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Life Cycle Assessment of Retrofitting Large Prefabricated Panels Low-Rise Collective Dwellings

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Abstract. During the 1970s, the urban landscape of the major cities in Romania has suffered significant changes. The rapid growth of the urban population, even doubled in some cases has led to an increased demand on the housing market. In order to quickly provide new homes, standard housing units using large reinforced precast concrete components (LRPCC) were used. Today, these units' house more than half of the urban population. Buildings have a high energy demand during their life cycle starting from construction to demolition and are one of the main factors responsible for the negative impact on the environment. Therefore, applied LCA strategies on the built environment, in the last years, has developed into a distinct working area within other LCA practices. This is not only because of the complexity of a building but also due to numerous factors that make this sector so unique. Firstly, buildings are designed to have a long lifetime, usually more than 50 years. Currently LRPCC housing units have not yet even reached half of their intended lifespan and are now failing to meet the modern living standards. Secondly, with the constant changes of daily routines, social lifestyle and needs, buildings usually undergo changes in their forms and functions. This aspect can be as significant or more, than the original element. Third, a building has the highest impact on the environment during its use. Therefore, proper design and selection of materials are important to minimize the in-use environmental loads. LRPCC buildings have a huge energy savings potential and because they are project types, extensive retrofitting strategy on the whole building, extending to the community, can be implemented. By taking the ISO 14040 and 14044 standards into consideration, a Life Cycle Assessment on energy efficiency is carried out on a chosen LRPCC collective housing unit in four distinct phases following an iterative process, to evaluate the behaviour of the building components, materials and systems before and after the retrofitting process.

1. Introduction

"The building and construction industries, and the processes that create, modify and remove built structures, and, the whole-of-life operation of those facilities represent half of our opportunity to resolve today's climate challenge" [1].

Today, due to significant population growth and a more evolved technology, the energy consumption and the burdens on the surrounding environment are steadily increasing. It is also a time when social, economic and environmental concerns are becoming more and more important. The security and stability of energy is also a topic of concern. A reduced energy consumption and



increased use of renewable energy sources also have an important role in promoting security and stability of energy supply, developments in technology and in providing new opportunities for employment and regional development. In addition to focusing on designing new buildings that require low amounts of energy from conventional sources, it is important to address the high levels of consumption of the already existing buildings. Buildings are a primary focus element of EU Member States policy regarding energy efficiency, being responsible for approximately 40% of total energy consumption (figure 1) and 36% of greenhouse gas emissions, according to the Buildings Performance Institute of Europe.

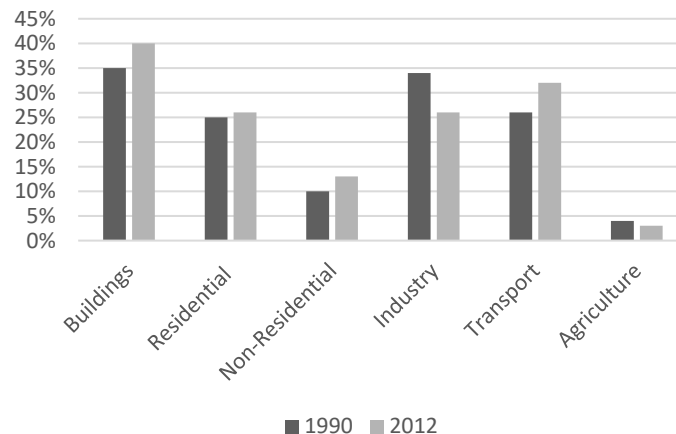


Figure 1. Energy consumption of buildings in EU. 1-Buildings; 2-Residential Buildings; 3-Non-Residential Buildings; 4-Industry; 5-Transport; 6-Agriculture

Currently in Romania there are very few initiatives and programs for existing residential building retrofitting. Also, most programs are inefficient because they only solve very few issues. The most frequent approach is to add a layer of polystyrene to the existing envelope. This is efficient only if thermal insulation is considered and other important aspects such social, architectural and environmental are overlooked. Adding an extra coating layer to the buildings leads to stopping the airflow and is the cause of mould and health problems for people living in those buildings. To get fresh air, residents open their windows. This heat losses and cancels what energy economy advantage that building might have after retrofitting.

In Romania, residents are offered to accept the option of attic block of flats in exchange for benefits of building thermal insulation. Some accept this offer because the upper part of the building cannot be accessed, and they are not properly informed, that this grey space could become positive. More so, in Romania residents have little information about green roofs or roof gardens. The main problem with the newly-added attics is the fact that other apartments are added. The population density is thus increased, and the existing building facilities for heating, cooling and plumbing are stretched. Furthermore, extra parking spaces are required [2]. The density grows more than the existing facilities can handle while the already existing problems are amplified instead of solved. Considering all this, one can say that despite having norms and technical guidelines for interventions such as over roofing as well as codes for reinforcing the buildings to withstand seismic loads, they are less strict than they should be. This usually leads to a poor quality of the final result.

2. LCA methodology

The general standards that define the framework of LCA are ISO 14040:2006 and ISO 14044:2006 [3,4]. These standards describe the four main phases of an LCA, first of which being goal and scope. In this preliminary phase, the purpose, scope of the study, boundaries and defining the functional unit (FU) have to be set. The FU should be as accurate as possible, since all inputs and outputs are computed per functional unit. To enable equivalent comparison between two products, each system

should be based on the same FU. Here, attention should also be paid towards other requirements, such as allocation principles or a closer look at the system boundaries [5].

The second phase represents the life cycle inventory (LCI). Here the process of collecting all relevant data (inputs and outputs) of a product life cycle, takes shape. In this phase it is mandatory to work with accurate data since it will directly influence the final LCA result [6]. The life cycle impact assessment (LCIA) will next evaluate potential environmental impacts, used resources based on the LCI data, depending on the chosen impact assessment method. In short there are two methods towards impact assessment: midpoint (problem orientated) methods and endpoint (damage-orientated) methods. The final step is the interpretation of results [7]. The three last stages refer to goal and scope definition. The complete procedure should be carried out as an iterative process in which, the collected data and information may lead to modification of scope in order to achieve the initial goal of the study [3].

3. Residential buildings in Romania

3.1. Statistics

The RCLPP collective dwellings stock represents 1.8% (83,799) of the entire built environment in Romania and house more than half of a city's population [8]. Compared to similar projects from other European countries, these projects were considered as the only possible housing option, while other design aspects such as accessibility for disabled people were not taken in consideration. Between the 1960s and early 1990s, Romania had one of the highest percentages of build RCLPP dwellings (60%) compared to other European countries. The highest was Estonia with 80% while Ireland was at the bottom of the list with 32%. On the other hand, considering the number of apartment owners, in Romania after 1990, 96% of the tenants became owners, meaning only 4% are tenants compared to other countries such as Switzerland with 65% tenants. Moreover, considering the number of square meters of net area for each person, Romania allocates 20m²/person where South and North Western Europe allocate between 31m²/person and 36m²/person [9].

3.2. Norms and regulations regarding heat transfer standards

The first norms on heat transfer values for building elements were given in the 1960s. Over the last decades the thermal resistance values have been changed numerous times. These changes however were not followed by the improving of the envelopes of the building stock. This is one of the main reasons that today buildings fail to meet the modern living norms. In table 1 a brief comparison is shown on the modifications of the thermal resistance values over the years

Table 1. Romanian norms on envelope thermal resistance [10]

Year	Normative	Outer walls	Flat roofs	Floor/basement
1962	6742-61	0,76	0.96	0,82
1984	NP15-84	1,2	1,55	1,08
1997	C107/3-1997	1,09	1,46	1,25
2010	C107/3-1997	1.80	5,00	2,90

Due to the significant changes in energy efficiency standards since the 1960's, these housing units are now being technically and morally out-dated. They consume large amounts of energy every day for lighting, cooling, heating and ventilation. Because they were build trough-out the entire country and in such numbers, the development of a strategy that improves their overall energy efficiency parameters would have a significant impact on the energy consumption values in the residential sector. To improve these parameters, the last five years marked the beginning of a governmental program which finances the thermal rehabilitation of apartment buildings using polystyrene, thus reducing the

energy consumption for heating and cooling with approximately 40%. This intervention is usually done without changing the entire plumbing which, in most cases, is 30-40 years old.

4. Retrofitting strategy

The retrofitting focuses on an integrated intervention. It significantly improves the thermal properties of the building envelope while at the same time having less impact on the environment through carefully selected materials and not affecting the existing structural system. From technical aspects, the new envelope should focus on reversibility of intervention, durability, operational, functionally and aesthetically compatible and complementary to the existing building, sustainability, technical capability, technical support, availability of material/device and quality control.

5. Building characteristics

5.1. Model T770

The 770 model is one of the most used 5-storey housing typology in Timisoara, as shown in figures 2-3. It was built during the 70s and the 80s and met the lowest building comfort standards. The model was designed to withstand high level seismic activities. It could be placed in different ways thus obtaining a variety in the designing and building of new neighbourhoods. The 770 was designed from 68 different components (walls, slabs, stairs or bathroom units) that, shipped on site, could be assembled in short time. The model has 3 main types of plan configurations and a total of 12 subtypes, each with 10-20 apartments bound together to form a building row.

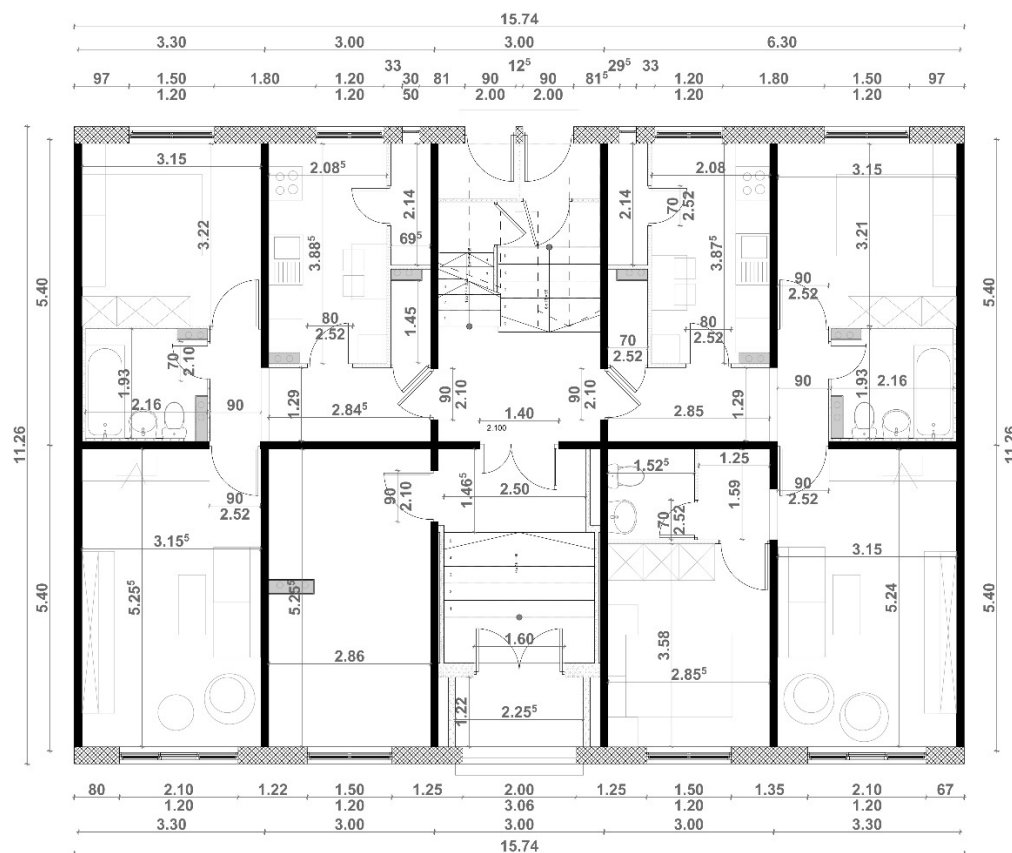


Figure 2. T770 ground floor plan

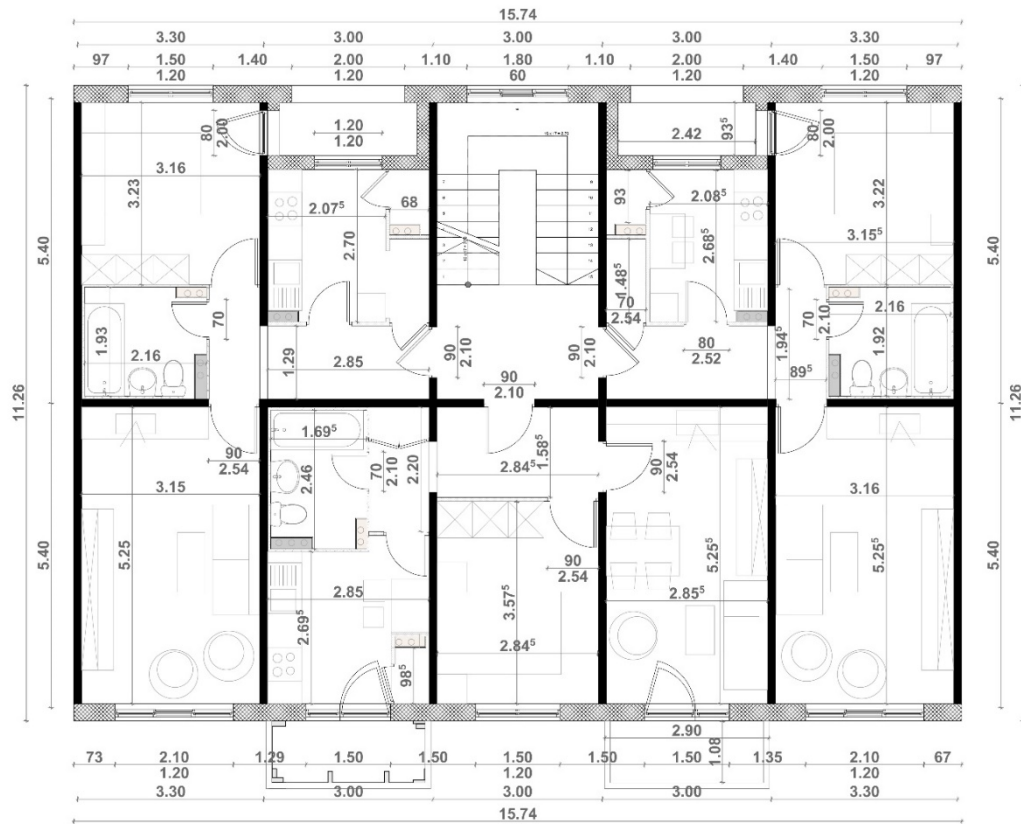


Figure 3. T770 typical floor plan

5.2. The existing envelope

The online thermal resistance evaluator U-wert [11] was used to study the behaviour of the current building components (figure 3) (table 2). The panel is composed of 2 reinforced concrete layers with and insulation of aerated concrete blocks or expanded polystyrene in between. Due to the low thermal resistance of the panel, the environmental impact of the element is very high. This is also do the significant heat loss, not only through the panel but also through the connection areas between them. Because these panels had to withstand high seismic activities, the design of connections between the panels led to solutions where thermal bridges are formed, further increasing the heat loss and weakening the thermal properties of the panel. By itself the thermal protection of the panel is $U=1,05 \text{ W/m}^2\text{K}$ and has a *thermal capacity* of $221 \text{ kJ/ m}^2\text{K}$ with a phase shift period of 8,3 hours

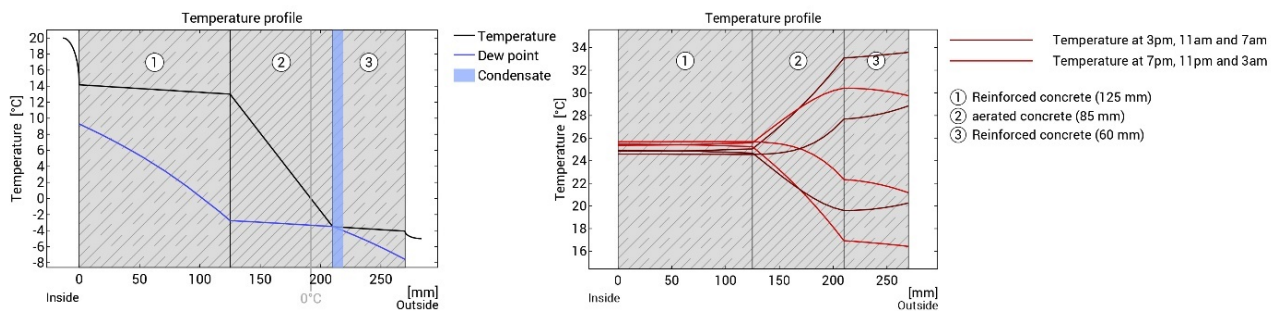


Figure 4. Existing façade temperature profiles

Table 2. Existing façade layers

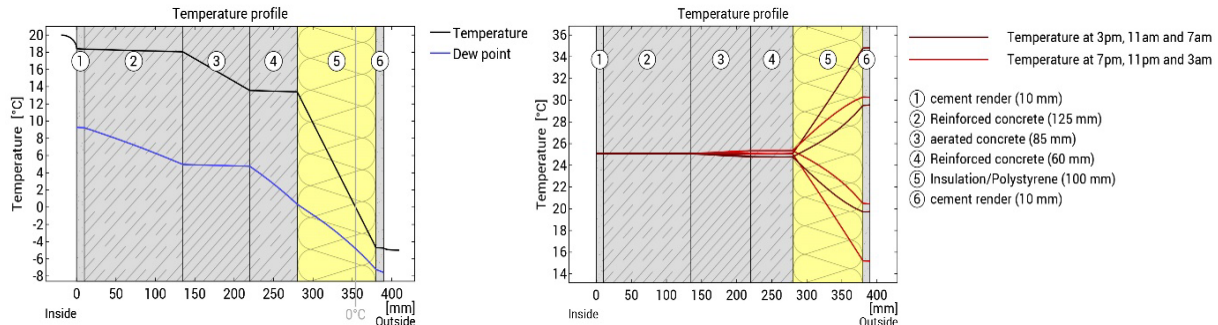
Material	λ [W/mK]	R [m ² K/W]	Temperature [°C]		Weight [kg/m ²]
			min	max	
Thermal contact resistance*		0,130	19,1	20,0	
1cm Cement render	1,400	0,007	19,1	19,1	20,0
12,5 cm Reinforced concrete	2,500	0,050	18,9	19,1	300,0
8,5 cm Insulation aerated concrete	0,120	0,708	16,3	18,9	42,5
6 cm Reinforced concrete	2,500	0,024	16,2	16,3	144,0
1cm Cement render	1,400	0,007	19,1	19,1	20,0
Thermal contact resistance*		0,130	19,1	20,0	
29 cm		1,056			526,6

*Thermal contact resistances according to DIN 6946 for the U-value calculation. [12]

6. Retrofitting scenarios and performance evaluation

6.1. Thermal resistances

The first option for retrofitting (figure 5) represents the most applied solution. It consists of a 10 cm polystyrene layer, mechanically fastened on the LRPCC. On the exterior, the final finish is assured through a cement render on a glass fibre (table 3). It results an overall thermal protection of $U=0,28$ W/m²K with an inside thermal capacity of 396 kJ/ m²K. The main issue however with this system is the high flammability of the insulation layer thus requiring an addition of flame resistant chemicals. Furthermore, a poorly installed system can lead forming cavities between the insulation layer and the building structure thus reducing its overall performance.

**Figure 5.** Typical retrofitted façade temperature profiles**Table 3.** Typical retrofitted façade layers

Layer	Material	λ [W/mK]	R [m ² K/W]	Temperature [°C]		Weight [kg/m ²]
				min	max	
	Thermal contact resistance*		0.130	19.1	20.0	
1cm	Cement render	1.400	0.007	19.1	19.1	20.0
12.5 cm	Reinforced concrete	2.500	0.050	18.9	19.1	300.0
8.5 cm	Insulation aerated concrete	0.120	0.708	16.3	18.9	42.5
6 cm	Reinforced concrete	2.500	0.024	16.2	16.3	144.0
10 cm	Insulation/polystyrene	0.035	5.714	-4.9	16.2	5.5
1cm	Cement render	1.400	0.007	19.1	19.1	20.0
	Thermal contact resistance*		0.130	-5.0	-4.9	
39 cm						

*Thermal contact resistances according to DIN 6946 for the U-value calculation. [12]

The second option (figure 5) consists of a ventilated façade system using rigid wood-fibre insulation with wooden siding. In this case, the insulation is installed within a lightweight steel structure with adjustable elements. It is lighter than the first option, however special care needs to be taken on form of thermal bridge breakers in the connection areas between the steel profile and the LRPCC. In this case, the thermal protection is $U=0,148 \text{ W/m}^2\text{K}$, which is according to passive house standards such as EnerPHIT [13]. Furthermore, the thermal capacity of the element has increased to $421 \text{ kJ/m}^2\text{K}$ and the overall thermal resistance has doubled compared to the first solution (table 4).

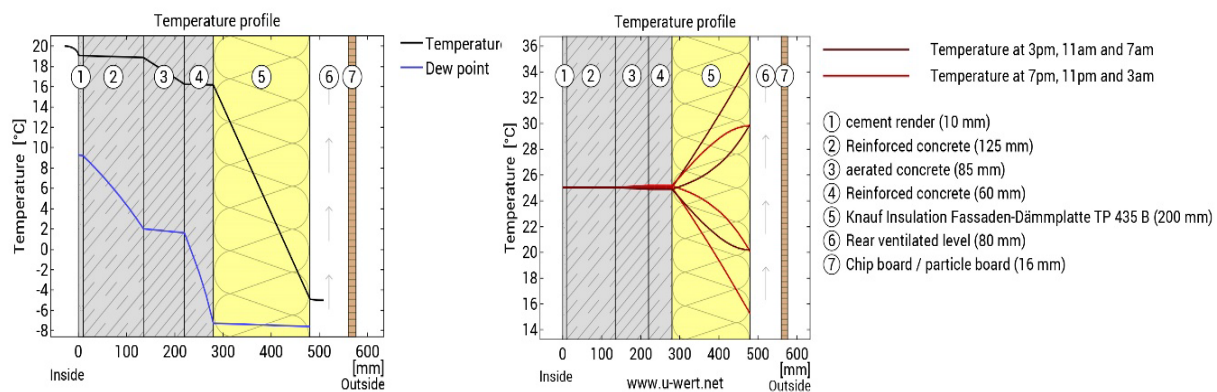


Figure 6. Ventilated façade temperature profiles

Table 4. Ventilated façade layers

Layer	Material	λ [W/mK]	R [m ² K/W]	Temperature [°C]		Weight [kg/m ²]
				min	max	
	Thermal contact resistance*		0.130	19.1	20.0	
1cm	Cement render	1.400	0.007	19.1	19.1	20.0
12.5 cm	Reinforced concrete	2.500	0.050	18.9	19.1	300.0
8.5 cm	Insulation aerated concrete	0.120	0.708	16.3	18.9	42.5
6 cm	Reinforced concrete	2.500	0.024	16.2	16.3	144.0
20 cm	Wood fibre insulation	0.035	5.714	-4.9	16.2	5.5
	Thermal contact resistance*		0.130	-5.0	-4.9	
8 cm	Ventilation layer	-	-	-5.0	-5.0	0.0
1.6 cm	Wooden cladding	-	-	-5.0	-5.0	10.4
57.6 cm			6,764			522,4

*Thermal contact resistances according to DIN 6946 for the U-value calculation [12].

6.2. Environmental impact

The environmental impact was conducted using Graphisoft Archicad21s EcoDesigner energy evaluator [14] add-on. The reinforced concrete elements were not considered when defining CO₂ emissions do to the multiple variations of the material composition.

Table 5. Used material end of life scenarios

Material	Reuse [%]	Recycling [%]	Burn [%]	Landfill [%]
Cement render	-	-	-	100
Insulation/polystyrene	-	-	100	-
Wood fibre insulation	25	-	75	-
Steel	-	80	-	-
Wooden materials	30	-	70	-
Other inert materials	-	-	-	100
Other combustible materials/foils	-	-	100	-

Table 6. Embodied carbon of materials

	CO ₂ e g/kg	CO ₂ fossil g/kg	CO ₂ uptake g/kg	Unit weight kg/m ³	CH ₄ g/kg	N ₂ O g/kg
Polystyrene(EPS)	3300	2500	0	10-60	31	0
Polyurethane (rigid foam)	4200	3400	0	30-100	32	0.01
Glass wool	3148	2909	0	22	7.7	0.16
Wood fibre insulation	243	-	1240	25-65	-	-
Aerated concrete block	442.3	429.2	-	433	0.49	3.5*10 ⁻⁶
Pre-cast concrete C20/25	120.5	117.7	0	2400	0.1	9.6*10 ⁻⁷
Gypsum plasterboard	1967	1846	0	800	4.03	6.8 * 10 ⁻²
Laminate flooring	750	750	1476	900	-	-
Massive parquet	2942	2942	1696	11,7	-	-
Multi-layer parquet	7292	7292	1638	8.87	-	-
Sand						
Glass (Float glass)	1230	-	-	2500	-	-

Where, **CO₂e** – the sum of fossil-based emissions calculated with help of IPPC weighting factors (for 100 years); **CO₂uptake** - the amount of sequestered carbon

To compare the energy performance of the three envelopes, thermal blocks were defined within the EcoDesigner [14] add-on. The simulations were carried out on the middle apartment from the current floor, it having the most disadvantageous position.

The apartment has the following characteristics:

- Gross Floor Area: 51,60 m²
- Treated Floor Area: 46,60 m²
- Ventilated Volume: 118,37 m³
- Glazing Ratio: 6%

Table 7. Energy performance of the building envelopes

Envelope system	Total annual energy yield [kWh/m ² y]	CO ₂ emissions [kg/m ² y]	Heating [kWh/m ² y]	Hot water	Artificial Lighting	Renewable energy
Existing envelope	259.32	60.59	197.92	50.40	11	-
Classic rehabilitation	150.88	34.56	89.48	50.40	11	-
Ventilated façade	62.31	15.94	11.91	50.40	0	11

7. Conclusions

Most of the LRPCC collective housing in Romania need thermal retrofitting to improve their overall energy efficiency and the quality of life for the inhabitants. An integrated design is needed that includes sustainability pillars. It is better to take something existing and use it in a new way with the help of current technology than building something new. It also lessens the burden the building process has on the surrounding environment. The final choice in a retrofitting scenario, is however a decisional task which is based on a multi-criterial analysis that consider social, economic and environmental aspects.

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