

ASSESSMENT OF ENERGY EFFICIENCY OF EXISTING MULTI-APARTMENT RESIDENTIAL BUILDINGS USING THERMAL IMAGING AND HEAT BALANCE ANALYSIS (CASE STUDY OF FERGANA CITY)

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Abstract: Improving the energy efficiency of existing residential buildings is one of the key challenges in regions with continental climates. This study assesses the current energy performance of typical multi-apartment buildings in Fergana City, Uzbekistan, using non-destructive thermal diagnostics and heat balance calculations. Thermal imaging surveys, air velocity measurements, and indoor microclimate monitoring were conducted to identify heat loss zones and evaluate the thermal resistance of building envelope elements. Two representative buildings—a four-story large-panel reinforced concrete building and a two-story brick building—were analyzed. The calculated thermal resistance values of external walls, windows, roofs, doors, and basement slabs were compared with regulatory requirements. The results indicate that all major envelope components significantly deviate from normative values, leading to excessive heat losses and high specific heat consumption (83.7 W/m^2), which exceeds the standard by 46.8%. The investigated panel building was classified as energy efficiency class G. The findings highlight the urgent need for thermal modernization measures, including insulation upgrades and airtightness improvements, to reduce energy consumption and enhance indoor thermal comfort.

Keywords: energy efficiency, thermal imaging, residential buildings, heat loss, thermal resistance, building envelope

1. Introduction

The energy efficiency of residential buildings plays a crucial role in reducing energy consumption, greenhouse gas emissions, and operational costs while ensuring acceptable indoor thermal comfort. In many post-Soviet cities, a large share of the housing stock consists of buildings constructed between the 1950s and 1980s, which were designed according to outdated thermal standards and are characterized by high heat losses.

In Uzbekistan, particularly in regions with hot summers and cold winters such as Fergana, insufficient thermal insulation of building envelopes leads to increased heating demand during the cold season. Despite the availability of technical solutions for improving energy efficiency, their implementation in existing buildings remains limited due to economic constraints and insufficient diagnostics.

Thermal imaging is a non-contact, non-destructive diagnostic method that allows the visualization of surface temperature distributions and identification of heat loss zones, thermal bridges, and insulation defects. When combined with analytical heat balance calculations, it provides a reliable basis for evaluating the actual energy performance of buildings.

This study aims to assess the current energy efficiency of typical multi-apartment residential buildings in Fergana City using thermal imaging surveys and regulatory-based heat loss calculations, and to determine their compliance with modern thermal protection requirements.

2. Materials and Methods

2.1. Case Study Buildings

Two representative residential buildings commonly found in Fergana City were selected for the study:

- A **four-story large-panel reinforced concrete building** (series 1-464a, built in 1973, total area 1827.2 m²);
- A **two-story brick building** (series 1-204, built in 1957, total area 808.4 m²).

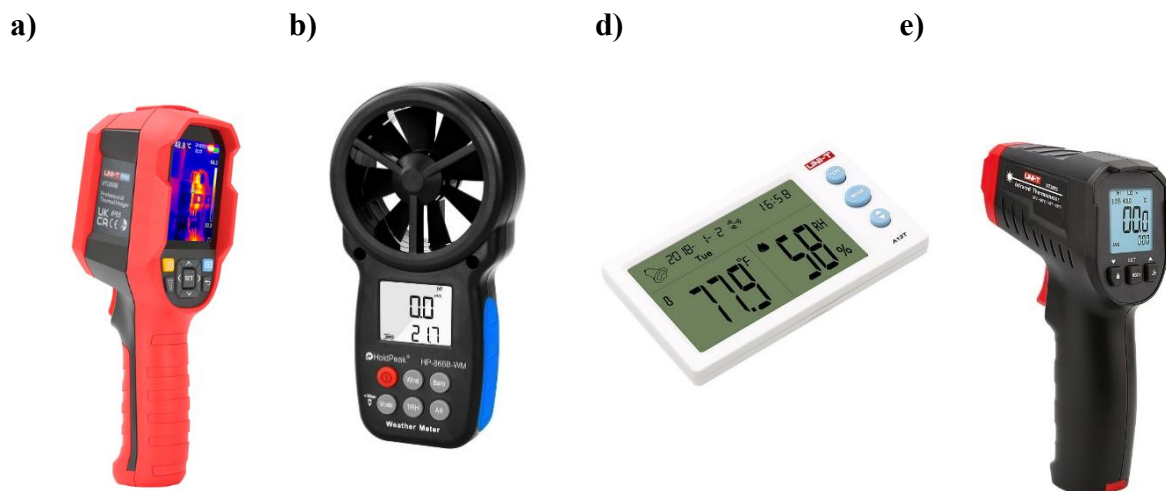
These buildings have been in operation for 52–68 years and are typical examples of the regional housing stock.

2.2. Measurement Equipment

The following instruments were used during field investigations:

- **UNI-T UTi260B thermal imager** (temperature range –15 to +550 °C, resolution 320 × 240 pixels);
- **HoldPEAK HP-866B anemometer** for air velocity and temperature measurements (0.3–30 m/s);
- **UNI-T A13T digital thermohygrometer** for indoor and outdoor air temperature and humidity;
- **UNI-T UT306S infrared pyrometer** for spot temperature measurements.

All measurements were conducted under stable winter conditions to ensure reliable thermal



1-Figure. Instruments used during the study.

a) UNI-T UTi260B thermal imager; b) HoldPEAK HP-866B anemometer; d) UNI-T A13T thermohygrometer; e) UNI-T UT306S pyrometer.

diagnostics.

2.3. Thermal Imaging Survey

Thermal imaging inspections were carried out on external walls, windows, doors, roof-wall junctions, panel joints, and basement zones. The surveys were performed in February 2024 under the following conditions:

- Indoor air temperature: +20.7 to +22.0 °C;
- Outdoor air temperature: +1.0 to +2.0 °C;
- Wind speed: 0.0–1.1 m/s.

Thermal images were analyzed to identify areas of increased heat loss and thermal bridges.

2.4. Heat Loss and Thermal Resistance Calculations

The heat balance of the buildings during the heating season was calculated according to national thermal engineering standards. Total heat loss was determined as the sum of heat losses through building envelope structures and ventilation, minus internal heat gains.

Thermal resistance (R_0) values were calculated for:

- External walls;
- Windows;
- Doors;
- Roof;
- Basement slab.

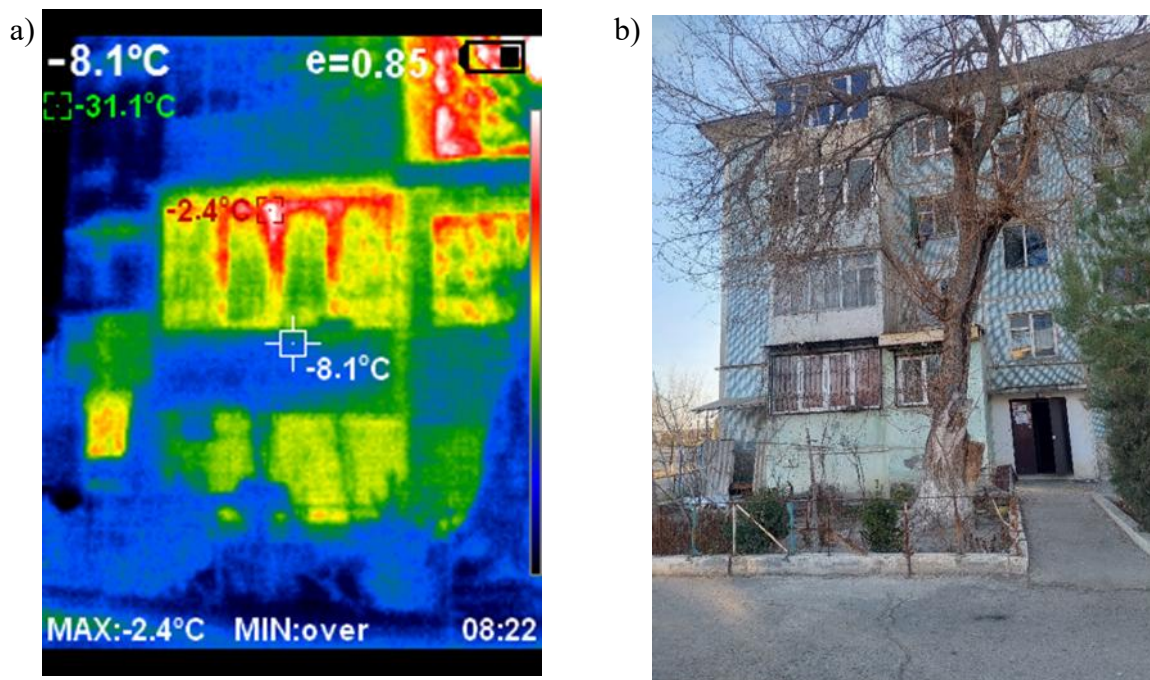
The obtained values were compared with normative thermal resistance requirements corresponding to the climatic conditions of the region.

3. Results

3.1. Thermal Imaging Analysis

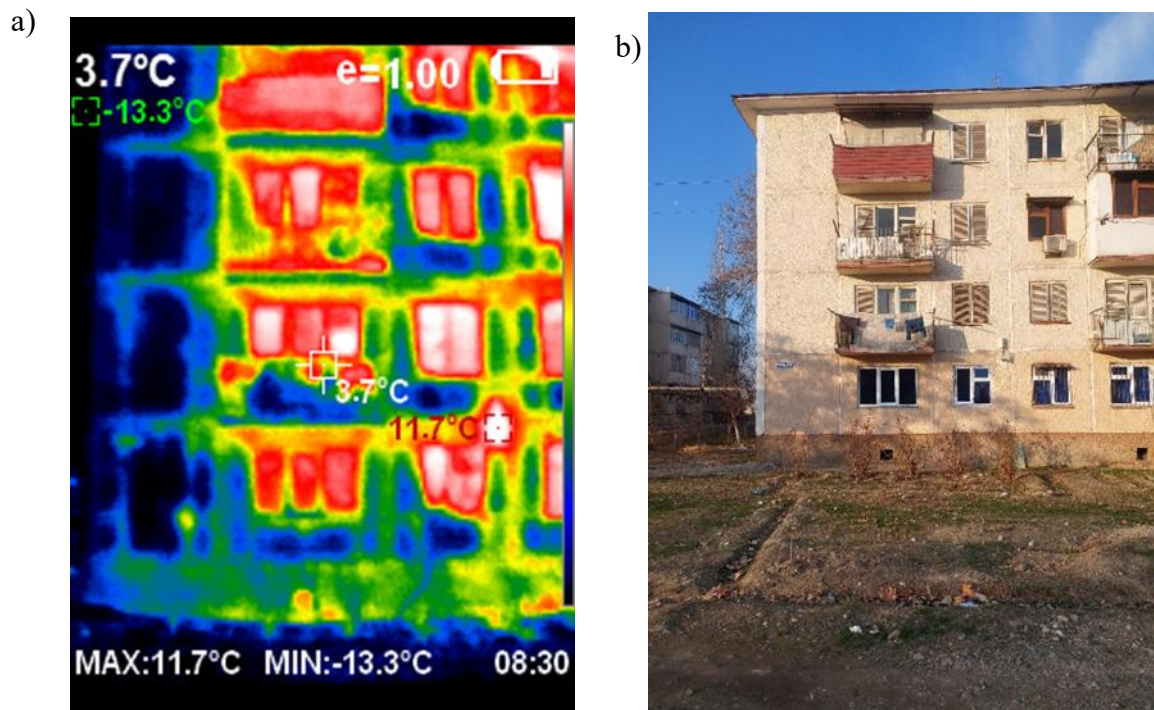
Thermal images of the panel building revealed significant heat losses at:

- Horizontal and vertical panel joints;
- Window and door perimeters;
- Roof-to-wall junctions;
- Basement and ground-floor connection zones.



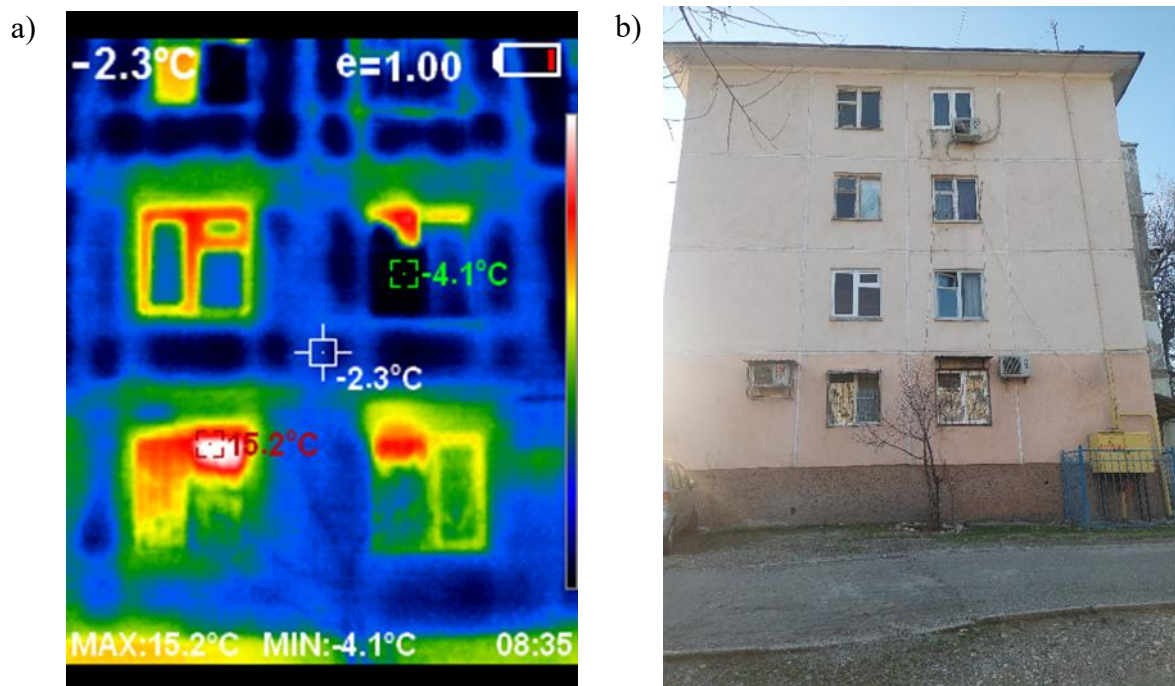
2-Figure. Image of the building's entrance (northwest corner).

a) Thermal image, b) Photograph.



3-Figure. Image of the building's front (northeast corner).

a) Thermal image, b) Photograph.



4-Figure. Image of the building's side (southern side).

a) Thermal image, b) Photograph.

Cooler zones (blue and light blue colors) indicated areas with relatively adequate insulation, while warmer zones (yellow, orange, and red colors) corresponded to intensive heat losses. Reinforced concrete ribs and connectors acted as pronounced thermal bridges.

In the brick building, thermal imaging showed:

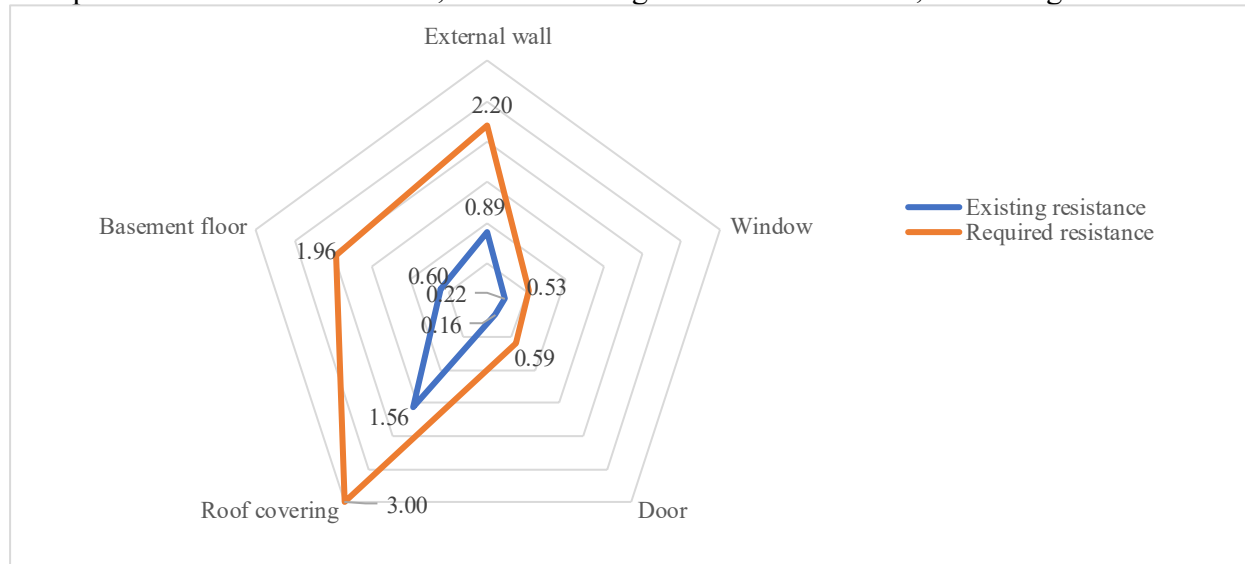
- Large temperature variations between apartments;
- High heat losses around window perimeters;
- Increased surface temperatures near radiators;
- Significant heat loss at junctions between brick masonry and reinforced concrete floor slabs.

3.2. Thermal Resistance of Building Envelopes

Calculated thermal resistance values for the panel building were:

No.	Construction element	R_o , $m^2 \cdot ^\circ C/W$	$R_o(norm)$, $m^2 \cdot ^\circ C/W$	Deviation from standard	Deviation from standard, %
1	External wall	0.89	2.20	-1.31	-59.55
2	Window	0.22	0.53	-0.31	-58.49
3	Door	0.16	0.59	-0.43	-72.88
4	Roof covering	1.56	3.00	-1.44	-48.00
5	Basement floor	0.60	1.96	-1.36	-69.39

Compared with normative values, deviations ranged from 48% to 73%, indicating insufficient



thermal protection of all envelope elements.

3.3. Heat Loss and Energy Performance

Total heat losses through building structures amounted to **131,866 W**, while ventilation losses reached **46,495 W**. Internal heat gains were estimated at **13,570 W**. As a result, the total heat loss during the heating period was **164,791 W**.

The specific heat consumption for heating and natural ventilation was calculated as **83.7 W/m²**, exceeding the regulatory limit of **57 W/m²** by **46.8%**. Accordingly, the building was classified as **energy efficiency class G**, which corresponds to very low energy performance.

4. Discussion

The results demonstrate that the primary causes of excessive heat losses in existing residential buildings are outdated envelope designs, insufficient insulation thickness, degraded window



and door airtightness, and the presence of multiple thermal bridges. Large-panel buildings are particularly vulnerable due to heat-conductive joints and reinforced concrete connectors. Thermal imaging proved to be an effective diagnostic tool for identifying critical heat loss zones and validating analytical calculations. The combination of field measurements and regulatory-based heat balance analysis provides a comprehensive assessment of actual building energy performance.

The findings confirm that without major thermal modernization measures—such as external wall insulation, replacement of inefficient windows and doors, roof insulation, and ventilation system improvement—significant reductions in energy consumption cannot be achieved.

5. Conclusions

This study evaluated the energy efficiency of typical multi-apartment residential buildings in Fergana City using thermal imaging diagnostics and heat balance calculations. The main conclusions are as follows:

1. Thermal imaging revealed significant heat losses at panel joints, window and door perimeters, roof-wall connections, and basement zones.
2. The calculated thermal resistance of all building envelope components was substantially below normative requirements.
3. The specific heat consumption of the investigated panel building exceeded the standard value by 46.8%, resulting in energy efficiency class G.
4. Existing buildings require comprehensive thermal modernization to reduce heat losses, improve indoor comfort, and enhance overall energy efficiency.

The proposed methodology can be effectively applied for energy audits of residential buildings and for developing targeted energy-saving renovation strategies.

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