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Analysis of Measurement Devices for Detecting Heat Loss in Existing Residential Buildings

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Abstract: This article analyzes modern measurement instruments used to identify heat losses in existing residential buildings. It is shown that heat losses in buildings primarily occur through external structures, such as walls, roofs, windows, doors, and balcony slabs. The study compares the technical specifications, advantages, and limitations of three types of infrared thermographic cameras: Bosch GTC400, UNI-T UTi120S, and UNI-T UTi320E. These devices were tested in practical experiments, particularly in a four-story reinforced concrete panel building, and their effectiveness was evaluated. The results indicate that the UTi320E, with its high accuracy, is the most effective for precise detection of heat losses. While the Bosch GTC400 provided sufficient results for medium-sized objects, the UTi120S proved suitable mainly for small objects and rapid inspections. Based on the research findings, criteria for device selection were developed, and practical recommendations for reducing heat losses were provided. This article is of practical significance for construction specialists, energy organizations, and scientific researchers.

Keywords: Energy efficiency, heat losses, thermographic camera, infrared camera, building diagnostics, energy audit, thermography, thermal insulation, residential buildings, practical testing.

Introduction. Today, the limited availability of energy resources, their steadily increasing prices, and the negative consequences of climate change are considered among the most pressing global issues. Therefore, the rational use and conservation of energy are priority areas for many countries, including Uzbekistan. In particular, buildings represent one of the largest sectors of energy consumption: according to various sources, they account for 35–40% of total energy use. A significant portion of energy in buildings is consumed by heating, cooling, and ventilation systems. Consequently, identifying and reducing heat losses plays a crucial role in improving the overall energy efficiency of buildings [1].

Heat losses occur through the external structures of buildings, such as roofs, walls, windows, doors, balconies, and other elements [2]. The thermal insulation properties of these structures degrade over time due to various factors, including construction defects, operational conditions, weather effects, and material aging. As a result, the building‘s heat loss rate increases, the internal microclimate deteriorates, and energy consumption rises. Therefore, assessing the thermal retention characteristics of existing buildings and identifying the sources of heat loss are essential preliminary steps in their modernization, repair, or reconstruction.

The primary challenge in determining heat flux from buildings is to measure it reliably and accurately [3]. This process, known as energy technical auditing, is performed using specialized measurement devices. These instruments enable the detection of energy-losing zones by recording heat flux density, surface temperature, or infrared radiation. Currently, a variety of modern devices based on different technological principles are available, among which infrared thermographic cameras are the most widely used. Thermographic cameras allow remote temperature measurements and highly accurate detection of temperature differences between surfaces [4]. Therefore, they are used not only to detect heat losses in construction but also to identify overheating in electrical systems, malfunctions in water pipelines, and thermal inefficiencies in ventilation systems.

In Uzbekistan, most existing residential buildings were constructed primarily between the 1970s and 1990s, and the majority of them are now outdated in terms of current energy efficiency requirements [5]. Their level of thermal protection is low, insulation is either deteriorated or completely absent. Therefore, assessing the thermal performance of these buildings, identifying sources of heat loss, and developing measures to mitigate them are pressing issues. The use of modern measurement instruments in this process allows obtaining results quickly, accurately, and reliably. However, the wide variety of measurement devices available on the construction market differs in terms of technical specifications, accuracy, cost, and scope of application. Hence, a scientific analysis is necessary to select the most appropriate device [6].

From this perspective, the present article analyzes measurement devices used to detect heat losses in existing residential buildings. The main objective of the study is to comparatively evaluate the technical capabilities, advantages, and limitations of three widely used thermographic cameras in the construction market: Bosch GTC400, UNI-T UTi120S, and UNI-T UTi320E, and to determine which types of buildings each device is most suitable for. The results of this analysis are of practical significance not only for research institutions but also for construction companies, energy providers, and municipal housing service organizations. Using properly selected measurement devices makes it possible to identify sources of heat loss, determine energy-saving opportunities in buildings, and develop modernization plans.

Comparison of Technical Specifications of Devices. The study conducted an in-depth analysis of the technical characteristics, operating principles, and functional capabilities of three selected infrared thermographic cameras: Bosch GTC400, UNI-T UTi120S, and UNI-T UTi320E. These devices are currently among the most widely used portable thermographic cameras in construction for detecting heat losses, performing energy audits, and conducting technical diagnostics [7].

Infrared thermographic cameras capture the heat radiation emitted from an object and visualize it in the form of thermograms. When selecting a thermographic camera, the most important technical parameters are as follows:

- **Detector size (image resolution):** The greater the number of pixels, the more detailed the image [8]. High resolution (e.g., 320×240 pixels) allows detecting small temperature differences, subtle heat spots, and cracks. Conversely, low-resolution cameras (120×90 pixels) display only significant temperature differences. Differences in this parameter determine the suitability of the device for large or small objects.
- **Thermal sensitivity (NETD – Noise Equivalent Temperature Difference):** This parameter indicates the device’s ability to detect minimal temperature differences [9]. For example, a NETD ≤ 0.05 °C means the camera is highly sensitive and can accurately detect temperature differences as small as 0.1 °C. This is particularly important in winter for identifying minor heat leakage zones between external walls and interior spaces.
- **Temperature range:** This indicates the minimum and maximum measurable temperatures of the device. In construction, a range from –20 °C to +150 °C is usually sufficient, while models with ranges up to +400…+550 °C are used for analyzing electrical equipment.

- **Accuracy:** This parameter shows how close the device's readings are to the actual temperature. ±2% accuracy is considered excellent for thermographic cameras. Devices with ±3 °C or ±3% accuracy are adequate for large-scale objects, but errors may occur in detailed analyses.
- **Ease of use:** The weight, ergonomic design, interface, and screen size of the device directly affect operational speed and efficiency. Lightweight cameras with user-friendly interfaces allow prolonged fieldwork.
- **Data storage and transfer capabilities:** Availability of SD card, USB connectivity, and Wi-Fi module facilitates post-processing of results. Construction sites often require capturing large volumes of thermograms, making memory capacity and export options crucial.

Comparison table of technical indicators of devices.

Parameters	Bosch GTC400	UNI-T UTi120S	UNI-T UTi320E
Detector resolution	160 × 120 pixels	120 × 90 pixels	320 × 240 pixels
NETD (Thermal sensitivity)	≤ 0.1 °C	≤ 0.1 °C	≤ 0.05 °C
Temperature range	–10 °C…+400 °C	–20 °C… +400 °C	–20 °C…+550 °C
Accuracy	±3 °C or ±3 %	±2 %	±2 %
Data storage	SD card	USB	SD card + USB
Portability (weight)	0.55 kg	0.35 kg	0.62 kg
Display size	3.5″	2.4″	3.5″
Price (approx.)	~$2,292.4	~$240.7	~$963.9

As can be seen from the table, the Bosch GTC400 device demonstrates mid-level technical specifications, yet it features a user-friendly interface and is well-suited for construction diagnostics [10]. This device provides sufficient accuracy for medium-sized objects, but it may face difficulties in detecting small temperature differences.

Scoring System Based Rating. Each device was rated on a scale from 1 to 5 based on technical specifications, ease of use, cost-effectiveness, and application areas. The evaluation was weighted as follows:

- Technical accuracy (detector, NETD, precision) — 40%
- Convenience (portability, interface) — 25%
- Cost-effectiveness (price) — 20%
- Application area (building size) — 15%

Device Rating Based on Weighted Criteria

Device	Technical Accuracy (40%)	Convenience (25%)	Cost-effectiveness (20%)	Application Area (15%)	Total Score (100%)
Bosch GTC400	3.5 (14)	4 (10)	2 (4)	4 (6)	34
UNI-T UTi120S	2 (8)	4.5 (11.25)	5 (10)	2 (3)	32.25
UNI-T UTi320E	5 (20)	3.5 (8.75)	4 (8)	5 (7.5)	44.25

Overall Ranking Based on Scores:

1st place – UNI-T UTi320E (44.25 points) 2nd place – Bosch GTC400 (34 points)

3rd place – UNI-T UTi120S (32.25 points)

These results indicate that the UNI-T UTi320E offers the highest technical capabilities and is suitable for large objects, the Bosch GTC400 is optimal for medium-sized objects, and the UNI-T UTi120S represents a budget-friendly choice for small objects [13].

Practical Testing Results. As the final stage of the study, practical thermographic tests were conducted on a four-story residential building with reinforced concrete panel exterior walls. The primary purpose of these tests was to evaluate the building's thermal insulation characteristics, identify the main sources of heat loss, and compare the results obtained using different thermographic cameras to assess their effectiveness.

The test building was fully operational, with four apartments on each floor. The exterior walls were made of 30 cm thick reinforced concrete panels, the facade covering was aged, and small cracks were observed in some areas. On the day of testing, the outdoor temperature was –8 °C, while the indoor temperature averaged +18 °C. These conditions provided a sufficient environment for evaluating the thermal conductivity of the walls.

The tests were conducted in the evening, when solar radiation was minimal. Each section of the walls, window perimeters, balcony slabs, and roof areas was examined separately. Prior to thermographic imaging, all apartment doors and windows were kept closed for at least two hours to maintain a stable indoor temperature, ensuring a more consistent heat flow [14].

During the tests, three types of thermographic cameras—Bosch GTC400, UNI-T UTi120S, and UNI-T UTi320E—were used sequentially under identical conditions. Using each device, the same points on the building façade were imaged at 1-meter intervals along parallel trajectories. The thermographic images were saved in JPG format and subsequently analyzed using specialized software.

Images obtained with the Bosch GTC400 showed general zones of heat loss, but their boundaries were relatively blurred, making it difficult to distinguish precise thermal bridges.

Due to its low resolution, the UNI-T UTi120S only highlighted the largest heat loss areas, and small temperature differences were not detected.

The UNI-T UTi320E provided the most precise images: temperature differences of 0.1–0.2 °C were recorded at joints, window frames, balcony slabs, roof covering, and even small cracks in walls.

Analysis of the thermograms revealed the main sources of heat loss on the building façades as follows:

Joints of exterior wall panels: Temperature was 3–4 °C lower than the surrounding wall surface, indicating that these zones acted as thermal bridges and that insulation was insufficient [15].

Perimeters of window frames: Especially in older wooden frames, temperature differences of 4–6 °C were observed, with evidence of air infiltration.

Balcony slabs and their junctions with walls: Heat loss was detected, with temperatures 2–3 °C lower than adjacent wall surfaces.

Lower part of the roof structure: Heat loss signs were observed at the ceiling of the fourth floor, indicating insufficient thermal insulation of the roof [16].

Additionally, some interior wall surfaces showed condensation traces, which may be associated with poor thermal insulation.

These practical tests allowed for the evaluation of the cameras' technical capabilities under real conditions. The results showed:

- The UNI-T UTi320E demonstrated the highest accuracy, detecting even small temperature differences and fully identifying thermal bridges. It was considered the most suitable option for large objects, particularly four-story buildings.

➢ The Bosch GTC400 provided medium-level results, showing general heat loss zones but with difficulty in precisely delineating them.

➢ The UNI-T UTi120S exhibited the lowest performance, only highlighting major heat loss zones and failing to detect minor thermal bridges.

The conducted practical tests indicated that high-resolution and highly sensitive thermographic cameras are essential for accurately identifying heat losses in construction objects. Especially during winter conditions, with outdoor temperatures at –8 °C and indoor temperatures at +18 °C, heat flows intensify, and low-quality devices cannot adequately capture these differences. Therefore, the practical tests provided scientific support for the study results and served as an important basis for the next stage—developing recommendations for thermal insulation [17].

Individual Analysis of Devices. Within the scope of the study, three types of thermographic cameras—Bosch GTC400, UNI-T UTi120S, and UNI-T UTi320E—were tested under identical conditions on a four-story reinforced concrete panel residential building. The impact of technical differences between these devices on practical results was assessed through individual analysis. For each device, image quality, sensitivity, usability, measurement accuracy, and data processing capabilities were evaluated separately.

The Bosch GTC400 is a mid-range thermographic camera equipped with a 160×120 pixel detector. Practical tests showed that this device was sufficient for detecting general heat loss zones. Zones with temperatures 3–4 °C lower at joints were clearly recorded, but their boundaries appeared blurred, making it difficult to precisely delineate thermal bridges.

Although the device's sensitivity (NETD ≤0.1 °C) was sufficient to detect minor temperature differences, small temperature gradients in high-accuracy areas occasionally merged with background noise. The camera's interface was very user-friendly, with a 3.5″ touchscreen and an intuitive menu system, which expedited the testing process. Its weight (0.55 kg) was relatively light, allowing for extended fieldwork.

Fig.1 Thermographic camera Bosch GTC400.

However, the main limitation of the GTC400 is its measurement accuracy of ±3 °C. Under the test conditions (outdoor temperature –8 °C, indoor +18 °C), this error prevented some minor thermal bridges from being captured. Nevertheless, the device can be recommended as a convenient option for initial diagnostic energy audits.

The UNI-T UTi120S is the most affordable and compact model, with a 120×90 pixel resolution. During the tests, this device was only capable of showing major heat loss zones. For example, temperature differences of 4–6 °C around window perimeters or exposed balcony slabs were clearly visible, but 1–2 °C differences at wall joints were not detected at all.

Fig.2 Thermographic camera UNI-T UTi120S.

The camera's low-resolution detector significantly reduced the accuracy of the thermograms. As a result, wall cracks, micro thermal bridges, and areas with condensation risk were not identified. The NETD sensitivity was also low (≤0.1 °C), insufficient for high-precision measurements.

However, the UTi120S has advantages: very low weight (0.35 kg) and ease of use. The device is equipped with a simple interface, a 2.4″ screen, and can be connected to a computer via USB. It is designed not for large objects but for rapid inspection of small objects or individual elements.

Under test conditions, this device's technical limitations made it unsuitable for creating a complete heat loss map of a large object like a four-story building. Therefore, it is only recommended for preliminary inspections or small rooms.

The UNI-T UTi320E is the highest-class device in terms of technical capabilities. It is equipped with a 320×240 pixel detector and a NETD sensitivity of ≤0.05 °C. During the tests, it produced the clearest and most precise thermograms. Even zones with temperature differences as small as 0.1 °C were accurately displayed.

Fig.3 Thermographic camera UNI-T UTi320E.

For example, in wall panel joints, thermal bridge areas, and around window perimeters, temperature gradients were clearly visible. Heat leakage on the internal surfaces of the roof structure was also clearly recorded. The device's high accuracy and sensitivity were decisive factors in practical test analysis.

The UTi320E features a modern interface, a 3.5″ screen, and a multifunctional menu system. Although the device weighs 0.62 kg, its ergonomic handle allowed for extended use. Data can be easily transferred via SD card or USB, facilitating rapid analysis of large thermogram datasets.

The analysis showed that the UTi320E provides the most effective results for mapping heat losses in large objects, particularly four-story buildings. Its high accuracy, sensitivity, and stable performance make it the optimal choice for professional energy audits and construction diagnostics.

Individual analyses demonstrated significant differences in technical characteristics among the three devices. The UTi320E offers the highest accuracy and sensitivity, enabling the creation of complete heat maps in large buildings. The Bosch GTC400 is suitable as a mid-range device for preliminary assessments but has limited accuracy. The UTi120S is suitable only for small objects and rapid inspections, and it is insufficient for detecting heat losses in large buildings.

Thus, practical tests indicate that selecting a high-accuracy and sensitive thermographic camera is crucial for correctly assessing the energy efficiency of building structures.

Conclusions and Recommendations. This study was conducted on a four-story residential building with reinforced concrete panel exterior walls. Its primary aim was to identify heat losses from the building and to evaluate the effectiveness of various thermographic cameras used in the process. During the study, technical parameters were compared, practical tests were conducted, results were thoroughly analyzed, and individual assessments were made for each device. Based on the obtained data, the following conclusions and practical recommendations were formulated.

7.1. Key Scientific Conclusions.

1. Analysis and test results indicate that the key technical characteristics of thermographic cameras—accuracy, sensitivity (NETD), temperature range, and detector resolution—directly affect the quality of thermograms obtained under practical test conditions. The high-accuracy UTi320E clearly detected heat loss zones at wall joints, window perimeters, balcony slabs, and under-roof layers, whereas the low-resolution UTi120S failed to identify such fine zones. This confirms the necessity of thoroughly analyzing technical parameters when selecting a thermographic device.

2. Thermographic tests conducted on the four-story building façade revealed the most common heat loss zones. Specifically, joints of external wall panels, window frame perimeters, connections between balcony slabs and walls, and the lower part of the roof structure were identified as primary points of heat leakage. In these areas, temperatures were 2–6 °C lower than the surrounding surfaces, indicating insufficient thermal insulation.

3. Individual analyses showed that the UTi320E, with the highest accuracy and sensitivity, produced the most complete thermograms under practical conditions. The Bosch GTC400 was capable of indicating general heat loss zones but struggled with precise delineation. The UTi120S could only detect major temperature differences and was ineffective at identifying thermal bridges.

7.2. Practical Recommendations.

1. It is recommended to identify heat loss zones in reinforced concrete panel residential buildings using a thermographic camera prior to commissioning or before reconstruction projects. This approach enhances construction quality control, allows early detection of insulation defects, and reduces energy consumption during operation.

2. Devices with resolutions of 120×90 or 160×120 pixels are suitable only for small objects or rapid inspections. Such devices cannot accurately detect thermal bridges in large buildings,

which may lead to incorrect conclusions. Therefore, for large-scale projects, it is recommended to use high-resolution thermographic cameras.

3. Thermograms should be analyzed using specialized software rather than by visual inspection alone. This method improves accuracy and allows quantitative assessment of heat loss.

4. Proper execution of thermographic inspections and accurate analysis of results require trained specialists. Therefore, it is advisable to introduce practical courses on thermographic technology for students in construction and energy programs.

The study results demonstrate that applying thermographic technologies in reinforced concrete residential buildings is one of the most effective methods for improving energy efficiency and reducing heat losses. High-resolution and high-sensitivity devices allow precise identification of heat loss zones, quantitative assessment of temperature differences, and, ultimately, significant improvements in energy efficiency.

Thus, widespread adoption of thermographic technologies in construction, proper device selection, and professional application are essential components of modern energy-efficient building practices. This approach not only reduces energy consumption but also extends building service life and improves indoor microclimate quality.

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