ASSESSING THE COSTS OF THE THERMAL REHABILITATIONS OF A STUDIO BLOCK ENVELOPE

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Abstract. A view to reducing thermal energy consumption for a block of studios, this paper presents an assessment of the costs of energy efficient building materials used for the thermal rehabilitation of the analyzed building's tire. Based on information obtained from the evaluation of heat energy consumption and of the actual heat balance of the studios block, resulted the necessity for thermal rehabilitation. These works aimed equally both exterior walls as well as exterior windows and doors and involves a certain level of initial costs wich will be recovered through lower cost of the consumed thermal energy after thermal rehabilitation of the building tire.

Keywords: thermal energy, thermal rehabilitation, costs, building, walls, windows, doors.

1. INTRODUCTION

The climate in our country is temperate continental and has three regimes (summer, winter, spring-autumn), which makes heating period to start in October and end in April.

Because the total energy consumption of a building is about 43 ... 54% represents the energy required to heat it [2] is necessary to reduce energy consumption related to heating buildings.

The concept of energy is closely related to the building and it's associated facilities, and energy saving issues implicitly refer to these.

The building is a set of spaces bounded by a series of surfaces that make up the building tire and through which heat loss occurs.

The tire of a building separates the heated volume of the building to the outside air, soil, unheated or less heated room annexes, enclosed from the volume of the building by walls and / or ceilings, insulated properly, as well as other buildings adjacent walls bounded by the building considered through joints.

A building can be regarded as a body in continuous evolution witch in time it has to be treated, restored and updated to correspond to the requiements set by the user to a certain stage.

The energy efficiency of a building means all the analyzes and interventions related to energy saving while ensuring appropriate conditions of comfort. While reducing energy demand, it accomplishes two important objectives of sustainable development, namely, primary resources saving and reduction of pollutant emissions into the environment.

2. BUILDINGS ENERGY CONSUMPTION IN ROMANIA

Buildings, whatever their purpose, must meet a number of requirements such as: strength and stability, operational safety, fire safety, hygiene, human health, rehabilitation and environmental protection, thermal insulation and energy saving, protection against noise [4].

The main construction systems that are applied to existing buildings in Romania are as follows [2]:

- *Fully prefabricated buildings,* mainly for height of 5 levels, and 9 levels, which were built between 1960 to 1990 (million apartments cca.1.2 about 37% of the total number of apartments);
- *Buildings with mixed structure,* with frames and reinforced concrete structural walls, having external walls of autoclaved aerated concrete masonry (BCA) or prefabricated facade panels, with a height of 5 to 9 levels;
- *Buildings with bearing walls of reinforced concrete,* made with the use of sliding formwork and the structure of the resistance of monolithic reinforced concrete floor with stores on the ground floor (made in a small number);
- *Building brick masonry structure with a height of 2 ... 4 levels;*
- *Buildings with wooden walls, adobe or paianta.*

In 2010, energy consumption in the domestic sector are presented, by fuel types (Table 1) and by type of housing (Figure 1).

3. BLOCK STUDIO TECHNICAL REPORT

The studio block is part of a set of residential buildings in an urban area located in the second climate zone and is placed directly on the ground having three floors: ground floor, first floor and second floor.

Functionally, the building is for housing, interior spaces are specifically made for activities related to the rest, and recreation.

Structurally, the building consists of 34 studios and 2 apartments, distributed as follows:

- on the ground 12 studios;
- on the 1st and 2nd floors there are 11 studios and one apartment on each floor.

Table 1. Energy consumption in the domestic sector by type of fuel [6]

Nr. crt.	Type of fuel	U.M.	In country		The living sector	
			U.M.	PJ	U.M.	PJ
1.	Solid fuel	thousands t	19.1	561.0	6.5	191.6
2.	Liquid fuel	Thousands t	26.9	788.1	3.8	112.1
3.	Fuel oils	Billions m^3	24.3	817.2	1.0	34.2
4.	Unconventional energy	PJ	1.3	1.3	0.7	0.7
	Total	-	-	2351.7	-	338.6
5.	Electricity	TW·h	49.5	178.2	7.1	25.6
6.	Heating	PJ	385.1	385.1	107.3	107.3

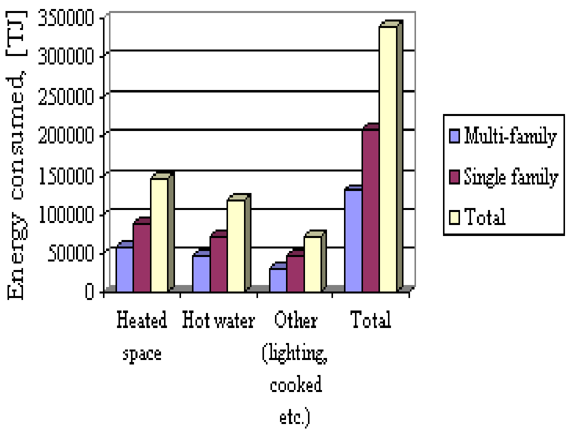

Fig. 1 - Energy consumption by type of housing in 2010 [10]

Fig. 2 - Seeping water in the opaque elements of the building tire at the end of the superior (terrace level - top floor) [12]

Characteristic elements of the building's location in the built environment are:

- climatic zone: II according to climatic zoning map of Romania of SR 1907-1 / 1997;
- calculated average outdoor temperature: t_e = -15°C;
- orientation towards the cardinal points of the main façade (entry into block): SE;
- wind zone: IV (4.0 m / s), according to the map of wind areas bounding the localities of SR 1907-1;
- building category in terms of air permeability: permeable building with windows with high degree of permeability;
- the soil temperature θp at a depth of 7 m from the ground level depending on the systematic construction is located: θp = 10°C.

The level heights are: $h_{groundfloor}$=2.60 m, h_{floor1}= 2.60 m, h_{floor2}= 2.60 m.

The shape in plan of the block is a rectangle, the size of the plan are:-width l≈12.66 m;- length L≈36,50 m; - height H≈8,50 m;

Analyzing the structure of the building at the time of expertise it was observed that:

- in the opaque elements outside of the building tire (walls) degradation in patches was observed, more or less pronounced, in the plaster layer outside, in some areas, at the upper end (terrace over the top floor) or at the lower end (floor level) a slight degree of infiltration of water, with the risk of toxic mold (Figures 2 and 3);
- the outside carpenters of windows, in particular that of the common areas, show signs of degradation, chopping wood rot is sometimes achieved with the coating, in some respects, shriveled. Carpentry damage is the result of external climatic factors, and the degree of appropriate leak that allowed water infiltration from weather (Figure 3);

Fig. 3 - Infiltration of water in the opaque elements of the tire of the building at the end of the lower bound - red border (ground level -building socket) and exterior joinery damaged (blue box) [12]

- the glass panels are in some places made by joining two piece of glass, which leads to increased infiltration of cold air outside, so to increase heat loss to the external environment, or those glasses are missing;
- the external access doors of the block are made from metal with a low degree of thermal insulation, which allow increased infiltration of outside air. The high degree of the outer door glazing favors higher heat transfer between the indoor and outdoor air's wind fang (Figure 4);
- the outer door of the block of studios, located on the right side (the geographic orientation NE) has windows instead of sheet metal, having a high degree of air permeability of the outside (Figure 5);
- the block has modern metering systems (electronic) for both heat and electricity. Heat metering is only at the block level, while electricity is metered block level (figure 4 - blue box) but for most of the studios there is also

individual metering, which allows tracking the level of energy consumption electricity and preventing theft;

Fig. 4 - The access exterior doors in the block are from metal with large glass surfaces [12]

Fig. 5 - Doors outer side of the block (the right in the direction of access in the block) presents metal sheet instead of glass - red marked area [12]

- the terrace above the top floor is equipped with a bituminous waterproofing layer which is intended to prevent the infiltration of rainwater in residential areas. Unfortunately, the existing hydro insulation provides little protection, as the common areas (stairway) from the top floor show clear evidence of infiltration;
- stairwell and wind fang do not feature radiators;
- common areas lighting (stairway and hallway access studios) is provided with filament lamps, the artificial lighting level is low.

In terms of interior installations of heat supply the following were observed:
- the heaters (type horizontal registers [3]) from visually point of view are in relatively good condition. There are 5 horizontal pipes with a diameter of 76 mm, having the thermal power of about 153.9 W/m for a $\Delta T=60K$;
- the heat transfer medium used is hot water, the adjusting exponent for such a space heater according to STAS 1797/3 the n = 5/4;
- the heat transfer medium introduced into the radiators is hot water, the radiators heat supply being made from a thermal point situated near the block;
- indoor air temperature recorded in the studio spaces are within the limits imposed by the specialists norms depending on destination and specific room (table II).
- the heat supply for heating varies depending on the outside temperature, resulting in an average annual heat input of 169 days, 12 hours/day;
- the heat supply for hot water consumption is continuous, 24 hours/day except during the annual inspections and repairs, which is 30 days /year.

The thermal energy used for heating and hot water preparation is purchased as [12]:
- some is purchased from SC Oltenia Energy Complex S.A;
- the other part is produced internally in two TERMOMAX type boilers, model COLOR 65P with a power of 57.4 kW and ACV Belgia, boiler GN 62 that use gas fuel and 5 boilers Romstal EPCO.L2 – 24 of 12 kW, using electricity.

The heat consumption for heating the studios is variable and depends on the external climatic conditions, mainly the outdoor temperature calculation.

Table 2 - Calculating conventional indoor temperatures for housing [15] and the actual temperature performed and determined by measurements

Nr. crt.	Room destination	Conventional calculated temperature [°C]	Measured temperatures [°C]
1.	Living rooms and hallways	20	20
2.	Lobbies apartments	18	-
3.	Bathrooms, showers	22	23
4.	Kitchens	18	18
5.	Toilets in the apartment	18	-
6.	Toilets outside the apartment	15	-
7.	Stairs and corridors outside apartment	10	11
8.	Inputs (wind fang)	12	11
9.	Laundry and ironing	15	-
10.	Dryers in apartment buildings	25	-
11.	Garages under house	10	-

4. ASSESMENT OF THE REQUIRED HEAT SUPPLY FOR HEATING IN THE EXISTING SITUATION

For the evaluation of the needed heat for heating, and performing calculations as accurate as possible, the method of SR 1907 / 1-1997 is used. This method allows the evaluation of the heat demand for each room from the studied block on the basis of the relation [11], [14]:

$$Q = Q_T \cdot \left(1 + \frac{\sum A}{100}\right) + Q_i \qquad [W] \qquad (1)$$

Where:
Q_T – transmission of heat loss, [W];

ΣA – the total correction coefficient, [%], determined as sum between the correction factor based on the orientation cardinal A_o and the cold surfaces addition to offset the effects on the human body, A_c;
Q_i - thermal load for heating from the outdoor temperature to indoor temperature of the infiltrated air leakages through the opening doors and windows,[W].

The heat loss through the building tire elements for the studied studio block is determined considering the size of buildings, the wind speed calculation v=4.0 m/s ($v^{4/3}$=6.35 [$(m/s)^{4/3}$], the calculated indoor temperatures specific to each room depend on its destination, θ_i, [°C] (table II), also the conventional average exterior temperature used in calculus for the climate zone II where the block is placed, for the heating season is (θ_e= -15°C).
Transmission heat loss through the elements of the building, QT is determined with (2) taking into account the corrected thermal resistance for solid or glass surfaces, R' [16].

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{(\theta_i - \theta_e)}{R'} + Q_s \quad [W] \qquad (2)$$

where:
C_M – calculation correction coefficient of the heat demand of the building based on specific mass;
M - thermal massive coefficient of the elements outside;
A - area of each construction element, determined in accordance with STAS 6472/3, [m^2];
Q_s – thermal flow thought ground, [W].

The addition of heat necessary for all block of studios leads to the evaluation of the total heat demand for the entire building (Table 2), which allows a final evaluation of the annual total heat requirement for heating (Table 3). Evaluation of the total annual heat demand for heating was realized for a period of 169 days / year, with a heat delivery system 12 hours / day.

Table 3 - Heat losses through opaque elements of the building tire and windows [12]

Nr. crt.	Looses category	U.M.	Studio block
1.	Through opaque elements of the building tire	[kW]	96.434
		[%]	68.920
2.	By glazing and exterior window and door openings	[kW]	43.488
		[%]	31.080
3.	Total loss of heat outdoors	[kW]	139.922
		[%]	100

Table 4 - Assessment of the annual consumption and annual specific heat consumption related to the studied studio block [12]

Nr. crt.	Building	Heating period, [days/year]	Supply hours number		Maximum heat required for heating	The annual heat	Specific consume
			[h/day]	[h/year]	Q, [kW]	Q, [kWh/year]	q, [kWh/m²·year]
1	Block studios	169	12	2028	139,922	283761,82	301,58

Taking into account the contributions of internal heat, Q, G, respectively external (solar), Qs, G, for the studied block, the following values of the heat demand result (3):

$$Q_{inc}^G = Q - Q_i^G - Q_s^G = \\ = 283761{,}82 - 27494{,}36 - 497{,}385 \Rightarrow$$

$$Q_{inc}^G = 255770{,}08 \text{ kWh/an} \qquad (3)$$

The annual consumption of heat for heating, in these conditions, at the source (the interior installation connected to the outdoor heat network) will be determined using (4), considering the distribution efficiency of the heating system (η_d=0.95) and the indoor heating system efficiency (η_{inc}= 0.98), [5]:

$$Q_{sinc}^G = \frac{Q_{inc}^G}{\eta_{inc} \cdot \eta_d} = \frac{255770{,}08}{0{,}95 \cdot 0{,}98} \Rightarrow$$

$$Q_{sinc}^G = 274726{,}19 \text{ kW} \cdot \text{h / an} \qquad (4)$$

Specific annual heat consumption for heating at the heat source is determined using (5):

$$q_{sinc}^G = \frac{Q_{sinc}^G}{S_u} = \frac{274726{,}19}{940{,}909} \Rightarrow$$

$$q_{sinc}^G = 291{,}98 \text{ kW} \cdot \text{h} / (\text{m}^2 \cdot \text{an}) \qquad (5)$$

Taking into account the specific values of annual heat consumption for heating at the heat source, the studied studio block, in terms of heating, the energy efficiency class **„E"** [4], [7].

5. EVALUATION THE THERMAL REHABILITATION COST AND THE NECCESARY HEAT FOR HEATING AFTER REHABILITATION

In compliance with Government Ordinance No. 29 of 31.01.2000 regarding the thermal rehabilitation of existing buildings and stimulating heat savings were developed alongside regulations NP047, NP048, NP049 and two technical regulations relating to the building tire:
- NP060 – 02 – establishing thermo-hygro-energy performance of the building tire, the rehabilitation and their thermal upgrading; SC007 – 02 – and contains provisions and solutions relating to the design principle and design in terms of meeting the essential requirement of thermal insulation and energy saving, the opaque areas

of the glass elements and closing of buildings rehabilitated and modernized.

Having the total surface of the block studio, an area of 1053.63 m^2, exterior walls 1297.65 m^2, including the floor (ceiling) then the surface of the outer doors is 12.82 m^2, representing 1.580% by glazing and the total area of the block studio glazing elements of 142.79 m^2, representing 17.604% by glazing, it was determined the cost for thermal rehabilitation of the building tire elements (table V).

It is recommended that works to improve the thermal protection to be effected with other existing buildings intervention works such as building and the seismic structural repairs. Also, improvement of thermal protection may be accompanied by the functional and architectural building and possibly increasing the level of acoustic protection, depending on the users / beneficiary's options.

To supplement the thermal insulation of building elements that are part of the existing building tire and to improve their characteristic nodes is important to follow, [8], [9]:

- adding additional thermal insulation (with appropriate hydrothermal characteristics: λ, ρ, $1/k_D$ etc.), with a corresponding thickness, avoiding materials that would require costly. It is recommended to use efficient thermal insulation (λ<0.06 [W/m·K]), as: expanded polystyrene extruded polystyrene, mineral wool rigid plates or glass wool, polyurethane foam;
- thermal bridges additional thermal insulation, following the reduction of their negative effect on heat loss and the temperature field of the inner surfaces of the tire building elements, thus avoiding condensation on the surface;
- judicious placement of additional thermal insulation, avoid faulty positioning of the point of view of water vapor diffusion and thermal stability;
- adopting efficient economical solutions and avoiding excessive material consumption and costs;
- thermal bridges correction as much as possible, taking into account the area of their influence;
- ensure continuity of insulation, both physical and as thermal resistance value (thermal resistance for the same areas with different embodiments);
-achieving linear coefficient of heat transfer ψ as small as possible at the nodes with thermal bridges: pointed out, the intersection of the outer walls of the terrace, the base, the exterior woodwork;
- positioning the thermal insulation to the outside of the building elements. In cases where the position inward insulating layer is thoroughly justified, it will examine very closely the behavior of water vapor diffusion, to avoid indoor condensation in winter and ensure its evaporation in summer. It will provide the appropriate vapor barrier;
-ensuring adequate thermal stability both for winter conditions, and for the summer. For light construction elements by supplementing proper insulation it will pursue solutions for construction elements with increased thermal resistance;
- provision of adequate plaster inside and outside to ensure impermeability to water and water vapor permeability.

Choosing rehabilitation solutions will be made jointly and in collaboration with building owners, given the composition and condition of the existing building elements, determined the drafting of technical expertise and priority criteria specific to each situation [1].

Choosing the insulation solution for a building element that forms part of the tire of residential buildings will conform to analytical methods and calculation set out in the technical regulations as (NP047 - Standard for achieving energy audit of existing buildings and the heating and hot water preparation; GP058 - Guidance on optimizing thermal protection for residential buildings).

To highlight the beneficial effects of the thermal rehabilitation of the studied studio block further evaluation of the heat consumption is carried out after the thermal rehabilitation of these buildings, keeping the annual heat supply unchanged (table VI).

Table 5 - Assessing the costs with thermal rehabilitation works of the studied block studios tire elements [13]

Nr. crt.	Rehabilitated element type	Quantity	Unitary price (materials and workmanship)	Total costs, [EUR]
1.	Exterior walls (10 cm thick expanded polystyrene)	690,44 m^2	17 EUR/m^2	11,737.48
2.	Day room exterior windows 1,56m×1,25m	36 pieces	113 EUR/piece	4,068.00
3.	Kitchen exterior windows 1,15m×1,26m	36 pieces	102 EUR/ piece	3,672.00
4.	Stair case exterior 1,57m×0,78m	3 pieces	63 EUR piece	189.00
5.	Stair case exterior, wind fang, hall 1,57m×0,56m	7 pieces	57 EUR/ piece	399.00
6.	Exterior door 1 1,75m×2,10m	1 piece	34 EUR/ piece	34.00
7.	Exterior door 2 1,30m×2,10m	1 piece	27 EUR/ piece	27.00
			TOTAL	20,126.48

Table 6 - Assessing the costs of thermal rehabilitation of the studied block studios tire elements

Nr. crt.	Building part	Heating period, [days/year]	Supply hours number		Maximum heat required for heating	The annual heat	Specific consume
			[hours/day]	[hours/year]	Q, [kW]	Q, [kWh/year]	q, [kWh/m^2·year]
A. The thermal rehabilitation of the outer walls of the blocks of studios							
1	studied block studios	169	12	2028	74.446	150976.49	160.46
B. The thermal rehabilitation of glass surfaces							
2	studied block studios	169	12	2028	129.132	261879.70	275.93
C. The thermal rehabilitation of the outer walls of the blocks of studios and glass surfaces							
3	studied block studios G5	169	12	2028	63.969	129729.13	137.88

6. CONCLUSIONS

The heating system should create an atmosphere in building spaces that meet the conditions of comfort and technological processe requirements. This environment depends on thermal power system in the room, for the placement of radiators, heat protection qualities of the building **tire**, other heat sources as well as heat loss occurring.

In the civil buildings, the main source of heat is the heating system and the most important heat losses of the buildings are through the tire.

Taking into account the actual consumption of heat for heating and internal temperatures in the accommodation studio block, the heat balance for heating system for the year 2015 was obtained, resulting in:

I. The amount of heat entering the building of 244.07 Gcal / year, of which:

- by radiators 219.99 Gcal/year (≈90.13%);
- introduced by the internal contributions 23.65 Gcal/year (≈9.69%);
- due to the solar radiation 0.43 Gcal/year(≈0,18%);

II. The amount of heat output the building is 24.,19 Gcal/year, of which:

- heat loss by transmission through opaque exterior elements 168.12 Gcal/year (≈68.18%);
- transmission heat loss through exterior glazing, 25.21 Gcal/year (≈10.33%);
- heat losses through air leakages along the opening doors and windows and natural ventilation, 40,76 Gcal/year (≈16.70%);
- loss of inner heat distribution network 9.86 Gcal/an (≈4.04%).

After the thermal rehabilitation of the building elements and the inner distribution installations for the same period of operation of the heating system and the same conditions results:

I. The amount of heat entering the building of 111,58 Gcal/year, of which:

- by radiators 87.63 Gcal/year (≈78.54%);
- introduced by the internal contributions 23.65 Gcal/year(≈21.19%);
- due to the solar radiation 0.30 Gcal/an (≈0.27%);

II. The amount of heat output the building is 111,51 Gcal/year, of which:

- heat loss by transmission through opaque exterior elements 64.04 Gcal/an (≈57.39%);
- transmission heat loss through exterior glazing 10.62 Gcal/an (≈9.52%);
- heat losses through air leakages along the opening doors and windows and natural ventilation 32.60 Gcal/an (≈29.22%);
- loss of inner heat distribution network 4.25 Gcal/an (≈3.81%).

Given the results achieved after thermal rehabilitation of the building studios, results a thermal energy saving 132.49 Gcal / year, what means in financial terms, for a price of thermal energy 220 RON/Gcal, a reduction of heating costs 29147.80 RON/an (the equivalent of 6624.50 EUR/an).

As a result, economic efficiency indicators based on the thermal rehabilitation of block studio tire will be:

- Net present value (VNA): 23.039.65 EUR;
- Project IRR(Internal rate of return): 63%
- The payback time: 3.05 years.

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