CASE STUDY REGARDING ENVIRONMENTAL IMPACT ASSESSMENT OF A THERMAL REHABILITATION OF A BUILDING

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ABSTRACT

Nowadays pollution became one of the biggest problems of humanity. The effects caused by the rising of global temperatures have a negative influence on ecological and social changes. In this paper the need to reduce carbon dioxide emissions is presented. The analysis is aimed at quantifying the amount of CO_2 from building heating, relative to the amount of emissions from the materials used in thermal rehabilitation, generated by producing and putting them into operation. The carbon footprint and energy consumption at each stage of the materials life cycle was determined using the OneClickLCA software.

Keywords: Energy efficiency, global emissions, sustainable development, carbon footprint.

REZUMAT

Poluarea a devenit una dintre cele mai mari probleme ale umanității. Efectele cauzate de creșterea temperaturilor globale au o influență negativă asupra schimbărilor ecologice și sociale. În această lucrare este prezentată necesitatea de a reduce consumul de emisii de dioxid de carbon. Analiza a urmărit cuantificarea cantității de CO_2 provenit din încălzirea imobilului raportat la cantitatea de emisii emanate de materiale folosite în reabilitarea termică, prin producerea și punerea lor în operă. Amprenta de carbon și consumul de energie în fiecare etapă a ciclului de viață a materialelor au fost determinate folosind programul OneClickLCA.

Cuvinte cheie: Eficiență energetică, emisii globale, dezvoltare durabilă, amprentă de carbon.

1. CONTEXT

Providing the energy needed to develop basic activities is one of the main problems, on the solution of which depends the development of our civilization.

The fact that we exhausted resources leads also to another problem: emissions contributing to global warming. Greenhouse gas emissions, generically called carbon emissions or CO_2 emissions, are gases in the atmosphere that absorb and issue infrared radiation. The existence of a balance between absorbed and emitted infrared radiation is an element of major importance for the climate and the global environment. The process of uncontrolled emission of greenhouse gases is the root cause of the controversial greenhouse effect in the atmosphere, which generates the phenomenon of global warming. The main greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone.

Constructions have a major impact on the environment, the buildings in which we live being an important pollution factor. According to the World Economic Forum, buildings produce about 40% of global carbon emissions. Part of the energy consumed by buildings, operational energy, comes from the need to ensure interior comfort (heating, domestic hot water, ventilation, air conditioning) and the other part is the energy incorporated from the production and operation of construction materials (processing, transport, use, including disposal).

Many of the substances used in the production of construction materials issue toxic substances, even carcinogenic and can be harmful to human health.

Thus, measures are needed on air quality standards and the reduction of greenhouse gas emissions as well as emission standards for the main sources of pollution, both in the industrial and energy sectors.

In order to limit the negative impact caused by buildings on global warming, it is necessary to carry out energy balance analyses, in which the primary energy needs of the building and the associated CO_2 emissions can be calculated. At the same time, all the materials that make up the building must be examined from the perspective of the amount of carbon incorporated.

The full life span of a building can be best understood using the life cycle approach. The life cycle approach reveals that over 80% of greenhouse gas emissions occur in the operational phase of the buildings, when energy is used for heating, ventilation, cooling, lighting, appliances and other applications (Vigovskaya, 2017).

The carbon incorporated in the materials can be defined as the total greenhouse gas emissions that are caused by their manufacture and supply, as well as by the construction process itself. It is important to note that embedded carbon must be approached from a life cycle perspective, as the results can greatly differ when looking at the short or long term.

There are many different alternatives for building construction, and these could be implemented in the construction phase of a building (Sharma, 2011). Achieving zero levels of net greenhouse gas emissions can only be achieved through conceptual and technological innovation (Dubină, 2010). The results show that both the emissions and the energy incorporated in the construction materials or the construction process have a high relevance, and the impact of the emissions is comparable to those due to the use stage.

For a given building, a significant reduction in the impact on the selected indicators can be achieved through a careful selection of construction solutions and sustainability strategies (through maintenance or renovation) in the design phase (Villar-Burke, 2014).

2. RESULTS AND DISCUSSIONS

2.1. Operational energy consumption

The paper aims at studying the effect of thermal insulation of the envelope elements of a building, in order to reduce pollutant emissions. The analysis is aimed at quantifying the amount of CO_2 from the heating of the building, relative to the amount of emissions from materials, coming from their production and putting into operation.

The analyzed project is a single-story house with brick masonry structure, with the structural system consisting of 25 cm-thick masonry walls, concrete floors, continuous foundations and a wooden structure for the roof. The usable area of the building is 63.57 m^2, and the heated volume is 170.42 m^3.

Following the same architectural plans, the exterior elements of the building envelope were thermally insulated as follows: in the first case: for the walls - 5 cm of mineral wool, for the floors - 10 cm of mineral wool, for the flooring - 5 cm extruded polystyrene, and, in the second case: for the walls - 15 cm of mineral wool, for the floors - 30 cm of mineral wool, for the flooring - 10 cm of extruded polystyrene.

The thermal conductivity of materials was taken as follows:

- for the mineral wool: λ=0.036 W/mK declared value, apparent density 40 kg/m^3;
- for the expanded polystyrene: λ=0.040 W/mK declared value, apparent density 28 kg/m^3.

The dimensional characteristics of the building elements, necessary for the calculation of the values of their thermal performance parameters, were established according to Romanian regulation in force.

For each exterior building element, the corrected thermal resistance was determined, taking into account the thermal characteristics and the thicknesses of the materials, the results being centralized in Table1.

The thermal specific corrected resistance was determined for building elements with inhomogeneous composition. It took into account the influence of thermal bridges on the specific thermal resistance value determined based on a unidirectional calculation into the current field, respectively in the area with predominant composition.

Fig. 1. Main facade

Table 1. *Corrected thermal resistance*

Element type	Without insulation R'	Solution 1 R'	Solution 2 R'	Area
	[m²K/W]	[m²K/W]	[m²K/W]	[m²]
NV Walls	0.783	1.356	2.141	14.59
NE Walls	0.768	1.318	2.046	19.37
SV Walls	0.798	1.356	2.141	14.59
SE Walls	0.801	1.389	2.223	23.21
Plate over the last floor	0.388	2.725	3.434	67.13
Plate on the floor	1.801	2.081	2.196	67.13
NV Windows	0.550	0.550	0.550	2.88
NE Windows	0.550	0.550	0.550	2.04
SV Windows	0.550	0.550	0.550	2.88
SE Windows	0.550	0.550	0.550	1.44
SV Door	0.550	0.550	0.550	2.80

In determining the energy performance of the building, the climatic zone (Cluj-Napoca - zone III), the orientation of the building elements towards the cardinal points (in order to determine the solar inputs), the dimensions of the glazed elements and their energy performance (PVC windows, double glazing), average indoor temperature (Ti = 20°C), and outdoor temperature (Te = -18°C), were taken into account.

According to the above data, the normal annual heat requirement is an extensive thermodynamic parameter whose value depends exclusively of the thermal response on building envelope components and on convection and radiation of heat gains from human activity in the main building area.

The heat demand for space heating Q_h is calculated as a difference between the heat losses of the building Q_L and the gain heat Q_g, corrected with a diminution factor η.

$$Q_h = Q_L - \eta \cdot Q_g \quad \text{[kWh]}$$

Q_h - heat demand for heating [kWh]
Q_L - building heat losses [kWh]
Q_g - building heat input [kWh]

The calculations were performed according to the methodology in force, MC 001 - 2006, Methodology for calculating the energy performance of buildings, and the following results were obtained:

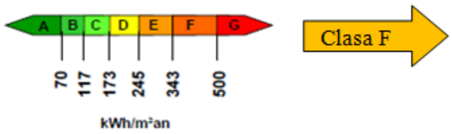
Table 2. *Energy consumption for heating*

Solutions	The energy consumption for heating
	[KWh/m²year]
Without insulation	408.22
Solution 1	151.51
Solution 2	69.35

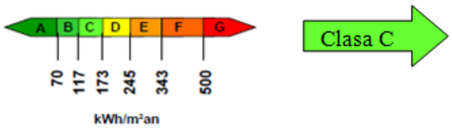
Table 3. *CO_2 emissions*

Solutions	CO_2 emissions
	[kg/m² year]
Without insulation	83.69
Solution 1	31.06
Solution 2	19.41

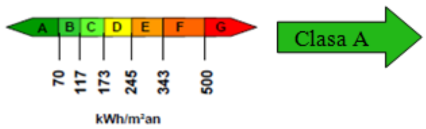
Unrehabilitated building



Solution 1- rehabilitated building



Solution 2- rehabilitated building



Having the required amount of energy, the CO_2 emission is calculated using an appropriate transformation factor, depending on the fuel used for heating According to the regulations in force, the emission factor f_{CO2} for gas is 0.205.

$$E_{CO2} = \Sigma\ (Q_{f,i}\ x\ f_{CO2,I} + \Sigma W_h \cdot x\ f\ C_{O2,i}) - \Sigma(Q_{ex,i}\ x\ f_{CO2ex,i})$$

$Q_{f,i}$ - energy consumption using energy i, in Joule (kWh / year);

W_h - auxiliary energy consumption for space heating (kWh / year);

$f_{p,i}$ - the conversion factor into primary energy, having tabulated values for each type of energy used (thermal, electrical, etc.)

$Q_{ex,i}$ - energy produced in the building and exported, (kWh / year);

$f_{pex,i}$ - primary energy conversion factor (MC 001)

2.2. Embedded energy

To determine the carbon footprint was used one of the most widely used calculation tools, i.e. Life Cycle Assessment (LCA). The assessment includes the extraction and processing of raw materials, the manufacture of the product, the packaging, transport and marketing, use, reuse and maintenance of the product, storage as waste, end-of-life destruction or recycling.

The life cycle assessment aims only at the impact of the product on the environment, not dealing with factors of a political, social or financial nature. Moreover, life-cycle approaches allow for better choices in the longer term (UNEP, 2004).

LCA comparative analysis of the influence of the thermal system on the environment was performed using the OneClickLCA calculation program. It contains a classified and structured database, using a dynamic algorithm that ensures the choice of data according to the requirements in force.

The materials used were chosen from the category of those who hold an EPD - Environmental Product Declaration certification. Such a statement confirms that all materials have been independently verified and recorded and provides transparent and comparable information on the environmental impact of their life cycle.

2.2.1. Defining the goal

The main objective of the analysis is to determine the carbon footprint when using different insulation thicknesses in terms of the impact of thermal insulation materials used on the environment.

2.2.2. Life cycle inventory

The inventory analysis was done taking into account certain limits of application of the system, in order to simplify the model and save time. In this respect, the following aspects were taken into account: all components and finishing materials for the walls were considered identical, and the distance for the transport of materials was the same for all cases analyzed. Given that the lifetime declared by the manufacturer for the thermal systems used is 50 years, the analysis did not address possible interventions to replace them or possible interventions to redevelop.

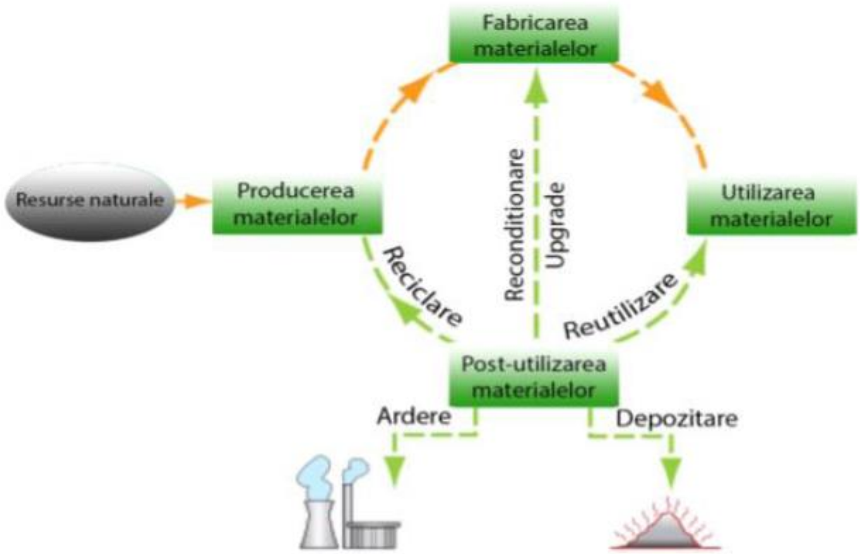


Fig. 2. Life cycle assessment scheme (Nicolae, 2013)

In the production stage (A1-A3) the following modules were included:

- A1 - extraction and processing of raw materials, processing of the input of secondary materials (ex: recycling processes),
- A2 - transport to the manufacturer,
- A3 - manufacture.

In the program, modules A1, A2 and A3 were considered as a unique module A1-A3, generated by a single result.

The construction process stage included the modules:

- A4 - transport to the construction site,
- A5 - installation in the building.

In the use stage (B1-B7) the modules were included:

- B1: use,
- B2: maintenance,
- B3: repair,
- B4: replacement,
- B5: reconditioning,
- B6: use of operational energy,
- B7: operational water use.

In the case of materials used (except plasters), after the completion of the installation, there are no actions or technical operations required during use until the end of life, therefore, the materials used do not impact this stage.

End-of-life, or post-use stage included modules:

- C1 - demolition,
- C2 - transport for waste processing,
- C3 - waste processing for reuse, recovery,
- C4 - elimination.

This includes the supply of all transport, materials, products and related energy and the use of water. For joint manual disassembly, the impact of insulation is considered very small and can be neglected in C1.

Module D included reuse, recovery and / or the possibility of recycling.

2.2.3. Life cycle assessment

For each stage of the life cycle, the quantities of materials and energy used, as well as the carbon emissions associated with these processes, were investigated.

The environmental impact was estimated by using the indicators associated with the CLM 2001 method.

The global warming potential (GWP) was the main indicator calculated and refers to the ability of different gases to contribute to global warming, relative to that of carbon dioxide over a time horizon of 100 years.

This indicator measures greenhouse gas emissions:

- carbon dioxide (CO_2),
- nitrogen oxides (N_2O),
- methane (CH_4),
- hydrofluorocarbons (HFCs),
- perfluorocarbons (PFCs) and
- sulfur hexafluoride (SF_6).

Carbon dioxide has an exact GWP of 1 (because it is the basic unit with which all other greenhouse gases are compared).

Fig. 3. Global warming potential (GWP) for the use of thermal systems for solution 1

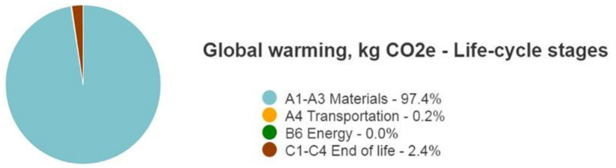


Fig. 4. Global warming potential (GWP) for the use of thermal systems for solution 2

As shown in Fig. 3 and Fig. 4., the global warming potential was clearly dominated by the impact of production processes. All impact indicators (Global Warming Potential - GWP, Acidification Potential - AP and Eutrophication Potential - PE) refer to the two proposed solutions and which have an influence between 68% and 72%, in favor of first solution.

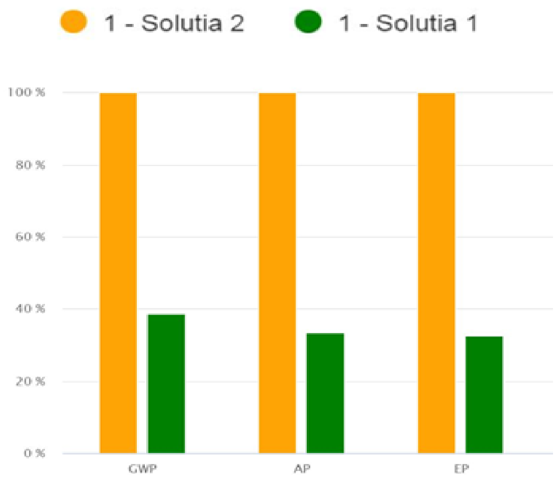


Fig. 5. Graph comparing the LCA indicators in the case of the two analyzed solutions

Life cycle assessment could provide a better understanding of the potential environmental impact of decision-making; however, the LCA cannot determine which product or process is most cost-effective.

Therefore, the information developed in an LCA study should be considered as part of a full-scale decision-making process for assessing compensation in terms of costs and performance. In recent decades, a complete LCA standardization system has been created, which makes the practice of LCA widespread in both industries and governments (Shi, 2015).

Neither of the two analyzed solutions included water and electricity consumption, because the comparisons focused only on the construction stage.

The differences between the energy requirements reached in the case of insulation for solution 1 is 256.71 KWh/m^2 year (62.88%), and for solution 2 is 338.87 KWh/m^2 year (83.01%), as compared to the case in which the building was not isolated.

The amount of CO_2 required to produce the heating system that insulates the vertical tire elements, when using a thickness of 15 cm is 60% higher than when using the same heating system with a thickness of 5 cm. For horizontal elements, the difference between the amount of CO_2 obtained from the production of mineral wool of 10 cm and that of 30 cm is 85%.

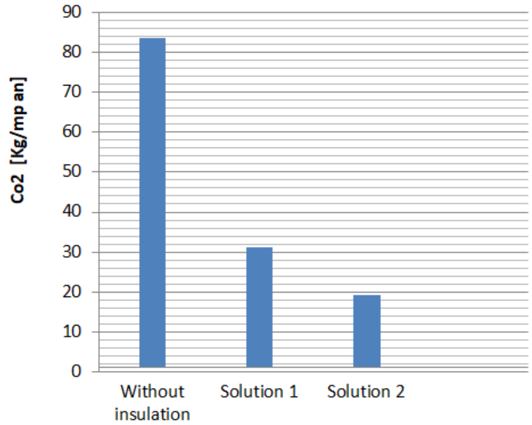


Fig. 6. The amount of CO_2 required to heat the analyzed building in the three solutions

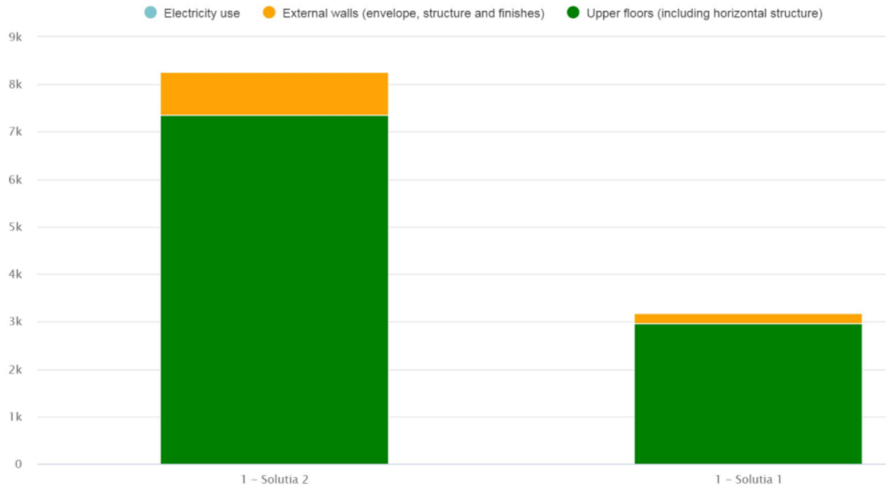


Fig. 7. The total amount of CO_2 embedded in the thermal systems of the envelope elements

The amount of CO_2eq issued for the production of thermal insulation in the life cycle analysis in case of solution 2 (5090 kg CO_2eq.) is 2.5 times higher than in solution 1 (1200 kg CO_2eq.).

Taking into account the fact that by rehabilitating the building the CO_2 emissions decrease by 52.63 kg/m^{2}year in the case of first solution and 64.28 kg/m^2 year, in the case of second solution, if we refer to a period of 100 years or even 50 years the recommendation of thermal insulation is still advantageous in terms of environment impact.

3. CONCLUSIONS

The study of the optimization of the process of reducing gas emissions is very modern. It is necessary to take measures at the legislative level for both new and existing buildings.

All results presented in the case studies were obtained taking into account a wide range of hypotheses and scenarios. By changing some of these scenarios, different results could be reached. Even if for the insulation of the building during the life cycle the thermal insulation materials issue a series of toxic gases, the effect they have in reducing the amount of energy required for building heating is more beneficial.

The materials must be designed in such a way as to preserve the resources and to minimize as much as possible the impact on the environment (Ciutină, 2014).

Thus, it is recommended to use locally produced materials, especially reusable, recyclable or biodegradable ones. Their use leads to the conservation of embedded energy and to the reduction of the consumption of natural resources.

Investing in sustainable materials means less maintenance over time, which leads to limiting carbon emissions, reducing the amount of waste generated and lower life cycle costs.

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