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Thermal Rehabilitation of an Educational Building in the Context of the Adaptation of Buildings to the Effects of Climate Change. Case Study

PhD. student Eng. **Nicoleta-Elena KABA**[1], Prof. Emeritus PhD. Eng. **Adrian RETEZAN**[1], Assoc. Prof. PhD. Eng. **Adriana TOKAR**[1,*]

[1] University Politehnica Timisoara

* adriana.tokar@upt.ro

Abstract: *In view of the Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services, it is requested, as a consequence, to ensure the Energy Audit of the building and propose energy improvement measures in order to access structural funds, inclusively for functional and structural rehabilitation. This article proposes to analyse the energy survey aimed at the issuing of the Energy Efficiency Certificate of the building, and finally the Energy Efficiency Audit of the thermally rehabilitated school building, in view of improving the energy efficiency of the building and of the related installations.*

Keywords: *Energy efficiency audit, energy certificate, rehabilitation, thermal insulation*

1. Introduction

Mitigation of the climate changes felt in the last period is a worldwide concern that in order to stabilize the global temperature would take about 20-30 years (approximately 1.1°C of warming since 1850-1900, and finds that averaged over the next 20 years, global temperature is expected to reach or exceed 1.5°C of warming) and hundreds of years to thousands of years in terms of continued sea level rise (Coastal areas will see continued sea level rise throughout the 21st century, contributing to more frequent and severe coastal flooding in low-lying areas and coastal erosion). It is already proven that the strong and sustained reduction of carbon dioxide emissions (CO_2) and other greenhouse gases would limit the effects of these climate changes [1].

In this context, it can be said that in the field of construction a rapid adaptation to the pace of climate changes is needed, both in terms of existing buildings and in terms of the decreasing environmental impact, with an emphasis on reducing CO_2 emissions. Vulnerability of buildings to climate change manifests itself through negative effects on the structural characteristics of building and indoor comfort conditions [2].

As far as Romania is concerned, it is estimated that a high percentage of buildings (77% [3]) do not meet the energy efficiency criteria related to the building envelope and therefore the application of energy renovation measures is necessary. Regarding Romania's total energy consumption, it is estimated that the building sector represents a percentage of 45% [3], so the energy efficiency of this sector will certainly contribute to reaching the targets, established by European and national strategies, in terms of energy efficiency.

Unfortunately, the rehabilitation rate of buildings in Romania is quite low, but it is worth appreciating the fact that buildings in the tertiary sector are given a lot of attention.

The urgent application of measures to combat climate change and implicitly their consequences also implies the energy efficiency of buildings, which is also a basic element in ensuring a sustainable energy future. Thus, the UN's 2030 Agenda for Sustainable Development will establish 17 sustainable development goals (SDGs) and 169 targets for their achievement. Figure 1 shows the progress registered in the EU until 2022, of objective 7 relating to energy (Fig. 1 a) and of objective 11 relating to climate change (Fig. 1 b) [4].

In achieving these objectives, from the point of view of the stock of existing buildings, their energy audit plays an important role. Thus, by establishing the energy performance of a building, correct and effective energy rehabilitation measures can be proposed. For this reason, the article proposes a case study that addresses the energy audit of an educational building.

a) b)

Fig. 1. SDG progress in the EU [4]
a) SDG7, b) SDG 11

The object of this audit is the Primary and Lower Secondary School of Giera (Fig. 2). The building was built in the 60s, but various improvements have been performed over the years. The school has two floors, having 664.80 m^2 footprint, gross building area of 1150.10 m^2 and 943.10 m^2 net area [5].

Fig. 2. Primary and Lower Secondary School of Giera

The building has one main entrance and several secondary entrances from the yard. The floor has an equal height of 3m, the roof is truss-type and has ceramic roof tiles. The framework of the building is made of burned brick masonry placed on a continuous concrete foundation. The interior floor is made partially of mosaic concrete and the rest is a boarding floor. The ceiling slab of the 1st floor is made of wood revetment nailed on the wooden boards placed over the rooms and covered in plaster on reed net support. The rooms have the ceiling made of resinous wood logs, platen with wood board and reinforced plaster on reed net. The slab under the roof truss is made of plastered wood, with beaten clay thermal insulation. The following finishing works are made in the interior of the building: warm floors; wood flooring; cold floors; hallways and pathways and the footsteps are

plated with mosaic precast plates. The entrance doors in the building are made of PVC joinery with double-glazed windows, being in very good shape [5, 6].
As a consequence of the Energy Efficiency Audit, the exterior wall, the floor slab and ceiling slab will be thermally insulated, and the installation will be modified. The main elements of the supporting structure are [5, 6]:

- Load-bearing walls made of full brick masonry;
- Concrete continuous foundations under the load-bearing walls;
- The floor under the roof truss is made of wood;
- The ceiling of the first floor is insulated with beaten clay. It is a structure of wood logs and boards, plaster on reed net support and beaten clay to provide thermal insulation.

2. Assessment

The building as a whole has remained in good shape over the time (from the point of view of load-bearing structure). No cracks due to unequal settlement of earth or to seismic effects have been noticed until now [5].
After the visual control, the building has no structural damages to the main elements. The interior and exterior finishing works of the building floors and ceilings are damaged [6].
The building also has non-load-bearing damages and depreciation signs of the ceramic tiles (without negatively affecting the load-bearing structure of the roof truss) and of the rain water gutters. The ceiling of the entire building is made of wood revetment nailed under the wood logs covering the ground floor; the ceiling is plastered on a Rabitz plastering net. Earth has been introduced among the wood logs serving as thermal insulation [6].
The interior floors also have signs of tear. The interior floor boarding of the building is made of wood board covered by carpet and other types of floor covering.
Dark stains are visible inside the building due to growth of microorganisms on wet surfaces. Therefore, the exterior thermal insulation is insufficient mainly at corners and in between.
The thermal insulation of the ground floor ceiling is made of beaten clay, but it is damaged due to the age of the building and to the roof truss defects [6].

2.1 Heating and hot water installation

The building has a functional heating installation, using hot water as thermal carrier and a distribution system of steel radiators. The heat carrier is supplied by a functional boiler. The calculation of thermal losses has been made according to the applicable standard [7]. All the afore mentioned facts are representing the motivation to perform this survey, according to the Construction Quality Law [8], considering the inefficient performance from an energy point of view. We mention that the survey of the building has been already done and requires the thermal rehabilitation. The evaluation of the building was done in accordance with the regulations and norms in force in Romania [9-18].

3. Information regarding the building

The total heated volume of the building is 3160.00 m^3 and the geometrical, thermal and technical characteristics of the actual building covering is presented in Table 1. The main elements of the building that refer to the walls (PE), joinery, ground slabs and loft floor are analyzed from the point of view of their orientation and thermal resistance [5, 6].

Table 1: Geometrical, thermal and technical characteristics of the actual building covering

Building elements	Orientation	Surface [m^2]	Total surface [m^2]	Thermal resistance [m^2K/W]
PE 1	N	210.70	817.80	3.634
	S	107.60		
	E	209.50		
	V	290.00		
PE 2	N	83.50	374.30	2.384

Building elements	Orientation	Surface [m²]	Total surface [m²]	Thermal resistance [m²K/W]
	S	38.50		
	E	108.70		
	V	143.60		
PE 3	N	-	161.20	4.53
	S	93.90		
	E	67.30		
	V	-		
PVC Joinery	N	22.50	228.60	0.50
	S	57.20		
	E	100.30		
	V	48.60		
Ground slab	O	928.80	928.80	3.055
Loft floor	O	928.80	928.80	4.226
Total			**3439.50**	-

The average resistance of the actual building covering is: $\bar{R} = 2.459$ m²K/W and compactness index of the building: S_{ext} / V = 0.56 [6].

From the point of view of the existing system for space heating, it was found [6]:
- Energy source for heating: gas fuel;
- Type of heating system: heating station;
- Distribution of heat carrier: two tubes;
- Computed heating requirements: 120 kW;
- Connection to the central heating source: -;
- Heat meter for heating system: -;
- Thermal and hydraulic automation elements: yes.

For annual heat consumption for heating (Q) and specific annual heat consumption for heating the rooms of the building (q), it is known [6]:
- at the level of the heated spaces: Q_{inc} = 223.50 MW/an;
- at the level of the heat source connection: Q_{inc} = 294.111 MW/a;
- at the level of the heated spaces: q_{inc} = 236.98 MW/m^2 an;
- at the level of the heated spaces: q_{inc} = 311.86 MW/m^2 an.

The performances of the distribution system and the heating installation are:
- η_d = 0.95 - distribution;
- η_{inc} = 0.80 - heating installation.

3.1. Information concerning the heating installation for domestic hot water

The consumption points for hot / cold water (16/32) are equipped with 12 sinks, 2 shower tubs, 24 lavatories and 8 toilet bowls [6].
For average specific normalized heat consumption of hot water, it was established the value of 15.00 kWh/m^2 an and in addition it was established for lighting, that the average specific electricity consumption is 32.81 kWh/m^2 an [6].

4. Calculation the global coefficient of thermal insulation, G_1 [W/m^{3}K]

Calculation of the global coefficient of thermal insulation was performed both for the current building and for the reference building [6].

4.1. Actual Building

The thermal resistance of the elements of the actual building covering is presented in Table 2 and the coefficients of heat loss through transmission (thermal coupling), in Table 3.

Table 2: Thermal resistance of the building, elements of the actual building covering

Building element /Symbol	R_j [m^2 K/W]	τ_j [-]	R'_j [m^2K/W]
North Wall (P N)	0.724	0.85	0.615
South Wall (P S)	0.724	0.85	0.615
East Wall(P E)	0.724	0.85	0.615
West Wall (P V)	0.724	0.85	0.615
North Facade (FT N)	0	0	0.5
South Facade (FT S)	0	0	0.5
East Facade (FT E)	0	0	0.5
West Facade (FT V)	0	0	0.5
Ground Slab (PLS)	1.131	1	3.18
Ceiling (PLF)	1.54	0.85	1.309
Average corrected thermal resistance of the covering [m^2K/W]			**0.96**

Table 3: Coefficients of heat loss through transmission (thermal coupling), L_j [W/K]:

Building element /Symbol	Aj [m^2]	R'j [m^2K/W]	Lj = Aj/R'j [W/K]	τ_j [-]	$\tau_j \cdot$Lj [W/K]
North Wall (P N)	296.4	0.615	481.95	1	481.95
South Wall (P S)	247.9	0.615	403.08	1	403.08
East Wall (P E)	163.9	0.615	266.50	1	266.50
West Wall (P V)	170.1	0.615	276.58	1	276.58
North Facade (FT N)	34.5	0.5	69	1	69
South Facade (FT S)	66.7	0.5	133.4	1	133.4
East Facade (FT E)	26.0	0.5	52	1	52
West Facade (FT V)	34.5	0.5	69	1	69
Ground Slab (PLS)	664.8	3.18	209.05	0.35	73.17
Ceiling (PLF)	664.8	1.309	507.86	0.9	457.08
TOTAL $t_j \cdot L_j$					**2281.7**

where:
A – element envelope area, [m^2];
R- real thermal resistance of the constructive element, [m^2K/W];
R′- value of the adjusted thermal resistance, [m^2K/W];
τ - dimensionless temperature correction factor, [-].
L_j - coefficients of heat loss through transmission (thermal coupling), [W/K]

For actual building, the global thermal insulation coefficient, G_1 [W/m^3K], was calculated with the relation (1):

$$G_1 = \frac{\sum_j L_j \cdot \tau_j}{V} 0.34 \cdot n \quad (1)$$

where:
V - building volume, [m^3];
n – ventilation rate, [h^{-1}].

After calculating the result: G1 = 0.563 [W/m^3K]
The building is in Category 2, having low / medium thermal inertia (M<400 kg/m2). In conclusion, comparing the values G_1 and G_{1ref} it results: G_1= 0.563 [W/m^3K] > G_{1ref} =0.311 [W/m^3K] and consequently the global level of thermal insulation of the building is inadequate; the correction of the geometrical, thermal, technical and the conformity characteristics of the building covering is required in order to comply with the standard stipulations.

4.2. Reference Building

The thermal resistance of the elements of the reference building covering is presented in Table 4 and the coefficients of heat loss through transmission (thermal coupling), in Table 5 [6].

Table 4: Thermal resistance of the building elements of the reference building covering

Building element /Symbol	R_j [sqmK/W]	τ_j [-]	R'_j [m K/W]
North Wall (P N)	2.997	1	2.997
South Wall (P S)	2.997	1	2.997
East Wall (P E)	2.997	1	2.997
West Wall (P V)	2.997	1	2.997
North Facade (FT N)	0	0	0.5
South Facade (FT S)	0	0	0.5
East Facade (FT E)	0	0	0.5
West Facade (FT V)	0	0	0.5
Ground Slab (PLS)	**3.231**	**1**	5.48
Ceiling (PLF)	**5.249**	**1**	5.249
Average corrected thermal resistance of the covering [m^2K/W]			**2.741**

Table 5: Coefficients of heat loss through transmission (thermal coupling), L_j [W/K]

Building element /Symbol	A_j [m^2]	R'_j [m^2K/W]	$L_j = A_j/R'_j$ [W/K]	τ_j [-]	$\tau_j \cdot L_j$ [W/K]
North Wall (P N)	296.4	2.997	98/899	1	98.899
South Wall (P S)	247.9	2.997	82/716	1	82.716
East Wall (P E)	163.9	2.997	54/688	1	54.688
West Wall (P V)	170.1	2.997	56/757	1	56.757
North Facade (FT N)	34.5	0.5	69	1	69
South Facade (FT S)	66.7	0.5	133/4	1	133.4
East Facade (FT E)	26	0.5	52	1	52
West Facade (FT V)	34.5	0.5	69	1	69
Ground Slab (PLS)	664.8	5.48	121/31	0/35	42.46
Ceiling (PLF)	664.8	5.249	126/65	0/9	113.98
TOTAL tj·Lj					**772.90**

For the reference building, the global thermal insulation coefficient, G_1 [W/m^3K], was calculated with the relation (1) and the resulting value was 0.191 [W/m^3K].
The building is in Category 2, having low / medium thermal inertia (M<400 kg/m^2). In conclusion, comparing the values G_1 and G_{1ref} it results: G_1= 0.191 [W/m^3K] > G_{1ref} =0.311 [W/m^3K] and consequently, the global level of thermal insulation of the building is adequate.

5. Technical solutions recommended for the energy efficiency refurbishment of the building

The energy efficiency refurbishment will be achieved by investment in the building and modification of the building installations [6].

5.1. Modifications of the building

The modifications brought to the building are aiming to reduce the heat needed by the thermal insulation of the structure and by reducing the infiltration through gaps:

- improvement of the thermal insulation - the thermal insulation of the existing building aims to reduce the thermal flow by conduction through the building covering;
- thermal insulation of the horizontal opaque building elements - thermal insulation of the floor below the roof truss shall be solved as follows:
  - o the following shall be laid over the last layer:

    - the waterproofing layer shall be eliminated, slope concrete, thermal insulation layer;
    - an equalizing screed shall be poured;
    - 1K Spezial Bituminous emulsion shall be applied at cold (vapors barrier and adhesive layer for stone wool);
    - 20 cm-thick stone wool;
    - polyethylene sheet; slope concrete; renewal of waterproofing layer.
  - thermal insulation of the boarded floor on soil:
    - dismantling of the existent boarded floor;
    - base slab;
    - 6 cm thick expanded polystyrene over the base slab; protection screed; renewal of boarded floor.
- thermal insulation of vertical opaque building elements - the exterior thermal insulation of the exterior walls is not necessary.

5.2 Improvement of air tightness

Replacing the existing windows and doors having wooden joinery with double-glazing glass R’=0.87 m^2K/W. The fresh air necessary for a quality comfort of the interior air and limitation of humidity and sweat that could have negative impact over the building will be provided by periodically opening of windows.
The exterior doors will be provided with automatic closing systems.

6. Modification of the installations

The proposal for the rehabilitation of the interior installations is the following [6]:

- Fitting of thermoregulator valves on the radiators;
- Replacement of the electrical installations with LED-type source lighting installation;
- Installing a solar panel system for domestic hot water production;
- Installing a thermal agent producing system using a heat pump;
- Installing a low temperature heating system for the thermal agent produced by the heat pump.

In order to carry out the works regarding the rehabilitation solutions, specific technical solutions or packages of solutions containing the above technical solutions may be proposed.

7. The following scenarios are proposed:

***Scenario no. 1*:** It contains the minimum measures package regarding the thermal refurbishment of the building [6].
This package contains rehabilitation solutions for:

- opaque horizontal surfaces, the floor below the roof truss/the floor above the soil, and improvement of air tightness - solutions are presented in chapters 5.1 and 5.2;
- the interior installations – by fitting of thermoregulator valves - solutions are presented in chapter 6;
- replacement of the electrical installations - LED-type source lighting installation - solutions are presented in chapter 6.

***Scenario no. 2*:** It contains the minimum measures package regarding the more efficient thermal refurbishment of the building [6].
This package contains rehabilitation solutions for:

- opaque horizontal surfaces, the floor below the roof truss / the floor above the soil, and improvement of air tightness - solutions are presented in chapters 5.1 and 5.2;
- the interior installations – installing a heat carrier producing system using heat pump, installing a low temperature heating system for the heat carrier produced by the heat pump and installing a solar panel system for domestic hot water production - solutions are presented in chapter 6;

- replacement of the electrical installations - LED-type source lighting installation, solutions are presented in chapter 6.

8. Advantages and Disadvantages of solutions:

- **Advantages of Scenario no. 1:**

Technical thermal rehabilitation solutions are solutions that increase the thermal resistance of vertical and horizontal opaque building elements, correcting most thermal bridges, protecting load-bearing elements and the overall structure against the effects of temperature variation; does not affect plastering, painting, and interior painting, and at the same time allows the facade to be rehabilitated. Fitting thermoregulator elements on the radiator’s feeding line increases the use performance of the energy generated by the use of fuel. Replacing the existing electrical installations with LED-type sources increases the safety of building operation, avoiding the eventual problems related to operation safety and fire hazards.

- **Disadvantages of Scenario no. 1:**

Implementing these measures, the building continues to use only non-renewable energy sources.

- **Advantages of Scenario no. 2:**

Technical thermal rehabilitation solutions are solutions that increase the thermal resistance of vertical and horizontal opaque building elements, correcting most thermal bridges, protecting load-bearing elements and the overall structure against the effects of temperature variation; does not affect plastering, painting and interior painting, and at the same time allows the facade to be rehabilitated. Installing the local heat carrier production system using a heat pump, the efficiency of the production system is maximized, this type of energy being renewable. Installing the low temperature heating system is a special requirement for using the heat carrier produced by the heating pump, using the built-in floor heating with serpentine heating tube. Installing the system for hot water production using solar panels is an efficient solution with low operation costs. Replacing the existing electrical installations with LED-type sources increases the safety of building operation, avoiding the eventual problems related to operation safety and fire hazards.

- **Disadvantages of Scenario no. 2:**

The disadvantages of the heat pump are related to the costs of the initial investment, by costs related to the heat pump and also to the primary heat exchanger needing great depth pit which is very expensive especially for this type of soil and also due to the small land plot which is available; Installing a low temperature heating system involves pretty high implementation costs and needs special operation and setting instructions.

9. Conclusions

Scenario no. 1 is recommended for the work performance. This package proposes rehabilitation solutions that are the best from a technical and economical point of view, depending on the type of activity carried out in the building. In order to perform these works, the building is brought to a high energy efficiency level both from the point of view of the exploitation and operation costs.
The following energy efficiency refurbishment of the building covering and of the interior installations have been taken into consideration:

- Thermal insulation of the floor below the roof truss with stone wool of 20 cm and waterproofing renewal;
- Insulation of floor boarding with 6 cm extruded polystyrene and renewal of floors;
- Replacement of existing windows with double-glazed and wood joinery windows (R’=0.87 m^2K/W);
- Fitting of thermoregulator valves; Installing solar panel systems for domestic hot water production. Installing a solar panel system for domestic hot water production;
- Replacement of the electrical installations, LED-type source lighting installation.

It can be concluded that the application of measures, established following the energy assessment of buildings, contributes to the reduction of energy consumption and CO_2 emissions, which will ensure the adaptation of buildings to effects of climate change.

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