

Environmental and Energy Assessment of a Family House

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Abstract. Term energy efficient building is well know from year 1991, when Austrian physicist Dr. Feist designed and built first passive house, using current physical and practical knowledge. In the next 25 years buildings using principles of energy efficient design have changed dramatically. In a good way. It is mandatory for Slovak Republic as a part of European Union to act according European parliament directives. One of directives concerns lowering total energy consumption and emissions in the building sector – Directive 2010/31/EU on Energy performance of buildings, also known as Directive “20-20-20”. According to this directive, Slovak Republic has agreed to lower total energy consumption in building industry by 20% until year 2020. Plan on lowering total energy consumption has affected creation of new – technical and energy efficient building materials with emphasis on environmental load. In this paper, ultra-low-energy family house located in Košice, Slovakia was assessed from environmental and energy point of view. With help on modern diagnostic methods and thermo-physical simulation software DesignBuilder, we will virtually evaluate energy need of house throughout the reference year, and indoor quality from the environmental point of view, such as CO₂ levels and bounded energy using LCA method.

Keywords: LCA method, ultra-low-energy house, energy load, heating and cooling.

Conference topic: Energy for Buildings.

Introduction

Building energy performance assessment is crucial to ascertain the efficiency of energy use in buildings and is the basis to make any decision for enhancing energy efficiency (Wang *et al.* 2012). Globally, buildings consume nearly half of the total energy produced, and consequently responsible for a large share of CO₂ emissions. A building’s life cycle energy (LCE) comprises its embodied energy (EE) and operational energy (OE) (Praseeda *et al.* 2016). The latest energy standards pertaining buildings mainly focus on the reduction of Operational Energy (OE). The adoption of highly efficient energy production systems as well as high performance materials is being encouraged more and more in order to achieve the Nearly Zero Energy Buildings target (Giordano *et al.* 2015). The construction industry causes a number of complex environmental effects, particularly carbon dioxide emissions (Chou, Yeh 2015). High energy consumption by the industry of developing countries has led to the problems of increasing emission of greenhouse gases (GHG) (primarily CO₂) and worsening energy shortages (Wu *et al.* 2016). The carbon dioxide (CO₂) emissions related to the residential and commercial building sector have been a global concern (Hong *et al.* 2016). As study state (Lu *et al.* 2016) global warming caused by greenhouse gas (GHG), especially CO₂ emissions (hereinafter interchangeably used with carbon emissions), continuously threatens the existence of human and ecological environment and has caused a series of global concerns, such as rising sea levels, crop failures, desertification, and pest proliferation. Application of Life Cycle Assessment (LCA) in buildings is usually performed at the envelope scale, mainly for comparison of several sample-solutions, and provides in-depth analyses of the related energy and environmental performances. In this way, it is possible to identify those solutions that perform best in energy and environmental terms, and that so are suitable for construction of sustainable buildings (Ingrao *et al.* 2016). Energy efficient design (to create ultra-low-energy building, net-zero building or even energy-plus building) is a response to local climate conditions and global energy consumption. In Europe, 30–40% of the current total energy demand and approximately 44% of the total material use are due to the building sector which is a significant percentage of the total environmental load of human activities (Belpoliti, Bizzarri 2015). Thermal building simulation is a powerful tool to assess the energy performance of a building (Andarini 2014). DesignBuilder is currently the most comprehensive user-friendly EnergyPlus interface (Yu *et al.* 2015). Many studies are focused on simulations in DesignBuilder. Study (Torre, Yousif 2014) is focused on Computational Fluid Dynamics (CFD) to study the effectiveness of natural ventilation through a chimney, forming part of the environmentally-friendly design features of a new brewery. Another study (Yu *et al.* 2015) is simulated process into the various conditions, variety of thermal performance walls, roofs and windows. Building energy consumption was simulated through EnergyPlus under different conditions. Study (Sertsungnern, Chaiwiwatworakul 2011) is focused on development of a performance rating scheme of

air-conditioning systems for buildings in Thailand using DesignBuilder. Another study (Rahman *et al.* 2010) used simulation software DesignBuilder for evaluation of various energy conservation measures on heating, ventilating and air conditioning (HVAC) and lighting systems for a four-storied institutional building in sub-tropical (hot and humid climate) Queensland in Australia. (Kovac, Kovacova 2015) studied energy demand for HVAC in a shopping center using DesignBuilder as well. Another study (Nie *et al.* 2015) is calculated energy consumption of building with different orientation by DesignBuilder. Martinaitis *et al.* (2015) presented the framework for integrated building design that involves the analysis of the energy-related impacts of all building components, including the building location, envelope, HVAC, domestic hot water, lighting, controls, and equipment as well as the impact of occupancy characteristics and the application of simulation tool EnergyPlus (DesignBuilder).

The aim of this paper is building thermal simulation of family house located in Košice using the simulation and visualization tool of DesignBuilder. The aim of this paper is also LCA analysis of selected family house.

Methods

Family house was simulated in DesignBuilder software. DesignBuilder is a state-of-the-art software tool for checking building energy, carbon, lighting and comfort performance. Developed to simplify the process of building simulation, DesignBuilder allows comparing functions and performance of building designs and delivers results (<https://www.linkedin.com/company/designbuilder-software-limited>). For software simulation, climate data for Košice region (reference year) were used.

Environmental indicators such as embodied energy and emissions of CO_{2eq} and SO_{2eq} of family house were calculated by the LCA method within the boundary “cradle to gate”. LCA is a universally accepted approach of determining the environmental consequences of a particular product over its entire production cycle. Embodied energy (EE) is the energy utilized during the manufacturing stage of building materials and represents the energy used to acquire raw materials (excavation), manufacture and transport. CO₂ emissions (ECO₂ – global warming potential GWP) and SO₂ emissions (ESO₂ – acidification potential AP) represent the equivalent emissions within the LCA boundary – cradle to gate. The input data of these indicators are extracted from the LCA database – IBO (Waltjen 2009).

Climate and situation

Košice, with 234000 citizens, is after the capital the second largest town in Slovakia. It is situated in the eastern part of the country, close to the border with Hungary (20 km) on the south, Ukraine in the east (80 km) and Poland in the north (90 km). The town is located in the valley of the River Hornád; on the west it is surrounded by the Slovak mountain – Slovenské rudohorie. Košice is the Eastern Slovakia’s centre of culture, industry, commerce, administration and science (<http://www.slovak-republic.org/kosice/>). In the figure (Fig. 1) is shown the location of assessed family house.



Fig. 1. Location of the family house (Source: <http://iearn2004.srobarka.sk/images/europe.gif>)

House evaluation

In the figure (Fig. 2) shape of the assessed family house is presented. As it can be observed (Fig. 2), family house is designed and constructed with strong emphasis to an A/V ratio to minimize heat losses through building envelope. In the table (Table 1) are shown envelope wall characteristics and in the table (Table 2) are shown floor on terrain characteristics. In the table (Table 3) are shown roof characteristics of assessed family house.



Fig. 2. Shape of the family house

Table 1. Envelope wall

	d[m]	λ [W/m.K]	c[J/kg.K]	ρ [kg/m ³]	m[kg/m ²]
Gypsum plaster	0.005	0.570	1000.0	1300.0	10.0
Reinforced concrete	0.070	1.580	1020.0	2400.0	29.0
Neopor insulation	0.330	0.031	1250.0	18.0	45.0
Adhesive mortar	0.005	0.800	920.0	1300.0	18.0
Silicon render	0.003	0.700	920.0	1700.0	37.0

Table 2. Floor on terrain

	d[m]	λ [W/m.K]	c[J/kg.K]	ρ [kg/m ³]	m[kg/m ²]
Ceramic tiles	0.010	1.010	840.0	2000.0	200.0
Concrete	0.090	1.300	1020.0	2200.0	20.0
RFC slab	0.250	1.580	1020.0	2400.0	27.0
EPS NEO	0.200	0.031	1250.0	18.0	45.0
Stud membrane	0.0005	0.140	1100.0	1200.0	50000
Sand layer	0.050	0.950	960.0	1750.0	4
Gravel	0.400	0.650	800.0	1650.0	15

Table 3. Roof

	d[m]	λ [W/m.K]	c[J/kg.K]	ρ [kg/m ³]	m[kg/m ²]
Gypsum plaster	0.005	0.570	1000	1300	10.0
Reinforced concrete	0.200	1.580	1020	2400	29.0
Vapor barrier	0.004	0.170	1470	1300	375000
EPS Stabil150	0.300	0.039	1250	19.0	40.0
Water-proofing	0.0015	0.350	1470	1313	24000
Gravel	0.100	0.650	800	1650	15.0

Tripple-glazed windows with 7 chambers plastic frame (SCHÜCO ALU INSIDE) were used in the simulation process. Heating on the ground floor is provided by floor heating system connected to NILAN Compact K unit (air-water heat pump). First floor uses ceiling infrared panels (carbon fibre with aluminium frame) for heating. Ground and first floor are air cooled with a forced ventilation system connected to a heat recovery unit within NILAN Compact K. In the figure (Fig. 3) is shown DesignBuilder graphical input for calculating energy for heating and cooling throughout the reference year.

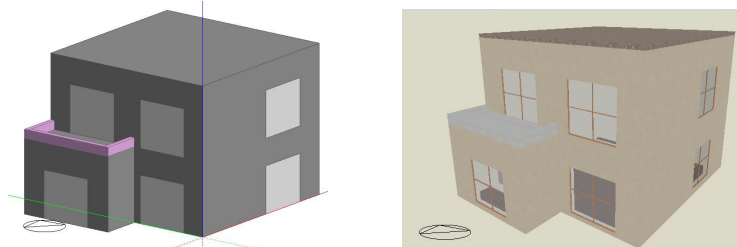


Fig. 3. DesignBuilder graphical input for calculating energy for heating and cooling throughout the reference year

Results

Results of DesignBuilder simulations

Figure 4 shows daily energy need for heating and cooling, its extremes in summer and winter time throughout the reference year for Košice, Slovakia. On the other hand Figure 5 illustrates total annual energy load on the family house. Maximum energy need for zone heating, 55.81 kWh, has been shown on the 12th of January. From that day onward, the daily energy need has decreasing tendency and it goes to the middle of April, when, as shown in Figure 4, cooling season starts. On the other hand, as for Kosice, Slovakia typical climate, hottest months with highest temperatures in month June, July, August and mid-September are showing the highest energy need for building cooling – up to 71.31 kWh in mid-July.

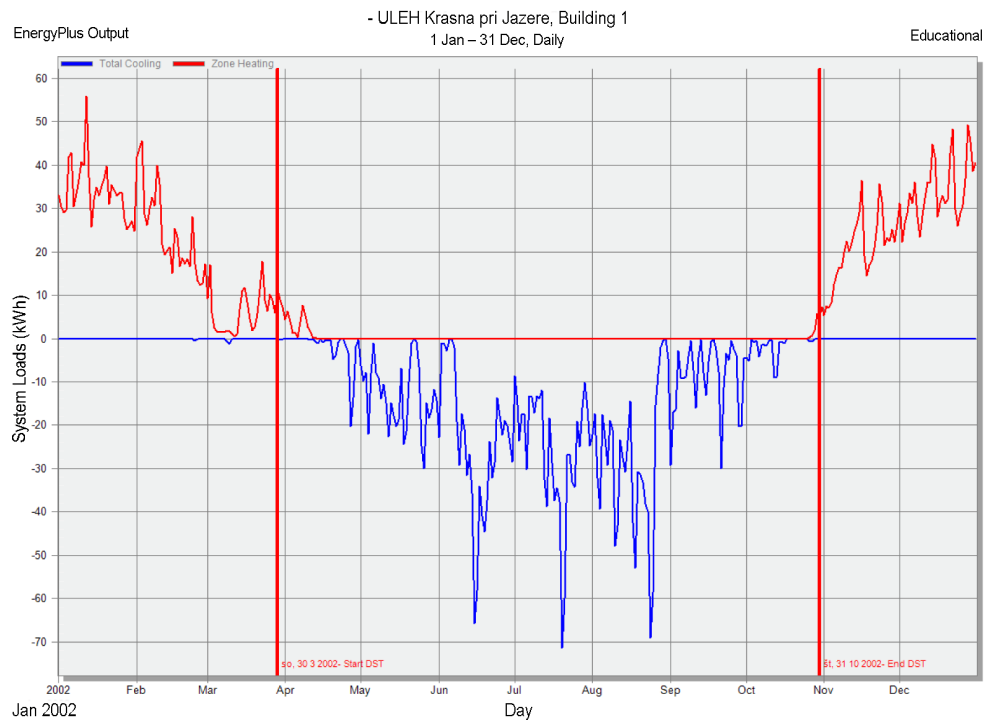


Fig. 4. DesignBuilder output of energy for heating and cooling throughout the reference year (daily)

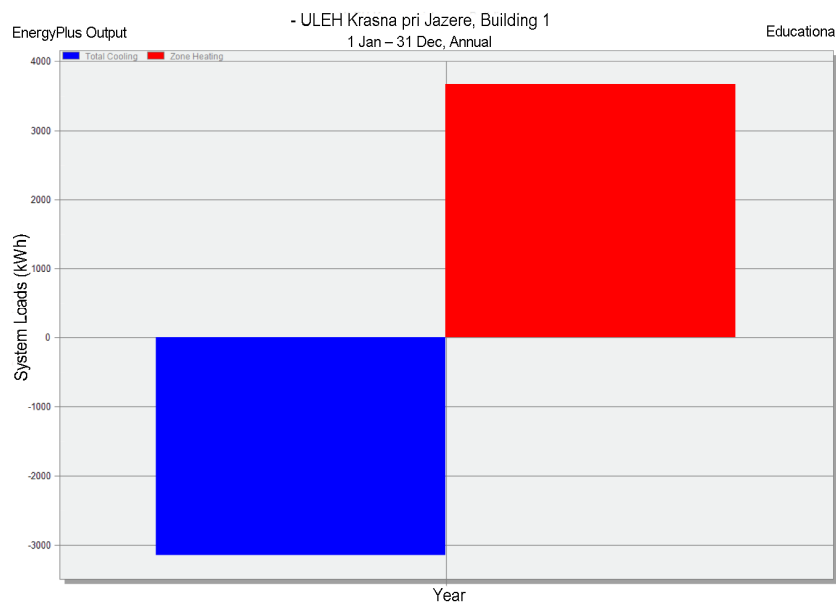


Fig. 5. DesignBuilder output of energy for heating and cooling throughout the reference year (annual)

Results of Life Cycle Assessment

In the figures below (Figs 6–8) are shown results of environmental indicator (primary energy (PEI), global warming potential (GWP) and acidification potential (AP)) of selected family house constructions. Most of the primary energy is embodied in bearing walls (1,350,924 MJ). Overall, in building construction is 2,453,107.49 MJ of embodied energy. In terms of indicator of global warming potential, most emissions were calculated in reinforced bearing wall with EPS thermal insulation (74,695 kgCO_{2eq.}) and least in windows (2,411 kgCO_{2eq.}). So it was with the acidification potential, most emissions were in the bearing walls (277 kgSO_{2eq.}) and least in windows (9 kgSO_{2eq.}).

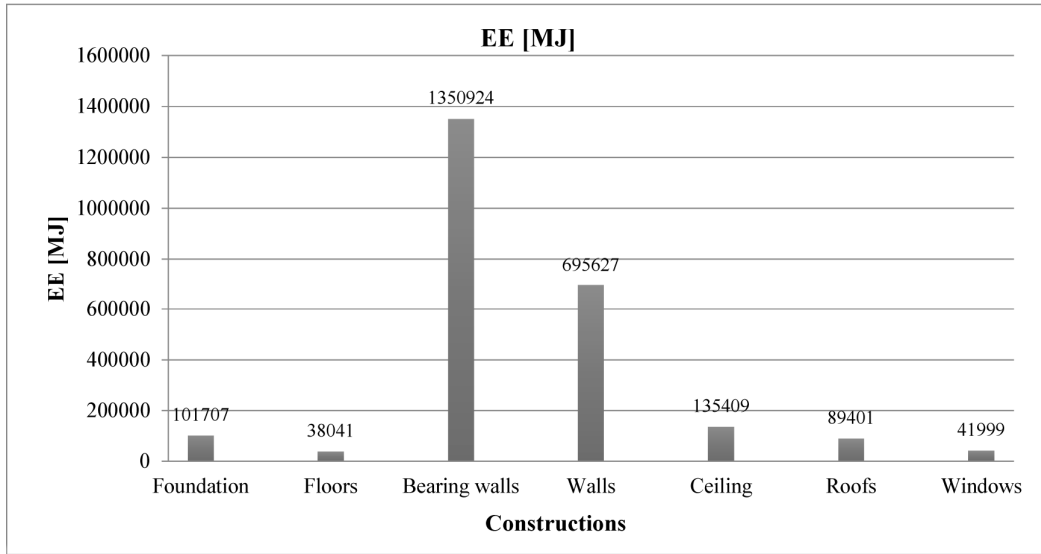


Fig. 6. Embodied energy of family house

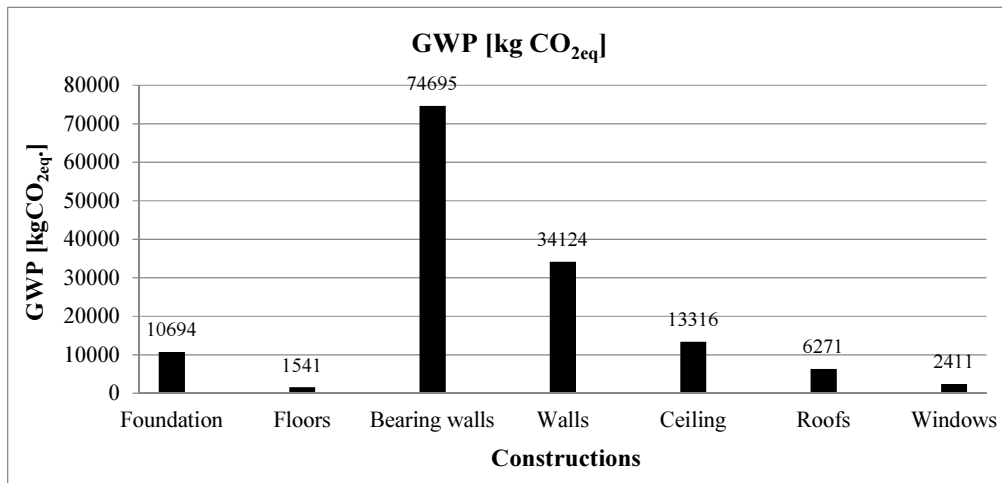


Fig. 7. Global warming potential of family house

Many studies deal with the environmental evaluation of whole buildings as well as building materials and their compositions. The results can be compared and discussed. Study (Kridlova Burdova *et al.* 2016) compares material composition of variant of roof constructions. The environmental impacts were expressed by indicators such as embodied energy from non-renewable resources, embodied CO_{2eq.} emissions and embodied SO_{2eq.} emissions within the system boundary from Cradle to Gate. Study (Sedláková *et al.* 2015) deals with analysis of material solutions for design of construction details of foundation, wall and floor for energy and environmental impacts. Another study (Sedláková *et al.* 2014) is focused on evaluation of design concept of lower structures from embodied energy and emissions point of view. Study (Vilčeková *et al.* 2015) is focused on analysis and identifying the environmental quality of material compositions of exterior walls.

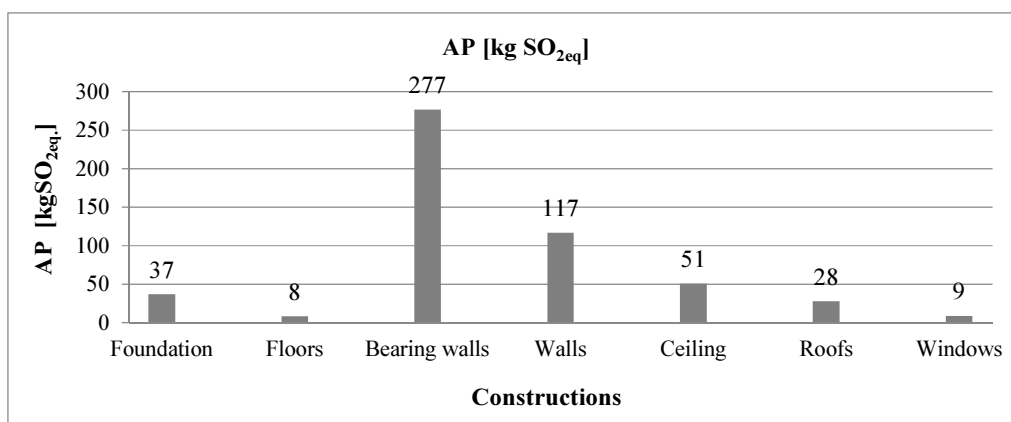


Fig. 8. Acidification potential of family house

Conclusions

The aim of this paper was building thermal simulation of family house located in Košice, using the simulation and visualization tool of DesignBuilder. The aim of this paper was also LCA analysis of selected family house. According to our climate (central Europe, with 4 seasons) we can divide a season from the energy need point of view to a heating season and cooling season. Heating season usually starts in November and ends in April (Fig. 4, red lines). As for the total annual energy performance of the assessed family house on the square meter (energy needed for heating together with the energy needed for cooling), family house will consume 54.43 kWh/m²/year – based on our simulation. From the energy point view shown in Figures 4–5, we can classify this building to an ultra-low-energy family house. Overall, in building construction is 2,453,107.49 MJ of embodied energy. In terms of indicator of global warming potential, most emissions were calculated in reinforced bearing wall with EPS thermal insulation (74,695 kgCO_{2eq.}) and least in windows (2,411 kgCO_{2eq.}). So it was with the acidification potential, most emissions were in the bearing walls (277 kgSO_{2eq.}) and least in windows (9 kgSO_{2eq.}). Our future work will be aimed at the investigation of significant set of low energy buildings and their indoor environmental quality.

Funding

This paper was financially supported by the Slovak Grant No. 1/0307/16.

Disclosure statement

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

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