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REPORT ON PILOT ACTION 2 EVALUATION PHASE

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A. INTRODUCTION

This study concerns the assessment of the effects of improving the thermal insulation of building partitions in a public utility building located at Ormiańska Street 11 in Zamość. The primary objective of this report is to determine the savings in usable energy for heating and ventilation resulting from the improvement of the thermal insulation of building partitions forming the thermal envelope of the heated zone.

The analysis of the annual heat demand was carried out based on a building model developed using the actual geometric, material, and operational parameters of the building located at Ormiańska Street 11 in Zamość. The building is part of a historic urban frontage of tenement houses with protected architectural value, which significantly influenced both the scope and the technical solutions adopted for the thermal modernization works.

The scope of this study includes, in particular, the presentation of the basic characteristics of the building model, a description of the construction of building partitions in the existing condition, calculations of thermal transmittance coefficients (U-values) in the existing state, a description of the thermal modernization measures, calculations of U-values in the target condition, determination of the annual energy demand for heating and ventilation in both states, evaluation of the resulting energy savings, and final conclusions.

The study was prepared on the basis of design and technical documentation, including in particular the executive design entitled “Renovation of external partitions of the usable attic together with internal installations of central heating, mechanical ventilation, air conditioning and electrical systems in a public utility building located on plot no. 97 at Ormiańska Street 11 in Zamość”, prepared by KWADRA Architekci (January 2025), the bill of quantities for construction works, fragments of architectural and construction inventory, technical data for applied insulation materials (including the Multipor system and sheep wool insulation mats), as well as photographic documentation and site inspection records.

The analysis was conducted in accordance with applicable legal regulations and technical standards, including the Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location, PN-EN ISO 6946:2017-10 standard for thermal resistance and thermal transmittance calculations, and the Regulation on the methodology for determining the energy performance of buildings. Calculations were performed using specialized software, namely Audytor OZC 7.0 Pro developed by Sankom.

It should be explicitly stated that all data used in the chapter concerning the analytical assessment of building partitions originate from the study entitled **“Oszczędność energii użytkowej z tytułu poprawy izolacyjności cieplnej przegród budowlanych w budynku użyteczności publicznej zlokalizowanym przy ul. Ormiańskiej 11 w Zamościu”**, prepared by **Energetyczna Pracownia Inżynierska ERG Spółka Cywilna A. Życzyńska, G. Dyś, ul. Głęboka 10 lok. 35, 20-612 Lublin**, authored by **MSc Eng. Grzegorz Dyś**. In particular, this applies to the characteristics of building partitions, material layer configurations, thermal parameters, and calculated thermal transmittance coefficients (U-values).

The analytical chapter does not constitute an independent calculation performed within this study; instead, it is **entirely based on the source data contained in the above-mentioned study**, which were adopted as the basis for further comparative analyses and evaluation of the effectiveness of the implemented thermal modernization measures.

Furthermore, selected analytical data and methodological assumptions were cross-referenced with the document “REPORT ON PILOT ACTION 2 EVALUATION PHASE”, ensuring consistency of the adopted approach and comparability of results.

This report therefore provides a comprehensive evaluation of the effectiveness of the applied thermal modernization solutions, based on both in-situ measurements (thermographic investigations and U-value measurements) and analytical calculations of the building's energy performance.

B. ANALYTICAL ASSESSMENT OF BUILDING PARTITIONS

The general characteristics of the building model under consideration are presented below in tabular form (Table 1).

Table 1. Characteristics of the building model

Specification	Description
Type of building	public utilities
Temperature of heated rooms	$t_{e,avg} = 20\ ^0C$
Location	climate zone III, $t_e = -20\ ^0C$; weather station - Zamość
Cellars	yes, under the entire building; unheated
Building construction technology	traditional
Number of above-ground floors	3
Number of underground floors	1
Building height	11.95 m
Building area	313.90 m^2
Heated usable area	620.3 m^2
Total volume	3645.0 m^3
Volume of heated rooms	1857.0 m^3
Type of ventilation	gravitational
Fresh air inflow	leaks in windows and external doors
Exhaust air extraction	ventilation ducts in sanitary facilities

1. Description of building partitions

Below is a description of the building partitions that form the balance shield of the heated part of the assumed building model (ground floor, first floor, attic).

- External walls: wall made of solid ceramic bricks or aerated concrete blocks, plastered on both sides;
- Internal walls: wall made of solid ceramic bricks or aerated concrete blocks, plastered on both sides;
- Basement walls: ceramic brick wall plastered on both sides;
- Ceiling above the attic: thermal insulation made of mineral wool, aerated concrete blocks, reinforced concrete slab, plaster;
- Roof (slopes): plaster, reinforced concrete slab, mineral wool thermal insulation, sheet metal roofing;
- Dormer ceiling: plasterboard and mineral wool insulation on wooden structure, sheet metal roofing;
- Inter-story ceilings: plaster, reinforced concrete slabs, finishing layers;
- Window joinery: several-year-old wooden windows;
- External doors: wooden, insulated;
- Internal doors between heated and unheated spaces: wooden, insulated.

Detailed construction of building partitions in their existing state (before improving thermal insulation) is included in point 5 of this study.

2. Heat transfer coefficients of building partitions – existing condition

The heat transfer coefficients of building envelopes separating heated spaces from outside air or unheated spaces were calculated based on the provisions of the PN-EN ISO 6946:2017-10 standard – *Building components and elements. Thermal resistance and heat transfer coefficient. Calculation method.*

The following relationships were used for the calculations:

$$U = \frac{1}{R_{si} + \sum \frac{d_i}{\lambda_i} + \sum R_i + R_{se}}$$

where: U – heat transfer coefficient, W/m ^{2}·K,

R_{si} – heat transfer resistance on the internal side, m ^{2}·K/W,

R_{se} – heat transfer resistance on the external side, m ^{2}·K/W,

d_i – thickness of the homogeneous layer, m,

λ_i – thermal conductivity coefficient for a homogeneous layer, W/m·K,

R_{and} – thermal resistance of the inhomogeneous layer, m ^{2}·K/W

Based on the detailed construction of building partitions, the following values of heat transfer coefficients (U expressed in the unit W/m ^{2}·K) were obtained in the existing state:

External attic walls (SZ.1.1):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
solid ceramic brick	38.0	0.77	0.494
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.04
heat transfer coefficient (W/m ² · K) - U			1,404

Internal attic walls (SW.1.1):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
solid ceramic brick	38.0	0.77	0.494
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.13
heat transfer coefficient (W/m ² · K) - U			1,246

External side walls of dormers (SZ.1.2):

Partition layer	d [cm]	λ(W/m·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
aerated concrete blocks	18.0	0.35	0.514
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.04
heat transfer coefficient (W/m ² · K) - U			1,364

Side walls of internal dormers (SW.1.2):

Partition layer	d [cm]	λ(W/m·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
aerated concrete blocks	18.0	0.35	0.514
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.13
heat transfer coefficient (W/m ² · K) - U			1,215

Ground floor walls (SZ-PAR):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
solid ceramic brick	69.0	0.77	0.896
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.04
heat transfer coefficient (W/m ² · K) - U			0.897

First floor walls (SZ-PIET):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
solid ceramic brick	55.0	0.77	0.714
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.04
heat transfer coefficient (W/m ² · K) - U			1,072

Basement walls (SZ-PIW):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
solid ceramic brick	83.0	0.77	1,078
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.04
heat transfer coefficient (W/m ² · K) - U			0.771

Basement walls in the ground (SZ-GR):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
cement-lime plaster	2.0	0.82	0.024
solid ceramic brick	83.0	0.77	1,078
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.13
equivalent heat transfer coefficient (W/m ² ·K) - U_{equiv}			0.519

Ceiling above the attic (PAGE 2.3) :

Partition layer	d [cm]	λ(W/m·K)	R (m ² ·K/W)
mineral wool	10.0	0.045	2,222
insulation made of aerated concrete blocks	24.0	0.35	0.686
reinforced concrete slab	18.0	1.70	0.106
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.10
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.10
heat transfer coefficient (W/m ² · K) - U			0.309

Sloping roof (SKOS.2.1):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
covering - sheet metal	-	-	-
foil	-	-	-
mineral wool	10.0	0.045	2,222
reinforced concrete slab	18.0	1.70	0.106
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ² ·K/W) - R_{si}			0.10
resistance to heat transfer to the outside (m ² · K/W) - R_{se}			0.04
heat transfer coefficient (W/m ² · K) - U			0.401

Sloping roof (SKOS.2.2):

Partition layer	d [cm]	λ(W/m ·K)	R (m ² ·K/W)
covering - sheet metal	-	-	-
foil	-	-	-
full formwork	1.5	0.30	0.050
mineral wool	10.0	0.045	2,222
reinforced concrete slab	18.0	1.70	0.106

cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ^{2}·K/W) - R_{si}			0.10
resistance to heat transfer to the outside (m ^{2}· K/W) - R_{se}			0.04
heat transfer coefficient (W/m ^{2}· K) - U			0.393
after removing the existing mineral wool			
heat transfer coefficient (W/m ^{2}· K) - U			3,700

Ceilings and slopes in dormers:

Partition layer	d [cm]	λ(W/m ·K)	R (m ^{2} ·K/W)
covering - sheet metal	-	-	-
foil	-	-	-
mineral wool	10.0	0.045	2,222
foil	-	-	-
plasterboard	1.25	0.82	0.054
internal heat transfer resistance (m ^{2}·K/W) - R_{si}			0.10
resistance to heat transfer to the outside (m ^{2}· K/W) - R_{se}			0.04
heat transfer coefficient (W/m ^{2}· K) - U			0.414

Ceiling above the first floor (in the corners):

Partition layer	d [cm]	λ(W/m ·K)	R (m ^{2} ·K/W)
insulation made of aerated concrete blocks	24.0	0.35	0.686
reinforced concrete slab	18.0	1.70	0.106
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ^{2}·K/W) - R_{si}			0.10
resistance to heat transfer to the outside (m ^{2}· K/W) - R_{se}			0.10
heat transfer coefficient (W/m ^{2}· K) - U			0.984

Ceiling above unheated basement:

Partition layer	d [cm]	λ(W/m ·K)	R (m ^{2} ·K/W)
finishing layer	1.0	1.00	0.010
concrete layer	5.0	1.30	0.038
rubble	10.0	0.30	0.333
reinforced concrete slab	18.0	1.70	0.106
cement-lime plaster	2.0	0.82	0.024
internal heat transfer resistance (m ^{2}·K/W) - R_{si}			0.17
resistance to heat transfer to the outside (m ^{2}· K/W) - R_{se}			0.17
heat transfer coefficient (W/m ^{2}· K) - U			1,174

The values of heat transfer coefficients of window and door joinery in the building model were assumed as follows:

- Wooden windows, several years old – **U = 1.8 W/m ^{2}·K**
- Internal doors to unheated spaces – **U = 2.2 W/m ^{2}·K**
- External doors – **U = 2.2 W/m2 · K**

The calculated U-values were compared with the maximum limit values given in the currently applicable legal act in this respect, i.e. the Announcement of the Minister of Development and Technology of April 15, 2022 *on the announcement of the consolidated text Regulation of the Minister of Infrastructure on the technical conditions that should be met by buildings and their location* (Journal of Laws of 9 June 2022, item 1225, as amended).

The existing U-values are significantly higher than the maximum allowable values for a given type of building partition according to the Technical Specifications. The values of these coefficients are summarized in Table 2.

Table 2. Heat transfer coefficients of building partitions - existing condition			
Type of building partition	Unit	U-value	
		Condition existing	Requirements conditions technical
External walls at $t_{and} \geq 16\ ^0C$	W/m^2K	1.404; 1.364; 1.072; 0.897	0.20
Internal separating walls heated room from unheated	W/m^2K	1.246; 1.215	0.30
Roof, ceiling under unheated attic at $t_{and} \geq 16\ ^0C$	W/m^2K	1.204; 0.984; 0.414; 0.401	0.15
Ceiling above unheated rooms at $t_{and} \geq 16\ ^0C$	W/m^2K	1,174	0.25
Windows at $t_i \geq 16\ ^0C$	W/m^2K	1.8	0.9
Doors in external partitions	W/m^2K	2.2	1.3
Doors in partitions between rooms heated and unheated	W/m^2K	2.2	1.3

3. Annual demand for usable energy for heating and ventilation – current status

The annual energy demand for heating and ventilation of the building in a standard year (**Zamość weather station, climate zone III**) and the building's existing heat load were determined based on applicable standards, in accordance with the principles of determining building energy performance, using Sankom's Audytor OZC computer program . Calculations were based on factors such as the geometric dimensions of the adopted building model, its function, location, and the design of the energy-efficient shield.

Table 3 summarizes the calculation results for the existing state.

Table 3. Energy performance of the building - existing condition

Specification	Symbol	Unit	Value
Building heat load	$\Phi_{HL,0}$	kW	55.09
Heat demand for heating and ventilation - **usable energy (without taking into account the efficiency of the system** **heating and heating interruptions)**	$Q_{H,nd,0}$	GJ/year	472.83
		kWh/year	131342
The seasonal heat demand index in relation to **up to 1 m2 of heated volume without taking into account efficiency** **heating system and heating interruptions**	$EU_{H,0}$	kWh/m^2 · year	211.7
Temperature-controlled building space **(net heated area of the building)**	A_f	m^2	620.3
Ventilation air flow	$V_{nom,0}$	m3 / h	1299.9

H values were calculated according to the relationship below:

$$EU_{H,0} = \frac{Q_{H,nd,0}}{A_f}$$

4. Thermal modernization of building partitions

This chapter describes the technologies for insulating existing building envelopes and provides the types and thicknesses of insulating materials. For attic envelopes, the technologies, types, and thicknesses of materials described in the detailed design (item 2, section 2 of this document) were adopted. The same technologies and materials were used for the ground and first floor exterior walls, and their thickness was selected to meet the requirements of the Technical Conditions in this regard.

Table 4 presents a description of the thermal modernisation technology of building partitions, parameters of insulating materials (thermal conductivity coefficient - λ [W/m·K], thickness d [cm]) and the value of the heat transfer coefficient U [W/m ^{2} ·K] of the partition after its insulation.

Table 4. Insulation technologies, types and thicknesses

Partition type construction	Thermal modernization technology	Insulating material	Value At the end insulation	Source information
External walls ground floor	1) Prepare the inner surface of the wall (remove any dirt and non-adhering plaster fragments, fill any gaps with cement-lime plaster or filler) 2) Glue the thermal insulation boards directly to the wall with mineral glue in a staggered pattern. 3) Fill any gaps with the same glue. 4) Cover the board surfaces with approximately 5 mm thick mineral glue using the system reinforcing mesh. 5) Paint the wall surfaces with a paint with high water vapor permeability	mineral plate MULTIPORE: **d = 16 cm** λ ≤ 0.040 W/m·K	0.196	own calculations; fulfillment WT requirements
External walls floor		mineral plate MULTIPORE: **d = 18 cm** λ ≤ 0.040 W/m·K	0.184	own calculations; fulfillment WT requirements
External walls attic (SZ 1.1.)		mineral plate MULTIPORE: **d = 10 cm** λ ≤ 0.040 W/m·K	0.311	own calculations based on project executive
External walls attic (SZ 1.2.)		mineral plate MULTIPORE: **d = 5 cm** λ ≤ 0.040 W/m·K	0.504	own calculations based on project executive
Interior walls attic (SW 1.1.)		mineral plate	0.303	own calculations

		MULTIPORE: **d = 10 cm** λ ≤ 0.040 W/m·K		based on project executive
Interior walls attic (SW 1.2.)		mineral plate MULTIPORE: **d = 5 cm** λ ≤ 0.040 W/m·K	0.482	own calculations based on project executive
Ceiling under unheated attic (2.3.)	Clean the surface, lay a vapor barrier, make a wooden grid, lay wool mats, lay a vapor-permeable membrane	sheep wool mats: **d = 15 cm** λ ≤ 0.035 W/m·K	0.133	own calculations based on project executive
Attic slope (2.1.) from the side of the wall internal	Use the same technology for external walls as described above on the inside.	mineral plate MULTIPORE: **d = 10 cm** λ ≤ 0.040 W/m·K	0.200	own calculations based on project executive
Attic slope (2.2.) at a length of 1 m from the ceiling side	Remove the insulation layers, clean the surface, lay a vapor barrier foil, make a wooden grid, lay a vapor-permeable membrane; from the side of the heated room (from the inside), use the same technology as for external walls as described above	sheep wool mats: **d = 15 cm** λ ≤ 0.035W/m·K and mineral plate MULTIPORE: **d = 10 cm** λ ≤ 0.040 W/m·K	0.142	own calculations based on project executive
Ceiling in the dormers	Remove insulation layers, clean the surface, lay a vapor barrier foil, make a wooden grid, lay wool mats, lay a vapor-permeable membrane	sheep wool mats: **d = 15 cm** λ ≤ 0.035 W/m·K	0.149	own calculations; fulfillment WT requirements
Ceiling above the first floor (in the corners)	Clean the surface, lay a vapor barrier, make a wooden grid, lay wool mats, lay a vapor-permeable membrane	sheep wool mats: **d = 20 cm** λ ≤ 0.035 W/m·K	0.149	own calculations; fulfillment WT requirements

Windows	Replace windows with care their forms and historical stylistics	wooden windows with air vents humidity-sensitive	0.9 the whole window	fulfillment WT requirements
External doors	Replace external doors while preserving their historical form	wooden doors	1.3 the whole door	fulfillment WT requirements
The door between heated rooms and unheated	Replace interior doors	wooden doors	1.3 the whole door	fulfillment WT requirements

5. Annual demand for usable energy for heating and ventilation - target state

The annual usable energy demand for heating and ventilation of the building in a standard year (**Zamość weather station, climate zone III**) and the building's heat load in its final state were determined using the same method as for the existing state. The geometric dimensions of the building model were used for the calculations, as in the existing state, while the range of changes and values of the heat transfer coefficients of the building envelope were assumed in accordance with Table 4. Table 5 summarizes the calculation results for the final state.

Table 5. Energy performance of the building - target condition

Specification	Symbol	Unit	Value
Building heat load - Annex 5	$\Phi_{HL,1}$	kW	32.97
Heat demand for heating and ventilation -	$Q_{H,nd,1}$	GJ/year	267.22
usable energy (without taking into account the efficiency		kWh/year	74228
The seasonal heat demand index in relation to	$EU_{H,1}$	$kWh/m^2 \cdot$ year	119.7
up to 1 m2 of heated volume without taking into account			
Temperature-controlled building space	A_f	m^2	620.3
Ventilation air flow	$V_{nom,1}$	m3 / h	1299.9

$_{H,1}$ values were calculated according to the relationship below:

$$EU_{H,1} = \frac{Q_{H,nd,1}}{A_f}$$

6. Summary and conclusions

As a result of the improved thermal insulation of building envelopes, their heat transfer coefficients decreased, as shown in Table 6. Based on the calculation results and their analysis, we determined the usable energy savings and the decrease in the building's annual usable energy demand index resulting from the thermal modernization of building envelopes described in this study (item 7). The resulting decrease is given in Table 7.

Table 6. Summary of heat transfer coefficients of building partitions

Type of building partition	Unit	U-value		
		Condition existing	Condition target	Requirements conditions technical
External walls ground floor	W/m ^{2}K	0.897	0.196	0.20
External walls of the first floor	W/m ^{2}K	1,072	0.184	0.20
External walls (SZ 1.1.) attic	W/m ^{2}K	1,404	0.311	0.20
External walls (SZ 1.2.) attic	W/m ^{2}K	1,364	0.504	0.20
Internal wall (SW 1.1.) of the attic	W/m ^{2}K	1,246	0.303	0.30
Internal wall (SW 1.2.) of the attic	W/m ^{2}K	1,215	0.482	0.30
Ceiling under unheated attic (2.3.)	W/m ^{2}K	0.309	0.133	0.15
Attic slope (2.1.) (from the inside wall side)	W/m ^{2}K	0.401	0.200	0.15
Attic slope 2.2. (1m long from the ceiling side)	W/m ^{2}K	0.393	0.142	0.15
The ceiling in the dormers	W/m ^{2}K	0.414	0.149	0.15
Ceiling above the first floor (in the corners)	W/m ^{2}K	0.984	0.149	0.15
Ceiling above unheated basements	W/m ^{2}K	1,174	1,174	0.25
Windows	W/m ^{2}K	1.8	0.9	0.9
Doors in partitions between heated and unheated rooms	W/m ^{2}K	2.2	1.3	1.3
External doors	W/m ^{2}K	2.2	1.3	1.3

Table 7. Decrease in annual demand for usable energy for heating and ventilation					
Specification	**Symbol**	**Unit**	**Value**		**Decrease**
			Condition	**Condition**	
Building heat load	$\Phi_{HL,0}$ / $\Phi_{HL,1}$ / $\Delta\Phi_{HL}$	kW	55.09	32.97	**22.12**
		%	-	-	**40.1**
Heat demand for heating and ventilation - usable energy (without taking into account the efficiency of the heating system and heating interruptions)	$Q_{H,nd,0}$ / $Q_{H,nd,1}$ / $\Delta Q_{H,nd}$	GJ/year	472.83	267.22	**205.61**
		kWh/year	131342	74228	**57114**
		%	-	-	**43.5**
Seasonal heat demand indicator in relation to 1 m2 of heated volume without taking into account the efficiency of the heating system and heating interruptions	$EU_{H,0}$ / $EU_{H,1}$ / ΔEU_H	kWh/m^2 · year	211.7	119.7	**2.0**
		%	-	-	**43.5**

Conclusions from calculations and analyses:

The heat transfer coefficients (U) of the building partitions that constitute the balance shield of the heated part of the building, except for the ceiling above the unheated basement rooms, have been reduced. For most partitions, the U-values meet the requirements of the currently applicable national requirements specified in the Regulation of the Minister of Infrastructure of April 12, 2002, *on the technical conditions which buildings and their location should comply* . However, for several building partitions located in the attic, these requirements are not met (Table 6), which is due to the fact that the use of a thicker layer of insulation results in too much reduction in the width of the rooms (e.g. passageways).

It should be noted that this analysis only addresses the building's energy demand for heating and ventilation, which allowed only the determination of the EU index in its current and target state. However, the analysis does not include the impact of the type of technical heating system on the building's annual final energy demand (EK_H), nor the impact of the type of energy carrier on the building's annual non-renewable primary energy demand (EP_H).

It's important to note that the building's non-renewable primary energy demand for various purposes is the indicator used in the final energy assessment of the building and is compared to the requirements assigned to the given building type. In public buildings, in addition to the thermal needs for heating and ventilation, the energy demand for hot water, built-in lighting, and air conditioning (if present) should also be considered.

It should be noted that, in accordance with national legal regulations, buildings subject to reconstruction should only meet the requirements regarding the values of heat transfer coefficients of partitions forming the balance shield of the heated zone.

The achieved energy savings resulting solely from the improvement of thermal insulation of building partitions (described in detail in Table 4) on the example of the analyzed building model, which is an element of the frontage of a quarter of urban tenement houses, amounted to **43.5%.**

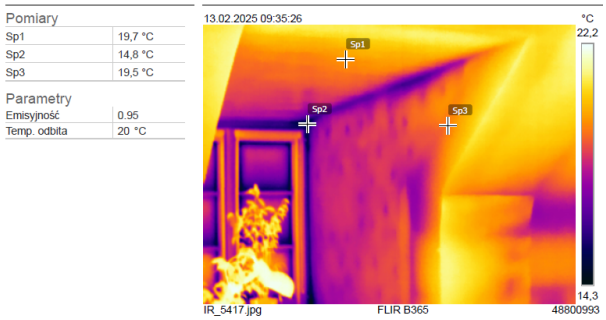
C. THERMOGRAPHIC INVESTIGATIONS

Thermographic investigations were carried out using a FLIR B365 thermal imaging camera. The measurements were conducted under conditions where the outdoor temperature was below 0°C, while indoor temperatures remained above zero.

The thermograms, based on the applied color scale, should be interpreted as follows: cooler areas (darker, violet-blue) and warmer areas (lighter, yellow-orange). In interior conditions, darker, violet-blue zones may indicate locations of thermal bridges, reduced insulation thickness, or insulation defects.

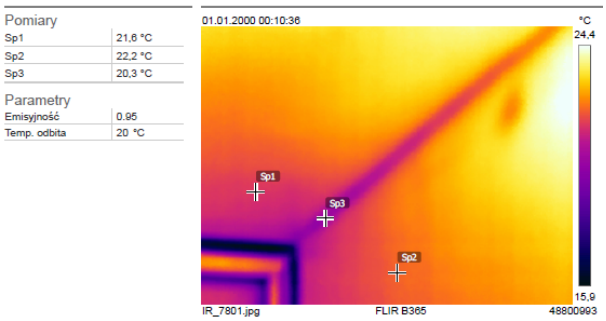
The investigations were performed in two stages. The first measurement was conducted prior to the commencement of thermal modernization works (2 February 2025), and the second measurement was carried out after the completion of the works (13 January 2026).

Ormiańska 11 – Investigation on 2 February 2025 – before thermal modernization





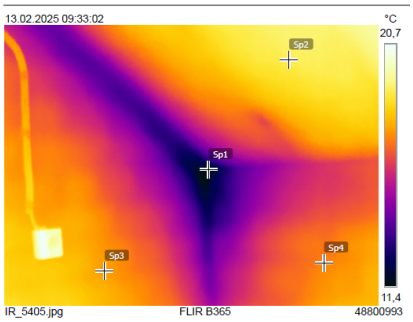
Ormiańska 11 – Investigation on 13 January 2026 – after thermal modernization





Pomiary	
Sp1	11,6 °C
Sp2	18,9 °C
Sp3	17,4 °C
Sp4	17,1 °C

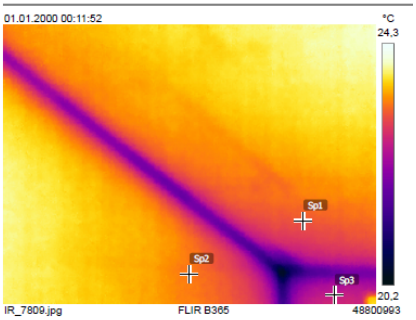
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	23,1 °C
Sp2	23,3 °C
Sp3	22,6 °C

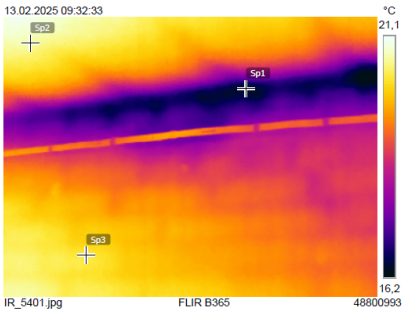
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	16,4 °C
Sp2	20,7 °C
Sp3	20,3 °C

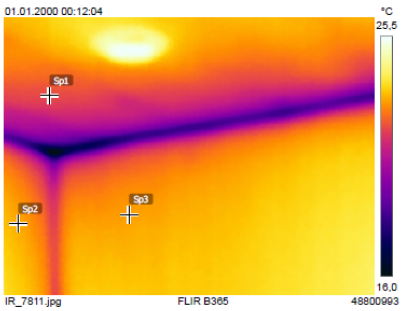
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	22,0 °C
Sp2	23,1 °C
Sp3	23,0 °C

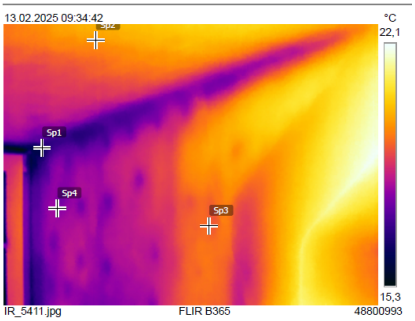
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	16,3 °C
Sp2	19,9 °C
Sp3	19,3 °C
Sp4	18,0 °C

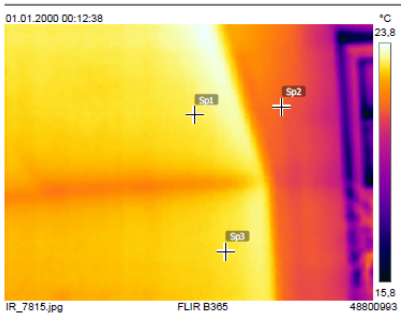
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	23,1 °C
Sp2	21,6 °C
Sp3	23,0 °C

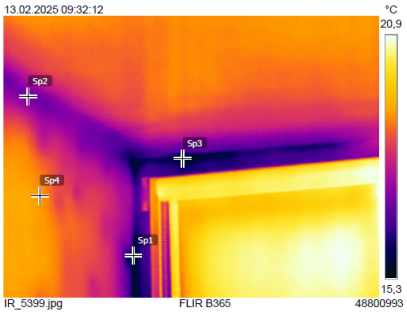
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	15,8 °C
Sp2	17,1 °C
Sp3	15,5 °C
Sp4	19,2 °C

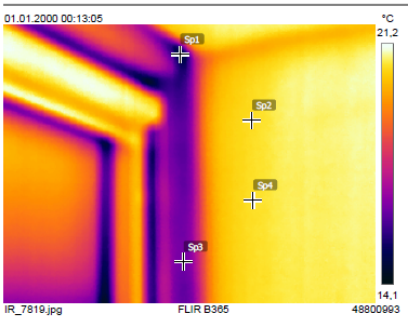
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	14,6 °C
Sp2	20,5 °C
Sp3	16,4 °C
Sp4	20,6 °C

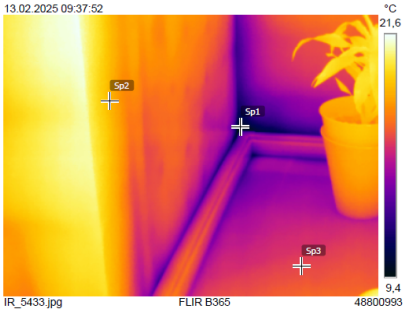
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	9,5 °C
Sp2	19,0 °C
Sp3	16,5 °C

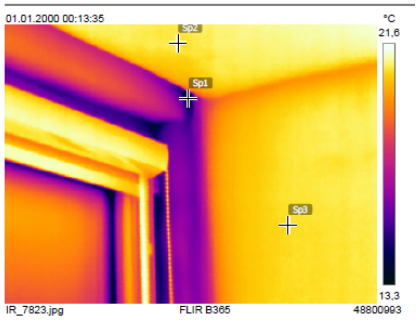
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C

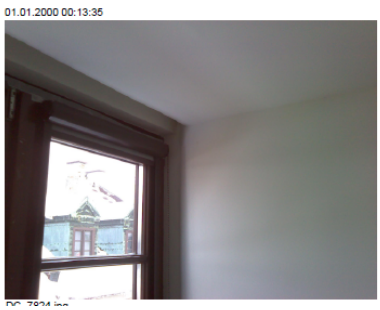




Pomiary	
Sp1	14,0 °C
Sp2	20,8 °C
Sp3	20,7 °C

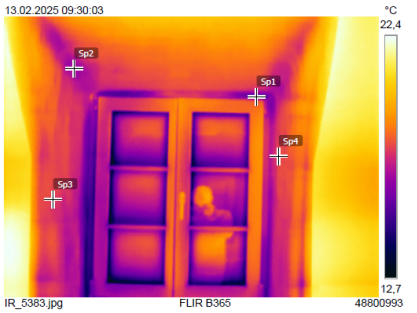
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	15,6 °C
Sp2	16,8 °C
Sp3	17,9 °C
Sp4	18,0 °C

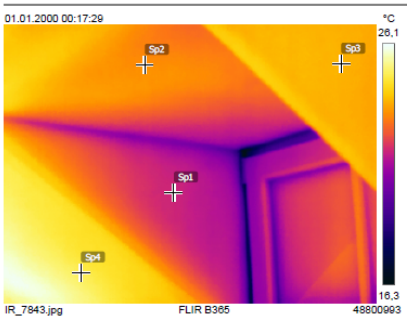
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	21,7 °C
Sp2	23,3 °C
Sp3	23,8 °C
Sp4	24,9 °C

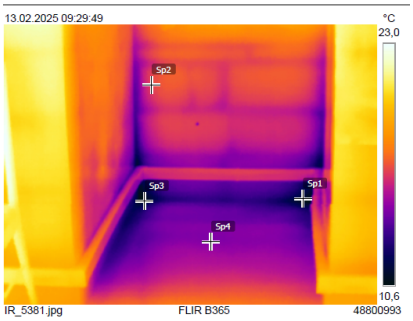
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	11,0 °C
Sp2	16,6 °C
Sp3	11,3 °C
Sp4	14,6 °C

Parametry	
Emisyjność	0.95
Temp. odbita	20 °C

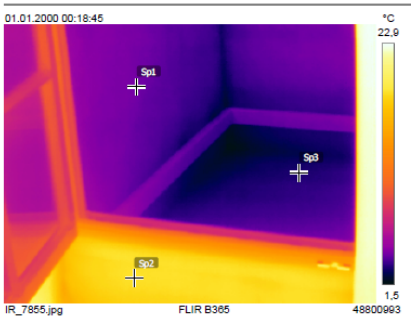




DC_5382.jpg

Pomiary	
Sp1	4,4 °C
Sp2	18,9 °C
Sp3	3,0 °C

Parametry	
Emisyjność	0.95
Temp. odbita	20 °C

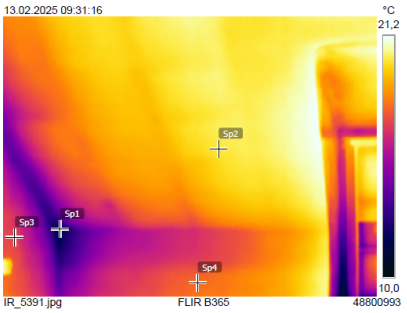




DC_7856.jpg

Pomiary	
Sp1	12,1 °C
Sp2	20,1 °C
Sp3	17,2 °C
Sp4	17,9 °C

Parametry	
Emisyjność	0.95
Temp. odbita	20 °C

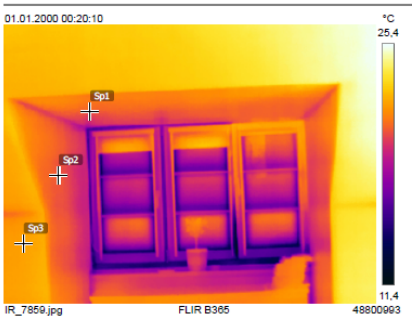




DC_5392.jpg

Pomiary	
Sp1	20,7 °C
Sp2	20,5 °C
Sp3	22,1 °C

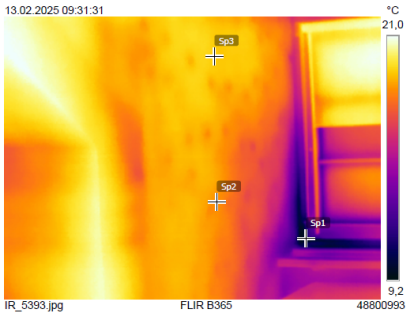
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	11,2 °C
Sp2	18,6 °C
Sp3	19,4 °C

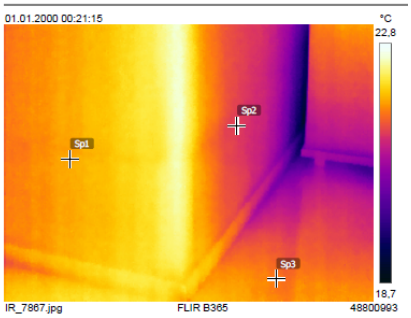
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	21,8 °C
Sp2	21,3 °C
Sp3	21,6 °C

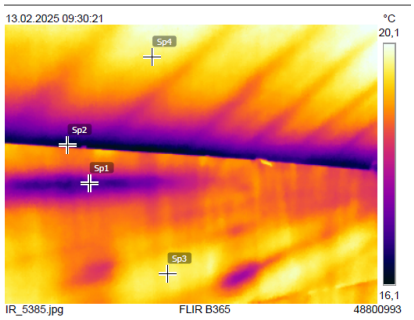
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	16,9 °C
Sp2	16,3 °C
Sp3	19,7 °C
Sp4	19,7 °C

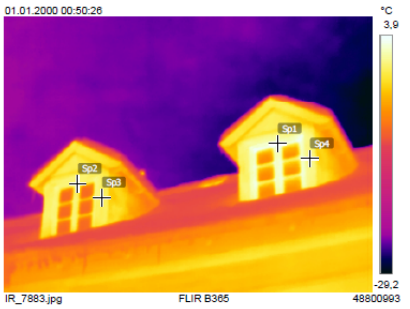
Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Pomiary	
Sp1	2,9 °C
Sp2	1,0 °C
Sp3	-0,1 °C
Sp4	0,8 °C

Parametry	
Emisyjność	0.95
Temp. odbita	20 °C





Conclusions from the investigations:

- Thermograms from 2025 show very significant temperature differences on the surfaces of building partitions, as well as at wall and ceiling junctions. These differences result from the presence of a large number of thermal bridges of both point and linear character. Another issue identified is the insufficient thermal insulation performance of the attic partitions. The internal surface temperatures of the walls increased from locally approximately 9–12°C (2025) to typically around 21–23°C (2026).
- As a result of the thermal modernization, the non-uniformity of temperature distribution has been reduced. After the retrofit, the surfaces of the investigated partitions exhibit a significantly more homogeneous temperature distribution. Temperature differences at corners and across partition surfaces are clearly lower. Previously observed dark areas on the surfaces of dormer walls are no longer present. The changes visible in the thermograms (2026) clearly indicate a reduction of thermal bridges.
- The risk of water vapor condensation has been significantly reduced. Prior to thermal modernization, temperatures on plaster surfaces near windows and corners were low enough that, even at relatively moderate air humidity levels, the dew point was exceeded, leading to a risk of moisture accumulation within the partitions. The clear increase in surface temperatures after thermal modernization has eliminated the risk of condensation.
- The works aimed at improving the thermal insulation of building partitions have minimized the potential for biological corrosion affecting building elements.
- At the junction between window frames and walls, zones of lower temperature are still observed compared to the surfaces of the dormer side walls. These differences are related to the reduced thickness of insulation material around the windows. This solution was applied intentionally, as the design did not provide for window replacement due to their good technical condition. The reduced insulation thickness results from the need to maintain full window functionality (i.e., the ability to open them).

Thermal modernization of slopes, ceilings, and walls has clearly improved the thermal comfort of the rooms. It has mitigated the two main problems typical for attics: excessive heat loss in winter and overheating in summer.

D. IN-SITU MEASUREMENT OF THERMAL TRANSMITTANCE (U-VALUE)

Measurements were carried out using a Heat Flow Meter (HFM). This method is considered the most accurate among in-situ techniques. A heat flux density sensor is placed on the internal surface of the building partition. Additionally, temperature sensors are installed on both sides of the partition (indoors and outdoors). This type of analysis is long-term in nature, and measurements should be conducted for at least several dozen hours. The figures below present the measurement setup in the pilot rooms.

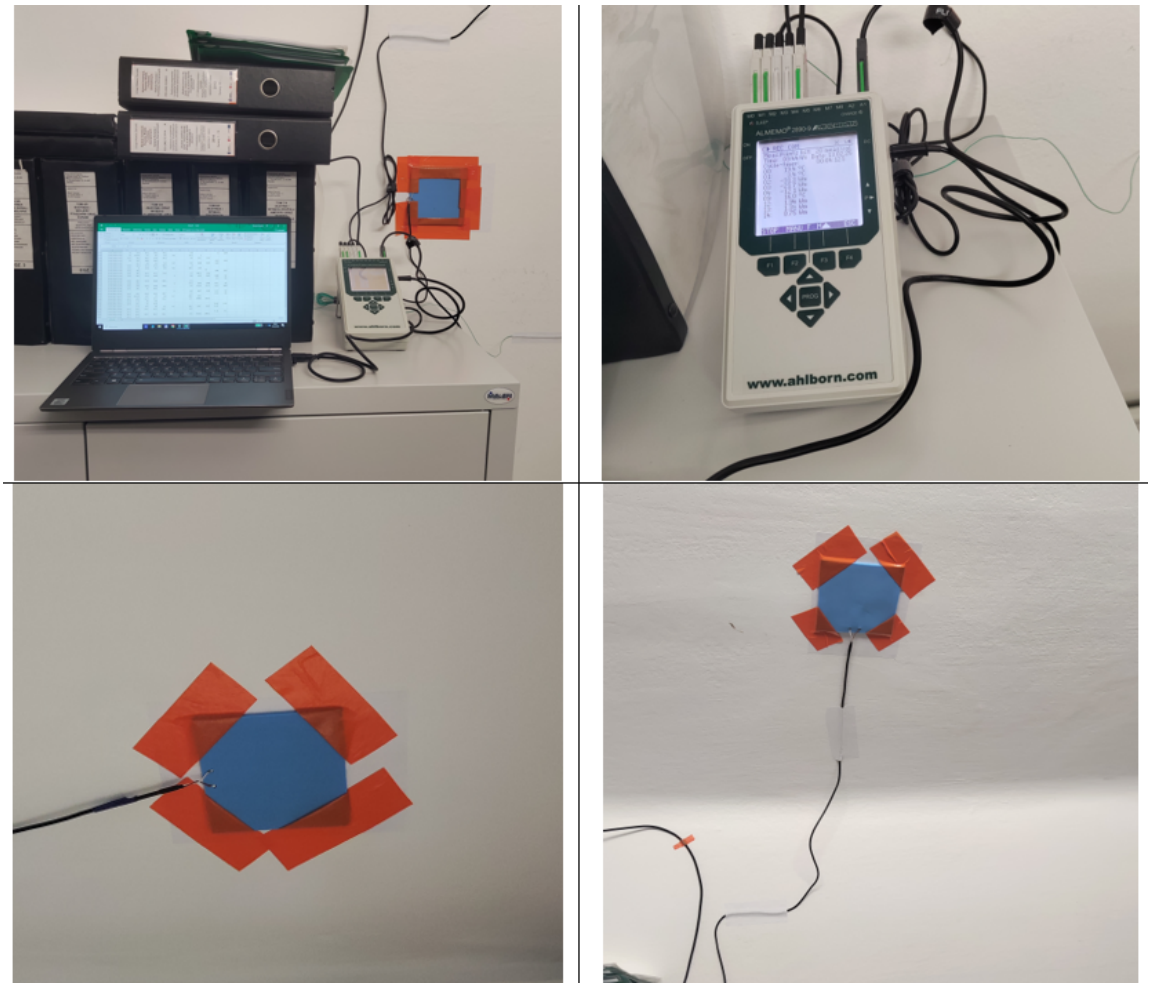


Table 8. Results of the thermal transmittance (U-value) measurements before and after thermal modernization

Type of building partition	Unit	February 2025 - before retrofit	January 2026 - after retrofit
External wall	W/m²·K	0.52	0.20
Attic slope	W/m²·K	0.61	0.37
Ceiling	W/m²·K	0.93	0.65

Conclusions from the investigations:

- For all three types of partitions, a significant reduction in the thermal transmittance coefficient (U-value) was observed after thermal modernization.
- In the case of external walls, the change from 0.52 W/m²·K to 0.20 W/m²·K represents a 62% reduction, which is the largest improvement among the analyzed partitions. This change resulted from the addition of an extra insulation layer.
- For attic slopes, a 39% reduction in the U-value was achieved. In this case, the existing insulation layer was removed and replaced with a new material with significantly improved thermal insulation properties.
- The smallest improvement was recorded for the attic ceiling. The change from 0.93 W/m²·K to 0.65 W/m²·K corresponds to a 30% reduction in the U-value. In this case, modifications included changes in layer composition and replacement of the insulation material.

All implemented solutions significantly reduced heat losses and had a positive impact on the thermal comfort of the attic spaces.

E. DESCRIPTION OF THE PILOT EVALUATION

The pilot evaluation was based on a comparative assessment of the building condition before and after thermal modernization works. The adopted methodology combined analytical calculations, thermographic investigations and in-situ measurements of thermal transmittance coefficients (U-values) in order to assess the effectiveness of the implemented retrofit solutions under real operational conditions.

The evaluation included analysis of the thermal performance of building partitions, verification of changes in heat transfer coefficients, assessment of thermal bridge reduction and comparative analysis of the building's calculated energy demand before and after implementation of the pilot intervention.

1. Baseline

The baseline condition of the building was established through detailed verification of its geometric, material and operational characteristics based on architectural inventory documentation, technical surveys and site inspections. The analytical model reflected the pre-retrofit state of the building and included the thermal parameters of the existing building envelope, ventilation conditions and operational assumptions corresponding to the actual use of the facility.

The baseline energy assessment was performed using Audytor OZC 7.0 Pro software in accordance with applicable Polish regulations and standards concerning building energy performance. The calculations were based on climatic data for climate zone III (Zamość weather station). In the baseline condition, the building was characterized by a seasonal usable energy demand index for heating and ventilation (EUH,0) equal to 211.7 kWh/m^2·year.

Additionally, pre-retrofit investigations included thermographic surveys and in-situ measurements of the thermal transmittance coefficient (U-value) for selected building partitions, providing reference data for comparative post-retrofit evaluation.

2. Savings projection

Projected energy savings were determined through comparative modelling of the existing and target conditions of the building. The calculations considered the improvement of thermal insulation parameters of building partitions, replacement of selected building components and modernization of selected building service installations.

The projected reduction in usable energy demand for heating and ventilation amounted to 205.61 GJ/year (57,114 kWh/year), corresponding to an estimated reduction of approximately 43.5% compared to the baseline condition. This value comes from a whole-building model, which also covers partitions outside the implemented attic works; it shows the potential of extending the solution and is not the result of the pilot works alone. The savings attributable to the attic works alone are therefore lower than this value. The reduction of the building heat load from 55.09 kW to 32.97 kW additionally confirmed the expected improvement in thermal performance.

The projections were developed using material parameters declared by manufacturers for the applied insulation systems, including mineral insulation boards and sheep wool insulation. The analysis primarily focused on the thermal performance of the building envelope. However, the pilot intervention also included modernization of selected heating system components, replacement of radiators, modifications to central heating pipework and installation of air-conditioning units intended both to improve indoor thermal comfort and to support environmental control, including humidity regulation within the historic building spaces.

3. Design, construction, and commissioning

The design phase was prepared on the basis of previous analytical investigations and conservation requirements applicable to the historic urban fabric of Zamość. The executive design documentation was prepared by KWADRA Architekci and included architectural, construction and installation-related solutions adapted to the specific conditions of a heritage-protected building.

The implementation phase required two consecutive public procurement procedures. The first procedure was cancelled due to budgetary limitations resulting from bids exceeding the financial resources allocated by the City of Zamość. Following the repeated procurement procedure, construction contract No. 631/2025 with Vector Construction Patryk Daniluk was signed on 17 June 2025.

The works included thermal modernization of building partitions, selected modernization works related to the heating installation, replacement of radiators, modifications of central heating distribution systems and installation of air-conditioning units. During construction works, additional interventions became necessary due to conditions identified after commencement of works, which is typical for interventions carried out in historic structures.

The construction works were supervised by the investor and author supervision of KWADRA ARCHITEKCI Sp. z o.o. Final acceptance and commissioning of the works took place on 7 October 2025 (final acceptance protocol; acceptance procedure started on 3 October 2025) and confirmed compliance of the executed works with the approved executive documentation and conservation requirements.

4. Operations, maintenance, and monitoring (O&M)

The operational recommendations developed for the pilot building focus primarily on maintaining appropriate hygrothermal conditions within internally insulated historic partitions. Due to the application of vapor-permeable insulation systems, it is recommended to use finishing materials characterized by high vapor permeability in order to maintain proper moisture transport within the building envelope and minimize the risk of interstitial condensation.

The building is additionally equipped with standard operational sensors monitoring indoor temperature and relative humidity in occupied spaces. These systems are used by the building administrator for operational control and user comfort management; however, they do not constitute a dedicated scientific monitoring system.

The City of Zamość continuously monitors building energy consumption and heat source operation parameters as part of standard facility management procedures. No operational problems, moisture-related defects or evidence of biological corrosion have been identified following completion of the thermal modernization works.

The final acceptance protocol recommended a prompt inspection and repair of the existing roof covering above the renovated rooms and the technical room, where local leaks and traces of moisture were observed. Until the repair, the ventilation unit should be operated with particular care and the condition of the room monitored, because moisture could damage the new equipment and the new insulation. The roof was subsequently repaired to the extent necessary for the pilot works. The protocol also recommends protecting the sheep wool insulation against rodents and concluding service contracts for the ventilation and air-conditioning equipment for the seven-year warranty period.

The installed air-conditioning systems additionally support stabilization of indoor environmental conditions, particularly in situations requiring humidity regulation within the historic interior spaces.

5. Measurement & Verification (M&V)

Post-retrofit verification activities were based on comparative measurements and field investigations carried out before and after implementation of the pilot intervention. The adopted methodology included thermographic investigations and in-situ measurements of thermal transmittance coefficients (U-values) for selected building partitions.

The post-implementation measurements were performed between 13 and 16 January 2026 by a research team from the Lublin University of Technology under environmental conditions suitable for thermal performance investigations. The measurements included Heat Flow Meter (HFM) testing and thermographic inspections using a FLIR B365 thermal imaging camera.

The investigations confirmed a significant improvement in the thermal performance of the analyzed building partitions after thermal modernization. Thermographic investigations demonstrated a clear reduction of thermal bridges and improved uniformity of surface temperature distribution. In-situ U-value measurements additionally confirmed a reduction in heat transfer coefficients for the investigated partitions compared to the pre-retrofit condition.

The applied comparative evaluation methodology enabled verification of the effectiveness of the implemented retrofit solutions under real operational conditions and confirmed the positive impact of the pilot intervention on the thermal performance and indoor comfort conditions of the historic building.

F. EVALUATION RESULTS: MEASURED PERFORMANCE AND MODELLED SAVINGS

This chapter separates the results that were physically measured from the annual savings that were calculated. No full heating season of measured consumption is included in this evaluation; annual energy, emission and cost savings are therefore modelled values.

6. Measured results

Partition	Before (February 2025) [W/m²K]	After (January 2026) [W/m²K]	Measured reduction
External wall	0.52	0.20	62 %
Attic slope	0.61	0.37	39 %
Attic ceiling	0.93	0.65	30 %

Thermal imaging confirmed a clear reduction of thermal bridges and a more uniform surface temperature distribution. Lower temperatures remain at the junctions of window frames and walls, where the insulation thickness was intentionally reduced. These in-situ values refer to selected measurement locations. They are not directly comparable with the calculated U-values in the analytical chapter, which are based on assumed material data for whole partitions.

7. Modelled annual savings

Indicator	Whole-building model (potential)
Final energy savings	57,114 kWh/year (approx. 43.5 %)
Primary energy savings	68,537 kWh/year
CO_2 emission savings	11.42 t CO_2/year
Energy cost savings	approx. 5,083 €/year

The values were calculated with the common project MRV methodology, using for district heating a CO_2 factor of 0.2 kg CO_2/kWh, a primary energy factor of 1.2 and a unit cost of 0.089 €/kWh. The whole-building model also covers partitions outside the implemented attic works and shows the potential of extending the solution to the whole building; the savings attributable to the attic works alone are lower. It must not be read as the result of the pilot works alone.

Table 4 of the analytical chapter presents the measures assumed in the energy model, including window replacement. In the implemented pilot works the historic windows were not replaced; as confirmed by the final acceptance protocol, an internal window in a historical form was installed.

8. Financial and environmental evaluation

According to the final acceptance protocol, the value of the construction works was PLN 251,639.65 net (PLN 309,516.77 gross). The environmental benefit results from lower heat demand and the related reduction of emissions. Solutions were selected to preserve the historic fabric. Air conditioning improves summer comfort, but its use should be limited through the improved envelope and controlled ventilation.

9. Completion of the evaluation

The evaluation, including the measurements of January 2026, was completed in February 2026, within the project period ending on 31 March 2026.

G.CONSTRUCTION WORKS PHASE - 03.2025 - 10.2025

This chapter summarises the **execution of the pilot investment** in the historic building at **Ormiańska 11 in Zamość**, following the completion of the design, permitting and approval procedures described in Deliverable D.2.2.2. This phase represents the transition from a fully authorised technical concept into a **real, physical intervention** aimed at improving the energy performance of a listed building within a UNESCO-protected historic urban area.

The construction phase involved not only the physical implementation of the thermal modernisation works, but also a series of **public procurement, contractual and regulatory steps** that are inseparable from investment processes in public, heritage-protected buildings. The pilot required two consecutive tender procedures, the signing of a construction contract, and later an amendment to cover additional works that proved necessary during implementation. This reflects the practical realities of working in historic structures, where hidden conditions and conservation constraints frequently necessitate adaptations to the original scope of works.

The chapter further covers the **completion and formal acceptance of the works**, followed by an **energy audit and post-implementation performance measurements** carried out by the Lublin University of

Technology. These final verification steps ensured that the implemented solutions could be evaluated against the baseline conditions established during the research and design phases, thereby closing the full cycle from testing and design to construction and performance assessment.

Together, these activities demonstrate how a technically validated and conservator-approved project can be successfully delivered in a real heritage context, while maintaining control over quality, scope and regulatory compliance.

The following calendar presents the construction phase as a chronological sequence of procurement, contracting, implementation and verification steps, providing a clear timeline of how the pilot investment was delivered from contract award to final acceptance.

1. 2–17 April 2025 – execution of the first tender procedure for the selection of a contractor for the pilot works. The procedure was cancelled because the only submitted bid exceeded the budget allocated by the Contracting Authority (City of Zamość).
2. 28 April – 20 May 2025 – implementation of a repeated tender procedure for the selection of a contractor for the pilot works within the project.
3. 17 June 2025 – signing of contract No. 631/2025 with the contractor Vector Construction Patryk Daniluk for the execution of the pilot works. The planned completion date was 18 September 2025.
4. 18 July 2025 – commencement of works in the pilot building.



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5. 10 September 2025 – signing of Amendment No. 1 to the contract for the execution of the pilot actions. During the execution of the contract, it became necessary to perform additional works that were not included in the original scope but proved to be necessary for the proper completion of the contract.
6. 5 September 2025 – protocol of necessity agreeing additional works: replacement of the existing cast-iron radiators and of the expansion vessel.
7. 25 September 2025 – completion of the structural, sanitary and electrical works recorded in construction log No. 26/2025; the contractor notified completion and readiness for final acceptance, confirmed by the supervision inspector in the construction log.
8. 2 October 2025 – contractual completion date of the works under Amendment No. 1.








9. 3 October 2025 – performance of the analytical energy audit.
10. 7 October 2025 – signing of the final acceptance protocol. The acceptance committee appointed by the Mayor of Zamość, whose work began on 3 October 2025, accepted the works without defects.
11. 13–16 January 2026 – execution of measurements by the Lublin University of Technology in the pilot building at Ormiańska Street 11 in Zamość. The purpose of the measurements was to determine the heat transfer coefficient (U-value) of the building partitions after the thermal modernisation.



H.SUMMARY

This document presents the complete implementation pathway of **Pilot Action 2** carried out in the historic building at **Ormiańska 11 in Zamość** within the framework of the ZEB4ZEN project. It documents how the research-based concepts and technical solutions developed during the preparation phase were transformed into a **fully designed, permitted and constructed pilot investment** in a UNESCO-protected historic urban area.

This report covers three successive and interlinked phases. The **Preparation Phase (10.2023-07.2024)** establishes the conservation, institutional and organisational framework required to carry out energy-related research in a listed monument. It includes the selection of the research facility at the Zamoyski Palace, conservation investigations, installation of the research station and long-term monitoring activities that provided the technical foundation for the pilot.

The **Design Phase (07.2024-03.2025)** demonstrates how the results reported in **Deliverable D.2.2.1** were translated into a **buildable and fully authorised technical project**. This phase includes analytical studies of thermal bridges, preparation of architectural and construction documentation, in-situ U-value measurements in the pilot building, and the full sequence of heritage and building permits required for intervention in a protected historic structure.

The **Construction Works Phase (03.2025-10.2025)** documents the execution of the pilot investment, including public procurement, contracting, physical implementation of the thermal modernisation works, contract amendments, final acceptance, energy auditing and post-implementation performance measurements. These steps confirm that the Zamość pilot was delivered in compliance with conservation, technical and public-procurement requirements while maintaining the targeted energy performance objectives.

This report therefore provides a complete, verifiable and replicable model for how energy-efficient modernisation can be implemented in historic buildings under real regulatory and conservation constraints. The actual performance and effectiveness of the applied solutions are assessed in this report on the basis of post-implementation measurements and energy audits, completing the full evidence chain from research and design to construction and verified energy performance.

I. CONCLUSION

The conducted pilot action confirmed that thermal modernization of historic buildings can be successfully implemented while respecting conservation requirements and preserving the architectural character of protected heritage structures. The adopted solutions demonstrated that improvement of energy performance in historic buildings is achievable without the use of invasive interventions that could negatively affect the cultural value of the building.

The performed analytical calculations, thermographic investigations and in-situ measurements confirmed a clear improvement in the thermal performance of the building envelope after completion of the retrofit works. The implemented insulation systems contributed to the reduction of thermal bridges, improvement of surface temperature distribution and enhancement of indoor thermal comfort conditions within the attic spaces.

The investigations additionally confirmed that the use of vapor-permeable insulation materials is an appropriate solution for historic masonry structures insulated from the interior side. The applied systems contributed to reducing the risk of moisture accumulation and biological corrosion while maintaining proper hygrothermal behavior of the building partitions.

The pilot action also demonstrated the importance of combining analytical studies with field investigations and post-implementation verification measurements. Comparative thermographic investigations and in-situ thermal transmittance measurements provided valuable confirmation of the effectiveness of the implemented retrofit solutions under real operational conditions.

The implementation process highlighted the complexity of carrying out modernization works in heritage-protected buildings, where conservation requirements, technical limitations and unforeseen conditions identified during construction frequently require adaptation of the original project assumptions. At the same time, the project confirmed that effective cooperation between designers, contractors, conservation authorities and technical experts makes it possible to successfully complete energy retrofit interventions in historic structures.

The modernization works contributed not only to improving the thermal performance of the building but also to stabilizing indoor environmental conditions and improving user comfort. The introduction of selected installation-related improvements additionally supported environmental control within the historic interior spaces.

Overall, the pilot action provides a practical and replicable example of how energy-efficiency measures can be integrated into historic buildings in a technically effective and conservation-compatible manner. The experience gained during the implementation and evaluation phases may serve as a valuable reference for future thermal modernization projects carried out in heritage-protected buildings and historic urban areas.