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REDUCING ENERGY CONSUMPTION AND GHG EMISSIONS FOR BUILDING CONSTRUCTION

BY

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Abstract. Climate change is a very serious problem with negative consequences on all life aspects. Each economy sector, including building construction, must seek some means for the decrease of GHG emissions, creating the premises of sustainable development. During last decades, several high energy performance building concepts have been proposed, from low-energy building through passive building and zero-energy building to positive energy building, active building and even autonomous building. Similar to energy, GHG lifecycle emissions resulting from buildings consist of two components: operational and embodied emissions. Embodied impacts (embodied energy and embodied GHG emissions) should be considered starting with preliminary design stages, by the examination of alternatives at the building materials and components level. In the case study, the embodied energy and embodied GHG emissions are evaluated for different solutions of partition walls and floors widely used in Romania. The paper presents some options to reduce embodied impacts.

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1. Introduction

The burning of fossil fuels to meet the increasingly energy demand of the modern society coupled with the deforestation caused the greenhouse gas (GHG) concentrations to shift out of balance. Besides carbon dioxide – the main and most well-known cause of climate change - methane, nitrous oxides, sulphur oxides and volatile organic compounds are also GHGs contributing to global warming. According to the Intergovernmental Panel on Climate Change (IPCC), between 1880 and 2012 the globally averaged combined land and ocean surface temperature data revealed a warming of 0.85 [0.65 to 1.06] °C and the continued emission of GHGs will cause further warming and long-lasting climate changes (IPCC, 2014).

Climate change has been approached by a series of global events of particular importance that created the premises of sustainable development:

– the *United Nations Conference on Environment and Development*, also referred as the *Earth Summit* (Rio de Janeiro, 1992) addressed global environmental issues facing the planet, focusing on sustainable development, climate change, protection of endangered species, and population growth;

– in 1997, many governments signed the *Kyoto Protocol* which set targets for reducing greenhouse gas emissions emitted in industrialized countries and introduced three flexible mechanisms to achieve them, thereby creating what is now known as the "carbon market": clean development mechanism, joint implementation and emissions trading;

– in 2015 (December), 195 countries adopted a binding and universal climate deal. The *Paris Agreement* establishes a global action plan to reduce emissions in order to keep the global warming to "well below 2°C and to drive efforts to limit the temperature increase even further to 1.5°C above pre-industrial levels".

Many countries, including the EU member states, are oriented to satisfy these objectives. Each economy sector must seek some means for the decrease of GHG emissions.

The building sector is responsible for an important share of the whole energy consumption. It is estimated that 32% of total global final energy use and approximately one third of carbon emissions are assigned to this sector (Edenhofer *et al.*, 2014). According to the United Nations, in many industrialized more developed nations, this number is higher, and in the United

States, estimates range from 43% (Brown *et al.*, 2007) to 49% (Mazria & Kershner, 2008) of total emissions. All of these are significant, and building emissions are always the single largest source, higher than emissions from industry and transportation. Into the next decades, it is expected that the global energy demand will grow by 79% in residential buildings and 84% in commercial buildings (Ürge-Vorsatz *et al.*, 2016). So, it is very important to set new rules of designing and producing buildings. Buildings of nowadays need to be *customizable* in order to increase the sustainability level in accommodating users' requirements and also *affordable,* meaning initial and operating low costs.

2. Performant Buildings Concepts

Because of the connection between energy use, GHG emissions and climate change and the reality that the built environment emits an important part of total emissions, the construction industry has considerable potential to reduce emissions and a key role in mitigating global warming.

This is a challenge for the new sustainable buildings cities to implement a new relation between mankind and the natural environment.

In order to achieve this, the implementation of new building codes associated with the high energy performance must be seen as a top priority. As a result, during last decades, several high energy performance building concepts have been proposed, from low-energy building through passive building and zero-energy building to positive energy building, active building and even autonomous building.

A *low-energy building* is an energy efficient building which uses less energy, from any source, than traditional or average contemporary buildings. Its energy use is below the standards demanded by current buildings codes. Because the national standards vary from country to country, there is no common definition of low-energy buildings and their performances evolve in time. For example, in Germany a low-energy house has an energy consumption limit of 30 kWh/m^2 per year for space heating, while in Switzerland low-energy buildings should not exceed more than 75% of the average building energy consumption.

In comparison, the German *Passive House* standard, which has also been adopted in some other European countries, requires a maximum space heating demand of 15 kWh/m^2 per year and a total primary energy consumption (which includes energy required for heating, hot water, lighting, electrical equipment) of 120 kWh/m^2 per year. Also, passive houses should have low levels of air leakage through cracks and interstices (an air change rate less than

0.6 h^{-1} for an inside air overpressure of 50 Pa). The main characteristics of low-energy buildings are: compact volume, well-insulated building elements, thermal bridges avoided or minimised, energy efficient windows, good air tightness, heat recovery ventilation, and passive or active solar technologies.

A *nearly Zero-Energy Building* has a very high energy performance, in which power consumption is nearly zero or very low and is covered to a very significant extent by energy from renewable sources, including renewable energy produced on-site or nearby. The Directive 2010/31/EU sets for all Member States until 31 December 2020 all new buildings are buildings whose energy consumption will be nearly zero.

A *Net Zero Energy Building* is one with the total amount of energy used on an annual basis roughly equal to the amount of renewable energy created on the site; the wording "Net" emphasizes the energy exchange between the building and the energy infrastructure, the Net Zero Energy Building being an active part of the renewable energy infrastructure.

The *Energy Plus Buildings* produce a surplus of energy over the year.

A quite similar concept is *Zero Emissions (Carbon) Building*, which means that the carbon emissions generated from on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production. There are more definition levels, depending on the different phases of the building life-cycle that are taken into consideration (production of building materials, construction of the building, operation and demolition/recycling – see Fig. 1).

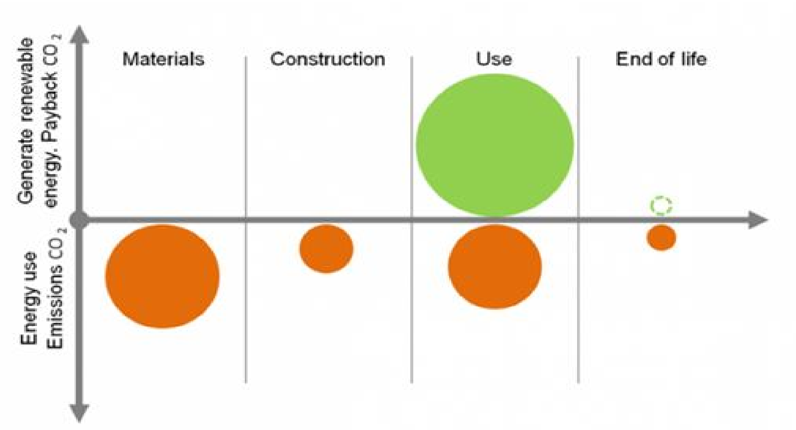


Fig. 1 – The building's life phases included in the various Zero Energy Buildings definition levels (source: https://zeb.no/index.php/en/about-zeb/zeb-definitions).

Active House is another concept aimed at buildings that provides healthy and comfortable living conditions to their occupants, without having a negative impact on the environment. In fact it is a holistic approach, the Active House being evaluated on the basis of three main performance domains: indoor climate conditions, energy consumption and the environmental impact.

Smart buildings contain an array of sensors and an integrated, optimized control system that could dynamically adjust lighting and HVAC flows based on actual, real-time presence rather than scheduled occupancy; by combining sensor networks, active ventilation, adjustable lighting, and adjustable windows and doors into integrated and optimized compound systems, much higher quality living and working environments are possible, with 50% greater energy efficiency than current systems offer.

All these concepts represent an optimization of one or more sustainable construction principles: siting and structure design efficiency, energy - water - materials efficient use, indoor environmental quality enhancement, operation and maintenance optimization, and waste and toxics reduction.

3. Life Cycle Analysis of Buildings

Life cycle analysis (LCA) is a method used to assess the environmental impacts associated with the production, use, and disposal or recycling of products, by quantifying the efficiency of the resource use, and the full range of environmental effects (Dumitrescu *et al.*, 2014). The considered impacts include (among others) embodied energy, global warming potential (GWP), resource use, air pollution, water pollution, and waste. LCA is recognised as the best way to evaluate the environmental impact of buildings and is used in order to identify the most efficient solutions adopted for a building over the lifetime, from cradle to grave (Fig. 2).

Two key elements to address when working towards a more sustainable building sector are energy efficiency and diminishing GHG emissions in buildings, as buildings are responsible for more than 40% of global energy used and one third of global GHG emissions (UNEP, 2009).

The total life cycle energy consumption of a building is made up of two components:

– operational Energy (the energy requirement of the building during its life from commissioning to demolition, including the energy used to heat and cool the building, run appliances, heat water and light rooms).

– embodied Energy (the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. Embodied energy can be divided into three parts: initial embodied, recurring embodied and demolition. Sometimes, the initial embodied energy also includes energy used in construction stage, but often this term is used only for the manufacturing phase, finishing at the factory gate (see Fig. 2). The recurring embodied is the energy consumption related to material or component replacement during the building's use stage. The demolition embodied energy is associated with the disassembly and demolition of the building, also including waste treatment, transport and disposal processes. Embodied energy should be expressed as consumption of primary energy non-renewable resources.

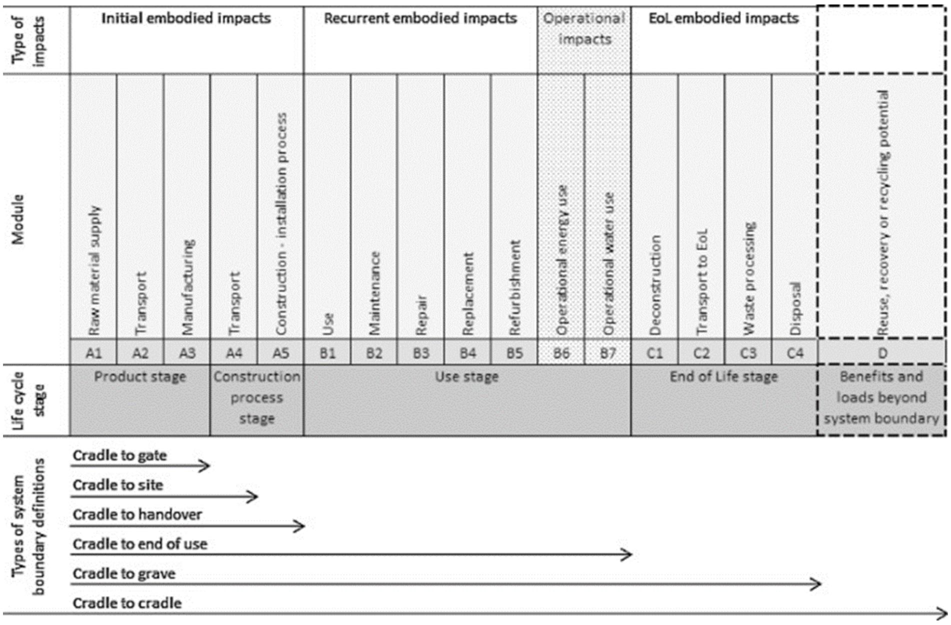


Fig. 2 − System boundaries definitions in relation to the life cycle stages of a building (source: Nygaard Rasmussen *et al.*, 2018).

Similar to energy, GHG lifecycle emissions resulting from buildings consist of two components: operational and embodied emissions. Because different greenhouse gases have different contributions to climate change, their effects are quantified relative to the GWP of 1 kg of CO_2, usually considering a 100-year timeframe. GHG calculation includes all GHG emissions, not only due to fossil fuel consumption, but also non-fossil fuel related GHG emissions (from chemical and physical processes during the life cycle of the building materials, *e.g.* CO_2 from the cement clinker process or leakage of fluorocarbon gasses from air condition appliances) (Lützkendorf *et al.*, 2016). Building materials of biological origin (*e.g.* timber) may sequester and temporarily store CO_2. Calculating how much CO_2 is locked up in a natural product is a controversial topic and there are no internationally accepted standards for this yet.

Until recently it was thought that the embodied energy content of a building was small compared to the energy used in operating the building over its life. Therefore, most effort was put into reducing operating energy by improving the energy efficiency of the building envelope. Research has shown that this is not always the case and the embodied energy can be the equivalent of many years of operational energy (Giordano *et al.*, 2015). Operational energy consumption depends on the occupants. Embodied energy is not occupant dependent — the energy is built into the materials. Embodied energy content is incurred once (apart from maintenance and renovation) whereas operational energy accumulates over time and can be influenced throughout the life of the building (Fig. 3).

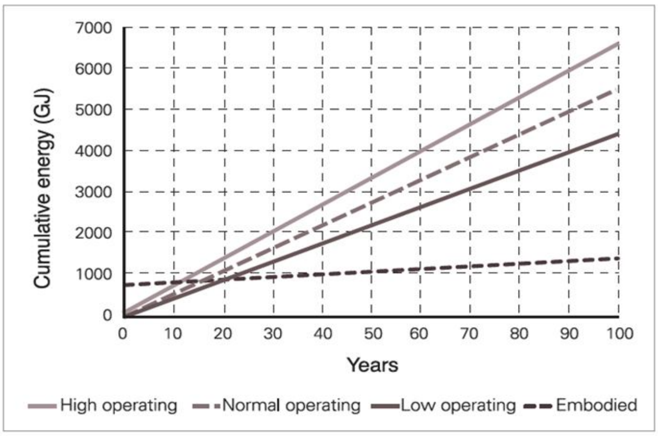


Fig. 3 − Cumulative comparison of operating energy and embodied energy (source: Adams, Connor and Ochsendorf, 2006).

Design, energy intensity of materials, transportation distances influence the embodied energy. Embodied impacts (embodied energy and embodied GHG emissions) should be considered starting with preliminary design stages, by the examination of alternatives at the building materials and components level (*e.g.* load-bearing structure, closing elements, windows etc.). Design professionals can use building-specific LCA tools like BEES (Building for Environmental and Economic Sustainability) or Athena Impact Estimator for Buildings. They can also use national LCI (life cycle inventory) databases or information from EDPs (environmental product declarations) for different building materials. The spatial boundary may range from a single building material or component to the entire neighbourhood, with eventual simplifications or omissions, especially in early design stage.

In the following case study, the embodied energy (EE) and embodied GHG emissions (EC) are evaluated for different solutions of partition walls and floors which are widely used in Romania. System boundary is of type "cradle-to -gate" and the feedstock energy is included in calculation. The functional unit is 1 square meter of building element. The EE is expressed as primary energy demand (MJ) from non-renewable resources and the EC as GWP-100 in kg $CO_{2\text{–equivalent}}$, including both fossil carbon emissions and process carbon emissions and taking into account the CO_2 absorption in the forest.

The analyses are based on the GaBi software databases, which are in line with the recommendations of the International Reference Life Cycle Data System (ILCD) Entry Level Conformity Rules of the European Commission's European Platform on Life Cycle Assessment (ILCD, 2010).

The results are presented in Table 1 for internal walls and Table 2 for intermediate floor slabs.

Table 1

Values of EE (MJ) and EC (kg $CO_{2\text{–equiv}}$) for 1 m^2 of Internal Wall in Different Constructive Solutions

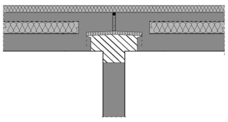
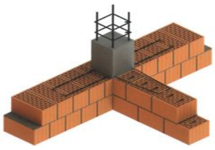
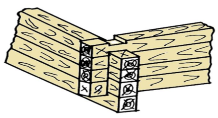
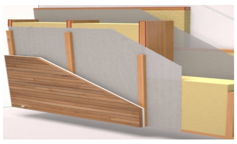
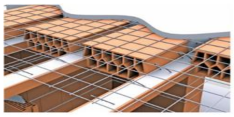
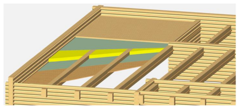
No.	Building element		EE (MJ)	EC (kg $CO_{2\text{–equiv}}$)
1	Reinforced concrete wall of 14 cm thickness		366	57.6
2	Brickwork masonry wall of 24 cm thickness		657	64.4
3	Solid wood wall of 15 cm thickness		462	–109
4	Timber frame wall of 14 cm thickness		340	–19.7

Table 2

Values of EE (MJ) and EC (kg $CO_{2–equiv}$) for 1 m^2 of Intermediate Floor Slab in Different Constructive Solutions

No.	Building element	EE (MJ)	EC (kg $CO_{2–equiv}$)
1	Reinforced concrete slab of 15 cm thickness 	445	69
2	Ceramic blocks slab of 23 cm thickness 	420	51.1
3	Wood elements slab of 24 cm thickness 	371	–35.2

The results suggest that replacing the traditional building solutions for load bearing structures based on reinforced concrete and masonry with solutions with timber elements or other natural materials could drastically reduce the embodied emissions. Accounting for carbon storage in wood products leads to “neutralising” the GHG emissions from other building materials and products.

Also, the use of recycled and reused materials can contribute to the lowering the embodied energy of buildings, but only if the energy use for recycling is smaller than the energy consumed for the production of virgin materials. The longer the service life of a building material, the less recurring embodied energy/GHG emissions due to maintain, repair, refurbish or replace material. Other options to reduce embodied impacts could focus on light-weight construction, design for flexibility and adaptability, reuse of building structures, service life extension (Birgisdottir *et al.*, 2017).

According to the 2010/31/EU Directive, from 2021 all new buildings will have “nearly-zero energy” in operation and their contribution to resource depletion and climate change will significantly decrease (Baran *et al.*, 2016). This means that the embodied impacts can no longer be ignored as part of the overall performance and sustainability of buildings.

4. Conclusions

Traditionally, energy demand and GHG emissions from buildings’ operation are greater than the embodied ones. But, it is expected that the future buildings will consume less energy in use and this energy will come from renewable sources, so the importance of embodied energy will increase.

The current regulations to reduce the energy consumption and GHG emissions from buildings which include only the operational phase of buildings should be completed with measures and calculation methods to reduce the embodied impacts.

It is imperative to take measures to increase the resource efficiency and environmental performance of buildings because they have a long lifetime and their impact on the environment will last for many decades.

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REDUCEREA CONSUMULUI DE ENERGIE ŞI A EMISIILOR DE GES ÎN CONSTRUCȚII

(Rezumat)

Schimbările climatice reprezintă o problemă importantă, cu consecințe negative asupra tuturor aspectelor vieții. Fiecare sector economic, inclusiv cel al construcțiilor, trebuie să caute soluții pentru reducerea emisiilor de GES, creând premisele dezvoltării durabile. În ultimele decenii, au fost propuse câteva concepte de clădiri performante energetic, de la clădiri cu consum redus de energie, clădiri pasive, clădiri cu consum zero, până la clădiri autonome şi plus energie. Similar energiei, emisiile de gaze cu efect de seră generate de clădiri constau în două componente: emisii din exploatare şi înglobate. Energia şi emisiile de GES înglobate ar trebui luate în considerare începând cu etapele preliminare de proiectare, prin analiza alternativelor la nivelul materialelor şi componentelor de construcție. În studiul de caz, energia înglobată şi emisiile de GES înglobate sunt evaluate pentru diferite soluții de pereți despărțitori şi planşee, utilizate pe scară largă în România. Lucrarea prezintă câteva opțiuni pentru reducerea acestora.