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A CASE STUDY OF THE INCREASE OF CARBON DIOXIDE DUE TO THE APPLICATION OF ENERGY EFFICIENCY REGULATIONS IN SERBIA

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Abstract: In order to demonstrate the environmental impact of the increased flow of thermal insulation materials and facade joinery with improved thermal characteristics, the analysis of the carbon footprint for two scenarios for the needs of the research was done as a consequence of the new regulations on the energy efficiency of the facilities. For each of the analyzed scenarios, a project and an overview of works on the basis of which quantities of construction materials, activities and processes that participate in the construction of the analyzed scenarios were calculated (S1 and S2), were made. The reference object (S1) is designed without thermal insulation layers, the energy class „G“, and the scenario (S2) is designed in the energy class „C“, which according to the new regulations is a condition for the construction of new facilities. The study uses the Life Cycle Analysis (LCA), a methodology that is the basis for Carbon Lifecycle Analysis (LCACO$_2$), or calculation of the carbon footprint of the facility. Construction carbon calculator, Environmental Protection Agency UK, is used to calculate the carbon footprint, and for the calculation of operational energy, the URSA Construction Physics 2 program. The study showed that the embodied carbon for the scenario (S1) is 138,40 tonnes CO$_2$ e, with less impact on the environment. The higher values of the embodied carbon have a scenario (S2) of 148,20 tonnes CO$_2$ e. The carbon imprint from the phase of construction, or less impact on the environment, has a scenario (S1). However, after ten years of using the facility, the scenario (S1) due to the larger carbon footprint from the operational phase becomes a scenario with a higher environmental impact, with a total carbon footprint of 186,16 tonnes CO$_2$ e, and the scenario (S2) after ten years of use of the facility has a total carbon footprint of 163,86 tonnes CO$_2$ e. The scenario (S1) and (S2) achieve the same values of the total carbon footprint after 3,05 years of use of the facility and (S2) has since then become a better choice from the aspect of the environment. The research has shown that the embodied carbon is neglected in the calculation of the environmental impact of the facility, as well as the average when the benefits can be expected from the application of measures for energy-efficient buildings. The research also points to the need for low-carbon thermal insulation materials to bridge the gap between the demand for the extinguishing of buildings on the one hand and the efforts to reduce greenhouse gas emissions to mitigate climate change.

Keywords: thermal insulation materials, energy class, embodied carbon, operational carbon, total carbon imprint.

1. INTRODUCTION

The impact of the construction sector on the environment has been recognized as a factor due to which the construction sector must also be involved in activities to implement measures to reduce climate change [1]. Demand for suitable resources, water and energy consumption for the production of building materials, as well as the constructions of buildings and their exploitation affect the environment [2]. Therefore, the European Commission concluded that the construction sector must be involved in the implementation of measures to reduce emissions and mitigate climate change [1]. 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 phase of the facility, viewed from the aspect of embodied CO$_2$, has not yet been recognized as a way to reduce the impact of the construction sector.

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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 LCA is recommended by the European Commission as a methodology to identify the potential impacts of a product or service over the life cycle on the environment [5]. The International Organization for Standardization (ISO) is a life cycle methodology (LCA) methodology prescribed by ISO 14040: 2006 standard that is accepted as a method for identifying and assessing environmental stresses from products, processes or services by identifying energy and materials used as well as emission during life cycle [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.

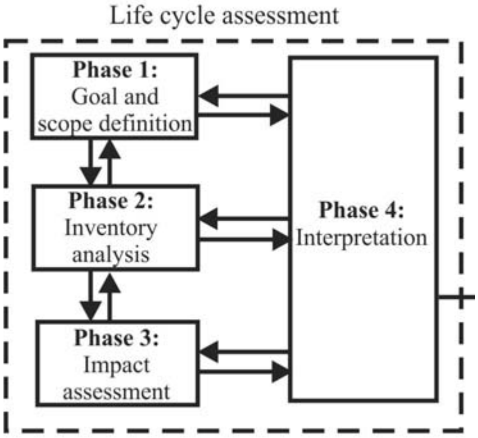

Figure 1. Implementation of LCA method to obtain information on the impact of the applied materials and processes throughout the life cycle

The research on the impact of products used for construction by applying LCA can help when deciding which 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]. These studies have initiated the application of recycled and waste materials in the cement industry around the world and new cements and concrete, commonly known as green concrete, with a lower impact on the environment. Cement and concrete are materials with significant application in construction in Serbia and also in the world, and the benefits that can be achieved by applying green cement mixtures and concrete in the construction process are noticed by some authors [10].

LCA methodology for building structures is defined by Standard EN 15978:2011 [10]. The standard is the life cycle of a building divided into four phases, and as an additional phase outside the boundaries of the system, the phase (D) is reused and recycled.

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 [12]. The indicators for production and consumption of energy in Serbia in 2013, show the reduction in CO_2 emissions per capita, but still it was the highest in the region with 6,33 t CO_2/capita [13]. 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 [14]. More than 50% of ecological footprints in Serbia comes from the production of CO_2 [14]. 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 legislation, 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 to whole life carbon of the building [16-17], so the exploitation period of 10 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 [17]. 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 110m^2 on the outskirts of Belgrade. For that purpose, two scenarios are made: scenario (S1) house in energy rating G, and scenario (S2) house in energy rating C.

Energy needs and calculation of thermal cover for both scenarios are made in program URSA construction physics 2 [18], which precisely calculates the quantities of necessary materials in compliance with the norms and standards in civil engineering [19], as well as the energy consumption for heating on annual level [18]. 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 CO_2 emissions. ICE database version 2 [20] as well as the Carbon calculator Building from Environment Agency UK [21] 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 the second phase of the survey, the boundaries of the system include the operational phase of the facility, for a period of 10 years. 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 G to band C. In addition, this paper will show, through calculations of the embodied carbon in the design stage of the building, the influence of the creation of a short and long-term policy of reducing carbon footprint from the construction sector at the national level.

2. DESCRIPTION OF THE RESEARCH

The research was 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 m^2 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 Chart 1. The first phase of the research should show us whether there is a difference between the embodied carbon for the model (S1) object designed in the energy class G, and compared to the model (S2) object designed in the energy class C, which is the minimum energy class for building a new facility according to the valid legislation in Serbia.

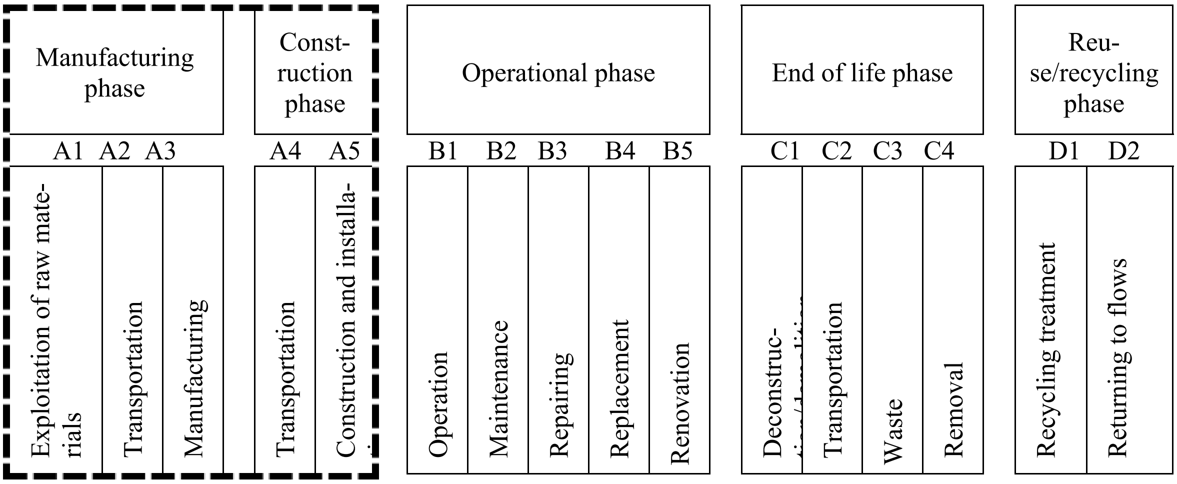

Chart 1. Boundaries of the system to estimate embodied carbon

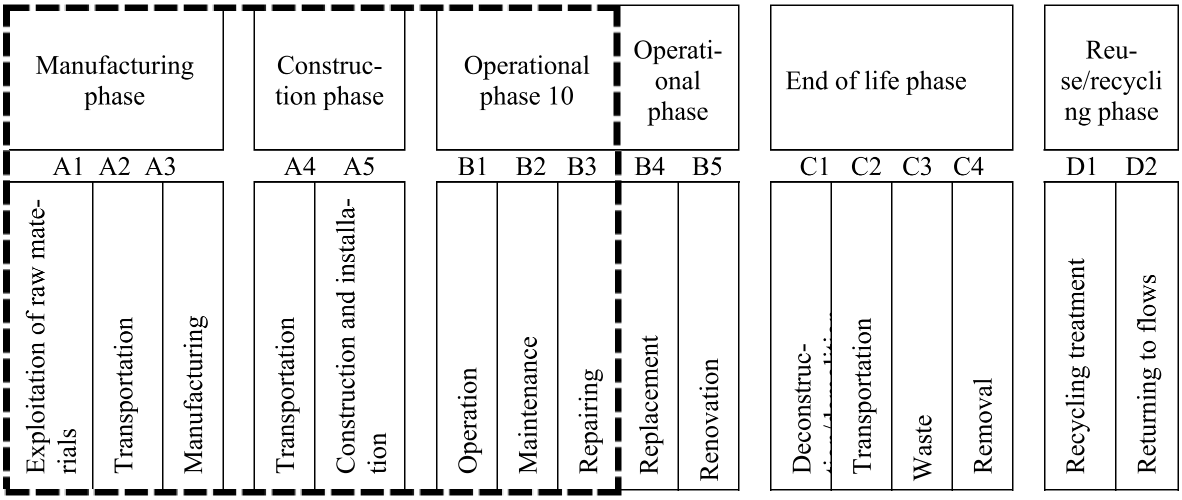

Chart 2. Boundaries of the system to estimate embodied and operational carbon in 10 years

In the second phase of the survey, the boundaries of the system include the operational phase of the facility, for the period from the cradle and the first 10 years of use. Outside the boundaries of the system, there are: replacement, renovation, deconstruction of a building and recycling of construction waste. The system boundaries are shown in Figure 2.

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

Scenario 1 (S1) is an object designed in the energy rating G. An object designed in a massive constructive system. Walls of bliter block in the beam 25 cm, plastered on the outside and on the inside by an extension mortar. RC columns, vertical and horizontal RC ring girders. LMT (easy assembly plaster) without thermal insulation to the attic space. The floor slab is a lightweight reinforced concrete slab, over it there is hydro insulation, but without thermal insulation, cement screed and finishing floor 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 [19], and shown in Table 1.

Scenario 2 (S2) 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 [19], 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	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)	0,00	37,50

Type of material and energy source	Units of measure	Replaced quantities	
		S1	S2
Thermal insulation mineral wool	(m^3)	0,00	21,50
Thermal insulation austrotherm	(m^3)	0,00	14,00
Facade mortar	(kg)	800	800
Interior paint for walls	(kg)	100	100
Mass for skimming	(kg)	500	500
Window glass	(m^3)	0,60	0,80
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)	5.400	5.760
Transporation of waste to landfill	(m^3)	110,00	112,00
Water consumed on the site	(litre)	20600	20800
Power consumed on the site	(kWh)	13500	13500
Diesel fuel consumed on the site	(litre)	900	900

3. RESULTS AND DISCUSSIONS

3.1. 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 scenario (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 %
Quarried Material	44,40	32,08	44,40	29,96%
Timber	3,40	2,46	3,40	2,29%
Concrete, Mortars & Cement	28,40	20,52	28,40	19,16%
Metals	23,90	17,27	23,90	16,13%
Plastics	5,80	4,19	5,80	3,91%
Glass	1,40	1,01	3,70	2,50%
Miscellaneous	1,60	1,16	9,00	6,07%
Finishings, coatings & adhesives	7,10	5,13	7,10	4,79%
Plant and equipment emissions	5,40	3,90	5,40	3,64%
Waste Removal	1,10	0,80	1,10	0,74%
Portable site accommodation	2,00	1,45	2,00	1,35%
Material transport	5,50	3,96	5,60	3,78%
Personnel travel	8,40	6,07	8,40	5,67%
Operational	0,00	0,00	0,00	0,00%
Total Carbon Footprint	138,40	100,00	148,20	100%

Table 3. Embodied carbon benchmark for scenarios S1, S2

Analysed scenario		Embodied carbon			
		Tonnes of CO_2 e per building	Tonnes of CO_2 e per gross m2	More tonnes of CO_2 e than (S1)	% Increase in CO_2 e
1.	S1 energy rating G	138,40	1,26	0,00	0,00%
2.	S2 energy rating C	148,20	1,35	9,80	7,09%

3.2. Discusion on the research results in phase one on embodied carbon in scenarios S1 and S2

After the first phase of the screening of the embodied carbon for the scenario (S1) was conducted, 138,40 tonnes of CO_2 e (equivalent, as a measure of all impacts of greenhouse effect gases) and for the scenario (S2) 148,20 tonnes of CO_2 e. The first phase of the research shows that the embodied carbon in model (S2) is 9,80 tonnes CO_2 e (equivalent of a measurement of all GHG impacts) higher which is 7,09% more compared to 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.

3.3. Research results in phase two on embodied carbon in scenarios S1 and S2 after 10 years

After the second phase of the study, the results of the total carbon footprint (embodied and operational) were obtained for each of the scenarios after 10 years of use. 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 10 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 10 years of operation. The values of thermal cover in scenarios (S1) and (S2), energy consumption per gross m^2 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 analysed scenarios after 10 years

Groups of materials and activities	S1		S2	
	tonnes CO_2e	%	tonnes CO_2e	%
Quarried Material	44,40	32,08	44,40	29,96
Timber	3,40	2,46	3,40	2,29
Concrete, Mortars & Cement	28,40	20,52	28,40	19,16
Metals	23,90	17,27	23,90	16,13
Plastics	5,80	4,19	5,80	3,91
Glass	1,40	1,01	3,70	2,50
Miscellaneous	1,60	1,16	9,00	6,07
Finishings, coatings & adhesives	7,10	5,13	7,10	4,79
Plant and equipment emissions	5,40	3,90	5,40	3,65
Waste Removal	1,10	0,80	1,10	0,74
Portable site accommodation	2,00	1,45	2,00	1,35
Material transport	5,50	3,96	5,60	3,78
Personnel travel	8,10	6,07	8,40	5,67
Operational	47,76	25,65	15,66	9,56
Total Carbon Footprint	186,16	100,00	163,86	100,00

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

Analyzed scenarios		Embodied and operational carbon footprint after10 years				
		Tonnes of embodied CO_2 e	Operational CO_2e	Total CO_2 e	Fewer tonnes CO_2 e than (S1)	Reduction of total CO_2 e.
1.	S1	138,40	47,76	186,16	0,00	0,00%
2.	S2	148,20	15,66	163,86	22,30	11,98%

Table 6. Crucial elements of thermal cover in scenarios (S1) and (S2)

Analyzed scenarios		U_{val} Façade wall	U_{val} Ceiling	U_{val} Floor	Annually for heating per gross m2 [kWh/(m2a)]	Total tonnes of CO_2 from heating
1.	S1 energy rating G	1,433	1,8932	0,7222	165,20	4,774
2.	S2 energy rating C	0,27678	0,2391	0,2615	64,66	1,5648

3.3. Discusion on the research results in phase two on total carbon footprint in scenarios S1 and S2 after 10 years

After ten years of using the facility, the total carbon footprint in which carbon is embodied is included and the operational carbon scenario (S1) has a value of 186,16 tonnes of CO_2 e, which is 22,30 tonnes of CO_2 e more than the scenario (S2) whose total carbon footprint is 163,86 tonnes of CO2 e. Lower values of operational carbon in model (S2) compared to model (S1) have brought savings of 11,98% in CO_2 e emissions in the long run period of 10 years. Lower embodied carbon achieved in the construction phase of scenario (S1), proven in the phase one of the research, had positive effects on the environment in the short run. The short term scenario (S1) will have a smaller total carbon imprint at the construction phase and the period of up to 3,05 years. After 3,05 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 you want a long-term effect, better effect in terms of reducing the environmental footprint from the construction sector, choosing scenarios (S2) after 3,05 years, you can expect less overall environmental impacts.

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 CO_2 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 [22] and Serbia [3-4]. Two models of the same building are designed, but in different energy ratings G and C. 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 G, and the second one is scenario (S2) building in energy rating C. Both models consume gas for heating, so that the emissions in operational phase are calculated in accordance with that energy source.

The scenario (S1) from the aspect of the environmental impact measured through embodied carbon is a more favorable scenario. This stems from the fact that the scenario carbon (S1) is carbon sequestered, less by 9,80 tons of CO_2 e, of the embodied carbon for the scenario (S2). Despite less emissions from the operational phase for the scenario (S2), it is necessary that a time period of 3,05 years passes in order to equalize these two scenarios by the total carbon footprint. From that point on, the scenario (S2) becomes a better choice from the aspect of the overall carbon footprint of the analyzed scenarios. If in the long term, they want better effects in terms of reducing environmental footprint from the construction sector, choosing scenarios (S2) can be expected after 3,05 years of positive results.

In the short term, the scenario (S1) will, in the construction phase and the period of up to 3,05 years, provide a smaller total carbon footprint from the construction sector. In the short term, raising the energy class for new projects, as well as projects for remediation of existing buildings from the energy class G to C, means initially a greater impact in terms of a larger carbon imprint from the construction phase of the building - through higher values of the embodied carbon, which is not in the focus of interest in Serbia at the moment.

However, in the long term, after several years of exposing the building in the energy class C, this first impact through the increased embodied carbon becomes a benefit, and in the course of further use of the object, the total carbon imprint of the object is smaller.

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.

The results of the research indicate the need for research to be directed towards low-carbon thermal insulation materials that would help bridge the gap between the demands at the expense of buildings on the one hand and the efforts to reduce greenhouse gas emissions to mitigate climate change.

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.

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СТУДИЈА СЛУЧАЈА ПОВЕЋАЊА ЕМБОДИРАНОГ УГЉЕНИКА УСЛЕД ПРИМЕНЕ ПРОПИСА ЗА ЕНЕРГЕТСКУ ЕФИКАСНОСТ ОБЈЕКАТА У СРБИЈИ

Сажетак: Да би се показало колики је утицај на животну средину од повећаног присуства термоизолационих материјала и фасадне столарије са побољшаним термичким карактеристикама, као последице нових прописа о енергетској ефикасности објеката, урађена је анализа угљеничног отиска за два сценарија за потребе израде истраживања. За сваки од анализираних сценарија је урађен пројекат и предмер радова на основу кога су израчунате количине грађевинских материјала, активности и процеса који учествују у изградњи анализираних сценарија (C1 и C2). Референтни објекат (C1) је пројектован без термоизолационих слојева, енергетски разред „Г“, а сценарио (C2) је пројектован у енергетском разреду „Ц“, који је према новим прописима услов за изградњу нових објеката. У истраживању се користи анализа животног циклуса (LCA), методологија која је основ за анализу животног циклуса угљеника (LCACO_2), односно обрачун угљеничног отиска објекта. За обрачун угљеничног отиска се користи Construction carbon calculator, Агенције за заштиту животне средине Уједињеног Краљевства, а за обрачун оперативне енергије програм URSA грађевинска физика 2. Истраживање је показало да мање утицаја на животну средину из фазе изградње има сценарио (C1) јер је његов ембодирани угљеник 138,40 тона CO_2 e, а веће вредности ембодираног угљеника има сценарио (C2) са 148,20 тона CO_2 e. Међутим, после десет година коришћења објекта сценарио (C1), због већег угљеничног отиска из оперативне фазе постаје сценарио са већим утицајем на животну средину, са укупним угљеничним отиском од 186,16 тона CO_2 e, а сценарио (C2) после десет година коришћења објекта има укупни угљенични отисак од 163,86 тона CO_2 e. Сценарио (C1) и (C2) постижу исте вредности укупног угљеничног отиска после 3,05 година коришћења објекта и (C2) од тада постаје бољи избор са аспекта животне средине. Истраживање је показало да се ембодирани угљеник неправедно занемарује код обрачуна утицаја објекта на животну средину, као и процену када се могу очекивати бенефити од примене мера за енергетски ефикасним објектима. Истраживање указује и на потребу за нискоугљеничним термоизолационим материјалима како би се премостио јаз између захтева за утопљавањем објеката са једне стране и настојања за смањење гасова са ефектом стаклене баште ради ублажавања климатских промена.

Кључне речи: термоизолациони материјали, енергетски разред, ембодирани угљеник, оперативни угљеник, укупни угљенични отисак.

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