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# Analysis of Environmental Aspects in High Energy Performance Family House - Case Study

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In general, high energy performance building design ranges from architectural design to the application of technologies for energy conversation. Many applications are focused on insulation of facades, roofs and floors to those that are used systems for renewable energy sources. The aim of the innovations is not only energy saving but also reduce costs and preserve natural resources. One key element of high energy performance building design is use of basic form and enclosure of a building to save energy while enhancing occupant comfort. Besides energy need for building operation the significant part of the total energy is energy used in the extraction, processing and transportation of materials used in building structures. Integrated assessment of building includes energy produced over the entire life cycle of building. In order to reduction of embodied energy and embodied emissions, this study is aimed to analyze the building materials and structures used in high energy performance buildings. The paper deals with evaluation of energy and environmental aspects of the building structures for selected family house and its optimization in order to reduction of embodied environmental impacts.

## 1. Introduction

In past years, there has been growing interest among stakeholders, architects and entrepreneurs in incorporating energy efficiency tools and techniques into buildings, as a way of achieving energy efficient buildings that comply with stringent energy codes and national goals of reducing dangerous emissions, together with improving the corporate image (Ferrante, 2012). According to study (Feist, 2009) the good results at an acceptable cost were achieved with “low energy houses”, where improved thermal qualities of the building envelope, connected with a mechanical ventilation system for good indoor air quality, resulted in space heating demands of 50 to 70 kWh/($m^2$.y). In this study is showed that physical analysis of the energy balance of buildings has resulted in the development of the Passive House standard, a strategy for saving approximately 90 % of the heating energy required in an average existing building. In the study (Blengini et al., 2010) a low-energy family house in Northern Italy is selected by Regione Piemonte as an outstanding example of resource efficient building. A detailed LCA of this house has highlighted that, when addressing energy-saving and sustainability performances of low-energy buildings, the role and significance of all life cycle phases and subsystems must be carefully considered. Moreover, the lower the operation energy, the more important is the adoption of a life cycle approach. The study confirmed that in comparison to a standard house, while the winter heat requirement was reduced from 109 to 10 kWh/$m^2$ (10:1 ratio), the life cycle energy was only reduced by 2.1:1 and the carbon footprint by 2.2:1. According to study (Yohanis et al., 2006) the impact of the variation of building parameters on embodied energy varies from very small to negligible. The reasons for this are two-fold: embodied energy compared with operational energy is much smaller even when the life of a building of 30 years is considered (in reality, building life would be much longer), a large part of the embodied energy in buildings is in the

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substructures, frame, roof, floor, internal wall, external wall, etc. so that a variation in one component (e.g. insulation) does not have a significant impact on embodied energy. LCA approach based on the input-output hybrid analysis demonstrates that the embodied energy can be as significant as the operational energy over the lifespan of the building. On average, the embodied energy represented 77 %, 60 % and 43 % of the life cycle operational energy for the passive house, low-energy house and normal construction respectively (Stephan et al., 2011). Correct evaluation should adopt to a life cycle perspective (Edwards, 2003; Horvath, 2004), considering not only the impact of material production stage (raw material supply, transport, manufacturing of products and all upstream processes from cradle to gate), but also its contribution in the building construction process (transport to the building site and building installation/construction), use phase (energy losses, maintenance, repair and replacement, refurbishment), and finally end-of-life (recycling and disposal, including transport). Study (Thormark, 2002) deals with values on embodied energy, energy needed for operation and the recycling potential of the most energy efficient apartment housing in Sweden (45 kWh/$m^2$). The embodied energy accounted for a considerable part, 40 % of the total energy use in low energy buildings during an assumed lifetime of 50 years. About 37–42 % of the embodied energy can be recovered through recycling. The recycling potential was about 15 % of the total energy use during an assumed lifetime of 50 years.

## 2. Case study

### 2.1 Methods of analyses

Environmental analysis of this case study is based on Life Cycle Assessment (LCA). LCA is a well known tool for analyzing environmental impacts on a wide extent throughout the life cycle of the building (cradle-to-grave). It involves the assessment of specific elements of product system to determine its environmental impacts. However it has some limitations in practical building design by reason of highly data-demanding and work-intensive (Benedetto and Klemeš, 2008 and 2009). This case study evaluates the used building materials and structures by using LCA within system boundary: “cradle to gate” and LCA provides better decision support when optimising environmentally suitable solutions. The input data are especially extracted from IBO database (Waltjen, 2009). The material compositions are compared calculated environmental indicators such as embodied energy from non-renewable resources (EE, global impact), embodied $CO_2$eq. emissions ($ECO_2$, global warming potential, global impact) and embodied $SO_2$eq. emissions ($ESO_2$, acidification potential, regional impact).
Calculation procedure for determination of environmental indicators is based on the multiplication of values of embodied energy and emissions of $CO_2$ and $SO_2$ from IBO database and mass of building materials.
Calculation of value of embodied energy is following:

$$EE = \sum EE_i \cdot m_i \text{ [MJ]} \quad (1)$$

where $EE_i$ is the value of embodied energy for building material from IBO database [MJ/kg] and $m_i$ is the mass of building material [MJ/kg]
Environmental and energy analysis is an integral component of sustainable building practice. Assessing amount of different criteria can help to make better decision which solution is the most optimal for a given building design in a given context.

### 2.2 Low energy house – case study

The evaluated low-energy house is situated in Košice - Pereš (Slovakia) (Figure 1 and 2). This family house with a rectangular ground plan is seated on the flat terrain. It is a one floor house with sloping roof. It is a brick house with a massive envelope structures. The building is based on the foundation strips and base plate. Envelope walls are made of ceramic bricks of 300 mm thickness with rock wool insulation with thickness of 200 mm. Horizontal supporting structures consist of ceiling beams with rock wool insulation of thickness of 180 mm. Windows are aluminum with brake thermal bridge. Glazing system is designed as a triple glazing. The ground floor is insulated with a layer of polystyrene with thickness of 250 mm on the base plate.
Source of heat is gas boiler. In a house is installed hot air heating and heating by the system Duplex RK2 (ATREA). It is a dual-zone heating and circulation of hot air at the same time for comfort ventilation with heat recovery. Heating is designed as underfloor heating. The whole HVAC system is regulated by Logamatic.
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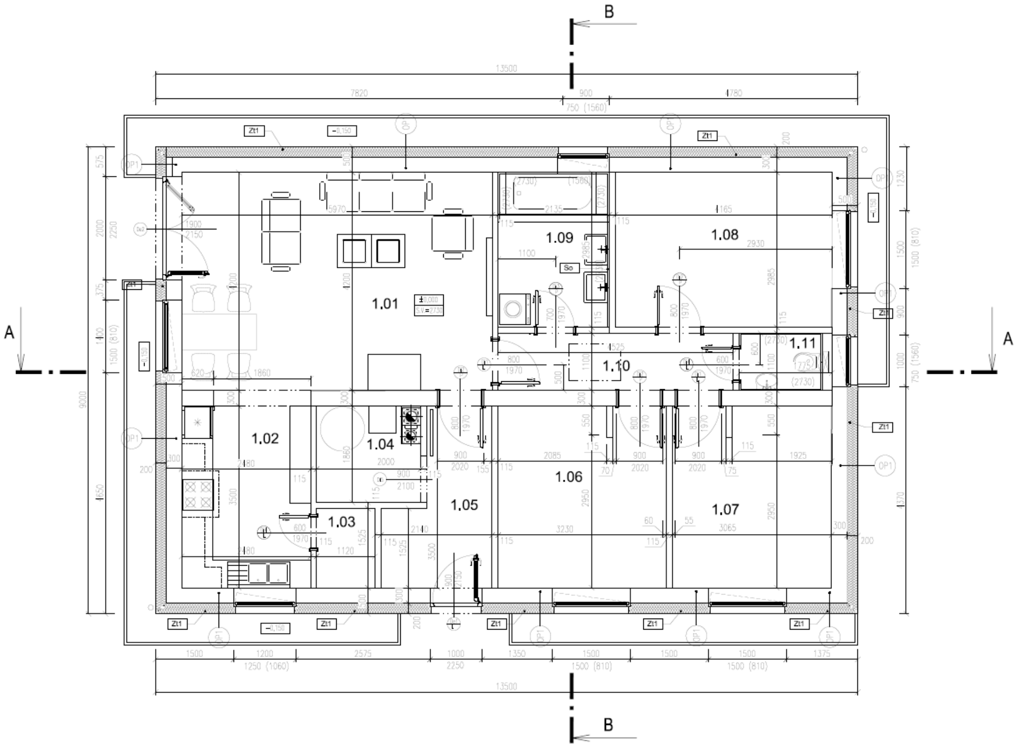


*Figure 1: Ground plan*

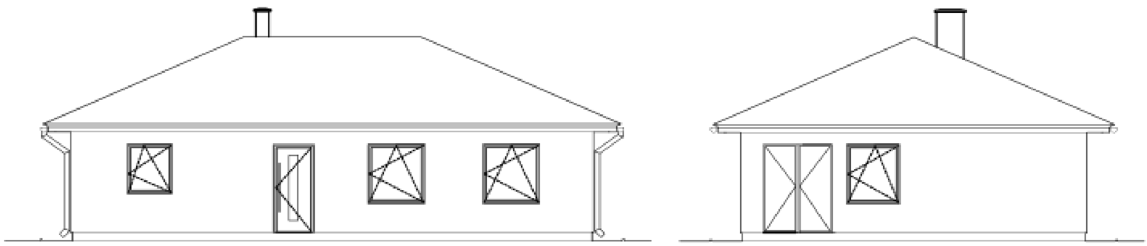

*Figure 2: Views*

Building structures:
Foundations: gravel, concrete strip, reinforced concrete plate (150 mm), waterproofing.
Bearing walls: brick Porotherm (300 mm), thermal insulation from mineral wool (200 mm), textile net, silicon plaster (3 mm).
Partitions: brick Porotherm (115 mm), textile net, lime plaster (200 mm).
Ceiling: OSB plate (30 mm), vapor permeable foil, mineral wool insulation between wood (100/180), vapour foil, gypsum board.
Roof: RUUKI, lathens (50/30), contralathes (60/50), vapor permeable foil, wood (80/160).
Floor: laminate floor/ceramic tiles, concrete screed, separate foil, EPS (120 mm).
Windows: alluminium, triple glass insulation.

## 3. Results

The aim of this case study is to determine values of environmental indicators for selected low energy house. The results of environmental assessment are presented in Table 1.

*Table 1: The results of assessments of environmental indicators*

| | EE [MJ] | $ECO_2$ [kg $CO_2$eq] | $ESO_2$ [kg $SO_2$eq] |
|---|---|---|---|
| Foundations | 234,044 | 31,700 | 84 |
| Bearing walls | 318,759 | 29,108 | 103 |
| Partitions | 18,021 | 1,255 | 4 |
| Ceiling | 126,156 | 389 | 46 |
| Roof | 32,460 | 1,242 | 10 |
| Floor | 92,302 | 3,237 | 29 |
| Opening structures | 14,753 | 841 | 3 |
| Total | 836,494 | 67,772 | 279 |

The percentage share of structures on total embodied energy and embodied emissions are presented on Figure 1.

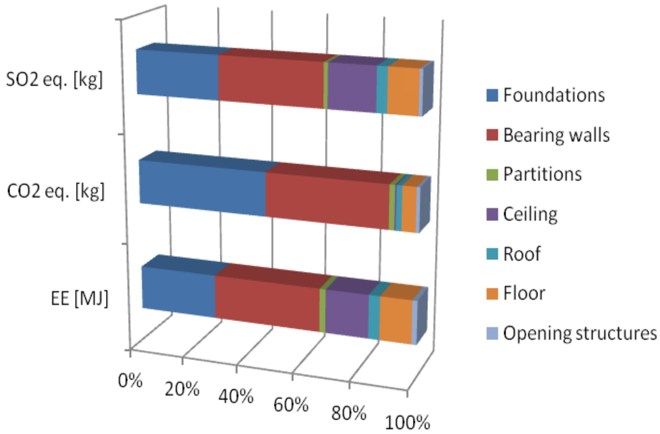


*Figure 1: Embodied energy and embodied emissions of $CO_{2eq.}$ and $SO_{2eq.}$*

Total results of environmental analysis for this family house are following: 6.9 GJ/$m^2$ for floor area, 558 kg $CO_2$eq/$m^2$ for floor area and, 2.3 kg $SO_2$eq/$m^2$ for floor area. In comparison with results of other case studies, this family house requires higher reduction of embodied energy and embodied emissions with optimalized material compositions of structures for the purpose of possible way towards sustainable future. As an effective measure can be designed insulation from sheep wool between wood profiles. The environmental profile for this measure is presented in Table 2.

*Table 2: The results of assessments of environmental indicators for measure – insulation from sheep wool*

| | EE [MJ] | $ECO_2$ [kg $CO_2$eq] | $ESO_2$ [kg $SO_2$eq] |
|---|---|---|---|
| Foundations | 234,044 | 31,700 | 84 |
| Bearing walls | 318,759 | 29,108 | 103 |
| Partitions | 18,021 | 1,255 | 4 |
| Ceiling | 97,123 | -2,508 | 28 |
| Roof | 32,460 | 1,242 | 10 |
| Floor | 92,302 | 3,237 | 29 |
| Opening structures | 14,753 | 841 | 3 |
| Total | 807,465 | 64,875 | 262 |

The percentage share of structures on total embodied energy and embodied emissions are presented on Figure 2.

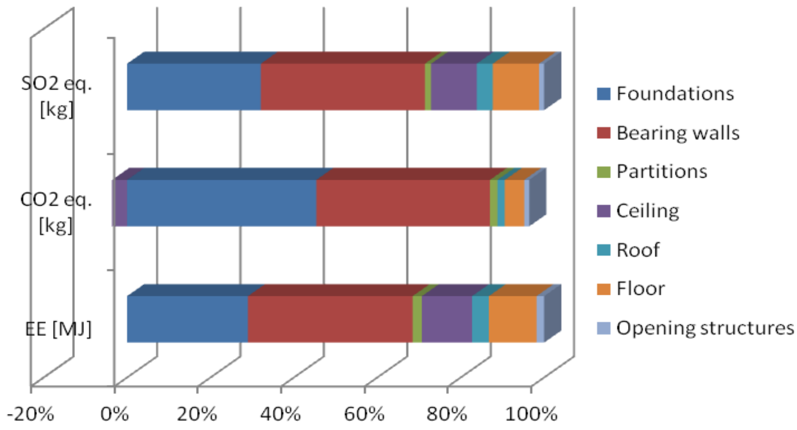


*Figure 2: Embodied energy and embodied emissions of $CO_{2eq.}$ and $SO_{2eq.}$*

The values of environmental indicators for ceiling with insulation from sheep wool are reduced by 23 % for EE, 645 % for $CO_2eq/m^2$ and 40 % for $SO_2eq/m^2$. It can note that by using natural materials can be significantly reduced values of environmental indicators.
In comparison with results of other case studies, this family house requires higher reduction of embodied energy and embodied emissions with optimized material compositions of structures for the purpose of possible way towards sustainable future.

## 4. Conclusions

The building sector is known to be dominant consumer of energy resources, contributor to greenhouse gas emissions and other environmental impacts. Over the last decade, the development towards sustainability has become important issue in building design decisions. Mitigation of environmental impacts is become a priority in energy and environmental policies of development Europe countries. The policies are focused on increasing energy performance of buildings and the deployment of renewable energy supply technologies. The recast of the European Energy Performance of Buildings Directive (EPBD) targets nearly-zero energy performance for all new buildings by the end of 2020.
Life cycle assessment (LCA) belongs to broadly used methodology which helps to make decisions in sustainable building design. The relative contribution of embodied impacts of building materials has been recognized as being significant, especially for high energy effective residential buildings. The overall environmental and energy performance of building structures is important in achieving more sustainable solution. The careful choice of building materials play significant role in increasing the sustainability of buildings and represent the easiest way for designers to begin incorporating environmental criteria in building project.
This case study implements life cycle assessment within “cradle to gate” (especially low energy houses). The aim is to assess environmental indicators such as embodied energy from non-renewable resources, embodied emissions of $CO_2$-eq. and $SO_2$-eq.
Although operational energy participates the highest proportion in total energy consumption over whole life cycle of building, it is important to take into account embodied energy. Values of embodied energy and associated emissions grow by improving energy quality of building envelope by using extra components and insulation materials. Improvement energy performance of building envelope in order to reduction of operational energy consumption in buildings may result in rise proportion of embodied impacts of building materials on total life cycle environmental impacts.


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