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Possibilities of Green Technologies Application in Building Design from Sustainability Dimensions

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Abstract. The aim of this paper is to summarize knowledge of green technologies and their applications in buildings, as well as high performance green buildings. Two alternatives of family house design are performed. The first alternative uses conventional building materials and it doesn't follow the sustainability principles. On the other hand, the second one is designed by using the environmentally friendly materials and with sustainability principles in mind. Designs of conventional and green family house are mutually compared from energy efficiency, embodied energy and greenhouse gas emissions such as CO_{2eq}. and SO_{2eq}. point of view. A special focus is put on the sustainability assessment of designed houses by the Slovak environmental assessment system of buildings.

Keywords: Green technology, green building, sustainability principles, sustainability assessment of buildings.

Conference topic: Energy for buildings.

Introduction

The 21st century has been called the "century of the environment". Governments – and individual citizens – can no longer assume that social challenges such as pollution, dwindling natural resources and climate change can be set aside for future generations. Through policy, research, education, incentives and forward-looking relationships with industry, government can play a central role in building a green future, community by community. The prospects for success have never been greater. A dawning era of creativity and innovation in "green technology" is bringing the promise of a healthier planet – as well as the prospect of growing businesses that can sustain its health. The excitement building around this sector is reminiscent of the early years of the information technology revolution (Green Technology 2015). In the long term, the solution to the many problems with fossil fuels is to transition to using solely renewable energy sources including solar, wind, geothermal, hydropower, bio fuels, and waste-to-energy technologies. Maximizing the potential of these power sources will require innovation in areas such as photovoltaic materials to lower the cost and increase the efficiency of solar power, gas separation materials for efficient use of gaseous fuels, and improved heat-resistant materials for use in solar power plants. Another example of a technology intended to reduce both air pollution and CO_2 emissions is the use of photovoltaic cells to generate electricity (actually electrons) from photons emitted by the sun. As policies and technologies were created to address pollution, it became clear that the real long term goal must be to ultimately establish a fully sustainable planet: one that could perpetually sustain itself in its present form through better management of its resources. This would require efforts on several technological fronts. First, products needed to be designed and built with an eye towards eliminating wasteful materials used and the reuse and recycling of the materials that are used once the product has exhausted its useful life. Second, reliance on difficult to replenish resources from timber to oil needed to be drastically reduced through the development of new recyclable advanced materials (American Elements 2016). To design a house with low environmental footprint requires a multidisciplinary approach that may incur higher costs. Therefore, even nowadays, less costly proposals are still being taken into consideration. Last but not least, cost savings have considerable effect on what materials and systems are chosen in realisation phase. That said, investment costs are favoured over environmental aspects such as environmental impacts, health and well-being of building inhabitants. Whereas the aim of this paper is to assess environmental impacts of conventional and green house from energy efficiency, embodied energy and greenhouse gas emissions such as CO_{2eq} and SO_{2eq} point of view.

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. It can be also heard green technology being referred to as environmental technology and clean technology. Relying on the availability of alternative sources of energy, the purpose of this technology is to reduce global warming as well as the green house effect. Its main objective is to find ways to create new technologies in such a way that they do not damage or deplete the planets natural resources. It also expresses less harm to human, animal, and plant health, as well as damage to the world, in general (Deepgreen 2016). Similar to conventional building projects, green building projects have a variety of objectives that may not necessary be compatible. 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 (Shi *et al.* 2016). 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 (Sulakatko *et al.* 2016). The complexity of the Life Cycle Assessment (LCA) method requires many subjective choices throughout the procedure, which make decision making difficult and LCA results insecure. The approach consists in combining life cycle thinking and sensitivity analysis to provide information to the actor of a foreground system within a product's life cycle. For any parameter of a foreground system, the trends and quantifiedin fluence on impact categories are systematically compared to determine the most effective action leversfor actors controlling the process. This approach has been previously applied to a single actor, the farmer, in a case study of hemp crop production (Kiess *et al.* 2016). The green building thinking in urban cities is a long-term arduous task that aims to develop a stronger synthesis of social, economic, and environmental aspects. By investigating the green technologies together with urban development decision making. Green roof and green wall and "Light-emitting diode (LED)" technologies are most significant in contributing the green city. It is recommended that the government needs to make stronger actions such as ratifying regulations or offering incentives to promote green buildings towards sustainable development (Lee *et al.* 2015).

Figures 1 to 4 show examples of application of green building materials and whole family houses in Slovakia. The photos were made by authors of presented article.

Fig. 1. Thermal insulation – hemp fibres

Fig. 2. Insulation boards made of natural wooden fibres

Fig. 3. Family house in Budimír

Fig. 4. Family house in Rozhanovce

Design and assessment of family house alternatives

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 house is designed in a flat terrain at an altitude of approximately 190 metres. It is designed as a single storey, detached family house without basement that should provide comfortable living for four inhabitants. 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). Table 1 summarizes basic data for each alternative.

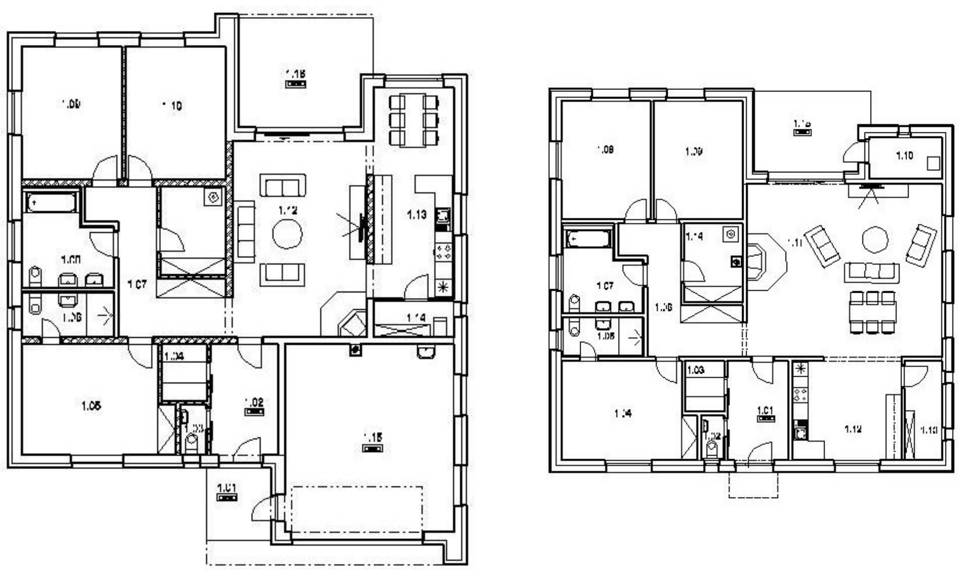
Table 1. Information for designed alternatives of family house

	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
Enclosed volume	1350 m^3	986 m^3

The first house has two entrances. The main one is oriented to the north-east side. The other one is situated on the south-west side from a terrace into the living room. Spread strip foundation is designed. 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 respectively. Double glazed (U = 1.0 $W/m^2.K$) PVC windows and doors 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 forward layering. The 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 the recommended in the whole house except of larder, boiler-room and garage.

Situation of entrances as well as the foundation in the second house is identical to alternative 1. External and internal bearing walls are designed as CLT panels with thickness of 170 mm. Triple insulating glass windows (U = 0.79 $W/m^2.K$) and doors as well as floors are designed as wooden constructions. Horizontal structures consist of CLT panels with thickness of 170 mm above the ground floor. The roof structure is a flat green roof. We suggest to use a special substrate. Nevertheless, an ordinary soil can be used. The substrate thickness is proposed with thickness of 150 mm. The 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 a 300 l insulated hot water tank.

Figures 5 and 6 illustrate disposition of the ground floor and views for designed alternatives of family house.



a) alternative 1 b) alternative 2

Fig. 5. Ground floor of family house

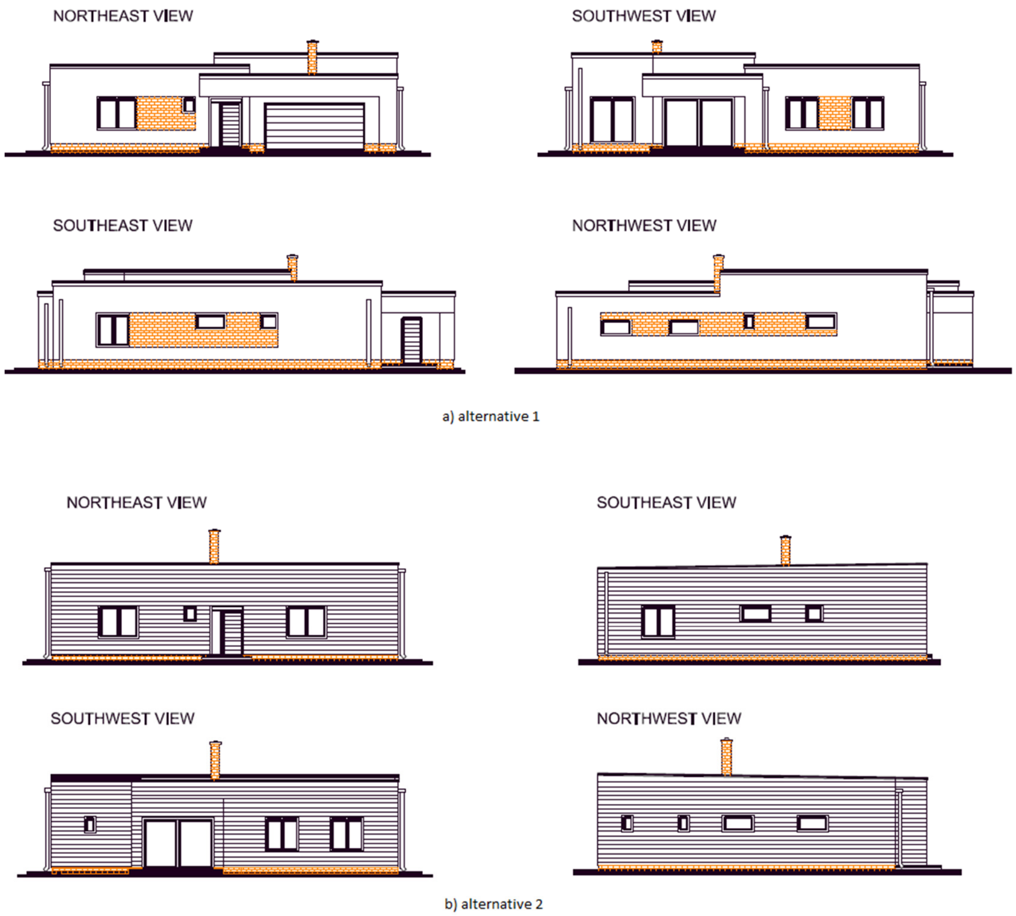


Fig. 6. Views of designed family house

In Tables 2–4 we can see the basic and thermo physical paramters of building structures: thickness of the structure d [m], thermal conductivity λ [W/mK], specific thermal capacity c [J/kgK], factor of diffusion resistance μ, thermal resistance R [m^{2}K/W], heat coefficient U [W/m^{2}K] and phase difference thermal vibrations Ψ [h].

Table 2. External wall

Alternative 1					
Composition	d [m]	λ [W/mK]	c [J/kgK]	μ	
Internal plaster	0.010	0.800	790	19	R = 7.61 m^{2}K/W U = 0.131 W/m^{2}K Ψ = 4.96 h
Aerated concrete blocks	0.300	0.084	1000	5–10	
PENOPOL EPS 100 PENOGREY	0.150	0.039	1270	20–40	
External plaster	0.008	0.800	790	19	
Alternative 2					
Composit ion	d [m]	λ [W/mK]	c [J/kgK]	μ	
Crosslam/CLT panel	0.170	0.110	1600	20–50	R = 7.75 m^{2}K/W U = 0.129 W/m^{2}K Ψ = 18.06 h
Hemp insulation boards	0.230	0.039	1600	3,9	
Wooden panelling	0.025	0.180	2510	157	

Table 3. Floor

Alternative 1					
Composition	d [m]	λ [W/mK]	c [J/kgK]	μ	
Laminate floor/ Ceramic pavement	0.010	0.34/ 1.010	1470/ 840	94000/ 10–20	R = 2.84 m^2K/W U = 0.288 W/m^2K
Cement screed	0.060	1.360	1020	23	
Thermal insulation EPS 100S	0.100	0.036	1270	20–40	
Alternative 2					
Composition	d [m]	λ [W/mK]	c [J/kgK]	μ	
Wooden floor/ Ceramic pavement	0.028/ 0.010	0.18/ 1.010	2510/ 840	157/ 10–20	R = 3.28 m^2K/W U = 0.259 W/m^2K
OSB board	0.024	0.170	1630	12,50	
Mineral wool ROCKWOOL	0.120	0.040	840	2–3,5	

Table 4. Roof and ceiling

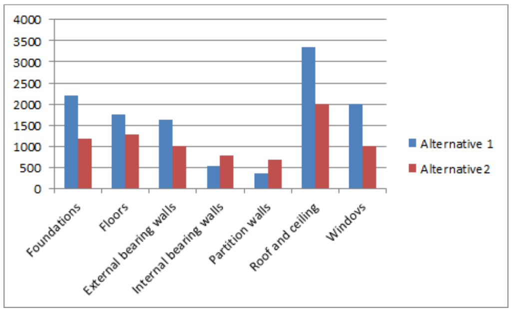
Alternative 1 / flat roof					
Composition	d [m]	λ [W/mK]	c [J/kgK]	μ	
Modified asphalt strips	0.005	0.210	1470	8000	R = 10.084 m^2K/W U = 0.099 W/m^2K Ψ = 26.52 h
ISOVER EPS 100S	0.340	0.036	1270	20–40	
Cement screed	0.050–0.300	0.150	1150	14	
Reinforced concrete ceiling	0.250	1.74	1020	32	
Alternative 2 / Vegetation layer					
Composition	d [m]	λ [W/mK]	c [J/kgK]	μ	
Substrate	0.150	1.500		2	R = 10.43 m^2K/W U = 0.096 W/m^2K Ψ = 29.42 h
Drainage	0.150	0.930	840	5–23	
ISOVER EPS 200S	0.280	0.033	1270	20–40	
Crosslam/CLT panel	0.170	0.110	1600	20–50	

Environmental assessment of designed alternatives by BEAS

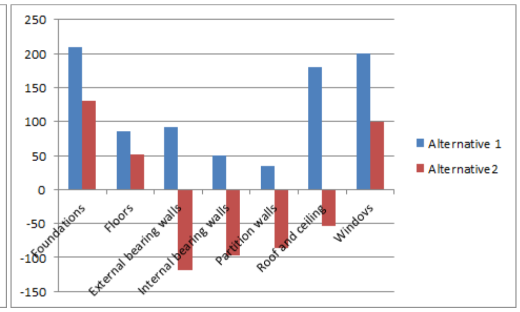
Building environmental assessment system (BEAS) is used for evaluation of selected family house. Tool of BEAS contains six evaluation areas and 53 indicators. The main fields are site selection and project planning, building construction, indoor environment, energy performance, water management and waste 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 whole building and its site, building is certified (Table 5) (Krídlová Burdová, Vilčeková 2013).

Table 5. Key for total assessment of building and certification by BEAS

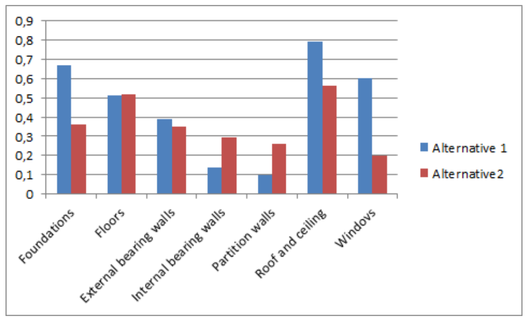
	Key for assessment	Certification scale
–1	negative practice	Environmentally unacceptable building
0	acceptable practice	Environmentally acceptable building
3	good practice	Environmentally friendly building
5	best practice	Sustainable building



a) Embodied energy expressed as MJ/m²



b) CO_2 equivalent emissions expressed as $kgCO_2/m^2$



c) SO_2 equivalent emissions expressed as $kgSO_2/m^2$

Fig. 7. Comparison of environmental indicators for alternatives of designed family house

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. 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. The most dominant polluter is US Steel Košice (OECD 2011). Based on the assessment house in the field "A – Site selection and project planning" the designed house reached points of 2.49 out of 5 possible points. According to the tool of BEAS the weight significance for this area is 20.59%.

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. Such eco-label awarded Ministry of Environment to those products that meet strict environmental and functional criteria. Within the European Union 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 11,818 MJ/m^2, total CO_2 emissions causing global warming are 843.44 kg/m^2 and total SO2 emissions are 3.198 kg/m^2. Alternative 2 obtained values for embodied energy 7,695 MJ/m^2, CO_2 emissions in minus values and SO_2 emissions 2.5 kg/m^2. On the figure (Fig. 7) are compared values of environmental indicators for designed alternatives of family house. Based on the assessment in the field "B – Building constructions" the alternative 1 and 2 reached points – 0.17, respectively 1.91 out of possible 5 points. According to the tool of BEAS the weight significance for this area is 20.59%.

The total area of the 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 outdoors 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 release 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 1.90 and 3.50 out of a possible 5 points. Weight significance for this area is 23.56%.

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 in field "D – Energy Performance" the alternative 1 and 2 reached values of 1.32, respectively 2.69 from possible of 5 points. Weight significance for this area is 26.47%.

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 1.25 and 2.90 points from possible of 5 points. Weight significance of this area is 8.88%.

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 of alternatives 1 and 2 in the field "F – Waste management" they reached 0.69 respectively 1.31 points out of 5 possible points. Weight significance for this area is 5.88%.

Results

From the evaluation of both proposals of family house it can be concluded that the alternatives meet the demand for energy, but 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 required for buildings built up since 2016. The advantage of the use of environmentally friendly materials in alternative 2 is increasing of useful area by reason of decreasing the thickness of external walls from 450 to 425 mm, and also reduction of 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.

Table 6. Comparison of designed alternatives of family house by BEAS

Fields of assessment		Percentage weight	Alternative 1	Alternative 2
A	Site selection and project planning	14.71%	2.64	2.82
B	Building constructions	20.59%	–0.17	1.91
C	Indoor environment	23.56%	1.90	3.50
D	Energy performance	26.47%	1.32	2.69
E	Water management	8.88%	1.25	2.90
F	Waste management	5.88%	0.69	1.31
Total assessment		100%	1.30 Environmentally acceptable building	2.83 Environmentally friendly building

In Table 6 we can see the results of assessment of two alternatives of designed family house. There are also presented the main assessment fields and their percentage weights of significance.

Conclusions

Comparing the two designs of family house 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 original design. Thermo-physical parameters of both alternatives meet up requirements for energy performance, but alternative of green design meet 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 is the better shape factor of the house. The difference between the above alternatives occurred in the comprehensive assessment by BEAS. Here, the alternative 1 reaches 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 obtains higher level and is certified as environmentally friendly building. This result is achieved by changing the building materials, replacement of gas boiler by 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. It can be said that the green technologies are on the rise. There are a lot of materials and technologies that can operate 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 the 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.

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Contribution

Silvia Vilcekova had the original idea and design of the study. Andrea Monokova and Eva Kridlova Burdova performed evaluation of designed alternatives of family house. All authors interpreted the results, prepared the text, and provided the final version of the manuscript. All authors read and approve the final manuscript.

Disclosure statement

Authors declare that not have any competing financial, professional, or personal interests from other parties.

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