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The role of thermography in the energy assessment of buildings

Rolul termografierii în evaluarea energetică a clădirilor

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Abstract. *Thermography is a method used for rapid and accurate diagnosis of the energy status of buildings, which can identify obvious problems, reduce uncertainties or identify anomalies (that could be neglected) before they cause serious problems. The present study addresses the thermography method for a building that was brought from efficiency class G to class C by optimizing the installation systems that provide space heating and cooling, as well as hot water for consumption. The thermography method identified the areas of the building envelope elements where energy leaks are recorded and proposed measures to reduce or even eliminate these losses so that the building can be classified in higher energy classes.*

Key words: energy losses, thermography, energy efficiency, measures, energy class

1. Introduction

The scenario proposed by ANRE regarding the evolution of electricity consumption in Romania compared to GDP (Gross Domestic Product), indicates [1]:

- for the period 2023-2028 - average annual growth of approximately 3.4% in the medium term;
- for the period 2028-2033 - an average annual growth of the economy of 2.4%.

Thus, it is estimated that gross domestic consumption will register in 2028 a minimum limit of 56.5 TWh and a maximum of 58.4 TWh, and in 2033 it will increase to 61.4 TWh for the minimum limit and to 63.5 TWh for the maximum limit [1].

According to the report by the Global Alliance for Buildings and Construction (GlobalABC), buildings are responsible for 37% of global CO_2 emissions.

Regarding buildings, the main sources of CO_2 emissions come from [2]:

- 10% of total emissions generated by the production and transport of construction materials;

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- 27% from the operation of installation systems that ensure the comfort of occupants (heating, cooling, lighting and hot water).

The difference between these percentages is due to the fact that installation systems are operated throughout the entire life of the building, therefore generating emissions over a long period of time compared to the construction phase, which has relatively short execution limits compared to the operating periods. Also, from the point of view of construction elements, insulation materials play an essential role in a building's contribution to energy consumption and the amount of CO2 emitted into the atmosphere. In this regard, a study conducted by Isover [3] shows that compared to Germany, which consumes 53% of total energy for heating and cooling, Romania records a consumption of 22.5% more for the same services (Figure 1).

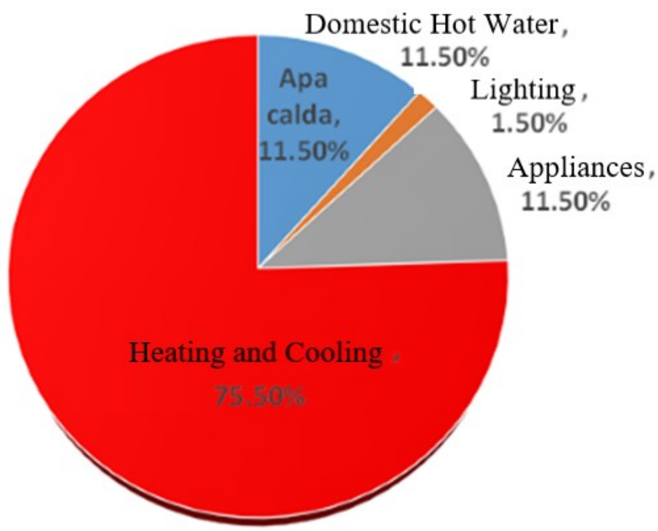


Fig. 1. Energy consumption in buildings in Romania by service categories [3]

Analyzing Figure 1, it could be said that making heating and/or cooling systems more efficient could solve the problems of buildings that fall into low energy efficiency classes, as was the building analyzed in this study. However, to achieve the increasingly severe requirements that are and will be imposed on buildings, these measures are not sufficient. In practice, both active and passive energy efficiency measures are necessary to achieve climate targets. On the other hand, to align with the "Energy Efficiency First" principle, new buildings must be powered almost entirely from renewable sources, while keeping the total primary energy consumption (from renewable and non-renewable sources) below the maximum limit values allowed depending on the type of building (new nZEB or existing), destination (individual/collective housing, offices, education, tourism, intended for the health system, commercial, for sports activities) and climate zone (I-V for Romania) [4], [5], [6].

The built environment being a critical sector for decarbonization action, achieving zero carbon emissions by 2050 puts huge global pressure on existing buildings, which in the EU, 75%, are still energy inefficient [7], [8].

So, the first energy efficiency measure that should be taken in the case of buildings is to rethink the thermal systems followed by the other types of installations. Also, in residential buildings, which are the largest energy consumers in the building sector (63%) [6], [9], the energy consumption required for the preparation of domestic hot water represents a quarter of the total energy consumption.

The technical process by which, in a building, the energy consumption for the service systems (heating, cooling, hot water preparation, lighting and ventilation) is determined in order to identify their efficiency is called energy assessment. After establishing the energy efficiency level of the building, the efficiency measures are established, which generally address the reduction of energy consumption while ensuring environmental comfort.

In the energy assessment, the same importance as that of the installation systems is the quantification of energy losses through the building envelope elements.

Practically, the energy audit of buildings is the scientific process by which the types and costs of energy exploitation in a building are determined.

Results provided by specialized literature show that over 50% of the total energy consumption of a building comes from cooling systems (usually air conditioners), with lighting having the smallest contribution, even if we are talking about lighting with fluorescent lamps [6], [10].

One way to assess both the energy status of the installation systems and the building envelope elements is thermography, for which an infrared thermal imaging camera is usually used.

The method, being a non-invasive method, is highly appreciated by evaluators.

In this context, the article proposes a thermographic evaluation of the building of the “Energy Conversion and Storage” laboratory within the Politehnica University of Timisoara, for which, through experimental studies carried out by some of the authors of this article, the building was classified from class G to class C [11], [12].

From the point of view of the installation systems, efficiency measures integrate the most modern and efficient solutions. The functional diagram of the existing system is presented in Figure 2.

On the other hand, from the point of view of the envelope elements, possible areas that can generate considerable energy losses have been identified.

The purpose of this study is to propose measures that will contribute to reducing the energy needs of the building, bringing the building into energy efficiency class A and perhaps even nZEB.

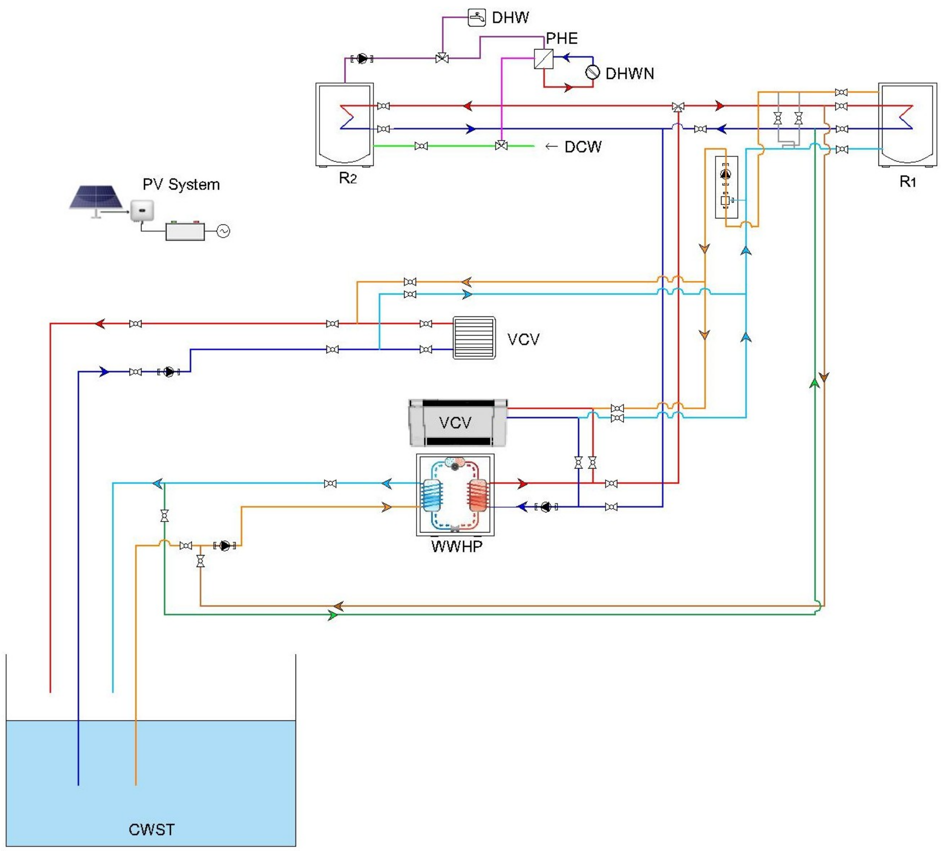


Fig. 2. Functional diagram of the system that ensures thermal and hygienic-sanitary comfort in the laboratory building

DHW – Domestic hot water (own consumption); DCW – Domestic cold water; DHWN – Domestic hot water network; R_1 – Thermal agent storage tank for heating or cooling; R_2 – Domestic hot water storage tank; VCV – Fan coils floor/ceiling unit; WWHP – Water-water heat pump; CWST - Cold Water Supply Tank, PV System – Photovoltaic Systems

2. Infrared thermography method of buildings. Principle, parameters and sources of error

Infrared (IR) thermal imaging cameras produce images of thermal patterns and are calibrated to measure the emissivity of surfaces in an area, at different temperature ranges [13].

The focusing of the radiation is achieved using a lens. The camera sensor detects the infrared radiation and converts it into electrical response signals that are digitally converted into colored pixels (images whose colors correspond to the temperature levels of the surface). The colors are established by mapping the intensity of the infrared radiation (temperature) onto a color palette (false color), established as follows: warm colors (white/yellow/red) allocated to high temperatures, and cool colors (blue/violet) for low temperatures. This conversion transforms the invisible radiation into visible images on the thermal imaging camera screen. With the help of the camera software, the thermographic images are analyzed and these differences are quantified. This technology makes it possible to visualize the surface temperature of objects, that is to say the effect of heat transfer by conduction from the interior to the surface, which makes it possible to evaluate the amount of radiated heat, which is associated with the estimation of the body's surface temperature.

An important parameter of thermal imaging cameras is the measurement accuracy which is dependent on: emissivity, ambient temperature, wind speed and distance from the target. Another advantage of this method is that measurements can be made at a distance from the object, although atmospheric conditions can affect the amount of energy detected as a result of absorption. Emissivity depends greatly on the material of the thermographed surface or their coating materials. In practice, reading is influenced by emissivity less than or equal to 0.5. Therefore, emissivity can introduce measurement errors if not corrected.

Another possible source of error is the loss of energy in the transmission of radiation from the object being measured to the detector. Particles that may be present in the atmosphere (water vapor, carbon dioxide molecules and large size ozone) will attenuate the radiation, as well as the scattering effects of dust particles and water droplets. This attenuation produces two main transmission bands, approximately 3-5 µm and 8-12 µm. Thermal imaging cameras are designed to respond to one or the other of the bands, thus being insensitive to absorption effects. For high-performance cameras, the 8-13 µm band is generally preferred due to its greater sensitivity to objects at ambient temperature and good transmission through smoke. Cameras that transmit in the 3-5 µm band are more suitable for hotter objects or if sensitivity is less important than contrast.

Air temperature influences the temperature of the thermal imaging camera, which can lead to erroneous measurements. For this reason, thermal imaging cameras have an internal compensation system that corrects this variation. At very high or very low temperatures, there is a risk that these equipment will lose their stability, and at high temperatures the thermal information may be transmitted erroneously, especially when working with reflective surfaces.

Measurements obtained by thermography can be influenced by wind. Thus, winds with a speed exceeding 5 m/s will increase heat transfer from the surface, and higher heat losses by convection can reduce the surface temperature. Therefore, outdoor inspections in windy conditions (above 5 m/s) should be avoided during measurements. Also, when identifying air leaks around openings, strong winds will make them easier to detect during the inspection of interior windows and doors.

Another factor that can disrupt the thermal imaging measurement process is the distance and the angle of visibility, factors that play an important role in the interpretation of the results. It is obvious that the resolution decreases with increasing distance between the object and the thermal imaging camera (each point on the thermographic image corresponds to a specific area of the surface of the thermographed object, so as the distance increases, each point on the image will have to represent a larger surface area of the object). Therefore, this is the explanation for the fact that some details are lost. On the other hand, orienting the camera at angles smaller than 90 degrees will obtain less information, but even for this type of orientation the images can still be distorted, depending on the surface material and its ability to radiate in different directions.

In conclusion, the images obtained are digital (visual) images that show that the hotter the object, the brighter it appears on the screen of the thermal imaging camera. In raw infrared radiation, a white color represents a hot area, while a dark color represents a cooler area. Thus, irregular thermographic patterns, called "thermal anomalies" (increases or decreases in surface temperature or retained residual heat) that indicate specific problems, can be easily identified. Therefore, the thermography method can be used either for building audits in order to establish renovation solutions or to assess the functional/defective state of equipment or installation systems. Compared to other types of methods, IR thermography is fast and accurate.

3. The role of thermography in the energy assessment of buildings

In the process of energy assessment of buildings, the thermography method is used to visualize and quantify temperature variations on the surfaces of building elements or services systems. The process is based on the detection of infrared radiation emitted by building elements (envelope and installation systems), which varies depending on temperature.

The use of the thermography method in the energy assessment of the building is a valuable tool for inspecting and performing inspections, considered very useful primarily because it is a non-destructive method. This method allows the detection of zones and mode where is transferred through the building envelope. The data collected allows to clarify the operating conditions of the installation systems (heating, ventilation, air conditioning, cold and hot water supply, electrical), service systems that are difficult to access being buried (in walls, screed, ceilings, etc.) or apparently being masked by various elements (plasterboard cladding, false ceilings, etc.). The information collected is used to identify and locate potential problems, quantify potential energy savings, schedule interventions and establish priorities for preventive and predictive maintenance or the need for immediate service to minimize the risk of failure.

4. Thermography of areas identified with suspected energy losses

4.1. Laboratory building description

The laboratory building, which is located in Timisoara, Romania, is constructed of Porotherm hollow brick with dimensions of 250 x 300 x 238 mm, and the interior cladding is made of 12.5 mm thick gypsum boards. The building is insulated on the outside with 5 cm polystyrene and is naturally ventilated. The roof of the building is a non-circulatory terrace with a slope of 3 degrees and is made of prefabricated sandwich panel sheets and polyurethane foam. An image of the building is shown in Figure 3.

Fig. 3. Laboratory building - Image

4.2. Potential energy loss areas

From the point of view of the envelope elements, the areas generating considerable losses are specified in Figure 4. Practically, the main areas with major energy losses (marked in red in the figure), which were investigated, refer to:

- the water tank from which the circulation pump for free cooling is powered and respectively the water-to-water heat pump that provides energy for heating and cooling the building as well as for hot water consumption;
- thermal bridges in the foundation area at the entry points of the power cables, but also in the roof and window areas;
- thermal energy losses through other entry gaps of various power cables or pipes for water supply.

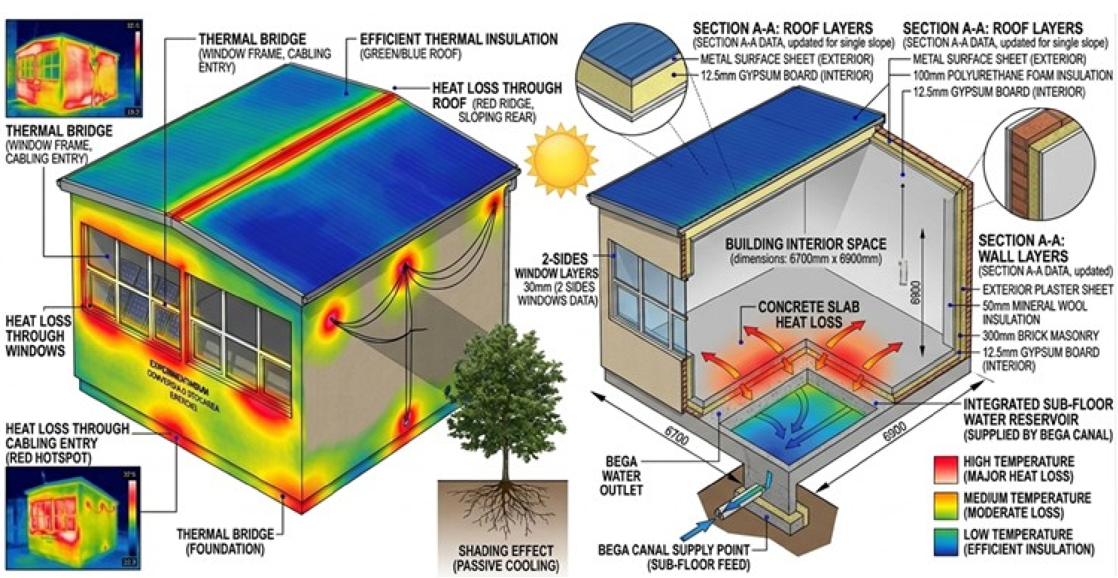
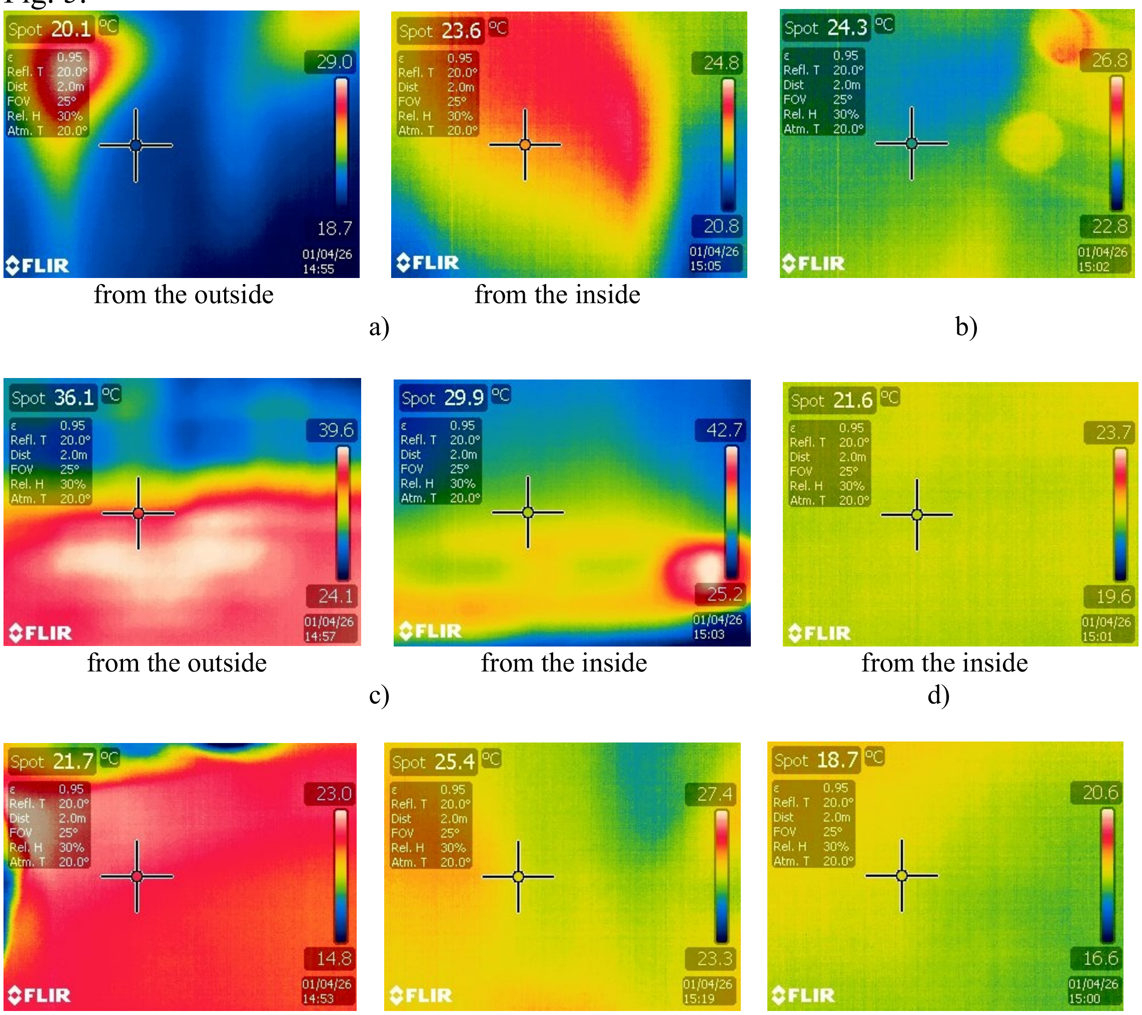


Fig. 4. Integrated thermographic analysis: Model

5. Results and Discussion

The results of thermography of areas with potential energy leaks are presented in Fig. 5.



from the outside from the inside

a) b)

from the outside from the inside from the inside

c) d)

power cables (outside) power cables (inside) from the outside

c) d)

Fig. 5. Energy leaks - thermography of the laboratory building

a) Heat leaks around door to the outside, b) Poor ceiling insulation, c) Heat leaks around windows, d) Heat leaks around cold water supply tank (CWST), e) Heat leaks around cable and pipe penetrations zones through walls f) Poor floor insulation

Thermal images were taken of the windows, door, ceiling, floor, the water tank and areas where cables and pipes pass through the walls in order to check for heat leaks, infiltrations and thermal bridges that cannot be seen with the naked eye. Analyzing the thermographic images, significant temperature differences (between inside and outside) are found in the analyzed areas.

To obtain the results, both exterior and interior thermography were performed because this combination offers complementary perspectives. Interior thermography was used to precisely identify air leaks and thermal bridges, while exterior thermography was used to verify the overall picture of potential energy losses (shown in Figure 4). It can be seen that results with greater accuracy and more detail are obtained with interior thermography.

For this reason, the following measures are proposed:

- insulating the floor or at least of the cold water supply tank (CWST) - on the contour;
- insulating the gaps for cable/pipe penetration through the envelope elements;
- restoring the door insulation in areas where it has heat leaks;
- solving thermal bridges around the windows - areas with the greatest losses.

4. Conclusions

The use of the thermography method of building elements is a valuable tool for inspecting and evaluating buildings, being useful primarily because it is a non-destructive method. For the "Energy Conversion and Storage" laboratory building, possible measures that can be taken to bring the building into a class higher than energy class C in which the building was evaluated after optimizing the installation systems that serve it were identified. Basically, passive measures were evaluated through which interventions that can be made to the building (walls, ceiling, floor, door, windows, water tank located under the foundation of the building - CWST) can contribute to reducing energy requirements. Thus, all these areas identified as having potential for energy transfer to the outside were thermographed. Following the evaluation of the thermographic images, insulation measures and, respectively, replacement of some elements were proposed, measures that the authors will address in future studies. The study conducted by the authors contributes to the identification of energy losses, to the establishment of opportunities for improving energy practices and to the implementation of all proposed measures that will contribute to the reduction of carbon emissions and can bring progress in cost-benefit applications for Politehnica University Timisoara. Therefore, awareness of the use of scientific tools for the study and analysis of energy performance is a current need for all types of energy users with applicability in all life stages of buildings.

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