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Analysis of the Impact of Residential Building Shape and Orientation on Energy Efficiency

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Abstract: The construction of residential buildings and structures is a complex process in which the economic component plays a key role. It is essential to maintain a balance between saving construction materials and the costs of additional engineering solutions while ensuring the functionality and comfort of the building's operation. To achieve this goal, researchers initially analyze the impact of the climatic environment and spatial planning solutions—i.e., building shapes—that directly affect the building compactness ratio when evaluating the efficiency of the designed building. In this regard, the objective of this study was to analyze the shapes and orientations of buildings in the Republic of Kazakhstan across eight territorial units located in the I, III, and IV climatic zones between latitudes 42°18′ and 52°16′ N. The study identified the most favorable building orientations for each climatic zone: the meridional orientation is preferable for the I and III zones, while the latitudinal orientation is optimal for the IV zone. Four residential building shapes—square, rectangular, cylindrical, and triangular—were analyzed based on a floor area of 1000 m^2 and a building volume of 3000 m^3 during the coldest five-day period and the hottest month. According to the specific thermal characteristic values, it was found that a cylindrical residential building is 1.1, 1.37, and 1.27 times more efficient than square, rectangular, and triangular residential buildings, respectively. Additionally, the compactness ratio was determined for different residential building shapes and heights, ranging from 8 to 16 floors in increments of four floors. The results showed that under these conditions, the compactness ratio increases by an average of 1.3 times due to the increase in the area of external walls. However, if the initial condition is changed to account solely for the floor area, the compactness ratio decreases by up to 2.3 times. The conducted research shows that when solving the problem of the energy efficiency of a building, taking into account shapes and orientations, it is necessary to carry out a full assessment of the specified energy efficiency parameter depending on the expected results, which requires a comprehensive analysis to achieve energy-efficient buildings. At the same time, the results of this study will be used and will positively complement the results of a comprehensive study by the authors on the development of energy-efficient exterior enclosing structures, which, together with general solutions, will significantly affect the thermal balance of the building and complement the research conducted earlier.

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Keywords: shape and orientation; residential building; energy efficiency; climatic impact; thermal resistance; minimum specific heat loss characteristics

1. Introduction

One of the main objectives of modern construction is to reduce energy consumption during the operation of residential buildings and structures for various purposes. Building energy efficiency can be achieved through a combination of various architectural, structural, and engineering solutions that best serve to minimize energy consumption while maintaining a comfortable indoor climate. According to well-known data, approximately 40% of the total thermal energy consumption is used to maintain a comfortable indoor climate in buildings [1–3]. One of the primary factors affecting the thermal balance of a building is the external climate of the specific construction area. To mitigate the impact of the external environment, researchers focus on determining the optimal shape and orientation of buildings [4–6]. Accurate selection of these parameters can lead to significant energy savings for maintaining a favorable indoor climate. The relevance of choosing the optimal shape and orientation is particularly emphasized by the fact that most populated areas are located in regions with variable climatic conditions. Therefore, the correct utilization of environmental climatic parameters remains a pressing issue and is being actively investigated by scientific and technical communities worldwide [7–9].

For instance, Mooneghi M. et al. [10], in a review study, analyzed various aerodynamic methods for mitigating wind loads on residential buildings considering different building shapes. Zhou Y. et al. [11] conducted a comprehensive review of the impact of building shapes and orientations on the environment throughout the building's lifecycle. Their findings identified eight key design solutions [12] that influence environmental effects during the design phase, with the building's shape, orientation, and aspect ratio playing significant roles. Coğul I. et al. [13] revealed that contemporary energy efficiency strategies primarily focus on passive building design, which includes window properties, shading, and building orientation. Kumar D. et al. [14] demonstrated that building orientation has a more significant impact on energy consumption than the shape factor. They highlighted the necessity of a comprehensive approach to design solutions that consider building shape, materials, and the thickness of enclosing structures [15,16]. A study by Nazari F. et al. [17] showed that changes in building shape could affect energy consumption by 17.9% due to variations in the surface area of the enclosing structures by 60.7%, while the building's floor area remained constant. However, their research did not account for the influence of external climatic parameters. Jeong-Tak J. et al. [18] proposed a method for assessing thermal loads on free-form buildings using a genetic algorithm [19]. Their method demonstrated its applicability by optimizing the shape of a model building across different climate zones, allowing for rapid prediction and optimization of heat loss characteristics due to shape modifications [20]. Ahmadi P.S. et al. [21] conducted a theoretical study on energy consumption based on three standard building shapes using national standards. Their analysis of the impact of building orientation on energy loads revealed that the most uncertain results were associated with facade orientations. However, this study only considered hot climate conditions. Research on the thermal performance of school buildings by Salameh M. et al. [22] showed that the orientation of a school building significantly affects its thermal balance. Proper courtyard configuration and building orientation can reduce indoor temperatures by up to 1.8 °C, depending on the season. However, this study was limited to hot climates and did not examine the impact of building shape [23]. Rubtsova M. et al. [24] conducted a theoretical analysis of spatial planning parameters and

their effect on building heat loss. While various building configurations were examined, the study did not address the impact of building orientation. Ryabova O. et al. [25] analyzed the influence of building shape and orientation on solar radiation and wind. They concluded that selecting appropriate parameters has a significant impact on energy savings. However, their research was limited to a specific geographic area and did not cover diverse climate conditions. Vassiliades C. [26] investigated the impact of building orientation and building-integrated photovoltaic (BIPV) systems on energy consumption for heating, cooling, lighting, and hot water supply in single-family homes. The study demonstrated that proper orientation reduces energy consumption while integrating photovoltaic systems, which leads to additional significant energy savings. However, this research only addressed small residential buildings and did not account for building shape. Jurshari M. et al. [27] conducted a theoretical analysis of the influence of building shape and orientation. Their findings indicated that rectangular buildings with a latitudinal orientation exhibit the highest energy efficiency. However, the study was limited to a specific building shape. Renuka S.M. et al. [28] analyzed the impact of building orientation by considering location-specific factors such as building height, neighboring structures, roof materials, window area, window frame materials, and projections [29,30]. Their results indicated that the highest percentage reduction in energy consumption occurred in Delhi (26.42%) and Chennai (20.90%) when buildings faced north. However, the study did not consider building shapes or cold climates. Foroughi R. et al. [31] analyzed the effect of the window-to-wall ratio using a two-story commercial building in different U.S. climate zones. The results showed that optimizing window placement can reduce overall energy consumption by 2% to 15%, depending on whether the climate is cold or hot [32]. However, this study did not consider varying building shapes. The analysis of existing research highlights significant knowledge gaps in evaluating building energy efficiency based on shape and orientation. Most studies focus on isolated aspects such as spatial planning solutions or the influence of climate conditions as defined by building orientation. There is a noticeable lack of research addressing these parameters on a national scale in the Republic of Kazakhstan and similar regions worldwide.

In this regard, analyzing the experience and gaps of international research, the authors set the task of solving the issue of energy conservation of residential buildings, taking into account the forms and climatic effects on it in the context of cold and hot climates in the characteristic territories of the Republic of Kazakhstan. Based on the calculation methodology, the minimum specific heat loss of the residential building will be determined, depending on the shape and climate impact. Based on this, the most preferred orientation and shape of residential buildings for the specified territories will be framed. The methodology of designing the energy efficiency of a building should be based on a systematic analysis of the building as a single energy system, depending on the period. To obtain a complete assessment, the analysis periods are considered to be cold and hot. The results obtained in the course of this study will serve as a prerequisite for the continuation of the authors' comprehensive research on the development of energy-efficient structures of exterior fences in the context of the regions of the Republic of Kazakhstan [33].

2. Materials and Methods

2.1. Key Climatic Indicators of the Studied Area

This study presents an analysis of characteristic regions of the Republic of Kazakhstan based on climatic zoning classifications [34,35], as shown in Table 1. These areas are primarily located between latitudes 42°18′ and 52°16′ N.

Table 1. Climatic Zoning of the Republic of Kazakhstan [34,35].

No.	Climatic Zone	Cities Located in the Specified Climatic Zone	Climatic Factors Determining General Typological Requirements for Buildings
1	I	Astana, Ust-Kamenogorsk	Cold, prolonged winters require maximum thermal insulation of buildings.
2	II	No major cities	Moderate winter requires adequate thermal insulation of buildings.
3	III	Almaty, Aktobe, Pavlodar	Sub-zero winter temperatures and hot summers require winter thermal insulation and summer overheating protection.
4	IV	Aktau, Shymkent, Kyzylorda	Hot summer and relatively short winter require active summer overheating protection and appropriate winter thermal insulation.

The main meteorological indicators of the zones used in this study, as outlined in Table 1, were presented in the authors' previous work [35]. These indicators were determined based on the analysis of data from sources [35,36] and are summarized as key climatic parameters for characteristic zones in the form of climatic profiles [35]. The climate analysis considers both solar radiation patterns and wind conditions. The results are presented as a circular diagram divided into sectors representing favorable, acceptable, unfavorable, and unacceptable orientations, identifying the optimal building and facade orientation for each characteristic city [35]. To further determine the optimal orientation for the characteristic zones, this study additionally analyzes the frequency of different wind directions (Table 2).

Table 2. Wind Regime Analysis for January and July across the Zones Specified in Table 1 [34].

No.	City	Wind Frequency: January/July (m/s)							
		N	NE	E	SE	S	SW	W	NW
1	Astana	2/15	10/20	5/10	12/9	31/10	30/10	8/14	2/12
2	Ust-Kamenogorsk	5/13	3/11	21/19	30/15	11/6	8/7	9/11	13/18
3	Almaty	30/18	13/10	5/8	13/25	12/15	12/11	7/7	8/6
4	Aktobe	3/16	12/17	15/14	15/6	20/5	17/7	13/18	5/17
5	Pavlodar	3/15	4/16	7/11	14/8	24/10	26/9	18/16	4/15
6	Aktau	12/14	17/13	30/7	20/4	2/4	2/8	7/32	10/18
7	Shymkent	3/6	6/16	26/27	26/17	9/5	15/5	9/11	6/13
8	Kyzylorda	13/25	28/18	15/5	6/1	13/2	13/8	9/21	3/20

2.2. Methodology for Optimal Consideration of External Climate Impact on Residential Building Shape

2.2.1. Geometric and Thermal Performance Indicators

According to the research objective, the study examines various building shapes presented in Figure 1. The building volume is assumed to be 1000 m^3 for all shapes, ensuring consistent comparison. The glazing ratio is set at 15% of the total vertical surface area, in accordance with references [37–39]. To ensure analytical accuracy, the thermal resistance (R-value) of external enclosures is taken to be equal to the required value calculated based on the degree-days of the heating period (DDHP), as specified in [37] (see Figure 2).

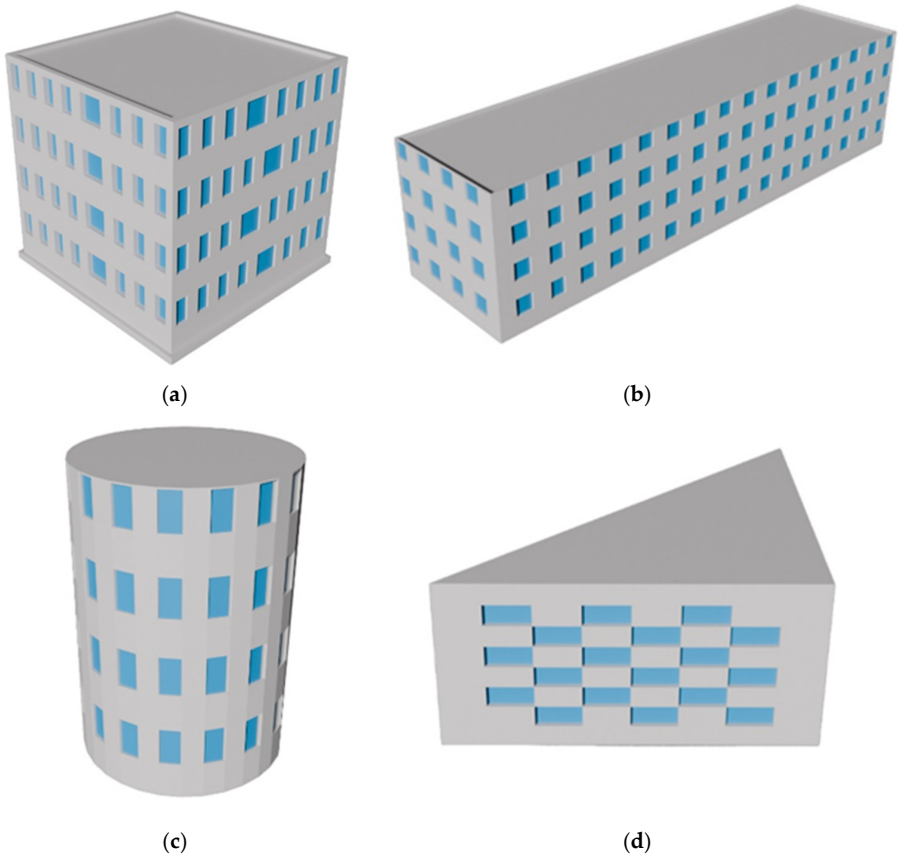


Figure 1. Residential building shapes under study: (**a**) square-shaped; (**b**) rectangular-shaped; (**c**) cylindrical-shaped; (**d**) triangular-shaped.

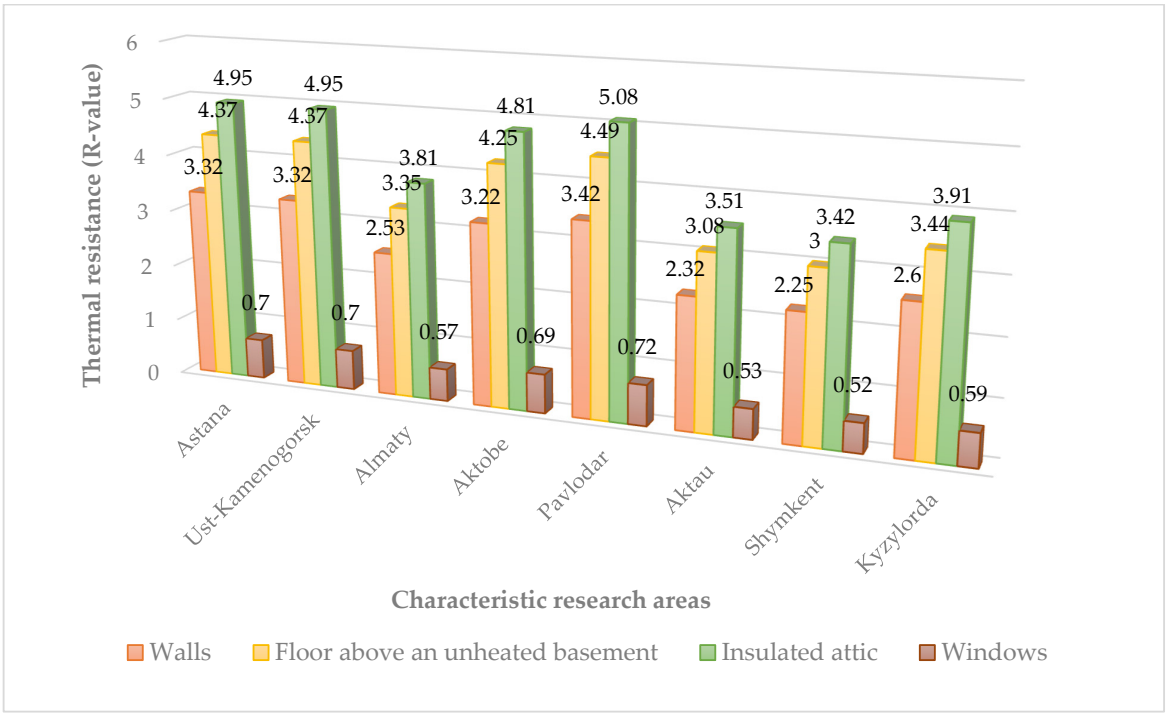


Figure 2. Required thermal resistance values according to degree-days of the heating period (DDHP), $m^2 \cdot °C/W$.

2.2.2. Methodology for Calculating the Influence of Residential Building Shapes and Orientations on Thermal Performance Indicators

To study the influence of the shapes and orientations of residential buildings, taking into account the climatic parameters of the characteristic areas presented in Tables 1 and 2, we will use the calculation method presented in [40]. In the analysis of the specific heat loss of residential buildings at the first stage, according to the design standards [34] or the compilation of climate passports [35], the climatic parameters of the study area are determined. By determining the necessary climatic parameters based on the norm [37], the thermal engineering values of external fences are determined in the form of the required value of heat transfer resistance. Further, according to the established restrictions on residential building shape, the geometric parameters and shapes of residential buildings necessary for the analysis are taken. In this case, the buildings are square, rectangular, cylinder, and triangle. Having determined the optimal buildings, the specific thermal characteristics are determined according to [40], taking into account the climatic features of the territory characteristic of the territory of the Republic of Kazakhstan in the context of cold and hot periods, which will help to determine in detail the heat loss in a particular period and the effectiveness of the adopted shape and orientation of the residential building. Given the volume of the study, in order to understand the full methodology by the authors, a calculation algorithm was developed based on the proposed methodology [40], shown in Figure 3.

In the presented algorithm, the calculation to determine the minimum specific characteristics originally defined the average monthly values of heat flow through the building envelope, given the glass of the building (q_{w_i}), where depending on a cold (q_{Enc1_i}; $q_{Enc1_{fl}}$) and hot (q_{Enc2_i}; $q_{Enc2_{fl}}$). The periods are determined by heat flows, including vertical external fences and floors of the building. After determining the specified parameters, depending on the type of exterior fence (a, b, c, d, cd, v—for walls, r—for covering, fl—for covering the first floor), the corresponding index is assigned in the expression q_i, which gives us the opportunity to determine the appropriate surface for further analysis of the minimum specific characteristics of the building. A full description of these parameters and the unit of measurement is provided in the Abbreviations section.

Summarizing the methods and materials section, the following sequence of actions appears for analyzing the effectiveness of a building, taking into account the shape of the orientation. Thus, from the analysis of Figure 3, the authors determined the most preferred orientations for each characteristic area based on the value of wind repeatability. After using the obtained values for the most preferred orientation of the building, it is necessary to continue the analysis, taking into account the methodology presented in the algorithm in Figure 3. At the same time, the data presented in Tables 3 and 4 on the geometric parameters and characteristics of the exterior surfaces of fences must also be taken into account in the methodology presented in Figure 3. Together, the required values in Tables 3 and 4 are fully used in the analysis of the algorithm shown in Figure 3. In conclusion, after analyzing all the presented parameters, the most effective building shape is determined by the value of the minimum specific heat loss.

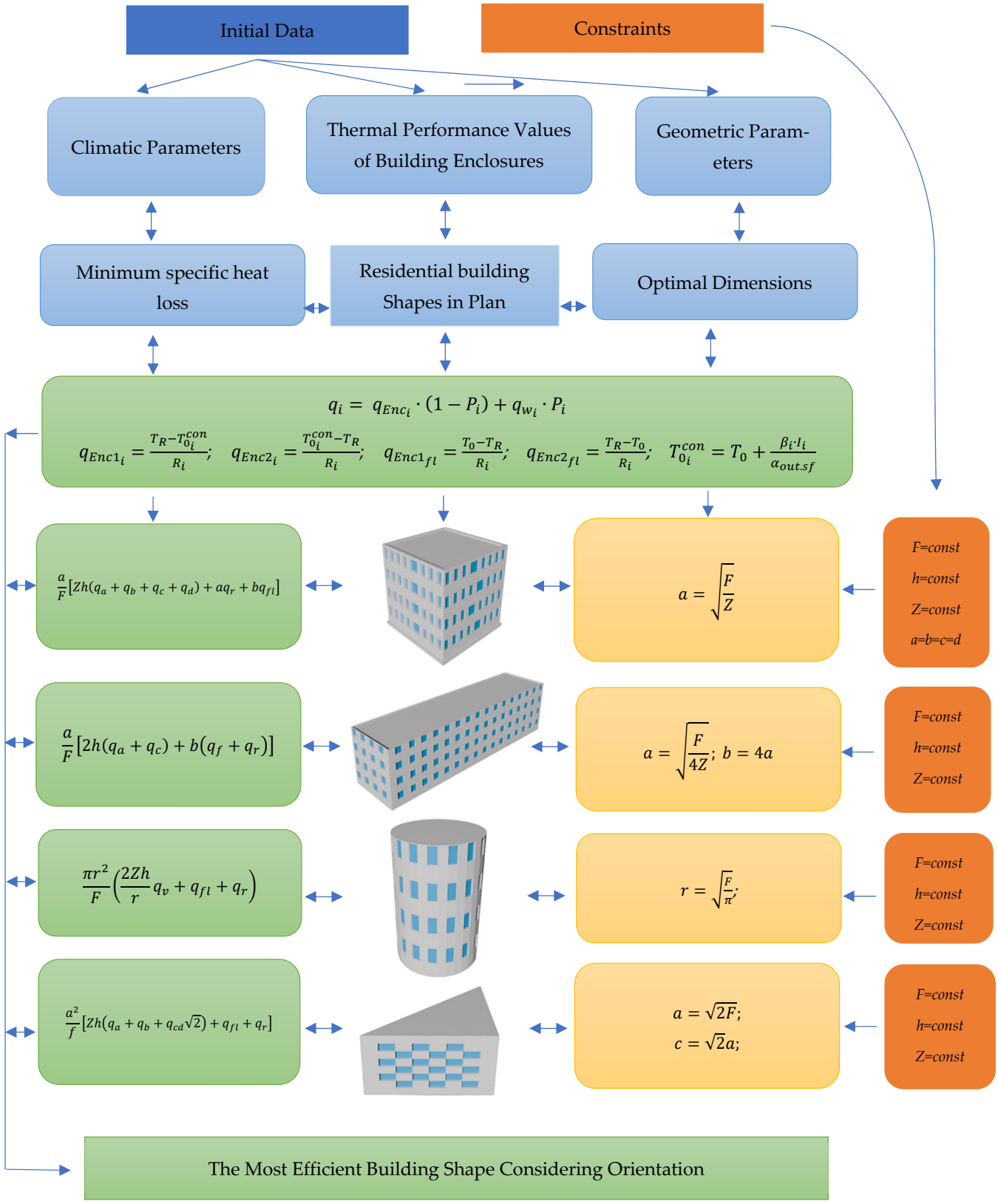


Figure 3. Methodology for determining specific heat loss in the form of an algorithm of actions.

Table 3. Preferred Orientation Relative to Wind Recurrence [34].

Zone	Cities	Preferred Orientation Based on Wind Recurrence
I	Astana	Meridional
	Ust-Kamenogorsk	Meridional
III	Almaty	Meridional
	Aktobe	Meridional
	Pavlodar	Meridional
IV	Aktau	Latitudinal
	Shymkent	Latitudinal
	Kyzylorda	Latitudinal

Table 4. Geometric Parameters of Residential Buildings.

Residential Building Variants		Square-Shaped	Rectangular-Shaped	Cylindrical-Shaped	Triangular-Shaped
Number of stories		4 stories	4 stories	4 stories	4 stories
Dimensions, m	Height	12	12	12	12
	Plan	15.81 × 15.81	31.62 × 7.91	8.92	22.36 × 22.36 × 31.62
Surface area, m^2	Walls	758.9	948.6	672.2	916.1
	Floor area	≈1000	≈1000	≈1000	≈1000
	Windows	113.8	142.3	100.8	137.4
	Doors	2.1	2.1	2.1	2.1
	Total surface area	1874.8	2093.0	1775.1	2055.6
Building volume (V), m^3		≈3000	≈3000	≈3000	≈3000

3. Results and Discussion

The shape of residential buildings and climatic parameters play a key role in their energy efficiency and operational performance. Studies show that the optimal consideration of climatic factors significantly reduces heat loss in winter and overheating in summer, which affects living comfort and operational cost-effectiveness. Therefore, this section presents research and wind regime analysis based on recurrence to obtain results for the optimal consideration of the impact of external climate on residential building shape, following the methodology presented in Section 2.2.2.

3.1. Result of Wind Regime Analysis Based on Wind Recurrence According to Table 2

Figure 4 presents the results of the wind recurrence analysis for the characteristic regions of the study area.

Based on the analysis of recent climatic indicators for wind frequency [36], compared with standard values [34], actual and accurate indicators were determined, based on which, analyzing the schemes presented in Figure 4, taking into account cold and hot periods, the values of wind frequency in the characteristic eight territories of the Republic of Kazakhstan studied were determined. As a result, the preferred orientation of the residential building was determined according to the climatic zone in the context of densely populated cities. The main results are presented in Table 3. The obtained indicators for the preferred orientation of residential buildings contribute to rapid further analysis of the heat loss of buildings instead of lengthy calculations of each direction (orientation) of residential buildings.

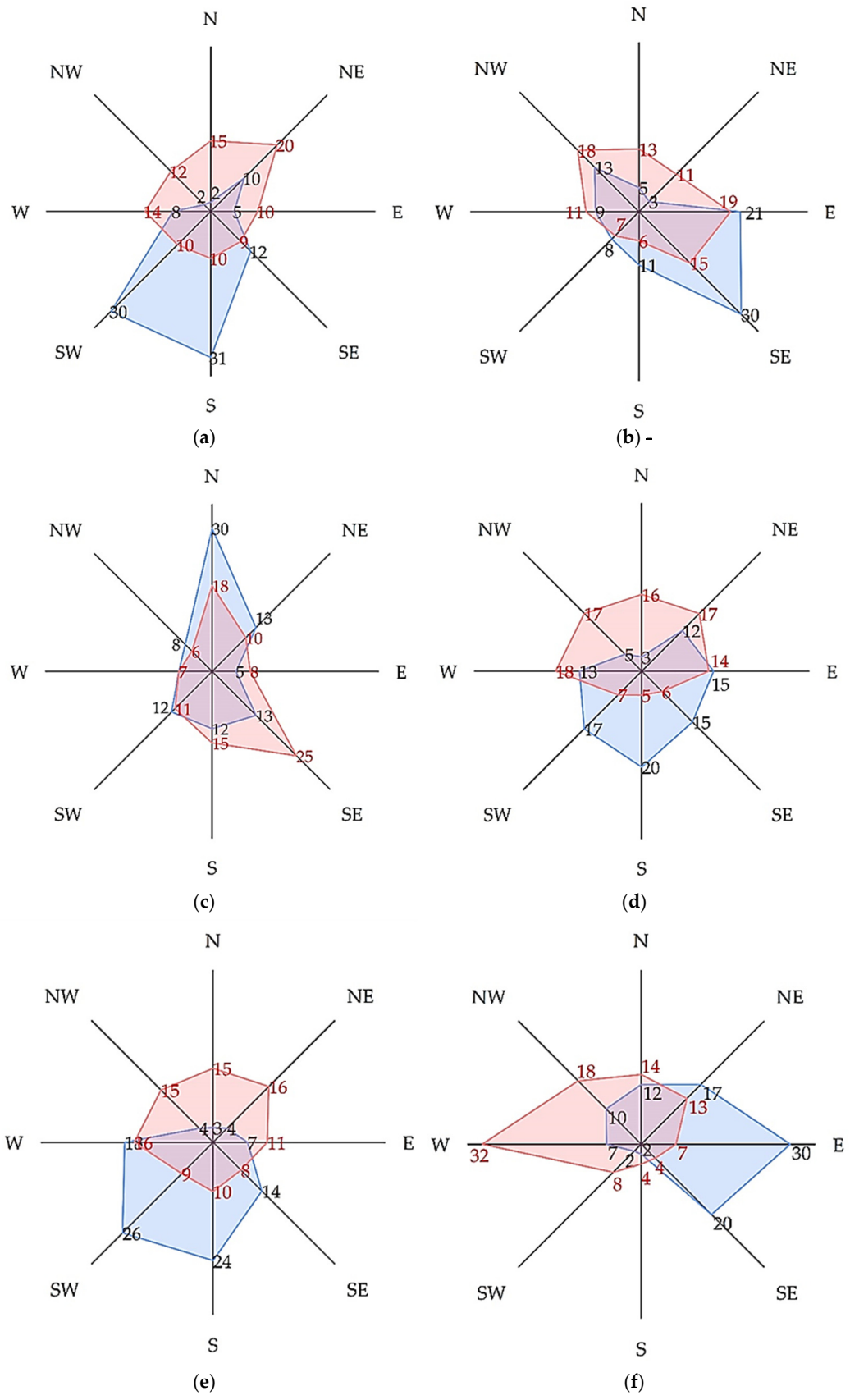


Figure 4. *Cont*.

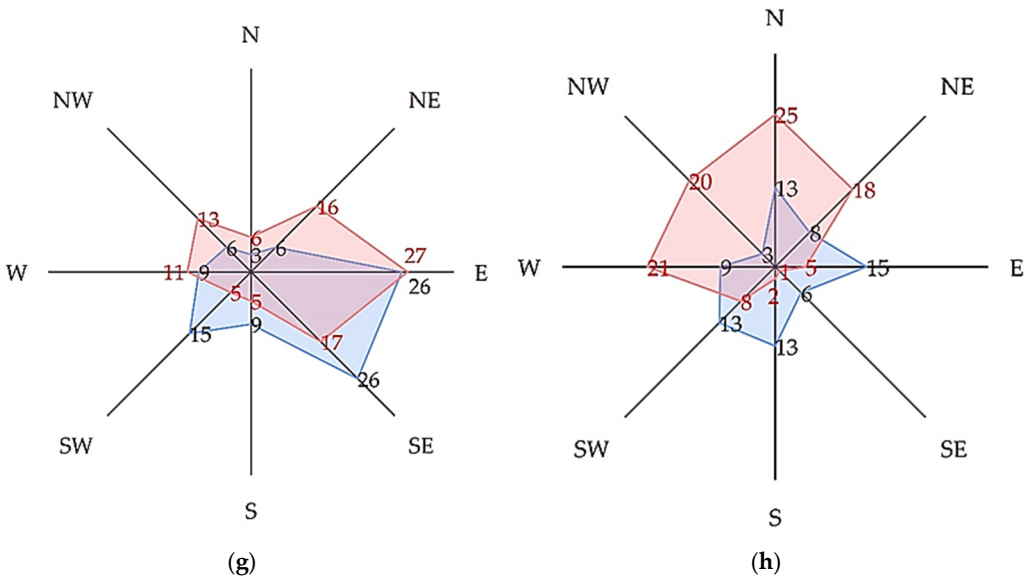


Figure 4. Wind Recurrence Analysis Results for Various Directions in the Characteristic Regions of the Republic of Kazakhstan: (**a**). Astana; (**b**). Ust-Kamenogorsk; (**c**). Almaty; (**d**). Aktobe; (**e**). Pavlodar; (**f**). Aktau; (**g**). Shymkent; (**h**). Kyzylorda. —January; —July.

3.2. Results of the Study on the Optimal Consideration of External Climate Impact on Residential Building Shape

Based on the building shapes presented in Figure 1, the geometric parameters of the building envelopes relative to the building volume were determined and are presented in Table 4.

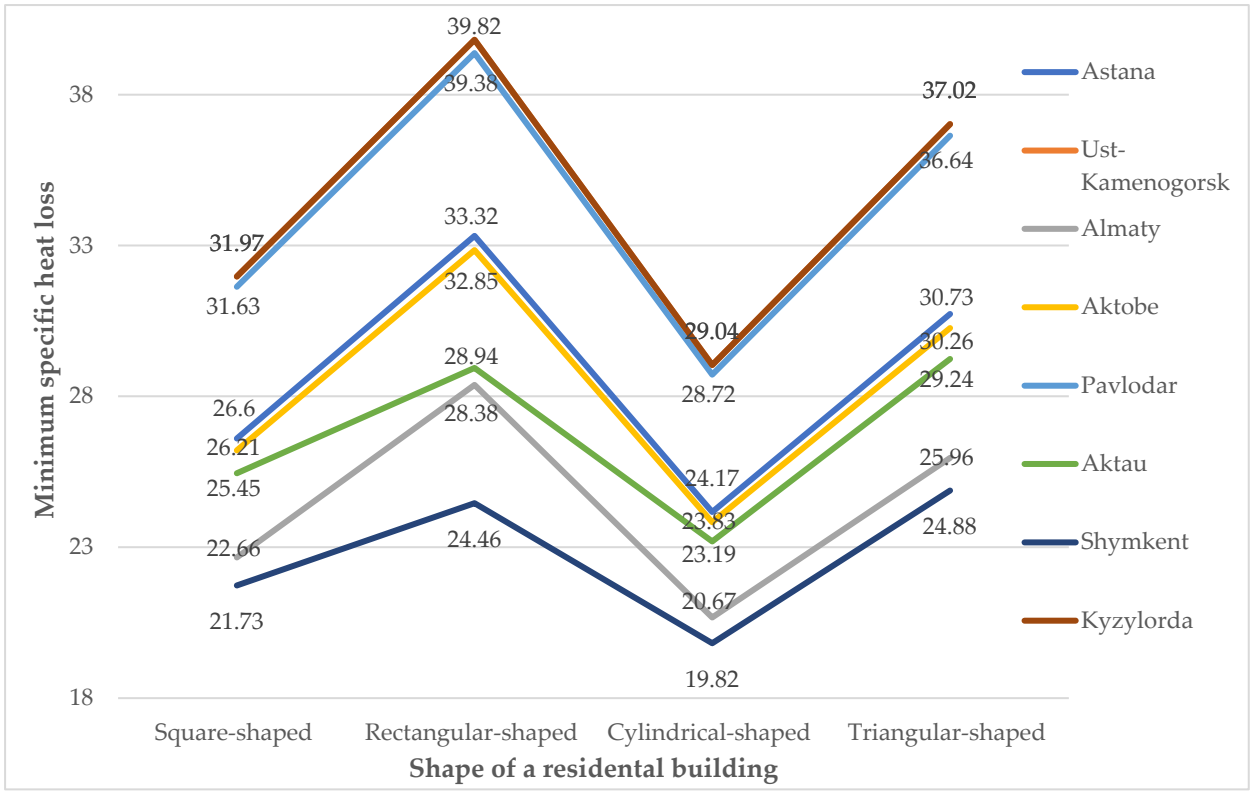
According to the calculation methodology presented in Section 2.2.2, the data on the preferred building orientation across the characteristic regions shown in Table 3, and the adopted geometric parameters of the buildings presented in Table 4, the minimum specific heat loss characteristics of the buildings were analyzed concerning the coldest five-day period and the hottest month (Figure 5).

The analysis of the impact of minimum specific heat loss characteristics on the number of stories (8, 12, and 16 stories) with the same floor area and building volume during the coldest five-day period and the hottest month is presented in Figures 6–8.

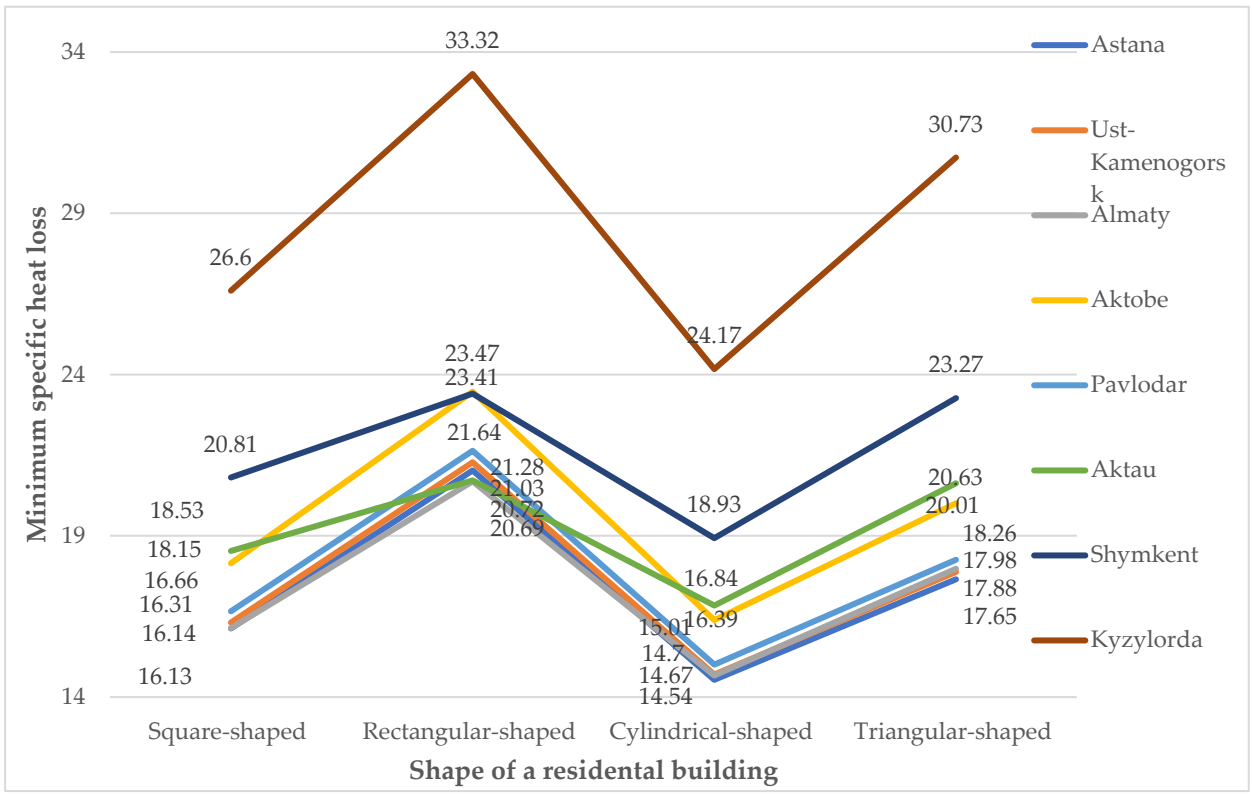
The analysis of the building compactness ratio depending on the building shape, floor area, height, number of stories, building volume, and the area of enclosing structures is presented in Figure 9.

The conducted analysis of the influence of residential building shape, considering the number of stories, floor area, fixed building volume, and the area of external enclosing structures during the cold five-day period and the hot month in the characteristic regions, demonstrated that all these parameters affect the building's minimum specific heat loss characteristics. An examination of Figures 4–7 shows that during both the cold five-day period and the hot month, the most efficient building shape in terms of specific thermal performance is the cylindrical form. Compared to square, rectangular, and triangular buildings, the cylindrical shape proved to be 1.1, 1.37, and 1.27 times more efficient, respectively. This finding aligns with the building compactness coefficient presented in Figure 8, which indicates that the compactness coefficient increases with the number of stories due to the growth of the wall area. Lower buildings are more compact in terms of external enclosures. The compactness coefficient evaluates the efficiency of spatial planning solutions, which influence the building's energy performance. A lower compactness coefficient corresponds to greater building compactness, reducing heat loss through a smaller external surface area. Conversely, an increase in the compactness coefficient leads to higher heat losses through external enclosures due to thermal

transmission. Therefore, compactness significantly impacts the share of transmission losses in the building's overall energy balance.

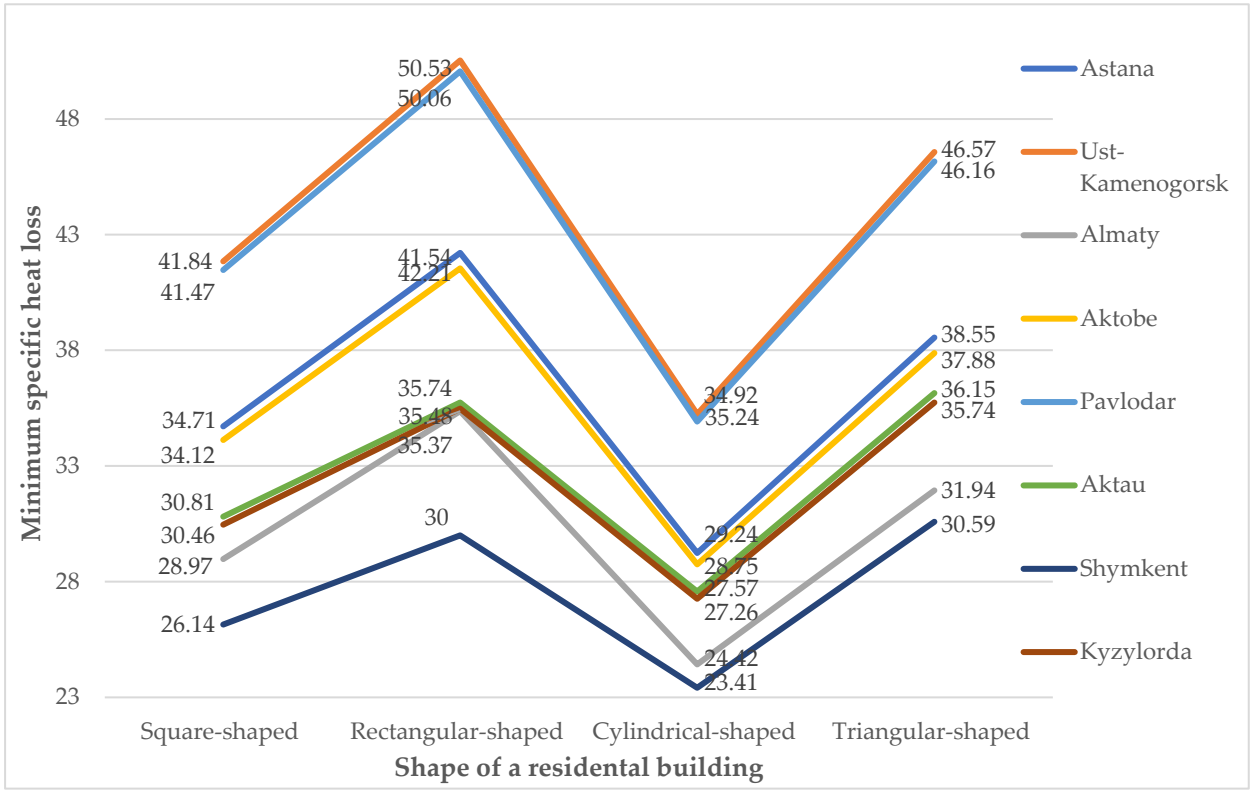


(**a**)

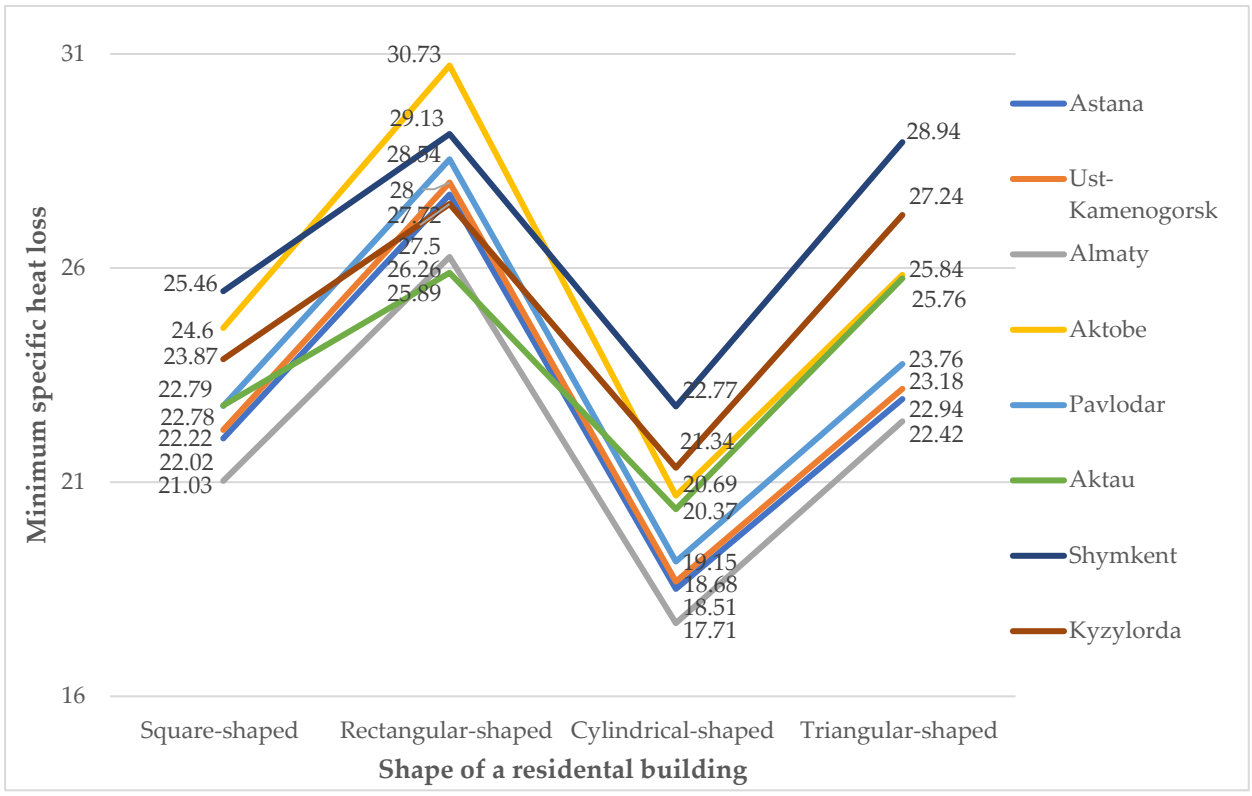


(**b**)

Figure 5. Minimum specific heat loss characteristics of a 4-story residential building: (**a**) Coldest five-day period; (**b**) Hottest month, W/m^2.

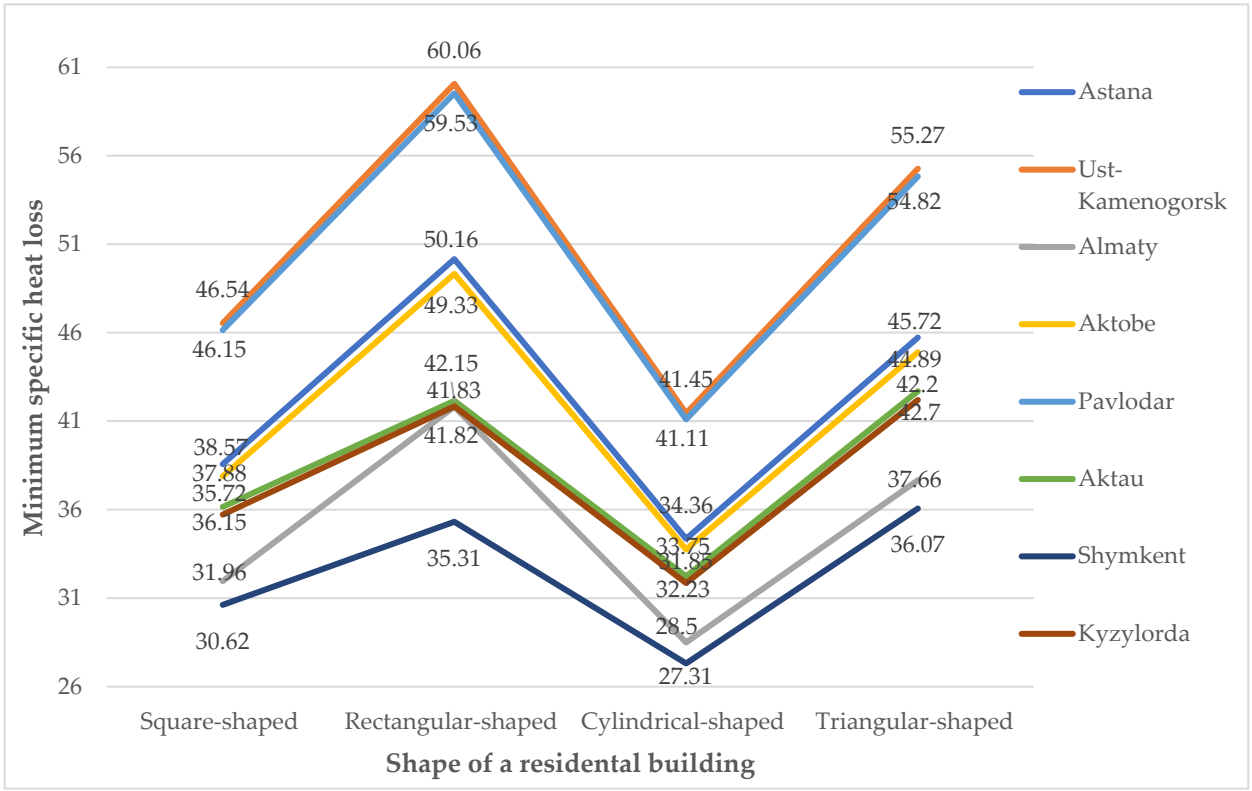


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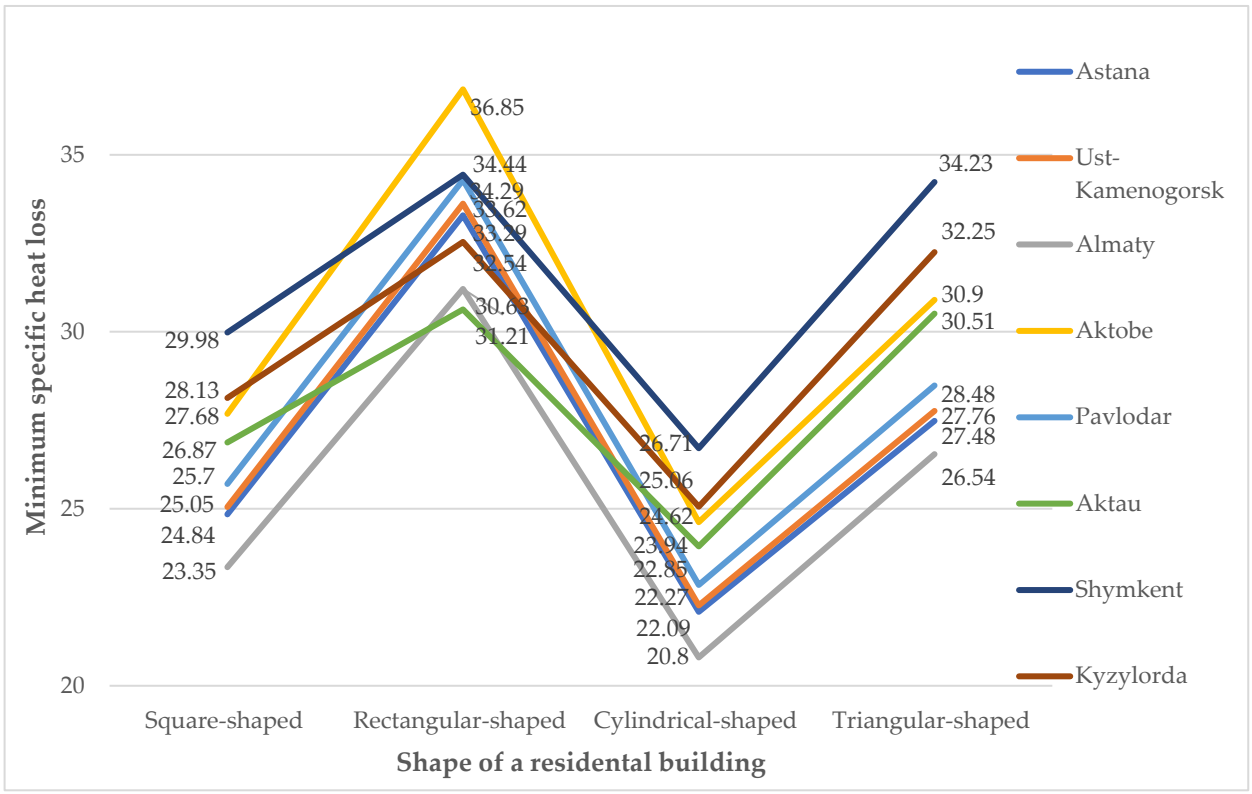


(**b**)

Figure 6. Minimum specific heat loss characteristics of an 8-story residential building: (**a**) Coldest five-day period; (**b**) Hottest month, W/m^2.

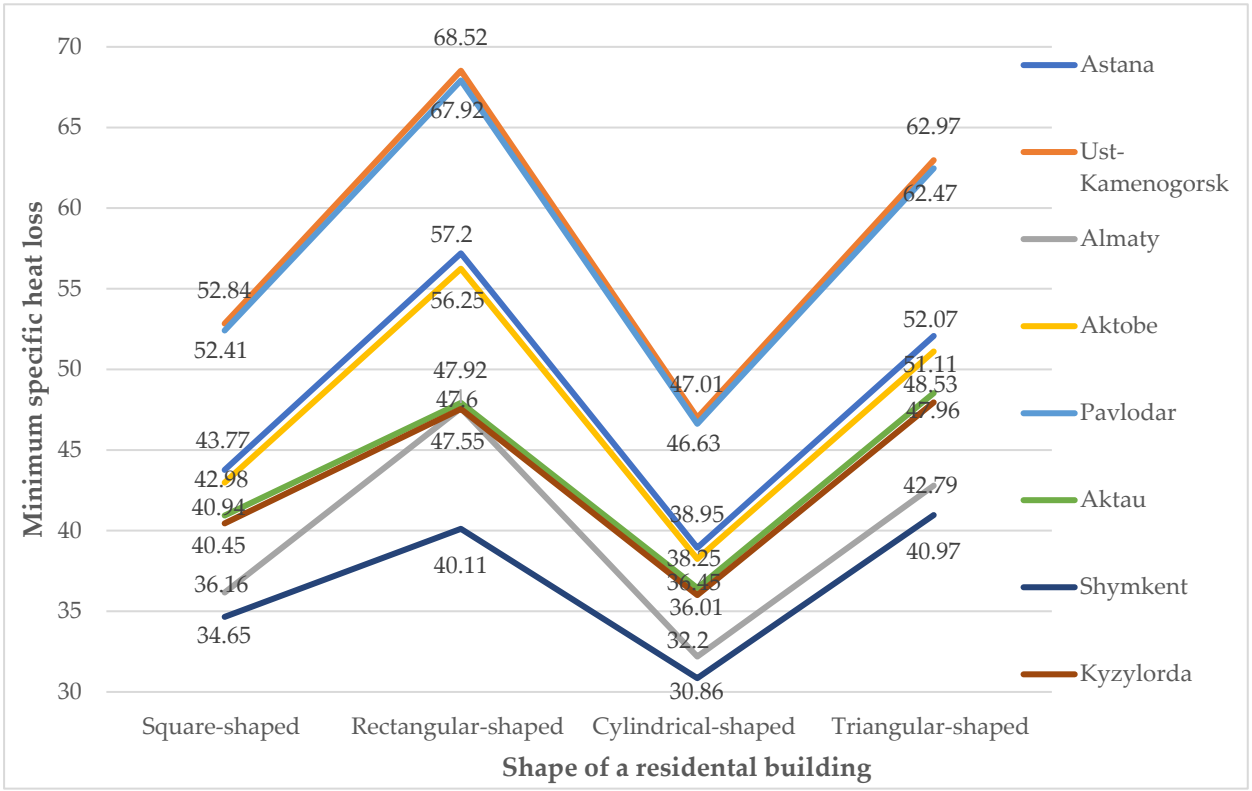


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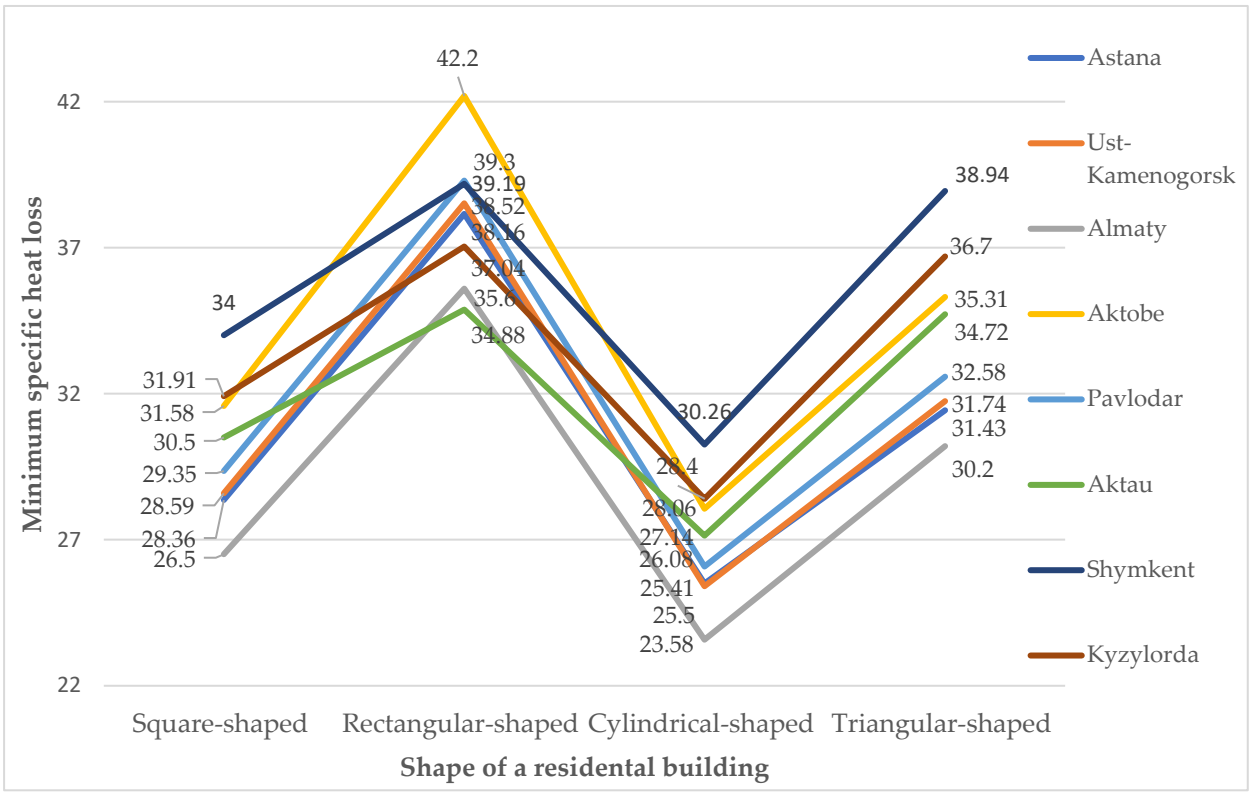


(**b**)

Figure 7. Minimum specific heat loss characteristics of a 12-story residential building: (**a**) Coldest five-day period; (**b**) Hottest month, W/m^2.



(**a**)



(**b**)

Figure 8. Minimum specific heat loss characteristics of a 16-story residential building: (**a**) Coldest five-day period; (**b**) Hottest month, W/m^2.

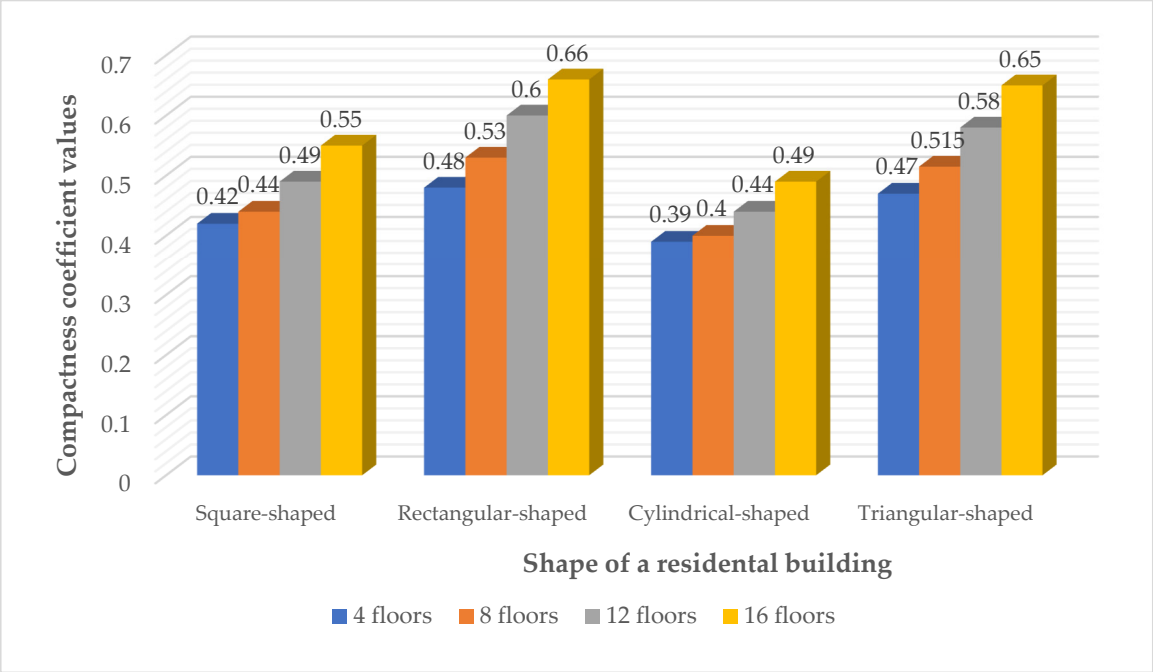


Figure 9. Residential building compactness ratio coefficient depends on the shape, considering the number of stories, floor area, and building volume.

Based on the presented methodology and calculations that account for the floor area but are independent of residential building volume, an analysis was conducted on how building shape affects the compactness coefficient. The analysis revealed that as the building's number of stories increases, the compactness coefficient shows an inverse trend. This is because the building's volume grows faster than the external wall area (Figure 10). The optimal number of stories depends on balancing compactness, construction costs, and functionality.

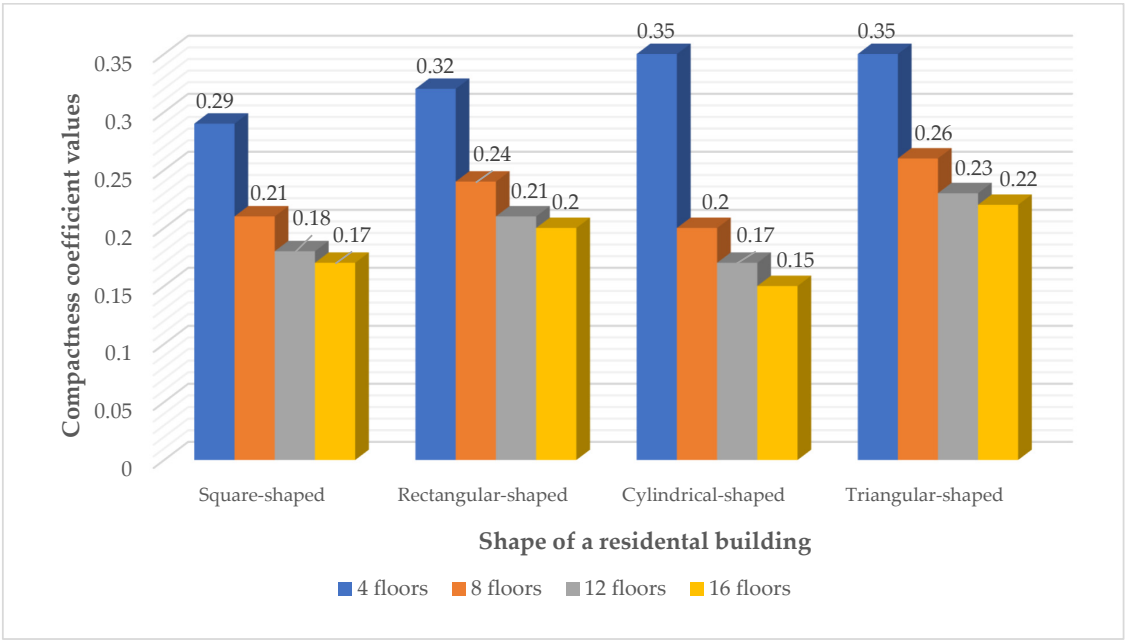


Figure 10. The value of the residential building compactness coefficient depends on the shape, considering the number of stories and floor area without reference to the building volume.

Construction of buildings and structures is a complex process where the economic component plays a key role. One of the most critical indicators affecting the economic efficiency of construction is the building compactness coefficient. This parameter defines the ratio of the area of the building's external enclosing structures to its construction volume and directly influences construction costs, operational expenses, and the building's energy efficiency. The optimal compactness coefficient depends on the building's purpose, climatic conditions, and the project's economic model. For residential buildings, the optimal values range from 0.25 to 0.4 [37,41–45]. Thus, the compactness coefficient is a crucial parameter that determines the economic efficiency of construction. Optimizing this coefficient reduces construction and operational costs, enhances energy efficiency, and enables the rational use of land resources. However, designers must balance saving construction materials with the costs of additional engineering solutions while ensuring the building's functionality and comfort.

In the present study, the authors analyzed the influence of building shapes, considering the preferred orientation for specific regions. The results that were obtained align well with previous studies conducted on individual territorial units. The distinction of this study lies in its comprehensive approach and the ability to adjust for specific climatic conditions and geometric parameters to achieve the most efficient energy performance. A special point of this study is the fact that on the territory of the Republic of Kazakhstan, a significant densely populated part is located on the territories located at the parallels 42°00–46°00 N, which is characterized by the influence of solar radiation in the summer, where the duration is more than five months. Considering these circumstances, taking into account the impact and costs of maintaining a comfortable indoor climate in the context of different periods will be relevant for further research and for the design of appropriate buildings. At the same time, the adoption of the exterior wall design of buildings on a national scale is based on DDHP indicators, according to [37], which does not accurately reflect the costs during the hot period. In this regard, the results of the analysis will have a positive impact on the development of the necessary structural solutions for exterior wall structures in the future. A limitation of this study is that the analysis was conducted using regular building shapes, excluding irregular, block-type, or rounded-corner structures. However, this limitation does not diminish the value of the results and will be addressed in future research by the authors. Furthermore, the findings of this study will contribute to the authors' broader research on developing energy-efficient external enclosing structures for the conditions of the Republic of Kazakhstan. In combination with general design solutions, these findings will significantly impact the building's thermal balance and supplement previously conducted research.

4. Conclusions

As a result of the study on the influence of residential building shapes and orientations on the building's thermal balance, it was established that both the shape and orientation of the building significantly affect its thermal performance. To achieve the research objective, the energy-efficient characteristics of multi-story buildings were analyzed across the most representative regions, consisting of eight cities in the Republic of Kazakhstan. These cities are located in different climatic subregions between the geographical parallels of 42°18′ and 52°16′ N. For the analysis, in addition to the condition of building insolation, the most favorable orientations were determined based on wind frequency. It was found that for climatic subregions I and III, the meridional orientation is preferred, while for subregion IV, the latitudinal orientation is more suitable. The study analyzed four characteristic building shapes: square, rectangular, cylindrical, and triangular. The primary condition was that the floor area remained 1000 m^2, and the building volume was 3000 m^3. Based on these

conditions, the cylindrical shape was found to be the most energy-efficient, outperforming the square, rectangular, and triangular shapes by factors of 1.1, 1.37, and 1.27, respectively, in terms of specific thermal characteristics. The analysis of the effect of residential building height (from 4 to 16 stories in 4-story increments), while maintaining the same floor area and building volume, revealed that the compactness coefficient increases with building height: square residential building: from 0.42 to 0.55, rectangular residential building: from 0.48 to 0.66, cylindrical residential building: from 0.39 to 0.49, triangular residential building: from 0.47 to 0.65. This increase is explained by the growth in the external wall area as the building height increases. Additionally, using the same methodology, the study examined the influence of floor area alone on the compactness coefficient, considering different building shapes. It was found that as building height increases, the compactness coefficient decreases: square building: from 0.29 to 0.17, rectangular building: from 0.32 to 0.20, cylindrical building: from 0.35 to 0.15, triangular building: from 0.35 to 0.22. The study demonstrates that achieving energy efficiency requires adjusting the initial parameters to the specific case, as the optimal building design depends on balancing compactness, construction costs, and functionality.

The findings of the study indicate that building design must consider the dominant climatic features of the region. This approach not only reduces heating and cooling costs but also improves operational comfort. Optimizing building shape according to external climatic factors is a crucial step toward creating energy-efficient and sustainable architecture.

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Nomenclature

F	Usable floor area, m^2
h	Story height, m
Z	Number of stories
a	For meridional building orientation: the width on the southern side; for latitudinal building orientation: the length on the southern side, m
b	For meridional building orientation: the length on the eastern side; for latitudinal building orientation: the width on the eastern side, m
c	For meridional building orientation: the width on the northern side; for latitudinal building orientation: the length on the northern side, m
d	For meridional building orientation: the length on the western side; for latitudinal building orientation: the width on the western side, m
q_i	Monthly average values of heat fluxes through enclosing structures, taking into account the glazing of the building of the i-th element (a, b, c, d, cd, v—for walls, r—for covering fl—for covering the first floor), W/m^2

q_{w_i}	Monthly average values of heat flow through the filling of light openings in the cold season, W/m^2
q_{Enc1_i}	Monthly average values of heat flow through walls and coverings in the cold season in the absence of filtration, W/m^2
q_{Enc2_i}	Monthly average values of heat flow through walls and coverings in the hot season in the absence of filtration, W/m^2
$q_{Enc1_{fl}}$	Monthly average values of heat flow through the overlap in the cold season, W/m^2
$q_{Enc2_{fl}}$	Monthly average values of heat flow through the overlap in the hot season, W/m^2
$T_{0_i}^{con}$	Conditional outdoor temperature, taking into account solar radiation, °C
T_0	Monthly average outdoor temperatures, °C
T_R	Internal air temperature, °C
R_i	Heat transfer resistance of enclosing structures, (m^2°C)/W
β_i	Coefficient of absorption of solar radiation by the material of the outer surface of the enclosing structures
I_i	The average daily value of the total solar radiation incident on the surface of the i-th external enclosing structure for the month of the billing period, W/m^2
$\alpha_{out.sf}$	Heat transfer coefficient of the outer surface of the enclosing structures, W/(m^2°C)

References

1. Yu, F.; Feng, W.; Luo, M.; You, K.; Ma, M.; Jiang, R.; Leng, J.; Sun, L. Techno-economic analysis of residential building heating strategies for cost-effective upgrades in European cities. *iScience* **2023**, *26*, 107541. [CrossRef]
2. Xian, Y.; Wang, H.; Zhang, Z.; Yang, Y.; Zhong, Y. Driving factors and reduction paths dynamic simulation optimization of carbon dioxide emissions in China's construction industry under the perspective of dual carbon targets. *Environ. Impact Assess. Rev.* **2025**, *112*, 107789. [CrossRef]
3. Zhangabay, N.; Abshenov, K.; Bakhbergen, S.; Zhakash, A.; Moldagaliyev, A. Evaluating the Effectiveness of Energy-Saving Retrofit Strategies for Residential Buildings. *Int. Rev. Civ. Eng.* **2022**, *13*, 118–126. [CrossRef]
4. Hilliaho, K.; Nordquist, B.; Wallentèn, P.; Hamid, A.; Lahdensivu, J. Energy saving and indoor climate effects of an added glazed facade to a brick wall building: Case study. *J. Build. Eng.* **2016**, *7*, 246–262. [CrossRef]
5. Tu, D.; Tang, J.; Zhang, Z.; Sun, H. Thermal environment optimization in a large space building for energy-saving. *Case Stud. Therm. Eng.* **2023**, *51*, 103649. [CrossRef]
6. Zhangabay, N.; Tagybayev, A.; Baidilla, I.; Sapargaliyeva, B.; Shakeshev, B.; Baibolov, L.; Duissenbekov, B.; Utelbayeva, A.; Kolesnikov, A.; Izbassar, A.; et al. Multilayer External Enclosing Wall Structures with Air Gaps or Channels. *J. Compos. Sci.* **2023**, *7*, 195. [CrossRef]
7. Lauzet, N.; Rodler, A.; Musy, M.; Azam, M.; Guernouti, S.; Mauree, D.; Colinart, T. How building energy models take the local climate into account in an urban context—A review. *Renew. Sustain. Energy Rev.* **2019**, *116*, 109390. [CrossRef]
8. Hu, S.; Zhou, X.; Yan, D.; Guo, F.; Hong, T.; Jiang, Y. A systematic review of building energy sufficiency towards energy and climate targets. *Renew. Sustain. Energy Rev.* **2023**, *181*, 113316. [CrossRef]
9. Lionar, R.; Kroll, D.; Soebarto, V.; Sharifi, E.; Aburas, M. A review of research on self-shading façades in warm climates. *Energy Build.* **2024**, *314*, 114203. [CrossRef]
10. Mooneghi, M.; Kargarmoakhar, R. Aerodynamic Mitigation and Shape Optimization of Buildings: Review. *J. Build. Eng.* **2016**, *6*, 225–235. [CrossRef]
11. Zhou, Y.; Ma, M.; Vivian, W.Y.; Khoa, N. Design variables affecting the environmental impacts of buildings: A critical review. *J. Clean. Prod.* **2023**, *10*, 135921. [CrossRef]
12. Li, Y.; Zhao, Y.; Chi, Y.; Hong, Y.; Yin, J. Shape-morphing materials and structures for energy-efficient building envelopes. *Energy* **2021**, *22*, 100874. [CrossRef]
13. Coğul, I.; Kazanasmaz, Z.; Ekici, B. A literature review on sustainable buildings and neighborhoods in terms of daylight, solar energy and human factors. *J. Build. Eng.* **2025**, *103*, 111989. [CrossRef]
14. Kumar, D.; Alam, M.; Memon, R.; Bhayo, B. A critical review for formulation and conceptualization of an ideal building envelope and novel sustainability framework for building applications. *Clean. Eng. Technol.* **2022**, *11*, 100555. [CrossRef]
15. Hafez, F.S.; Sa'di, B.; Safa-Gamal, M.; Taufiq-Yap, Y.H.; Alrifaey, M.; Seyedmahmoudian, M.; Stojcevski, A.; Horan, B.; Mekhilef, S. Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. *Energy Strategy Rev.* **2023**, *45*, 101013. [CrossRef]
16. Marincu, C.; Dan, D.; Moga, L. Investigating the influence of building shape and insulation thickness on energy efficiency of buildings. *Energy Sustain. Dev.* **2024**, *79*, 101384. [CrossRef]

17. Nazari, F.; Dixit, M.; Yan, W.; Aryal, A. Building shape optimization based on interconnected embodied and operational energy and carbon impacts. *Energy Build.* **2024**, *325*, 114933. [CrossRef]
18. Jeong-Tak, J.; Jae-Weon, J. Optimization of a free-form building shape to minimize external thermal load using genetic algorithm. *Energy Build.* **2014**, *85*, 473–482. [CrossRef]
19. Borovkov, A.I.; Vafaeva, K.M.; Vatin, N.I.; Ponyaeva, I. Synergistic Integration of Digital Twins and Neural Networks for Advancing Optimization in the Construction Industry: A Comprehensive Review. *Constr. Mater. Prod.* **2024**, *7*, 7. [CrossRef]
20. Zheng, Z.; Xiao, J.; Yang, Y.; Xu, F.; Zhou, J.; Liu, H. Optimization of exterior wall insulation in office buildings based on wall orientation: Economic, energy and carbon saving potential in China. *Energy* **2024**, *290*, 130300. [CrossRef]
21. Ahmadi, P.S.; Khoshgard, A.; Ahmadi, H. Investigating Energy Performance Criteria in Compliance with Iranian National Building Regulations: The Role of Residential Building Envelope Adjacency. *Buildings* **2025**, *15*, 44. [CrossRef]
22. Salameh, M.; Abu-Hijleh, B.; Touqan, B. Impact of courtyard orientation on thermal performance of school buildings' temperature. *Urban Clim.* **2024**, *54*, 101853. [CrossRef]
23. Geraldi, M.; Gnecco, V.; Neto, A.; Martins, B.; Ghisi, E.; Fossati, M.; Melo, A.; Lamberts, R. Evaluating the impact of the shape of school reference buildings on bottom-up energy benchmarking. *J. Build. Eng.* **2021**, *43*, 103142. [CrossRef]
24. Rubtsova, M.; Shevchenko, E.; Semenova, E. Research of the influence of the form of a building on its energy efficiency. *Eng. Syst. Struct.* **2020**, *3*, 28–33. Available online: https://elibrary.ru/item.asp?id=44411307 (accessed on 10 March 2025).
25. Ryabova, O.; Malyuk, E. Selection of Orientation and Shape of Energy-Efficient High-Rise Buildings to Optimize the Thermal Impact of the Outdoor Climate on the Building's Heat Balance: A Case Study of Donetsk. *Probl. Archit.* **2012**, *4*, 58–60. Available online: https://adcitymag.ru/vybor-orientacii-i-formy-energoeffektivnyx-vysotnyx-zdanij/ (accessed on 11 March 2025).
26. Vassiliades, C. Optimizing energy efficiency in mediterranean single-family homes: A parametric study of building typology, orientation, and BIPV integration. *Renew. Energy* **2024**, *237*, 121541. [CrossRef]
27. Jurshari, M.; Tazakor, M.; Yeganeh, M. Optimizing the dimensional ratio and orientation of residential buildings in the humid temperate climate to reduce energy consumption (Case: Rasht Iran). *Case Stud. Therm. Eng.* **2024**, *59*, 104484. [CrossRef]
28. Renuka, S.M.; Maharani, C.M.; Nagasudha, S.; Priya, R. Optimization of energy consumption based on orientation and location of the building. *Proceedings* **2022**, *65*, 527–536. [CrossRef]
29. Zhangabay, N.; Oner, A.; Rakhimov, M.; Tursunkululy, T.; Abdikerova, U. Thermal Performance Evaluation of a Retrofitted Building with Adaptive Composite Energy-Saving Facade Systems. *Energies* **2025**, *18*, 1402. [CrossRef]
30. Zhangabay, N.; Tagybayev, A.; Utelbayeva, A.; Buganova, S.; Tolganbayev, A.; Tulesheva, G.; Jumabayev, A.; Kolesnikov, A.; Kambarov, M.; Imanaliyev, K.; et al. Analysis of the influence of thermal insulation material on the thermal resistance of new facade structures with horizontal air channels. *Case Stud. Constr. Mater.* **2023**, *18*, e02026. [CrossRef]
31. Foroughi, R.; Asadi, S.; Khazaeli, S. On the optimization of energy efficient fenestration for small commercial buildings in the United States. *J. Clean. Prod.* **2021**, *283*, 124604. [CrossRef]
32. Zhangabay, N.; Bonopera, M.; Baidilla, I.; Utelbayeva, A.; Tursunkululy, T. Research of Heat Tolerance and Moisture Conditions of New Worked-Out Face Structures with Complete Gap Spacings. *Buildings* **2023**, *13*, 2853. [CrossRef]
33. Zhangabay, N.; Tursunkululy, T.; Ibraimova, U.; Abdikerova, U. Energy-Efficient Adaptive Dynamic Building Facades: A Review of Their Energy Efficiency and Operating Loads. *Appl. Sci.* **2024**, *14*, 10979. [CrossRef]
34. Code of Rules of the Republic of Kazakhstan 2.04-01-2017. Building Climatology: State Standards in the Field of Architecture, Urban Planning and Construction. Code of Rules of the Republic of Kazakhstan. JSC "KazNIISA", LLP "Astana Stroy-Consulting", 2017. Approved and Enacted on 20 December 2017. 43p. Available online: https://gos24.kz/uploads/documents/2022-12/sp-rk-2.04-01-2017-stroitelnaya-klimatologiya.pdf (accessed on 5 March 2025).
35. Zhangabay, N.; Giyasov, A.; Ibraimova, U.; Tursunkululy, T.; Kolesnikov, A. Construction and climatic certification of an area as a prerequisite for development of energy-efficient buildings and their external wall constructions. *Constr. Mater. Prod.* **2024**, *7*, 1. [CrossRef]
36. Available online: https://www.kazhydromet.kz/ru/ (accessed on 5 March 2025).
37. Code of Rules of the Republic of Kazakhstan 2.04-107-2022. Building Heat Engineering: State Standards in the Field of Architecture, Urban Planning and Construction. Code of Rules of the Republic of Kazakhstan. JSC "KazNIISA", LLP "Astana Stroy-Consulting", 2013. Approved and Enacted on 1 July 2015. p. 80. Available online: https://online.zakon.kz/Document/?doc_id=39838250 (accessed on 15 March 2025).
38. Code of Rules of the Republic of Kazakhstan 2.04-106-2012. Designing of Thermal Protection of Buildings: State Standards in the Field of Architecture, Urban Planning and Construction. Code of Rules of the Republic of Kazakhstan. JSC "KazNIISA", LLP "Astana Stroy-Consulting", 2013. Approved and Enacted on 1 July 2015. Astana, Kazakhstan, p. 153. Available online: https://online.zakon.kz/Document/?doc_id=35957424 (accessed on 15 March 2025).
39. EN ISO 6946 Building Components and Building Elements. 2017. Available online: https://www.en-standard.eu/iso-6946-2017-building-components-and-building-elements-thermal-resistance-and-thermal-transmittance-calculation-methods/ (accessed on 17 March 2025).

40. Tabunshchikov, Y.A.; Brodach, M.M. *Mathematical Modeling and Optimization of Building Thermal Efficiency*; M.: AVOK-PRESS: Astana, Kazakhstan, 2002; 194p. Available online: https://reallib.org/reader?file=480084 (accessed on 10 April 2025).
41. Code of Rules of the Republic of Kazakhstan 50.13330.2024. Thermal Protection of Buildings. Russian Institute for Standardization. Moscow, 2024. p. 74. Available online: https://rsoserv.ru/wp-content/uploads/2025/02/SP-50.13330.2024-Svod-Pravil.-Teplovaya-zashhita-zdanij.pdf (accessed on 5 March 2025).
42. EN 16012 Thermal Insulation for Buildings—Reflective Insulation Products—Determination of the Declared Thermal Performance. 2010. Available online: https://cdn.standards.iteh.ai/samples/30882/98ce4dcd9c5844a3a002f2b280b61cac/SIST-EN-16012-2012.pdf (accessed on 8 March 2025).
43. Interstate Building Regulations 2.04-02-2004 Thermal Protection of Buildings, 2011. p. 48. Available online: https://online.zakon.kz/Document/?doc_id=30075061 (accessed on 13 March 2025).
44. Interstate Code of Rules 2.04-101 Design of Thermal Protection of Buildings, 2001. p. 154. Available online: https://www.arxkom.gov.az/qanunvericilik/normativler/muhendis-sistemleri/proektirovanie-teplovoy-zashchity-zda (accessed on 11 March 2025).
45. EN 13788 Hygrothermal Performance of Building Components and Building Elements—Internal Surface Temperature to Avoid Critical Surface Humidity and Interstitial Condensation—Calculation Methods. 2001. Available online: https://cdn.standards.iteh.ai/samples/22203/9af8a82659944443b0873c17f99960e7/ISO-13788-2001.pdf (accessed on 12 March 2025).

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