



TECHNO-ECONOMIC MEASURES FOR REDUCING THERMAL ENERGY LOSSES IN RESIDENTIAL BUILDINGS UNDER EMERGENCY CONDITIONS

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Abstract. *This study develops a screening-level techno-economic framework for reducing heat-energy losses and strengthening the emergency resilience of residential buildings in Samarkand, Uzbekistan. The analysis combines a heat-supply baseline with a building-envelope retrofit case and a rooftop photovoltaic scenario. The baseline comprises ten heat-supply sources consuming 4.5 million m³ of natural gas per day over a normative 129-day heating period. For the assessed building group, the envelope measure applies 60 mm insulation with thermal conductivity not exceeding 0.035 W/(m·K) to 3,976 m² of external wall. Annual thermal-energy demand decreases from 1,665,771 to 974,525 kWh, equivalent to a 41.5% reduction. The corresponding saving of 364,453 m³ of natural gas yields an annual monetary benefit of 236.894 million UZS at the 2024 baseline tariff of 650 UZS/m³. A separate rooftop scenario allocates 755 m² to a 151 kWp photovoltaic system. Under the stated assumption of eight equivalent full-load hours per day for 300 days, annual generation is 362.4 MWh. At an initial cost of 1.6459 billion UZS and a unit electricity benefit of 1,000 UZS/kWh, the simple payback period is 4.54 years. The results show that envelope insulation and distributed solar address different components of emergency risk: the former lowers peak heat demand and slows indoor-temperature loss, whereas the latter diversifies electricity supply. The estimates are transparent screening results; investment decisions require hourly simulation, measured performance, full installed costs, system losses, maintenance, degradation and discounted cash-flow analysis.*

Keywords: *residential buildings; energy efficiency; thermal insulation; heat loss; emergency resilience; natural-gas saving; rooftop photovoltaics; simple payback period; Samarkand; Uzbekistan.*

1. Introduction

Improving the energy performance of the existing building stock is simultaneously an energy-security, economic and climate-resilience task. In Uzbekistan, buildings account for a substantial share of final energy demand, and space heating is the dominant residential end use. Much of the stock was constructed before contemporary energy-efficiency requirements became established, which makes heat transmission through walls, roofs and windows a persistent source of avoidable demand [1, 2]. During severe cold spells or interruptions in gas and electricity supply, the same transmission losses acquire a safety dimension: they increase peak loads and accelerate the decline of indoor temperature.

International guidance therefore treats the building envelope as the first layer of demand reduction, to be followed by efficient technical systems and low-emission energy supply [3]. For Uzbekistan, prior research has demonstrated that the financially favourable thickness of common wall-insulation materials depends on wall construction, orientation, climate and energy prices; reported optima for typical Tashkent walls range from 3.75 to 11.0 cm [4]. A 60 mm insulation layer is consequently within the technically credible range, but its performance and economic effect must be tied to a clearly defined building group, tariff scenario and cost boundary.

The second component of resilience is decentralised electricity generation. Uzbekistan has substantial solar resources and a national policy framework that encourages small photovoltaic installations through tax privileges and a subsidy for surplus electricity supplied by households to the grid [5, 6]. Nevertheless, an optimistic energy-yield assumption or an incomplete capital-cost estimate can make

a payback result appear more certain than it is. A journal-ready assessment must therefore state each assumption, equation and system boundary explicitly.

The aim of this article is to quantify, within one transparent framework, the energy and economic effects of two complementary measures for residential buildings under emergency conditions: (i) upgrading external-wall thermal protection and (ii) installing rooftop photovoltaic capacity. The objectives are to reconstruct the heat-supply baseline, calculate thermal-energy and natural-gas savings, determine the screening-level material cost and monetary benefit of the envelope measure, size the photovoltaic scenario, and identify the limitations that must be resolved before implementation.

2. Materials and methods

The study is a deterministic case assessment based on the numerical inputs contained in the source calculation for residential buildings in Samarkand. Two analytical boundaries are deliberately distinguished. The first is a city heat-supply context consisting of ten heat sources, used to characterise seasonal gas demand and carbon dioxide emissions. The second is a specific group of assessed buildings, used for the envelope and rooftop-PV calculations. Separating these boundaries prevents city-wide contextual quantities from being interpreted as savings attributable to the smaller retrofit case.

The calculation logic follows the principles of transparent energy-balance assessment. ISO 52016-1 provides the general framework for calculating heating and cooling energy needs, internal temperatures and thermal loads, while the national thermal-engineering and building-energy norms establish the local regulatory context [7-9]. The present article does not repeat an hourly building simulation; it checks and reports the arithmetic of the underlying annual results and converts them into comparable technical and economic indicators.

For the heat-supply context, seasonal natural-gas consumption V_h is the product of average daily consumption V_d and the normative heating-period duration

nh. Carbon dioxide emissions MCO_2 are estimated using an effective coefficient of 1.795 kg CO_2 per m^3 of natural gas, consistent with the 56.1 t CO_2 /TJ default factor and the net calorific-value assumption used in the underlying calculation [10].

$$V_h = V_d \times nh = 4.5 \times 129 = 580.5 \text{ million } m^3 \text{ per heating season}$$

$$MCO_2 = V_h \times EF = 580.5 \times 10^6 \times 1.795 = 1.042 \times 10^9 \text{ kg } CO_2$$

For the envelope case, a 60 mm insulation layer with thermal conductivity $\lambda \leq 0.035 \text{ W/(m}\cdot\text{K)}$ is applied to an external-wall area A_w of 3,976 m^2 . The annual thermal-energy reduction $etaE$ is calculated from the reported baseline demand E_0 and level-2 thermal-protection demand E_2 . Natural-gas cost saving S_g is the product of the saved volume V_{sav} and the 2024 household baseline tariff T_g of 650 UZS/ m^3 established under Cabinet of Ministers Resolution No. 204 [11]. Material cost C_m uses the reported market allowance of 70,000 UZS/ m^2 .

$$etaE = [(E_0 - E_2) / E_0] \times 100 = [(1,665,771 - 974,525) / 1,665,771] \times 100 = 41.5\%$$

$$S_g = V_{sav} \times T_g = 364,453 \times 650 = 236,894,450 \text{ UZS/year}$$

$$C_m = A_w \times cm = 3,976 \times 70,000 = 278,320,000 \text{ UZS}$$

The rooftop-PV scenario uses 50% of the reported total roof area of 1,509.76 m^2 , giving $APV = 755 \text{ m}^2$ after rounding. Specific installed capacity is assumed to be 0.20 kWp/ m^2 . Annual energy EPV is calculated from installed capacity PPV , eight equivalent full-load hours per day and 300 operating days. The capital-cost allowance is 10.9 million UZS/kWp, and the unit electricity benefit is 1,000 UZS/kWh. The latter corresponds to the household surplus-electricity subsidy specified by Presidential Resolution No. PQ-57; its direct use as a benefit for all generated electricity is a scenario assumption, not a statement that every kilowatt-hour will necessarily be exported [5].

$$PPV = APV \times pA = 755 \times 0.20 = 151 \text{ kWp}$$

$$EPV = PPV \times 8 \times 300 = 151 \times 8 \times 300 = 362,400 \text{ kWh/year}$$

$$SPP = C_0 / (EPV \times Te) = 1,645,900,000 / (362,400 \times 1,000) = 4.54 \text{ years}$$

All financial results are reported in nominal Uzbek soum (UZS) and represent simple, undiscounted screening calculations. No residual value, financing cost, tariff escalation, module degradation, inverter replacement, operation and maintenance, downtime or tax effect is included. Consequently, the simple payback period is not equivalent to net present value, internal rate of return or discounted payback.

3. Results

The ten heat-supply sources consume an average of 4.5 million m³ of natural gas per day. Over 129 days, the seasonal total is 580.5 million m³. Applying the effective emission coefficient gives approximately 1.042 million t CO₂ per season. These figures describe the scale of heating-related exposure in Samarkand: even a short episode of extreme cold can raise demand at the same time that fuel delivery and power-system capacity are under stress.

For the assessed building group, level-2 thermal protection reduces annual thermal-energy demand from 1.666 to 0.975 GWh. The exact calculated reduction is 41.5%, which supports the rounded 42% value used in the source material. Because the result is expressed as an annual total, kWh/year is the dimensionally consistent unit; using kW/m² for the same quantity would mix power, energy and area and is therefore avoided.

The reported natural-gas saving of 364,453 m³/year corresponds to 236.894 million UZS/year at 650 UZS/m³. The insulation-material allowance is 278.32 million UZS. Dividing material cost by annual monetary saving gives a lower-bound simple payback of approximately 1.18 years. This value must not be presented as the installed-project payback because the available cost excludes labour, anchors and profiles, façade finishing, scaffolding, design, quality control and future maintenance. Figure 1 summarises the technical boundary and the verified results.

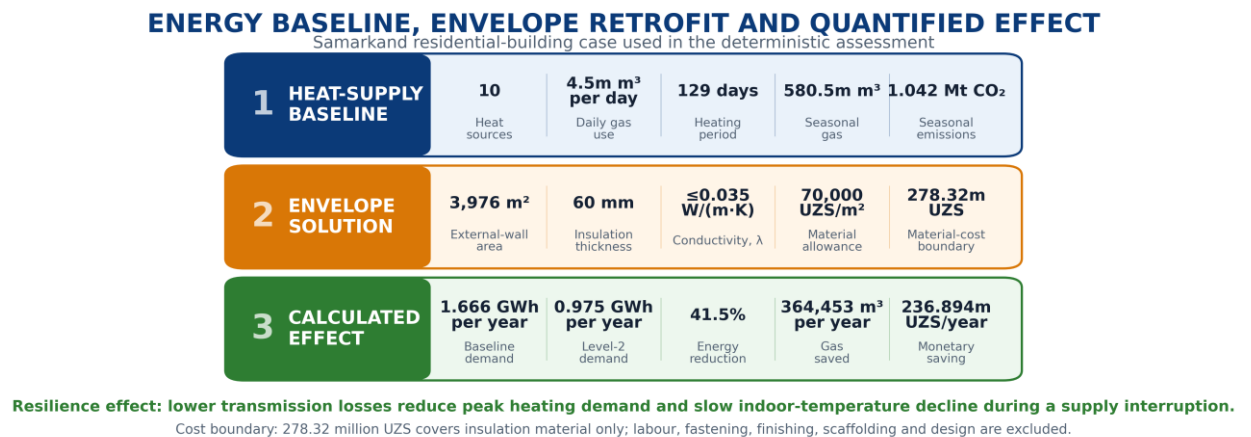


Figure 1. Heat-supply context, envelope-retrofit assumptions and calculated effects for the Samarkand case.

The rooftop calculation produces an installed capacity of 151 kWp. Under the stated solar-availability assumption, annual generation is 362.4 MWh. Multiplication by 1,000 UZS/kWh gives an annual gross benefit of 362.4 million UZS. The reported unit investment of 10.9 million UZS/kWp gives a total initial investment of 1.6459 billion UZS and a simple payback period of 4.54 years (Figure 2).

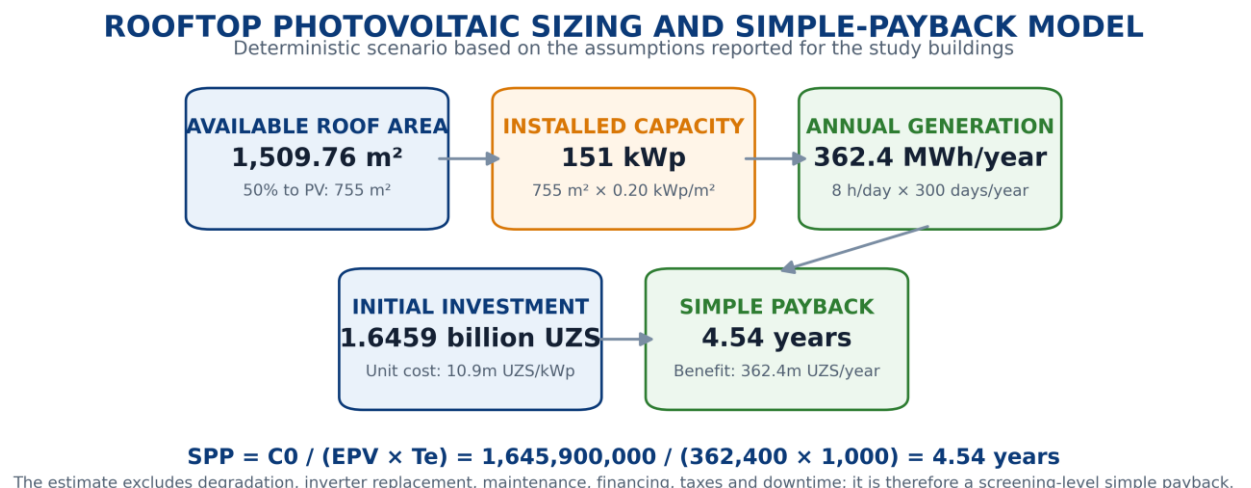


Figure 2. Deterministic sizing and simple-payback sequence for the 151 kWp rooftop photovoltaic scenario.

At constant annual benefit and without discounting or operating costs, cumulative cash flow changes from -1.6459 billion UZS at commissioning to 0.166

billion UZS at the end of year 5 and 5.602 billion UZS at the end of year 20. The zero crossing occurs after 4.54 years (Figure 3). This corrected cash-flow representation avoids mixing cumulative profit, annual benefit and investment cost on incompatible axes.

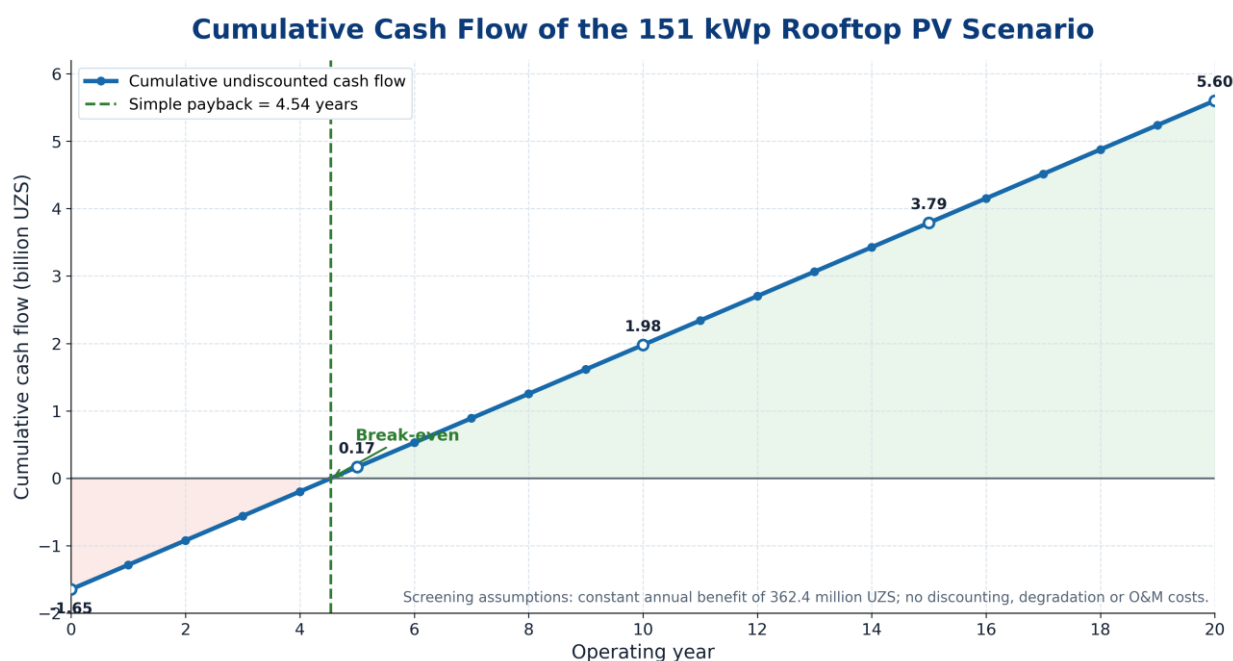


Figure 3. Cumulative undiscounted cash flow for the rooftop photovoltaic scenario over 20 years.

4. Discussion

The results support a two-layer resilience strategy. Envelope insulation acts on demand: it reduces heat transfer, lowers the fuel required to maintain indoor conditions and lengthens the time before indoor temperatures reach unsafe levels during a supply interruption. Rooftop photovoltaics act on supply diversification: they can support daytime electric loads and reduce dependence on centrally generated electricity. The two measures are therefore complementary rather than interchangeable. International renovation guidance likewise recommends combining passive envelope improvement with efficient systems and renewable supply [3].

The 41.5% thermal-energy reduction is material and is consistent with the large saving potential reported for Uzbekistan's older building stock [1, 2]. The selected

60 mm insulation thickness also falls within the 3.75-11.0 cm financially favourable interval obtained for common wall configurations in Tashkent [4]. However, similarity of thickness does not replace project-specific verification. Wall composition, orientation, thermal bridges, moisture risk, workmanship and actual indoor-temperature schedules may shift both the achieved saving and the optimum thickness.

The economic conclusions must be read against their tariff dates and boundaries. The 650 UZS/m³ natural-gas value is a 2024 baseline tariff under Resolution No. 204 [11], not a permanent real price. The 1,000 UZS/kWh photovoltaic benefit originates in the 'Solar Home' policy for qualifying surplus electricity [5]. A building that self-consumes most of its production, exports only a fraction, or faces a different tariff will have a different annual benefit. The IEA roadmap for Uzbekistan also emphasises that solar deployment depends on appropriate regulation, grid integration, finance and data, not only on resource availability [6].

The photovoltaic yield assumption is intentionally retained from the source calculation so that its arithmetic can be audited. Yet eight equivalent full-load hours for 300 days gives 2,400 kWh/kWp-year, which should be validated with a location-specific irradiance series, module plane-of-array geometry, temperature losses, soiling, shading, inverter efficiency and availability. Before procurement, the scenario should be recalculated with hourly meteorological data and a recognised PV performance model. Sensitivity cases should cover lower annual yield, capital-cost variation, degradation and inverter replacement.

The study has four principal limitations. First, the annual building-energy values are inherited from the underlying calculation rather than independently reconstructed from complete geometry, U-values, infiltration and weather data. Second, the gas-saving value is not derived in this article from boiler efficiency and fuel calorific value. Third, the envelope cost is material-only and cannot establish a

full project payback. Fourth, the PV analysis is a simple-payback screen rather than a discounted life-cycle model. These limitations do not invalidate the comparative result, but they define the next stage of research: calibrated hourly simulation, on-site monitoring, complete bills of quantities and discounted cash-flow analysis under several tariff and emergency scenarios.

5. Conclusion

A transparent recalculation confirms that upgrading the assessed external walls to level-2 thermal protection reduces annual thermal-energy demand from 1,665,771 to 974,525 kWh, a 41.5% saving. The associated natural-gas saving of 364,453 m³/year is worth 236.894 million UZS/year at the specified 2024 baseline tariff. The 278.32 million UZS insulation figure is a material-cost boundary and yields only a lower-bound 1.18-year payback; a complete installed-cost estimate is required before an investment decision.

For the rooftop scenario, 755 m² supports 151 kWp at the assumed packing density. The source solar assumption produces 362.4 MWh/year, and the resulting screening-level simple payback is 4.54 years at 1,000 UZS/kWh and a capital cost of 1.6459 billion UZS. Because the calculation excludes losses, degradation, maintenance, replacement and discounting, the value should be treated as an optimistic benchmark to be tested by detailed modelling.

The principal practical conclusion is that thermal protection and distributed solar should be designed as a coordinated resilience package. Insulation permanently lowers heating demand and moderates indoor-temperature decline during fuel or heat-supply disruptions; photovoltaics diversify daytime electricity supply and can reduce net grid demand. Their combined use offers a technically coherent route to lower operating cost, reduced greenhouse-gas emissions and improved continuity of essential residential services under emergency conditions.

REFERENCES

1. World Bank Group. Uzbekistan: Scaling Up Energy Efficiency in Buildings: Short-to-Medium-Term Priorities and Recommended Actions. Report No. ACS19957. Washington, DC: World Bank; 2016. Available at: <https://hdl.handle.net/10986/25093>
2. Kenisarin M., Kenisarina K. Energy saving potential in the residential sector of Uzbekistan. Energy. 2007;32:1319-1325. <https://doi.org/10.1016/j.energy.2006.09.014>
3. International Energy Agency. Renovation of near 20% of existing building stock to zero-carbon-ready by 2030 is ambitious but necessary. Paris: IEA; 2022. Available at: <https://www.iea.org/reports/renovation-of-near-20-of-existing-building-stock-to-zero-carbon-ready-by-2030-is-ambitious-but-necessary>
4. Axaopoulos P.J., Fylladitakis E.D., Shabdurakhmanovich S.A., Ogli A.N.A. Financially optimum insulation thickness of external building walls. AIP Conference Proceedings. 2019;2190:020034. <https://doi.org/10.1063/1.5138520>
5. President of the Republic of Uzbekistan. On Measures to Accelerate the Introduction of Renewable Energy Sources and Energy-Saving Technologies in 2023. Resolution No. PQ-57 of 16 February 2023. Tashkent; 2023. Available at: <https://lex.uz/uz/docs/-6385716>
6. International Energy Agency. Solar Energy Policy in Uzbekistan: A Roadmap. Paris: IEA; 2022. Available at: <https://www.iea.org/reports/solar-energy-policy-in-uzbekistan-a-roadmap>
7. International Organization for Standardization. ISO 52016-1:2017. Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures. Geneva: ISO; 2017.
8. ShNQ 2.01.04-18. Qurilish issiqlik texnikasi [Building thermal engineering]. Tashkent: Ministry of Construction of the Republic of Uzbekistan; 2018.

9. ShNQ 2.01.18-24. Binolar va inshootlarni isitish, shamollatish va konditsiyalashtirish uchun energiya sarfi normalari [Energy-consumption norms for heating, ventilation and air conditioning of buildings and structures]. Tashkent: Ministry of Construction and Housing and Communal Services of the Republic of Uzbekistan; 2024.

10. Intergovernmental Panel on Climate Change. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2: Energy. Hayama: Institute for Global Environmental Strategies; 2006. Available at: <https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html>

11. Cabinet of Ministers of the Republic of Uzbekistan. On Additional Measures to Introduce Market Mechanisms in the Fuel and Energy Sector. Resolution No. 204 of 16 April 2024. Tashkent; 2024. Available at: <https://lex.uz/uz/docs/-6884060>

12. World Bank. Clean Energy for Buildings in Uzbekistan Project (P176060): Project Appraisal Document. Washington, DC: World Bank; 2022. Available at: <https://projects.worldbank.org/en/projects-operations/project-detail/P176060>

13. Rashidov, S., Khotamov, A., Kholbekov, S., Abdikhalilov, F., & Oltiyev, U. (2026, May). The use of artificial intelligence (AI) systems in evaluating the technical condition of buildings and structures. In *AIP Conference Proceedings* (Vol. 3447, No. 1, p. 070014). AIP Publishing LLC.