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Environmental sustainability assessment of family house alternatives and application of green technologies

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Abstract. Transition to environmentally friendly technologies provides a comprehensive solution to problem of creating an economic value without destroying the nature. Buildings using green technologies lead to lower operating costs, healthier living and working environment and protect the environment more. The aim of this paper is to assess the environmental impact of two alternatives of family house designed as conventional building and building with green technologies. Evaluated family house are located in village Kokšov Bakša, which is situated 12 km south-east from city of Košice, a metropolis of eastern Slovakia. This analysis investigates the role of applied green technologies in single family houses for impact categories: global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) expressed as CO_{2eq}, SO_{2eq} and $PO_4^{3-}{}_{eq}$ within “Cradle to Grave” boundary by using the LCA assessment method. The main contribution of the study is a proof that green technologies have significant part in the reduction of environmental impacts. Results show that alternative of family house designed as green one contributes to CO_{2eq}, SO_{2eq} and $PO_4^{3-}{}_{eq}$ emissions by 81%, 73% and 35% less than alternative of conventional family house, respectively.

1. Introduction

LCA (Life Cycle Assessment) is a tool to evaluate the environmental impacts of building materials. The concept of environmental life cycle assessment (LCA) was developed from the idea of comprehensive environmental assessments of products, which was conceived in Europe and in the USA in the late 1960s and early 1970s. Originally, LCA was used as a tool by environmental consultants. The steps of most concern here are the life cycle inventory analysis (LCI) and initial stages of impact assessment. LCI involves detailed tracking of all the flows - in and out - of the system of interest, raw resources or materials, energy by type, water, and emissions to air, water and land by specific substance. LCI data can then be characterized in terms of impact potentials (e.g., global warming, ozone depletion, etc.). The aim of rating a building is to minimise its environmental impacts and to create more sustainable buildings. Thus, architects through their architectural design and selection of materials would create sustainable designs [1]. Study [2] states that construction activity introduces an essential role in socio-economic development of the country as it provides infrastructure set-out, on which all sectors of economy firmly depend. Therefore, it makes the building industry one of the most strategic sectors. In the European Union, this sector contributes to GDP roughly by 10% and it is also the largest industrial employer (employing 30% of the total number of employees in the industry), with an estimated 14.8 million employees and 3.1 million companies. Construction sector plays a significant role in the EU economy but on the other hand it is a major energy consumer and greenhouse gases emitter. For example, 42% of the total energy consumption in the EU, 35% of greenhouse gas emissions, about 50% of the mined crude, and 22% of production waste is related to the construction of all types of buildings [2]. The development of science and research allows building industries to move forward in the development of new materials on different basis. Building materials are thus gaining another dimension. While in the past natural materials were used exclusively, nowadays a great deal of them are produced artificially and often by technologies that have negative impacts on the environment. A part of the concept of sustainable development is the right choice of building materials for implementation of the selected object. By selection of environmentally friendly building materials a reduction in depletion of natural resources and factory emissions as well as creation of more suitable microclimate in building interior can be achieved [3,4].

The aim of this study is to analyse how different building envelope solutions as well as the usage of different building technologies may affect the impact on the environment. The LCA assessment of two alternatives of family house has been performed by One Click LCA software available online [5]. It's the highest rated LCA software for BREEAM, supporting up to 19 credits in various BREEAM schemes. For LEED, the software allows simple baseline comparison with ready-to-use templates to help achieve the Materials and Resources credits easily. Software One Click LCA allows by Life-Cycle Assessment to evaluate the effect on the environment of a product, service, or process over its entire life-cycle. This means that LCA takes into consideration all the steps that lead from raw material to manufactured product, including extraction of the materials, energy consumption, manufacture, transportation, use, recycling, and final disposal or end of life. It is a holistic methodology that quantifies how a product or process affects climate change, non-renewable resources, and the environment as a whole. Life-Cycle Assessment's strength lies in the fact that it takes into account what happens before and after the final product is used by customers, and can effectively measures effects over a long time of period.

2. Green technologies and green buildings

Green technology can be defined as the technology which is environmentally friendly, developed and used in such a way so that it doesn't disturb our environment and conserves natural resources. The construction industry has significant environmental, social and economic impacts on the society. As a result, the last decades have witnessed the rapid growth of the green building sector in order to mitigate the negative impacts associated with construction related activities. These include upfront cost vs. ongoing savings; and energy savings vs. building users' health and wellbeing. In China, it has been reported that some green buildings consume 26% less energy compared to conventional buildings. However, due to the incremental cost, it is not uncommon that enterprises and governments in China are unwilling to bear this kind of risk [6]. European climate strategy foresees measures to increase energy efficiency, competitiveness and the energy security of Europe by decreasing energy consumption. As buildings are responsible for 40% of the total energy consumption in the European Union, the Energy Performance of Buildings Directive sets energy consumption reduction targets for the member states [7].

3. Design of family house alternatives

3.1. Construction of building envelopes

The first alternative of family house uses solely conventional approaches and materials in construction, while the second one uses sustainable approaches with strong focuses on environmental and energy aspects. The alternatives are mentioned to be located in Kokšov Bakša, a municipality in Košice Region of Eastern Slovakia. The houses are placed in a flat terrain at an altitude of approximately 190 metres. They are designed as a single storey, detached family houses without basement. Interior layout consists of vestibule, hall, living room with kitchen and dining room, larder, three bedrooms, two bathrooms with WC, toilet, wardrobe, boiler room, terrace, garage (only in alternative 1) and a laundry room (only in alternative 2). Both houses are founded on strip foundation. The strip footing is 600 mm wide and at least 650 mm deep made of reinforced concrete of C16/20. Two rows shuttering form-work blocks are used on top of in-ground part. Aerated concrete blocks with the thickness of 300 mm and 250 mm are suggested for external and internal bearing walls in alternative 1. Double glazed PVC windows and

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doors with U=1.0 W/m^{2}K are proposed. Floors are designed as self-levelling poured screeds with ceramic and/or laminate finishing. The horizontal structures consist of reinforced concrete ceiling with thermal insulation of EPS liners above the ground floor and reinforced concrete ring beam wreaths and lintels made of C20/25 concrete class. The roof structure is proposed as flat with gravel ballast layering. External and internal bearing walls in alternative 2 are designed as CLT panels with thickness of 170 mm. Triple insulating glass windows and doors with U = 0.79 W/m^{2}K are designed as wooden - aluminium constructions. Floors are designed as self-levelling poured screeds with ceramic or wooden finishing. Horizontal structures consist of CLT panels with thickness of 170 mm above the ground floor. The roof structure is a flat green roof. The substrate thickness of 150 mm is proposed. Table 1 summarizes basic information about alternatives of family house.

Table 1. Information for designed alternatives of family house.

	Alternative 1	Alternative 2
Built-up area	250 m^2	224 m^2
Living area	98.06 m^2	117.11 m^2
Floor area	183.52 m^2	174.45 m^2
Built-up volume	1350 m3	986 m3

Figure 1 illustrates views for designed alternatives of family house.

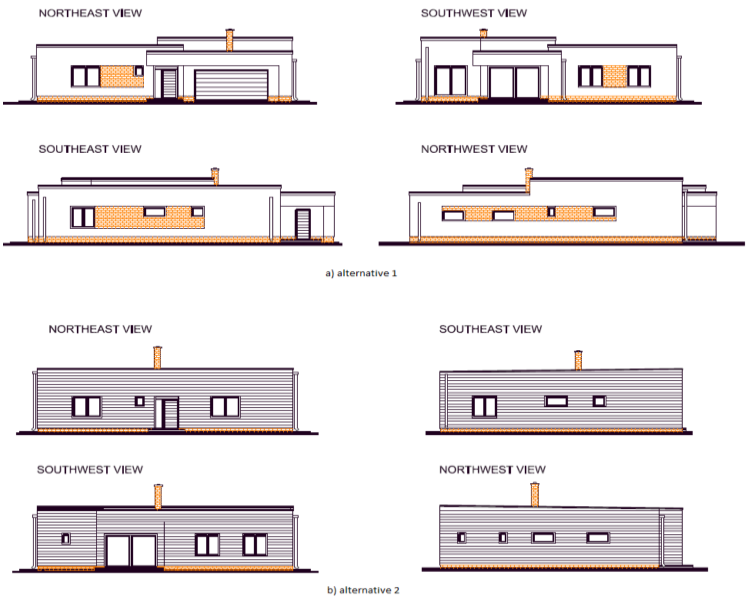

Figure 1. Views of designed family house.

3.2. Technologies of investigated houses

The first house is connected to public utilities except of sewage which shall be drained to a septic tank. A condensing gas boiler is used for domestic central heating and hot water preparing. Floor heating is installed in the whole house except of larder, boiler-room and garage. Supposed yearly gross energy consumption is around 22.0 MWh of which 14.8 MWh is consumed by heating the living part of the interior space during heating period (from October till April for a given latitude).

The second family house is connected to public utilities with sewage designed as a pressure sewage system. Heat pump is used as the source of heating and hot water preparation, which is stored in 300 l insulated hot water tank. The supposed total energy consumption per year is 7 MWh of which 2.5 MWh is used for heating.

4. Environmental assessment of designed alternatives

Table 2 presents results of the environmental impacts for individual phases of the life cycle of assessed family house alternatives.

Table 2. Indicators characterizing the environmental impacts.

Sector	GWP kg CO_{2eq}		AP kg SO_{2eq}		EP kg $PO_4^{3-}{}_{eq}$	
	Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2
Construction Materials	99,200	64,000	306.00	364.00	80.70	109.00
Transportation to site	7,560	4,150	20.30	12.40	4.59	2.66
Maintenance and material replacement	42,900	11,300	75.50	29.90	12.40	5.70
Energy use	343,000	150	1,200.00	0.96	108.00	0.14
Deconstruction	13,200	14,200	18.20	27.90	4.84	19.10
Total	505,860	93,800	1,620.00	435.16	210.50	136.60

Figures 2 and 3 depict the percentage ratio of designed materials for environmental impact expressed as GWP.

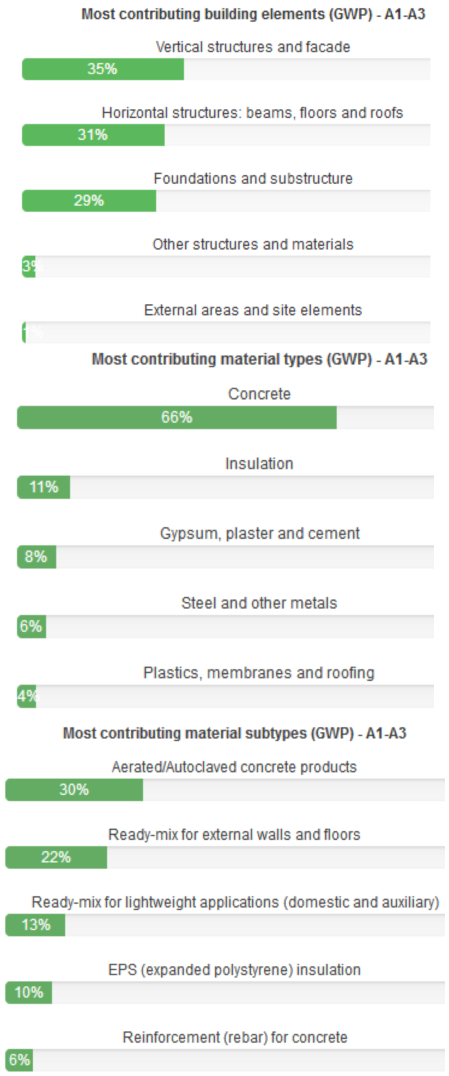

Figure 2. Alternative 1.

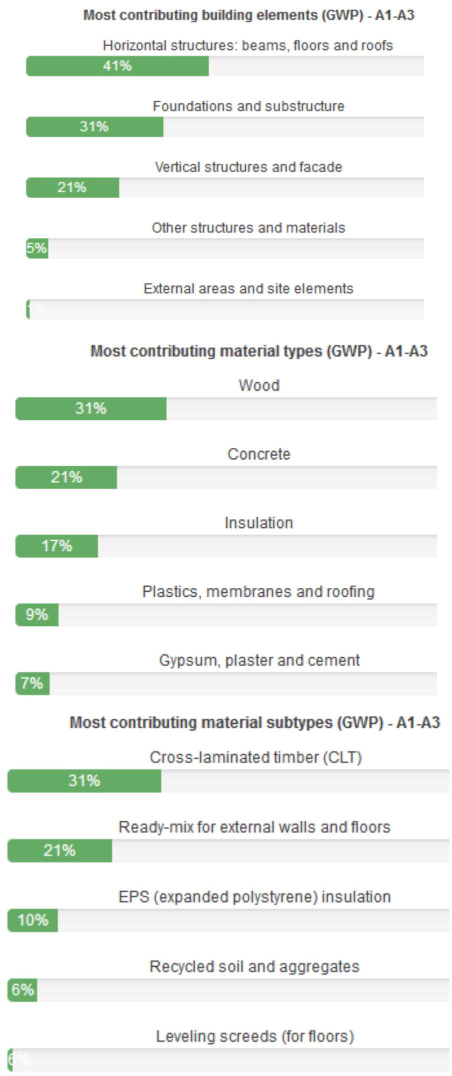

Figure 3. Alternative 2.

We can see that most contributing building elements are vertical structures and facade with value of 35% for alternative 1 and horizontal structures (beams, floors and roofs) with value of 41% for alternative 2. Most contributing material types are concrete with 66% for alternative 1 and foundation and substructure with value of 31% for alternative 2. And finally, most contributing material subtypes are aerated concrete products with 30% for alternative 1 and cross-laminated timber (CLT) with 31% for alternative 2. Figure 4 shows that alternative 2 contributes to CO2eq emissions by 81% less than alternative 1 and from SO2eq and PO43-eq by 73% and 35% less than alternative 1, respectively.

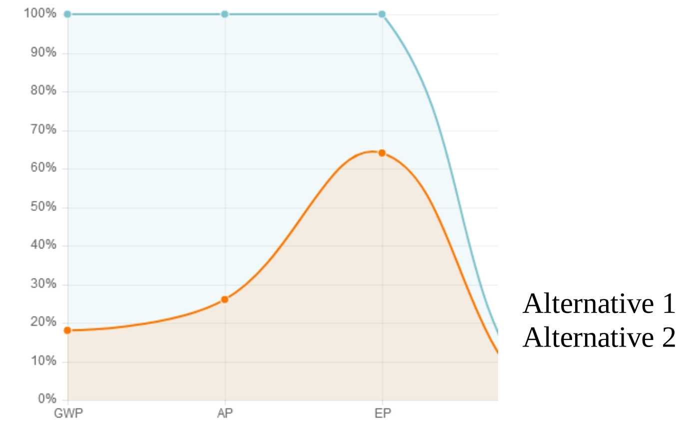

Figure 4. Comparing the impacts for both alternatives.

5. Conclusions

Based on calculations it can be seen that the house with the use of environmentally friendly materials and green technologies is more than a comparable alternative to the conventional design. This result is achieved by using the building materials, environmentally friendly technologies, as well as by modifications of roof to the green one. In Slovakia there are a number of buildings classified as green or high performance green buildings that are certificated from sustainability aspects. Design the high performance green buildings for the future of a sustainable life on Earth is indisputable. Therefore the certification of buildings from three dimensions of sustainability (environmental, social and economic) gives some assurance that the buildings do not burden the environment.

Acknowledgments
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