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Life Cycle Assessment (LCA) of a LEED certified building

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Abstract. Life cycle assessment (LCA) is a widely used tool to assess the environmental impact of buildings and building products. When results of building life-cycle assessment are in place, there appears an opportunity to make relevant changes in design and construction solutions to optimize energy performance of the building and minimize impacts on environment. LCA tool can be applied in various tasks, and is useful in case of buildings that take part in green building certification programs, such as, for example, LEED® (USA), BREEAM (UK), DGNB (Germany), CASBEE (Japan). The paper describes aspects of conducting LCA for the building obtaining LEED certificate. LEED (Leadership in Energy and Environmental Design) – is an internationally accepted and one of the most popular green building certification programs, that includes a set of rating systems for different types of buildings. LEED focuses on promoting the use of LCA tools and LCA-based decision-making, thus spurring market transformation and improving the quality of databases. There exists a wide range of programs to perform an LCA. For the purposes of the study, the One Click LCA software was used. The result of the study is a comparison of a created model baseline building and the proposed building with the analysis of applied measures of improvement.

1. Introduction

Although scientists may differ on the pace of climate change, and economists may argue about the optimal maximum mean temperature increase, they agree that climate change is happening now, the anthropogenic emissions are contributing to this climate change, and that humanity can dramatically mitigate the impact of climate change by reducing greenhouse gas emissions (Fig. 1). [1]

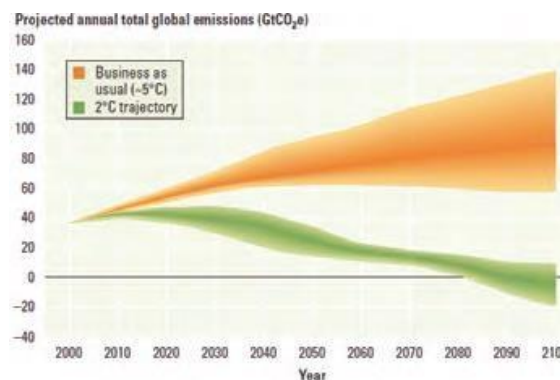


Figure 1. Total global emissions (GtCO₂e)

Buildings account for about 40% of worldwide energy use — which is much more than transportation, and one third of global greenhouse gas emissions. Energy is consumed during the following activities: manufacturing of building materials, transport of these materials from production plants to building sites; construction of the building; operation of the building; and demolition of the building (and recycling of its parts, if applicable).

A 2012 Life Cycle Assessment (LCA) study found that “Specifically within commercial buildings, the

use and operation phase of the material and building life cycle is so dominant that the impacts of construction, demolition/disposal, and transportation are nearly irrelevant for most traditionally constructed buildings.” By LCA tool it was revealed, that over 80% of greenhouse gas emissions take place during the operational phase of buildings, when energy is used for heating, ventilation, cooling, lighting, appliances, and other applications. From 10% to 20%, of the energy consumed is for materials manufacturing and transportation, construction, maintenance, renovation and demolition [2], [3].

Given the massive growth in new construction in economies in transition, and the inefficiencies of existing building stock worldwide, if nothing is done, the amount of greenhouse gas emissions from buildings will be increasing. This problem should be considered and relevant measures need to be taken to decrease negative impacts.

Building sector has the largest potential for significantly reducing greenhouse gas emissions compared to other major emitting sectors. Greenhouse gas reductions from buildings is common to both developed and developing countries, as well as countries with economies in transition. It means that with proven and commercially available technologies, the energy consumption in both new and existing buildings can be cut by an estimated 30 to 80 percent with potential net profit during the building life- span. [4]

Sustainability in construction is not widely spread in Russia, but there are a lot of opportunities for development in this field. There are several standards that represent general principles and requirements to assess sustainable development of construction facilities by ecological, social and economic parameters, considering technical and functional requirements to the project: GOST R 57274.1-2016 Sustainability of construction works. Part 1. General framework; GOST R 57274.2-2016 Sustainability of construction works. Part 2. Framework for the assessment of environmental performance; GOST R 57274.3-2016 Sustainability of construction works. Part 3. Framework for the assessment of social performance; GOST R 57274.4-2016 Sustainability of construction works. Part 4. Framework for the assessment of economic performance.

There are also several international green building standards, used in construction industry in Russia, that are voluntary (LEED® - Leadership in Energy & Environmental Design, BREEAM - Building Research Establishment Environmental Assessment Method, DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen/German Sustainable Building Council), but development, that is occurred according to the requirements of these standards, is aimed at reducing negative impacts on the environmental, social and economic spheres of human life. To promote sustainable construction in Russia and use of BREEAM standard, the Russian version of BREEAM rating system – BREEAM International New Construction 2016 was published in August 2017.

Sustainable development practices have also been actively used in the construction of international level facilities of the Winter Olympics in Sochi at 2014 and then for the FIFA World Cup 2018. [5]

Negative impacts from construction can be controlled at the early stages of building design by using LCA tool. That is why it is already widespread in many countries, and requires dissemination in the construction industry in Russia.

2. Life Cycle Assessment (LCA)

LCA is a management tool that covers the whole life-cycle of the building, and aids in architectural decision making.

The LCA methodology dates back to 1960s and early 1970s, and focused on issues such as energy efficiency, the consumption of raw materials and, to some extent, waste disposal. It was developed by industrial ecologists, chemists, and chemical engineers seeking to understand and reduce the impact of manufacturing and process chemistry.

LCA has become a widely used methodology, because of its integrated way of treating the framework, impact assessment and data quality. [6] Today, LCA is being promoted as a tool for analyzing the environmental impact of buildings and making decisions to reduce these concerns.

The output of an LCA can be thought of as a wide-ranging environmental footprint of a building — including aspects such as energy use, global warming potential, habitat destruction, resource depletion, and toxic emissions. Of many environmental impacts of development, the one with the highest profile currently is global warming. Global warming is the consequence of long term build up of greenhouse gases (e.g., CO₂, CH₄, N₂O) in the higher layer of atmosphere. Global warming is a serious problem, because it is affecting many places around the world. It is accelerating the melting of ice sheets, permafrost and glaciers which is causing average sea levels to rise [7], [8]. It is also changing precipitation and weather patterns in many different places, making some places dryer, with more intense periods of drought and at the same time making other places wetter, with stronger storms and increased flooding. [9], [10].

Using LCA tool, project team is able to highlight those building components that cause the highest environmental impact, and whether the impact of a project is coming primarily from site selection or the

ongoing operation of the building. The method allows the designer to assess tradeoffs in building design, such as those in selecting a steel or concrete frame or a clay masonry or stone veneer. [11]

As specified in ISO 14040 LCA is a “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”.

This tool examines the entire life cycle of a product, from extraction and acquisition of raw materials, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Life cycle assessment framework is shown in Figure 2.

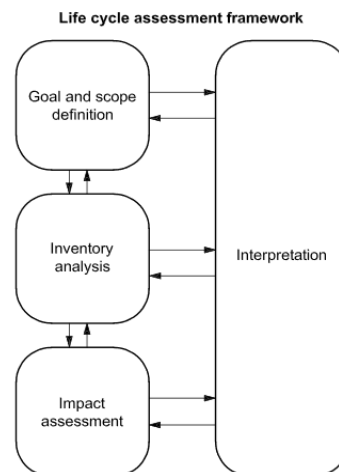


Figure 2. Relationship of LCA stages according to standard ISO 14040 [12]

ISO 14040 describes four phases: 1) the goal and scope definition: the goal includes the intended application, the reasons for the study, the audience, and whether the results are disclosed to the public, and the scope defines the product to be studied, the functional unit, system boundaries, impact categories, and treatment of uncertainty; 2) life cycle inventory analysis phase (LCI): involves compiling and quantifying inputs and outputs for a product through its life cycle, and collection of the data necessary to meet the goals of the defined study; 3) life cycle impact assessment phase (LCIA): evaluate the significance of the potential environmental impacts for a product system throughout the life cycle of the product.; 4) interpretation: the phase in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

The depth and the breadth of LCA can differ essentially depending on purposes of a particular LCA. There are a lot of opportunities to use LCA tool and one of them is to use it in green building rating systems, such as LEED® (Leadership in Energy and Environmental Design), BREEAM (BRE Environmental Assessment Method) and other.

3. Green building rating systems. LEED®

Use of sustainable development practices is the way for developers to mitigate negative impacts from construction works. Green building rating systems aid architects and builders by providing guidelines for green buildings and third party evaluations.

Rating systems assign point values for different measures that reduce the building’s environmental impact and require a minimum amount of points to be certified as a green building.

3.1. BREEAM

BREEAM was developed and put into practice in England in 1990 and it is the first example of systems which make assessment based on environmental standards. BREEAM label is provided in Figure 3.



Figure 3. BREEAM label

As defined on the website of the BREEAM rating system: “BREEAM is the world’s leading

sustainability assessment method for masterplanning projects, infrastructure and buildings. It recognises and reflects the value in higher performing assets across the built environment lifecycle, from new construction to in-use and refurbishment”. BREEAM does this through third party certification of the assessment of an asset’s environmental, social and economic sustainability performance, using standards developed by BRE (Building Research Establishment).

BREEAM measures sustainable value in a series of categories, ranging from energy to ecology. Each of these categories addresses the most influential factors, including low impact design and carbon emissions reduction; design durability and resilience; adaption to climate change; and ecological value and biodiversity protection. The BREEAM categories are: Energy, Health and Wellbeing, Innovation, Land Use, Materials, Management, Pollution, Transport, Waste and Water. [13]

3.2. DGNB

The German Sustainable Building Council (DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen e.V.) was founded in 2007 with the aim to promote sustainable and economically efficient building more strongly in future. DGNB label is provided in Figure 4.



Figure 4. DGNB label

DGNB Certification System provides an objective description and assessment of the sustainability of buildings and urban districts. Quality is assessed comprehensively over the entire life cycle of the building, and it can be applied internationally. Fulfilment of up to 50 sustainability criteria from the quality sections ecology, economy, socio-cultural aspects, technology, process work flows and site are certified. The system is based on voluntarily outperforming the concepts that are common or usual today. [14]

3.3. LEED®

LEED® was developed by U.S. Green Building Council (USGBC), non-profit organization that promotes sustainability in building design, construction, and operation. LEED® is a voluntary, market driven, consensus-based tool, a guideline and assessment mechanism, that seeks solutions to optimize the use of natural resources, promote regenerative and restorative strategies, maximize the positive and minimize the negative environmental and human health consequences of the construction industry, and provide high-quality indoor environments for building occupants. LEED v4 is the current version of the rating system. [15]



Figure 5. LEED® label

As a market transformation instrument, LEED engages building project teams in a way that connects strategies to a defined set of goals, that are referred to as “Impact Categories”. Seven Impact Categories were developed and approved by the LEED Steering Committee for incorporation into LEED v4. Impact Categories answer the question: “What should a LEED project accomplish?”

- Reverse Contribution to Global Climate Change
- Enhance Individual Human Health and Well-Being
- Protect and Restore Water Resources
- Protect, Enhance and Restore Biodiversity and Ecosystem Services
- Promote Sustainable and Regenerative
- Material Resources Cycles
- Build a Greener Economy
- Enhance Social Equity, Environmental Justice, and Community Quality of Life

To get LEED certificate a project team should pursue all prerequisites (mandatory requirements) and required number of points. Prerequisites are the green building standards every project must meet. Credits

allow project teams to customize how they pursue certification. By fulfilling credits, projects earn points that determine its certification level: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+).

For the year 2017 there are 69 projects in Russia that have LEED certificate and are going to have the certificate in the nearest future.

4. Study

In this study, the LCA of industrial warehouse building with area of 15 000 m² is reviewed. The LCA was conducted to get 3 points in Materials and Resources credit of LEED certification system: Building Life-Cycle Impact Reduction, Option 4.

The requirements of the Option 4 are: to conduct a life-cycle assessment of the project's structure and enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building, in at least three of the six impact categories listed below, one of which must be global warming potential. No impact category assessed as part of the life-cycle assessment may increase by more than 5% compared with the baseline building.

Six impact categories are:

- global warming potential (greenhouse gases), in CO₂e;
- depletion of the stratospheric ozone layer, in kg CFC-11;
- acidification of land and water sources, in moles H⁺ or kg SO₂;
- eutrophication, in kg nitrogen or kg phosphate;
- formation of tropospheric ozone, in kg NO_x or kg ethene; and
- depletion of nonrenewable energy resources, in MJ.

The service life of the baseline and proposed buildings must be the same and at least 60 years to fully account for maintenance and replacement.

To conduct LCA the One Click LCA software was used. This software allows to calculate life cycle impacts across the standard impact categories and compare those impacts to a comparable baseline building.

All building materials, applied to the project are required to be added to the software as the input data. Types of materials and structures, that are described are the following: foundations and substructure, vertical structures and façade (including external walls and façade, columns and load-bearing vertical structures, internal walls and non-bearing structures), horizontal structures: beams, floors and roofs (floor slabs, ceilings, roofing decks, beams and roof), other structures and materials (including staircase, windows and doors). For each material in the structure the following information is required: quantity (and size, if applicable), transport (distance between the place of sourcing and the project site, and the way of transportation (by dumper truck, trailer combination, concrete mixer truck, ship, train, etc.), service life (as building, 25, 30, 50 years, etc.).

Baseline building information is imported primarily. Baseline building usually represents conventional structures and measures applied. The proposed building should comply with the requirements of the LEED credit, so optimized materials and structures are to be used.

According to LEED specification, all the background data must be compliant with ISO 14040/44 standard and the chosen impact assessment methodology. Each material has an EPD (Environmental Product Declaration), a document that contains all necessary information about the product during its life cycle. Environmental product declarations (EPDs) following EN 15804 or ISO 21930 standards automatically also follow ISO standards. In Russia there are very few EPDs available, that is why the EPDs for the project materials was replaced by the EPDs of the same materials, but from another country or another manufacturer.

The results of the performed LCA are provided in Figure 6.

Table: Life-cycle assessment impact measures

Complete the table below for all six impact categories for both the baseline building and proposed building.

	Baseline Building Value	Proposed Building Value	Units	Percent Reduction (%)
Global warming potential GHG	5,940,000	4,950,000	CO ₂ e	16.67
Stratospheric ozone depletion	3.54	3.26	kg CFC-11	7.91
Acidification of land and water	11,800	10,000	● moles H ● kg SO ₂	15.25
Eutrophication	4,180	4,110	● kg N ● kg PO ₄	1.67
Tropospheric ozone formation	11,600	11,000	● kg NOx ● kg C ₂ H ₄	5.17
Depletion of non-renewable energy resources	77,700,000	65,200,000	MJ	16.09
Number of measures with at least a 10% reduction				3

Figure 6. Life-cycle assessment impact measures (from LEED online)

The table shows the reduction of negative impacts compared with baseline building, and that the requirements of the LEED credit are achieved.

5. Conclusions

The following conclusions were drawn from this study:

1. The problem of climate change is one of the most urgent problems which should be addressed with particular attention. Construction sector has the large potential for significantly reducing greenhouse gas emissions to mitigate the impact of climate change.
2. Sustainability in construction is not widely spread in Russia, but there are already several standards in place, and the application of international standards and green building certification systems is becoming more popular.
3. LCA is a “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”, that has four phases: 1) the goal and scope definition; 2) life cycle inventory analysis; 3) life cycle impact assessment; and 4) interpretation.
4. Green building certification systems provide tools to evaluate the applied sustainable development practices during design, construction, and maintenance of the building. BREEAM and LEED are the most popular green building certification systems in Russia.
5. LCA needs to be conducted when pursuing LEED certification, Materials and Resources credit: Building Life-Cycle Impact Reduction, Option 4. LCA shows how the negative impacts from the building construction can be reduced.

In addition, it should be noted, that LCA is a very useful management tool that provides an opportunity to assess impacts on every stage of building service life. The results, obtained from LCA should be taken into account, and then appropriate measures are to be applied to mitigate negative impacts.

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