17th International Conference on DEVELOPMENT AND APPLICATION SYSTEMS, Suceava, Romania, May 23-25, 2024

Monitoring energy losses of a residential building through thermographic assessments

Iavorschi Eugen
Faculty of Electrical Engineering and Computer Science, Department of Electrical Engineering
"Stefan cel Mare" University of Suceava
Suceava, Romania
eugen_iavorschi@yahoo.com

Milici Dan Laurențiu
Faculty of Electrical Engineering and Computer Science, Department of Electrical Engineering
"Stefan cel Mare" University of Suceava
Suceava, Romania
dam@usm.ro

Abstract— **One of the significant opportunities for reducing energy waste and carbon emissions is the renovation, modernization, and rehabilitation of existing buildings. Replacing the windows of existing residential buildings with new energy-efficient ones is an easy way to upgrade an existing home into a nearly zero-energy building, NZEB (nearly zero-energy building). There is a wide variety of methods to discover the thermal weak points of a building, and the continuous innovation of construction materials provides solutions to maximize energy savings and minimize heat transfer to the exterior. This document presents a methodology for visualizing and recording the temperature distribution on the investigated surface of the building envelope to identify and locate vulnerable points where heat losses to the exterior are substantial. The objective was to highlight the need for upgrading the insulation system and replacing the existing windows of the analyzed building based on a multi-objective approach to maximize the building's energy performance and increase thermal comfort indoors. Using a Fluke Ti300+ Thermal Camera, energy losses were visualized through thermographic assessments, which could provide an adequate picture for accurately assessing the building's condition before renovation, to evaluate the need for partial renovation. For the case study, a residential building with one floor and mansard roof located in a region with hot summers and cold winters in Romania was chosen. The results showed that there are several options for significantly reducing the building's energy consumption. Thus, multiple energy efficiency solutions were proposed for the building to reduce heat losses.**

Keywords— energy performance, energy losses, carbon emissions, thermographic assessment, residential building, heat transfer, nearly zero-energy buildings.

I. INTRODUCTION

In the European urban environment, housing in developed cities has significantly evolved over the past twenty years. A major change is that people, to an increasing extent, choose their homes based on personal preferences related to comfort, annual maintenance costs, and, recently, carbon emissions. While housing selection used to be limited to few options, housing in Europe has reached a historic moment where people are beginning to choose where and how they live [1]. In Romania, although this trend is still timid and sometimes awkward, housing selection is becoming increasingly important, significantly impacting how homes are designed. Even though budget remains the predominant factor preselecting residential options, alongside concepts of square meters and price per square meter, housing needs to start rearticulating around the current needs of families, as they are now delineated, and the impact our existence has on the surrounding environment.

Measures aimed at improving the energy performance of buildings should be adapted to local climate conditions, taking into account indoor climate as well, and assessing cost-effectiveness. It is important that these measures do not compromise other essential building requirements, such as accessibility, safety, and intended use.

Buildings have a long-term impact on energy consumption. Considering the prolonged period of building renovation, it is essential for both new buildings and existing ones undergoing significant renovations to meet minimum energy performance requirements adapted to the local climate. Given that the potential of alternative energy supply systems is not fully explored routinely, the integration of these systems for new buildings, regardless of their size, should be considered. This should be done in accordance with the principle of prioritizing the reduction of energy demand for heating and cooling.

II. LITERATURE REVIEW

A. The National Integrated Plan for Energy and Climate Change (PNIESC) for the period 2021-2030

According to information provided by the International Energy Agency, existing buildings contribute to 40% of total energy consumption in Europe [2]. Within this segment, buildings constructed between 1945 and 1990 represent 45% of the total buildings [3]. A large part of this energy demand is met through the use of fossil fuel materials, which will result in increased carbon dioxide emissions. Although the finite nature of fossil fuel resources is no longer at the center of attention due to its focus on climate protection aspects, in the medium and long term, energy resources will decrease. For this reason, energy saving and energy efficiency will become the main issue in maintaining our current standard of living.

The European Union has committed to leading the global energy transition by fulfilling the objectives set out in the Paris Agreement on climate change, which aims to provide clean energy throughout the European Union. To meet this commitment, the European Union has set energy and climate objectives for 2030 as follows:

- objective regarding reducing internal greenhouse gas emissions by at least 40% by 2030, compared to 1990;
- objective regarding a consumption of energy from renewable sources of 32% by 2030;
- objective regarding improving energy efficiency by 32.5% by 2030;

- the objective to interconnect the electricity market at a level of 15% by 2030.

In order to achieve these objectives, each member state was required to submit to the European Commission a Draft of the Integrated National Plan for Energy and Climate Change (PNIESC) for the period 2021-2030. The PNIESC projects establish the national objectives and contributions to achieving the EU objectives on climate change. Romania submitted its own PNIESC project in 2018, thus we have the Integrated National Plan for Energy and Climate Change 2021-2030 adopted in April 2020 [4]. On the other hand, the European Commission mentioned that Romania will need to propose a greater reduction in primary and final energy consumption by 2030 in order to achieve the Union's energy efficiency objective [4].

Romania targets a primary energy consumption of 32.3 Mtoe, respectively a final energy consumption of 25.7 Mtoe, thus achieving energy savings of 45.1%, compared to the primary consumption for the year 2030, and 40.4% for final energy consumption, compared to the reference scenario PRIMES 2007. Furthermore, in order to comply with the obligations provided for in Article 7 of Directive (EU) 2018/2002 amending Directive 2012/27/EU on energy efficiency, Romania must achieve a cumulative value of new energy savings equivalent to 10.12 Mtoe in the period 2021 - 2030 [4].

B. *Methodology for calculating the energy performance of buildings, designation Mc 001-2022*

Measures are needed to increase the number of buildings that not only meet but also exceed the current minimum requirements for energy performance, thereby reducing both energy consumption and carbon dioxide emissions. To this end, the Romanian Government through the Ministry of Public Works and Administration issued, on January 17, 2023, the order approving the technical regulation "Methodology for calculating the energy performance of buildings, designation Mc 001-2022"*) [5].

The subject of Regulation Mc 001- Methodology for calculating the energy performance of buildings is manifold and consists mainly of:

- evaluating and certifying the energy performance of buildings for various categories of new and existing buildings - single-family/multi-family residential buildings, office buildings, educational buildings, hospitals, daycare centers, polyclinics, hotels and restaurants, buildings for sports activities, wholesale and retail trade services, buildings with other purposes and human occupation where at least heating, hot water supply, and lighting are provided, as well as for building units in all these, including apartments;
- energy auditing of buildings to be energetically upgraded;
- establishing minimum performance requirements for existing buildings and new buildings with nearly zero energy consumption (NZEB);
- defining the measures and standard packages of measures that can be applied to increase the energy performance of existing buildings/building units and establishing the method for quantifying the costs associated with these measures;
- presenting the minimum energy performance requirements for residential and non-residential buildings, either renovated existing ones or for buildings with nearly zero energy consumption.

Scope of Application of Methodology Mc 001:

- assessment and certification of the energy performance of existing and new buildings/ building units, whose energy consumption is nearly equal to zero (NZEB);
- assessment and certification of the energy performance of apartments.
- thermal and energy analysis, as well as the preparation of the energy audit of existing buildings to be energetically modernized.

III. METHODOLOGY

A. *Methodology for thermographic determinations in constructions, indicative MP-037-04, approved by Order no. 711/13.04.2004.*

The process of monitoring energy losses in a residential building through thermographic assessments involves the use of thermal imaging technology to identify and analyze areas where heat transfer between the building and the external environment is more pronounced. This method provides valuable information about the thermal performance of the building envelope and helps identify areas that may require improvements to enhance energy efficiency.

The most commonly analyzed element of the building using this method is its thermal insulation because it has a significant impact on energy efficiency and, consequently, on energy costs. Efficient insulation can reduce building energy consumption by approximately 30-40%. Since the quality of insulation in building envelopes is essential for improving energy efficiency, owners strive to highlight the ecological characteristics of their buildings to increase their value. At the same time, potential buyers seek credible reports on the energy performance of the buildings they intend to purchase. In European countries and many others, providing an energy performance certificate is a common practice when selling a property [6].

The method of analyzing and monitoring energy losses in a building through thermographic assessments is detailed and regulated by the Ministry of Transport, Construction, and Tourism through the Methodology for Thermographic Determinations in Constructions, with the indicative code MP-037-04, approved by Order no. 711/13.04.2004. According to this regulation, thermography represents a qualitative method used for visualizing, recording, and representing the temperature distribution on the surface of the building envelope, through an infrared detection system [7].

B. *The physical principle of monitoring energy losses through thermographic assessments involves detecting infrared radiation emitted by objects.*

The inequalities in the thermal characteristics of a building envelope's components result in fluctuations in temperature across its surfaces. Surface temperature is also influenced by the insulation's moisture content and the airflow within and/or through the building envelope. Thus, knowing the temperature distribution across the envelope's surface allows for the assessment of the structure and the identification of thermal bridges through which heat loss occurs. Additionally, the temperature distribution on the surface can be used to detect thermal irregularities caused by insulation defects, moisture content, and/or air infiltration from the building envelope's closure elements.

During the design phase, construction elements have a well-defined structure, and the thermal parameters of the materials used are known. However, during the construction execution, geometric elements can undergo various modifications. Throughout the lifespan of the construction, due to climatic, temporal, and anthropogenic factors, construction elements may undergo changes such as deformations due to seismic activity, variations in thermal properties, and modifications caused by human factors (occupants).

Infrared thermography is a technique used to visualize the temperature distribution on the surface of objects (invisible to the naked eye) and to measure the values of these temperatures at any point in the image. Thermography makes heat "visible" and measurable. Infrared thermography allows temperature measurement from a distance and without direct contact, which is essential, for example, when visualizing heat losses from a residential building from the outside during the winter season. It is a non-destructive testing method, as it does not intervene or influence in any way the material, object, or process under investigation. It is an ultra-sensitive measuring technique, highlighting temperature variations of tens of degrees, both spatially (from one point to another in the image) and temporally.

C. Mathematical principle for monitoring energy losses

The mathematical calculation method for determining the energy losses of a structure (facade) [8] in a residential building involves establishing the thickness of the structure and the thermal properties of the materials used in its construction. The thermal properties of the materials were determined by the thermal transmittance, denoted as U (W/m2K), which indicates the rate of heat transfer through 1 m2 of structure divided by the temperature difference across that structure. The calculation was based on an approximation of thermal transfer in a state of equilibrium, which is an acceptable approximation for buildings in climatic conditions with low solar gains and minimal fluctuations in exterior temperature compared to the average temperature difference between interior and exterior. For simplification purposes, it was considered that the values of thermal transmittance U remain constant at a temperature of 25°C, thus excluding the effect of solar input on heat transmission through the structure. This parameter is defined by equation (1).

$$U = \frac{1}{R_t} \tag{1}$$

where it was noted:

U represents the thermal transmittance [W/m2K];

R_t is the total thermal resistance of the building element [m2K/W];

Considering that the wall of the studied building consisted of multiple layers of different materials, the total thermal resistance was calculated as the sum of the thermal resistance of each layer plus the surface thermal resistances of the indoor and outdoor air.

The effect of thermal bridges was taken into account by calculating the heat transfer through the transmission coefficient H_T, calculated according to equation (2).

$$H_T = \sum_i A_i U_i + \sum_i l_k \psi_k \tag{2}$$

where it was noted:

A represents the surface area of the wall under study [m2];

U represents the thermal transmittance of the analyzed wall [W/m2K];

l is the length of the thermal bridge [m];

ψ is the linear thermal transmittance of the thermal bridge [W/mK];

After calculating the heat transfer through the wall's transmission coefficient, the energy loss can be determined. The heat loss due to conduction through the envelope of a building, caused by the thermophysical properties of the construction materials, can be determined by equation (3).

$$Q = H_T \cdot (T_{int} - T_{ext}) \tag{3}$$

where it was noted:

Q the heat loss through the analyzed wall [W];

H_T heat transfer through the coefficient of transmission [W/K];

T_{int} şi T_{ext} are the indoor and outdoor temperatures [K];

The thermal transmittance of openings is calculated using knowledge about the materials composing these elements and their corresponding thermal transmittances, as well as the percentage of opening occupied by each material. The total thermal transmittance of the openings, U_H was calculated using equation (4).

$$U_H = (1 - FM) \cdot U_{H,v} + FM \cdot U_{H,m} \tag{4}$$

where it was noted:

U_H represents the total thermal transmittance of the opening [W/m2K];

$U_{H,v}$ is the thermal transmittance of the semitransparent surface [W/m2K];

$U_{H,m}$ is the thermal transmittance of the window frame [W/m2K];

FM represents the percentage of opening occupied by the frame [%];

In this case, evaluating the effect of any thermal bridge is not necessary, as it is possible to calculate directly the heat loss through openings using equation (5).

$$Q_H = U_H \cdot A \cdot (T_{int} - T_{ext}) \tag{5}$$

where it was noted:

Q_H represents the heat loss through the analyzed opening [W];

The heat losses can be calculated following the described protocol, which would reflect the energy loss under ideal facade conditions. However, reality shows the presence of thermal irregularities in building envelopes, directly affecting energy consumption. As a result, additional heat loss through the building envelope on critical surfaces was calculated using equations (2) and (3), but considering only the area of these irregular surfaces without the effect of thermal bridges and the temperature difference between the irregular surface and the intact wall. For simplification purposes, the increased heat loss through critical surfaces can be calculated using equation (6).

$$Q_C = U \cdot A_C \cdot (T_m \cdot T_c) \tag{6}$$

where it was noted:

Q_C represents the additional energy loss through critical surfaces [W] in addition to the heat loss as a function of the building's composition;

U is the total thermal transmittance of the wall [W/m2K];

A_C is the total critical surface area [m2];

T_m is the average temperature of the wall under normal conditions [K];

T_c is the average temperature of the critical surface in the wall [K];

The mathematical calculation method of energy losses for a structure refers to the process of evaluating and estimating the amount of energy lost through a building's structural element. This calculation model involves using mathematical formulas and methods to quantify heat losses through the analyzed element, taking into account various factors such as indoor and outdoor temperatures, thermal properties of building materials, dimensions, and structural characteristics of the element, as well as any other external influences that may affect heat transfer. It is an essential method for assessing the energy efficiency of a building and identifying areas where thermal insulation needs to be improved to reduce energy losses.

Because solving the equations for each element of the building requires a significant amount of time and effort, conducting thermographic assessments using a thermal camera is a rapid and non-destructive method for visualizing temperature distributions on the surface of building elements. In the presented case study, this thermal investigation method was utilized for the residential building analysis.

D. *Model specifications*

- the analyzed building is intended for residential use, being a single-family house with one floor and mansard roof;
- the building's usage is residential, occurring throughout all 24 hours of the day and 7 days a week;
- the assumed number of residents in the building is 4;
- the building's structural framework consists of a raft foundation, reinforced concrete support pillars, while the exterior and interior walls are made of aerated concrete blocks with a thickness of 25 cm;
- the building's exterior insulation was done with expanded polystyrene, 20 cm thick in a single layer on the exterior walls, while the plinth (upper part of the foundation) was insulated with extruded polystyrene, 10 cm thick;
- he windows are double-glazed, with 3 mm thick glass in each pane and the use of argon gas in the 13 mm thick intermediate space.
- the analyzed property is located in the village of Pătrăuți in Suceava county, a region in Romania characterized by hot summers and cold winters [9].

E. *Analysis of energy losses in a residential building through thermographic determinations*

Thermographic assessments were conducted on the residential building described above using a Fluke Ti300+ Thermal Camera [10] on March 4, 2024, around 7 o'clock in the morning. The emissivity of the materials was set to 0.95. The exterior temperature was 5°C (41°F), while the interior temperature of the building was 20°C (68°F).

Fig. 1. The eastern part of the analyzed building 1.

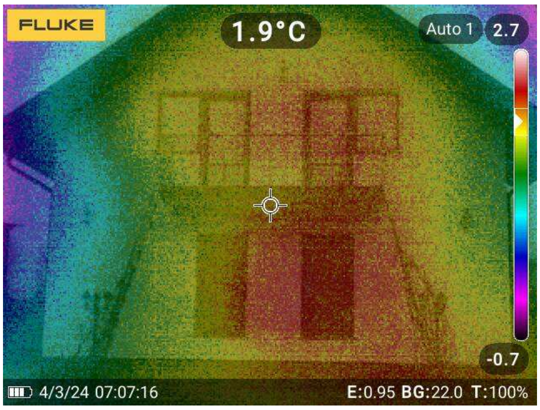

Fig. 2. The eastern part of the analyzed building 2.

Fig. 3. The southern part of the analyzed building.

Fig. 4. The entrance to the analyzed building 2.

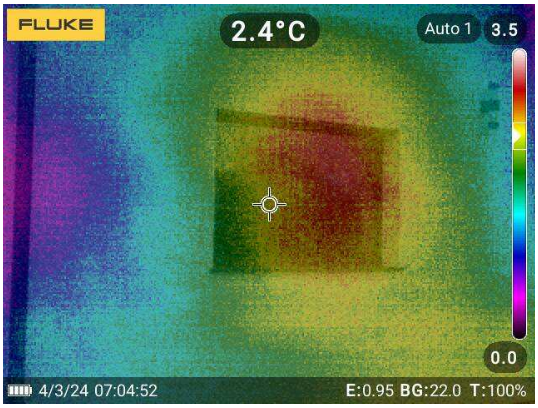

Fig. 5. The western side of the analyzed building 1.

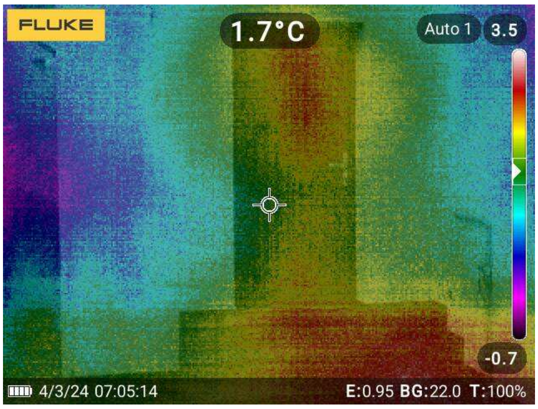

Fig. 6. The western side of the analyzed building 2.

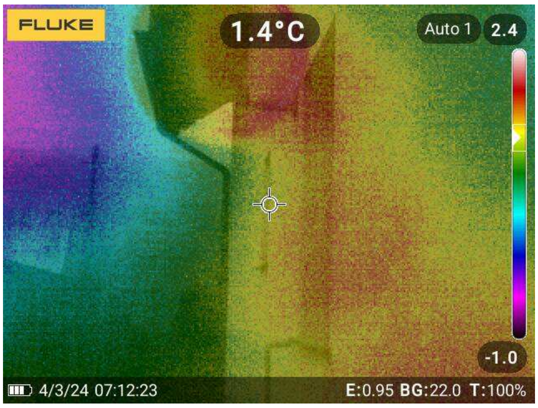

Fig. 7. The northern side of the analyzed building.

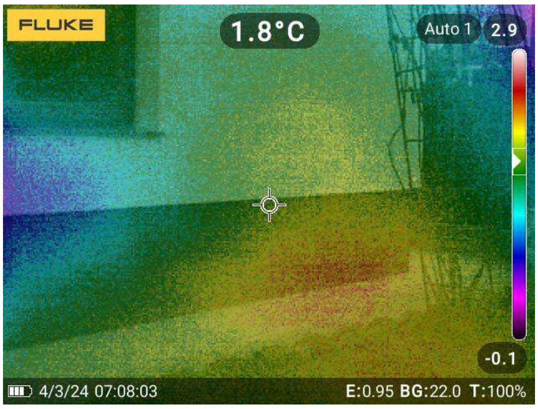

Fig. 8. Plinth on the eastern side of the analyzed building.

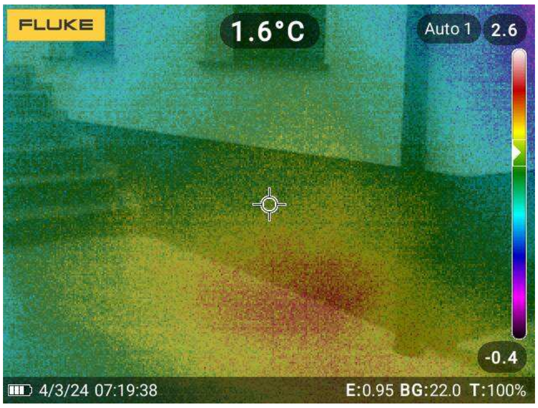

Fig. 9. Plinth on the southern side of the analyzed building 1.

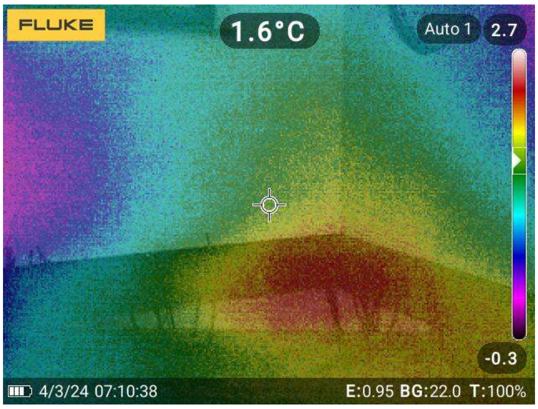

Fig. 10. Plinth on the southern side of the analyzed building 2.

Fig. 11. The eaves area on the southern side of the analyzed building 1.

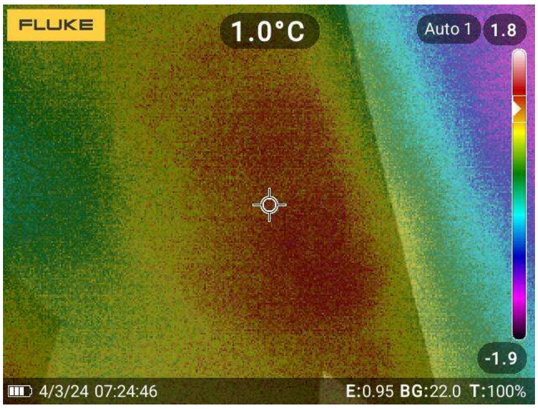

Fig. 12. The eaves area on the southern side of the analyzed building 2.

IV. RESULTS AND DISCUSSIONS

As can be observed in figures 1 to 3, where thermographic assessments were conducted on the eastern and southern sides of the building, the areas highlighted in red represent zones where heat loss to the exterior is maximum, unlike the areas highlighted in yellow and green where the building insulation acts as a thermal barrier. The eastern and southern sides of the building have the largest glazed surfaces to gain energy from solar radiation during the day and also serve an architectural purpose by providing natural light into the building. However, in this scenario, these two parts are the ones with the highest heat losses.

Figures 4 and 5 highlight the energy losses through the access door to the building, with the intensely red-colored area indicating significant heat loss through the door. It is not made of materials with energy-insulating properties and represents a vulnerable point of the building in terms of energy efficiency.

In figures 6, 7, and 8, thermographic assessments were conducted on the western and northern sides of the building. Here, the glazed surfaces are smaller, resulting in lower energy loss to the exterior. A decrease in the red areas can be observed across the total glazed surface, as the heat exchange with the exterior is reduced in these areas. The assessments reveal extensive areas of yellow, green, and blue colors, indicating the reduced transfer of thermal energy from the interior to the exterior, ranging from low values highlighted in yellow to nearly zero values represented by the blue color.

Figures 9 to 13 depict the areas with the largest surface area, relative to the total surface area of the building, where energy losses to the exterior are significant, and the proposed energy efficiency measures should primarily target these areas. These include the plinth and the eaves aria of the building. For the plinth area of the building, different energy losses to the exterior were identified on each side of the building. The part highlighted intensely in red, as shown in figure 11, represents the southern part of the building, which is the most vulnerable point in this area. Here, the flow of energy from the interior to the exterior through the plinth of the building is maximal. For the eaves area of the building, where thermographic assessments were conducted on the southern side, the area highlighted in red is significant, indicating substantial energy loss to the exterior through the upper part of the building.

Monitoring energy losses of a residential building through thermographic assessments provides a comprehensive picture for accurately evaluating the building's condition before renovation, aiming to assess the need for partial or total facade refurbishment and calculating an approximation of the renovation's effect on heat loss transmission, leading to energy savings.

In this case, aiming to improve the energy efficiency of the analyzed building and reduce heat losses, it is proposed to replace the existing windows with new energy-efficient ones, with characteristics similar to those for certified passive houses [11] [12].

It is recommended to replace the entire access door to the building as it exhibits significant deficiencies in thermal insulation with a new one that is energy efficient.

Implementing a multilayer insulation for the foundation (adding an additional 10 cm of extruded polystyrene insulation, on top of the existing 10 cm of insulation). In figure 11, a significant energy loss from inside the building to the outside through the plinth area of the building on its southern side was observed. Therefore, it is proposed to apply additional insulation in this area to eliminate the existing energy vulnerability. The energy loss on the southern side of the plinth could be due to the massiveness of the building elements. Here, the access stairs to the building are constructed, made of monolithic concrete with high thermal mass.

Another recommendation to increase the energy efficiency of the studied building is to insulate the attic to reduce heat losses through the eaves, which are significant. The eaves have a considerable area relative to the total area of the building, and insulation can be achieved using energy-efficient thermal insulation materials.

To reduce heat loss through windows, it is proposed to install thermal insulation shutters [13]. Thus, the insulating shutters made of aluminum with slats filled with polyurethane foam for better thermal insulation are recommended [14].

There are many situations where conducting thermal imaging of a building becomes the only quick solution for investigating a structure directly on-site. By simply scanning its facade, areas where the walls do not provide adequate insulation become visible (such as incorrectly performed insulation, existing cracks in the structure, infiltrations, fungal growth, etc.). This can lead to excessive energy consumption during the cold season for heating indoor spaces and, at the same time, to excessive heating of the building's interior during the warm season. [15].

The main issue with the presented method is the complexity of automating the detection of thermal irregularities, especially due to the multitude of factors to consider in interpreting thermal images. These factors include environmental conditions, the impact of solar radiation, the surface condition of the studied element, the viewing angle of surfaces, the massiveness of construction elements, and the emissivity of materials. [16][17].

These impediments can be alleviated by specifying a suitable temperature range for representing temperature differences for the analyzed object, thus maximizing the detection of areas affected by defects, allowing for appropriate binarization of the orthothermograms. [8].

V. CONCLUSIONS

Monitoring energy losses can help ensure compliance with standards and regulations regarding energy efficiency in construction, which can have legal and economic benefits. It can provide a more secure assessment of whether a specific passive house condition, namely the energy requirement of 15 kWh/(m2/year), is truly met or if it falls short at 19 kWh/(m2/year). In the latter scenario, during the detailed design phase of the building, it would be the responsibility of the designers to reduce the building's energy requirement by 4 kWh/(m2·year) to qualify the proposed building for passive energy status. This would involve incorporating, right from the design stage, all elements of the building that connect the interior and exterior, ensuring that they are made from thermally insulating materials. For example, the entrance door to the building should be constructed with such materials. Additionally, detailed execution plans should be made to enhance the building's energy efficiency, such as insulating the attic and adding supplementary insulation to the plinth. Another recommendation is to select energy-efficient windows with characteristics similar to those certified for passive houses [11].

Another aspect revealed by the thermographic analysis is that certain elements of the building, in our case, the southern part of the plinth, represent a highly vulnerable energy point through which the flow of thermal energy from the interior to the exterior is intense. In this case, the designer can recommend, even at the design stage, for buildings with similar characteristics to those analyzed, located in similar climatic zones, additional measures to insulate the plinth only for a certain side of the building.

Future research in this regard can be conducted after implementing the proposed measures to increase the energy efficiency of the analyzed residential building. Also, with this opportunity, a more precise calculation can be made regarding this reduction in heat loss. Such calculations can accurately determine the energy gains after the energy renovation of the building.

Another way to continue the research is to conduct multiple thermographic assessments over a longer period of time, during which there is a noticeable variation in external temperature. Certainly, with a larger volume of data and using statistical analysis methods, more precise results can be obtained, and other energetically vulnerable areas can be identified, with more proposals for increasing energy efficiency.

What happens if the destination of the building is changed? In another possible scenario, the building has been purchased by an investor who wants to establish a beauty salon in the analyzed building. On this occasion, they intend to reconfigure and renovate the building for its new purpose. The measures proposed in the case study presented are similar if the interior temperature throughout the building's use is 25°C (77°F).

As a result, improving the energy efficiency of residential buildings, whether existing or newly constructed, becomes particularly important. Homes with higher energy efficiency require less energy for heating, cooling, and lighting, bringing financial benefits to homeowners through reduced costs. This initiative contributes to reducing greenhouse gas emissions and combating climate change. By providing improved thermal comfort, maintaining constant temperatures, and eliminating extreme variations, energy-efficient buildings support the creation of sustainable communities resilient to climate change.

REFERENCES

[1] S. (eds) Fioretti, C., Pertoldi, M., Busti, M. and Van Heerden, “Handbook of Sustainable Urban Development Strategies, EUR 29990 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-16425-8, doi:10.2760/020656, JRC118841.” [Online].Available:https://urban.jrc.ec.europa.eu/urbanstrategies/territorial-focus#introduction, Accessed: Mart. 05, 2024.

[2] IEA, “International Energy Agency - Energy Eficiency 2019.” [Online]. Available: https://www.iea.org/reports/energy-efficiency-2020/energy-efficiency-in-2019; Accessed: Mart. 05, 2024.

[3] G. Tsionis, “European building inventory framework,” JRC Technical Reports. p. 32, 2015.

[4] The Government of Romania through the Ministry of Energy, "National Integrated Plan in the Field of Energy and Climate Change 2021-2030.”[Online]. Available:https://energy.ec.europa.eu/system/files/2020-04/ro_final_necp_main_ro_0.pdf; Accessed: Mart. 05, 2024.

[5] The Government of Romania through the Ministry of Development, Public Works, and Administration, "Methodology for Calculating the Energy Performance of Buildings, indicative Mc 001-2022.” [Online]. Available: https://aaecr.ro/wp-content/uploads/2023/01/Mc-001-2022-Metodologie-calcul-performanta-energetica-cladiri.pdf,Accessed: Mart. 05, 2024.

[6] O. Mejri, B. Peuportier, and A. Guiavarch, “Comparison of different methods for estimating the building envelope thermal characteristics,” Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association. pp. 630–635, 2013. doi: 10.26868/25222708.2013.2030.

[7] Ministry of Transport, Construction, and Tourism, "Methodology regarding thermographic determinations in construction, indicative MP-037-04, approved by Order no. 711/13.04.2004,” 2004. [Online]. Available: https://www.mdlpa.ro/userfiles/reglementari/Domeniul_XXVII/27_8_MP_037_2004.pdf; Accessed: Mart. 05, 2024.

[8] L. López-Fernández, S. Lagüela, D. González-Aguilera, and H. Lorenzo, “Thermographic and mobile indoor mapping for the computation of energy losses in buildings,” Indoor Built Environ., vol. 26, no. 6, pp. 771–784, Jul. 2017, doi: 10.1177/1420326X16638912.

[9] Climatic and meteorological data, Available: https://www.meteoblue.com/ro/vreme/historyclimate/climatemodelled/suceava_rom%C3%A2nia_665850; Accessed: Mart. 06, 2024.

[10] Fluke Ti300+ Thermal Camera, Available: https://fluke.com/en-us/product/thermal-cameras/ti300plus; Accessed: Mart. 05, 2024.

[11] R. Hart, S. Selkowitz, and C. Curcija, “Thermal performance and potential annual energy impact of retrofit thin-glass triple-pane glazing in US residential buildings,” Build. Simul., vol. 12, no. 1, pp. 79–86, Feb. 2019, doi: 10.1007/s12273-018-0491-3.

[12] Rivo Construct, Available: https://rivo.ro/cele-mai-bune-termopane/; Accessed: Mart. 12, 2024.

[13] M. Gil-Baez, Á. B. Padura, and M. M. Huelva, “Passive actions in the building envelope to enhance sustainability of schools in a Mediterranean climate,” Energy, vol. 167, pp. 144–158, Jan. 2019, doi: 10.1016/j.energy.2018.10.094.

[14] Overlapping roller blinds ELVIAL made of aluminum, Available: https://www.rulourisiobloane.ro/produse/rulouri/casetasuprapusa; Accessed: Mart. 12, 2024.

[15] F. Harkouss, F. Fardoun, and P. H. Biwole, “Passive design optimization of low energy buildings in different climates”, Energy, vol. 165, pp. 591–613, Dec. 2018, doi: 10.1016/j.energy.2018.09.019.

[16] N. Amani and E. Kiaee, “Developing a two-criteria framework to rank thermal insulation materials in nearly zero energy buildings using multi-objective optimization approach,” J. Clean. Prod., vol. 276, p. 122592, Dec. 2020, doi: 10.1016/j.jclepro.2020.122592.

[17] M.R. Milici; L.D. Milici; P. Atănăsoae; V. Ștefanescu, ” Studies on Energy Consumption Using Methods of Exponential Smoothing”, 2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), DOI: 10.1109/ATEE.2019.8724946.