Applications of Thermal Visual Measurements in Light of Toughened Up Legislation

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Applications of Thermal Visual Measurements in Light of Toughened Up Legislation

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Abstract. The purpose of research was to verify the impact of thermal modernization of existing buildings on their energy performance in light of toughened up legislation. The paper answers the question - how thermo-modernization can affect the reduction of its needs for the building and contribute to the reduction of dust emitted, when heating is based on solid fuels. Some houses of similar typical construction which was very popular in Poland in 70', were tested. In one of them, doors and windows were replaced, but its elevation was left without insulation, while in another one, the thermal insulation was made, but old wooden door and window framing has been left. The research carried out with the thermovision camera allows a qualitative estimation of heat leakage from buildings. The test results were developed in detail in the Flir Tools software and the value of the building's heat demand was estimated before and after the thermo-modernization of the building or replacement of framing. On the basis of the conducted research, it is justified that even very high quality framing not accompanied by the insulation of the building, is definitely insufficient to meet the requirements. Only a comprehensive approach to the thermo-modernization of any building can get the desired results. In article, solutions were chosen to meet the requirements of the DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings.

1. Introduction

The standards for suspended dust PN-10, which values are determined in Directive 2008/50/Ec of The European Parliament and of The Council of 21 May 2008 on ambient air quality and cleaner air for Europe, have been often exceeded. The PM-10 fine dust standards are set at three levels: acceptable level 50µg/m^3 (daily), information level 200µg/m^3 (daily) and alarm level 300µg/m^3 (daily). Information level in several areas in Poland is exceeded per day regularly. Among the 50 most polluted cities in Europe up to 100,000 inhabitants, as many as 33 of them are situated in Poland. The National Program for the Protection of Air, makes the same mandatory task for the state. It includes: replacement of heat sources with ecological ones, increase of energy efficiency (thermal modernization of buildings, application of Renewable Energy Sources - RES), ecological and health education [1]. In 2018, the government Smog Stop program was launched, which assumes the thermo-modernization of 15,000 houses by 2027.

Thermal imaging technology measurements, allows to assess building current quality and quantify heat losses in the studied buildings solutions, to meet the European Union legislation requirements. Places of discontinuity or lack of thermal insulation of the building cause a temperature difference on the surface of building partitions [2]. On the basis of its distribution, thermal inhomogeneity can be identified. One of the methods that allows to measure and visualise the temperature distribution is thermal imaging. A thermal imaging camera records the intensity of radiation in the infrared part of the electromagnetic spectrum and converts it into a visible image. These measurements are applicable in construction, among others in such areas as: location of thermal bridges, determination of local reduced thermal properties of partitions, assessment of the quality of window and door installation, assessment of the extent and intensity of occurrence of moisture, quality testing of gravity and mechanical ventilation, or assessment of the quality of underfloor heating, as it was described extensively in reference but this paper shows the application in a particular comparison case study. In addition, thermal imaging studies can also be used in industry, energy, fire protection, and thermal imaging systems. The paper presents the analysis of the buildings in which thermos modernization works were partially carried out.

2. Methods

The method is used primarily for qualitative assessment of building envelope with respect to correct selection (designing and performance) of thermal insulation in partitions, location of thermal bridges, and contamination of partitions by moisture, identification of places with excessive air infiltration through building partitions and to test failures of installations in buildings [3]. Infrared thermography is a very efficient and effective tool to locate hidden defects in building envelope by locating surface anomalies of temperature distribution on external surfaces of partitions. This is testing method which on the basis of temperature distribution on the surface of the inspected element provides for anticipating or identifying thermal damage to the elements without contact, destruction or invasion. The method of analysis assumes that building partitions are considered as laminar structures of nonhomogeneous materials. The mentioned uniformity of material and construction results from porous structure and gaps between layers of various origin. The most important problem in infrared inspections in building is correct interpretation of thermograms, assuming all required conditions for the satisfying inspection.

2.1. Theoretical basis of conducted research

Heat transport can be done by convection, conduction and radiation. In real conditions, it happens, that these phenomena occur together, leading to the phenomena of loss or heat transfer. Thermal transmission takes place between two fluids or gases of different temperature values, separated by a partition. Its course can be divided into subsequent stages: heat transfer, heat conduction and again heat transfer. This phenomenon occurs in the considered construction of building partitions. The heat flow, due to the temperature values difference, always takes place from a room with a higher temperature to a room with a lower temperature [4]. Figure 1 shows the temperature distribution in one and two-layer external walls, that are considered in this paper.

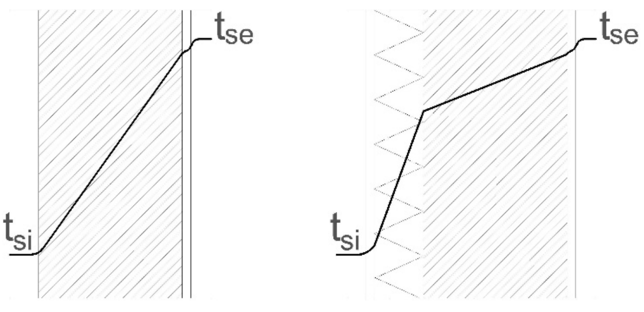

Figure 1. Temperature distribution in external walls of analyzed buildings, t_{si} - calculated outside air temperature, t_{se} - design air temperature in the room [own elaboration]

The flow of heat through building partitions is always transient over time. This is mainly due to the variability of external environment elements that determine the heat flow (air temperature, solar radiation intensity, wind speed and direction, etc.), unevenness of heating devices and variable heat gains in the room [5]. The process of transient heat exchange is closely related to the dynamic thermal characteristics of the building, which essentially affect the heat accumulation and thermal stability of partitions in summer and winter.

Determination of the dynamic thermal properties of the building is reduced to the solution of the differential equation of the unidirectional Fourier heat conduction, which expresses the temperature variation function in the cross-section of the element that is assumed as characteristic for the selected sector of the partition [6].

$$\frac{\partial T}{\partial \tau} = \frac{\lambda}{\rho_O c_p} \frac{\partial^2 T(x,\tau)}{\partial x^2} \tag{1}$$

where:
τ – time, [s]
x – coordinate normal to the surface of the partition, [m]
$T(x,\tau)$ – function dependence of temperature on the point position and time
λ – thermal conductivity of the material, [W/mK]

In the presented analysis a desirable feature of building materials is the large heat capacity, which consists of high specific heat and high apparent density. The specific heat of building materials is in the range of 0.8-1.0 k/kgK. The volume heat capacity, referring to $1m^3$ of material well describes thermal dynamic properties of materials. In the building discussed in the article, materials have been used which are characterized by the volumetric heat capacity [J/(m^3K)]: ceramic brick 1150-1670, expanded polystyrene 100.

The basic dependency used by the infrared camera system is the equation of radiation [6]:

$$W_{tot} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau W_{refl} + (1-\tau)W_{atm} \tag{2}$$

where:

$\varepsilon\tau W_{obj}$ – thermal radiation emissivity from the object
ε – emissivity coefficient of the tested surface
W_{obj} – thermal power of the object
$(1-\varepsilon)\tau W_{refl}$ – emissivity of reflected radiation from sources in the environment
$(1-\varepsilon)$ – reflectance coefficient of the surface to be tested
$(1-\tau)W_{atm}$ – emissivity of thermal radiation from the atmosphere along the measurement path

The formula 2 is applicable of some important precautions. Measurements carried out with a thermovision camera enable mainly a qualitative analysis of selected elements. However, they are also used to quantify the heat transfer coefficient U [6]. This method, however, requires knowledge of the room temperature T_p, and temperature values on the inside and outside of the partition T_{si}, T_{se}

$$U = \frac{h_{si} h_{se}(T_p - T_{si})}{h_{se}(T_p - T_{se}) + h_{si}(T_p - T_{si})} \tag{3}$$

These measurements to provide the data to the formula can be taken separately but thanks to incorporated meters and sensors.

2.2. *Methodology of conducting research with a thermal imaging camera*

In the work, the thermovision method was applied to a qualitative estimation of local heat losses, called thermal bridges. They are a threat to buildings in which biological and physicochemical corrosion can occur. They lead to condensation of water vapor, moisture, fungal growth and structural changes in the partitions. Thermal bridges are created as a result of design and implementation errors. The first of these is among others: incomplete heat and humidity calculations, incorrect solutions for insulating thermal bridges, lack of description of insulation performance for external walls, incompatibility between technical description and drawings.

FLIR Systems, Inc., T400 series, Flir T440bx model with universal application in power engineering and industry, was used for the research. It allows to read the electromagnetic emission of invisible waves in the spectral spectrum from 7.5 to 13 µm, at a temperature from -20 ° C to 350 ° C. The camera is equipped with a sensitive detector with a resolution of 320x240 pixels, visualizing temperature differences of 0.045°C and working with a refresh rate of 60Hz. In addition, the camera has the function Multi Spectral Dynamic Imaging (MSX), which improves the image of the thermogram, the function of the linear profile, the dew point, touch monitor, the ability to sketches on the thermal image and connectivity via WiFi and Meterlink.

Correct measurements with thermal imaging camera require knowledge and skills in the field of building physics [7, 8]. Parameters that must be defined before the test: emissivity of the surface to be tested, reflected temperature, relative humidity, air temperature, distance to the object, compensation of the IR window. The camera takes two photos simultaneously: thermographic and digital, which allows for a detailed analysis of the images received.

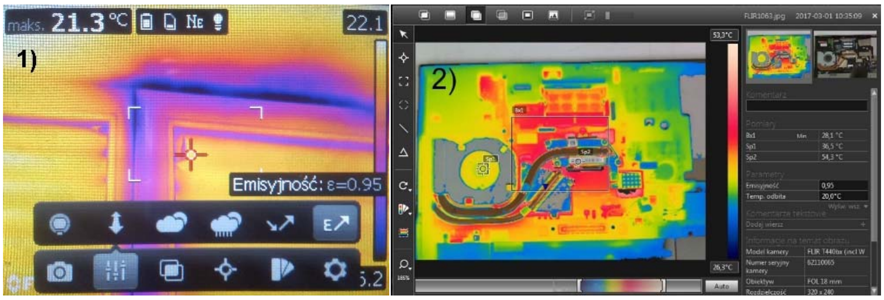

Figure 2.1. Flir T440bx camera screen interface, tab view, measurement parameters [own study], Figure 2.2. Flir Tools + program interface [authors discography resources]

Emissivity is a measure of radiation from the test object in relation to the intensity of the radiation of the surface of a perfectly black object at the same temperature. It is in the range of 0.1 to 0.95 and depends on the temperature of the object and the degree of surface roughness (value 0.1 accept perfectly polished surfaces, i.e. mirrors) [9]. Emissivity of the surface can be determined experimentally, or use tables or approximate values available directly from the software level of the camera - figure 2.1.

To labour obtained results, the software of the camera manufacturer was used, the FLIR Tools + program, figure 2.2 shows a fragment of its interface. This program allows for the processing of thermograms, their extensive analysis and the creation of thermographic reports based on selected thermographic images. It also allows to define specific measuring points and areas, change the scale between the colour palette and thermal measurement, temperature waveform, temperature maxima indications, to determine temperature differences, enter and modify a number of parameters available from the camera interface.

2.3. *Selection of facilities and carrying out tests*

The research involved two buildings located on one building plot in Mielec, Polnd, in the third climate zone. Both were erected in 1975, using the same structural and material solutions. The characteristic block of objects, colloquially called "cube", was a very popular and often chosen solution by investors throughout the country in the 80' and 90' in Poland. Some of them have been thoroughly modernized architecturally. However, most of the buildings were subject only to thermo-modernization works on the elevation, or replacement of doors and windows framing. These are single-family residential buildings with basements of 2 above-ground floors, each with a height of 2.5m, external walls made of ceramic brick, monolithic reinforced concrete ceiling, wooden roof covered with eternit.

Figure 3 shows a digital photograph of objects, that are subject to the study. In the building located on the left, the wooden door and window framing on the first floor, was replaced by a polyvinyl chloride. For needs of the article, this building was given the number II. In the 1st building, thermo-modernization of the elevation was carried out. External walls were insulated with polystyrene boards with a thickness of 12cm, characterized by a thermal conductivity λ = 0,04 [W/mK]. After installing the expanded polystyrene boards, the walls were pargeted with cement and lime plaster 1,5cm thickness. Thermovision studies were carried out for the western elevation. Before carrying out work, the following parameters were inputted in the measuring device:

- emissivity of the pargeted wall, adopted from the Flir catalogue for 1st building: 0.86;
- emissivity of the wall from the ceramic hollow block for 2nd building: 0,90;
- outdoor temperature: -4,9°C;
- distance from the reflected object: 10m;
- relative humidity: 65%;
- temperature inside heated rooms: 20°C.

Figure 3. Residential buildings subjected to thermal imaging. On the right side – 1st building, on the left side – 2nd building [authors discography resources]

3. Results and discussions

Figures 4-7 show digital and thermovision photographs of the analyzed buildings. On the received thermograms, numerous thermal bridges were found. They were created primarily in places where the building partition is thinner (e.g. balcony space), in the places where walls and ceilings are jointed, over window frames, under window sills and in the corners of window and door framing. The colour palette used by the program reflects the current temperature range - bright colours are assigned to the highest recorded values and the dark ones to the lowest, actually measured in situation.

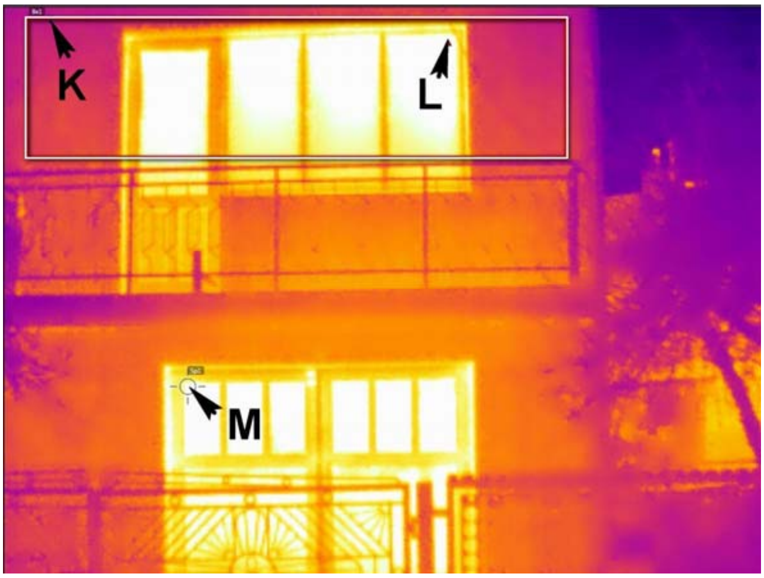

Figure 4. Thermovision image of the west elevation of the 1st building [authors resources]

Figure 5. Digital photo of the west elevation of the 1st building [authors resources]

In the thermovision pictures of the 1st building, shows clearly the heat loss through the wooden door and window framing, which has not been replaced, since the construction of the building. In the corners of windows and balcony doors on the 1st floor, heat losses are comparatively large. In figure 4, in the area marked with a white rectangle, the temperature extremes can be read: for the L point the maximum is 0,8°C, while in the K point the minimum is -4,6°C. So the values difference between the points separated from each other by only 2,7m points is 5,4°C. The highest temperature value on the whole analysed elevation, was recorded in the corner of the garage gates, at the M point and amounted to 1,3°C. Considering that, the ambient temperature during the measurements was -4.9°C, the amplitude value was 6.2°C. Such large heat leakage is a very unfavorable phenomenon, causing cooling of rooms and leading to destructive action of the weather conditions [10]. Moreover, in the connect area between the balcony slab and the wall, some increase in the temperature value is visible. The reason for the occurrence of this phenomenon is the incorrect construction of the supporting structure of the balcony slab and insufficient thermal insulation of its passage through the building's wall. This is a common phenomenon and often occurs in residential buildings, constructed in old technologies. In addition, badly performed drainage of water and residual snow from the balcony, causes the accumulation of moisture around the passage through the wall and intensifies the phenomenon of heat transport. The remaining surface of the elevation is characterized by steady temperature distribution, without clearly marked thermal bridges. Therefore, it can be concluded that the thermal insulation was done correctly. A frequently occurring mistake, which in this case was avoided, is heat transport through improperly insulated anchors for the installation of expanded polystyrene boards.

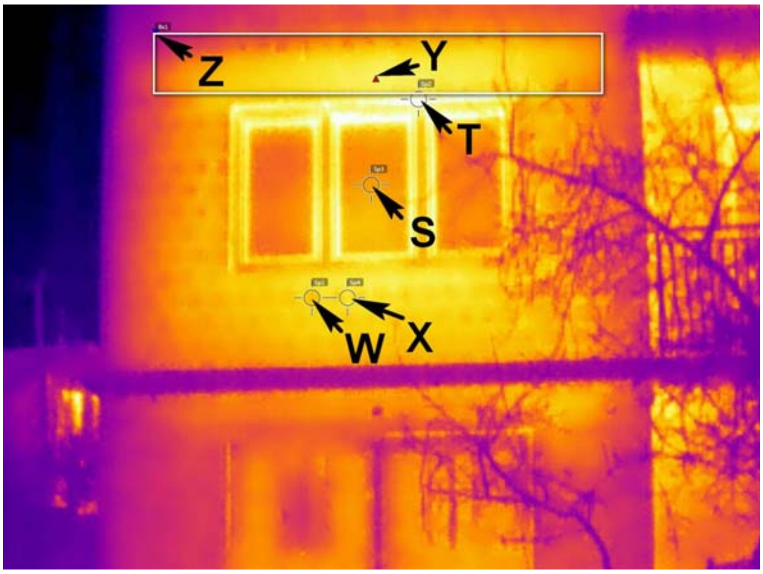

Figure 6. Thermographic picture of the west elevation of the 2nd building [authors resources]

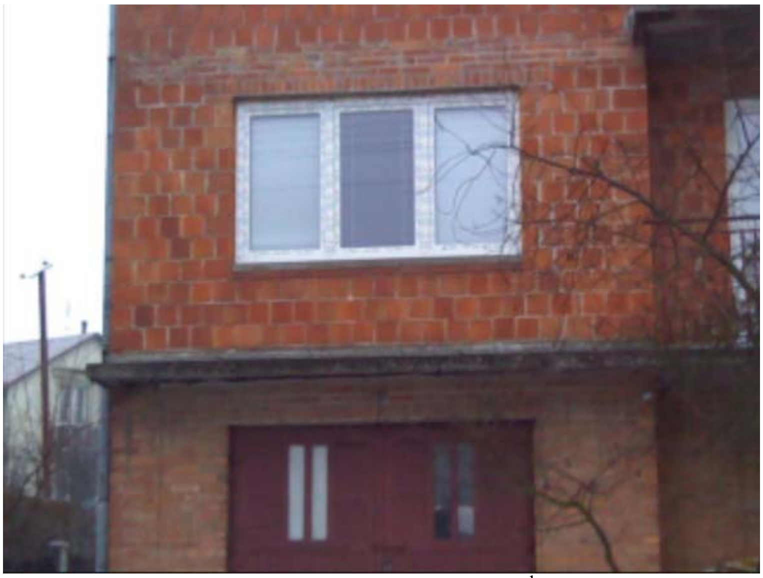

Figure 7. Digital photo of the west elevation of the 2nd building [authors resources]

On the elevation of 2nd building, thermal insulation wasn't applied, but window and door framing has been replaced on the first floor. During the measurements, only the rooms of this storey were heated, which can also be seen on the basis of the colour distribution on the elevation, reflecting the temperature values. On the obtained thermogram of the analyzed eastern wall, construction errors are visible:

• a wide yellow band over the window (the area marked with a white rectangle) is the place of heat leakage from the building. The probable cause of this unfavourable phenomenon is improper, or lack of thermal insulation of the window lintels. In the construction of this type of objects a beam, reinforced with double-T bar was used. Incorrectly insulated metal element forms a big thermal bridge. The temperature difference in this area between Z and Y points is 2.7°C;

- on the thermogram, contours of uncovered welds between the ceramic bricks are distinctly outlined, absorbing humidity from the environment, in greater extent than ceramic blocks. This is a very disadvantageous phenomenon occurring in monolayer walls, unadapted to the atmospheric conditions prevailing in Poland in the third climatic zone. Measurement of the temperature value between the points X - weld, and point W - the surface of the block, showed a difference of 0.5°C;

- despite the fact that the new, replaced PVC framing has a low heat transfer coefficient (U=0,15W/m^{2}K), around the window frame - a special one in its upper part, there is a large loss of heat. In the middle part of the window glazing - point S, a temperature of -1.2°C was noted, whereas at the point T=1.4°C. This unfavourable phenomenon arises due to incorrect installation of the framing [10]. The most common mistakes are: incorrect positioning of the window, incorrectly selected window sizes, poor window positioning in the wall, badly prepared reveals, incorrect fixing of the framing, leaks around the windows, installation without supporting blocks - preventing the filling of the void with the mounting foam. In passive and low energy buildings, it is common to place the framing in the insulation layer.

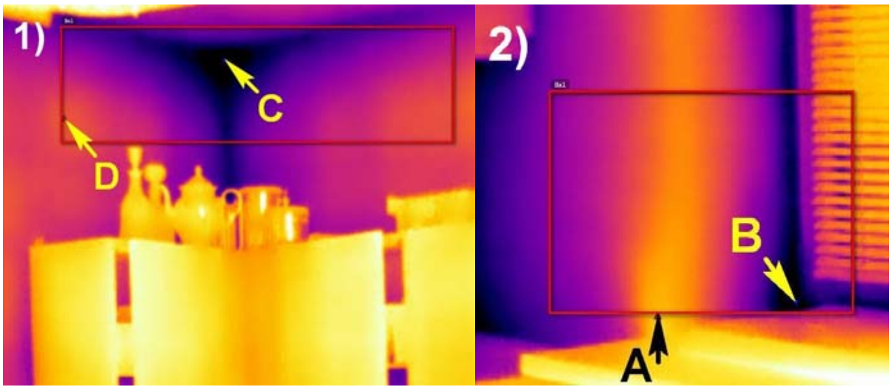

Figure 8. Thermograph of a wall corner inside the 1st building, Figure 8.2. Thermograph of window corners of the interior of the 2nd building [authors resources]

It is very important for the correct analysis of the obtained results, to carry out thermovision research outside and inside the facility. Figure 8 shows thermal images taken inside and outside the rooms of the analyzed building. Figure 8.2 shows the lower left window corner of the 2nd building, in which the old wooden framing was replaced. The temperature values were measured in a marked rectangular area (red line). At point A, the temperature is 13.9°C, while at B it is only 7.7°C. The reason for such a large difference in value is improperly made installation of window frames. Figure 8.1 shows the wall corner in 1st building. The temperature difference between points C and D is 3.9°C. In spite of the fact that thermal insulation was made on the elevation of the building, due to its poorly selected parameters, the corner of the building is still the place of heat migration.

4. Conclusions

The measurement of the temperature distribution carried out with the thermographic technique has made it possible to locate the incorrectness of the thermal insulation performance. The conducted thermovision research confirmed the usefulness of this method for the analysis of surface temperatures, and allowed a qualitative assessment of the building condition.

The results of thermographic researches are consistent with the results of calculations of the thermal conduction coefficient values, carried out with the calculation method. The value of the coefficient, determined in accordance with the formula 3. The value of the coefficient of heat for external partitions in 1st building U=1.03 [W/m^{2}K], while in 2nd building U=0.28 [W/m^{2}K]. For the new doors and window framing in 1st building the value of the coefficient of heat U=1.3 [W/m^{2}K], while for the old in the 2nd one U=3.4 [W/m^{2}K]. Unfortunately, despite the thermo-modernization was carry out, the solutions adopted in these buildings do not meet the standard requirements, consistent with Directive [11] on the energy performance of buildings. Permissible value of heat transfer coefficient for framing in rooms, in which the computational temperature is over 16°C, from January 2017 is 1.1 [W/m^{2}K], and from January 2021 it will be 0.9 [W/m^{2}K]. Whereas permissible value of heat transfer coefficient for external walls from January 2017 is 0.23[W/m^{2}K], and from January 2021 it will be 0.20 [W/m^{2}K]. Unfortunately, this is a common practice, that in order to reduce the cost of thermo-modernization, the investor strives only to meet the minimum requirements.

The insulation of the walls of the 1st building allowed to minimize the impact of design and implementation errors on the passage of heat from the object, and as a result led to the partial elimination of thermal bridges. The difference in mean temperature values between selected areas of the elevation fragment with the same area was 3,8°C. However, unrepresented and incorrectly attached, wooden door and window framing is the reason for cooling down rooms in winter and overheating in the summer. The measured average temperature of the external glazing area of all windows of the 2nd building, on the first storey is -1.27°C, while for the 1st building it is 1.7°C.

Despite the fact that the 1st building is characterized by good thermal insulation properties of the partitions, it is recommended to replace the door and window framing in order to minimize heat losses. In the 2nd building, it is necessary to make thermal insulation of elevation, taking into account the research results presented in the article. They indicate that the parameters of the thermal insulation of 1st building were insufficient to avoid local heat losses - figure 8.1. The research carried out at the same time indicates that even small building with proper maintenance and conservation, with single-layer walls, erected in the 70' and 80' of the last century, require a comprehensive thermo-modernization, simultaneous exchange of framing on energy-efficient, and insulation of external partitions. Only this approach allows to reduce heat loss, increase thermal efficiency of buildings and ensure thermal comfort, positively affecting the health and safety of users.

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