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SUSTAINABILITY ASSESSMENT OF DESIGNED FAMILY HOUSE ALTERNATIVES WITH APLICATION OF GREEN TECHNOLOGIES

The paper aimed at an assessment of environmental and energy impacts of designed family house using green technologies. Investigated buildings are located in Kosice region. The analysis investigates the role of applied green technologies in proposed variants of family house from embodied energy and equivalent emissions of CO_2 and SO_2 by using LCA assessment method within "cradle to gate" boundaries. The main contribution of the study is underlining that green technologies have significant part in the reduction of the environmental and energy impacts.

Keywords: green technology, green building, sustainability principles to building design, sustainability assessment of buildings

1. Introduction

To achieve the goal of reducing CO_2 emissions, a life cycle approach is required. A life cycle assessment (LCA) quantifies the potential environmental impact of a product or a service according to the ISO 14040:2006 and ISO 14044:2006 standards. The application of LCA in architecture is constantly growing, and it has been used repeatedly to evaluate new buildings [1]. Study [2] denotes that a lot of LCA studies differ in approach, system boundaries, database and scope, and therefore cannot be compared. They reveal that calculations over the whole life cycle show a slightly different picture. Here, the advantages are generated mainly through benefits outside system boundaries (module D). In Europe the EN 15978:2012 is a widely agreed framework to clearly specify LCAs. Through division of the life cycle in modules, there is an agreement to

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calculate the benefits regarding energy recovery separately and to further show all potential benefits like recycling outside the life cycle of the building. This understanding is also applied on product level (EN 15804:2014). Product category rules for various material fractions were introduced. This means based on this framework comparative LCAs can be conducted on comprehensible manner. Another study [3] is focused on an addressing the gaps between the requirement of dynamic consideration and static implementation of LCA methodology. Therefore, the main goal of this study is developing a dynamic LCA (DLCA) withtime-varying factors and occupancy behaviors into consideration. Four dynamic properties (i.e., technological progress, occupancy behaviors variance, dynamic characteristic factors, and dynamic weighting factors) are brought into a static LCA model to develop a dynamic one that could be used to quantify building environmental impacts overtime. In addition, residential occupancy profiles were described at personal level, family level, and social level; and three potential quantification methods were introduced to explore the relationship between occupancy profiles and household energy consumption. The new DLCA framework could help improve the building LCA theoretical base, extend the connotation of LCA system from a new perspective, assess the influences of occupancy behaviors, and promote sustainable buildings. A novel approach which allows evaluating the relative importance of climate change and energy transition on environmental impacts of buildings is presented in study [4]. The methodology is illustrated using a simple case study: a low-energy single family house located in France. Two design options were evaluated: the choice of a heating system and the integration of photovoltaic (PV) modules on the roof. Using an attributional approach and compared to a static LCA considering no prospective parameters, the carbon footprint of the house (total life cycle) varies from +21% to +43% for the electric heating alternative, −7% to +4% for the gas boiler alternative, −6% to +15% for the PV alternative depending on climate change intensity and evolution of the energy mix. By using the consequential approach have a larger magnitude of variation from −36% to −13% for the electric heating alternative, 0 to +16% for the gas boiler alternative and −14% to +1% for the PV alternative compared to a static LCA. Accounting for climate change and the evolution of the energy system has a large influence on LCA results.

2. Green technologies and green buildings

The term "green technology" generally refers to the application of advanced systems and services to a wide variety of industry sectors in order to improve sustainability and efficiency. That means that goals could include: reduction of waste, spoilage and shrinkage; improvement of energy efficiency and energy conservation; creation of systems that are energy self-sustaining; the reduction of carbon emissions; a reduction in toxic waste and emission of toxic gasses such as volatile organic compounds; creation of products that are biodegradable; enhancement of water conservation and water quality; and promotion of the reuse and recycling of materials of all types [5]. Green technology development is accelerating in some areas. The number of patented inventions in renewable energy (+24 %), electric and hybrid vehicles (+20 %), and energy efficiency in building and lighting (+11 %) increased more rapidly than total patents (+6 %) between 1999 and 2008. Most of the green technology development is concentrated in a relatively small number of countries and there is a considerable specialisation across countries. For selected climate mitigation technologies, Japan's patent applications in 2008, for example, were relatively more concentrated in innovation related to energy-efficient buildings and lighting, as well as electric and hybrid vehicles, while the United States was particularly prominent in the area of renewable energy. While some data are available on green technologies, much less information is available on the related non-technological changes and innovation, such as in the introduction of new business models, work patterns, city planning or transportation arrangements, that will also be instrumental in driving green growth. There is some evidence that the scope of green innovation is broadening, however. For example, manufacturing firms have moved from end-of-pipe solutions to approaches that minimise material and energy flows by changing products and production methods and reusing waste as a new resource for production. Advances are also being made through better management practices and integrated strategies that are contributing to a range of new business models [6]. Fig. 1 depicts some examples of green technologies.

a) b) c)

Fig. 1. Green technologies: a) Cool roof, based on [7]; b) Electro kinetic road ramp, based on [8]; d) Crosslam timber/CLT, based on [9]

3. Design of family house

Up-to-date design of buildings requires a multidisciplinary approach. However, even today, there are often proposed drawings which do not respect the requirements for sustainable building construction. Total investment costs are preferred to sustainability aspects like environmental impacts, health and well-being of building users. It leads to the need to present sustainable or green designs of buildings with application of green technologies. For this reason, this article is aimed at design and evaluation of two alternatives of family house. Family house is designed in flat terrain in village of Kokšov Bakša, district of Košice in the Košice Region. The alternative 1 of family house denotes design from conventional materials and building services. In contrast, the alternative 2 represents one of the possible solutions concerning the using of resources, the comfort of building users and the protection of natural environment. It is a single storey family house without basement with numbers of occupants of four. On the ground floor there is a vestibule, entrance hall, kitchen, living room, dining room, two bedrooms, and bathroom with toilet, pantry, and boiler room. Table 1 presents basic data about designed alternatives of family house.

Table 1. Information about 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	165.61 m^2
Built up volume	1350 m^3	986 m^3

3.1. Alternative 1

Family house has two entrances, the main oriented to the northeast side and entrance from the terrace into the living room from the northwest side. It is designed as a single-storey brick house basement with garage, covered with a flat roof. Foundation strips are designed as monolithic with wide of 600 mm, high of 650 mm from concrete C16/20, on which foundation structures are designed in two rows shuttering formwork blocks. External and internal bearing walls are designed from concrete blocks with thickness of 300 mm, respectively 240 mm; windows and doors as plastic. Floors are designed as ceramic, laminate and screeding. The horizontal structures consist of reinforced concrete ceiling with EPS liners above the ground floor and reinforced concrete ring beam wreaths and lintels from concrete of C20/25. The roof structure is designed as a flat sheathed with modified asphalt strips.

Family house is designed to be connected to a public network of wiring and water. Sewage water will be drained to a septic tank. Family house will be connected to the public water supply. Floor heating is designed in all rooms of house. Source of the heating is gas boiler.

3.2. Alternative 2

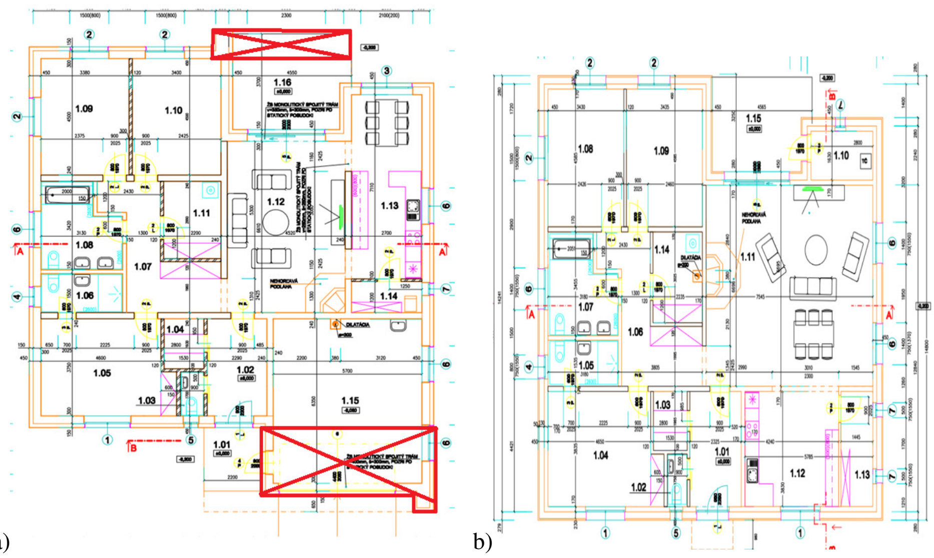
Alternative 2 of family house has two entrances, the main oriented to the northeast side and entrance from the terrace into the living room from the northwest side. It is designed as a single-storey house with wooden structure and without basement as well as garage, covered with a flat green roof. Foundation strips are designed as monolithic with wide of 600 mm, high of 650 mm from concrete C16/20, on which foundation structures are designed in two rows shuttering formwork blocks. External and internal bearing walls are designed from CLT panels with thickness of 170 mm. Windows and doors as well as floors are designed as wooden structures. Horizontal structures consist of CLT panels with thickness of 170 mm above the ground floor. The roof structure is designed as a flat green roof using the extensive vegetation to a height of 100 mm; substrate for green roof has a thickness of 100 mm. Water drainage is provided by drainage pipes and a built-in gravel drainage layer. Drainage layers are placed around the perimeter of a width of 500 mm. Pipes are fitted into a gravel layer at the lowest roof height. Family house is designed to be connected to a public network of wiring, water and sewage. Family house is connected to the public water supply. Sewage is designed as pressure sewage system. Floor heating is designed in all rooms of house. Source of the heating is heat pump. Hot water is stocked in tank of 300 litters.

Table 2 presents designed material compositions of building envelope for two mentioned alternatives.

Table 2. Constructions of building envelope

Assembly	**Alternative 1**	**Alternative 2**
External wall	Concrete blocks EPS 100 PENOGREY	Crosslm /CLT panel Fleece Diffusive open wall
Floor	Laminate floor Ceramic pavement Thermal insulation EPS	Wood floor Ceramic pavement Mineral wool
Roof and ceiling	Flat roof Modified asphalt strips Reinforced concrete ceiling	Green roof CLT panels
Opening construction	Plastic windows Plastic door	Wooden windows Triple insulating glass 44 mm with argon

On the figures 2 and 3 we can see the ground floor dispositions and views for designed alternatives of family house.



a) b)

Fig. 2. Ground floor of family house: a) Alternative 1; b) Alternative 2

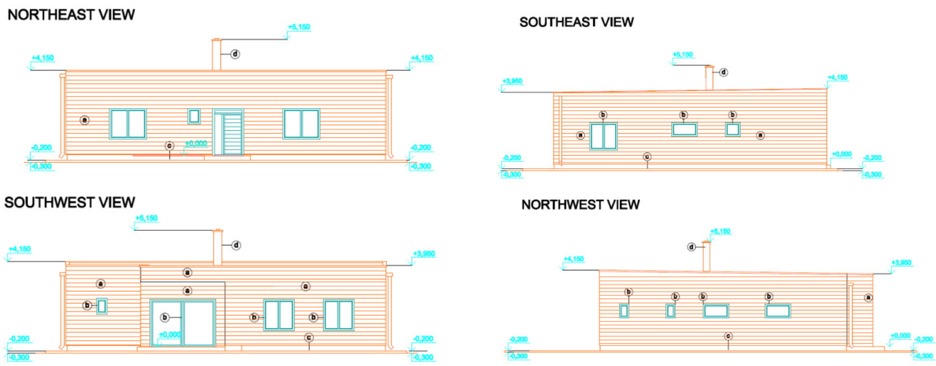


Fig. 3. Views of alternative 1 of designed family house

4. Sustainability assessment of designed alternatives of family house

Building environmental assessment system (BEAS) is used for evaluation of selected family house. Evaluative program BEAS contains six evaluation areas and 52 indicators. The main fields are site selection and project planning, building construction, indoor environment, energy performance, water management and waste management. Each indicator is assessed according to scale: negative practice (-1 point), acceptable practice (0 point), good practice (3 point) and best practice (5 point). The results of each indicator assessment are obtained so that the point from the scale is multiplied by weight of the indicator.

After the assessment of the whole building and its site, building is certified according to scale introduced in Table 3 [10].

Table 3. Key for total assessment of building and certification by BEAS

	Key for assessment	Certification scale
-1	negative practice	Environmentally unacceptable building
0	acceptable practice	Environmentally acceptable building
3	good practice	Environmentally friendly building
5	best practice	Sustainable building

4.1. Site selection and project planning

Environmental regional classification of Slovakia represents a cross-sectional source of information on the state of the environment and reflects its differentiated situation in different parts of the Slovak territory. Slovak regions show diverse load situation for individual components of the environment and the risk factors show various degree of representation in them. A map assessing the Slovak territory by 5 degrees of quality of environment developed by the Slovak Environment Agency represents one of the outputs. This map helped identify the most loaded areas - their core typically comprises territories within the 5th degree with the most damaged environment. Family house is designed to be situated in the southern part of eastern Slovakia. Kokšov Bakša is located in the south-eastern part of the city of Košice on the side of the river Hornád. It is 191 m above sea level. Construction site is located in an area with environmental class level that falls within a category 5, i.e. environment heavily deteriorated/disturbed environment. The most important pollutants are suspended particulate matters, SO_2, NO_x, CO. Based on the assessment in the field "A - Site selection and project planning" the designed house reached points of 2.49 from 5 possible points. According to the tool of BEAS the significance weight is 14.71%.

4.2. Building constructions

Currently we are highly strived to incorporate into construction work materials with the lowest negative effects on humans and the environment. Efforts of building materials producers are to be designated as environmental labelling of products. In the EU we can found on the market the official European label for products and services known as Ecolabel. Products with the Ecolabel meet strict environmental and quality requirements, plus it is also assessed their life cycle from the inception to the destruction. According to LCA analysis the embodied energy for alternative 1 is 4221.14 MJ/m^2, total CO_2 emissions causing global warming are 245.79 kg/m^2 and total SO_2 emissions are 1.28 kg/m^2. Alternative 2 achieved values for embodied energy 1072.66 MJ/m^2,

CO_2 emissions -56.5 kg/m^2 and SO_2 emissions 0.355 kg/m^2. In the figure 5 we can see the comparison of values for environmental indicators. Based on the assessment in the field "B - Building constructions" the alternative 1 and 2 reached points -0.82, respectively 2.07 from possible 5 points. According to the tool of BEAS the significance weight is 20.59%.

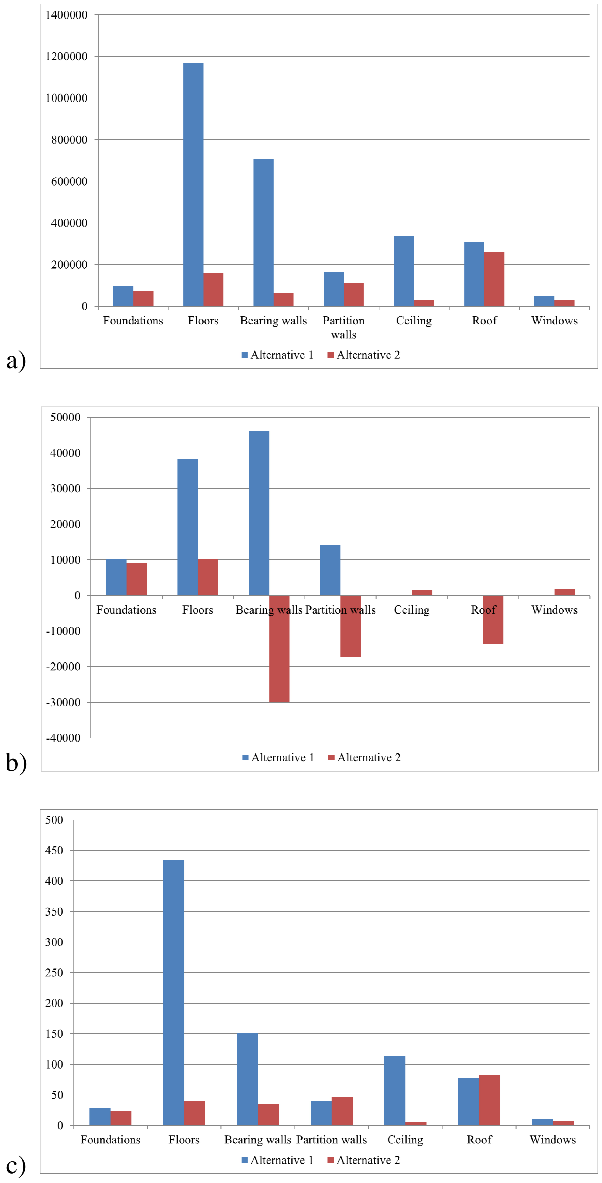


Fig. 4. Comparison of environmental indicators: a) Embodied energy; b) CO2 equivalent emissions; c) SO2 equivalent emissions

4.3. Indoor environment

The total area of openings in the enclosure is at least 5% of the total floor area, and over 50% of the cross-ventilation. Mechanical ventilation in some areas meets the minimum requirements of the standard. External walls are proposed in terms of sound insulation in accordance with requirements of legislation and ensure the required degree of protection of the internal spaces. The windows that are most exposed to the source of the noise from the outside according to drawings have good quality class of sound insulation. According to the drawings, airborne sound insulation between some space meets the minimum requirements of the standard. Ensure sufficient daylight in some areas reaches a minimum value for the scheduled tasks. To ensure minimum glare in the main occupancy areas in the period with a maximum brightness from outdoor is proposed appropriate measures by shading elements. All interior materials, including paints, sealants, adhesives, carpets and composite wood products are selected as materials with low-level of VOC emissions and are not used in composite wood products containing urea formaldehyde resin. Based on the assessment in the field "C - Indoor environment" alternatives 1 and 2 reached points of 1.20 and 3.30 from possible 5 points. Significance weight of is 23.56%.

4.4. Energy performance

The field D–Energy Performance, was evaluated in subfields: D1 - Operation energy, D1.1 - Energy for heating, D1.2 - Energy for domestic hot water, D1.3 - Energy for mechanical ventilation and cooling, D1.4 - Energy for lighting, D1.5 - Energy for appliances, D2 - Active systems used renewable energy sources, D2.1 - Solar system/heat pump, D2.2 - Photovoltaic technology, D2.3 - Heat recuperation and D3.1 - System of energy management. Based on the assessment the alternatives 1 and 2 reached values of 0.74, respectively 2.51 from possible 5 points. Significance weight is 26.47%.

4.5. Water management

The field "E - Water Management" was assessed in subfields: E1 - Reduction and regulation of water flow in water systems, E2 - The water management of surface runoff, E3 - Drinking water supply and E4 - System of grey water. Based on the assessment in the "E - Water management" the alternatives 1 and 2 reached 1.65 and 2.40 points from possible 5 points. Significance weight is 8.88%.

4.6. Waste management

The field F-Waste Management, was assessed in subfields: F1 - Plan of waste disposal originated in construction process, F2 - Measures to minimize waste resulting from building operation and F3 - Measures to minimize emission resulting from building construction and demolition. Based on the assessment the alternatives 1 and 2 reached 0.58 respectively 1.62 points from 5 possible points. Significance weight is 5.80%.

5. Summary

Evaluation of designed alternatives of family house reveals that these alternatives meet the requirement for energy demand. Significant differences are noted in the comprehensive assessment. Values of heat conductivity for building envelope are almost the same, and both alternatives can meet the desired aims, whether being a classic house or a house designed from environmentally friendly materials and using green technologies. In terms of energy demand both alternatives meet requirements for energy performance of buildings, but alternative 1 complies with the requirements determined for years to 2016 and alternative 2 meets the requirements designated for buildings built up since 2016. The advantage of the use of environmentally friendly materials in alternative 2 is in increasing the useful area by reducing the thickness of external walls from 450 to 400 mm, and also reducing the thickness of internal bearing walls. The most significant differences were observed in the assessment of the two alternatives by BEAS where it was clearly showed that alternative 2 is more appropriate and acceptable with respect to the environment and to the comfort of the user. In Table 4 it can be seen the results of assessment of two alternatives of designed family house. Table 4 shows the whole assessment of designed alternatives of family house with presenting the main fields and their percentage weights of significance.

Table 4. Comparison of designed alternatives of family house by BEAS

Fields		**Percentage weight**	**Alternative 1**	**Alternative 2**
A	Site selection and project planning	14.71 %	2,49	2.49
B	Building constructions	20.59 %	-0.18	2.07
C	Indoor environment	23.56 %	1.20	3.30
D	Energy performance	26.47 %	0.74	2.51
E	Water management	8.88 %	1.65	2.40
F	Waste management	5.80 %	0.58	1.62
Total assessment		100 %	0,99 Environmentally acceptable building	2.54 Environmentally friendly building

6. Conclusions

Results of sustainability assessment of two alternatives of family house show that the house with environmentally friendly building materials and green technologies is preferable. Thermo-physical parameters of both alternatives meet up requirements for energy performance, but alternative of green design met the target recommended requirements for all constructions of building envelope. It can be said that the alternative 1 can also meet the advanced requirements by minor adjustments. But the benefits of green alternative are also in the reduced thickness of external walls, which ultimately means the increase of living space inside the house. Energy demand is comparable in both alternatives of the house. Benefits of alternative 2 are the better shape factor of the house. The difference between alternatives occurred in the comprehensive assessment by BEAS. Here, the alternative 1 reached the score near to 1, therefore this design of family house is certified as Environmentally acceptable building. The alternative 2, which can be consider as green alternative obtained higher level and is certified as Environmentally friendly building. This result is achieved by changing the building materials, replacement of gas boilers for heat pump, as well as by modifications the roof for the green roof. In conclusion it can be stated that the alternative 2 of family house is more appropriate and more acceptable to the environment.

In the end it is possible to conclude that the green technologies are on the rise. There are a lot of materials and technologies that can function effectively or have suitable properties and at the same time be acceptable to the environment. In Slovakia there are a number of buildings classified as green or high performance green buildings that are documented and have the required certifications from sustainability aspects. Design of high performance green buildings for the future of a sustainable life on Earth is indisputable. Certification of buildings from three dimensions of sustainability (environmental, social and economic) gives some assurance that the buildings do not burden the environment. Building users will create an environment where they can carry out their daily activities with the objective and subjective positive feelings.

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