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ANALYSIS OF FACTORS AFFECTING THE ENERGY EFFICIENCY OF LOW-RISE RESIDENTIAL BUILDINGS UNDER THE CLIMATIC CONDITIONS OF FERGANA REGION

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Abstract
This article analyses the natural-climatic, constructive, urban-planning and operational factors affecting the energy efficiency of low-rise residential buildings under the climatic conditions of Fergana Region. According to climatic data, the average annual temperature in Fergana city is about 15.3 °C and the annual precipitation is approximately 308 mm. The hot and dry summer, together with the relatively short but cold winter period, creates a dual energy load in buildings: heating demand in winter and cooling or overheating risk in summer. The study evaluates heat losses, heating degree-days and the relative contribution of building-envelope elements for a sample 120 m² low-rise dwelling. The calculations show that integrated improvement of external walls, roof, ground floor, windows and infiltration parameters may reduce the calculated annual space-heating demand from 188.0 to 87.9 kWh/m²·year. The results confirm the need to design energy-saving measures for the housing stock of Fergana Region on the basis of local climatic characteristics.

Keywords: Low-rise residential building, energy efficiency, Fergana Region, heat loss, heating degree-days, external wall, roof, infiltration, SHNQ.

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Introduction

At the global level, the buildings and construction sector is one of the largest areas of energy consumption. According to UNEP and GlobalABC, in 2023 the buildings sector accounted for approximately 32% of global energy consumption and 34% of CO_2 emissions [1]. In Uzbekistan, the building sector also has strategic importance: the World Bank reports that buildings account for 50% of the country's final energy consumption [2]. Therefore, reducing heat losses in residential buildings, using natural climatic resources rationally and introducing energy-efficient constructive solutions are urgent from both practical and economic perspectives.

Fergana Region is one of the densely populated and actively developing housing-construction areas of Uzbekistan. The volume of construction works performed in the region in 2024 amounted to 15.8 trillion UZS, which is 3.76 times higher than the 2019 figure of 4.2 trillion UZS [4]. At the same time, official statistics indicate that the housing provision level in Fergana Region is 20.1 m² per person [5]. The expansion of the housing stock may increase energy consumption; therefore, it is necessary to evaluate new and existing low-rise dwellings from the standpoint of energy efficiency.

The purpose of the article is to analyse the main factors affecting the energy efficiency of low-rise residential buildings under the climatic conditions of Fergana Region using statistical data, tables and calculation-based graphs, and to identify priority improvement directions for the region.

The research tasks are as follows: 1) to assess the effect of the Fergana climate on heating and cooling energy loads; 2) to summarise regional construction and housing-stock statistical indicators; 3) to calculate heat-loss factors for a sample low-rise residential building; and 4) to systematise constructive and operational factors affecting energy efficiency by priority level.

Materials and Methods

A statistical and calculation-based analysis method was applied in the study. Climatic statistics were generalised on the basis of average monthly temperature, minimum and maximum temperature, precipitation, relative humidity and sunshine-hours data for Fergana city for the period 1991-2021 [6]. Regional

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construction activity was assessed using the volume of construction works for 2019-2024 published by the Fergana Regional Department of Statistics [4]. Housing stock and housing provision indicators were presented on the basis of data from the National Statistics Committee of the Republic of Uzbekistan [3; 5]. In the calculation part, the heating degree-day approach was used to estimate the building's heating demand. Heating degree-days were determined using the following expression: $HDD18 = \Sigma(18 - T_i) \times n_i$, where T_i is the average monthly temperature and n_i is the number of days in the month. To estimate summer overheating risk, the $CDD24 = \Sigma(T_i - 24) \times n_i$ indicator was used. In this case, 18 °C was accepted as an approximate base temperature for heating demand, while 24 °C was accepted as the threshold for the beginning of cooling stress.

A 1-2-storey individual residential building with a total floor area of 120 m² and a volume of 360 m³ was selected as the sample. The external wall area was assumed to be 120 m², the roof and ground-floor area 120 m², and the window area 18 m². The heat-loss coefficient was calculated using the formula $H = \Sigma(U \times A) + 0.33 \times n \times V$. Here U is the heat-transfer coefficient of the construction element, A is the area, n is the air-change rate, and V is the building volume. Annual calculated heating energy was then determined by $E = H \times HDD \times 24 / 1000$.

As the regulatory basis, SHNQ 2.01.18-24 "Energy consumption norms for heating, ventilation and air-conditioning of buildings and structures" and SHNQ 2.01.04-2018 "Construction heat engineering" were considered. SHNQ 2.01.18-24 establishes the normative specific heat consumption for heating and natural ventilation in residential buildings depending on heating-season degree-days [7].

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Table 1. Climatic indicators and calculated degree-days for Fergana city

Month	Tavg, °C	Tmin, °C	Tmax, °C	Prec., mm	Humidity, %	Sun, h	HDD18	CDD24
Jan	1.7	-1.7	5.7	22	67	7.0	505.3	0.0
Feb	4.0	-0.2	8.4	30	66	8.0	392.0	0.0
Mar	9.8	4.5	15.1	43	62	10.0	254.2	0.0
Apr	15.2	8.8	21.2	45	56	11.0	84.0	0.0
May	21.2	13.7	27.7	34	46	13.0	0.0	0.0
Jun	26.5	18.3	33.3	23	32	13.0	0.0	75.0
Jul	29.0	21.2	35.5	10	30	13.0	0.0	155.0
Aug	27.6	20.3	34.1	7	33	12.0	0.0	111.6
Sep	22.5	15.7	29.1	9	40	11.0	0.0	0.0
Oct	15.0	9.2	21.0	24	50	10.0	93.0	0.0
Nov	7.9	3.4	12.6	30	64	8.0	303.0	0.0
Dec	2.6	-0.8	6.6	31	67	7.0	477.4	0.0
Year/total	15.3	-	-	308	51.1	10.2	2108.9	341.6

Source: author's calculations based on Climate-Data.org data [6].

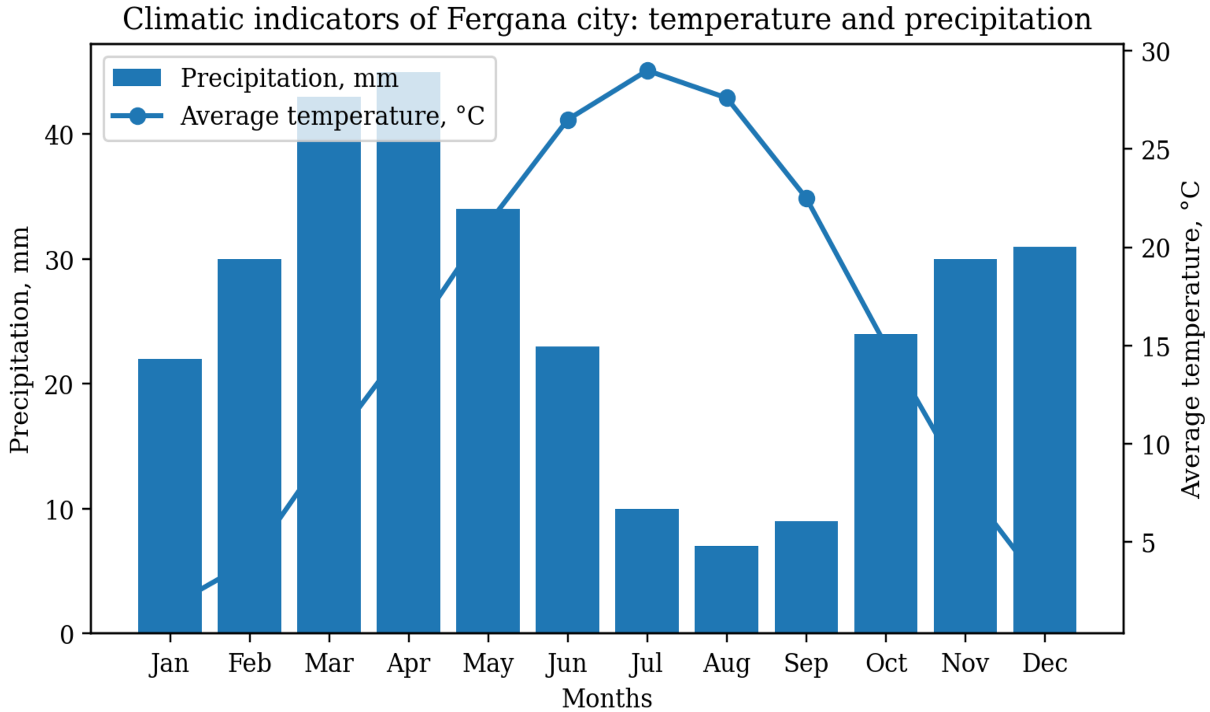

Figure 1. Monthly distribution of temperature and precipitation in the Fergana climate. Source: author's work based on Climate-Data.org data [6].

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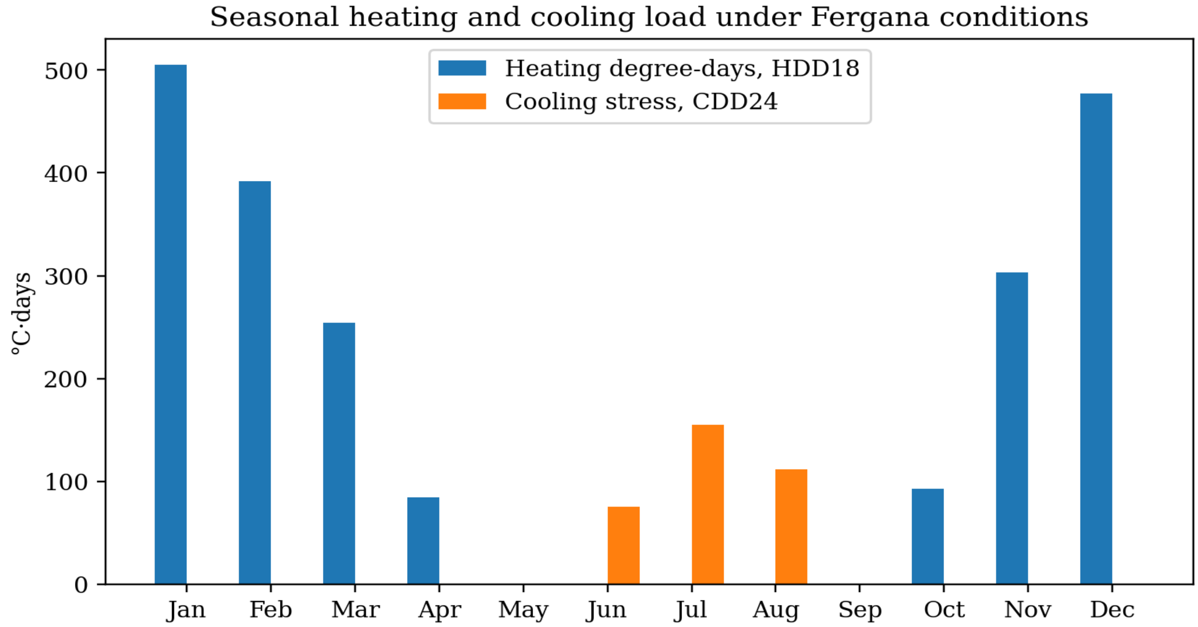

Figure 2. Heating degree-days and summer cooling stress. Source: author's calculations.

Regional Statistical Indicators for Fergana Region

The rapid growth of construction volume in Fergana Region increases the importance of evaluating the energy efficiency of housing at the design stage. In 2019, the volume of completed construction works was 4.2 trillion UZS, while by 2024 it had reached 15.8 trillion UZS [4]. Such growth creates a favourable stage for the broad introduction of energy-saving structures and normative thermal-protection requirements.

Table 2. Key regional statistical indicators used in the study

Indicator	Value	Comment
Construction works in Fergana Region, 2019	4.2 trillion UZS	Baseline indicator of regional construction activity [4]
Construction works in Fergana Region, 2024	15.8 trillion UZS	3.76 times higher than in 2019 [4]
Total housing-stock area of Fergana Region	82,582.3 thousand m^2	Latest indicator in the SIAT/stat.uz data series [3]
Housing provision level	20.1 m^2/person	Data of the National Statistics Committee [5]
Share of Uzbekistan's building sector	50% of final energy consumption	World Bank data [2]

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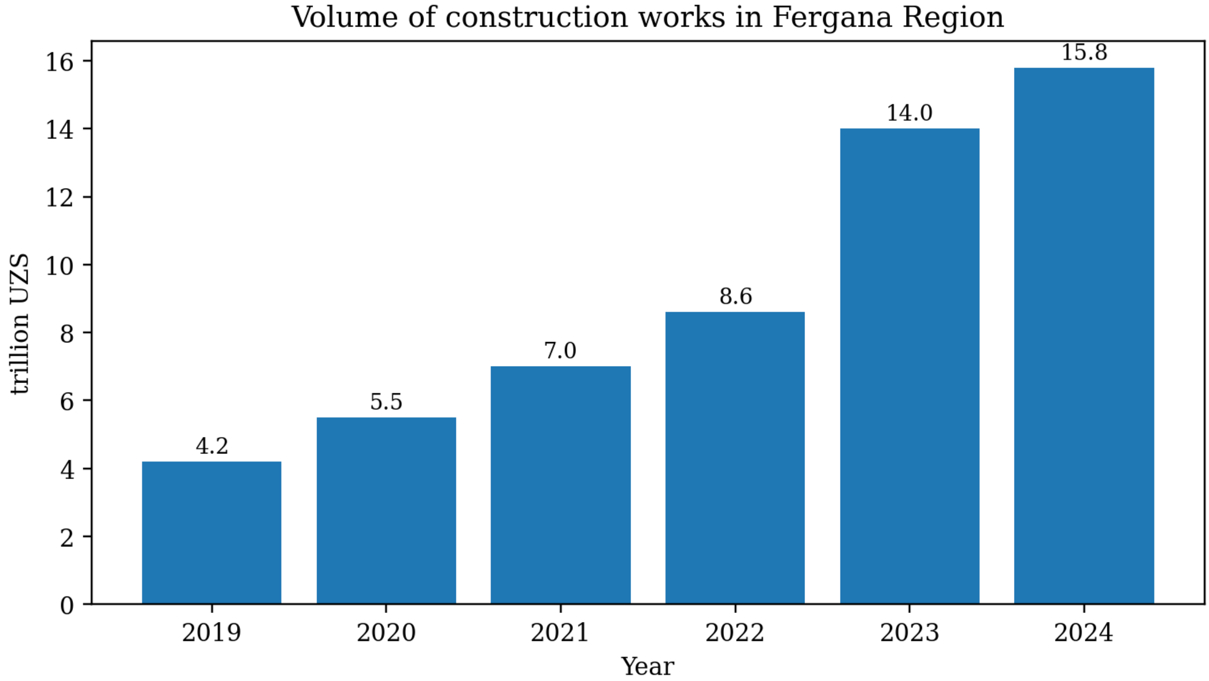

Figure 3. Volume of construction works in Fergana Region in 2019-2024.
Source: Fergana Regional Department of Statistics [4].

Analysis of Factors Affecting Energy Efficiency

Under Fergana conditions, the energy efficiency of a low-rise residential building does not depend only on wall thickness. It is formed through the interaction of climate, building-envelope constructions, orientation, window area, infiltration, operation regime and engineering systems. In low-rise houses in particular, the ratio of roof and ground-floor surfaces to the total heated area is large; therefore, heat losses may be higher than in multi-storey buildings.

Climatic factor. In Fergana, the average temperature in July reaches 29.0 °C and the average maximum temperature reaches 35.5 °C, while in January the average temperature is 1.7 °C [6]. Under such conditions, it is important to limit heat losses through external walls, roof, floor and windows during winter, and to reduce solar radiation and internal overheating during summer. Low precipitation and dry summer conditions allow the use of natural ventilation; however, unshaded windows and structures with low heat capacity increase cooling demand during periods of intense heat.

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Constructive factor. The thermal resistance of external walls, the insulation layer of the roof, heat exchange between the floor and the ground, the U-value of the glazing unit and the airtightness of installation joints directly affect energy consumption. Amendments to SHNQ 2.01.04-2018 update the design parameters of thermal-insulation materials, including mineral wool and glass-fibre mats [8]. This allows a more accurate justification of material selection in practical design. Operational factor. Poor airtightness of doors and windows, uneven heating regimes, low efficiency of boilers or heating equipment, occupants' ventilation habits and indoor humidity conditions also have a significant effect on energy consumption. SHNQ 2.01.18-24 requires compliance with energy-consumption norms in heating, ventilation and air-conditioning design [7].

Table 3. Factors affecting the energy efficiency of low-rise residential buildings

Factor group	**Main indicators**	**Impact mechanism**	**Recommended solutions**
Climatic factors	External temperature amplitude, dry hot summer, short cold winter, sunshine hours	Heating and cooling loads increase	Orientation, shading, passive solar use, natural ventilation
External walls	Material type, thickness, thermal insulation, thermal bridges	Winter heat loss and summer overheating	Mineral wool/EPS/XPS insulation, airtight joints
Roof / attic	Heat exchange through the upper surface and solar radiation	Summer overheating and winter losses	Roof insulation, ventilated roof, reflective coating
Windows	Area, U-value, solar heat gain, installation quality	Heat loss and excessive solar gains	Double/triple glazing, low-emissivity coating, shading devices
Infiltration	Door-window joints, cracks, wind effect	Uncontrolled air exchange increases energy use	Airtight installation, potential use of heat-recovery ventilation
Engineering systems	Boiler, radiator, thermostat, pump, air-conditioner efficiency	Energy consumption and comfort regime change	Automatic control, efficient boiler, thermostatic regulators

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Calculation-Based Assessment for a Sample Low-Rise Dwelling

The purpose of the calculation model is to determine the relative contribution of different construction elements under Fergana climatic conditions. The model does not replace a real design project, but it indicates which construction elements should be improved first. In the existing condition, the following values were accepted: external wall U = 1.35 W/m²K, roof U = 0.75 W/m²K, ground floor U = 0.70 W/m²K, window U = 2.80 W/m²K and air-change rate n = 0.50 h^{-1}. In the improved condition, the values were taken as follows: wall U = 0.45 W/m²K, roof U = 0.25 W/m²K, ground floor U = 0.45 W/m²K, window U = 1.60 W/m²K and n = 0.35 h^{-1}.

Table 4. Heat-loss coefficient calculations for a 120 m² sample dwelling

Element	Area/volume	Existing U or n	H, W/K	Improved U or n	H, W/K	Reduction, %
External walls	120	1.35	162.0	0.45	54.0	66.7
Roof / attic	120	0.75	90.0	0.25	30.0	66.7
Ground floor	120	0.70	84.0	0.45	54.0	35.7
Windows	18	2.80	50.4	1.60	28.8	42.9
Ventilation and infiltration	V=360 m³	n=0.50	59.4	n=0.35	41.6	30.0
Total	-	-	445.8	-	208.4	53.3

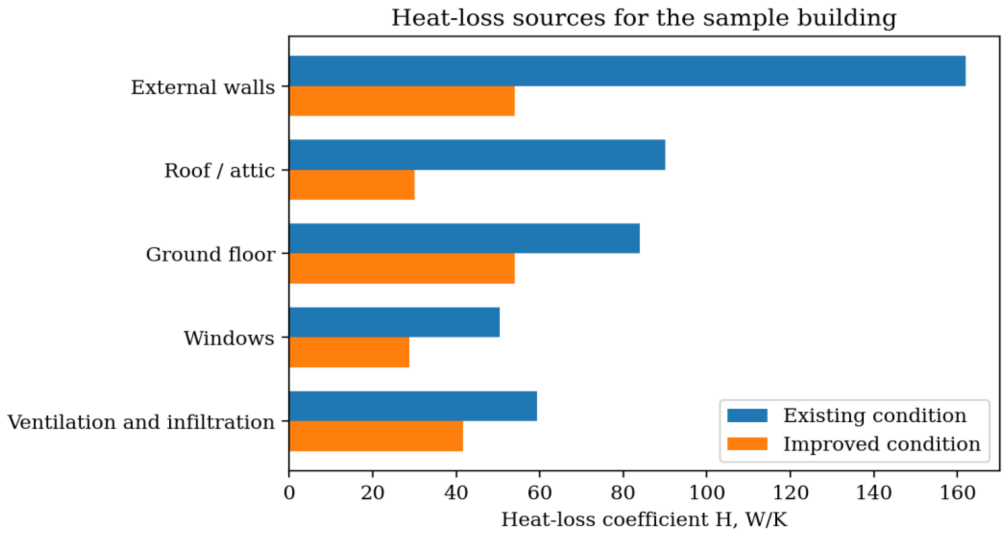

Figure 4. Heat-loss sources in existing and improved conditions. Source: author's calculations.

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On the basis of Fergana climate data, HDD18 was calculated as 2108.9 °C·days. Accordingly, the annual useful heating energy for the 120 m² sample dwelling was 22,564 kWh/year, or 188.0 kWh/m²·year, in the existing condition. In the improved condition, it was 10,548 kWh/year, or 87.9 kWh/m²·year. The difference is 100.1 kWh/m²·year, corresponding to a relative reduction of 53.3%.

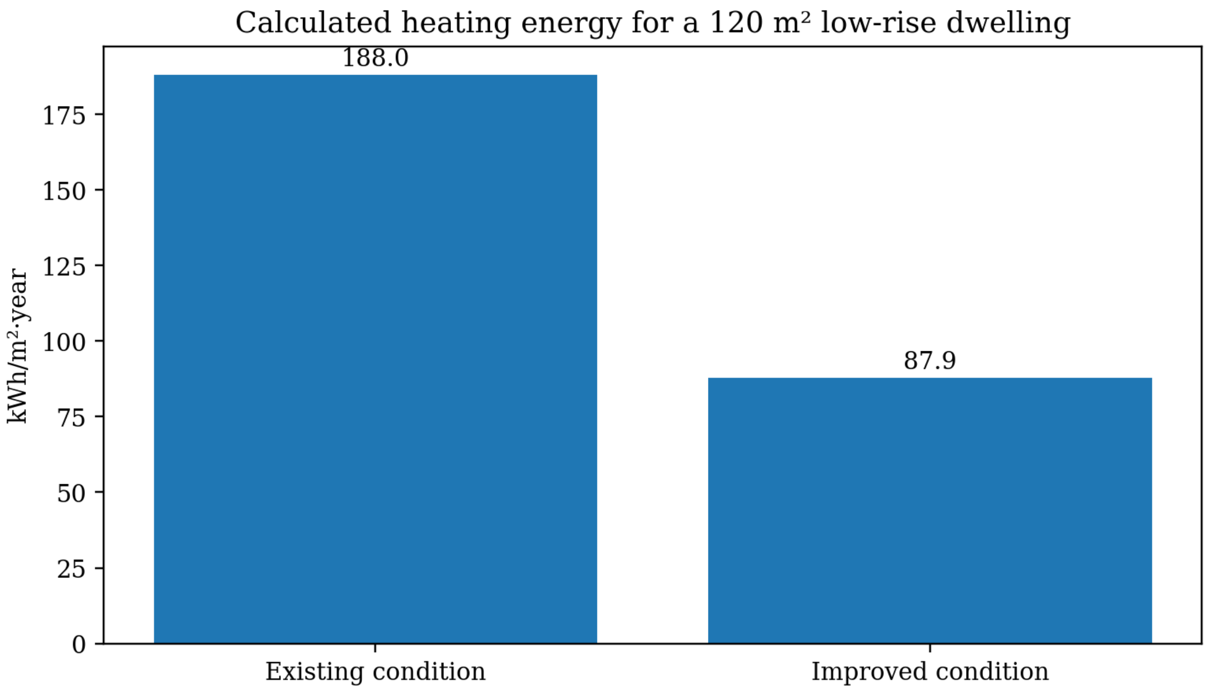

Figure 5. Heating-energy demand in the sample dwelling: existing and improved conditions. Source: author's calculations.

Regional Energy-Saving Potential

Statistical data indicate that the total housing-stock area of Fergana Region is 82,582.3 thousand m² [3]. If comprehensive energy-saving modernisation of external walls, roof, windows and infiltration reduction were implemented for only 10% of this stock, the conditional annual saving potential based on the above model would be approximately 827 GWh/year. This figure may vary depending on actual energy consumption, building age, number of storeys, type of heating system, operation regime and condition of the construction elements. Therefore, practical design requires clarification through energy audits and thermographic surveys.

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Table 5. Conditional energy-saving scenario for the housing stock of Fergana Region

Indicator	Value	Comment
Scenario area	10% of housing stock	8.26 million m²
Existing-condition energy	188.0 kWh/m²·year	Useful heating energy according to the model
Improved condition	87.9 kWh/m²·year	Integrated thermal protection and reduced infiltration
Specific saving	100.1 kWh/m²·year	Model result
Conditional annual saving	827 GWh/year	Assessment for the 10% scenario

Discussion and Priority Improvement Directions

The calculation results show that replacing windows alone is not sufficient to increase the energy efficiency of low-rise residential buildings. In the existing condition, the largest share of heat loss is associated with external walls and the roof. At the same time, infiltration is also an important source of uncontrolled energy consumption, and improving the airtightness of installation joints and door-window units is one of the measures that can produce a relatively quick economic effect.

The climate of Fergana Region requires a dual approach. In winter, increasing the thermal resistance of the building, reducing thermal bridges and limiting uncontrolled ventilation losses are priorities. In summer, roof design, southern and western facades, window shading, natural ventilation and materials with high heat capacity are important. Therefore, energy efficiency is not simply "thick insulation"; it is a system of climate-adapted constructive, architectural and operational solutions.

From a regulatory point of view, SHNQ 2.01.18-24 provides normative specific heat-consumption values for heating and natural ventilation in residential buildings depending on the degree-day value of the heating season [7]. The calculated HDD18 ≈ 2109 °C·days for Fergana places the region close to the 2000-3000 °C·day range. This indicates the need to select climatic parameters correctly when designing normative heat-consumption values for 1-2-storey residential buildings.

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Table 6. Priority energy-saving measures under Fergana conditions

No.	Measure	Justification	Priority
1	Roof and attic insulation	Reduces summer overheating and winter heat loss simultaneously	High
2	Strengthening the thermal insulation of external walls	The model shows that walls account for the largest share of H	High
3	Improving windows and installation joints	Reduces U-values and infiltration	High
4	Canopies, verandas and facade shading	Reduces July-August cooling stress	Medium-high
5	Thermostats and automatic control	Limits excessive heating caused by occupant behaviour	Medium
6	Energy audits and thermographic monitoring	Identifies the weakest element accurately	Mandatory diagnostic stage

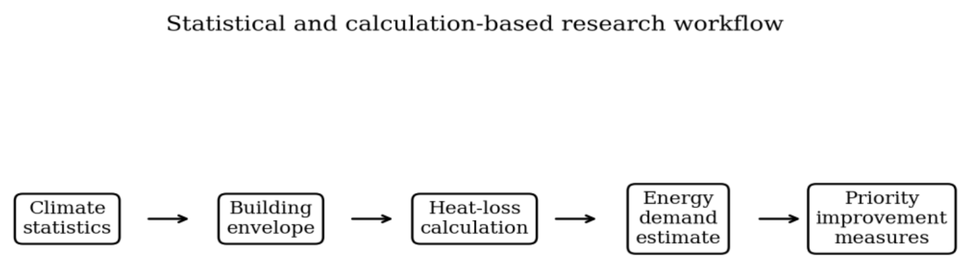

Figure 6. Statistical and calculation-based workflow for energy-efficiency assessment. Source: author's work.

Conclusion

1. The climate of Fergana Region creates winter heating demand and summer overheating or cooling demand in low-rise residential buildings. For Fergana city, the average annual temperature is 15.3 °C, annual precipitation is 308 mm, the

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average July temperature is 29.0 °C, and the average January temperature is 1.7 °C.

2. Based on climatic data, HDD18 = 2108.9 °C·days and CDD24 = 341.6 °C·days were calculated. This indicates that, along with thermal protection, summer shading and natural ventilation must also be considered in the region.

3. In Fergana Region, the volume of construction works increased from 4.2 trillion UZS in 2019 to 15.8 trillion UZS in 2024. The intensification of construction creates an important opportunity for the mass introduction of energy-saving solutions in new projects.

4. According to the model of a 120 m^2 sample low-rise dwelling, comprehensive improvement can reduce the heat-loss coefficient from 445.8 W/K to 208.4 W/K. As a result, calculated heating energy may decrease from 188.0 kWh/m^2·year to 87.9 kWh/m^2·year.

5. Under Fergana conditions, the most important measures are strengthening roof and external-wall insulation, sealing windows and installation joints, organising facade shading, controlling natural ventilation and equipping heating systems with automatic control.

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