Analysis of the impact of thermal rehabilitation on the heat demand. Case Study

STAN IVAN FELICIA ELENA, DUINEA ADELAIDA MIHAELA
Department of Electrical Engineering, Energetic and Aerospatiale
University of Craiova
Address Bld. Decebal, no. 107
ROMANIA

Abstract:-The article presents a case study on the impact of thermal rehabilitation of buildings heat demand. In order to reduce specific heat consumption and, in general, heat consumption for heating and hot water preparation, measures are needed to rehabilitate and modernize the thermal protection of buildings and heating and hot water installations. The present study aims to determine the influence of thermal rehabilitation of buildings (insulation of exterior walls - in this case) making for this purpose a comparison of the values of thermal requirements before and after the thermal rehabilitation process for a building. Regarding the thermal insulation used in the case study, expanded polystyrene with a thickness of 10 cm was used for the exterior walls and mineral wool for ceiling. The main purpose of the work is to highlight the importance of thermal insulation of buildings mainly in terms of reducing energy costs and maintaining thermal comfort in homes.

Key-Words: buildings, energy, insulation, thermal rehabilitation, economic efficiency.
Received: May 22, 2021. Revised: September 15, 2021. Accepted: October 1, 2021. Published: October 14, 2021.

1 Introduction

Referring to the energy aspects of buildings, the importance of the external climatic stress of the heated space on the heat consumption separate from the conformation and structure of the building envelope is underlined [1].

The heat demand for heating an objective (building) generally includes: heating, hot water supply (ACC), ventilation, technology and losses in the transmission and distribution networks.

For construction, the concept of energy is closely linked to the building and related facilities. Lately, more and more attempts have been made to solve priority problems related to construction energy, such as:

- reducing energy consumption in old buildings, taking a series of measures from a technical and economic point of view;
- using measures for new constructions aimed at energy saving while increasing the degree of comfort

The use of these data implies the existence of one of the following cases:

- choosing the optimal construction materials from a thermal and hygrothermal point of view that will make up the structure of the future building;
- thermal and hygrothermal verification of the structure of an existing construction or considered given at the design phase [1],[2],[8].

The choice of the construction elements is made on the basis of the design from a thermotechnical point of view in order to achieve:

- the minimum resistance required for heat transfer, by limiting the heat flow and avoiding condensation on the inner surface of the construction element;
- the necessary thermal stability, in order to avoid the oscillations of the indoor air temperature and on the inner surface of the construction elements;
- resistance to vapor permeability, to limit the condensation of vapors inside the construction elements;
- resistance to air infiltration, to ensure thermal insulation capacity.

The first aspect presented reflects the fact that a relatively small number of components of the building envelope have a majority share on the annual heat consumption and this share is also given by the orientation of the respective component.

Therefore, it can be decided whether or not two rehabilitation measures should be taken on two components with the same orientation, but with a different structure, from the point of view of the constructive elements.

The second aspect investigates the influence of climate on demand the annual heat consumption of the building and tries to separate contribution of the conformation and structure of the building envelope. Naturally, if the shape and structure of the building envelope leads to a good degree of thermal insulation, the climatic stress remains less influential.

As can be seen, in general, the whole building with all the equipment, must undergo a functional reconsideration and a comprehensive process that refers to the energy performance and performance standards of the building in all aspects (energy consumption - thermal resistance, lighting, pollutant emissions, etc.) uninterrupted process supported by the market and commercial by suppliers of construction materials and thermal insulations [2], [3], [10].

2 Problem Formulation

What does thermal rehabilitation entail?
• thermal insulation of exterior walls;
• replacement of existing windows and exterior doors, including carpentry for access to the apartment building, with energy-efficient carpentry;
• thermal-waterproofing of the terrace / thermal insulation of the floor above the last level in case of the existence of the frame;
• thermal insulation of the floor above the basement, if by designing the block are provided apartments on the ground floor;
• dismantling works of the installations and equipment apparently mounted on the facades / terrace of the block of flats, as well as their reassembly after the thermal insulation works;
• restoration works of the tire finishes [4].

2.1 Thermal insulation of exterior walls

Additional thermal insulation of the exterior walls - the opaque part, is usually done on the outside, with well-developed technologies and verified over the years.

The insulating materials and systems used must be accompanied by declarations of conformity from the manufacturers, attesting compliance with the technical specifications recognized by law.

Additional benefits:

Protection of the wall-resistant component against seasonal thermal variations is achieved.

The useful space of the rooms is not affected.

The appearance of thermal bridges is avoided by the continuity of the external thermal-insulating layer.

The aesthetic aspect of the blocks of flats and implicitly of the localities is improved [5], [6].

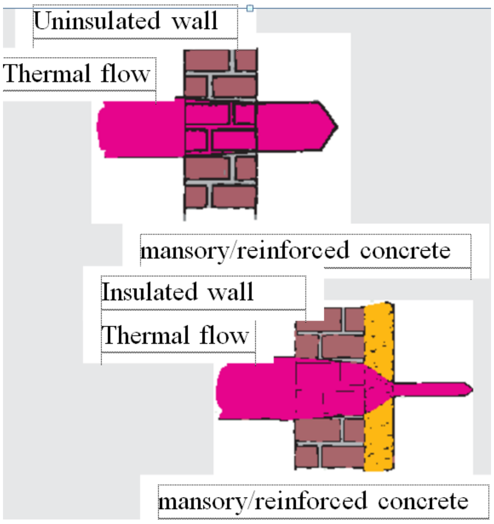

Fig.1. Uninsulated wall/ insulated wall

3 Calculation of heat requirement for the analyzed building

The assessment of annual energy consumption for heating is necessary in order to determine energy efficiency of a building. Annual consumption refers to the final energy (EF) (heat and electricity) used in the building for space heating and in the form of hot water and to the primary energy (EP) contained in the fuels used and from which the secondary energy (ES) covering the final energy requirement of the building.

The heat demand for heating can be determined by four methods:
- The method of thermal characteristic of the building;
- Calculation method on the exterior contour of the building;
- The method according to the Normative SR1907-1 / 1997;
- The method of global thermal insulation coefficients "G".

In this section it is presented the calculation of heat demand requirement for a building situated in Romania. The method used is this study case is the method according to the Normative SR1907-1 / 1997 [1] [2].

3.1 Architectural description of the studied building

The evaluated apartment is located in a block of flats in Craiova, Romania, the construction was executed in 1996. The studied apartment is located on the ground floor, the main orientation being south. The apartment is detached and has three rooms.

Access to the apartment is on a common interior staircase with a single ramp.

Existing architectural partitioning solution for the apartment:

Table 1. The constructive dimensions of the apartment

Nr. crt.	Room name	Usable area [m^2]
1	Livingroom	17,4
2	Kitchen	11,34
3	Bedroom 1	12,02
4	Bedroom 2	11,92
5	Bathroom	3,75
6	Wardrobe 1	0,60
7	WC	1,44
8	Hall	11,09
9	Wardrobe 2	2,25
	Total usable area	71,81
10	Balcony	5,41
	Total surface	77,22

The free level height is 2.5 m.

Description of the types of indoor and common installations and their composition (heating, ventilation/ air conditioning, hot water consumption, lighting)

The heating and hot water of the analyzed apartment is provided by a thermal power plant with a flow rate of 3 m^3 / h.

The heating elements in the apartment are made of cast iron.

The house stairwell is not heated directly.

The apartment is supplied with cold water from the city network. There are 2 cold water points in the apartment.

The conventional calculation conditions are set by the values: θ_T = 80ºC, θ_R = 60ºC, θ_i = 20ºC, θ_e = -15ºC.

The lighting system is equipped with incandescent bulbs.

The occupation regime of the apartment

The apartment is occupied 24 hours a day, and the heat supply is considered continuous. The apartment is not equipped with mechanical ventilation, cooling or air conditioning systems.

The envelope of the apartment and the heated volume of the apartment

The envelope of a building represents the totality of the perimeter construction elements that delimit the interior space of a building from the external environment [1].

3.2 Thermophysical characteristics of construction materials

The main thermophysical characteristics of the construction materials used for the thermal protection of the building envelope are presented.

Description of the composition of the construction elements and the resistance structure:

The exterior walls that make up the apartment envelope are made up as follows:

- plasters of approx. 2 cm thick inside;
- BCA masonry;
- plasters of approx. 2-5 cm thick on the outside;

The exterior walls and those in contact with the stairwell are made of BCA.

The exterior carpentry of the apartment is made of PVC with double glazing.

The entrance door to the apartment and the indoor doors of the apartment are made of wood.

Interior finishes are common:

-plasters of approx. 2 cm thick inside, watercolor paintings;

-the walls of the bathrooms and kitchens were provided with tiles on the entire surface of the walls;

- plasters of approx. 2 cm thick on the outside, with stone dust finish;
- parquet floors in the rooms; tiled floors, in kitchens, bathrooms and common areas;

The resistance structure of the block above the ground level 0.00 is composed as follows:

- vertical elements made of monolithic reinforced concrete - resistance pillars;
- horizontal elements - prefabricated reinforced concrete floors and beams made of both prefabricated and monolith; the stairs are made from prefabricated materials (concrete).

The infrastructure is made as follows:

- reinforced concrete structural walls both on the line of the structural elements of the superstructure and additional to them;
- the floor above level made of reinforced monolithic reinforced concrete;
- continuous foundations of reinforced concrete sole and bearing type.

For the thermal analysis there are considered the main types of walls: vertical exterior walls, walls adjacent to the staircase, the walls and construction materials used for the enclosed terrace, floor above the basement and exterior carpentry.

For all these types of walls we will determine the thermal resistances and the corrected thermal resistances.

We will also analyze the case if the apartment would have placed a layer of thermal insulation on the surface of the exterior walls (10 cm), respectively placement of a layer of thermal insulation made of polystyrene on the exterior surface of the walls on the staircase (5 cm).

The following abbreviations are used for the constructive elements considered:

PE – exterior wall, FE –exterior window, PI-interior wall, UE/UI – exterior/interior door, TV-ceiling, PD-floor. N, S, E,V – cardinal points used to specify the orientation of the constructive elements.

3.2.1 Calculation of heat demand for bedroom 2, after rehabilitation

The exterior wall situated on S (south), PE (S)

Is calculated the heat loss through transmission, Q_T:

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{\theta_i - \theta_e}{R'} + Q_S \text{ [W]} \quad (1)$$

were:

C_M – correction coefficient of the calculation heat demand depending on the specific mass of the construction (m_{pi});

m –coefficient of thermal mass;

A –surface area of each construction element, determined according to STAS 6472/3, [m^2];

θ_i, θ_e – internal / external temperature, [°C]

R' – the corrected specific thermal resistance of the considered construction element, established according to STAS 6472/3, [m^{2}K / W];

Q_s – heat flux released through the ground, [W].

The corrected specific thermal resistance, R' for the considerate construction element:

$$R' = \frac{1}{\alpha_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_e} \text{m}^2\text{K/W} \quad (2)$$

$$R_{plaster\ var} = \frac{0{,}05}{0{,}70} = 0{,}07 \text{ m}^2\text{K/W}$$

$$R_{autoclaved\ concret} = \frac{0{,}35}{0{,}23} = 1{,}52 \text{ m}^2\text{K/W}$$

$$R_{polystirene} = \frac{0{,}10}{0{,}04} = 2{,}50 \text{ m}^2\text{K/W}$$

$$R_{plaster\ var} = \frac{0{,}05}{0{,}93} = 0{,}05 \text{ m}^2\text{K/W}$$

$$R' = \frac{1}{\alpha_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_e} = \frac{1}{8} + 4{,}15 + \frac{1}{24} = 4{,}31 \text{ m}^2\text{K/W}$$

$A_{PE(S)} = A_{PE(S)} - A_{FE(S)} = 3{,}20 \cdot 2{,}5 - 1{,}2 \cdot ,15 = 6{,}20$ m^2

The coefficient of thermal mass:

$$m = 1{,}225 - 0{,}05 \cdot D \quad (3)$$

C_M=1 – for residential buildings

m = 1,106

D - index of thermal inertia of the construction element, calculated according to STAS 6472/2.

The heat loss for the outer wall located on S:

$$Q_{PE(S)} = c_M \cdot m_{PE(S)} \cdot A_{PE(S)} \cdot \frac{ti - te}{R'_{PE(S)}} \quad \text{[W]}$$

$$Q_{UI(V)} = 1 \cdot 1{,}106 \cdot 6{,}20 \cdot \frac{20+15}{4{,}31} = 55{,}68 \text{ W}$$

For the outer window located on S, FE (S)

Is calculated the heat loss through transmission, Q_T:

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{\theta_i - \theta_e}{R'} + Q_S \quad \text{[W]}$$

Is determined the corrected specific thermal resistance, R' for the considered construction wall:

$$R' = \frac{1}{\alpha_i} + \sum_{i=1}^{n} \frac{\delta}{\lambda} + \frac{1}{\alpha_e} \quad \text{[m}^2\text{ K/W]}$$

R' = 0,714 m^2 K/W

$A_{FI(S)} = 1{,}2 \cdot 1{,}50 = 1{,}80$ m^2

The heat loss for the exterior window situated on the south, S, FE (S):

$$Q_{FE(S)} = c_M \cdot m_{FE(S)} \cdot A_{FE(S)} \cdot \frac{ti - te}{R'_{FE(S)}} \quad \text{[W]}$$

$$Q_{FE(S)} = 1 \cdot 1{,}20 \cdot 1{,}80 \cdot \frac{20+15}{0{,}714} = 106{,}48 \text{ W}$$

For the exterior wall located on north, N, PI (N)

The heat loss for the exterior wall located on north:

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{\theta_i - \theta_e}{R'} + Q_S \quad \text{[W]}$$

The corrected specific thermal resistance, R' for the considered construction wall:

$$R_{plaster\ var} = \frac{0{,}02}{0{,}70} = 0{,}03 \text{ m}^2\text{K/W}$$

$$R_{mortar} = \frac{0{,}03}{0{,}93} = 0{,}03 \text{ m}^2\text{K/W}$$

$$R_{autoclaved\ concret} = \frac{0{,}1}{0{,}23} = 0{,}43 \text{ m}^2\text{K/W}$$

$$R' = \frac{1}{\alpha_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_e} = \frac{1}{8} + 0{,}50 + \frac{1}{24} = 0{,}66 \text{ m}^2\text{K/W}$$

$A_{PI(N)} = 3{,}20 \cdot 2{,}5 - 0{,}88 \cdot 2 = 6{,}24$ m^2

Is determined the heat loss for the interior wall situated on north, N, PI (N):

$$Q_{PI(N)} = c_M \cdot m_{PI(N)} \cdot A_{PI(N)} \cdot \frac{ti - te}{R'_{PI(N)}} \quad \text{[W]}$$

$$Q_{PI(N)} = 1 \cdot 1{,}19 \cdot 6{,}24 \cdot \frac{20-18}{0{,}66} = 22{,}50 \quad \text{W}$$

For the interior wall situated on the north N, UI (N)
The heat loss Q_T:

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{\theta_i - \theta_e}{R'} + Q_S \qquad [W]$$

The corrected specific thermal resistance, R' for the considerate construction element:

$$R' = \frac{1}{\alpha_i} + \sum_{i=1}^{n} \frac{\delta}{\lambda} + \frac{1}{\alpha_e} \qquad [m^2\,K/W]$$

R' = 1,50 m^2 K/W

$A_{UI\,(S)}$ = 0,88·2= 1,76 m^2

Is determined the heat loss for the interior wall situated on north, N:

$$Q_{UI(N)} = c_M \cdot m_{UI(N)} \cdot A_{UI(N)} \cdot \frac{ti - te}{R'_{UI(N)}}$$

$$Q_{UI(N)} = 1 \cdot 1{,}08 \cdot 1{,}76 \cdot \frac{20-18}{1{,}50} = 2{,}53\ W$$

For the floor:
Is calculated the heat loss through transmission, Q_T:

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{\theta_i - \theta_e}{R'} + Q_S \qquad [W]$$

It is determined the corrected specific thermal resistance, R' for the considerate construction element:

$$R_{cement\ mortar} = \frac{0{,}05}{0{,}93} = 0{,}05\ m^2K/W$$
$$R_{mineral\ wall} = \frac{0{,}10}{0{,}045} = 2{,}22\ m^2K/W$$
$$R_{concrete} = \frac{0{,}15}{2{,}03} = 0{,}07\, m^2K/W$$
$$R_{gravel\ filing} = \frac{0{,}10}{0{,}70} = 0{,}14\, m^2K/W$$
$$R_{ground\ filing} = \frac{0{,}25}{2} = 0{,}13\, m^2K/W$$
$$R' = \frac{1}{\alpha_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_e} = \frac{1}{8} + 2{,}62 + \frac{1}{24} = 2{,}78\ m^2K/W$$

A_{Pd}= 3·3,80 = 12,16 m^2

The heat loss for the floor, Pd:

$$Q_{Pd} = c_M \cdot m_{Pd} \cdot A_{Pd} \cdot \frac{ti - te}{R'_{Pd}} \quad [W]$$
$$Q_{Pd} = 1 \cdot 1{,}11 \cdot 12{,}16 \cdot \frac{20-10}{2{,}78} = 48{,}55W$$

For the ceiling:
The heat loss, Q_T:

$$Q_T = \sum C_M \cdot m \cdot A \cdot \frac{\theta_i - \theta_e}{R'} + Q_S \qquad [W]$$

It is determined the corrected specific thermal resistance, R' for the considerate construction element:

$$R_{cement\ mortar} = \frac{0{,}05}{0{,}93} = 0{,}05\ m^2K/W$$
$$R_{concrete} = \frac{0{,}25}{2{,}03} = 0{,}12\, m^2K/W$$
$$R_{gravel\ filing} = \frac{0{,}10}{0{,}70} = 0{,}14\, m^2K/W$$
$$R_{ground\ filing} = \frac{0{,}1}{2} = 0{,}05\, m^2K/W$$
$$R' = \frac{1}{\alpha_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_e} = \frac{1}{8} + 0{,}37 + \frac{1}{24} = 0{,}54\ m^2K/W$$

A_{Tv} = 3,20·3,80= 12,16 m^2

Is determined the heat loss for the interior wall situated on south, S, PI (S):

$$Q_{PTv} = c_M \cdot m_{Tv} \cdot A_{Tv} \cdot \frac{ti - te}{R'_{Tv}} \quad [W]$$

$$Q_{Tv} = 1 \cdot 1{,}11 \cdot 12{,}16 \cdot \frac{20-18}{2{,}78} = 27\ \ W$$

Total transmission losses for bedroom 2 **:**
QT bedroom 2 = $QT_{PE(S)}$ + $QT_{PI(N)}$ + $QT_{UI(N)}$ + $Q_{FE(S)}$ + QT_{Pd} + QT_{Tv} = 447,82W

In the table 2 and table 3 are presented the numerical analysis of the heat demand and the specific consumption, depending on the heating duration (heating days / year).

Table 2. Determining the annual heat demand and specific consume for the building without insulation

Heating period, [zile/an]	Heating hours number		Maximum heat required for heating		Annual heat demand		Specific consume
	[h/day]	[h/year]	Q, [kW]	Q, [Gcal/h]	Q, [kWh/year]	Q, [Gcal/year]	q, [kWh/m²year]
151	24	3624	4,765	4,098	17266,588	14,851	223,603

Table 3. Determining the annual heat demand and specific consume for the rehabilitated building

Heating period, [zile/an]	Heating hours number		Maximum heat required for heating		Annual heat demand		Specific consume
	[h/day]	[h/year]	Q, [kW]	Q, [Gcal/h]	Q, [kWh/year]	Q, [Gcal/year]	q, [kWh/m^{2}year]
151	24	3624	2,563	2,204	9286,879	7,988	120,265

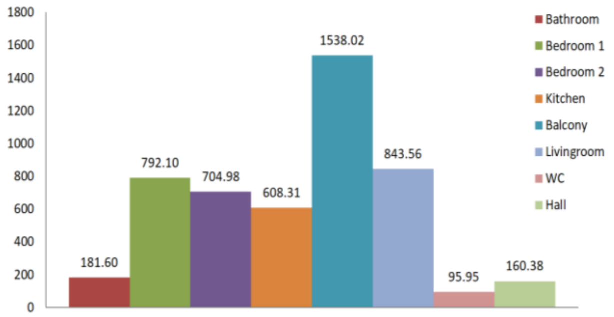

Fig.2. The heat requirement calculated, on each room, the case of the building not thermally rehabilitated

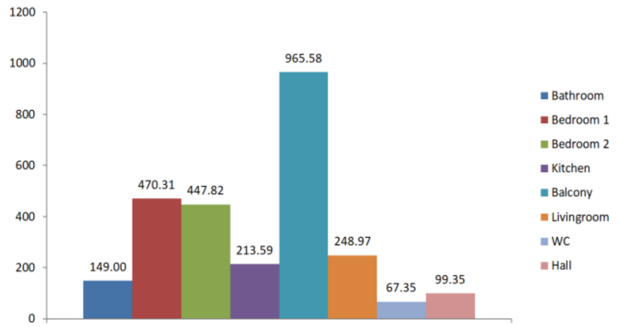

Fig.3. The heat requirement calculated, on each room, the case of the building thermally rehabilitated

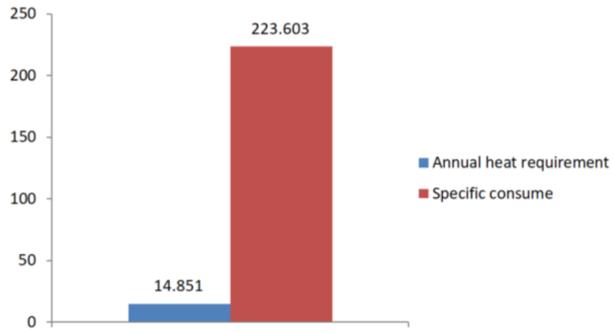

Fig.4. The specific consume and annual heat requirement the case of the building not thermally rehabilitated

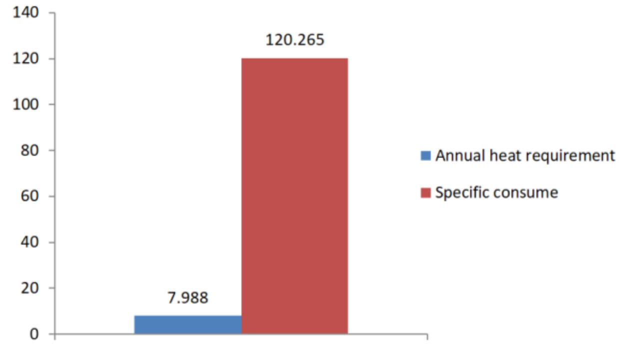

Fig.5. The specific consume and annual heat requirement the case of the building thermally rehabilitated

Determination of heating costs:
It is considered a heating cost of 46 euro / Gcal.

The case of the original building, without thermal insulation.
Heating costs/year = 772.26 euro/year

The case of the rehabilitated building
Heating costs/year 415,362 euro / year

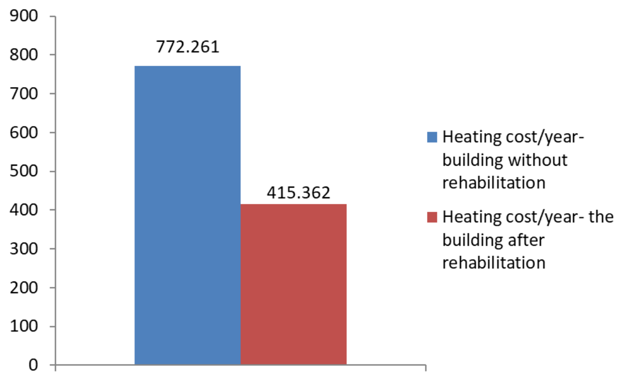

Fig.6. Heating costs, for both analysed cases, building without thermal insulation and building after rehabilitation process (insulated with expanded polystyrene 10 cm situated on the exterior walls)

4 Conclusion

Following the calculations, tables and graphs presented in the article it can be presented the following conclusions.

The rehabilitation process, and here it refer to thermal insulation, involves a series of positive effects including:

- reduction of temperature variations between indoor and outdoor environment;
- increasing thermal comfort;
- reducing the heat demand for the cold period of the year;
- reduction of thermal energy bills for heating.

Considering the studied case in the article, an improvement can be observed in terms of both the reduction of heat demand and cost prices, in the case of the thermally rehabilitated building compared to the original building, the one considered without being thermally insulated.

Figures 2 to 5 present graphically the variations in heat demand and specific consumption for each of the two types of buildings studied.

Thus, in terms of heat demand, it is reduced in the case of thermally rehabilitated building by a percentage of 46.21% compared to the case of building that has no thermal insulation.

For specific consumption the percentage reduction is the same as for heat demand.

The investment made in the thermal rehabilitation process will be recovered in a very short time, because the price with the thermal energy bill will be greatly reduced, so the money due to this reduction involves covering the expenses with the rehabilitation process.

Figure 6 present graphically the variations of the heating cost, for each case (the building without insulation and the insulated building).

The cost reduction is about 356,898 euro/year, that a reduction of 46.21% per year. That means that using a thermal insulation is a very efficient way to improve the comfort, by maintaining a relatively constant temperature, with quite small variations between the cold and hot seasons and also to save money.

Also taking into account the fact that in the next period, the price of thermal energy will increase considerably, it is very important to mention that a house with good insulation allows both a good indoor thermal environment and a reduction in heating / cooling costs.

References:

[1] F. E. Stan Ivan, I. Mircea, "Eficienţa energetică şi economică a clădirilor", Editura SITECH, Craiova 2014, ISBN 978-606-11-3880-7

[2] Ghid privind reabilitarea termică a clădirilor de locuit: Partea I şi partea a II a, Direcţia tehnică în construcţii - M.D.R.T, iunie 2012

[3] http://www.icpe.ro/ro/plans_parc_icpe_ro

[4] www.ec.europa.eu/energy/efficiency/buildings/implementation_en.html

[5] fiz. B. Brumă, Phd: "Studii numerice comparative privind performanţa termică a elementelor anvelopei clădirii", Universitatea Tehnică din Cluj-Napoca, 2015

[6] F. E. Stan Ivan, R. C. Dinu, D. Popescu, "Assessing the costs of the thermal rehabilitations of a studio block envelope", *a 23-a Conferinţă de Inginerie Energetică CIE 2017, "Energie curată şi accesibilă"*, 08 Iunie - 09 Iunie 2017, Oradea, Băile Felix**,** Journal of sustainable energy, vol. 8, no. 2, pag. 66 -71.

[7] F. E. Stan Ivan, "Economic efficiency analysis of buildings", *Recent Reseaches in Applied Economics and Management, Economic Aspects of Environment, Development, Tourism and Cultural Heritage-Volume 2, Proceedings of the 5th WSEAS International Conference on Applied Economics, Business and Development (AEBD '13)*, Chania, Crete Island, Greece, August 27-29, 2013, pag. 299-345

[8] F. E. Stan Ivan, I. Mircea, "Economic And Financial Analysis Of The Buildings Rehabilitation Solutions", *a 22-a Conferinţă de Inginerie Energetică, C.I.E.-2016, "Energie curată şi accesibilă", 02 Iunie - 04 Iunie 2014, Oradea, Băile Felix, Journal of Sustainable Energy*, vol. 7, nr. 2, 2016, pag. 48- 52.

[9] Fl.Mateescu, "Izolarea termică a locuinţelor – Colecţia Poţi face şi singur", *Editura M.A.S.T.*, Bucureşti, 2007, ISBN 973-8011-79-5.

[10] BPIE: "*Clădirile Europei sub Microscop*", BPIE, Bruxelles, Belgia, 2011. www.bpie.eu

[11] G.Ciubotă, A., G. A. Obîrşeanu, "Analiză comparativă privind costurile cu energia termică pentru asigurarea parametrilor de confort într-o locuinţă individuală", *Simpozionul Naţional „Brainstorming în Agora Cercurilor Studenţeşti" BACStud 2015*, organizat de Universitatea Agora Oradea, www.dzitac.ro/files/simona/programBACStud2015.pdf.