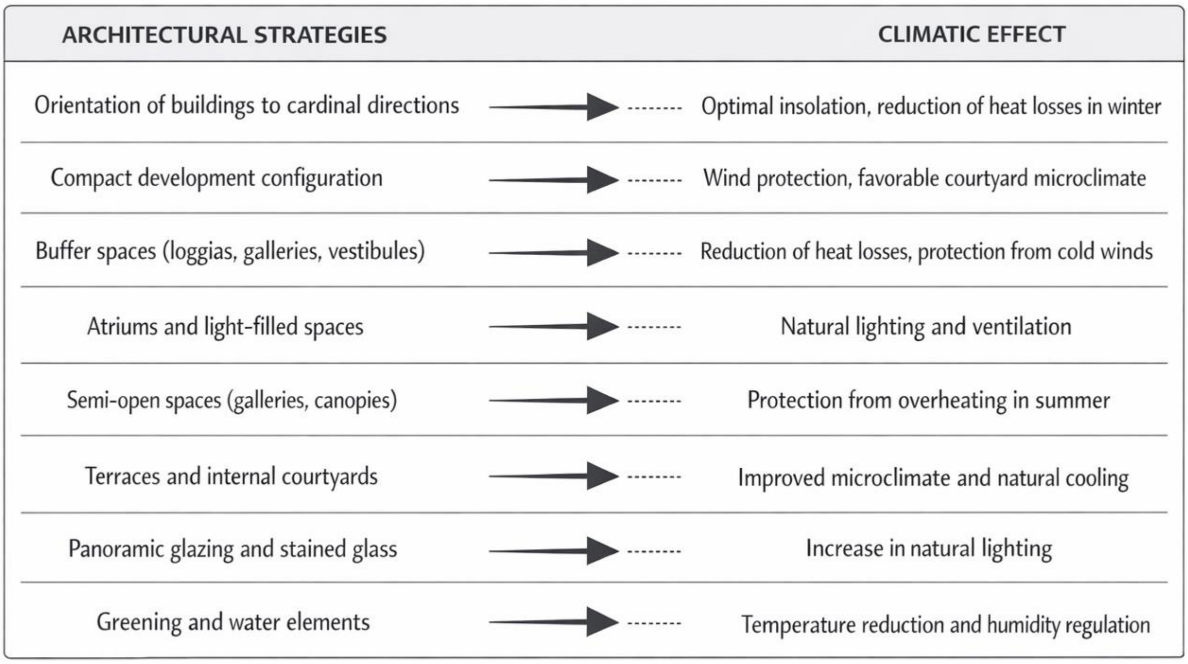

Figure 3 - Climatic effects of spatial-volumetric solutions in low-rise housing (solar control, ventilation, and thermal response) [Authors' material]

The comparative analysis allows identifying several key directions of climate-sensitive low-rise housing formation in the region: adaptation to sharply continental climatic conditions, integration of natural elements into the residential environment, application of passive design strategies, and the use of adaptive architectural elements. Together, these directions define the spatial logic of environmentally responsive low-rise housing in South-Eastern Kazakhstan.

The placement of low-rise housing within the urban system varies significantly among the three cities and reflects differences in relief, morphology, and environmental conditions. In Almaty, low-rise housing is strongly influenced by foothill terrain, vegetation, and variations in air circulation. In Konaev, development is often more exposed to wind due to open spatial conditions, while in Taldykorgan the effectiveness of similar housing forms varies depending on construction quality and local environmental context.

The analysis confirms that urban territory is not environmentally homogeneous. Instead, it consists of areas with different combinations of climatic and morphological characteristics, which directly affect residential comfort and environmental performance. This heterogeneity is illustrated in Figure 4, which presents the microclimatic zoning of the study area. the spatial distribution of environmentally different site conditions and Figure 4 highlights supports the subsequent classification of five site types used for design differentiation.

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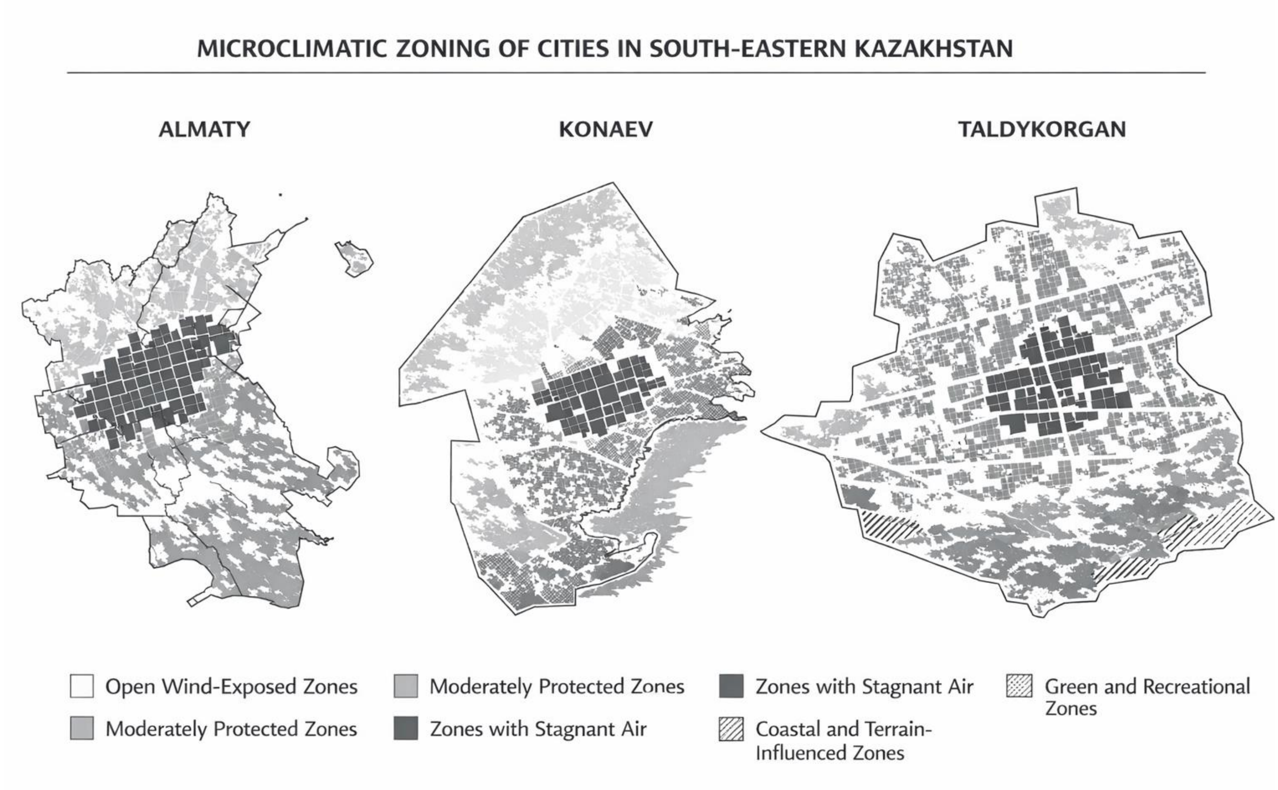

Figure 4 - Microclimatic zoning of the study area [Authors' material]

Based on the comparative analysis, five site types were identified (Table 2). Open wind-exposed zones are characterized by strong wind activity and increased environmental exposure, requiring compact layouts and protective planning solutions. Moderately protected zones provide more balanced conditions and allow greater flexibility in design decisions. Stagnant-air zones are associated with weak ventilation and less favorable summer microclimatic conditions, which necessitate the introduction of aeration corridors and reduced development density. Green and recreational zones provide more favorable environmental conditions and emphasize the importance of preserving vegetation and integrating landscape elements. Coastal and terrain-influenced zones require careful adaptation to relief, local air flows, and specific microclimatic conditions.

Table 2 - Classification of low-rise housing by site type, bioclimatic characteristics, and architectural responses [Authors' material]

Zone type	Bioclimatic characteristics	Architectural solutions
Open, wind-exposed zones	High wind activity; intensive cooling; increased environmental exposure	Wind-protective screens; compact development; orientation considering prevailing wind directions
Moderately protected zones	Balanced microclimate; moderate ventilation; relatively comfortable living conditions	Optimal orientation; use of buffer spaces (loggias, terraces); regulation of development density
Zones with stagnant air	Low aeration; less favorable summer microclimatic conditions; reduced ventilation potential	Aeration corridors; breaks in development; reduced density; improved ventilation
Green and recreational zones	More favorable microclimatic conditions; moderated temperature regime; greater landscape potential	Preservation of greenery; integration of green spaces into development; biophilic design solutions
Water-influenced and terrain-influenced zones	Local wind flows, the influence of water bodies and terrain, and temperature fluctuations	Consideration of terrain; terracing; orientation toward water and airflow; protection from erosion and wind

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Table 2 systematizes these site types, their environmental characteristics, and the corresponding architectural responses. The results demonstrate that the same housing typology requires different spatial and planning solutions depending on microclimatic context. Therefore, the study translates environmental differentiation into a practical design tool and extends existing approaches to urban morphology and residential environmental quality by emphasizing the role of ventilation, landscape integration, and spatial configuration.

The final stage of the study synthesizes the obtained results into an integrated model of bioclimatic low-rise housing formation in South-Eastern Kazakhstan. As shown in Figure 5, the proposed model combines three interrelated components: natural-climatic factors, urban-planning conditions, and architectural-planning solutions, into a coherent analytical sequence. The Figure 5 visualizes how climatic analysis, site classification, and design response are integrated into a single decision-making framework applicable to low-rise housing design.

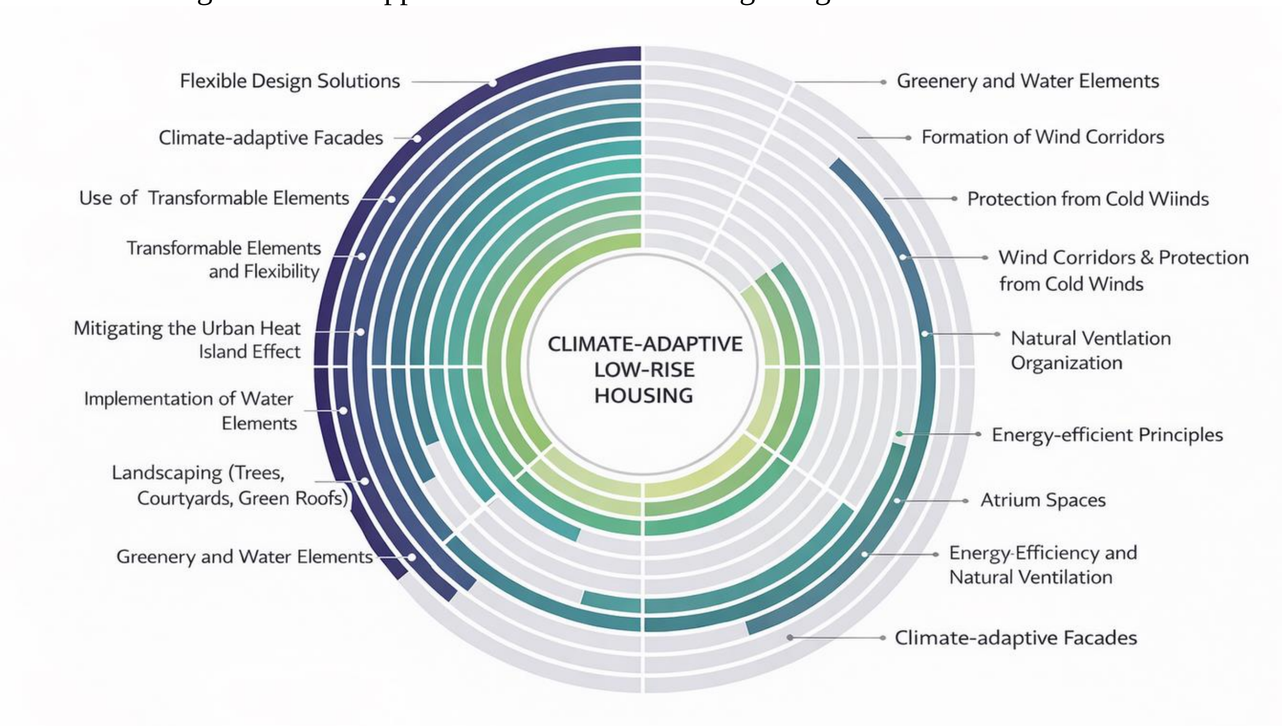

Figure 5 - Author’s model for the formation of bioclimatic low-rise housing in South-Eastern Kazakhstan [Authors’ material]

The model is based on a step-by-step process that includes climatic analysis, identification of local microclimatic conditions, classification of site types, and selection of differentiated design strategies. This sequence reflects the analytical framework presented in Figure 1 and provides a systematic link between environmental assessment and architectural decision-making.

In contrast to conventional bioclimatic approaches, which are often focused on building scale performance or generalized climatic zoning, the proposed model introduces a microclimate oriented design logic at the level of urban residential structure. The key distinction of the model lies in its ability to translate spatial and environmental heterogeneity into specific architectural-planning responses.

Unlike standard climate-responsive design frameworks, the model does not rely on averaged climatic parameters but operates through the classification of site-specific conditions, including aeration patterns, insolation variability, development density, and terrain influence. This allows the model to function not only as an analytical tool but also as a decision-making instrument for context sensitive design.

Overall, the results confirm that the transition from generalized climatic assumptions to differentiated microclimatic analysis allows for more precise and effective design solutions and

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contributes to improving the environmental performance and sustainability of low-rise housing in South-Eastern Kazakhstan.

4 CONCLUSIONS

The results of the study confirm that low-rise housing in South-Eastern Kazakhstan should be understood as a microclimatically differentiated system rather than a uniform architectural category. Based on the conducted analysis, the following conclusions can be drawn.

1. Urban residential territories in South-Eastern Kazakhstan are characterized by pronounced microclimatic heterogeneity, where variations in wind conditions, insolation, terrain, and urban morphology significantly influence environmental performance and residential comfort.

2. The environmental effectiveness of low-rise housing is determined not by typology alone, but by the interaction between spatial configuration, building orientation, development density, and exposure to local climatic factors.

3. A classification of five microclimatic site types - wind-exposed, moderately protected, stagnant-air, green/recreational, and terrain-influenced zones - has been developed and systematized, providing a structured basis for interpreting environmental conditions at the urban scale.

4. The identified site types were translated into a set of differentiated architectural and planning strategies, enabling the adaptation of low-rise housing to specific microclimatic conditions and improving environmental performance.

5. The proposed analytical framework and design model establish a direct link between microclimatic analysis, site classification, and architectural decision-making, offering an operational approach to context-sensitive design.

The practical application of the results includes architectural design of low-rise housing adapted to local environmental conditions, urban planning and zoning based on microclimatic performance, and the development of methodological recommendations for climate-responsive residential design. The proposed approach can also be applied in architectural education as a tool for teaching bioclimatic and context-sensitive design principles.

The study is limited by the use of comparative and analytical methods without detailed instrumental measurements or numerical simulation. Further research may involve the application of BIM- and CFD-based modeling for quantitative validation of the identified design strategies and refinement of the proposed model.

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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