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DESIGN OF ENERGY-EFFICIENT LOW-RISE RESIDENTIAL BUILDINGS BASED ON THE INTEGRATION OF GEODESY AND ARCHITECTURE

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Abstract

This article examines how geodetic data and architectural design can be integrated to improve the energy performance of low-rise residential buildings in Fergana region. The relevance of the study is determined by the rapid growth of housing construction in the region, the hot and dry summer climate, winter heat demand, and the need to reduce energy consumption in the building sector. The study combines regional statistical information, climatic indicators, geodetic site analysis, and a comparative assessment of four design scenarios for a 120 m² model house. The analysis uses topographic data, slope and aspect information, solar exposure, prevailing wind direction, and drainage patterns as primary geodetic inputs for site-responsive architectural planning. Results show that the conventional reference house with an annual specific energy demand of 235 kWh/m²·year can be improved to 152 kWh/m²·year when geodetic site planning is integrated with energy-efficient architectural and constructive measures. This represents an estimated reduction of 35.3%, equivalent to 9,960 kWh/year and about 2.01 t/year of CO_2 emissions for the model house. The findings confirm that the integration of geodesy and architecture is not only a spatial and design issue, but also an effective pathway to energy saving, cost reduction, and improved thermal comfort in low-rise housing.

Keywords: Geodesy, architecture, low-rise residential buildings, energy efficiency, Fergana region, site planning, topographic survey, climate-responsive design.

1. Introduction

The building sector remains one of the most significant energy consumers in Uzbekistan. A World Bank assessment notes that the average specific heat consumption of residential buildings in the country is about 290 kWh/m²·year, which indicates substantial inefficiency and a large potential for energy savings in both new and existing housing. For low-rise residential buildings, energy performance is influenced not only by the thermal properties of the building envelope, but also by how the building is placed on the site and how well the design responds to local climatic conditions.

Fergana region is one of the most densely populated and actively developing territories of Uzbekistan. The regional housing context is shaped by continuing urbanization, the expansion of private house construction, and the need for affordable and energy-efficient architectural solutions. Official statistics show that as of 1 April 2024 there were 2,527 construction enterprises in Fergana region, equal to 8.0% of the national total, while new construction works reached 1,304.2 billion UZS in the first quarter of 2024. In 2023, non-state organizations performed 9.9 trillion UZS of construction works in the region. These figures demonstrate the scale of construction activity and the importance of integrating energy efficiency principles at the design stage.

In practice, many residential houses are still designed with insufficient attention to relief, solar orientation, wind exposure, and natural drainage. Such omissions lead to unnecessary earthworks, poor microclimatic adaptation, avoidable overheating in summer, and increased heating demand in winter. Geodesy provides a strong technical basis for solving these issues, because topographic survey data, contour models, slope analysis, aspect analysis, and spatial referencing can support better architectural and planning decisions.

The purpose of this article is to evaluate the effectiveness of energy-saving low-rise housing design when geodetic information is integrated with architectural planning and constructive solutions. The study focuses on Fergana region and presents a model-based assessment supported by statistical data, tables, and specially designed figures.

Table 1. Key climatic indicators of Fergana relevant to low-rise energy-efficient design

Indicator	Value
Mean annual temperature, °C	15.3
Annual precipitation, mm	308
Average temperature in January, °C	1.7
Average temperature in July, °C	29.0
Wettest month	April (45 mm)
Driest month	August (7 mm)
Maximum average sunshine duration	13 h/day (May–July)
Approximate HDD18	2,109 °C·day
Approximate CDD24	342 °C·day

Source: Compiled by the author based on Climate-Data.org monthly climate statistics for Fergana.

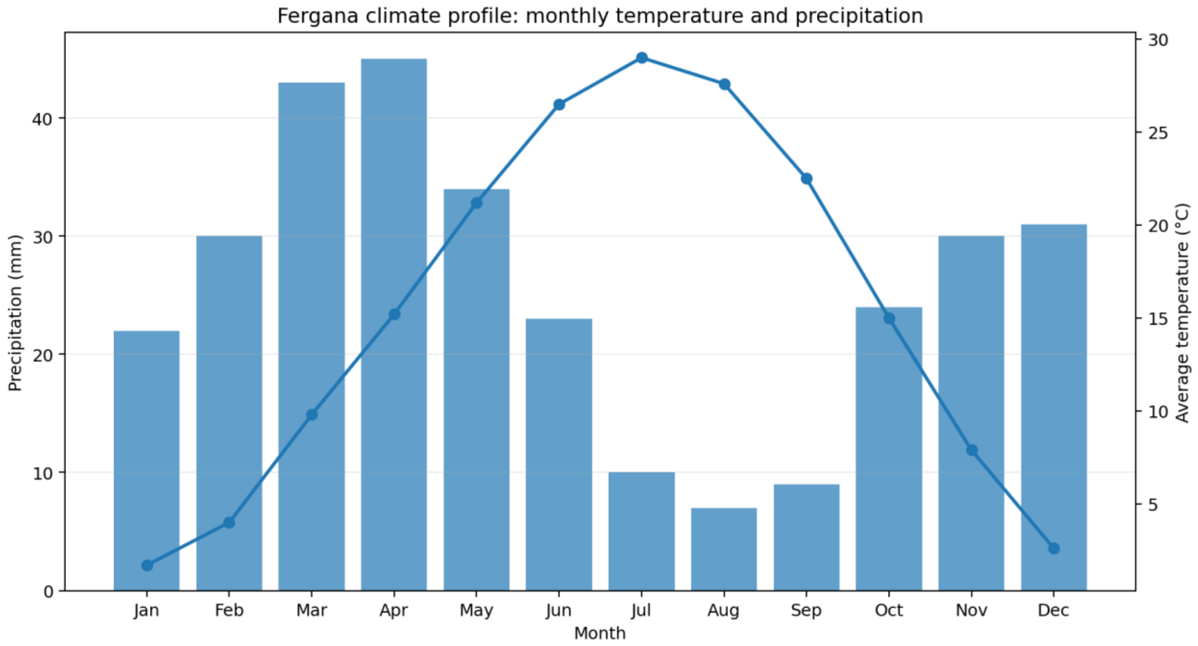

Figure 1. Fergana climate profile: monthly temperature and precipitation
Source: Prepared by the author using Fergana monthly climate data.

2. Materials and Methods

The research uses a mixed method that combines regional statistics, climatic analysis, geodetic interpretation, and engineering comparison of design scenarios. The methodological logic is based on the assumption that site-specific geodetic information can improve spatial planning decisions and, consequently, reduce building energy demand.

The first group of materials consists of official statistics on the construction sector and regional development. The second group includes climatic indicators such as monthly temperature, precipitation, solar exposure patterns, and degree-day conditions that are relevant to heating and cooling demand. The third group includes geodetic and planning data: topographic survey information, contour lines, slope direction, building orientation, setback geometry, and natural drainage patterns.

A model low-rise residential building with a floor area of 120 m^2 was used as the reference object. Four design scenarios were evaluated: (1) a conventional reference solution; (2) a design improved only by orientation and shading; (3) a design improved by thermal envelope modernization; and (4) an integrated geodesy–architecture design combining site-adaptive planning with envelope improvement. Annual specific energy demand was used as the main comparative indicator. Economic and environmental effects were estimated on the basis of annual energy savings, a simplified energy tariff assumption, and a natural-gas-related CO_2 emission factor.

Table 2. Construction and energy-efficiency context relevant to the study

Parameter	Value	Reference period / note
Population context	Fergana region population exceeded 4 million	2023 context
Construction enterprises	2,527 enterprises (8.0% of national total)	1 April 2024
New construction works	1,304.2 billion UZS	Jan–Mar 2024
Non-state construction works	9.9 trillion UZS	2023
Residential heat consumption benchmark (Uzbekistan)	About 290 kWh/m^2·year	World Bank study
Potential reduction after efficiency measures	About 30–40%	World Bank / project monitoring

Source: Compiled by the author based on data from Stat.uz, World Bank, and project documentation.

Table 3. Main parameters of the model house and site used in the assessment

Parameter	Description
Building type	Single-family low-rise residential house
Gross floor area	120 m²
Number of storeys	1
Plot size	600 m²
Site slope	4–7%
Preferred orientation	Long axis east–west; main glazing to south
Climate exposure	High summer solar gains, moderate winter heating demand, NW winter winds
Geodetic inputs	Topographic survey, contour lines, slope, aspect, drainage paths, setback geometry
Digital tools	GIS-based site analysis and architectural planning model
Assessment output	Annual specific energy demand and environmental/economic effect

Source: Author’s model assumptions for a representative low-rise residential building in Fergana region.

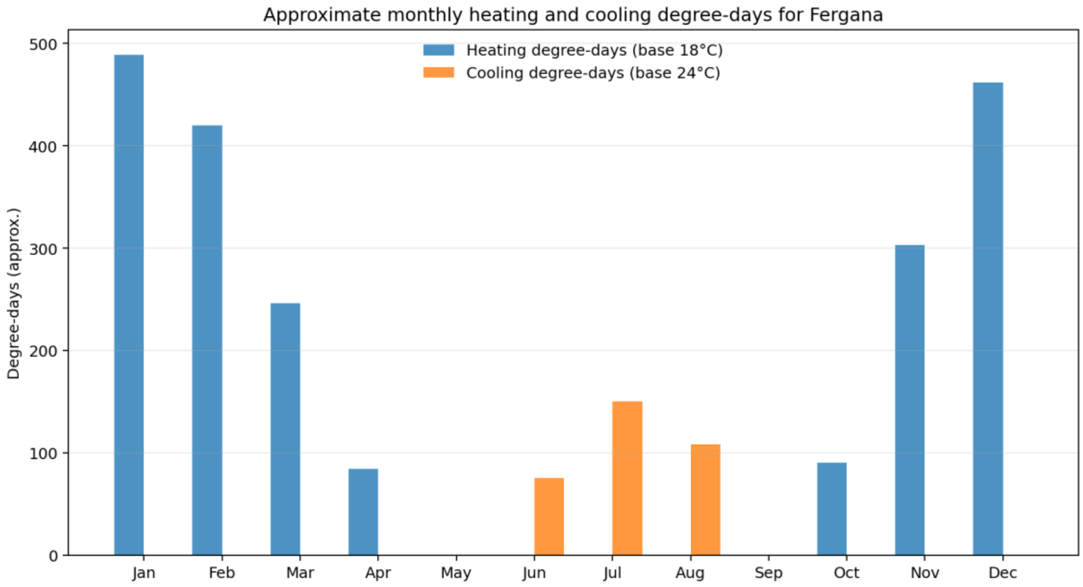

Figure 2. Approximate monthly heating and cooling degree-days for Fergana

Source: Prepared by the author using monthly average temperatures; HDD base 18°C and CDD base 24°C.

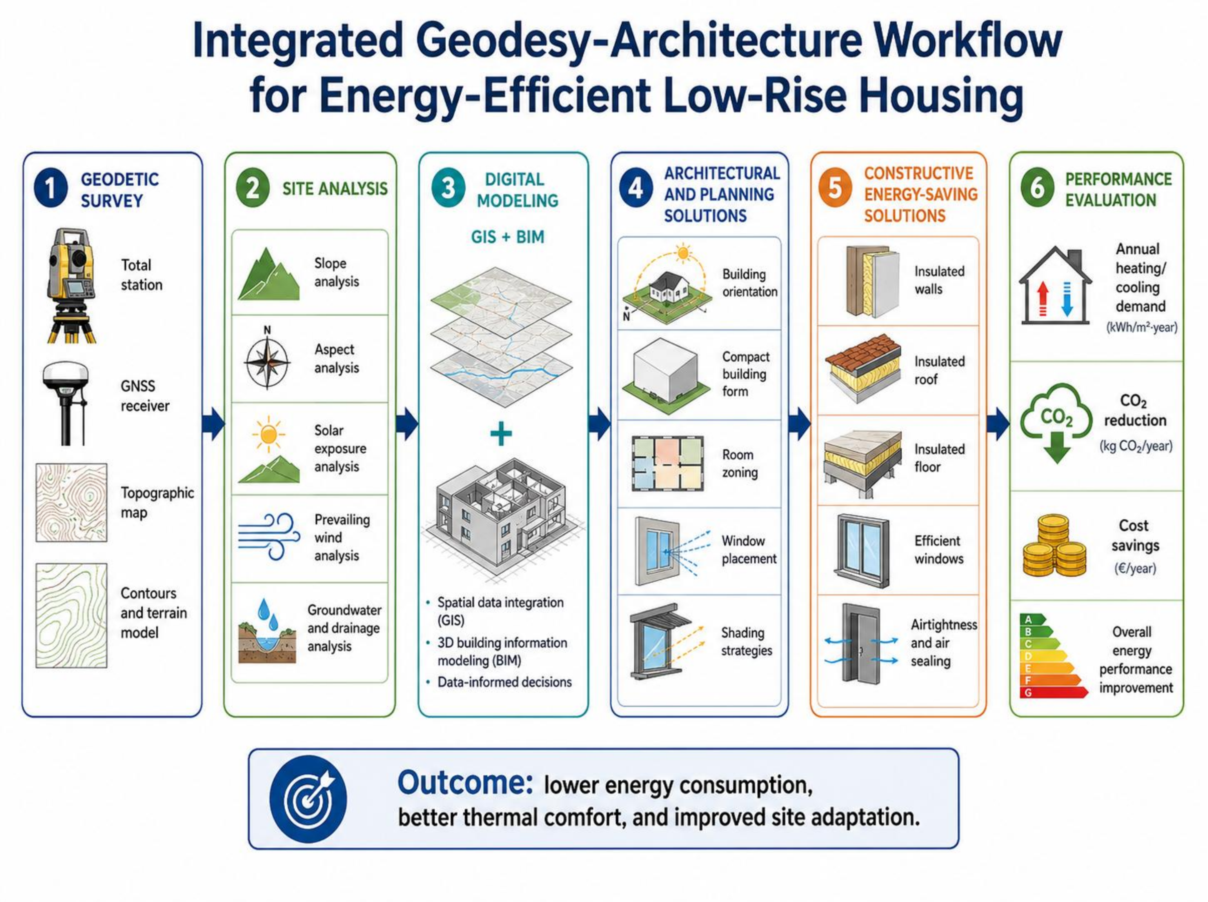

Figure 3. Integrated geodesy–architecture workflow for energy-efficient low-rise housing

Source: Special design figure prepared for this article.

3. Results and Discussion

3.1. Climatic and geodetic design preconditions

The climatic profile of Fergana demonstrates a clear requirement for climate-responsive architectural solutions. The hot season is characterized by high solar gains, especially in June–August, while winter still creates a notable heating demand. The annual mean temperature is 15.3°C, but the average temperature varies from 1.7°C in January to 29.0°C in July. Annual precipitation is relatively low (308 mm), while August is extremely dry. These conditions confirm the importance of solar control, natural ventilation, and the reduction of unwanted heat loss.

From a geodetic perspective, the key design variables are slope, aspect, contour geometry, drainage lines, and site orientation. When these parameters are ignored, buildings often require excessive cut-and-fill operations and may be placed in thermally unfavorable positions. When they are integrated early in the design process, it becomes possible to orient the building more rationally, use terrain for wind protection, preserve natural drainage, and reduce site disturbance.

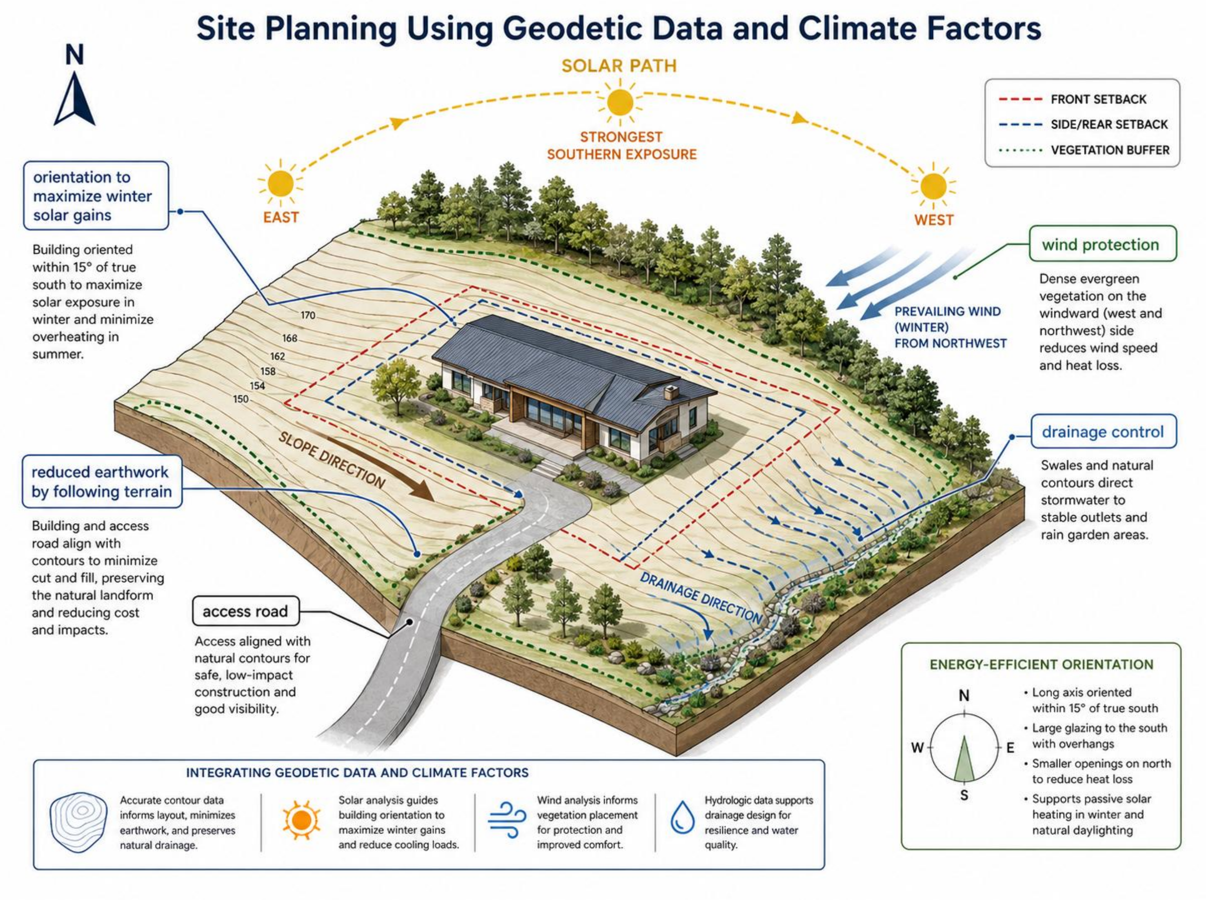

Figure 4. Site planning using geodetic data and climate factors
Source: Special design figure prepared for this article.

3.2. Constructive parameters and expected influence on energy performance

The constructive improvement package was structured around the thermal modernization of the envelope and the reduction of uncontrolled air leakage.

Table 4 summarizes the key performance assumptions for the reference and improved building envelope. The selected target values correspond to a direction of improvement consistent with current thermal regulation requirements and practical energy-saving design principles.

Table 4. Thermal characteristics of the main envelope elements in the comparative assessment

Element	Reference value	Improved value	Design note
External wall	1.20	0.35	Mineral wool / insulated block wall
Roof / attic	0.90	0.25	Insulated roof assembly
Ground floor	0.80	0.30	Thermal insulation over slab/foundation
Windows	2.80	1.60	Low-e double glazing, improved frame
Air tightness	1.2 ACH	0.7 ACH	Improved sealing / infiltration control

Source: Author's assumptions based on standard energy-efficient envelope practice and SHNQ thermal design guidance.

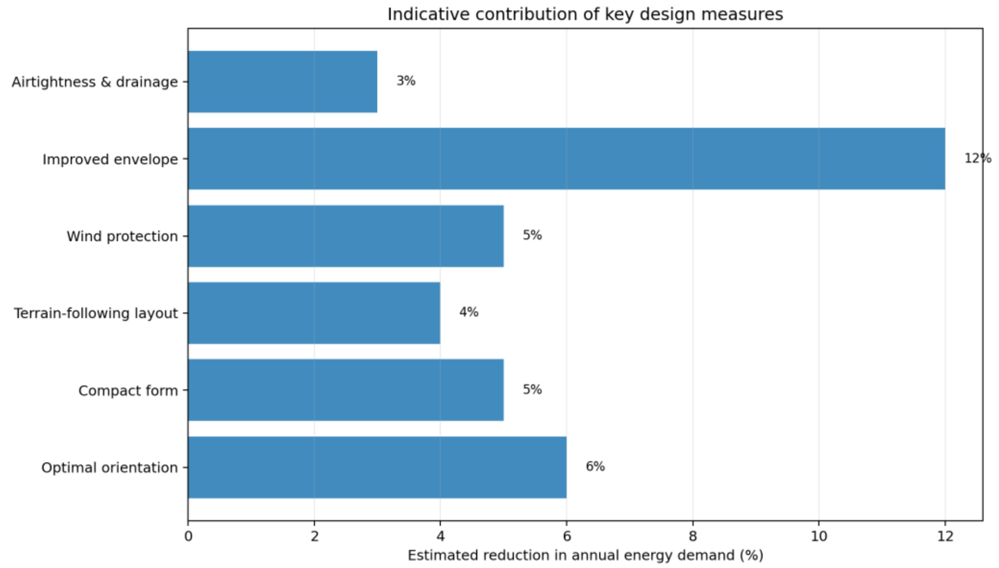

Figure 5. Indicative contribution of key design measures to energy-demand reduction

Source: Author's calculation for the model house.

3.3. Comparative performance of design scenarios

The comparison of annual energy demand shows that the integrated geodesy–architecture approach performs significantly better than isolated design measures. Orientation and shading alone reduce annual specific energy demand from 235 to 219 kWh/m²·year. Envelope improvement without full site integration reduces it further to 183 kWh/m²·year. The best result is obtained by the fully integrated option, which combines topography-sensitive placement, climatically appropriate orientation, wind protection, drainage-aware layout, and improved constructive solutions.

The integrated option reaches 152 kWh/m²·year, which is 35.3% lower than the conventional reference design. For the 120 m² model house, this corresponds to a reduction from 28,200 to 18,240 kWh/year. The scale of this reduction is broadly consistent with the 30–40% improvement range observed in energy-efficiency projects reported by the World Bank.

Table 5. Comparative assessment of annual energy demand under different design scenarios

Scenario	Specific energy demand (kWh/m²·year)	Annual energy use for 120 m² house (kWh/year)	Reduction compared with reference (%)
Conventional reference design	235	28,200	0.0
Orientation and shading only	219	26,280	6.8
Envelope upgrade without full site integration	183	21,960	22.1
Integrated geodesy–architecture design	152	18,240	35.3

Source: Author’s model calculation.

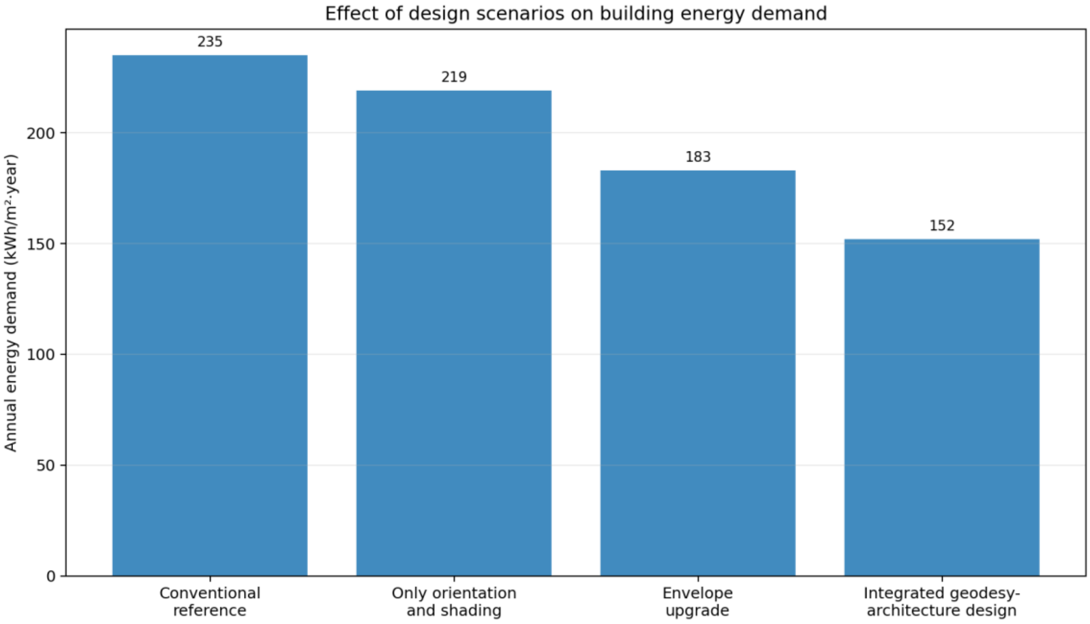

Figure 6. Effect of design scenarios on building energy demand

Source: Author’s model calculation.

Table 6. Heat-loss structure in the reference and integrated design options

Heat-loss component	Reference house share (%)	Integrated design share (%)
Walls	31	27
Roof	22	19
Floor	16	13
Windows	19	25
Infiltration	12	16

Source: Author’s interpretation of residual heat-loss structure after improvement.

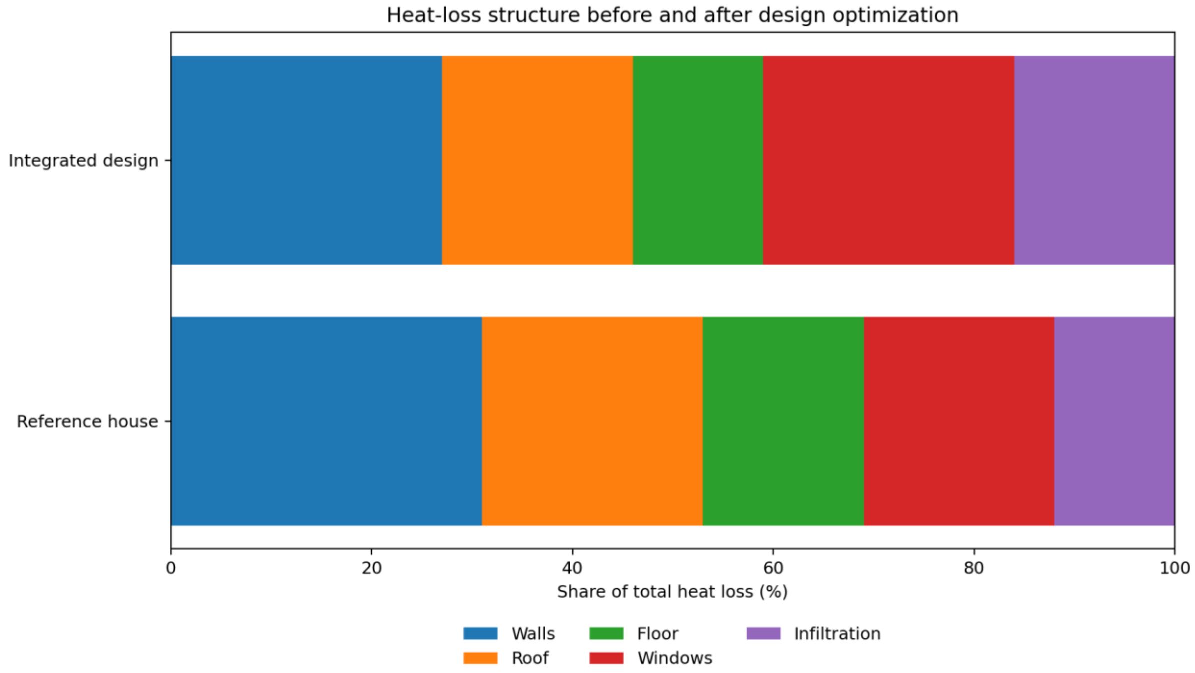

Figure 7. Heat-loss structure before and after design optimization
Source: Author's interpretation of residual heat-loss structure.

3.4. Economic and environmental effect

The integrated design option produces not only technical but also economic and environmental benefits. Under the adopted assumptions, annual energy saving reaches 9,960 kWh. At an assumed energy cost of 650 UZS/kWh, this provides a monetary saving of approximately 6.47 million UZS per year. If the additional investment in site-adaptive and envelope-improvement measures is around 35 million UZS, the simple payback period is approximately 5.4 years.

The environmental effect is also meaningful. Using an assumed emission factor of 0.202 kg CO_2 per kWh of final energy, the annual reduction reaches about 2.01 t CO_2 for the 120 m^2 model house. At the level of larger housing programs, such savings can become substantial and support regional low-carbon development objectives.

Table 7. Economic and environmental effect of the integrated design option

Indicator	Value
Annual energy saving compared with reference	9,960 kWh/year
Relative reduction	35.3%
CO_2 emission factor (assumed natural gas equivalent)	0.202 kg CO_2/kWh
Annual CO_2 reduction	2,012 kg/year (2.01 t/year)
Assumed energy cost	650 UZS/kWh
Annual monetary saving	6,474,000 UZS/year
Additional investment for integrated measures	35,000,000 UZS
Simple payback period	≈ 5.4 years

Source: Author’s calculation using scenario data and assumed unit cost / emission factor.

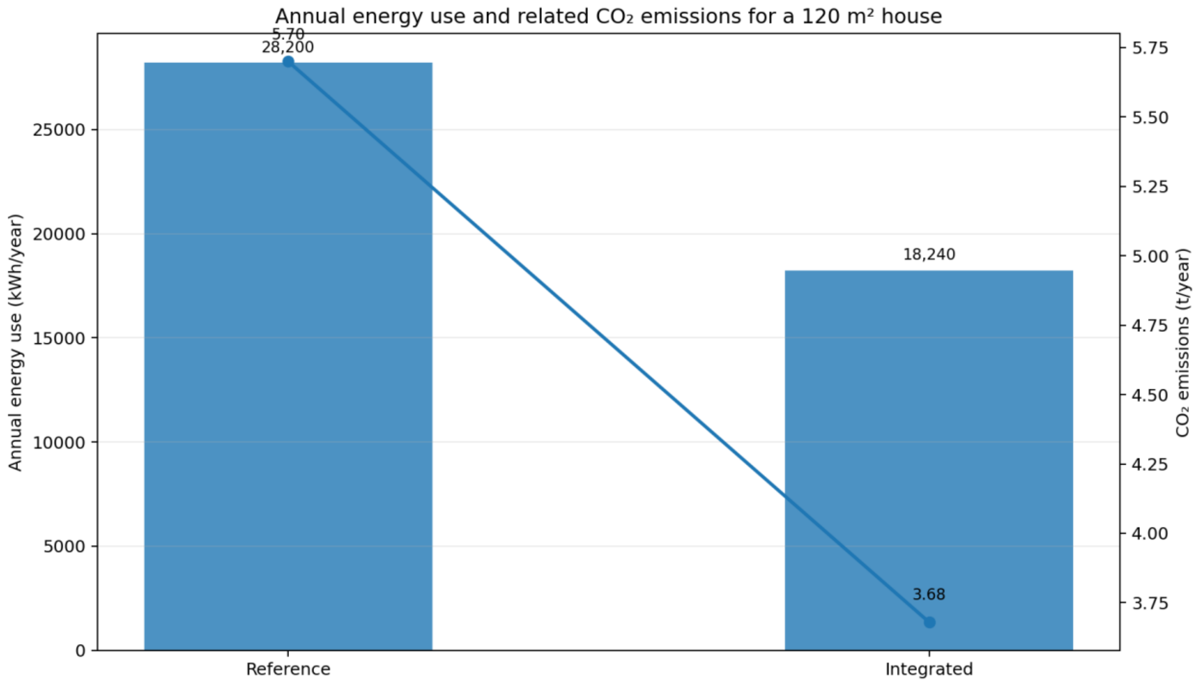

Figure 8. Annual energy use and related CO_2 emissions for a 120 m² house
Source: Author’s calculation.

4. Discussion

The results confirm that energy-efficient low-rise housing should not be treated only as a matter of adding insulation or using better windows. In the conditions of Fergana region, the energy performance of a residential building begins with the correct interpretation of the site. Geodetic information makes it possible to define the most favorable position of the building relative to contours, sun, and wind, while architecture transforms this information into spatial and constructive solutions.

The study also indicates that a fully integrated approach produces more consistent results than fragmented interventions. If only the thermal envelope is improved, significant savings are obtained; however, part of the potential remains unrealized because the building may still be poorly oriented or inadequately adapted to relief and drainage. Therefore, the integration of geodesy, GIS/BIM-based planning, and climate-responsive architecture should be considered a strategic design framework for new low-rise housing in Fergana and similar regions.

The article is based on a model house and indicative calculations; therefore, the numerical results should be interpreted as analytical estimates rather than exact operational measurements. Future work may expand the study through dynamic simulation, field monitoring of occupied houses, and detailed cost optimization for different construction materials and plot conditions.

5. Conclusion

1. Fergana region has climatic and construction conditions that make energy-efficient low-rise housing a priority for sustainable residential development.
2. Geodetic data—especially contour information, slope, aspect, drainage, and orientation—play a decisive role in forming energy-efficient architectural and planning solutions.
3. For the 120 m^2 model house, annual specific energy demand was reduced from 235 to 152 $kWh/m^2 \cdot year$ through the integrated geodesy–architecture approach, corresponding to a 35.3% reduction.
4. The integrated option yields an estimated annual saving of 9,960 kWh, about 2.01 t of CO_2, and approximately 6.47 million UZS under the adopted assumptions.

5. The study confirms that the integration of geodesy and architecture is an effective methodological basis for improving the energy performance, climatic adaptation, and economic efficiency of low-rise residential buildings in Fergana region.

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