Budownictwo i Architektura 21(4) 2022, 5-12
DOI: 10.35784/bud-arch.3294

Received: 14.11.2022; Revised: 23.11.2022;
Accepted: 05.12.2022; Available online: 14.12.2022

Orginal Article

Analysis of environmental consequences occurring in the life cycle of a retail facility

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Abstract: The increasing importance of environmental protection issues has recently forced a low–emission approach to investment processes. To accomplish the European Union's climate, energy and environmental goals, action is needed to achieve high levels of energy efficiency and low environmental damage. Among the energy–intensive sectors, construction deserves a distinction due to its leading share in gross energy consumption in developed countries. Therefore, it is necessary, and at the same time more and more popular, to analyse the environmental loads generated in individual phases and throughout the life cycle of building objects. This subject is also gaining importance in the context of the recent increases in the prices of energy carriers, which forces the search for new construction and exploitation solutions in line with the philosophy of sustainable development and the circular economy. The aim of the analysis was to assess the environmental consequences in the life cycle of a real commercial building located in Janikowo (Kuyavian–Pomeranian Voivodeship), which was carried out using the LCA (Life Cycle Assessment) methodology. The obtained results indicated the dominance of the facility exploitation phase in the level of cumulative environmental loads.

Keywords: retail facility, sustainable development, Life Cycle Assessment (LCA), Ecological Footprint

1. Introduction

As part of each type of economic activity, natural resources are used to obtain products or end objects [1], [2]. Manufacturing processes are sources of many different substances and wastes, which constitute burdens causing significant changes to the environment in a specific time perspective [3]–[5].

Nowadays, most countries and international organizations are intensifying activities aimed at mitigating the negative effects of this type of influence on the environment [2], [4], [6]. Indispensable for this are therefore appropriate assessment tools that allow taking into account emerging environmental problems [7]–[9]. The basic tool used for this type of assessment is the environmental analysis covering the full life cycle, i.e. LCA (Life Cycle Assessment) [10]. After the introduction of standards from the ISO 14000 family, the LCA methodology became more and more known in the world [11]–[13]. It is an evaluation tool ensuring obtaining comparable results of analyses while considering many different environmental problems [14]–[16].

From the environmental point of view, it is important to develop and implement new, effective technologies and products with good performance parameters, limiting the demand for non–renewable energy and primary raw materials. These technologies should promote the use of energy obtained from renewable sources as well as facilitate the use of recycled raw materials. The use of recyclable materials should, in addition to environmental benefits, also reduce the investment or operating costs of the building [17]. These trends correspond to the requirements of sustainable construction.

The previous LCA studies showed that the greatest environmental burden may be related to the exploitation phase of an analysed building (78% percent of all revenues, apart from generating solid waste) [18]. According to the authors, significant savings in the field of running water supply and sewage disposal (about 6%) can be achieved by reusing grey sewage and rainwater. Moreover, it was shown that the environmental costs related to the demolition and transportation of materials were only 0.3%, excluding material recycling. The GWP (Global Warming Potential) index was also estimated, where 84% of the index was related to the exploitation phase of the building. A comparable analysis conducted for a public utility building in Michigan, assuming a 75–year exploitation phase of the building, showed the percentage share of environmental impacts in this phase at 83% [19]. A similar analysis was carried out basing on the analysis of a public utility building with a concrete structure in [20]. The study showed that the environmental impact during the useful life cycle of the building reaches the highest value among all phases, due to the natural resources consumed and pollutants emitted, and the duration of this phase. The share of environmental impacts due to the exploitation phase was about 97%. Similar results were obtained in [21] for the assessment of environmental burdens with the IMPACT 2002+ method.

The subject of the assessment of environmental inputs in relation to construction objects using the LCA methodology has already been conducted to a limited extent [22]–[25]. However, there are still no effective solutions to reduce environmental outlays in commercial facilities [26]–[28]. Considering the existing legal conditions in the field of reducing energy consumption and environmental impacts, the aim of the work was a detailed analysis of the assessment of energy and environmental expenditure in the life cycle of a selected commercial building. The procedure was carried out using the LCA methodology [29] and the Ecological Footprint method [16], taking into account three basic phases in the life cycle of a commercial building [30], [31]: production, exploitation and post–use management in the form of landfill and recycling.

2. Materials and Methods

Life Cycle Assessment was used in this study to deeply analyse the impact of particular life stages on environmental burdens connected with commercial building, using the Ecological Footprint method. The research object is a commercial building located in Janikowo in central Poland , being in operation for already several years. The lifetime of the facility assumed by the operator is 40 years, after which the operator decides to demolish it, and build a new facility which meets the current requirements and expectations. The total area of the building is approximately 1000 m^2. The associated infrastructure (parking lots, access roads and sidewalks), the environmental impact of which has also been considered, has an area of approximately 2500m^2. The average annual consumption of energy and energy carriers related to the exploitation phase is as follows: natural gas about 11000 m^3 and electricity about 213 MWh. The first stage of the environmental analysis covering the full life cycle is in accordance with the ISO 14000 standards family, the definition of the system boundary, and next the identification of in– and output streams (Fig. 1). As input streams, the following were identified; energy resources, non–energy resources, water and land. While as output streams; pollution of the atmosphere, solid waste, pollution of water and soil and land degradation [32]. The Ecological Footprint method is based on the quantitative indicator of human impact on the environment. It illustrates the size of the biologically productive area (both lands, seas and oceans) necessary for the production of resources and products consumed by its user or users. The calculations also consider the area of land necessary to store the generated wastes and absorb the emitted pollutants. The Ecological Footprint (EF) is calculated for a specific period of time (usually one year) and for a specific population (on a global, regional or a single person scale). Since all impact categories are expressed in the same unit, a weighting factor of 1 is used for each of them [33].

The Ecological Footprint method can be successfully used in the environmental assessment of buildings in terms of energy and environmental optimization, which seems to be of a great importance for the performed study. The Ecological Footprint analysis of an academic building in India [34] revealed, that the replacement of energy from conventional sources with energy from PV panels would reduce the environmental burden by about 60%.

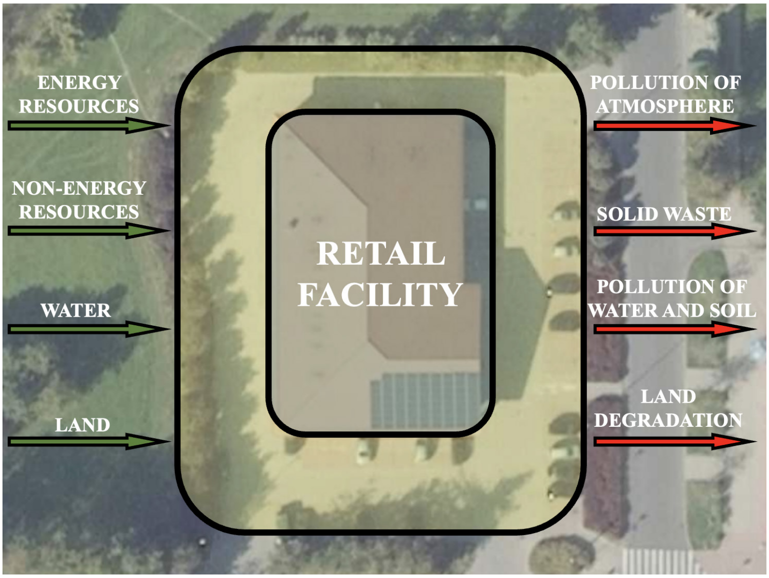

Fig. 1. Retail facility building as a subsystem in the eco–industrial facility system based on [10]

The cumulative environmental load over time is the sum of the loads from unit processes occurring at individual stages of the life cycle (Eq. 1) and is determined basing on the characteristics and exploitation plan of the building.

Knowledge about the amount of building materials and energy used, etc. allows to determine the total level of the cumulative environmental load over the life cycle of a commercial building (L_{RF}), which is the sum of:

$$L_{RF} = Lc_{RF} + Le_{RF} + Lpc_{RF} \tag{1}$$

where:

Lc_{RF} – cumulative environmental load in the production phase (incl. production of plastics, materials, elements and the construction of building objects);

Le_{RF} – cumulative environmental load in the exploitation phase, considering the consumption of energy and matter during exploitation and periodic repairs;

Lpc_{RF} – cumulative environmental load in the post–consumer phase, for example, landfilling or recycling [10].

3. Results

The results of the conducted environmental analysis are presented with division into three sections, comparing the impact of post–consumer management in the form of landfill or recycling and presenting the results for individual life cycle stages (production, exploitation, landfill, recycling).

To obtain comparable results expressed in environmental points (Pt), the results were grouped and weighted in accordance with the Ecological Footprint procedure, and subsequently summed up. This made it possible to compare with each other the individual stages of the research object's life cycle. The largest number of negative environmental consequences in the life cycle of the analysed commercial building, both in the case of post–use management in the form of landfill and in the form of recycling, is related to the emission of carbon dioxide to the atmosphere ($2.43 \cdot 10^7$ and $2.41 \cdot 10^7$ Pt, respectively). The total level of impacts is higher in the case of post–use management in the form of landfilling ($2.50 \cdot 10^7$ Pt) than the analogous cycle ended with recycling ($2.47 \cdot 10^7$Pt) (Table 1).

Table 1. Results of grouping and weighing of the environmental consequences occurring in the life cycle of the analysed commercial building, considering the form of post–use developments

	Life cycle with post-use management in the form of landfill	Life cycle with post-use management in the form of recycling
Carbon dioxide emissions	2.43×10^7	2.41×10^7
Radioactive substances	5.91×10^5	5.00×10^5
Processes related to land use	1.59×10^5	1.33×10^5
Total	$\mathbf{2.50 \times 10^7}$	$\mathbf{2.47 \times 10^7}$

The comparison of the successive phases of the life cycle of the analysed object shows the dominant share of the exploitation phase in the cumulative level of negative environmental consequences. This is due to the high demand for energy throughout the exploitation phase (electricity and gas), which is necessary for the proper use of the building. Electricity in Poland is generated primarily in conventional processes, and as a result, a large amount of carbon dioxide is released into the atmosphere. It is also the reason for small differences in the cumulative level of environmental impacts of the building with post–use management in the form of landfilling and in the form of recycling, because the operating costs for both cases are comparable (Table 2).

Table 2. Results of grouping and weighing of the environmental consequences occurring at stages of the analysed commercial building's life cycle

	Manufacture	Exploitation	Landfill	Recycling
Carbon dioxide emissions	5.04×10^{5}	2.36×10^{7}	2.00×10^{5}	-
Radioactive substances	3.85×10^{4}	4.62×10^{5}	9.10×10^{4}	-
Processes related to land use	4.60×10^{4}	8.66×10^{4}	2.67×10^{4}	-
Total	$\mathbf{5.89\times10^{5}}$	$\mathbf{2.41\times10^{7}}$	$\mathbf{3.18\times10^{5}}$	**-**

The use of the conventional energy sources is the dominant cause contributing to the climate change aggravation, which globally is one of the key aspects in environmental protection. Utilities consumption in the exploitation phase of the analysed building is characterized by the highest emission level of compounds causing global warming ($2.40\cdot10^{7}$ Pt) (Table 3).

Table 3. Results of grouping and weighing of the environmental consequences of the compounds emissions causing global warming, occurring at the stage of exploitation of the analysed commercial building

	Construction works	Sanitary installations	Electrical installations	Roads and parking lots	Utility consumption
Carbon dioxide emissions	4.87×10^{4}	6.24×10^{3}	6.72×10^{2}	2.98×10^{1}	2.35×10^{7}
Radioactive substances	8.97×10^{3}	1.31×10^{3}	5.85×10^{1}	5.72×10^{-1}	4.51×10^{5}
Processes related to land use	1.63×10^{3}	6.57×10^{2}	8.44×10^{1}	1.07×10^{-1}	8.42×10^{4}
Total	$\mathbf{5.93\times10^{4}}$	$\mathbf{8.20\times10^{3}}$	$\mathbf{8.15\times10^{2}}$	$\mathbf{3.05\times10^{1}}$	$\mathbf{2.40\times10^{7}}$

4. Summary and Conclusions

In recent years, there has been a noticeable increase in importance of the energy and environmental efficiency issues of buildings in Europe. Legislators are increasingly strictening the requirements for environmental protection, which could potentially constitute a serious developments limitation for business entities that will not follow the ideology of sustainable development. For the above reason, it has become rational in recent years to carry out energy and environmental analyses for buildings.

Considering the previously presented results of LCA, it has to be noted that the highest amount of environmental burdens, as well as greenhouse gas emissions has been recorded for the exploitation stage of the analysed building. This is due to the high level of conventional energy sources used for energy production at this stage of life cycle. These outcomes are similar to the previously performed LCA studies [17]–[19].

The results of the conducted analysis indicated the exploitation phase as the main cause of environmental burdens at the total level of 96%. The above-mentioned results are consistent with literature studies, which have been reviewed in chapter 2 of this paper, e.q. [19] and [21].

The life cycle of commercial buildings is characterized by a high level of utilities consumption, which is related to emissions of harmful substances. Additionally, the amount of energy accumulated in building materials is large and may range between 5.5–6.5 $GJ\times Mg^{-1}$.

Due to very energy–consuming production process, cement is the material that significantly increases the level of accumulated energy. The other essential material influencing the amount of energy consumption is the reinforcing and structural steel. Increasing the use of lightweight concretes and insulating materials makes it possible to significantly reduce the energy demand in the production phase. In addition, their use is also of key importance in reducing exploitation energy consumption.

Keeping in mind the analysis which has been carried out, and also the facts described above, it should be noted that the reuse of building materials after the end of their life cycle, to the extent that technical and economical possibilities, as well as the knowledge in the field of recycling currently allow, has a positive effect on the amount of environmental burdens. An aspect not covered by the classic LCA analysis is the lack of need to obtain raw materials for materials that can be recovered in the recycling process and reused. On the one hand, it is associated with a relatively large energy expenditure related to transport, possibly steel melting or crushing concrete, while the savings resulting from the lack of use of raw materials are significant. Such a procedure is in line with the idea of sustainable development.

There are various methods in the field of science and civil engineering aiming at reducing the environmental loads of buildings caused during the exploitation phase. The environmental burden can be influenced already at the building design stage by appropriate selection of the facility area and volume in reference to the needs. An important aspect is to design the building in a compact form to reduce its energy consumption. Efforts to reduce energy consumption from conventional sources are also important, e.g. by using renewable energy sources (photovoltaic panels, heat pump) and ensuring an appropriate operation plan and the high efficiency of heating and air-conditioning installations.

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