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CASE STUDY: THE EFFECTS THE IMPROVEMENTS IN ENERGY RATING BAND C TO BAND B HAS ON THE FLOW OF NECESSARY MATERIALS AND EMBODIED

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Abstract: The impact of global climate changes has indicated the necessity for the reduction in the emissions of greenhouse gases. The need for the lower energy consumption in buildings in Serbia since 2012 and the introduction of energy performance certificates, have led to the increased use of thermal insulation materials. The selection of materials or systems which are used for energy rehabilitation of a building is observed only through energy consumption in operational phase, while emissions from production, transportation, ongoing and investment maintenance are unjustly neglected. The analysis of carbon footprint of the building in energy rating C scenario (S1) and its comparison with the building in energy rating B scenario (S2) will explain to what extent the impact of these two models on the environment. In order to show the environmental impact of the increased flow of thermal insulation materials, as a consequence of the new regulations on the energy efficiency of the facilities, a carbon footprint analysis for two scenarios for the needs of the research was made. The study uses the Life Cycle Analysis (LCA), a methodology that is the basis for Carbon Lifecycle Analysis (LCACO2), or calculation of the carbon footprint of the facility. Calculation of the carbon footprint uses the Carbon calculator, the Environmental Protection Agency UK, and for the calculation of operational energy URSA program construction physics 2. The research was done in two phases, in the first phase there are boundaries from the cradle to the beginning of the use of the object for which it was done the calculation of the embodied carbon. In the second phase, the boundaries of the cradle and the first 25 years of use of the facility, for which the calculation of the total carbon footprint. The survey showed that the embodied carbon for the scenario (S1) is 148.20 tonnes CO2 e. has a lower environmental impact than the scenario (S2) of 153.00 tonnes CO2 e. After twenty five years of use of the facility, the scenario (S1) has a total carbon imprint of 187.32 tonnes CO2 e. and scenario (S2) has 172.78 tonnes CO2 e. The short term scenario (S1) is a more favorable choice from the aspect of environmental impact. However, in the long run, the scenario (S1) and (S2) achieve the same values of total carbon imprint after 6.49 years, and after that (S2) becomes a better choice from the aspect of environmental impact. The study pointed to the need for the embodied carbon to be taken into account when calculating the environmental impact of an object.
Keywords: thermal insulation materials, energy rating, embodied carbon

1. INTRODUCTION

On the global level civil engineering is recognized as an industry which greatly contributes to the consumption of resources, primary materials, energy and water, and to the waste production [1]. Due to that fact the European commission decided that the sector of civil engineering has to start taking part in implementing measures to reduce carbon emissions and mitigate climate changes [2]. Through the implementation of the energy efficiency measures Serbia is trying to reduce the operational energy in buildings by introducing building energy ratings [3-4]. The construction stage of a building, regarding the embodied carbon, is still not recognized as an approach to the reduction of the impact civil engineering has on GHG emission. The carbon footprint is one of the crucial parameters to assess the impact of the building construction on the environment and can contribute to the reduction in national carbon footprint).

The European Commission recommended life cycle assessment LCA as a methodology for identification and environmental intervention and potential impacts which a product or service has on the environment during its life cycle [5]. LCA methodology is detailed by the International Organization for Standardization (ISO) in ISO 14040:2006 which is accepted as a method for identification and assessment of impact on the environment caused by a product, process or service by identifying energy and materials and their life cycle emissions [6].

According to ISO standard [6], inventory of life cycle impact assessment (LCIA) is LCA phase whose goal is to understand and assess the participating inventories. In the interpretation phase, the results or analysis of inventory or impact assessments, or both, are combined in accordance with the defined goal and scope of the study. The graph of LCA methodology is shown in Figure 1.

The research on the impact of products used for construction by applying LCA can help when deciding what product and system [7-8] to choose when construction is planned. By applying LCA methodology it has been concluded that concrete is responsible for 8.60% of carbon emission in the world [9]. Cement and concretes are construction materials widely used in Serbia and on the global level.

LCA methodology for building structures is defined by Standard EN 15978:2011 [10]. The life cycle of a building is divided into four phases, and the additional phase, beyond the system boundaries, is the reuse and recycling in phase (D).

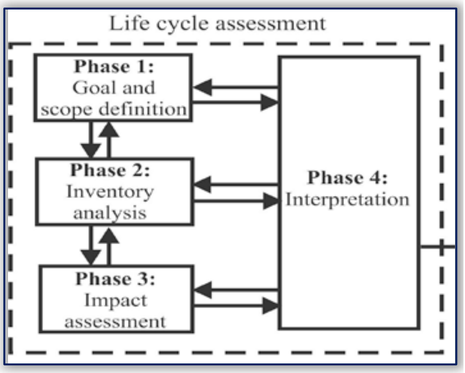

Figure 1. Implementation of LCA method to obtain information on the impact of the applied materials and processes throughout the life cycle

The impact of global climate changes has indicated the necessity for the reduction in the emissions of greenhouse gases (GHG). In 2008, the building sector in Serbia participated with over 41% in energy consumption [11].]. The indicators for production and consumption of energy in Serbia in 2013, show the reduction in CO2 emissions per capita, but still it was the highest in the region with 6.33 t CO_2/capita [12]. The production and consumption of energy is in direct connection with the generation of CO_2 and other greenhouse gases (GHG) emissions. National ecological footprint in Serbia in 2014 was 2.92 g.ha [13]. More than 50% of ecological footprints in Serbia comes from the production of CO2 [21]. By implementing the measures of energy efficiency starting from 2012 [3-4], Serbia has been trying to reduce the necessity for energy in building constructions, through energy ratings and rehabilitation. Such measures are directly linked to the increasing need for thermal insulation materials, which is again connected to additional pressure on resources and more GHG emissions from production, transportation and construction. The amount of these impacts is often neglected, and according to the current legislative, only the energy from the operational phase is assessed. LCA of a building is a support to the analysis of the embodied carbon to calculate the total energy impact of a building on the environment. The researches done by various scientists' show that it is also necessary to analyze embodied carbon and compare it with whole life carbon of the building [15-16], so the exploitation period of 25 years will be analyzed.

So far 1600 energy performance certificates have been issued in Serbia both for the new buildings and for the energy rehabilitations. Approximately 98% of issued certificates are for energy rehabilitation of the existing buildings as well as the new ones in energy rating C, but only 2% of buildings are in higher energy ratings B and A. The measurement of embodied and operational carbon can change the image of building energy consumption and emphasize the role of architects in attempting to lower the emissions from the construction sector [16]. Identifying embodied carbon in the design stage can change perspective regarding the investments into improvement of energy ratings from band C to band B, which depends on what the targets for the reduction of national footprint are.

The research is carried out on the residential house project with gross area of 110m2 on the outskirts of Belgrade. For that purpose, two scenarios are made: scenario (S1) house in energy rating C, and scenario (S2) house in energy rating B.

Energy needs and calculation of thermal cover for both scenarios are made in program URSA construction physics 2 [17], which precisely calculates the quantities of necessary materials in compliance with the norms and standards in civil engineering [18], as well as the energy consumption for heating on annual level [17]. In operational phases of both scenarios the planned energy source for heating is gas.

The research follows LCA methodology, which is the basis for calculation of CO2 emissions. ICE database version 2 [19] as well as the Carbon calculator from Environment Agency UK [20] are used for the calculation of embodied carbon.

In the phase one of the research the boundaries of the system for embodied carbon calculation are from cradle to site. The aim is to investigate if there are differences and how different the values of embodied carbon in these two models are.

In phase two of this research the boundaries of the system include also the operational phase for the period of 25 years, when, according to some authors [15], investment maintenance occurs and there is the need for certain components to be replaced, which generates new emissions of embodied carbon, which is not the subject matter of this research. Outside the boundaries of the system there are: replacement, renovation, deconstruction of a building and recycling of construction waste. The aim of this research is to determine the total amount of carbon footprint in construction and operational phase, and to compare these two models.

This research will show that through the calculation of embodied carbon in the design stage it is possible to estimate the impact on the environment that results from the improvement in energy performance rating from band C to band B. Also, there will be shown how short and long-term policy for reduction of carbon footprint in civil engineering sector can be created through the measurement of embodied carbon in the design stage of a building.

2. DESCRIPTION OF THE EXPERIMENT

The experiment is done on a family house construction project on the building site on the outskirts of Belgrade. It is a ground floor house for a four-member family, with gross area of 110 m2 designed in load bearing structural system, common in Serbia, by using brick blocks in combination with vertical and horizontal RC (reinforced concrete) ring girders, easy installed ceilings, roof woodwork with roofing tile. All materials used in the construction come from domestic manufacturers, and the calculation involves transportation routes from manufacturers to the site on the outskirts of Belgrade, duration of construction, transportation of workers within 30 km, energy sources needed for the machines, electric power, generated waste, its transportation and depositing onto the landfill 20 km away from the building site.

In phase one only the embodied carbon is measured so the boundaries of the system are from cradle to site, which is shown in Chart1. This phase will show if there are differences between embodied carbon in model S1 in energy rating C, which is the lowest energy rating for new buildings according to legislative in Serbia, and model (S2) in energy rating B.

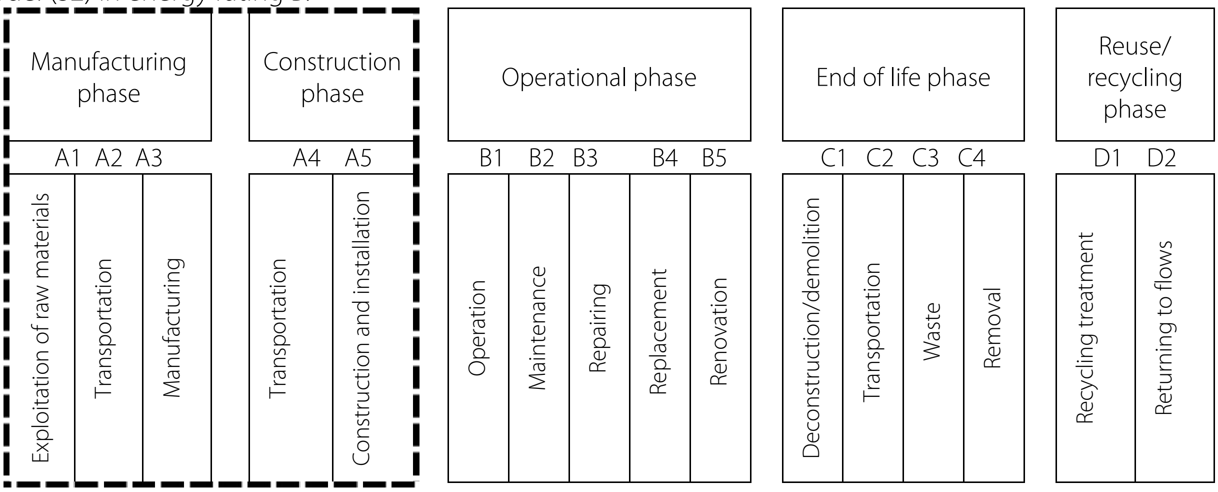

Chart 1. Boundaries of the system to estimate embodied carbon

In phase two, the boundaries of the system involve also the operational phase from cradle to 25 years of operation, when replacement and renovation start. Outside the boundaries of the system there are: replacement, renovation, deconstruction of a building and recycling of construction waste. These boundaries are shown in Chart 2.

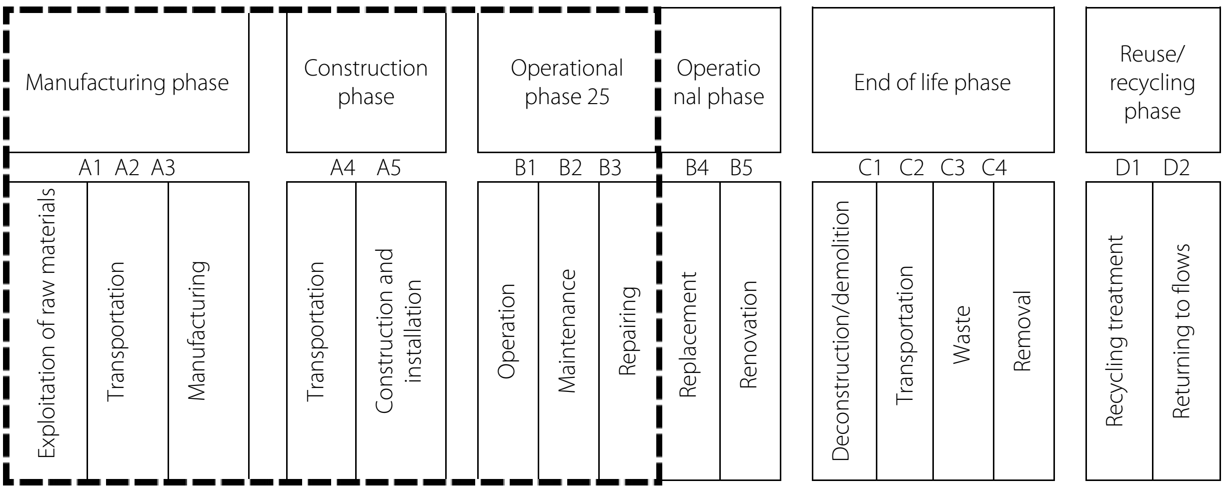

Chart 2. Boundaries of the system to estimate embodied and operational carbon in 25 years

Two scenarios (S1, S2) are made to compare carbon footprint generated during the construction.

— Scenario 1 (S1) is designed in energy rating C in load bearing structural system. The walls are of hollow brick blocks 25 cm thick, with 12 cm of thermal insulation on the façade walls with decorative external plaster and internal gauged mortar. RC columns, vertical and horizontal RC ring girders, easy installed ceilings with 15 cm of attic thermal insulation. Lightweight reinforced floor slab is covered with 10 cm of thermal insulation, cement screed and the floor finishing in accordance with the purpose of the room. Primary materials are used in quantities obtained in project design and calculated in compliance with the norms and standards in civil engineering [18], and shown in Table 1.

— Scenario 2 (S2) is designed in energy rating B in load bearing structural system. The walls are of hollow brick blocks 25 cm thick, with 20 cm of thermal insulation on the façade walls with decorative external plaster and internal gauged mortar. RC columns, vertical and horizontal RC ring girders, easy installed ceilings with 25 cm of attic thermal insulation. Lightweight reinforced floor slab is covered with 15 cm of thermal insulation, cement screed and the floor finishing in accordance with the purpose of the room. Primary materials are used in quantities obtained in project design and calculated in compliance with the norms and standards in civil engineering [18], and shown in Table 1.

Table 1. Quantity of materials and energy sources used for each scenario

Type of material and energy source	Units of measure	Replaced quantities S1	Replaced quantities S2
Tamping gravel	(m^3)	75,00	75,00
Crown tile	(pc)	10.240	10.240
Bricks and clay blocks, easy installed ceiling	(m^3)	92,00	92,00
Cement mortar	(m^3)	23,40	23,40
Lime mortar	(m^3)	7,80	7,80
Steel reinforcement	(tons)	6,50	6,50
Concrete MB30	(m^3)	38,00	38,00
Concrete MB20	(m^3)	62,50	62,50
Ceramic tiles	(m^2)	87,00	87,00
Glue for tiles and parquet	(kg)	490	490
Lacquer for parquet	(litre)	30	30
Total of timber	(m^3)	18,70	18,70
Parquet or match floor	(m^3)	3,10	3,10
Thermal insulation polystyrene	(m^3)	37,50	67,50
Thermal insulation mineral wool	(m^3)	21,50	35,83
Thermal insulation austrotherm	(m^3)	14,00	21,00
Facade mortar	(kg)	800	800
Interior paint for walls	(kg)	100	100
Mass for skimming	(kg)	500	500
Window glass	(m^3)	0,80	1,21
Electrical installation	(kg)	520	520
Heating installation	(kg)	750	750
Waterworks and sewage works	(kg)	150	150
Roofing paper	(kg)	150	150
Hydro insulation	(m^3)	1,50	1,50
Personal transportation within 30 km	(km)	5.760	5.820
Transportation of waste to landfill	(m^3)	112,00	112,00
Water consumed on the site	(litre)	20800	20800
Power consumed on the site	(kWh)	13500	13500
Diesel fuel consumed on the site	(litre)	900	900

3. RESULTS AND DISCUSSION

— Research results in phase one on embodied carbon in scenarios S1 and S2

Upon the completion of the research, the values of the embodied carbon for each scenario from cradle to site are obtained. The results from phase one are shown in Table 2, as well as the percentage of the groups of materials which participated in embodied carbon. The values of the embodied carbon benchmarks for the scenarios (S1) and (S2) are given in Table 3.

Table 2. Values of embodied carbon footprint in analyzed scenarios

Groups of materials and activities	S1		S2	
	tonnes CO_2e	participation%	tonnes CO_2e	participation%
Brick Material	44,40	30%	44,40	29%
Timber	3,40	2%	3,40	2%
Concrete, Mortars & Cement	28,40	19%	28,40	19%
Metals	23,90	16%	23,90	16%
Plastics	5,80	4%	5,80	4%
Glass	3,70	3%	5,60	4%
Miscellaneous	9,00	6%	11,90	8%
Finishing, coatings & adhesives	7,10	5%	7,10	5%
Plant and equipment emissions	5,40	4%	5,40	4%
Waste Removal	1,10	1%	1,10	1%
Portable site accommodation	2,00	1%	2,00	1%
Material transport	5,60	4%	5,70	4%
Personnel travel	8,40	6%	8,40	5%
Operational	0,00	0%	0,00	0%
Total Carbon Footprint	148,20	100%	153,30	100%

Table 3. Embodied carbon benchmark for scenarios S1, S2

Analyzed scenario		Embodied carbon			
		Tonnes of CO_2e per building	Tonnes of CO_2e per gross m2	More tonnes of CO_2e than (S1)	% Increase in CO_2e
1.	S1 energy rating C	148,20	1,35	0,00	0,00%
2.	S2 energy rating B	153,30	1,39	5,10	3,44%

— Discussion on the research results in phase one on embodied carbon in scenarios S1 and S2

The first phase of the research shows that the embodied carbon in model S2 is 5,10 tonnes higher (equivalent of a measurement of all GHG impacts) which is 3,44% more compared with model S1. This increase in the value of embodied carbon in model S2 results from greater quantity of thermal insulation materials and the need for triple pane windows designed for buildings in energy rating B. In the short run, scenario S2 in the construction phase has greater impact on the environment than scenario S1. To understand long term aspects, it is necessary to extend the research to the operational phase of a building.

— Research results in phase two on embodied carbon in scenarios S1 and S2 after 25 years

Upon the completion of the phase two of the research, the results of the total carbon footprint (embodied and operational) are obtained for each scenario. The results from phase two are shown in Table 4, as well as the percentage of the groups of materials together with the emissions from operational phase in scenarios S1 and S2. Total carbon footprint benchmark from cradle to 25 years of operation is given in Table 5 showing values of embodied, operational and total carbon footprint as well as the percentage of lower carbon footprint in scenario S2 after 25 years of operation. The values of thermal cover in scenarios S1 and S2, energy consumption per gross m2 and the quantity of CO_2 emissions on annual level in scenarios S1 and S2 are given in Table 6.

Table 4. Values of embodied carbon and carbon in operational phase in analyzed scenarios after 25 years

Groups of materials and activities	S1		S2	
	tonnes CO_2e	%	tonnes CO_2e	%
Brick Material	44,4	23,70%	44,40	25,70%
Timber	3,40	1,82%	3,40	1,97%
Concrete, Mortars & Cement	28,40	15,17%	28,40	16,44%
Metals	23,90	12,77%	23,90	13,83%
Plastics	5,80	3,10%	5,80	3,35%
Glass	3,70	1,97%	5,60	3,23%
Miscellaneous	9,00	4,82%	12,05	6,98%
Finishing, coatings & adhesives	7,10	3,79%	7,15	4,14%
Plant and equipment emissions	5,40	2,89%	5,40	3,13%
Waste Removal	1,10	0,59%	1,10	0,64%
Portable site accommodation	2,00	1,07%	2,00	1,15%
Material transport	5,60	2,99%	5,80	3,36%
Personnel travel	8,40	4,49%	8,40	4,85%
Operational	39,12	20,89%	19,48	11,27%
Total Carbon Footprint	187,32	**100%**	172,78	**100%**

Table 5. LCA values of embodied carbon in scenarios S1and S2 and achieved savings

Analysed scenarios		Embodied and operational carbon footprint after25. years				
		Tonnes of embodied CO2 e	Operational CO_2e	Total CO_2 e	Fewer tonnes CO_2 e than (S1)	Reduction of total CO2 e.
1.	S1	148,20	39,12	187,32	0,00	0,00%
2.	S2	153,30	19,48	172,78	14,52	7,75%

Table 6. Crucial elements of thermal cover in scenarios S1 and

Analysed scenarios		U_{value} Façade wall	U_{value} Ceiling	U_{value} Floor	Annually for heating per gross m2	Total tonnes of CO_2 from heating
1.	S1 energy rating C	0,27678	0,2391	0,2615	64,66	1,5648
2.	S2 energy rating B	0,17951	0,151	0,1983	32,20	0,7792

— Discussion on the research results in phase two on total carbon footprint in scenarios S1 and S2 after 25 years

Obtained results on total carbon footprint, which include both embodied and operational carbon in 25 years of operation, show that scenario S2 has lower values of CO_2 e by 14.52 tonnes in comparison to scenario S1. Lower values of operational carbon in model S2 compared to model S1 have brought savings of 7.75% in CO2 e emissions for the long run period of 25 years. Lower embodied carbon achieved in the construction phase of scenario S1, proved in the phase one of the research, had positive effects on the environment in the short run. During the construction phase and in the following 6.49 years scenario S1 will have lower total carbon footprint. After 6.49 years the values of total carbon footprint in both scenarios S1 and S2 will match. From that moment on, scenario (S2) becomes a better choice regarding the total carbon footprint of the analyzed scenarios. If the reduction in ecological footprint in civil engineering sector is considered in the long run, positive effects and results can be expected after 6,49 years if scenario (S2) is selected.

4. CONCLUSION

In the sector of civil-engineering considerable efforts have been put lately into decreasing the consumption of energy, which has led to the certification of buildings and the introduction of energy ratings for the new buildings, or energy rehabilitation for the existing ones. Consequently, the need for thermal insulation materials is increased, i.e. the pressure on primary materials and energy consumed to produce additional quantities of thermal insulation materials. When calculating the energy rating of a building, the embodied carbon is not considered when measuring the reduction of CO2 e emissions (carbon footprint). The research includes the analysis of the embodied carbon and not only the whole life carbon, which is the usual method of energy consumption in regulations both in EU [21] and Serbia [3-4]. Two models of the same building are designed, but in different energy ratings C and B. The study includes all building materials, activities, and transportation which participate in construction of the observed building shown in two scenarios: the first one is scenario (S1) building in energy rating C, and the second one is scenario (S2) building in energy rating B. Both models consume gas for heating, so that the emissions in operational phase are calculated in accordance with that energy source.

Higher amount of embodied carbon in scenario (S2), in the first 6,49 years, consequently shows that scenario (S1), regarding the carbon footprint impact on the environment, is the preferable scenario. This is because the embodied carbon in scenario (S1) is lower by 5.10 CO_2 tonnes e. Despite the lower emission in operational phase in scenario (S2), it takes the period of 6.49 years for the two scenarios to match their total carbon footprint. From that moment on, scenario (S2) becomes a better choice regarding the total carbon footprint of the analyzed scenarios. If the reduction in ecological footprint in civil engineering sector is considered in the long run, positive effects and results can be expected after 6.49 years if scenario (S2) is selected.

In the short run, scenario S1 will release lower carbon footprint in total starting from the construction phase and throughout the following 6.49 years. Also, in the short run, raising the energy rating from C to B of new projects, as well as through reconstruction of the existing buildings, will result in higher impact of carbon footprint in the construction phase, as the value of embodied carbon will increase, which is not a central point of interest in Serbia.

However, in the long run, after a couple of years of exploitation of a building in energy rating B, this first blow of increased carbon footprint becomes beneficial and in subsequent use of a building the total carbon footprint is lower.

The research results indicate that it is necessary to analyze not only the whole life phase but also the embodied carbon to observe realistically the benefits for the environment both on local and national level. Additionally, they show the necessity to analyze carbon footprint in the design stage as in that way the impact of the embodied carbon can be measured and together with whole life carbon the final total impact of construction and exploitation of the observed building in Serbia can be made.

Each building is specific, so, apart from calculating the energy rating i.e. whole life carbon through design stage, it is necessary to calculate embodied carbon to reach the right decision when choosing the project design, and clearly explain what these decisions bring throughout the construction as well as exploitation of the building.

Explanation of embodied CO_2 e will indicate the necessity for change in carbon footprint calculation in the construction sector, both on global and national level.

Government is one of the important participants in terms of providing support to investors who design and construct buildings in energy rating B and in the long run help reduce the national footprint in civil engineering sector.

This research does not include the financial effects of the increased energy rating of a building, they are the separate part of the research. The explanation of embodied CO_2 will disclose the real savings in CO_2 emissions of buildings which are created with the higher energy rating, unlike the current legislation applied in Serbia and majority of EU.

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