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ANALYSIS OF THE ENVIRONMENTAL IMPACT OF DIFFERENT ENERGY EFFICIENCY BUILDINGS

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Abstract. Sustainable development has been slowly but surely penetrating many areas of society's activity and life for about three decades since 1992, when "Agenda 21" was prepared. Taking into account the concept of sustainable development of the World Commission on Environmental Development, it is obvious that the various activities of the construction sector must be analyzed and organized in the future according to the provisions of sustainable development. The development of urban areas can be carried out at various levels - from the whole city to an individual building or its components. Social and economic and environmental impacts and changes are analogously manifested in all spaces: global, national, regional, urban, district, adjacent environment, property, individual object and components and materials. The urbanized environment and its most important components - buildings, are complicated complex systems. They embody the culture of people formed over centuries. Buildings differ from other industrial products in terms of durability and the abundance of resources required for their creation and use.
Keywords: impact of buildings, life cycle, energy, materials, consumption, emissions, waste.

INTRODUCTION

One of the main energy consumers around the world is the construction sector. The national and international efforts are required to mitigate climate change. The largest potential to reduce greenhouse gases has been found in the construction sector, where residential buildings use about 27 percent of energy.

Sustainable construction means not only lower consumption of energy but also the application of sustainable development principles in the construction design and building processes, for example by using less primary materials, less energy for construction process, less pollution and less waste; this is the application of the "Life-Cycle" approach to design, construction and exploitation of buildings.

Construction sector is one of the main industries where changes in economic and social aspects and energy consumption are fastest. While achieving the goals of energy efficiency in buildings, not only requirements for construction of new buildings are getting stricter, but also a lot of attention is paid on the residential and public buildings renovation process. However, the greatest attention is paid only to the energy consumption during the operational stage of the buildings and does not take into account how much energy is consumed during the production of materials. It also underestimates how the waste will be managed after the buildings are demolished.

It is important to apply modern construction technologies at all stages of the life cycle of structures (extraction of raw materials, production of building materials, construction, operation, demolition, waste disposal), because all of them require energy consumption. As a result, construction and design, like other areas of human activity, must also be based on the principles of sustainable development. In this case, construction and design activities should aim at creating a safe and healthy living environment, rational use of resources and to pursue economic progress for the benefit of man and nature.

ASSESSMENT OF THE LIFE CYCLE

Life cycle assessment (LCA) is a way to assess the environmental impact of the product:

- at each stage of product's life cycle: from their origin, production (including raw materials) to the end of life and final processing ("from birth to death");
- evaluating all aspects related to environmental impact: CO_2 emission, energy and water consumption, air pollution, consumption of natural raw materials, waste generation.

There are quite a few articles examining the life cycle of buildings or their components from one point of view or another in the scientific literature. Most of the publications related to the life cycle of buildings are published in the USA. It is the leading country in the field, with the most publishers and articles, shaping global opinion and having the most influence in the field. Norwegian universities of science and technology are leaders in life-cycle research in Europe.

Five most relevant topics for building research throughout the life cycle are presented in Figure 1.

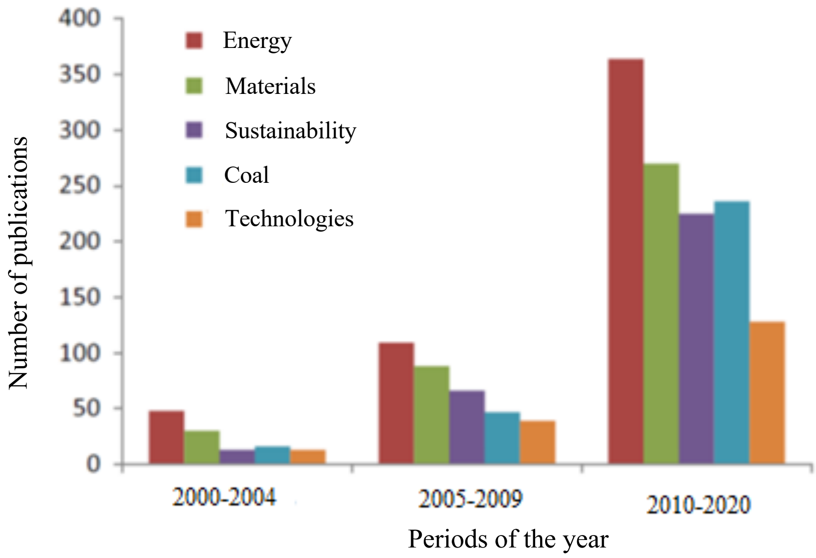

Figure 1. **The growth trend of the five most relevant areas of research in LCA**

Figure 1 illustrates the trends of these topics related to the life cycle of the building over the last 20 years. Energy consumption in buildings has become the fastest growing area of life cycle research in the last 15-20 years. Another topic where a lot of research is done in assessing the environmental impact of buildings throughout their life cycle would be the materials used in construction and carbon dioxide and the sustainability associated with it. The number of publications on these topics is not far behind that of energy. The life cycle of buildings is shown in Figure 2.

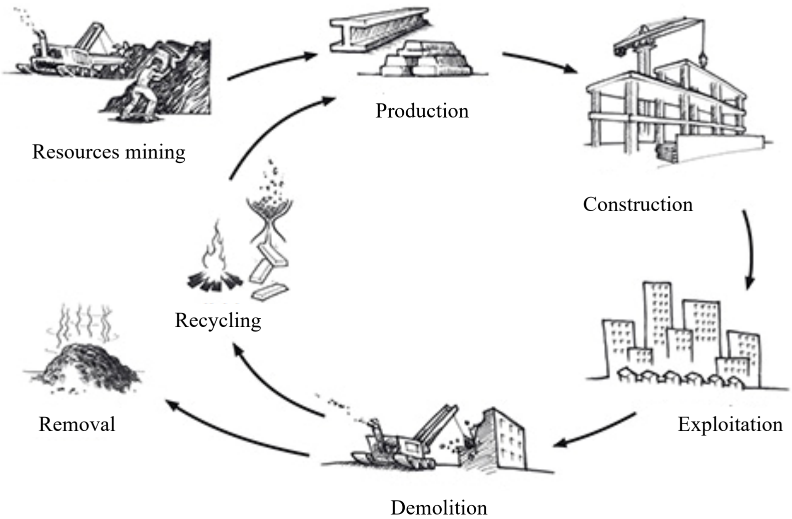

Figure 2. **The life cycle of the building**

Life cycle analysis is useful in that it helps to make decisions related to project alternatives when designing a building, select structural materials, determine which of the building's elements and in which phase of the building's life cycle have the greatest environmental impact.

The assessment is based on well-known and universally recognized international standards (ISO). A comprehensive assessment of the environmental impact covers each stage of the product's life cycle and all possible aspects of the environmental impact (Figure 3). Life cycle assessment provides an opportunity to improve our impact on the environment, create ecological innovations, i.e. innovative products that are environmentally friendly throughout their entire life cycle, from the development stage to the end of their life. The life cycle of any building consists of four stages, i.e. production of building materials, construction, building operation and demolition (Kofoworola O. F. et al. 2008). The stages of production and operation of building materials consume large amounts of energy, so these stages have the greatest impact on the environment (Fay R., 2000; Kofoworola O. F., 2008; Junnila S., 2004).

The efficiency of renovation of the building walls is usually evaluated only from an economic point of view. In addition to the economic evaluation, it would be appropriate to evaluate the fences in other aspects

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as well. By applying the life cycle assessment methodology, it is possible to choose the most efficient combination of renovation of the barriers, after evaluating the primary energy (PE) costs and CO_2 emission into the environment. All materials: thermal insulation, finishing and waterproofing materials, protective coatings and fastening elements emit emissions and use primary energy during their life cycle (production, exploitation and destruction).

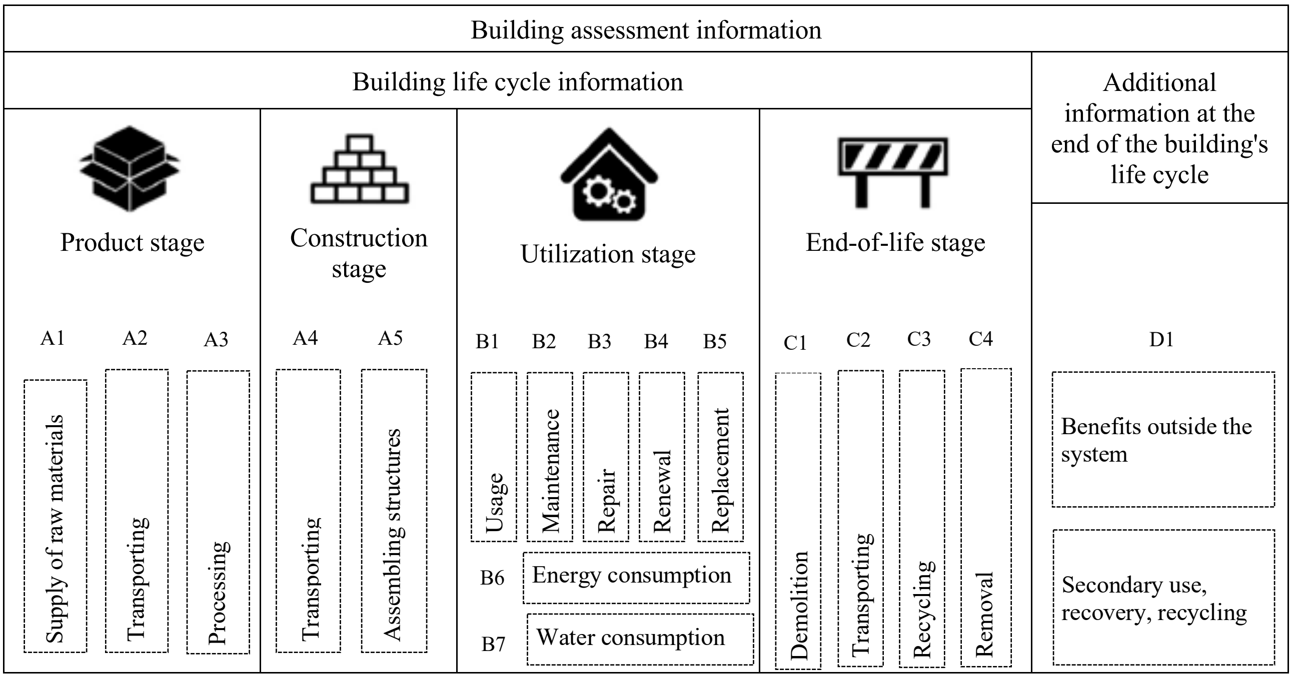

Figure 3. **Building life cycle stages and assessment**

One of the main indicators that determine the building's energy class is the heat transfer coefficient of the external walls, therefore, in order to achieve the aforementioned goals, its reduction (insulation of the walls) remains the main priority. In order to comprehensively examine the efficiency of fence renovation, one of the best ways is to apply the life cycle assessment method.

The advantage of life cycle assessment compared to other environmental impact assessment methods is the expansion of system boundaries to include environmental impacts during the product's life cycle, not limited to emissions and waste generated only within the company. Modeling is a key tool in performing LCA. The model is formed during inventory analysis by examining the phases of production, use and destruction of the research object.

IMPACT OF CONSTRUCTION MATERIALS AND ENERGY CONSUMPTION ON THE ENVIRONMENT

The life cycle of any building consists of four stages, i.e. production of building materials, construction, building exploitation and demolition (Kofoworola O. F. et al. 2008). The stages of production and operation of building materials consume large amounts of energy, therefore these stages have the greatest impact on the environment (Fay R., 2000; Kofoworola O. F., 2008; Junnila S., 2004). Energy is necessary throughout the entire life cycle of a building, not only in the operational stage, but also in the production of building materials, during their transportation, construction processes, maintenance of buildings, and later during the demolition process (Blengin, G. A.; Di Carlo, T. 2010). Energy plays a vital role in building operations, while at the same time having the greatest impact on the environment due to its associated emissions, which are responsible for major environmental impacts worldwide (Kofoworola O.F. et al., 2008).

The State Performance Analysis (SPA) method is very often used to assess the environmental impact of the energy used in buildings. The most widely used terms are "renewable energy", "operating energy", "embodied energy", "energy consumption", "energy efficiency" and "energy conservation". Usually, the long life span of a building is always associated with a large amount of energy used in buildings. This includes energy used for building cooling, heating, lighting, ventilation and equipment operation and plumbing (Zhao Z. Y. et al., 2014). After examining the energy consumption figures for these listed building-specific systems, the environmental aspects of the building during the operational phase become important. From the SPA point of view, it is possible to define and provide more practical suggestions regarding the listed aspects, which, if implemented, can maximize energy savings (Kylili A. et al., 2017).

The energy related to the construction product includes not only the production processes, but also the construction processes (Li J.F., 2011). There are a number of articles dealing with the embodied energy of a building, and it is becoming an important research topic. Embodied energy is difficult to measure. However, it is very important to achieve a balance between the energy embodied in the building and the energy used throughout the life cycle of the building (Zuo J. et al., 2012).

Building materials are closely related to embodied energy, i.e. all the energy used to produce the materials and products used in the building or structure. Such materials are mainly used in buildings made of prefabricated reinforced concrete structures. In order to save energy, it is very important to use not only new materials for construction, but also recycled ones.

When assessing the impact of construction materials on the environment throughout their entire life cycle, concrete, wood, steel, and cement are mainly tested.

Evaluationof the environmental impact of construction and buildings goes beyond the simple assessment of individual products and materials (Risholtn, B. et al., 2013). Studies attempt to evaluate buildings, building systems and construction processes. These studies often identify the stages of the life cycle that have the greatest impact. Direct impacts include all consumption-related impacts of energy use, while indirect impacts include other impacts of material extraction, manufacturing, construction, demolition, etc. pre- and post-construction process. Research results show that the direct impact on the environment can be significantly reduced by increasing the thickness of thermal insulation and using renewable energy sources.

The biggest influence on the environmental efficiency of the building has its construction, especially the walls, floor and roof. All engineering systems combined require only 15% of total embodied energy. One of the main reasons why building structures require so much energy and emit the most global warming emissions is the large amount of thermal insulation material required to insulate the structures. Research supports the claims of some scientists that it takes several times more energy to create a low-energy building than a standard building. Therefore, in order to reduce the environmental impact, it is necessary to pay more attention to the selection of structural materials of the building. Although life cycle analysis has been practically dispensed with so far, in the future it may become widely used in assessing the efficiency of buildings (not only energy). For example, building certification systems such as the world-renowned LEED (USA), BREEAM (UK), DGNB (Germany), ASHRAE/USGBC/IESDNA Standard 189 (USA) are starting to use or already use this assessment method. It is believed that it will soon become mandatory for use throughout the European Union).

The following types of houses were selected for the study: A class thatched house; A class log house; A class of ceramic blocks; A+ class of ceramic blocks; A++ class of ceramic blocks.

For the construction of the investigated buildings, different materials of supporting structures are used, the same energy efficiency class of the house (straw A, log A and ceramic A houses). The boundaries of the system are evaluated: from the extraction of raw materials to the exploitation phase (inclusive). The impact on the environment is assessed in the global warming potential category, which is measured in kg CO_2 eq. (IPCC 2013 GWP 100 (Methodology approved by the Intergovernmental Panel on Climate Change).

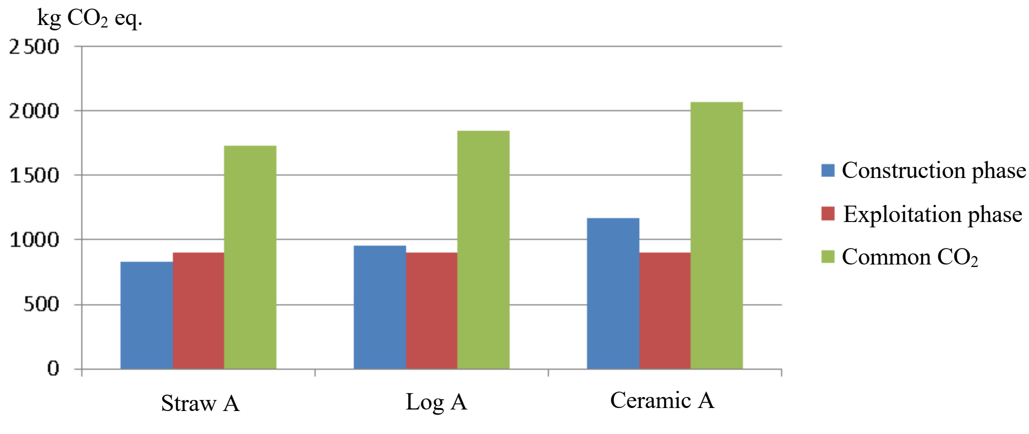

Figure 4. **Environmental impact of houses of different materials in the climate warming category during the construction and exploitation phase**

Evaluated in kg CO_2 eq. in the phases of construction (extraction of raw materials, production of materials, construction) and exploitation (house operation). A large amount of materials is used for the construction of buildings. Part of the materials are the same and the quantities used are the same, i.e. foundation, roof, decoration. The materials of the partitions and their quantities are different. Since the assessed houses are of the same energy efficiency class (A), their amount of energy consumed during operation does not differ, and at the same time, the impact on the environment does not differ (Figure 4).

The energy efficiency class differs, when the same materials of the supporting structures are used (ceramic A, ceramic A + and ceramic A ++ houses) (Fig. 5).

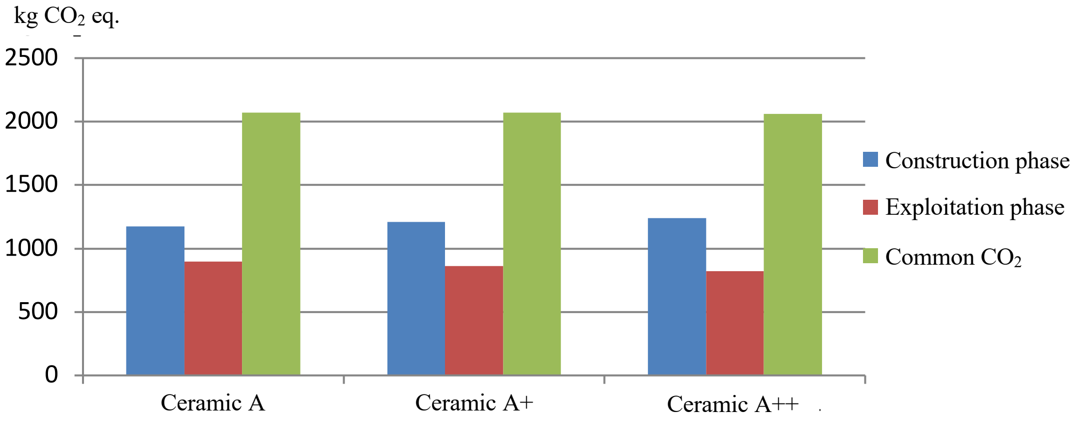

Figure 5. **The environmental impact of houses with the same materials and different energy efficiency in the climate warming category during the construction and exploitation phase**

The environmental impact of the materials of straw house A is about 831 kg CO_2 eq. The biggest impact is the general structure 501 kg CO_2 eq., the materials used for the floor 283 kg CO_2 eq., the ceiling - 18.3 kg CO_2 eq., the walls - 29.1 kg CO_2 eq. The environmental impact of log house A materials is 953 kg CO_2 eq. The impact of the materials used for the floor does not change, only the environmental impact of the installation of the overlay increased almost 10 times (constitutes 106 kg CO_2 eq.), the impact of the materials used for the installation of the walls - 64.7 kg CO_2 eq., the impact of the structures is the same. The environmental impact of the materials of ceramic house A is 1173 kg CO_2 eq. The impact of materials used for floors, structures and coverings does not change, the impact of materials used for wall installation increases by 5 times (286 kg CO_2 eq.).

CONCLUSIONS

1. Minimization of energy consumption in buildings and choosing suitable building materials, structural and design solutions are one of the main elements of sustainable construction. After the analysis of scientific literature, statistical data, and the juridical base, it can be seen that currently the greatest attention is paid to energy consumption in the operational stage of buildings, less attention is paid to how much energy and materials are consumed during the production of construction materials, and how waste will be handled after the demolition of buildings is also not evaluated. Various EU regulations are already applied for energy consumption in the stage of building exploitation (heating and lighting). The amount of energy consumed in the production of construction products and in the construction process also accounts for a large part of a building's environmental impact. According to research data, 5-10 percent of all EU energy consumption is related to the production of construction products. The balance is achieved by assessing and minimizing the impact of the building throughout its life cycle while ensuring the necessary satisfaction and comfort of people.

2. When comparing houses with different energy efficiency, it was found that the most energy efficient building (class A++) has an environmental impact of 2060 kg CO_2 eq. - slightly lower than A and A+ (2070 kg CO_2 eq.). The use of energy in the operational phase accounts for 43-46 percent. GHG emissions. Analyzing the impact of home energy use, it was found that as the energy efficiency class increases, energy consumption decreases very slightly. When comparing the impact of houses with different energy efficiency in other categories of environmental impact, it was found that the impact of a ceramic A++ house is the highest and varies within quite wide limits from 10 to 80% depending on the category. Evaluating impacts in damage categories, damage to human health and ecosystems increases from 7 percent. up to 20 percent, as the energy efficiency class of the house increases. However, the damage to resources remains very similar regardless of the energy efficiency class.

3. After calculating the cost of the investigated buildings in the entire life cycle, it was established that the majority of the costs are the construction cost. The cost of energy is about 20 percent. Of all price of the life cycle. The lowest price in the entire life cycle is that of a straw A house, the highest price during construction and operation is that of a ceramic A++ house.

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