Analysis of a single-family building life cycle – case study

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Abstract. Increasing the ecological awareness of society has contributed to the fact that the natural environment is no longer perceived only as a resource, but above all as a system necessary for protection and preservation for the future generations. Particular branches of industry, as well as consumption, cause multidimensional environmental damage. One of the industries that raise the standard of living, but also plays a significant role in environmental degradation is the construction industry. It is, therefore, necessary to strive to mitigate the effects of erecting building objects. The article made an environmental assessment of the life cycle of a building using the One Click LCA software, which was officially approved by BRE to categorize objects according to the Mat 01 procedure. The evaluation covered the production of construction materials, transport, construction process, use of a residential building, maintenance, repairs and replacements, operating energy and water consumption, total energy consumption and demolition phase.

1. Introduction

With the emergence of increasing global problems related to the demand for energy and global warming, the construction industry has become the main area of interest from the perspective of sustainable development. In Europe, the construction sector is responsible for nearly half of the carbon dioxide emission to the atmosphere and the consumption of about 40% of raw materials extracted from the lithosphere [1,2].

The life-cycle assessment method has been widely adopted as a tool for environmental impact assessment also for the construction, operation and demolition of buildings and is increasingly used [3]. LCA requires relevant information, especially to assess the real effects of using specific building materials. It is, therefore, the most commonly used ex-post method, i.e. once the object has been built and all the information needed to carry out the analysis is available. This means that the LCA method is limited to the description in retrospect, but it does not provide any significant guidelines on how to effectively improve the building which is already in the design phase [4].

Uncertainty regarding the effective lifetime of elements and the difficulty of having a complete list of components in the early design phases limit the use of LCA to the late stages, in which the implementation of changes is almost impossible without incurring significant additional costs [5]. However, the growing interest in the use of LCA in construction industry encourages the integration of this method at the early stages of building design. In such a situation, the obtained results could result...
in quick and easy design decisions, at low additional costs and with the possibility to monitor their impact [4,6].

The LCA analysis, as a strategy to reduce the environmental impact and energy consumption in the construction sector, has been subjected to consideration in several review articles [7,8]. Different, more or less comprehensive, LCA surveys were carried out for entire buildings or parts of buildings, to find elements that significantly shape the environmental profile of buildings and determine the possibilities of their improvement; Scheuer et al. [9] for example, they analyzed the life cycle of the new university building, Lalive d'Epinay developed the "Eco Check" method and applied it in an office building.

Similarly, Häfliger et al. [10] used the LCA analysis in the article on the environmental sensitivity of buildings, the results of which have been limited to one category of impact, namely the potential for creating a global warming effect (GWP - Global Warming Potential). The study was conducted for four newly built multi-family houses in Switzerland. The importance of the Reference Study Period (RSP), which in this case was 120 years and directly determines the results of the study, was emphasized.

The aim of the work is to evaluate the construction object in its full cycle of existence, “from the cradle to the grave”.

2. Material and methods
The building is located on a plot of land with an area of 0.1629 ha in the municipality Lipnica Wielka (Poland). Oriented with the front elevation in the north-west direction, it is a detached one-story building, partly with a basement, with a usable attic. Located in the V snow zone (characteristic snow load of soil Q = 2.0 kPa), in the 3rd zone (mountain area in the south) and in the zone with a conventional ground frosting depth of 1.2 m. The building refers to the surrounding architecture and is consistent with a local spatial development plan for the municipality of Lipnica Wielka. The shape of the building has a rectangular projection with dimensions of 15.00 x 12.70 m. It is covered with a multi-hipped roof made of ceramic tiles.

The object was made of brick and reinforced concrete structure, the walls were made of foam hollow blocks 24 cm thick, insulated with 15 cm thick polystyrene with white acrylic plaster, from the inside walls were covered with plaster, gypsum plaster and painted. Window and door woodwork were solved in a typical manner (PVC windows), panel doors. General technical data of the building - building area 153.5 m², total area 328.4 m², usable area of 259.4 m², cubic volume: 997.75 m³. In order to carry out the LCA assessment of the building, a combination of materials and products used in its construction was made. The quantities of materials were estimated based on the architectural and construction design and are summarized in Table 1.

The One Click LCA software was used to conduct the LCA lifecycle assessment. This software has been developed by the Bionova Ltd organization and is compliant with the EN 15978 standard. It is a standardized platform for conducting Life Cycle Costing (LCC) analysis and LCA assessment with the ability to estimate costs and reduce environmental impact. The tool that was used allows calculating the impact of the life cycle using data obtained from the technical documentation of the facility, from the stages of production and construction, through the use stage to the "grave" or the end of life of the building. In its database, One Click LCA uses EPD (European Product Declaration), environmental declarations based on ISO 14044 and EN 15804 standards. EPD is an externally verified, detailed and standardized description of the environmental profile of each product. It contains clear information on the environmental impact of the product throughout its useful life. In addition,
within the software, it is possible to change and select building materials and to simulate ways to reduce carbon dioxide emissions.

Table 1. List of materials and construction products according to the construction design

| L.p. | Material / construction                        | Quantity / Unit |
|------|-----------------------------------------------|-----------------|
| 1.   | Plain concrete B15                           | 4.96 m³         |
| 2.   | Plain concrete B20                           | 80.31 m³        |
| 3.   | Concrete blocks 60x20x24                     | 65.21 m³        |
| 4.   | Hollow brick 25x12x6.5 cm                    | 11.39 m³        |
| 5.   | Ceramic tile- 3.4 cm thick                   | 421.98 m²       |
| 6.   | Spruce wood                                  | 11.23 m³        |
| 7.   | PVC interior doors                           | 32.55 m²        |
| 8.   | PVC exterior doors                           | 13.22 m²        |
| 9.   | Concrete rubble or key aggregate             | 55.25 m³        |
| 10.  | Paving stones- 8 cm thick                    | 71.26 m²        |
| 11.  | PVC windows                                  | 36.35 m²        |
| 12.  | Parquet -3 cm thick                          | 175.4 m²        |
| 13.  | Sand                                         | 19.25 m³        |
| 14.  | Ceramic tile - 3 cm thick                    | 80.00 m²        |
| 15.  | “Gres” tiles with dimensions 30.0x30.0x1.0 cm | 64.25 m²        |
| 16.  | Aerated concrete blocks                      | 156.29 m³       |
| 17.  | Styrofoam - 5 cm thick                       | 198.40 m²       |
| 18.  | Styrofoam -10 cm thick                       | 392.95 m²       |
| 19.  | Styrofoam - 15 cm thick                      | 473.97 m²       |
| 20.  | Mineral wool -15 cm thick                    | 211.59 m²       |
| 21.  | Cement screed -5 cm thick                    | 319.65 m²       |

3. Results and discussions
The use phase is definitely dominant in the distribution and it accounts for 85%, while the production phase is 14%. The construction phase and the decommissioning phase have a lower impact factor amounting to 1% and less than 1% respectively (Figure 1). The total impact of all stages of the building’s life burden the environment with a load of approximately 1,260 tons of CO$_2$eq for the 99-year test period, which corresponds to 39 kg of CO$_2$eq per m$^2$ • year$^{-1}$.

The building production phase (product phase) includes three modules (A1-A3) in accordance with EN standards. All of these modules include the supply of necessary materials, products and energy, as well as waste treatment until the final residues are removed at the product stage.

The construction stage (building erection phase) includes modules A4-A5 and emits about 13 t CO$_2$eq or 1% of all impacts. The module (A4) is based on the transport distance from the material manufacturer to the building site and is included in the used software by default. The total emission from the material transportation stage is 3 t CO$_2$eq. The distance of transportation from a specific
manufacturer to the construction site, with an estimated CO$_2$eq emission, is added by the software for all building materials. Concrete materials have the biggest impact, it is at the level of 1.6 t CO$_2$eq, which corresponds to 49% of the total emission in the A4 module. The next module (A5) includes the production and transportation of auxiliary materials and energy needed for installations or activities carried out on the construction site.

![Figure 1. The impact of individual stages of the building's life cycle on global warming](image)

The next phase of the cycle, which is the use of the building includes: (B1) - use of the installed product, (B2) - maintenance, (B3) - repair, (B4) - replacement, (B5) - renewal / renovation and (B6) – energy consumption. The use phase emits CO$_2$eq at the level of approximately 1064 tons, which constitutes the largest share (85%), at the same time it should be remembered that this is the stage that is characterized by the longest time interval. In the software, modules (B1-B5) are considered together and provided that the impacts are calculated based on the lifetime of the building materials and the lifetime of the building. They emit about 15 t CO$_2$eq or constitute a 1.2% share. The module (B6) includes the operational energy consumption during the use phase of the building. The calculations are based on the total annual electricity consumption and the period of building use equal to 99 years. The total purchased energy emits around 1050 t CO$_2$eq or about 83% of the total global warming potential.

The main reason distinguishing exploitation phase is the high primary energy factor for electricity. The decommissioning phase (end-of-life cycle phase) consists of the following modules: (C1) - demolition, (C2) - transportation for waste treatment, (C3) - waste treatment for reuse, recovery and recycling, and (C4) - disposal. The total environmental impact for this phase is the lowest of all and amounts to 3.5 t CO$_2$eq or 0.3% of the total emission. All modules of this stage are assessed as one, which includes the supply and transportation of necessary materials, as well as products and related energy and water consumption.

4. Conclusions

Analysis of the life cycle of a single-family house, which Petrovic and others carried out [11], clearly indicates that the type of materials used directly affects the emission of greenhouse gases to the atmosphere. The cited case concerned a house, located in Sweden, in the construction of which mainly ecological materials were used and the use of concrete was limited. The results of such proceedings have been found in the results in which the values of carbon dioxide released into the atmosphere were as follows: the environmental impact during the adopted test period of 100 years amounts to about 102
tons of CO$_2$eq, and the annual load is equal to 6 kg CO$_2$eq per m$^2$ • year$^{-1}$. In this case, the materials with the highest quotations regarding greenhouse gas emissions were concrete, wood, gypsum, and elements such as roof, doors and windows. The production of these materials had the biggest negative environmental impact.

Emission values in the building phase of the analyzed object are higher in relation to the values presented in the literature for other buildings [11]; however, the share of this phase in the total CO$_2$eq emission, amounting to 1%, is insignificant. Comparing this result with the result obtained in the product phase assessment, it can be concluded that the burden on the environment during the raw material extraction processes, their transportation and processing into specific materials is clearly dominant.

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References
[1] P. Capros, N. Kouvaritakis, and L. Mantzos, “Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change - Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU,” Ecofys, AEA and NTUA, Report for European Commission, DG Environment, Brussels, 2001.
[2] M. Levine, D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A.M.M.S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino, P. Bertoldi, B. Boardman, M. Brown, S. Joosen, P. Haves, J. Harris, and M. Moezzi, “IPCC fourth assessment report: residential and commercial buildings”, IPCC, pp. 387-446, 2007.
[3] S. Valdivia, C. M. Ugaya, J. Hildenbrand, M. Traverso, B. Mazijn, and G. Sonnemann, “A UNEP/SETAC approach towards a life cycle sustainability assessment—our contribution to Rio+20,” The International Journal of Life Cycle Assessment, vol. 18, pp. 1673-1685, 2013.
[4] C. K. Anand, and B. Amor, “Recent developments, future challenges and new research directions in LCA of buildings: A critical review,” Renewable and sustainable energy reviews, vol. 67, pp. 408-416, 2017.
[5] E. Hoxha, G. Habert, J. Chevalier, M. Bazzana, and R. Le Roy, “Method to analyse the contribution of material's sensitivity in buildings' environmental impact,” Journal of cleaner production, vol. 66, pp. 54-64, 2014.
[6] B. Soust-Verdaguer, C. Llatas, and A. Garcia-Martinez, “Critical review of bim-based LCA method to buildings,” Energy and Buildings, vol. 136, pp. 110-120, 2017.
[7] M. Buyle, J. Braet, and A. Audenaert, “Life cycle assessment in the construction sector: A review,” Renewable and sustainable energy reviews, vol. 26, pp. 379-388, 2013.
[8] O. Ortiz, F. Castells, and G. Sonnemann, “Sustainability in the construction industry: A review of recent developments based on LCA,” Construction and building materials, vol. 23, pp. 28-39, 2009.
[9] C. Scheuer, G. A. Keoleian, and P. Reppe, “Life cycle energy and environmental performance of a new university building: modeling challenges and design implications,” Energy and buildings, vol. 35, pp. 1049-1064, 2003.
[10] I. F. Häfliger, V. John, A. Passer, S. Lasvaux, E. Hoxha, M. R. M. Saade, and G. Habert, “Buildings environmental impacts' sensitivity related to LCA modelling choices of construction materials,” Journal of cleaner production, vol. 156, pp. 805-816, 2017.
[11] B. Petrovic, J. A. Myhren, X. Zhang, M. Wallhagen, and O. Eriksson, “Life cycle assessment of a wooden single-family house in Sweden,” Applied Energy, vol. 251, pp. 113-253, 2019.