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Life Cycle Analysis of Single Family Houses and Effects of Green Technologies on Environment †

Andrea Moňoková *, Silvia Vilčeková and Iveta Selecká

Department of Environmental Engineering, Faculty of Civil University, Technical University of Košice, Vysokoškolská 4, 04200 Košice, Slovakia; silvia.vilcekova@tuke.sk (S.V.); ivetaselecka23@gmail.com (I.S.)

* Correspondence: andrea.monokova@tuke.sk, Tel.: +421-55-602-4262

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Abstract: Construction and using of buildings for many years produce long-lasting impacts on human health and the environment. Life cycle assessment (LCA) is the rapidly evolving science of clarifying these impacts in terms of their quality, severity, and duration. LCA of three selected new family houses located in Eastern Slovakia is performed with the aim to compare them in terms of built-in materials as well as used technologies. The main goal of the analysis is to investigate and underline the foreseeable reduction rate of environmental impacts resulting from applied green materials and green technologies. LCA impact categories of global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), eutrophication potential (EP), and photochemical ozone creation potential (POCP) are selected for this analysis. Investigated family houses are built from conventional materials, such as aerated concrete blocks, reinforced concrete, thermal insulation of silicate mineral slabs, and roofing mineral wool, as well as natural materials, such as clay, straw, wood, cellulose, and vegetation roofs. Product phase contributes greatly to the GWP for houses built of conventional materials. AP, EP, ODP, and POCP impact categories are considerable also in the product phase. Even an operational energy phase contributes a large share of the negative impact on the environment. Adoption of green design and technology in buildings, which can mitigate negative impacts on the environment, has been recognized as a key step towards global sustainable development. The main goal of this article is to make the case that green buildings are important for reducing negative effects on the environment and resources, while simultaneously enhancing positive effects throughout the building life cycle.

Keywords: LCA; green technologies; green buildings; environmental impacts; buildings materials

1. Introduction

Life cycle assessment (LCA) is a tool that allows architects and other building professionals to understand the energy use and other environmental impacts associated with all life cycle phases of the building: procurement, construction, operation, and decommissioning.

The LCA methodology dates back to the 1960s, when concerns over the limited availability of raw materials and energy resources led to new ways to account for energy use and the consequences of these uses [1]. In the early 1990s, LCA was used for external purposes, such as for marketing [2]. ts application broadened in the present decade to include building materials, construction, chemicals, automobiles, and electronics. This was primarily because of the formalization of LCA standards in the ISO 14000 series (1997 through 2002) and the launch of the Life Cycle Initiative, a combined effort by the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC), in 2002 [1].

The principles provided by ISO standards and SETAC are well structured for industrial processes. However, when applied to buildings, there are some basic differences that need to be considered [3]. The use life of a building is typically much longer than for industrial products. The unique character of every building project differs from the thousands of identical products in industrial systems. It is difficult to characterize the functional unit or boundary of analysis for a building, as compared as to an industrial product.

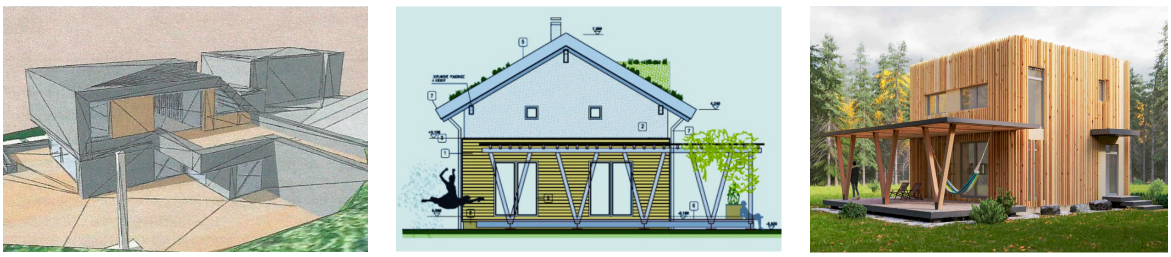
LCA analyses are performed for single family houses [4–8], residential [9, 10] as well as non-residential buildings [11,12], and office buildings [13]. Results from these studies are progressively being applied in the design phase. For example, Dahlstrøm et al. [4] carried out LCA of a single-family residence built in conventional as well as passive house standard. An interesting result of this study was that a standard building envelope with a heat-pump system reduced environmental impact to a level comparable with a passive house with only electric heating. A comparison of greenhouse gas emissions pointed out that the reduction in the passive design is almost 30%. The aim of another study [14] was to assess the environmental impacts of family houses designed as buildings with green technologies and green materials. The presented results show that a house with built-in green materials and technologies causes significantly lower environmental impacts compared to a house where both green technologies and conventional materials are built. The operation phase (B6) is characterized by greater environmental impacts compared to the product and construction phases, as well as deconstruction phase due to the use of green materials and technologies. The major contributors for global warming potential (GWP) expressed as equivalent emissions of CO_2 is energy use (B6) with percentage weights of 70% and 96%. The product phase (A1–A3) reduces CO_{2eq} emissions by 11% due to the use of natural building materials, such as wood and straw.

This article describes the process of life cycle assessment as it is applied to building design and construction. Tools like energy modelling assist in predicting and, through good design, reducing the operational energy in buildings. The main contribution of this study is highlighting the reduction rate of environmental impacts due to applying green materials and technologies as one of the measures to mitigate climate change.

2. Materials

Selected family houses are located in the villages near to Košice and Bardejov towns, located in the eastern part of Slovakia, and they are presented in Figure 1.

Fully built up areas are 248.45 m^2 (house 1), 120.0 m^2 (house 2), and 59.3 m^2 (house 3). Energy demands for heating are 43.73 kWh/m^2 per year (house 1), 20.7 kWh/m^2 per year (house 2), and 21.88 kWh/m^2 per year (house 3).



(**a**) House 1 (**b**) House 2 (**c**) House 3

Figure 1. View of family houses.

The first house uses only conventional approaches and materials in construction. The second and third houses use sustainable approaches with strong focuses on environmental and energy aspects. They are designed as three-storey and two-storey detached family houses without basements. All of them are founded on a strip foundation. The strip footing is 600 mm wide and at least 650 mm deep and made of reinforced concrete of C16/20.

Hollow bricks with a thickness of 300 mm (with thermally insulating facade boards EPS of 150 mm) and a 250 mm thick reinforced concrete wall are suggested for external and internal bearing walls in house 1. Double glazed PVC windows and 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 a 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. The roof structure is proposed as flat with gravel ballast layering. The house is connected to all public utilities. A condensing gas boiler is used for domestic central heating and hot water preparation. Floor heating is installed in the whole house. External bearing walls in houses 2 and 3 are designed as timber frame construction with straw insulation with a thickness of 500 mm. Triple insulating glass windows and doors with U = 0.79 W/m^{2}K are designed as wooden-aluminium structures. Floors are designed as self-levelling poured screeds with ceramic or wooden finishing. The roof on house 2 is saddle-shape and is designed as a green roof. House 3 has flat roof with vegetation. Both of these family houses are also connected to all public utilities. A heat pump is used as the source of heating and hot water preparation, which is stored in a 300 l insulated hot water tank.

3. Methods

For modelling life cycle impacts of the houses, the eToolLCD [15] software was used. This software is compliant with the IMPACT methodology and datasets in accordance with the EN ISO 14040, EN ISO 14044, and EN 15978. The software uses third party background processes aggregated as mid-point indicators and is stored in a number of libraries within the software which are coupled with algorithms and user inputs to output the environmental impact assessment.

Environmental impact categories including global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP), and ozone depletion potential (ODP) expressed as kg CO_{2eq}, SO_{2eq}, $PO_4{}^{3-}{}_{eq}$, ethylene, and CFC-11$_{eq}$, respectively, are considered within the “cradle to gate with options” boundary. The selected LCA methodology is CML-IA, whose midpoint characteristic is based on more scientifically based models than endpoints. The functional unit is 1m^2 of the total floor area. The estimated design life is 60 years, which has been adopted for the LCA study period.

4. Results and Discussion

Results of the LCA assessment for considered lifespan phases depict that the family house built of natural materials is characterized by bigger negative emissions of CO_{2eq} in the product phase. This phase contributes greatly to the potential GWP for house built of conventional materials, such as hollow brick, reinforced concrete, and thermal insulation. As for acidification, eutrophication, photochemical ozone formation potential, and ozone depletion potential, the results indicate that the product phase is the most important contributor. Higher values are also found for the renovation phase.

Table 1. Characteristic impacts on 1 m^2 of the total floor area of a family houses.

Characteristic Impact		House 1	House 2	House 3
Global warning potential	kg CO_{2eq}	1415.539	547.945	828.03
Acidification potential	kg SO_{2eq}	3.819	3.835	8.789
Eutrophication potential	kg $PO_4{}^{3-}{}_{eq}$	1.033	2.055	3.312
Photochemical ozone creation potential	kg ethylene	0.584	0.548	0.917
Ozone depletion potential	kg CFC-11$_{eq}$	2.92E-5	3.49E-5	8.6E-5

Comparisons between three family houses are presented in Table 1, in which five impact categories are determined for 1 m^2 of the total floor area. We can see that the global warming potential of family house 2 reduces CO_{2eq} emissions by 61.3% and of family house 3 by 41.5% due to using natural building materials, such as wood and straw, and due to using a heat pump for heating and hot water preparation. We can state, that the AP, EP, POCP, and ODP potentials have minimum differences for all houses.

5. Conclusions

LCA is ideally suited for evaluating the environmental impacts of alternative systems by comparing their material production impacts, operational considerations, and end-of-life recycling and disposal. The main use of LCA should be for strategic and significant decisions that could have far reaching consequences: i.e., choosing between different building systems.

This study indicates that green technologies, such as a green roof and natural building materials (e.g., wood and straw), produces lower negative impacts on the environment in the production phase as well as during their usage. Future research will be aimed at the evaluation of a large number of residential buildings using various green elements and technologies to find a point where more green technologies are no longer environmentally or economically effective.

Author Contribution: A.M. and S.V. conceived designed the experiments. A.M. performed and analyzed the experiments. A.M. and I.S. wrote the paper.

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Conflicts of Interest: The authors declare no conflict of interest

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